City Climate
Finance Gap Fund

GAP FUND TECHNICAL NOTES

PRIMER ON URBAN FORM AND GREENHOUSE GAS EMISSIONS

DECEMBER 2021

Primer on Urban Form and Greenhouse Gas Emissions

Gap Fund Technical Note[1]

Key takeaways

- Urban areas are responsible for the majority of GHG emissions. The next several decades will see the construction of a large amount of new urban area globally, which means that there is still an opportunity to encourage low-carbon urban growth.
- Urban form impacts GHG emissions in various ways:
  - Urban density impacts emissions from transportation, embodied emissions related to infrastructure, and building energy consumption.
  - Mixed land use, better street connectivity, and walkable urban design impact vehicular emissions by reducing the length and frequency of car trips.
  - Reducing the quantity of infrastructure that uses carbon-intensive materials like cement and steel, by using low-carbon materials, green infrastructure, or nature-based solutions can reduce embodied emissions related to infrastructure.
  - The use of certain materials and the orientation of buildings can reduce the intensity of the urban heat island effect, reducing emissions from the use of energy for cooling.
- The relative impact of urban form interventions can vary significantly depending on the context. Urban modeling tools can help quantify these impacts in a given city.

[1] Acknowledgements: This technical note, commissioned by the City Climate Finance Gap Fund, was authored by Chandan Deuskar with support from Daniel Hoornweg, Alexandrina Platonova-Oquab, Apoorva Narayan Shenvi, and the World Bank Gap Fund Team. It also incorporates feedback from the Global Covenant of Mayors for Climate and Energy.

Introduction

This knowledge note aims to summarize the relationships between urban form and greenhouse gas (GHG) emissions, for reference by practitioners and policymakers. It explores the ways in which various elements of urban form[2] can impact the carbon intensity of urban growth. In the context of GHG emissions, urban form is usually discussed in terms of population density, which is often visualized in terms of building heights, and its impact on transportation-related emissions. However, many different dimensions of the urban built environment, including not just density but also land use patterns, the configuration of street networks, and the materials and orientations of buildings, can impact urban GHG emissions in various ways. Urban density itself may or may not take the form of tall buildings. The impact of urban form on emissions is not restricted to its effect on transportation. The note clarifies these relationships, and also provides examples in which urban growth modeling tools quantify the emissions reductions from various growth scenarios.

This note focuses specifically on the relationship between urban form and GHG emissions reductions (i.e., climate change mitigation). It does not focus on the other important potential benefits of urban form interventions, including reduced costs, improved public health outcomes, increased economic productivity, and greater resilience against natural disasters and climate change (i.e., climate change adaptation). It also does not discuss technologies which may reduce urban emissions but do not relate directly with the built environment, such as clean energy technologies, electric vehicles, and energy-efficient buildings. Other elements of the built environment not discussed here may also be relevant to curbing emissions in cities.

The potential for low-carbon urban growth

The global urban population is expected to increase by between 2.5 to 3 billion by 2050, when it will include 64% to 69% of the world population. This population growth is expected to occur primarily in Asia and Africa. Despite the attention paid to the growth of megacities, the majority of the world's urban population will continue to be dispersed among small urban settlements with populations of less than 100,000 inhabitants (Figure 1).[3]

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[2] For the purposes of this note, "urban form" refers to any aspect of the urban built environment beyond the scale of individual buildings.

[3] K.C. Seto et al., "Human Settlements, Infrastructure and Spatial Planning," in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2014).

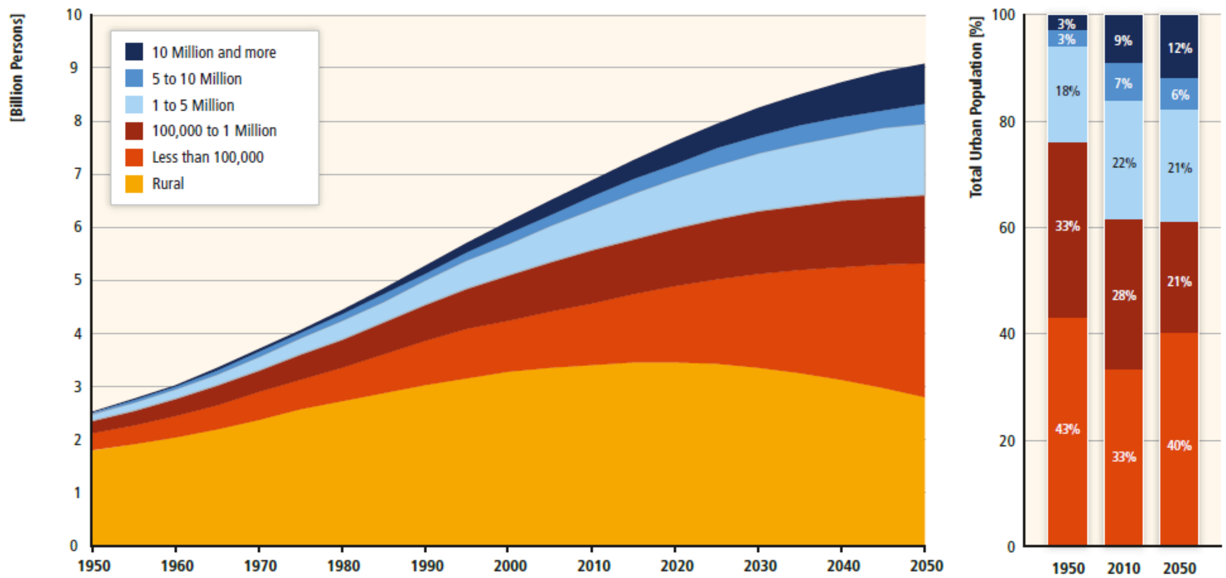

Figure 1: Population by settlement size using historical (1950 – 2010) and projected data to 2050: Most of the world's urban population will continue to be in small cities. (Source: Seto et al, 2014, using data from UN DESA, 2010, and Grubler et al, 2012)

Projections suggest that the global amount of built-up land by the year 2100 could range from 1.1 million to 3.6 million km^2, between roughly two and six times the total area of urban land in 2000 (0.6 million km^2) (Figure 2).[4] This means that most of the built-up areas in the world of 2100 are likely to have been built during this century. This points to the opportunity we still have to shape the urban areas of the future and emphasizes the need to act now to try to make this growth occur in a low-carbon manner.

According to one projection, 44% of the growth in built-up land between 2000 and 2100 will be in Asia. Another 31% will be in Europe and North America, where urban population growth will be low but per capita consumption of built-up land is much higher (Figure 3). Despite rapid urban population growth in Africa, the total amount of new built-up land there is projected to be relatively small, as built-up land consumption per capita will remain low. Despite the total amount of new built-up land in South and Southeast Asia being high, built-up land per capita will also remain low (Figure 4 and Figure 5).

[4] Jing Gao and Brian C. O'Neill, "Mapping Global Urban Land for the 21st Century with Data-Driven Simulations and Shared Socioeconomic Pathways," *Nature Communications* 11, no. 1 (December 2020): 2302, https://doi.org/10.1038/s41467-020-15788-7.

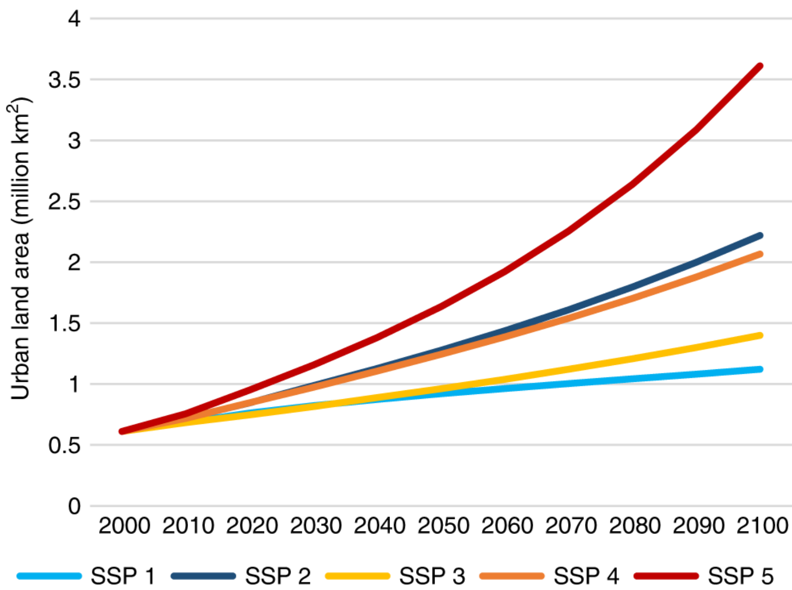

Figure 2: Under most scenarios, the majority of the world's built-up land area by the end of the 21st century will have been built during the 21st century itself. The Shared Sustainability Pathways (SSP) scenarios are Sustainability (SSP 1), Middle of the Road (SSP 2), Regional Rivalry (SSP 3), Inequality (SSP 4), and Fossil-Fueled Development (SSP 5).

(Source: Gao & McNeill, 2020)

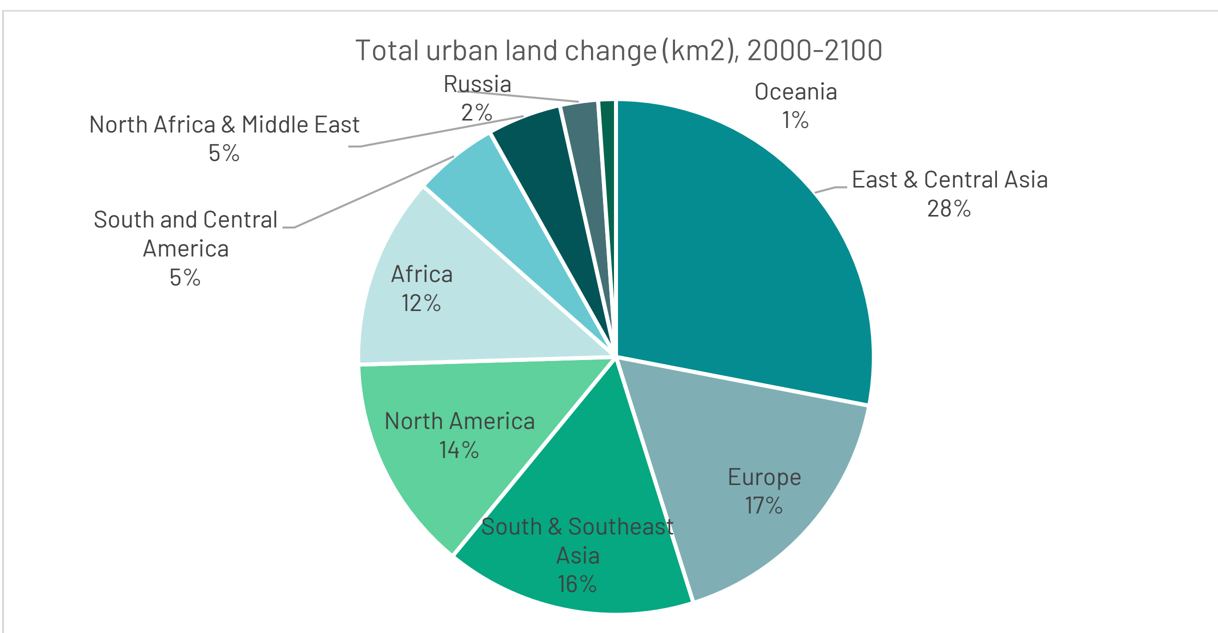

Figure 3: According to projections, 44% of the new built-up land between 2000 and 2100 will be in Asia (East & Central Asia and South & Southeast Asia).

(Source: data for SSP2 from Gao & McNeill, 2020)

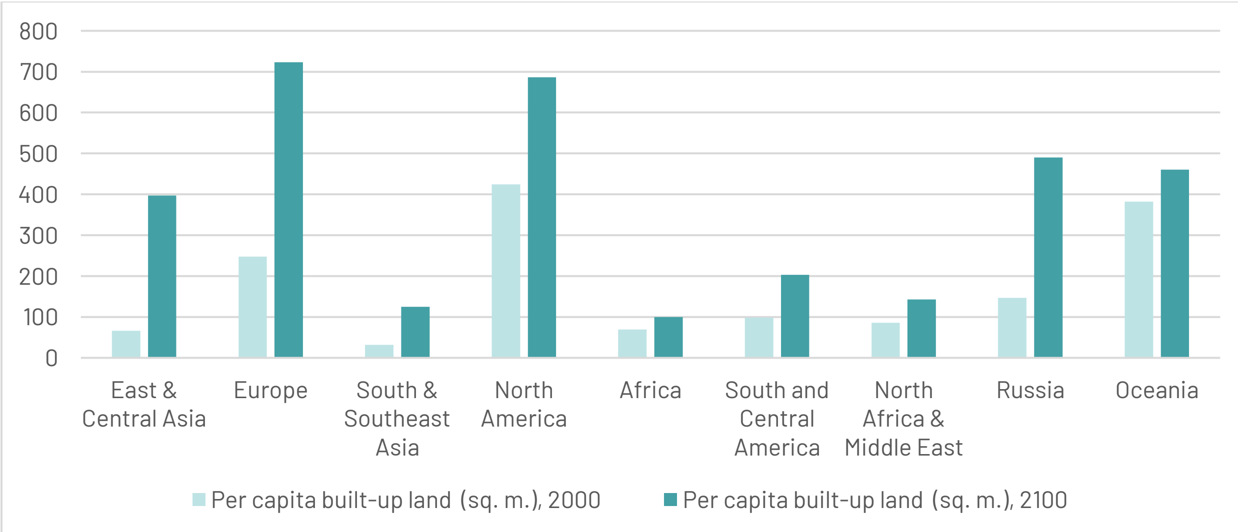

Figure 4: The consumption per capita of built-up land is expected to remain low in South & Southeast Asia and Africa.

(Source: data for SSP2 from Gao & McNeill, 2020)

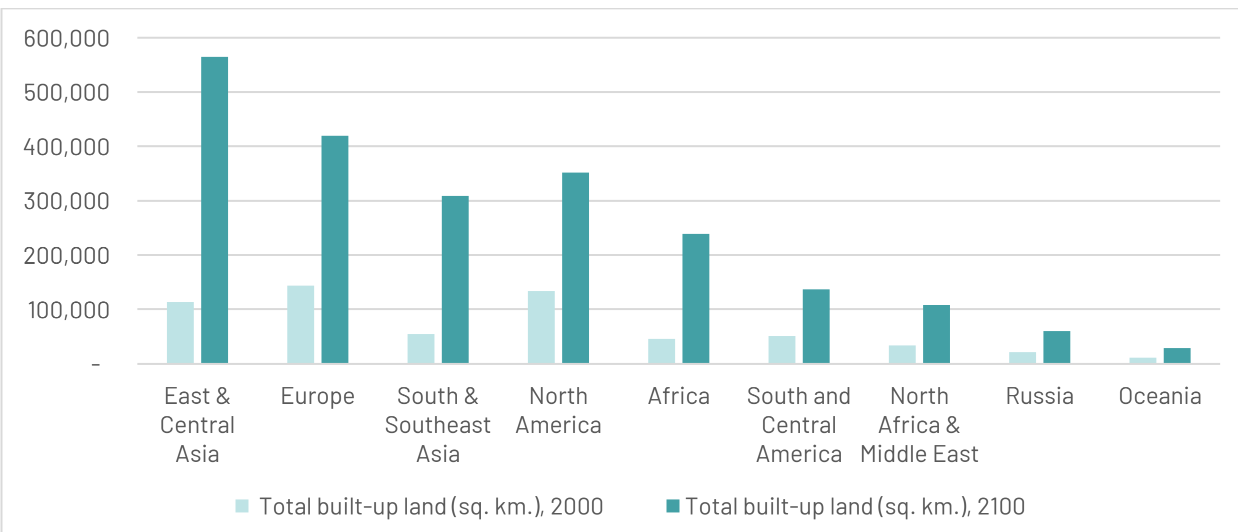

Figure 5: East & Central Asia will have the largest amount of built-up land in 2100.

(Source: data for SSP2 from Gao & McNeill, 2020)

In general, greenhouse gas (GHG) emissions in cities come from vehicles, the use of energy for heating and cooling buildings, electric lighting for streets and buildings, industrial processes, waste management, and embodied carbon in urban infrastructure.[5] Urban expansion may also reduce green cover which acts as a carbon sink.

Urban areas are responsible for over 70% of the world's carbon emissions from energy use. According to one study, potential actions in cities could achieve up to 40% of the emissions reductions necessary to limit global warming to 1.5 °C, suggesting an important role for cities in climate change mitigation.[6] Another study estimates that GHG emissions in cities can be brought close to net-zero by 2050.[7] However, while such studies tend to mention the importance of compact urban growth to reduce vehicular emissions, it is often unclear how urban form measures relate to these mitigation targets. They also usually do not explore the many other ways in which urban form impacts emissions.

Elements of urban form and their relationships with emissions

Urban form influences the urban component of these sources of emissions in various ways.

Density

All else equal, denser cities are responsible for lower emissions per capita. Density affects emissions in various ways:

Density and vehicular emissions: All else equal, greater density brings origins and destinations closer together, reducing the length of vehicular trips and enabling more trips to be made using nonmotorized transport (walking or bicycling). Greater density around public transportation nodes also makes public transportation more viable, as it brings a larger population within walking distance of stops. By reducing the length and frequency of private trips and increasing the share of public and nonmotorized transportation, density reduces vehicle kilometers traveled (VKT), thus reducing carbon emissions.[8] (For these reasons, higher density can also mean less traffic congestion, contrary to common assumptions, because reducing the length and frequency of vehicular trips means that at any given time there will be fewer vehicles on the road.) Figure 6 shows the relationship between population density and transport energy use per capita in several world cities.

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[5] By including embodied carbon in urban infrastructure in its purview, this note takes a "consumption-based" approach to emissions,

[6] C40 and Arup, "Deadline 2020. How Cities Will Get the Job Done - An Analysis of the Contribution C40 Cities Can Make to Delivering the Paris Agreement Objective of Limiting Global Temperature Rise to 1.5 Degrees," 2016, https://www.c40.org/other/deadline_2020.

[7] Sarah Colenbrander et al., *Climate Emergency, Urban Opportunity: How National Governments Can Secure Economic Prosperity and Avert Climate Catastrophe by Transforming Cities*, 2019.

[8] Seto et al., "Human Settlements, Infrastructure and Spatial Planning."

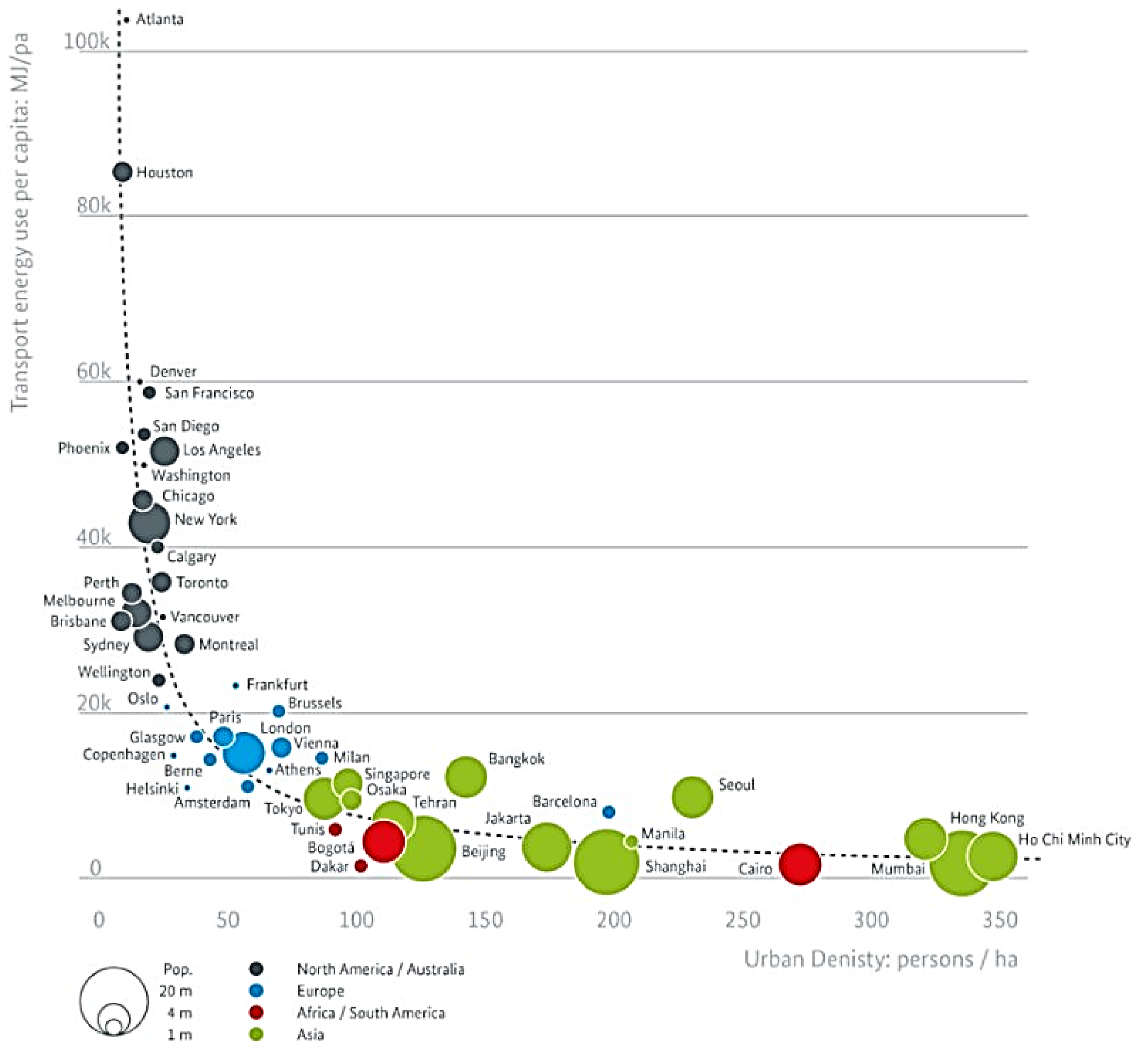

Figure 6: Transportation energy use and population density have in inverse relationship in cities around the world. (Source: Transformative Urban Mobility Initiative, based on data from Newman & Kenworthy reproduced in Rode et al, 2014)

With regard to supporting public transportation, it is not just the aggregate density of a city that matters but also the coordination between density and public transportation corridors. Transit-oriented development involves, among other things, having higher density in areas within walking distance of public transportation stops or stations. Density that is spatially differentiated in this manner is sometimes referred to as "articulated density."

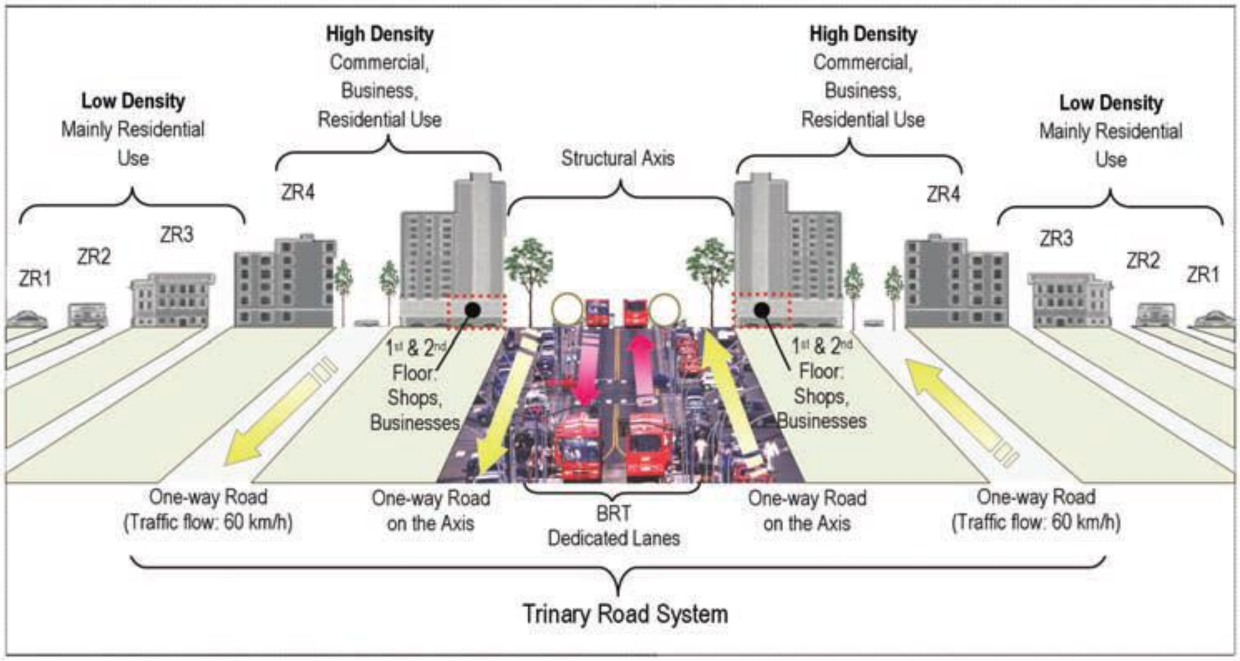

Figure 7: In Curitiba, higher density is permitted near transportation corridors. (Source: Suzuki et al, 2013[9])

Density and embodied emissions: Each stage of the life cycle of a structure (a building or piece of infrastructure)—its manufacture, maintenance and decommissioning—involves the emission of GHGs, which are referred to as embodied emissions or embodied carbon.[10] The steel and cement industries are responsible for an estimated 7% and 5% of global carbon emissions respectively.[11] All else equal, higher density cities require less infrastructure (such as buildings, roads and bridges, pipes for water and sewage, electric transmission infrastructure, etc.) per capita, and thus have lower embodied emissions per capita.

Density and emissions from heating and cooling buildings: Density in the form of lower consumption of floor space per capita reduces the energy used in heating and cooling buildings, and consequently reduces emissions. Globally, the impact of higher urban densities on reducing energy use for heating and cooling is equivalent to the impact of improvements in building energy efficiency. However, these impacts vary significantly by region. Building energy efficiency improvements can be more impactful than higher densities in North America and Europe, while in China, South Asia, Sub-Saharan Africa, and the Middle East and North Africa, two-thirds of the potential for reductions in

[9] Hiroaki Suzuki, Robert Cervero, and Kanako Iuchi, *Transforming Cities with Transit*, 0 vols., Urban Development (The World Bank, 2013), https://doi.org/10.1596/9780821397459_Overview.
[10] https://www.c40knowledgehub.org/s/article/Embodied-Carbon-of-Buildings-and-Infrastructure-International-Policy-Review?language=en_US
[11] https://www.iea.org/reports/iron-and-steel-technology-roadmap; https://www.iea.org/fuels-and-technologies/cement

building energy use can be achieved through higher densities. The two approaches have roughly equal impact in Latin America and the Caribbean and countries of the former Soviet Union).[12]

Density may not necessarily reduce energy consumption if it is in the form of high-rise buildings, which may in fact use more energy per unit of floor space than medium-rise buildings. A study of 600 office buildings in the UK found that energy use and carbon emissions per square meter of floor space were twice as high in buildings of more than 20 stories than in buildings of less than 6 stories. (Figure 8).[13]

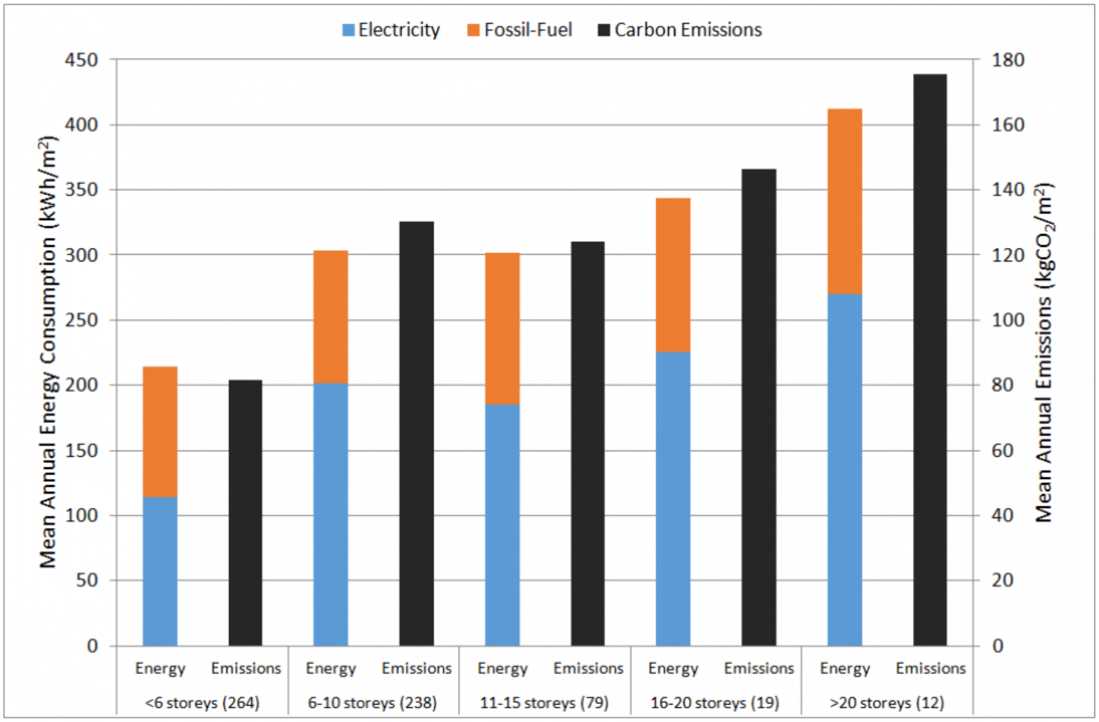

Figure 8: A study of 600 office buildings in the UK found that energy use and carbon emissions per square meter of floor space were twice as high in buildings of more than 20 stories than in buildings of less than 6 stories. (Source: UCL[14])

[12] Burak Güneralp et al., "Global Scenarios of Urban Density and Its Impacts on Building Energy Use through 2050," *Proceedings of the National Academy of Sciences* 114, no. 34 (August 22, 2017): 8945–50, https://doi.org/10.1073/pnas.1606035114.
[13] Seto et al., "Human Settlements, Infrastructure and Spatial Planning"; UCL, "UCL-Energy 'High-Rise Buildings: Energy and Density' Research Project Results," UCL Energy Institute, June 13, 2017, https://www.ucl.ac.uk/bartlett/energy/news/2017/jun/ucl-energy-high-rise-buildings-energy-and-density-research-project-results.
[14] UCL Energy Institute, June 13, 2017, https://www.ucl.ac.uk/bartlett/energy/news/2017/jun/ucl-energy-high-rise-buildings-energy-and-density-research-project-results

High-rise buildings require more energy for elevators, ventilation, and pumping water.[15] This finding may seem contradictory, as urban density is usually visualized in terms of building height. However, population density is not the same as building height. For example, the metropolitan areas of New York City and Mumbai accommodate similar populations, but Mumbai does so in a built-up area that is one-fourteenth the size of New York's.[16] This is despite the fact that Mumbai has fewer high-rise buildings than New York City does (Figure 9).

Figure 10 shows that urban density can be mathematically disaggregated into a number of constituent factors. A city may achieve high population density through any number of these factors, of which building height is just one. Figure 11 shows that the same floor area density can be achieved with varying combinations of plot coverage and building height.

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[15] https://www.greentechmedia.com/articles/read/getting-building-height-right-for-the-climate
[16] Shlomo Angel et al., *Atlas of Urban Expansion: The 2016 Edition (Volume 1: Areas and Densities)*, 2016.

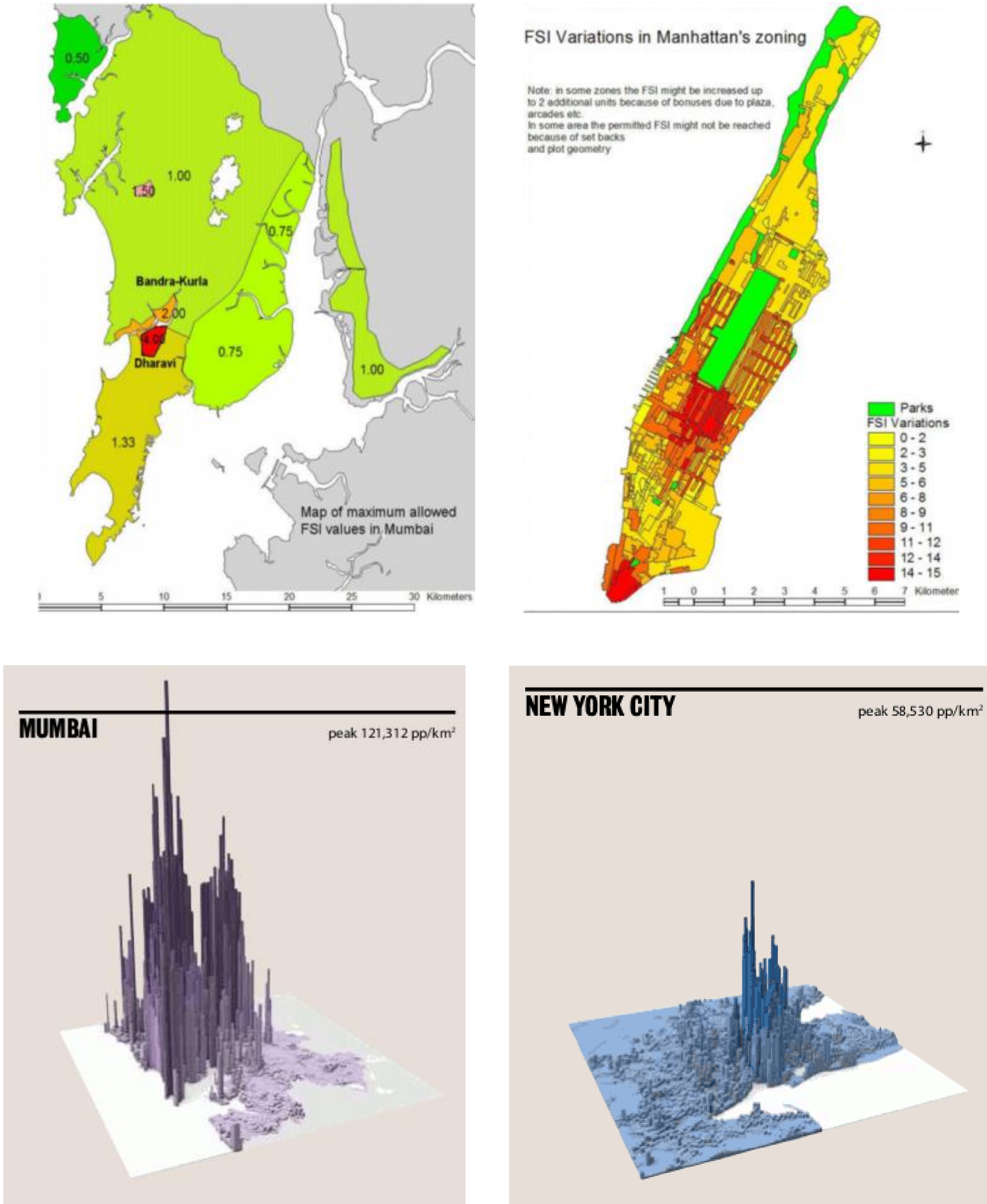

Figure 9: Mumbai has much more severe restrictions on building height than New York, as represented by Floor Space Index (FSI, also known as Floor Area Ratio) the ratio of floor space to land area (top). However, Mumbai has much higher residential density (bottom).

Source: IDFC Institute/ Alain Bertaud (top); LSE Cities (bottom)

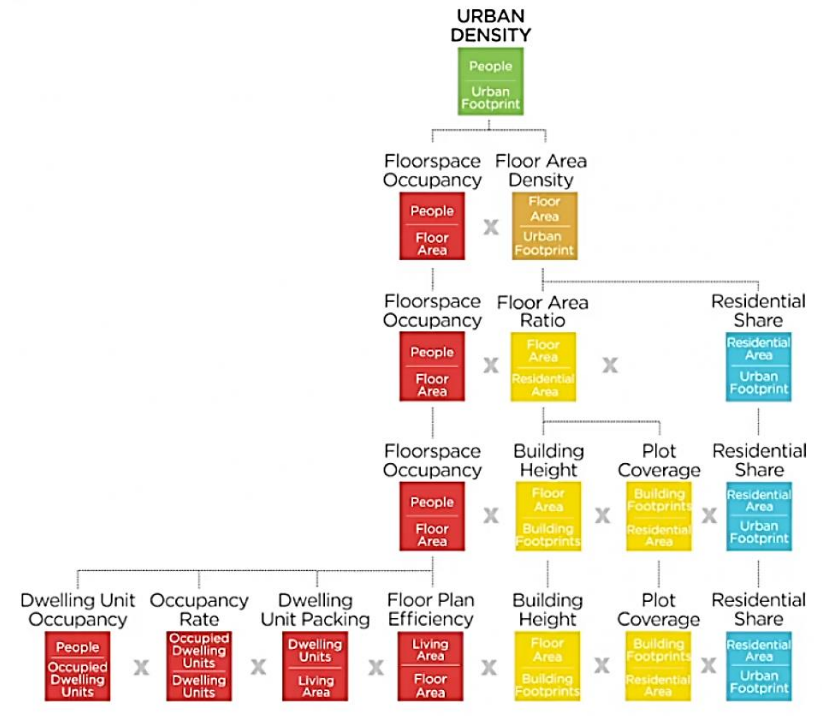

Figure 10: The two, three, four, and seven factors that, when multiplied together, constitute urban density. (Source: Angel et al[17])

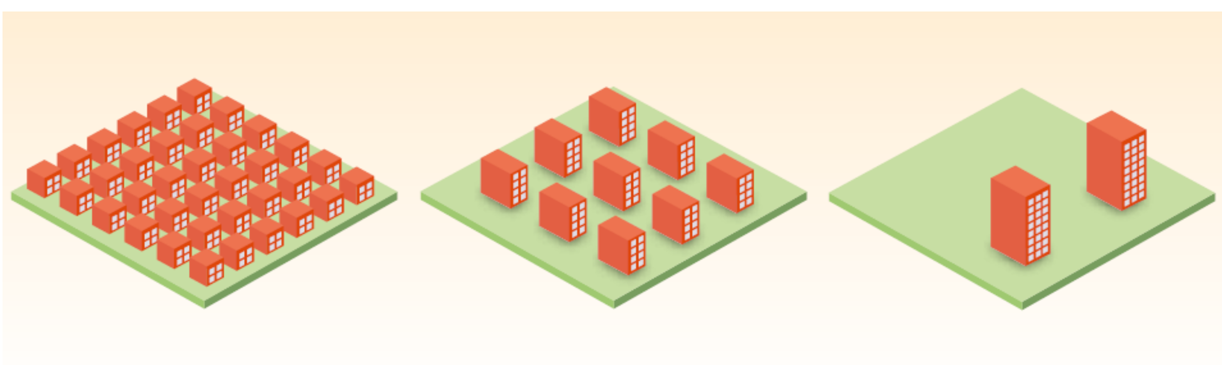

Figure 11: The same floor area density in three different layouts, achieved by varying plot coverage and building height. (Source: Seto et al, 2014[18])

[17] Shlomo Angel, Patrick Lamson-Hall, and Zeltia Gonzales Blanco, "Anatomy of Density I: Measurable Factors That Together Constitute Urban Density" (Marron Institute, August 2020), https://marroninstitute.nyu.edu/uploads/content/Anatomy_of_Density_I%2C_3_August_2020.pdf.

[18] Seto et al., "Human Settlements, Infrastructure and Spatial Planning."

The higher density of Mumbai compared to New York is partly a function of much lower per capita incomes, but cities with similar per capita incomes may also have very different densities. For example, London and Atlanta have similar per capita incomes, but London is more than seven times denser than Atlanta, for reasons that are likely related to planning, policy, politics, and culture (Figure 12).

The density of cities is at least partially determined by the actions of local governments, which can encourage density through zoning and building regulations, including allowing or requiring denser development; strategically locating public infrastructure and amenities such as roads, schools and parks; and other policy tools including taxation (varying property taxes by building type or applying a vacant land tax) and incentives for infill development.

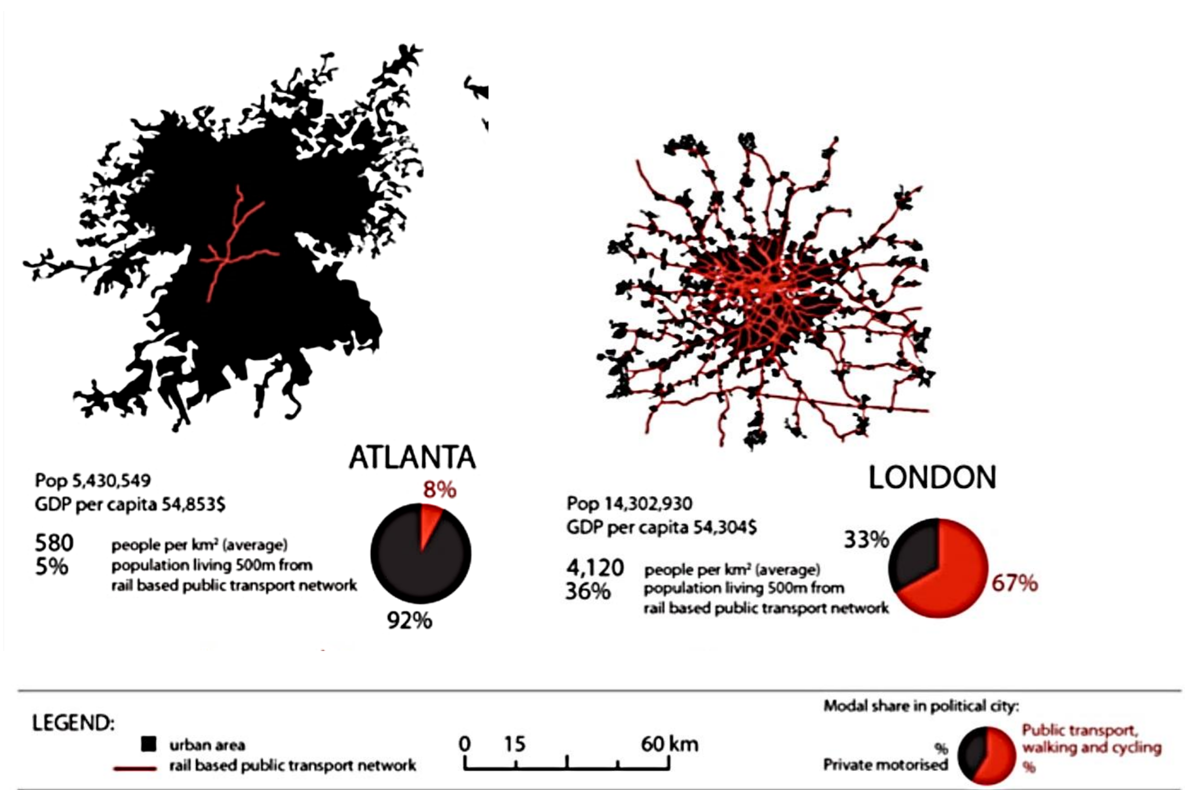

Figure 12: Atlanta and London have similar per capita incomes, but London's population density is nearly seven times greater, and is supported by an extensive public transportation network (Source: Rode et al, 2014[19])

[19] Philipp Rode et al., "Accessibility in Cities: Transport and Urban Form," NCE Cities Paper (LSE Cities. London School of Economics and Political Science, 2014).

Land use mix

A city with large monofunctional land use zones—e.g. a large residential-only zone, a large central business district, a large retail district—is likely to produce higher emissions than it would if it had the same land uses mixed more evenly. Mixed-use development increases the proximity between residences, jobs, retail, and other destinations, which reduces vehicular trip length and frequency, encourages walking and bicycling, and in turn reduces vehicular emissions. Traditional urban design around the world features a fine mix of uses at the neighborhood and even building scale. For example, older parts of many cities have buildings with retail on the ground floor and residences above.

At the regional scale, recent research in the US suggests that polycentric cities generate lower vehicle kilometers traveled (VKT).[20] However, determining whether or not the development of a secondary urban center would reduce VKT in any particular city depends on the specific mix of land uses, jobs, workers, public transportation options, etc. in the proposed center. For example, building a cluster of office buildings near a highway on the rural outskirts of a city, far from public transportation, shopping, restaurants, etc. may generate more VKT and emissions than locating it in a central business district (CBD) that is well connected to public transport and is closer to residential areas and other commercial areas. Conversely, situating some jobs and retail stores in a new center in an existing suburban residential area instead of in a CBD could reduce VKT and emissions, especially if the new center is served by public transportation and the jobs and businesses located there match the surrounding population.

Street connectivity

The route between an origin and destination is shorter in a city with a grid-like street network with frequent intersections (i.e. small blocks) than in a city with limited-access highways, cul-de-sacs, and large blocks (Figure 13). A street network with higher connectivity (i.e. with a higher density of four-way intersections) therefore requires shorter trip lengths, which lowers vehicular emissions. It also encourages walking and bicycling, not only by reducing distances but also because walking and bicycling is safer and more pleasant on smaller, well-connected streets than along large highways.

[20] Reid Ewing, "Regional Transportation Goals: Reducing Sprawl through Interconnected Centers (Project Brief)" (National Institute for Transportation and Communities, October 2020), https://ppms.trec.pdx.edu/media/project_files/1217_Project_Brief_-_Polycentric_Urban_Development_Al72iAt.pdf.

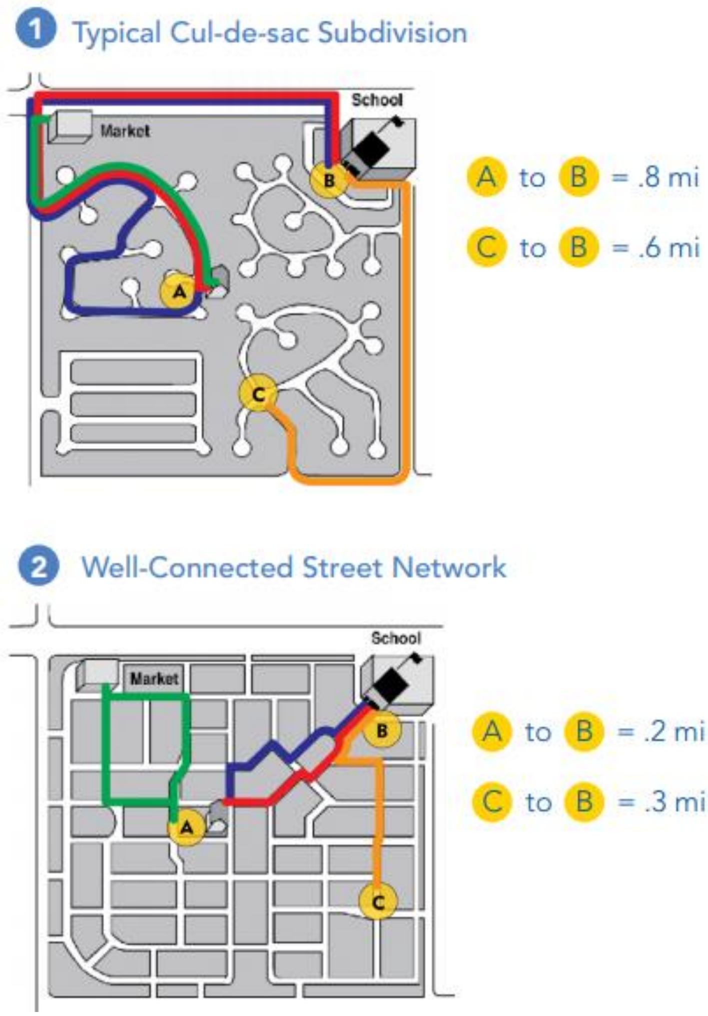

Figure 13: Greater street connectivity reduces trip lengths

(Source: Metro Transit, "A Developers Guide to Transit-Oriented Development (TOD)", adapted from Neighborhood Streets Project Stakeholders (2000), "Neighborhood Street Design Guidelines, An Oregon Guide for Reducing Street Widths")

As Figure 14 shows, traditional urban layouts typically feature highly connected street networks compared to automobile-oriented urban design. Note that what matters is not just the *proportion* of intersections but also the *spatial density* of intersections, as measured by the number of intersections per sq. km. or the distance between intersections. The street networks of Pudong in Shanghai and new areas in Beijing are well-connected, but form "superblocks" that are so large that they negate the benefits of connectivity. Even if these superblocks were to have public pedestrian paths through them, they would still increase the distance that vehicles need to travel.

	Turin, Italy	Barcelona, Spain	Paris, France	Pudong Shanghai, China	Hutong Beijing, China	New areas Beijing, China
Urban grid						
Intersections per km²	152	103	133	17	119	14
Distance between intersections	80	130	150	280	75	400

Figure 14: Street connectivity is much higher in three older European cities and a traditionally laid out neighborhood ('hutong') in Beijing than in two newer neighborhoods in China. (Source: World Bank[21])

Urban design for walkability

Even holding trip lengths and street connectivity constant, the design of the built environment can encourage walking and thus reduce vehicular emissions. Providing safe pedestrian infrastructure (adequate sidewalks, pedestrian crossings, etc.) is an important first step. In many cities in low- and middle-income countries, pedestrian infrastructure is non-existent or dilapidated, or is encroached on by vehicles and private businesses, making the walking experience challenging.

However, even having safe and unobstructed pedestrian space may not be enough to encourage people to walk. Studies show that elements of the built environment influence the perception of walkability. For example, people are likelier to walk next to buildings with several street-level windows and doorways, as this provides an experience that is livelier and is perceived as safer than walking along a continuous blank wall. Encouraging ground-level retail opening directly onto sidewalks can help in this regard. Streetscapes that provide a sense of enclosure also enhance the perception of safety, although if buildings are too close together, they may induce a feeling of claustrophobia and detract from walkability. Shorter blocks reduce the perceived length of walking trips. Trees and benches, as well as visually distinctive and memorable environments, e.g. with notable architecture or street art, also encourage walking.

[21] World Bank, *Urban China: Toward Efficient, Inclusive, and Sustainable Urbanization* (The World Bank, 2014), https://doi.org/10.1596/978-1-4648-0206-5.

Figure 15: Top: In Nairobi, Kenya expanded sidewalks and a bustling commercial fronts create a lively walking environment. Bottom: In Guangzhou, China, a fully pedestrianized space that includes shade from trees and well-maintained foliage along a commercial street gives residents reasons to stroll and linger. (Images and captions: ITDP)[22]

[22] https://www.itdp.org/2020/10/15/pedestrians-first-tool-guides-cities-on-the-path-to-walkability/

Construction materials

The materials used in construction of buildings and infrastructure impacts carbon emissions in the following ways:

Embodied emissions: As mentioned above, the steel and cement industries are responsible for an estimated 7% and 5% of global carbon emissions respectively.[23] The use of natural materials like sustainably sourced wood or earth in the construction of infrastructure and buildings reduces embodied carbon.[24] Green infrastructure and other nature-based solutions can reduce the need for steel and cement and thus reduce urban emissions.

Urban heat island effects: Urban areas tend to have higher temperatures as a result of the use of heat-absorbing artificial materials, lack of tree shade, restricted airflow due to tall buildings, heat emitted from vehicles, air-conditioners, and other mechanical sources, and other causes. The urban heat island effect has been documented in hundreds of cities around the world, where average temperature increases may exceed 4-5 °C. Besides its negative impact on human health, the phenomenon also increases the demand for energy for cooling, which in turn increases carbon emissions. Studies from several countries show that electricity demand for air conditioning increases by approximately 1–8% for each 1°C increase in temperature. The use of natural materials and materials that reflect heat, e.g. green roofs, cool roofs, cool pavements, etc. can reduce the urban heat island effect and thus reduce carbon emissions from energy required for cooling.[25]

Urban geometry

As discussed above, the urban heat island effect results in increased carbon emissions due to the need for additional energy for cooling. Urban geometry, i.e. the orientation of buildings and streets, can mitigate this effect by providing shade and allow cooling breezes to flow.

Wide streets (shallow street canyons) allow better ventilation but narrow streets (deep canyons) provide better shade. Studies show that temperatures are higher in more open spaces, suggesting that the cooling effect of increased shade outweighs the effect of reduced wind. More enclosed spaces are cooler during the day due to shade, but warmer at night when heat absorbed during the day is released. Streets with an East-West orientation receive more prolonged exposure to the sun than those with other orientations, and thus experience more heat. Streets oriented to allow breezes to flow can help reduce temperatures. Ideally, streets should run at a slight angle to the direction of wind to prevent the creation of wind vortices which reduce wind speed.[26]

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[23] https://www.iea.org/reports/iron-and-steel-technology-roadmap; https://www.iea.org/fuels-and-technologies/cement
[24] https://www.architectmagazine.com/technology/concrete-steel-or-wood-searching-for-zero-net-carbon-structural-materials_o
[25] https://www.epa.gov/heatislands
[26] Lai et al (2019). "A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces." *Science of The Total Environment* 661. DOI: 10.1016/j.scitotenv.2019.01.062

Quantifying the impact of urban form on emissions

While there are several studies that attempt to quantify the impact of urban form on emissions, the vast majority of these studies are based on cities in the United States. In most cases, the results of such studies cannot be easily applied to the rest of the world, particularly to rapidly urbanizing low- and middle-income countries. Not only is the US a wealthy country which is already urbanized, but it also has a very high rate of car ownership, even compared to other wealthy countries (see Figure 16), which has resulted in low-density, car-oriented urbanization.[27] The relative impact of urban form interventions can be very different from one place to another, as illustrated by the section above on the relationship between density and emissions from heating and cooling buildings. These impacts depend on a city's current density and land use mix, transportation mode share, building stock, rate of population growth, and other factors.

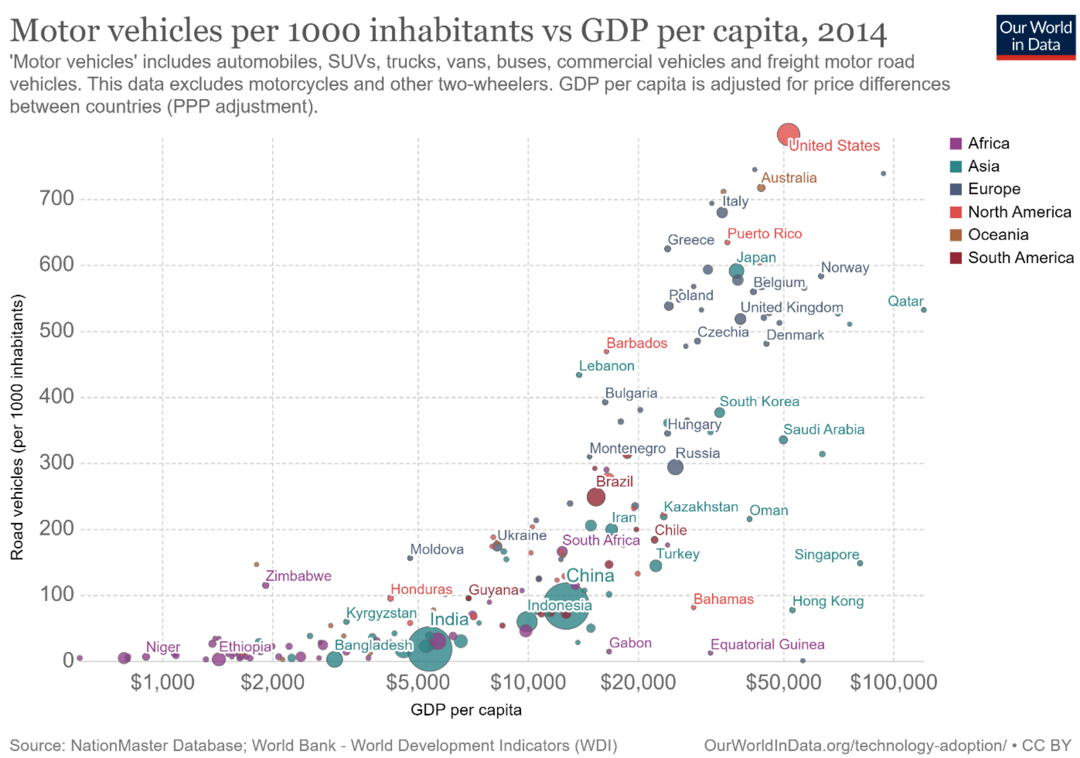

Figure 16: Motor vehicles per 1000 inhabitants vs. GDP per capita. The very high car ownership rate in the United States, even compared to other high-income countries, means that studies of the impact of urban form on vehicle kilometers traveled in US cities may not be relevant elsewhere.

(Source: Our World in Data, using vehicle ownership data from NationMaster and GDP data from the World Bank.)

[27] The Intergovernmental Panel on Climate Change (IPCC) summarizes the findings of mostly US-based studies on the relationship between urban form and emissions in a 2014 report (Seto et al).

It can be more instructive to examine these impacts in specific cities. Such estimates are often derived through urban modeling.[28] In the examples below, the modeled reduction in GHG emissions from compact, walkable, transit-oriented growth planning range from 8% to 40%.

Jordan (5 cities)

Urban modeling performed by the firm CAPSUS as part of a World Bank study estimated the potential for GHG reductions and other impacts arising from compact growth policies in five cities in Jordan.[29] The team modeled a compact growth scenario, among others, for the year 2030, in which new urban growth prioritizes infill development close to jobs and public transportation and reaches the maximum housing densities allowable. In all five cities, these compact growth conditions meant that, according to the model, the projected population growth could be accommodated within the existing urban footprints, with no new spatial growth. For each scenario, the model estimates the population density, GHG emissions, urban footprint, infrastructure costs, municipal service costs, water and energy consumption, proximity to jobs and other amenities, and other variables. The GHG emissions considered were those related to the energy consumed for public lighting, municipal water supply, solid waste management, electricity in dwellings and commuting (public transportation and private vehicles). It did not include embodied emissions in urban infrastructure.

Table 1 displays some of the results that relate to GHG emissions and urban form for two of the cities, both of which were expected to experience population growth of 28% by 2030. In Amman, the compact growth scenario for 2030 has a population density that is 20% greater than the business as usual (BAU) scenario for 2030, resulting in a reduction in GHG emissions per capita 14% from the BAU scenario. The GHG reductions from compact growth are slightly smaller for Irbid.

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[28] Another Gap Fund knowledge note discusses the urban GHG modeling tools currently available, including the ones whose results are outlined here, in detail.
[29] CAPSUS and World Bank, "Urban Growth Model and Sustainable Urban Expansion for the Hashemite Kingdom of Jordan: Final Report," May 2018, https://documents.worldbank.org/en/publication/documents-reports/documentdetail/983981555961147523/urban-growth-model-and-sustainable-urban-expansion-for-the-hashemite-kingdom-of-jordan.

Table 1: Selection of results from urban growth modeling for cities in Jordan

City	Scenario	Population	Population density (pop/km^2)	GHG emissions ($kgCO_2eq$ per capita per year)
Amman	Base – 2015	3,423,389	16,111	1,348
	BAU – 2030	4,367,902	17,202	1,308
	Compact growth – 2030	4,367,902	20,557	1,127
	Compact growth vs. base	+28%	+28%	-16%
	Compact growth vs. BAU	-	+20%	-14%
Irbid	Base – 2015	815,815	13,963	1,210
	BAU – 2030	1,040,898	13,766	1,217
	Compact growth – 2030	1,040,898	17,816	1,076
	Compact growth vs. base	+28%	+28%	-11%
	Compact growth vs. BAU	-	+29%	-12%

Chongqing, China

The firm Calthorpe Analytics modeled urban growth in Chongqing, China, up to 2035, as part of a World Bank study.[30] Chongqing, already a very large city with an urban population of 7.4 million in 2015, is expected to grow by 79% to 13.2 million in 2035. The team modeled two scenarios, a 'trend' or business-as-usual scenario and a compact growth scenario. The two scenarios projected the same population and job growth up to 2035, but differed in terms of the spatial distribution of the population and jobs, the development pattern ('superblocks' in the trend scenario vs. small-block, walkable, transit-oriented development in the compact growth scenario), and other variables. Among other differences, the compact growth scenario had a population density that was 20% higher than the trend scenario. The model then compared outcomes in terms of GHG emissions from passenger vehicles, as well as other metrics including job accessibility, land consumption, transportation mode share, travel time, household costs, and infrastructure costs. The model estimated that the compact growth scenario would reduce annual carbon dioxide emissions from auto travel by 39% (Figure 17).

[30] World Bank, "Chongqing 2035: Urban Growth Scenarios - Technical Report" (Washington, DC: World Bank, 2019).

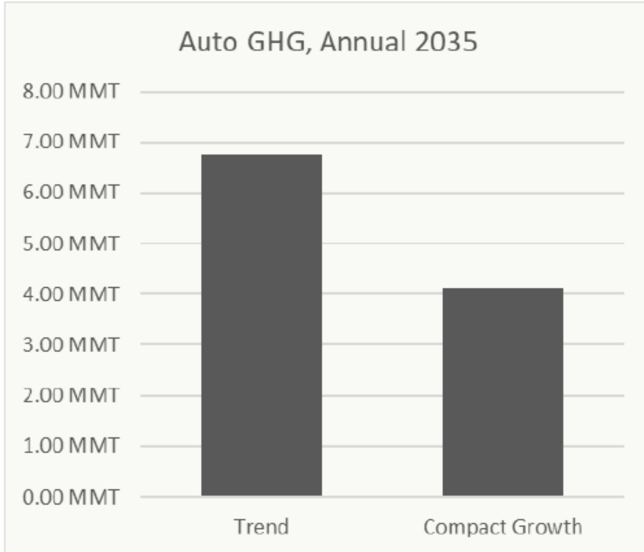

Figure 17: Compact growth in Chongqing can reduce annual GHG emissions from private vehicles by nearly 40%.

(Source: World Bank)

Mexico City and Merida, Mexico

Calthorpe Analytics, the Mario Molina Center, and others performed similar modeling for Mexico City and Merida. For Mexico City, they estimated outcomes for three scenarios for 2050: a trend scenario, characterized by inefficient land use policies and urban sprawl, and 'moderate' and 'vision' scenarios with varying levels of infill development, public transportation investment, alignment between jobs and housing, densification, and scaling down of blocks. The moderate scenario resulted in a 6% reduction in GHG emissions from transport, buildings and energy associated with water management, while the vision scenario resulted in a reduction of 8.4%.[31] In Merida, a vision scenario for 2030 resulted in 40% lower GHG emissions than a trend scenario.[32]

[31] Mario Molina Center, "Urban Planning Scenarios: Mexico City Metropolitan Area," September 2015, http://centromariomolina.org/english2/wp-content/uploads/2016/06/1.-UrbanPlanningScenarios_MCMA-1.pdf.

[32] Mario Molina Center, "Sustainable Cities: Merida Growth Scenarios and Sustainable Urban Development Models," 2014, http://centromariomolina.org/english2/wp-content/uploads/2014/08/1.-Sustainable-cities_Merida_EN.pdf.

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