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“Optimal” Needs to be Contextualized for Cities

A science of cities reveals insights on quantifying the universally applicable laws of urban forms and function. Geoffrey West, the British theoretical physicist slash urban scientist, has discovered the linear correlation between population size and wages, city size and savings on infrastructure. It is tempted to think that whether the same type of linear scaling will apply to the environmental aspects of cities as well, enabling us to get a better handle on optimizing the quality of life metrics in city planning and design. A study done by Boston University Department of Earth and Environment shows that as population density increases, carbon emissions per capita is likely to decrease in cities [1]. Using the datasets provided by Arizona State University Vulcan Project [2], I discovered the similar pattern. As a general trend, urban population density has a tendency to undermine carbon emissions per capita; however, carbon emission per capita by itself is not a sufficient indicator in determining an “optimal” city size.

The research data from the Vulcan Project contains information on total carbon emissions across different sectors in each county of the United States in 2002. Our goal is to combine this dataset with the census data in order to get carbon emission per capita on a Metropolitan Statistical Area (MSA) scale, then analyzing its relationship with population and density. To get the population and land area for each county, I joined this dataset with the census data provided by the ArcGIS book—“GIS Tutorial 1: Basic Workbook,” which has the census data in 2000 [3].

Then, referring to a county-to-MSA lookup table [4], I aggregated population, land area and carbon emissions by counties to get the corresponding data for each MSA. I eliminated all MSAs whose population is below 100,000, dropping a dozen out of over 300. After having everything in total on a "city" scale, I normalized carbon emissions by population to get per capita carbon emissions, population by land area to get density as in persons per square kilometer.

My analysis of the data shows that there exists a certain level of inverse correlation to carbon emissions for both city size and city density on a national scale, while this correlation needs to be examined in a more detailed context. Exhibit 1 is a scatter plot of carbon emissions per capita in the 48 contiguous states created using Tableau. The map gives us an idea on where the MSAs are located and shows that in most MSAs carbon emissions per capita are very low, compared to a few extremely high-value points in New Mexico, Arizona, Midwest and South. Then I used Python to plot the relationships mathematically in Exhibit 2. The result shows that the correlation coefficient is -0.10 for carbon emissions per capita vs population, and -0.17 for carbon emissions per capita vs density. While carbon emission per capita is inversely correlated to both city size and city density, it seems to have more to do with the latter. Since the relationship is not quite linear, the second-degree polynomial fit may reveal some insights on discovering the "optimal" city size and density mathematically. As a result, the city size that minimizes carbon emissions per capita is located at 10 million, and the city density at 540 persons per square kilometers. Compared to the mean MSA population at 700 thousand and density at 107 persons per square kilometers, the "optimal" city according to our data is much larger and able to house more people in each of its grids.

Another look into the statistics can provide some evidence to our semi-conclusion on the relationship between urban density and per capita carbon emissions. Let us sort the MSAs by per capita carbon emissions and take the half with less emissions, which are those less than the median—4.0 tons per person. Then, if we compare the the mean and median of those less-emission MSAs with the mean and median of the total in terms of both population and density, we will find out that the less-emission group is more populous and dense than the entire group. Moreover, if we are to look at the carbon emissions per capita in those most populous and dense MSAs, we will discover that only a couple out of the top ten exceeds the median number of emission, 4.0 tons per person. The combination of the four graphs in Exhibit 3 gives ground on the inverse relationship between city size, city density, and per capita carbon emissions. An environmental study conducted by researchers from University of California, Berkeley corroborates the findings [5]. The study displays the data of carbon dioxide emissions in each zip code on a map, reaching the conclusion that suburban areas tend to have more carbon footprints per household than urban areas, shown in Exhibit 4. The reason is that suburban areas have relatively inefficient infrastructure, including transportation, housing and services, than cities. As people gather in a compact urban settlement, they tend to have more shared usage of facilities and infrastructure, maximizing the share of rides, residence, network services and other resources. As a result, an urban settlement reduces carbon emissions per capita.

However, defining an "optimal" city size from a purely mathematical standpoint oversimplifies the problem. A dive into the specific types of carbon emissions is necessary in determining the possibility of such "optimal" number. In fact, per capita carbon emissions have a lot to do with the specific function of a certain urban area. Exhibit 5 is a comparison chart between the MSAs with most carbon emissions per capita and those with least. Electricity production and industrial activity account for most of the carbon emissions for the former, while they only account for a slight portion for the latter. Farmington is the fourth least dense city on our list, and it has a huge electric utility plant serving the surrounding four counties in New Mexico [6]. Ranking the first on our most carbon emissions per capita list does not necessarily imply the inefficiencies of resource utilization in its case, because the city functions as a supply center of electricity for its neighbors and itself. In contrast, seven out of the ten cities with least amount of carbon emissions per capita do not have any electric production. It is inappropriate to argue that those cities do a better job than Farmington at optimizing the utilization of local resources. The comparison does not stand to reason, because cities have different focus on the functions they serve on a state or larger scale, which leads to a different result in carbon emissions per capita. Therefore, if a city of higher density has a lower carbon emissions per capita than the other, it will be inappropriate to claim its superiority in terms of quality of life metrics. Indeed, the "optimal" city requires contextualized study and in-depth analysis.

A dive into the carbon footprints data tells us that as a general trend, per capita carbon emissions are inversely related to city size and density. Urban settlement is able to maximize the shared usage of infrastructure, such as transportation, housing and services; therefore, dense cities tend to use less resources on an individual scale. However, the legitimacy of an "optimal" city size needs to be analyzed more in depth, because different cities have difference focus on the functions they serve. Ultimately, it is not possible to find an "optimal" size and density for all cities, and to find an "optimal" size and density for a specific city requires thorough, elaborate and contextualized study.

Exhibits

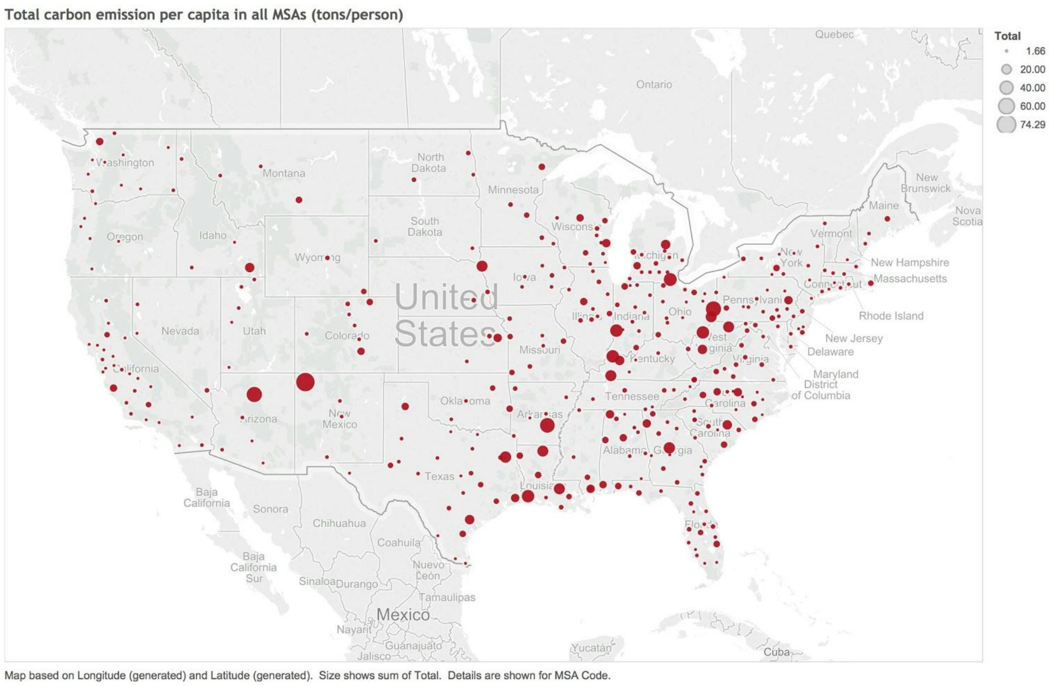

Exhibit 1. Carbon emissions per capita in the 48 contiguous states.

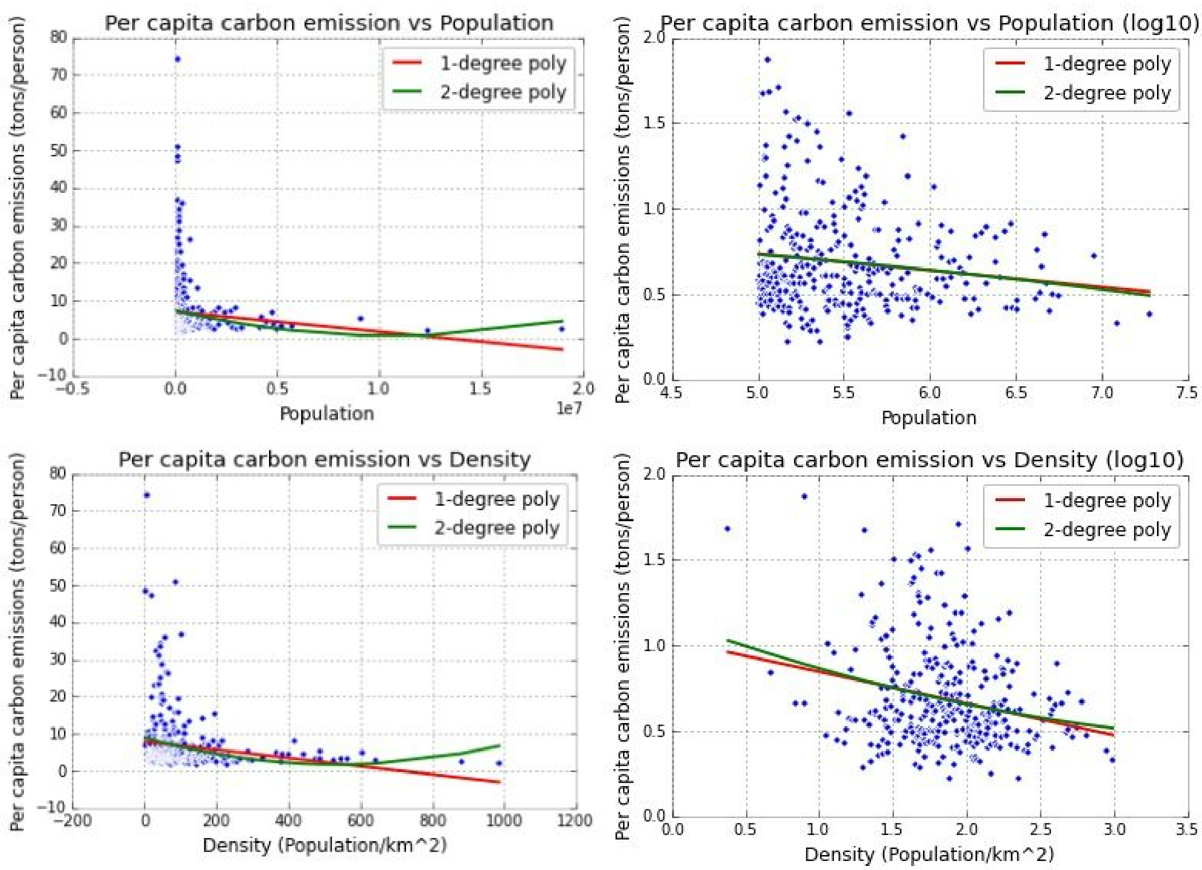

Exhibit 2. Per capita carbon emissions vs population and density.

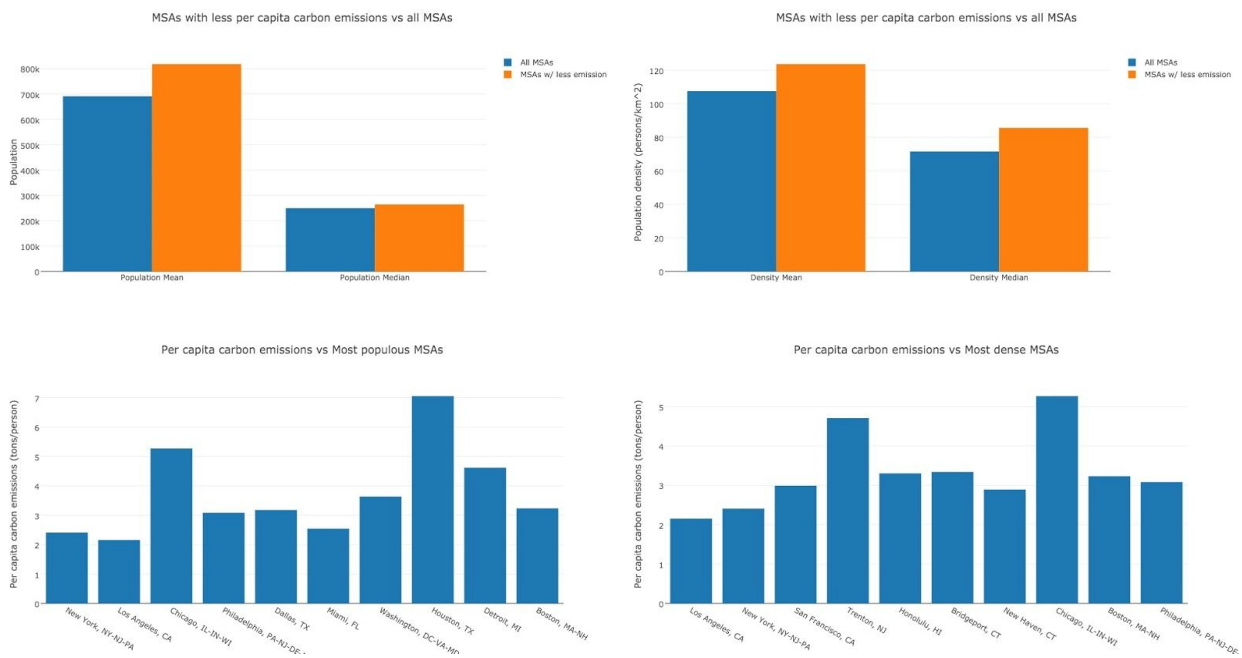

Exhibit 3. Bar plot of per capita carbon emissions in most populous and dense MSAs.

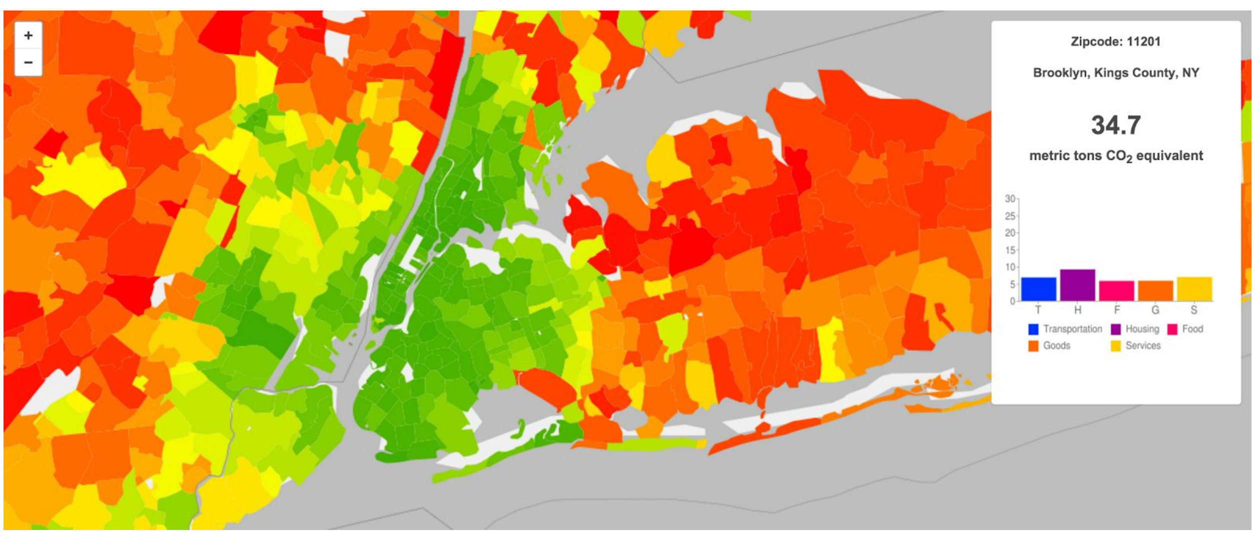

Exhibit 4. Per capita carbon footprint in New York City.

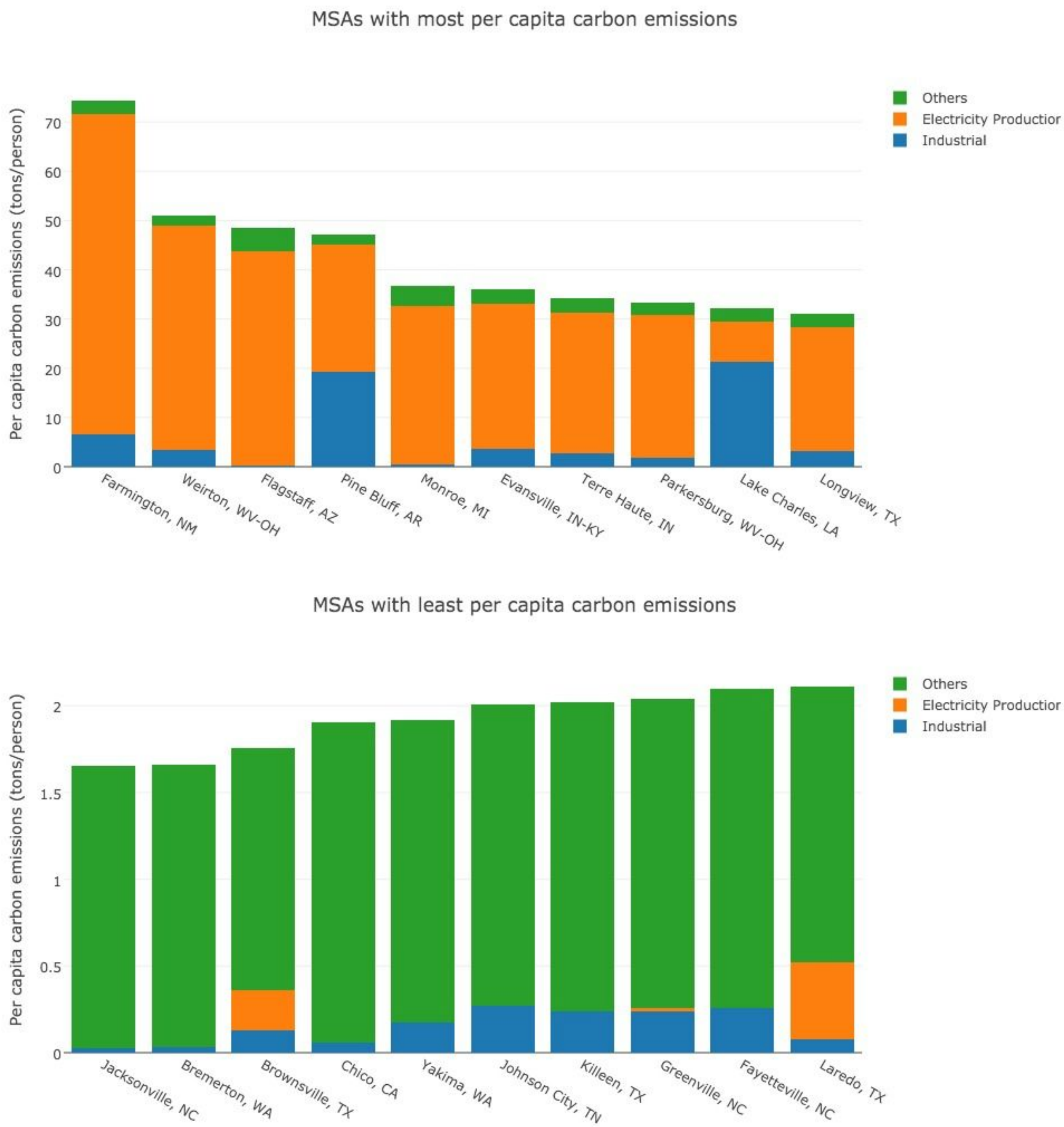

Exhibit 5. Emission components for MSAs with most and least per capita carbon emissions.

References

1. Burke, Amanda. “Researchers find correlation between population density, carbon dioxide emissions.” *The Daily Free Press*, April 10, 2015. Accessed on November 19, 2015. Web. URL: <http://dailyfreepress.com/2015/04/10/researchers-find-correlation-between-population-density-carbon-dioxide-emissions/>
2. Carbon emissions per capita 2002 dataset. “Vulcan Project.” *Arizona State University*. Accessed on November 19, 2015. Web. URL: <http://vulcan.project.asu.edu/research.php>
3. Gorr, Wilpen L. and Kristen S. Kurland. “GIS Tutorial 1: Basic Workbook.” *Esri Press*, May 3, 2013. Accessed on November 15, 2015. Book.
4. MSA to County Lookup Table. *Spatial Insights*. Accessed on November 15, 2015. Web. URL: <http://www.spatialinsights.com/catalog/downloads/products/32/MSAtoCounty.pdf>
5. Sanders, Robert. “Suburban sprawl cancels carbon-footprint savings of dense urban cores.” Berkeley News: Politics & Society, Research, Science & Environment, January 6, 2014. Accessed on November 19, 2015. Web. URL: <http://news.berkeley.edu/2014/01/06/suburban-sprawl-cancels-carbon-footprint-savings-of-dense-urban-cores/>
6. The Farmington Electric Utility System. *City of Farmington, NM*. Accessed on November 19, 2015. Web. URL: <http://fmtn.org/index.aspx?nid=181>