Working Paper Series

Working Paper # 37

The Transportation Energy and Carbon Footprints of the 100 Largest U.S. Metropolitan Areas[1]

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[1] The authors are grateful to the Brookings Institution for sponsoring this research as part of its Metropolitan Policy Program. The guidance and feedback provided by Andrea Sarzynski, Mark Muro, and Dave Warren are particularly appreciated.

1. Introduction

In this paper we present estimates of the automobile and truck travel based energy and carbon footprints of the largest 100 U.S. metropolitan areas. The footprints are based on the estimated vehicle miles traveled and the transportation fuels consumed. Results are presented on an annual basis and represent end use emissions only. Total carbon emissions, emissions per capita, and emissions per dollar of gross metropolitan product are reported. Two years of annual data were examined, 2000 and 2005, with most of the in-depth analysis focused on the 2005 results.

In section 2 we provide background data on the national picture and derive some carbon and energy consumption figures for the nation as a whole. In section 3 of the paper we examine the metropolitan area-wide results based on the sums and averages across all 100 metro areas, and compare these with the national totals and averages. In section 4 we present metropolitan area specific footprints and examine the considerable variation that is found to exist across individual metro areas. In doing so we pay particular attention to the effects that urban form might have on these differences. Finally, section 5 provides a summary of major findings, and a list of caveats that need to be borne in mind when using the results due to known limitations in the data sources used.

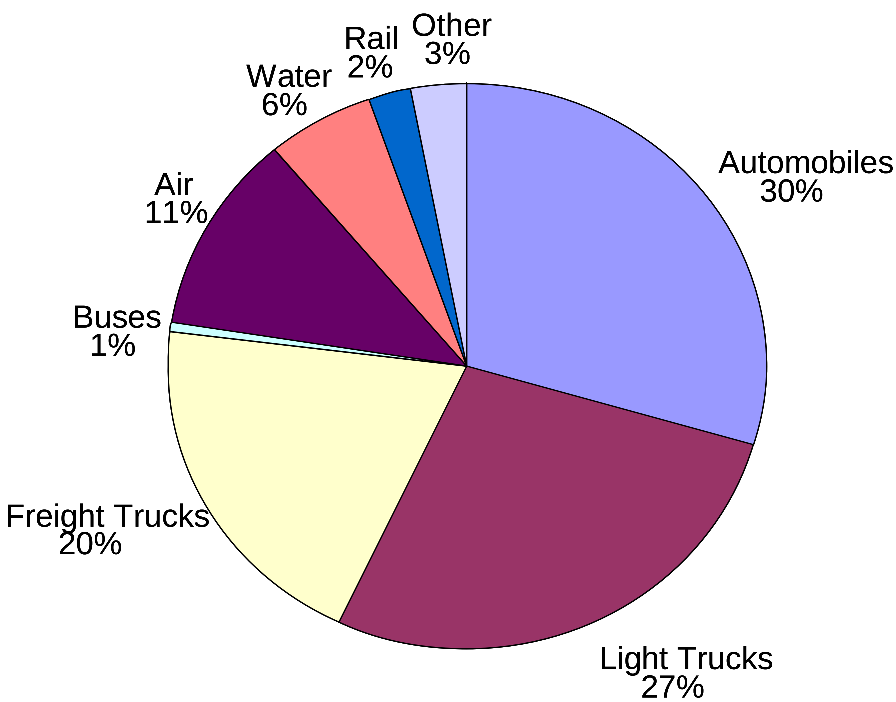
2. Energy Use and Carbon Emissions from Highway Transportation in the United States

The transportation sector has been estimated to account for 33 percent of the carbon emissions in the United States (EPA, 2007; Brown, Southworth, and Stovall, 2005). Within the transportation sector, passenger vehicles and light duty trucks are the main source of greenhouse gas emissions accounting for roughly 57 percent of the total. Freight, including light duty commercial trucks, account for an additional 20 percent. Figure 1 shows the breakdown of transportation emissions (based on EIA, 2007, *Annual Energy Outlook* Table 33).

The transportation sector is not only one of the main sources of carbon emissions it is also the fastest growing. Between 1990 and 2005 the sector accounted for almost half of the growth in U.S. greenhouse gas emissions. In a business as usual scenario, emissions from the transportation sector are expected to continue to grow rapidly between now and 2030 (Gallivan et al, 2008). According to the U.S. Energy Information Administration, energy consumption in the transportation sector will grow 0.7 percent annually, resulting in an increase of 17 percent between 2006 and 2030; similarly CO_2 emissions from transportation are forecast to grow 0.4 percent annually resulting in a 10 percent increase by 2030 (*Annual Energy Outlook 2008*). These growth rates have been adjusted downward from those reported in the *Annual Energy Outlook 2007,* which forecast transportation energy growing at 1.4 percent annually, resulting in a 40 percent increase in transportation energy consumption in 2030 and a 1.3 percent annual growth rate for carbon from transportation. The large adjustments in the latest EIA "business as usual" forecast are intended to reflect the energy efficiency provisions of the 2007 Energy

Independence and Security Act, inflationary energy prices, and the recent slowdown in GDP growth. Future trends are likely to lie somewhere between these two extremes.

The main fuel type consumed in the transportation sector is gasoline, followed by petro-diesel. In 2005 gasoline accounted for 77 percent of the vehicle fuel consumption and diesel for 22 percent. Alternative fuels (biodiesel, compressed natural gas, electricity, ethanol, methanol, hydrogen, liquefied natural gas and liquefied petroleum gas) accounted for less than 1 percent (EIA, 2007b).



Note: Pipeline mode excluded

Figure 1: Share of 2005 U.S. Transportation CO_2 Emissions by Mode.

2.1 Transportation Energy and Carbon End Use Totals for the United States

In 2005 the transportation sector is estimated to have consumed 27.38 quadrillion Btu (quads) of energy, up 4.25% since year 2000 (ORNL: *Transportation Energy Data Book 2007, Table 2.7*). Highway travel is estimated to account for some 22.04 quadrillion of these Btu, or 80.5 percent of the total transportation energy consumed in 2005. This highway total has been growing, up from 20.76 quadrillion Btu in 2000, a 6.2 percent increase over the first five years of this century, mainly due to increases in autos and light truck use (Table 1).

According to Oak Ridge National Laboratory's *Transportation Energy Data Book 2007* (ORNL, 2007, Table 11.4) total U.S. carbon emissions from energy consumption in the transportation sector in 2005 are estimated to be 534.1 million metric tons (mmtc) of carbon, up from 505.6 mmtc in 2000, or an increase of 5.6 percent since the beginning of the century.[2] Using the nationally averaged share of highway travel assigned to gasoline and diesel fuels in each year, and the Btu numbers reported in Table 1 yields an estimated 430.2 million metric tons of carbon assigned to highway travel in 2005, up by 7.7 percent from 399.6 million metric tons in year 2000. Note that these figures are given on the basis of the *gross carbon content of fossil fuels*,[3] using 125,000 Btu per gallon of gasoline, 138,700 Btu per gallon of diesel, 120,900 Btu per gallon of gasohol and 91,300 Btu per gallon of propane: see ORNL Appendix B, Table 4B.

Table 1. Transportation Energy and Carbon Totals for the United States

Estimated Annual Totals:	**Year 2000**	**Year 2005**	**% Change 2000-2005**
Highway VMT (trillion miles)[a]			
Total	2.74	2.99	9.1
Autos and other 2-axle 4 tire vehicles	2.52	2.75	9.1
Trucks[b]	0.205	0.223	8.8
Highway Fuel Consumed (billion gallons)[a]			
Total	162.6	174.3	7.2
Autos and Light Trucks	126.0	139.3	10.6
Heavy Trucks	35.2	33.5	-4.8
Highway Energy (Quads)[c]			
Total	20.8	22.0	5.8
Autos and Light Trucks	15.7	17.2	9.6
Heavy Trucks	4.8	4.6	-4.2
Carbon Emissions (million metric tons)[d]			
Highway Travel	399.6	430.2	7.7
Autos and Light Trucks	305.1	338.0	10.8
Heavy Trucks	93.5	88.9	-4.9

[a] Source: Highway Statistics 2000 and 2005, Table VM-1.
[b] Includes 2-Axle, 6 or more tire single unit as well as combination trucks
[c] Source: Transportation Energy Data Book 2007 (Table 2.7)
[d] Based on data reported in Transportation Energy Data Book 2007 (Tables 2.7 and 11.4)
Note: energy reported in gross Btu[2]

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[2] Highway mode specific end use carbon emissions are not reported.

[3] If the products of fuel combustion are cooled back to the initial air fuel-air temperature fuwl oxidizer mixture temperature and the water vapor formed during combustion is condensed, the energy released by the process is the *gross* heating value. If the products of combustion are cooled to the initial fuel-air temperature, but the water is considered to remain as vapor, the energy released is lower, producing a *net* heating value. The difference between gross and net heating values for transportation fuels is around 5% to 8. In net terms there are about 114,500 Btu per gallon of gasoline, 128,700 Btu per gallon of diesel, 112,417 Btu per gallon of gasohol, and 83,500 Btu per gallon of propane (ORNL, 2007, Appendix B).

2.2 Per Capita and Per GDP Footprints for the United States

As background, in year 2000, the United States had a population of 276.8 million and a GDP of $11,481 (billions of $2005). By 2005 the U.S. population had grown by 6.8 percent to 295.5 million, and U.S. GDP increased over the five year period between 2000 to 2005 by 9.15 percent, to $12,531 billion, again indexed to 2005 equivalent dollars.

Applying these population and GDP totals to the estimates from Table 1 above results in an estimated average annual per capita highway transportation energy consumption in 2000 of 75.1 million Btu/person, and an average annual per $GDP highway energy consumption of 1,808 Btu/$GDP, expressed in 2005 equivalent dollars. In 2005 the average per capita highway energy consumption is estimated to be 74.5 million Btu/person, a 0.9 percent decrease from 2000. Also in 2005 an average highway energy consumption of 1,812 Btu /$GDP is estimated, suggesting a decrease of 3.1 percent since 2000.

Table 2. Residential Energy and Carbon Footprints Per Capita and Per GDP for the United States

Estimated Annual Totals:	**Per Capita (MBtu/person)**			**Per GDP (thousand Btu/$2005 GDP)**		
	2000	**2005**	**% Change 2000-2005**	**2000**	**2005**	**% Change 200-2005**
Total	75.14	74.45	-0.92	1811.69	1755.65	-3.09
Autos and Light Trucks	56.72	58.21	2.62	1367.48	1372.60	0.37
Heavy Trucks	17.34	15.57	-10.23	418.08	367.09	-12.20

Estimated Annual Totals:	**Per Capita (Metric tons of carbon/person)**			**Per GDP (Metric tons of carbon/$2005 GDP)**		
	2000	**2005**	**% Change 2000-2005**	**2000**	**2005**	**% Change 200-2005**
Highway Travel	1.44	1.45	0.84	34.81	34.33	-1.36
Autos and Light Trucks	1.10	1.14	3.77	26.57	26.97	1.50
Heavy Trucks	0.34	0.30	-10.94	8.14	7.09	-12.89

Translated into carbon equivalents, these population and GDP numbers yield per capita carbon emissions for auto plus truck transportation of 1.44 and 1.45 metric tons/person for the years 2000 and 2005 respectively, suggesting no noticeable change over the five year period. In contrast, and allowing for 9.1% inflation over the five year period, the per GDP carbon emissions for this highway transportation are estimated to be 34.8 and 34.3 metric tons/million $2005 GDP equivalent for the years 2000 and 2005 respectively: a 1.3 percent decrease over the five year period (which difference may or may not have statistical significance).

Multiplying 1.45 metric tons per person by a 2005 U.S. population of 295.5 million yields an estimated 430.2 million metric tons of end use carbon emitted by auto and truck travel. It is estimated that 58.6 percent of this 2005 VMT was traveled within the nation's largest 100 metropolitan areas, providing a rough estimate of 252.1 million metric tons of carbon (mmtc) from metropolitan area auto and truck travel. This last result is quite close to the estimate of 252.7 mmtc emitted in 2005 derived by summing over each of the metro area estimates described below, suggesting a reasonable consistency in the above described national versus top 100 metropolitan area totals.

3. Energy Use and Carbon Emissions in the Top 100 Metro Areas

3.1 VMT, Fuel, Energy and Carbon Totals

Table 3 summarizes the results aggregated across all 100 metropolitan areas (see Appendix A for a description of the methodology).

Results are presented on a) an average daily and b) an annual basis. Put on an annual basis (i.e. multiplying the daily estimates by 365), a total of 232.3 million metric tons of carbon is estimated to have been emitted in 2000 within the boundaries of these 100 metropolitan areas. For 2005 the estimate rises to 252.7 mmtc. As shown in Table 3 this represents an 8.8% increase over the five year period, equated here with a net 10.2% increase in vehicle miles of travel (and a 6.3% increase in the US population).

Table 3. Results Summed Over All 100 Metro Areas for 2000 and 2005.

A) Average Daily Totals:	**Year 2000**	**Year 2005**	**% Change 2000-2005**
Travel (million vmt)	4357.0	4800.7	10.2
Fuel Use (million gallons)	256.3	280.8	9.6
Energy (trillion Btu)	32.7	35.6	8.9
Carbon (thousand metric tons)	636.3	692.4	8.8
B) Estimated Annual Totals:			
Travel (billion vmt)	1,590.3	1,752.3	10.2
Fuel Use (million gallons)	93,533.3	102,494.9	9.6
Energy (trillion Btu)	11,923.2	12,980.1	8.9
Carbon (million metric tons)	232.4	252.7	8.8

Figure 2 graphs this aggregate result for carbon emissions, broken down by auto versus single-unit and combination truck classes of highway traffic. Note that "autos" here includes SUVs and other small, principally (but not entirely) passenger vehicles under 8,500 lbs weight, including pickup trucks. This auto travel is estimated to contribute 69.8% (174.8 mmtc) to total highway travel induced carbon emissions in 2000, when summed over all 100 metro areas. Trucks contribute the remaining 30.2% (57.5 mmtc). The auto share is much higher in 2005, at 75.1% (193.9 mmtc), contributing most of the increase in total carbon emissions over the five year period. Truck travel contributes the remaining 23.6% (58.9 mmtc).

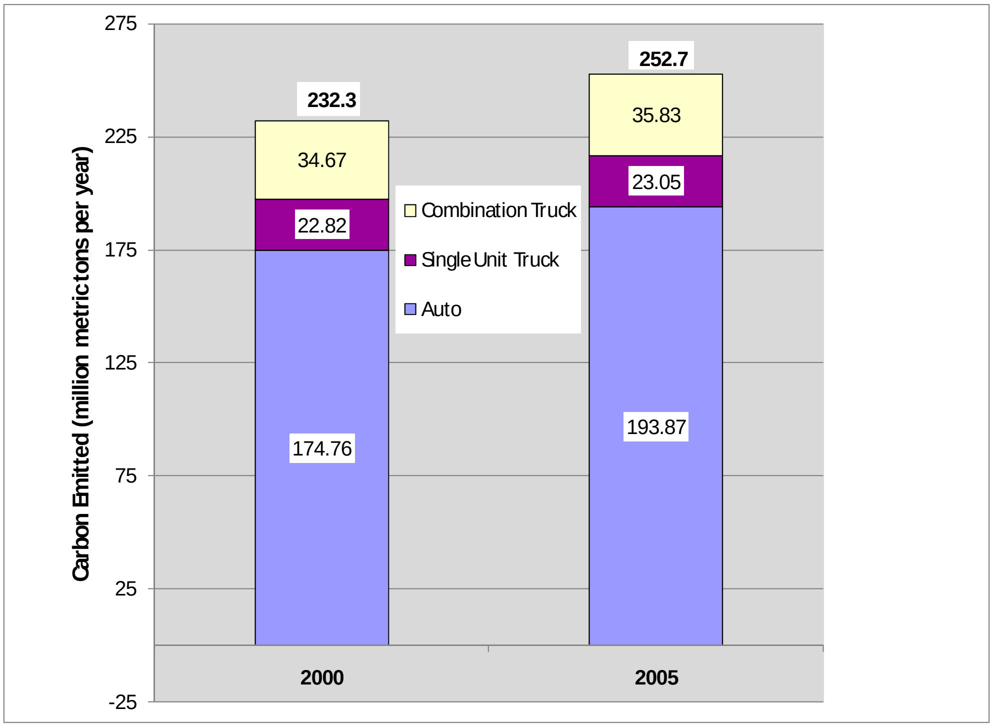

Figure 2: Carbon Emission Estimates from Automobile and Truck Traffic within Metropolitan Areas in 2000 and 2005.

The reason the truck share does not rise in line with the auto share is due to improvements in the mpg reported for these trucks, in both classes, over the five year period. Specifically, average light duty truck mpg is estimated to have increased from 7.4 to 8.6, with an increase in average combination truck mpg from 5.1 to 5.9.[4] These fuel efficiency increases offset much of the 20.5% estimated increase in metro area single unit truck vmt and the 16.1% estimated increase in metro area combination truck vmt over the five year period. In contrast, average auto mpg is taken to be 20.1 in 2000, averaged over

[4] *Highway Statistics.* Table VM1: FHWA, 2000 and 2005, also reported in the *2007 Transportation Energy Data Book:* ORNL, 2007, Tables 5.1, 5.2 and A.1

all fuel types (principally gasoline, gasohol and diesel), falling to 19.7 mpg in 2005,[5] so that vmt increases capture most of the carbon increase in this case.[6]

3.2 Per Capita and Per GMP Footprints for the 100 Metros

In order to arrive at carbon emissions totals for each of the top 100 metro areas, four measures of auto and truck highway travel activity were computed for the study:

Annual VMT (annual vehicle miles of travel)
Annual fuel consumption (by fuel type, in gallons)
Annual energy consumption (measured in British thermal units), and
Annual carbon emissions

The technical details of how each of these indices were developed is provided in Appendix A. The source for VMT data was the auto and truck traffic counts contained in the Federal Highway Administration's Highway Performance Monitoring System, with further breakdown of truck VMT provided by FHWA. Fuel consumption (miles per gallon) data was obtained from ORNL's Transportation Energy Data Book, and for trucks of different classes from the Census Bureau's Vehicle Inventory and Use Survey. Fuel specific Btu and carbon conversion factors were based on U.S. Energy Information Administration's (EIA) and other US Department of Energy supported publications.

To allow for meaningful comparisons across different metropolitan areas each of these four measures was standardized on:

a) a per capita basis[7], and
b) a per metropolitan area product ($ million of GMP) basis.

GMP is one of several measures of the size of the economy of a metropolitan area. Similar to gross domestic product (GDP), GMP is defined as the market value of all final goods and services produced within a metropolitan area in a given period of time. GMP data were first officially released by the Bureau of Economic Affairs (BEA) in late 2007, when data for 2005 were published.[8] As a result, official estimates are not available for 2000; however, in 2005, the sum of the GMPs for the 100 metros is estimated to be $9,282 in billions of 2005 dollars.

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[5] *Highway Statistics.* Table VM1: FHWA, 2000 and 2005, also reported in the *2007 Transportation Energy Data Book:* ORNL, 2007, Table 4.1.

[6] However, the reader should note that these estimates, and especially the implied growth rates between 2000 and 2005 suffer from some known discrepancies between the 2000 and 2005 vmt-based datasets used, as well as possible discrepancies in comparable metro area population statistics between the two years. A third concern is the reported jump in both light duty and combination truck mpg figures between 2002 and 2003, from 7.5 to 8.8 and from 5.2 to 5.9 respectively (see *Transportation Energy Data Book,* ORNL, 2007, Tables 5.1, 5.2).

[7] The population of the 100 largest U.S. metropolitan areas grew by approximately 6.3 percent from 181.6 million in 2000 to 193.0 million in 2005.

Summing these carbon emission results over all 100 metro areas, and again combining auto plus truck travel, yielded the results listed in Table 4. This table also summarizes the aggregate VMT, fuel consumption, and total Btu expended on this highway travel for the two survey years. Also shown are results standardized to per capita (= per metro area resident) and per dollar of 2005 GMP.

Table 4: Per Capita and Per GMP Results for Year 2000 and 2005.

Per Capita Carbon Footprints	**Year 2000**	**Year 2005**	**% Change 2000-2005**
Autos	0.96	1.00	4.38
Trucks	0.32	0.31	-3.63
Combination Truck	0.19	0.19	-2.76
Single Unit Truck	0.13	0.12	-4.96
Total Carbon (metric tons per capita)	1.28	1.31	2.36
Per GMP Carbon Footprints			
Autos	n.a.	20.89	n.a.
Trucks	n.a.	6.34	n.a.
Combination Truck	n.a.	3.86	n.a.
Single Unit Truck	n.a.	2.48	n.a.
Total Carbon (metric tons /$million GMP)	n.a.	27.22	n.a.

Notes: n.a. = GMP data not available for 2000

The per capita results show that residents of the nation's largest metropolitan areas probably consume a little less energy on highway transportation and emit less carbon than the average U.S. resident. Taken across all 100 metro areas the 2005 data yields population weighted averages of 9,079 VMT/capita, 67.3 million Btu/capita and 1.31 metric tons/capita, which equates to a $2005 dollar weighted average of 27.2 metric tons/$ million of Gross Metropolitan Product (GMP). These numbers compare with the above reported national average estimates of 1.45 metric tons/capita and a computed 34.3 metric tons/$million GDP.

Noting that 74 percent of the nation's $12,531 billion GDP in $2005 is assigned to the top 100 metropolitan areas, our 100 metro area carbon emission averages are respectively 11 percent lower per capita and 26 percent lower per $2005 GDP (GMP) than these national averages. Figure 3 shows these comparisons between U.S averages and the averages for the largest 100 metros for 2005. *Note, however, that we have no immediate method for assigning statistical significance to these differences, given that the national numbers are taken from Highway Statistics which, while also based on the National Highway Performance System data we used to compute metro results, reports only averaged mpg and fuel use figures for autos and trucks at the national level.*

[8] This GMP data can be found at: http://www.bea.gov/newsreleases/regional/gdp_metro/gdp_metro_newsrelease.htm

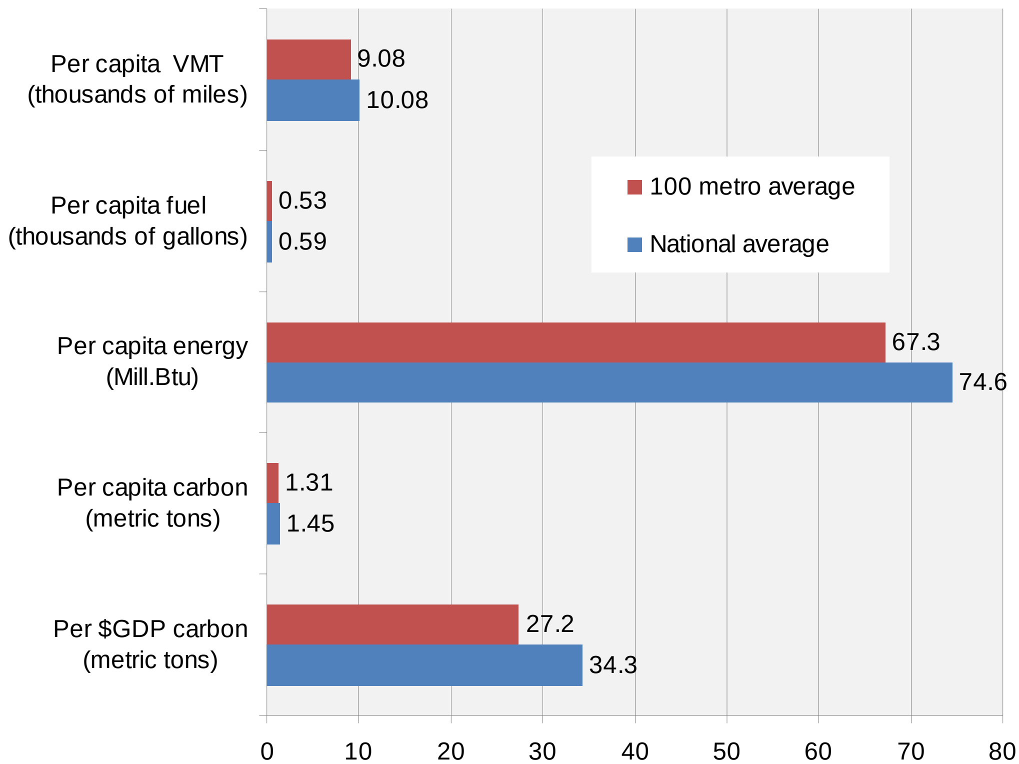


Figure 3: Footprint Comparisons: U.S. vs. Largest 100 Metros, 2005.

4. The Metro Area Specific Results

4.1 Metro Specific Carbon Footprints

Energy and carbon footprints can vary for a variety of reasons based on economic activity, lifestyles, geography, climate and prosperity. This section describes and discusses the range of results we obtained for the nation's largest 100 metropolitan areas. Figure 4 shows the location of these areas. Significant differences in carbon footprints were found to exist across the 100 metro areas when measured on a per person or per $GMP basis.

Focusing first on the 2005 data, Table 5a shows the annual total (auto plus truck) VMT, fuel use, Btu and carbon emissions totals for all 100 metro areas, in alphabetical order. Table 5b again lists these total carbon emission estimates for each of the 100 metro areas, this time along with their auto and truck shares. For each metro area estimates are supplied for a) total (i.e. auto plus truck) highway travel, b) autos, c) total trucks, d) single unit trucks, and e) combination trucks. Table 5c shows these same results on a per capita basis. Finally, Table 5d provides a comparison of the year 2005 total (auto plus truck) annual and per capita carbon emissions with the same statistics for year 2000.

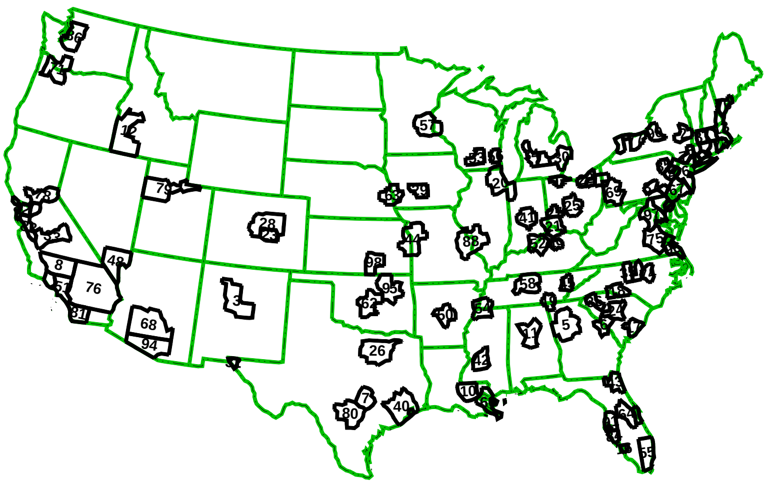


Figure 4. Map of the Top 100 Metropolitan Areas

1 Akron, OH
2 Albany-Schenectady-Troy, NY
3 Albuquerque, NM
4 Allentown-Bethlehem-Easton, PA-NJ
5 Atlanta-Sandy Springs-Marietta, GA
6 Augusta-Richmond County, GA-SC
7 Austin-Round Rock, TX
8 Bakersfield, CA
9 Baltimore-Towson, MD
10 Baton Rouge, LA
11 Birmingham-Hoover, AL
12 Boise City-Nampa, ID
13 Boston-Cambridge-Quincy, MA-NH
14 Bridgeport-Stamford-Norwalk, CT
15 Buffalo-Niagara Falls, NY
16 Cape Coral-Fort Myers, FL
17 Charleston-North Charleston, SC
18 Charlotte-Gastonia-Concord, NC-SC
19 Chattanooga, TN-GA
20 Chicago-Naperville-Joliet, IL-IN-WI
21 Cincinnati-Middletown, OH-KY-IN
22 Cleveland-Elyria-Mentor, OH
23 Colorado Springs, CO
24 Columbia, SC
25 Columbus, OH
26 Dallas-Fort Worth-Arlington, TX
27 Dayton, OH
28 Denver-Aurora, CO
29 Des Moines, IA
30 Detroit-Warren-Livonia, MI
31 Durham, NC
32 El Paso, TX
33 Fresno, CA
34 Grand Rapids-Wyoming, MI
35 Greensboro-High Point, NC
36 Greenville, SC
37 Harrisburg-Carlisle, PA
38 Hartford-West Hartford-East Hartford, CT
39 Honolulu, HI
40 Houston-Sugar Land-Baytown, TX
41 Indianapolis, IN
42 Jackson, MS
43 Jacksonville, FL
44 Kansas City, MO-KS
45 Knoxville, TN
46 Lancaster, PA
47 Lansing-East Lansing, MI
48 Las Vegas-Paradise, NV
49 Lexington-Fayette, KY
50 Little Rock-North Little Rock, AR
51 Los Angeles-Long Beach-Santa Ana, CA
52 Louisville, KY-IN
53 Madison, WI
54 Memphis, TN-MS-AR
55 Miami-Fort Lauderdale-Miami Beach, FL
56 Milwaukee-Waukesha-West Allis, WI
57 Minneapolis-St. Paul-Bloomington, MN-WI
58 Nashville-Davidson--Murfreesboro, TN
59 New Haven-Milford, CT
60 New Orleans-Metairie-Kenner, LA
61 New York-Northern New Jersey-Long Island, NY-NJ-PA
62 Oklahoma City, OK
63 Omaha-Council Bluffs, NE-IA
64 Orlando-Kissimmee, FL
65 Oxnard-Thousand Oaks-Ventura, CA
66 Palm Bay-Melbourne-Titusville, FL
67 Philadelphia-Camden-Wilmington, PA-NJ-DE-MD
68 Phoenix-Mesa-Scottsdale, AZ
69 Pittsburgh, PA
70 Portland-South Portland-Biddeford, ME
71 Portland-Vancouver-Beaverton, OR-WA
72 Poughkeepsie-Newburgh-Middletown, NY
73 Providence-New Bedford-Fall River, RI-MA
74 Raleigh-Cary, NC
75 Richmond, VA
76 Riverside-San Bernardino-Ontario, CA
77 Rochester, NY
78 Sacramento--Arden-Arcade--Roseville, CA
79 Salt Lake City, UT
80 San Antonio, TX
81 San Diego-Carlsbad-San Marcos, CA
82 San Francisco-Oakland-Fremont, CA
83 San Jose-Sunnyvale-Santa Clara, CA
84 Sarasota-Bradenton-Venice, FL
85 Scranton--Wilkes-Barre, PA
86 Seattle-Tacoma-Bellevue, WA
87 Springfield, MA
88 St. Louis, MO-IL
89 Stockton, CA
90 Syracuse, NY
91 Tampa-St. Petersburg-Clearwater, FL
92 Toledo, OH
93 Trenton-Ewing, NJ
94 Tucson, AZ
95 Tulsa, OK
96 Virginia Beach-Norfolk-Newport News, VA-NC
97 Washington-Arlington-Alexandria, DC-VA-MD-WV
98 Wichita, KS
99 Worcester, MA
100 Youngstown-Warren-Boardman, OH-PA

Table 5a. 2005 Annual VMT, Fuel Use, Btu and Carbon Emissions

METRO	*VMT (million)*	*Fuel (million gallons)*	*BTU (billion)*	*Carbon (million metric tons)*
Akron, OH	6,528.8	388.8	49,361.7	0.962
Albany-Schenectady-Troy, NY	9,306.9	536.9	67,868.1	1.321
Albuquerque, NM	7,364.3	458.5	58,491.5	1.141
Allentown-Bethlehem-Easton, PA-NJ	6,989.0	425.1	54,127.9	1.056
Atlanta-Sandy Springs-Marietta, GA	55,685.7	3,288.0	417,012.7	8.123
Augusta-Richmond County, GA-SC	5,936.2	362.5	46,190.9	0.901
Austin-Round Rock, TX	14,867.5	891.9	113,293.9	2.208
Bakersfield, CA	9,938.3	656.8	84,691.2	1.657
Baltimore-Towson, MD	25,136.8	1,458.0	184,537.5	3.593
Baton Rouge, LA	6,537.8	402.7	51,397.4	1.003
Birmingham-Hoover, AL	13,086.1	774.8	98,156.1	1.911
Boise City-Nampa, ID	4,012.9	234.9	29,675.1	0.577
Boston-Cambridge-Quincy, MA-NH	33,851.5	1,873.3	235,324.4	4.572
Bridgeport-Stamford-Norwalk, CT	7,713.5	438.2	55,254.6	1.075
Buffalo-Niagara Falls, NY	8,089.4	458.5	57,797.5	1.124
Cape Coral-Fort Myers, FL	6,858.2	398.4	50,505.5	0.984
Charleston-North Charleston, SC	6,394.2	389.9	49,672.7	0.969
Charlotte-Gastonia-Concord, NC-SC	17,566.4	1,057.9	134,567.8	2.624
Chattanooga, TN-GA	5,905.2	366.6	46,812.0	0.914
Chicago-Naperville-Joliet, IL-IN-WI	71,232.1	4,311.5	548,501.6	10.694
Cincinnati-Middletown, OH-KY-IN	21,857.0	1,326.9	168,900.0	3.293
Cleveland-Elyria-Mentor, OH	15,940.9	925.6	117,055.1	2.278
Colorado Springs, CO	4,791.1	266.5	33,481.1	0.650
Columbia, SC	7,843.2	490.3	62,667.6	1.223
Columbus, OH	18,516.6	1,134.4	144,574.1	2.820
Dallas-Fort Worth-Arlington, TX	56,443.6	3,318.6	420,336.1	8.185
Dayton, OH	7,086.5	444.1	56,778.1	1.108
Denver-Aurora, CO	23,256.0	1,318.0	166,054.8	3.229
Des Moines, IA	5,592.4	325.2	41,091.3	0.800
Detroit-Warren-Livonia, MI	44,605.4	2,477.3	310,869.7	6.037
Durham, NC	4,709.7	283.6	36,087.5	0.704
El Paso, TX	5,461.9	328.8	41,792.3	0.815
Fresno, CA	9,631.1	594.0	75,875.3	1.481
Grand Rapids-Wyoming, MI	8,205.2	480.4	60,776.2	1.183
Greensboro-High Point, NC	6,876.0	413.7	52,634.0	1.026
Greenville, SC	4,658.2	275.2	34,893.4	0.680
Harrisburg-Carlisle, PA	6,555.3	423.5	54,368.2	1.063
Hartford-West Hartford-East Hartford, CT	10,995.6	631.4	79,749.3	1.552
Honolulu, HI	6,043.5	317.5	39,541.9	0.766
Houston-Sugar Land-Baytown, TX	49,073.4	2,846.4	359,820.0	7.003
Indianapolis, IN	17,674.8	1,134.3	145,402.0	2.841
Jackson, MS	7,155.6	435.6	55,385.8	1.080
Jacksonville, FL	16,421.9	960.1	121,799.8	2.373
Kansas City, MO-KS	20,859.1	1,276.1	162,539.7	3.170
Knoxville, TN	8,368.1	495.5	62,864.2	1.225
Lancaster, PA	3,413.6	203.8	25,889.6	0.505
Lansing-East Lansing, MI	5,103.2	303.6	38,496.7	0.750
Las Vegas-Paradise, NV	12,663.1	719.9	90,690.7	1.763
Lexington-Fayette, KY	4,549.1	297.6	38,246.7	0.748
Little Rock-North Little Rock, AR	7,919.4	512.2	65,728.0	1.285
Los Angeles-Long Beach-Santa Ana, CA	99,231.4	5,429.8	680,716.6	13.217
Louisville, KY-IN	12,877.3	822.5	105,341.1	2.058
Madison, WI	6,597.4	393.7	49,987.6	0.974
Memphis, TN-MS-AR	13,694.2	854.1	108,981.3	2.126

Table 5a continued…

Miami-Fort Lauderdale-Miami Beach, FL	50,179.0	2,858.0	360,980.5	7.024
Milwaukee-Waukesha-West Allis, WI	13,947.0	804.6	101,644.9	1.978
Minneapolis-St. Paul-Bloomington, MN-WI	30,106.8	1,723.4	217,362.9	4.228
Nashville-Davidson--Murfreesboro, TN	17,444.8	1,076.8	137,387.7	2.681
New Haven-Milford, CT	6,566.6	378.7	47,854.0	0.931
New Orleans-Metairie-Kenner, LA	9,803.4	612.0	78,252.7	1.528
New York-Northern New Jersey-Long Island, NY-NJ-PA	110,810.4	6,320.6	797,595.3	15.515
Oklahoma City, OK	14,235.3	859.6	109,365.2	2.132
Omaha-Council Bluffs, NE-IA	8,456.7	514.1	65,322.2	1.273
Orlando-Kissimmee, FL	22,574.2	1,317.1	167,020.5	3.253
Oxnard-Thousand Oaks-Ventura, CA	7,890.5	442.8	55,738.8	1.083
Palm Bay-Melbourne-Titusville, FL	6,348.1	375.3	47,701.4	0.930
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	41,158.0	2,408.9	305,044.7	5.940
Phoenix-Mesa-Scottsdale, AZ	35,285.2	2,197.1	280,930.5	5.485
Pittsburgh, PA	19,506.3	1,144.0	144,903.8	2.822
Portland-South Portland-Biddeford, ME	5,058.3	299.6	37,994.4	0.740
Portland-Vancouver-Beaverton, OR-WA	16,021.7	901.8	113,552.2	2.207
Poughkeepsie-Newburgh-Middletown, NY	6,013.1	354.1	44,860.1	0.874
Providence-New Bedford-Fall River, RI-MA	14,222.0	777.3	97,430.5	1.892
Raleigh-Cary, NC	11,207.0	673.1	85,627.1	1.669
Richmond, VA	14,044.3	826.4	104,727.5	2.040
Riverside-San Bernardino-Ontario, CA	48,121.2	2,958.9	377,706.5	7.371
Rochester, NY	7,316.2	403.9	50,702.8	0.985
Sacramento--Arden-Arcade--Roseville, CA	19,486.0	1,117.9	141,220.5	2.748
Salt Lake City, UT	9,775.1	618.0	79,093.7	1.545
San Antonio, TX	16,404.6	961.0	121,659.0	2.369
San Diego-Carlsbad-San Marcos, CA	27,788.3	1,529.9	192,010.5	3.729
San Francisco-Oakland-Fremont, CA	36,506.5	2,033.8	255,715.9	4.969
San Jose-Sunnyvale-Santa Clara, CA	15,495.9	854.1	107,261.6	2.084
Sarasota-Bradenton-Venice, FL	8,549.0	513.5	65,321.6	1.274
Scranton--Wilkes-Barre, PA	5,285.2	335.9	42,978.5	0.839
Seattle-Tacoma-Bellevue, WA	27,435.7	1,566.8	197,854.8	3.849
Springfield, MA	5,649.0	313.6	39,370.2	0.765
St. Louis, MO-IL	32,029.5	1,916.1	243,684.8	4.750
Stockton, CA	6,815.9	430.7	55,203.1	1.078
Syracuse, NY	7,770.6	453.8	57,464.4	1.119
Tampa-St. Petersburg-Clearwater, FL	28,707.3	1,628.9	205,624.4	4.000
Toledo, OH	7,749.8	520.7	67,170.2	1.315
Trenton-Ewing, NJ	4,851.9	279.3	35,305.0	0.687
Tucson, AZ	8,259.3	516.2	66,038.7	1.289
Tulsa, OK	10,486.9	611.4	77,370.1	1.506
Virginia Beach-Norfolk-Newport News, VA-NC	14,170.7	773.1	96,845.9	1.880
Washington-Arlington-Alexandria, DC-VA-MD-WV	45,393.2	2,494.1	312,915.6	6.077
Wichita, KS	5,421.6	323.8	41,048.5	0.800
Worcester, MA	8,489.3	472.9	59,460.1	1.155
Youngstown-Warren-Boardman, OH-PA	5,753.4	367.7	47,147.6	0.921
Total Top 100 Metros	1,752,262.2	102,494.9	12,980,127.4	252.743

Table 5b. 2005 Carbon Emissions by Metro Area and Vehicle Class

	Million metric tons of carbon emitted annually				
METRO	*Total*	*Auto*	*Total Trucks*	*SU-Trucks*	*Comb. Trucks*
Akron, OH	0.962	0.718	0.244	0.081	0.163
Albany-Schenectady-Troy, NY	1.321	1.043	0.278	0.117	0.161
Albuquerque, NM	1.141	0.789	0.352	0.140	0.212
Allentown-Bethlehem-Easton, PA-NJ	1.056	0.761	0.294	0.116	0.178
Atlanta-Sandy Springs-Marietta, GA	8.123	6.084	2.039	0.969	1.070
Augusta-Richmond County, GA-SC	0.901	0.635	0.266	0.102	0.164
Austin-Round Rock, TX	2.208	1.628	0.579	0.228	0.351
Bakersfield, CA	1.657	0.987	0.671	0.197	0.474
Baltimore-Towson, MD	3.593	2.768	0.824	0.388	0.436
Baton Rouge, LA	1.003	0.699	0.304	0.113	0.191
Birmingham-Hoover, AL	1.911	1.453	0.458	0.195	0.264
Boise City-Nampa, ID	0.577	0.452	0.125	0.050	0.075
Boston-Cambridge-Quincy, MA-NH	4.572	3.879	0.693	0.342	0.351
Bridgeport-Stamford-Norwalk, CT	1.075	0.876	0.198	0.075	0.124
Buffalo-Niagara Falls, NY	1.124	0.917	0.207	0.095	0.112
Cape Coral-Fort Myers, FL	0.984	0.747	0.237	0.145	0.092
Charleston-North Charleston, SC	0.969	0.695	0.273	0.082	0.192
Charlotte-Gastonia-Concord, NC-SC	2.624	1.912	0.712	0.277	0.435
Chattanooga, TN-GA	0.914	0.626	0.288	0.109	0.179
Chicago-Naperville-Joliet, IL-IN-WI	10.694	7.743	2.951	0.850	2.101
Cincinnati-Middletown, OH-KY-IN	3.293	2.383	0.911	0.248	0.662
Cleveland-Elyria-Mentor, OH	2.278	1.789	0.489	0.145	0.345
Colorado Springs, CO	0.650	0.550	0.101	0.049	0.052
Columbia, SC	1.223	0.841	0.383	0.099	0.284
Columbus, OH	2.820	2.008	0.812	0.208	0.604
Dallas-Fort Worth-Arlington, TX	8.185	6.294	1.891	0.566	1.326
Dayton, OH	1.108	0.755	0.353	0.101	0.252
Denver-Aurora, CO	3.229	2.636	0.593	0.268	0.324
Des Moines, IA	0.800	0.631	0.169	0.050	0.118
Detroit-Warren-Livonia, MI	6.037	5.065	0.972	0.440	0.532
Durham, NC	0.704	0.510	0.193	0.075	0.119
El Paso, TX	0.815	0.598	0.216	0.073	0.143
Fresno, CA	1.481	1.006	0.475	0.180	0.295
Grand Rapids-Wyoming, MI	1.183	0.922	0.261	0.081	0.180
Greensboro-High Point, NC	1.026	0.744	0.282	0.117	0.165
Greenville, SC	0.680	0.516	0.164	0.062	0.102
Harrisburg-Carlisle, PA	1.063	0.687	0.375	0.110	0.265
Hartford-West Hartford-East Hartford, CT	1.552	1.240	0.312	0.113	0.199
Honolulu, HI	0.766	0.711	0.055	0.036	0.019
Houston-Sugar Land-Baytown, TX	7.003	5.513	1.490	0.486	1.004
Indianapolis, IN	2.841	1.849	0.992	0.267	0.725
Jackson, MS	1.080	0.760	0.320	0.134	0.186
Jacksonville, FL	2.373	1.791	0.582	0.276	0.306
Kansas City, MO-KS	3.170	2.253	0.917	0.343	0.574
Knoxville, TN	1.225	0.920	0.305	0.097	0.208
Lancaster, PA	0.505	0.376	0.129	0.051	0.078
Lansing-East Lansing, MI	0.750	0.567	0.183	0.059	0.124
Las Vegas-Paradise, NV	1.763	1.445	0.318	0.109	0.210
Lexington-Fayette, KY	0.748	0.473	0.275	0.077	0.198
Little Rock-North Little Rock, AR	1.285	0.831	0.454	0.091	0.363
Los Angeles-Long Beach-Santa Ana, CA	13.217	11.413	1.803	0.835	0.968
Louisville, KY-IN	2.058	1.366	0.691	0.215	0.477
Madison, WI	0.974	0.727	0.247	0.090	0.158
Memphis, TN-MS-AR	2.126	1.460	0.666	0.171	0.496

Table 5b continued….

Miami-Fort Lauderdale-Miami Beach, FL	7.024	5.591	1.432	0.786	0.646
Milwaukee-Waukesha-West Allis, WI	1.978	1.567	0.410	0.171	0.239
Minneapolis-St. Paul-Bloomington, MN-WI	4.228	3.425	0.803	0.251	0.551
Nashville-Davidson--Murfreesboro, TN	2.681	1.875	0.806	0.212	0.594
New Haven-Milford, CT	0.931	0.740	0.191	0.065	0.127
New Orleans-Metairie-Kenner, LA	1.528	1.037	0.491	0.185	0.306
New York-Northern New Jersey-Long Island, NY-NJ-PA	15.515	12.493	3.022	1.416	1.606
Oklahoma City, OK	2.132	1.525	0.607	0.249	0.358
Omaha-Council Bluffs, NE-IA	1.273	0.932	0.341	0.111	0.230
Orlando-Kissimmee, FL	3.253	2.466	0.788	0.414	0.373
Oxnard-Thousand Oaks-Ventura, CA	1.083	0.889	0.195	0.095	0.100
Palm Bay-Melbourne-Titusville, FL	0.930	0.684	0.245	0.131	0.114
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	5.940	4.583	1.357	0.657	0.699
Phoenix-Mesa-Scottsdale, AZ	5.485	3.646	1.839	0.745	1.093
Pittsburgh, PA	2.822	2.174	0.648	0.285	0.363
Portland-South Portland-Biddeford, ME	0.740	0.563	0.177	0.069	0.109
Portland-Vancouver-Beaverton, OR-WA	2.207	1.802	0.405	0.188	0.217
Poughkeepsie-Newburgh-Middletown, NY	0.874	0.674	0.200	0.049	0.151
Providence-New Bedford-Fall River, RI-MA	1.892	1.643	0.249	0.113	0.136
Raleigh-Cary, NC	1.669	1.215	0.454	0.185	0.270
Richmond, VA	2.040	1.566	0.474	0.126	0.347
Riverside-San Bernardino-Ontario, CA	7.371	5.042	2.329	0.954	1.375
Rochester, NY	0.985	0.842	0.143	0.072	0.071
Sacramento--Arden-Arcade--Roseville, CA	2.748	2.171	0.577	0.210	0.367
Salt Lake City, UT	1.545	1.026	0.518	0.216	0.302
San Antonio, TX	2.369	1.829	0.539	0.191	0.349
San Diego-Carlsbad-San Marcos, CA	3.729	3.165	0.564	0.324	0.240
San Francisco-Oakland-Fremont, CA	4.969	4.150	0.819	0.340	0.479
San Jose-Sunnyvale-Santa Clara, CA	2.084	1.777	0.307	0.148	0.159
Sarasota-Bradenton-Venice, FL	1.274	0.927	0.346	0.169	0.178
Scranton--Wilkes-Barre, PA	0.839	0.557	0.283	0.099	0.183
Seattle-Tacoma-Bellevue, WA	3.849	3.062	0.787	0.419	0.368
Springfield, MA	0.765	0.651	0.114	0.053	0.061
St. Louis, MO-IL	4.750	3.435	1.315	0.484	0.831
Stockton, CA	1.078	0.704	0.374	0.112	0.262
Syracuse, NY	1.119	0.867	0.252	0.086	0.166
Tampa-St. Petersburg-Clearwater, FL	4.000	3.208	0.793	0.411	0.382
Toledo, OH	1.315	0.780	0.534	0.178	0.356
Trenton-Ewing, NJ	0.687	0.543	0.144	0.066	0.078
Tucson, AZ	1.289	0.855	0.435	0.158	0.277
Tulsa, OK	1.506	1.156	0.350	0.150	0.200
Virginia Beach-Norfolk-Newport News, VA-NC	1.880	1.648	0.232	0.095	0.136
Washington-Arlington-Alexandria, DC-VA-MD-WV	6.077	5.167	0.910	0.372	0.538
Wichita, KS	0.800	0.603	0.196	0.062	0.134
Worcester, MA	1.155	0.971	0.185	0.079	0.105
Youngstown-Warren-Boardman, OH-PA	0.921	0.600	0.322	0.107	0.214
Total Top 100 Metros	252.74	193.87	58.88	23.05	35.83

Table 5c. 2005 Carbon Emissions Per Capita by Metro Area and Vehicle Class

	Annual tons of carbon emitted per person				
METRO	*Total*	*Auto*	*Total Truck*	*SU Truck*	*Comb. Truck*
Akron, OH	1.371	1.023	0.348	0.115	0.233
Albany-Schenectady-Troy, NY	1.559	1.231	0.328	0.138	0.190
Albuquerque, NM	1.431	0.990	0.442	0.176	0.265
Allentown-Bethlehem-Easton, PA-NJ	1.337	0.964	0.373	0.147	0.226
Atlanta-Sandy Springs-Marietta, GA	1.634	1.224	0.410	0.195	0.215
Augusta-Richmond County, GA-SC	1.740	1.226	0.514	0.197	0.317
Austin-Round Rock, TX	1.518	1.119	0.398	0.157	0.242
Bakersfield, CA	2.189	1.303	0.886	0.260	0.626
Baltimore-Towson, MD	1.355	1.044	0.311	0.146	0.164
Baton Rouge, LA	1.371	0.956	0.416	0.154	0.261
Birmingham-Hoover, AL	1.756	1.335	0.421	0.179	0.242
Boise City-Nampa, ID	1.059	0.830	0.229	0.091	0.138
Boston-Cambridge-Quincy, MA-NH	1.028	0.872	0.156	0.077	0.079
Bridgeport-Stamford-Norwalk, CT	1.193	0.972	0.220	0.083	0.137
Buffalo-Niagara Falls, NY	0.982	0.801	0.181	0.083	0.098
Cape Coral-Fort Myers, FL	1.808	1.373	0.435	0.266	0.169
Charleston-North Charleston, SC	1.637	1.175	0.462	0.138	0.324
Charlotte-Gastonia-Concord, NC-SC	1.724	1.256	0.468	0.182	0.286
Chattanooga, TN-GA	1.858	1.272	0.586	0.221	0.364
Chicago-Naperville-Joliet, IL-IN-WI	1.132	0.820	0.312	0.090	0.222
Cincinnati-Middletown, OH-KY-IN	1.575	1.140	0.436	0.119	0.317
Cleveland-Elyria-Mentor, OH	1.072	0.842	0.230	0.068	0.162
Colorado Springs, CO	1.109	0.937	0.172	0.083	0.089
Columbia, SC	1.771	1.216	0.554	0.143	0.411
Columbus, OH	1.652	1.176	0.476	0.122	0.354
Dallas-Fort Worth-Arlington, TX	1.406	1.081	0.325	0.097	0.228
Dayton, OH	1.318	0.898	0.420	0.120	0.300
Denver-Aurora, CO	1.367	1.116	0.251	0.114	0.137
Des Moines, IA	1.528	1.206	0.322	0.096	0.226
Detroit-Warren-Livonia, MI	1.348	1.131	0.217	0.098	0.119
Durham, NC	1.542	1.119	0.424	0.164	0.260
El Paso, TX	1.129	0.830	0.300	0.101	0.199
Fresno, CA	1.687	1.146	0.541	0.205	0.336
Grand Rapids-Wyoming, MI	1.536	1.197	0.339	0.105	0.234
Greensboro-High Point, NC	1.522	1.104	0.418	0.174	0.244
Greenville, SC	1.151	0.874	0.277	0.105	0.172
Harrisburg-Carlisle, PA	2.041	1.320	0.721	0.211	0.510
Hartford-West Hartford-East Hartford, CT	1.309	1.046	0.263	0.095	0.168
Honolulu, HI	0.847	0.786	0.061	0.040	0.021
Houston-Baytown-Sugar Land, TX	1.308	1.030	0.278	0.091	0.188
Indianapolis, IN	1.732	1.127	0.605	0.163	0.442
Jackson, MS	2.073	1.459	0.614	0.257	0.357
Jacksonville, FL	1.902	1.435	0.467	0.221	0.245
Kansas City, MO-KS	1.630	1.159	0.471	0.176	0.295
Knoxville, TN	1.867	1.402	0.465	0.148	0.317
Lancaster, PA	1.030	0.767	0.263	0.103	0.159
Lansing-East Lansing, MI	1.649	1.247	0.402	0.129	0.273
Las Vegas-Paradise, NV	1.032	0.845	0.186	0.064	0.123
Lexington-Fayette, KY	1.740	1.101	0.639	0.178	0.461
Little Rock-North Little Rock, AR	1.999	1.293	0.706	0.141	0.565
Los Angeles-Long Beach-Santa Ana, CA	1.022	0.882	0.139	0.065	0.075
Louisville, KY-IN	1.700	1.129	0.571	0.177	0.394
Madison, WI	1.814	1.353	0.461	0.167	0.294
Memphis, TN-MS-AR	1.692	1.162	0.530	0.136	0.394

Table 5c continued….

[redacted]

Table 5d. Auto plus Truck Carbon Emissions for 2000 and 2005.

	carbon emitted			
	2000		2005	
METRO	Annual Total (Million mtc)	Metric tons/ person	Annual Total (Million mtc)	Metric tons/ person
Akron, OH	0.864	1.243	0.962	1.371
Albany-Schenectady-Troy, NY	1.253	1.517	1.321	1.559
Albuquerque, NM	1.086	1.488	1.141	1.431
Allentown-Bethlehem-Easton, PA-NJ	1.020	1.378	1.056	1.337
Atlanta-Sandy Springs-Marietta, GA	7.363	1.733	8.123	1.634
Augusta-Richmond County, GA-SC	0.967	1.935	0.901	1.740
Austin-Round Rock, TX	1.918	1.535	2.208	1.518
Bakersfield, CA	1.598	2.415	1.657	2.189
Baltimore-Towson, MD	3.439	1.347	3.593	1.355
Baton Rouge, LA	0.907	1.285	1.003	1.371
Birmingham-Hoover, AL	1.673	1.590	1.911	1.756
Boise City-Nampa, ID	0.570	1.225	0.577	1.059
Boston-Cambridge-Quincy, MA-NH	4.126	0.939	4.572	1.028
Bridgeport-Stamford-Norwalk, CT	0.946	1.072	1.075	1.193
Buffalo-Niagara Falls, NY	1.149	0.982	1.124	0.982
Cape Coral-Fort Myers, FL	0.592	1.342	0.984	1.808
Charleston-North Charleston, SC	0.825	1.502	0.969	1.637
Charlotte-Gastonia-Concord, NC-SC	2.187	1.644	2.624	1.724
Chattanooga, TN-GA	0.390	0.818	0.914	1.858
Chicago-Naperville-Joliet, IL-IN-WI	10.202	1.121	10.694	1.132
Cincinnati-Middletown, OH-KY-IN	3.044	1.515	3.293	1.575
Cleveland-Elyria-Mentor, OH	2.235	1.040	2.278	1.072
Colorado Springs, CO	0.606	1.127	0.650	1.109
Columbia, SC	1.143	1.767	1.223	1.771
Columbus, OH	2.630	1.631	2.820	1.652
Dallas-Fort Worth-Arlington, TX	8.493	1.645	8.185	1.406
Dayton, OH	1.214	1.431	1.108	1.318
Denver-Aurora, CO	2.750	1.274	3.229	1.367
Des Moines, IA	0.744	1.545	0.800	1.528
Detroit-Warren-Livonia, MI	5.938	1.334	6.037	1.348
Durham, NC	0.538	1.260	0.704	1.542
El Paso, TX	0.906	1.334	0.815	1.129
Fresno, CA	1.404	1.757	1.481	1.687
Grand Rapids-Wyoming, MI	1.225	1.654	1.183	1.536
Greensboro-High Point, NC	0.991	1.540	1.026	1.522
Greenville, SC	0.607	1.084	0.680	1.151
Harrisburg-Carlisle, PA	0.999	1.963	1.063	2.041
Hartford-West Hartford-East Hartford, CT	1.564	1.362	1.552	1.309
Honolulu, HI	0.657	0.749	0.766	0.847
Houston-Sugar Land-Baytown, TX	6.422	1.362	7.003	1.308
Indianapolis, IN	2.981	1.955	2.841	1.732
Jackson, MS	1.024	2.059	1.080	2.073
Jacksonville, FL	2.041	1.818	2.373	1.902
Kansas City, MO-KS	3.156	1.719	3.170	1.630
Knoxville, TN	1.154	1.874	1.225	1.867
Lancaster, PA	0.444	0.944	0.505	1.030
Lansing-East Lansing, MI	0.647	1.445	0.750	1.649
Las Vegas-Paradise, NV	1.497	1.088	1.763	1.032
Lexington-Fayette, KY	0.756	1.851	0.748	1.740
Little Rock-North Little Rock, AR	1.111	1.820	1.285	1.999
Los Angeles-Long Beach-Santa Ana, CA	12.768	1.033	13.217	1.022
Louisville, KY-IN	1.942	1.672	2.058	1.700

Table 5d continued….

Madison, WI	0.888	1.771	0.974	1.814
Memphis, TN-MS-AR	1.891	1.569	2.126	1.692
Miami-Fort Lauderdale-Miami Beach, FL	5.611	1.120	7.024	1.295
Milwaukee-Waukesha-West Allis, WI	2.012	1.341	1.978	1.310
Minneapolis-St. Paul-Bloomington, MN-WI	3.989	1.344	4.228	1.346
Nashville-Davidson--Murfreesboro, TN	2.341	1.784	2.681	1.886
New Haven-Milford, CT	0.877	1.065	0.931	1.103
New Orleans-Metairie-Kenner, LA	1.476	1.121	1.528	1.163
New York-Northern New Jersey-Long Island, NY-NJ-PA	13.431	0.733	15.515	0.825
Oklahoma City, OK	1.970	1.798	2.132	1.846
Omaha-Council Bluffs, NE-IA	1.116	1.455	1.273	1.566
Orlando-Kissimmee, FL	2.347	1.427	3.253	1.684
Oxnard-Thousand Oaks-Ventura, CA	1.082	1.437	1.083	1.361
Palm Bay-Melbourne-Titusville, FL	0.676	1.420	0.930	1.759
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	5.488	0.965	5.940	1.023
Phoenix-Mesa-Scottsdale, AZ	4.377	1.346	5.485	1.414
Pittsburgh, PA	2.864	1.178	2.822	1.185
Portland-South Portland-Biddeford, ME	0.673	1.380	0.740	1.443
Portland-Vancouver-Beaverton, OR-WA	2.173	1.127	2.207	1.053
Poughkeepsie-Newburgh-Middletown, NY	0.892	1.436	0.874	1.309
Providence-New Bedford-Fall River, RI-MA	1.558	0.984	1.892	1.168
Raleigh-Cary, NC	1.288	1.616	1.669	1.754
Richmond, VA	2.141	1.952	2.040	1.738
Riverside-San Bernardino-Ontario, CA	6.868	2.110	7.371	1.885
Rochester, NY	0.956	0.921	0.985	0.950
Sacramento--Arden-Arcade--Roseville, CA	2.639	1.469	2.748	1.346
Salt Lake City, UT	1.301	1.343	1.545	1.476
San Antonio, TX	2.460	1.437	2.369	1.255
San Diego-Carlsbad-San Marcos, CA	3.306	1.175	3.729	1.270
San Francisco-Oakland-Fremont, CA	4.826	1.170	4.969	1.195
San Jose-Sunnyvale-Santa Clara, CA	2.108	1.214	2.084	1.183
Sarasota-Bradenton-Venice, FL	0.706	1.196	1.274	1.897
Scranton--Wilkes-Barre, PA	0.805	1.436	0.839	1.524
Seattle-Tacoma-Bellevue, WA	3.786	1.244	3.849	1.200
Springfield, MA	0.701	1.031	0.765	1.114
St. Louis, MO-IL	4.765	1.766	4.750	1.707
Stockton, CA	0.741	1.315	1.078	1.622
Syracuse, NY	1.079	1.660	1.119	1.720
Tampa-St. Petersburg-Clearwater, FL	2.859	1.193	4.000	1.512
Toledo, OH	1.239	1.880	1.315	2.005
Trenton-Ewing, NJ	0.371	1.057	0.687	1.877
Tucson, AZ	1.091	1.293	1.289	1.394
Tulsa, OK	1.396	1.624	1.506	1.700
Virginia Beach-Norfolk-Newport News, VA-NC	1.955	1.240	1.880	1.145
Washington-Arlington-Alexandria, DC-VA-MD-WV	5.612	1.170	6.077	1.157
Wichita, KS	0.750	1.314	0.800	1.362
Worcester, MA	1.082	1.441	1.155	1.478
Youngstown-Warren-Boardman, OH-PA	0.988	1.639	0.921	1.559
Total Top 100 Metros	232.256	1.279	252.743	1.310

Based on these estimates, Table 6 lists the 10 highest and 10 lowest carbon per capita areas respectively.[9] These per capita statistics range from an auto plus truck total carbon low of 0.825 metric tons per person (the New York – Northern New Jersey area, with its much higher share of public transit riders than other metro areas) to a high of 2.189 metric tons per person (Bakersfield, CA, which has the highest combination truck VMT share and one of the larger overall truck shares of all the 100 metro areas). These same two metros also returned the lowest and highest results for carbon emissions per $GMP (at 72.6 metric tons/$ million GMP and 14.7 metric tons/$ million GMP respectively). However, some re-ranking of the other metro areas takes place within both the top and bottom quarters of the list when comparing per person against per $GMP rates of carbon emission.[10] Table 7 shows these 10 highest and lowest emitters on a per GMP basis.

Table 6. Carbon per Person in 2005: 10 Highest and Lowest Metro Area Emitters

Top 10 Emitters per person	VMT /person	Fuel (gallons/ person)	Btu (million/ person)	Carbon (metric tons/person)	Carbon (metric tons/$ mill GMP)
Bakersfield, CA	13,128.9	867.7	111.9	2.189	72.6
Jackson, MS	13,742.9	836.5	106.4	2.073	53.9
Harrisburg-Carlisle, PA	12,589.6	813.4	104.4	2.041	43.1
Toledo, OH	11,820.6	794.2	102.5	2.005	52.7
Little Rock-North Little Rock, AR	12,323.4	797.1	102.3	1.999	48.5
Jacksonville, FL	13,160.4	769.4	97.6	1.902	45.1
Sarasota-Bradenton-Venice, FL	12,733.6	764.9	97.3	1.897	55.1
Nashville-Davidson--Murfreesboro, TN	12,275.4	757.7	96.7	1.886	39.1
Riverside-San Bernardino-Ontario, CA	12,307.5	756.8	96.6	1.885	72.6
Trenton-Ewing, NJ	13,254.0	763.0	96.4	1.877	31.9
Bottom 10 Emitters per person	***VMT /person***	***Fuel (gallons/ person)***	***Btu (million/ person)***	***Carbon (metric tons/person)***	***Carbon (metric tons/$ mill GMP)***
Portland-Vancouver-Beaverton, OR-WA	7,641.9	430.1	54.2	1.053	23.1
Las Vegas-Paradise, NV	7,408.1	421.2	53.1	1.032	21.9
Lancaster, PA	6,967.4	416.1	52.8	1.030	28.9
Boston-Cambridge-Quincy, MA-NH	7,609.0	421.1	52.9	1.028	17.5
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	7,088.8	414.9	52.5	1.023	20.1
Los Angeles-Long Beach-Santa Ana, CA	7,672.2	419.8	52.6	1.022	20.9
Buffalo-Niagara Falls, NY	7,066.3	400.5	50.5	0.982	28.8
Rochester, NY	7,055.9	389.5	48.9	0.950	23.5
Honolulu, HI	6,680.5	351.0	43.7	0.847	18.6
New York-Northern New Jersey-Long Island, NY-NJ-PA	5,889.9	336.0	42.4	0.825	14.7

Both the per capita and per $GMP results display significant ranges when examined across all 100 metro areas, with a highest/lowest emitter ratio of 2.7 (2.189/0.825) on a per capita basis and a much greater highest/lowest emitter ratio of 4.9 (72.6/14.7) on a per $ million GDP basis. The Top 10 emitters on both a per capita and per $GMP basis also tend to favor smaller MSAs and/or areas with higher contributions from truck VMT to their carbon totals. In contrast, among the lowest emitters per capita and per $GMP are some of our oldest, largest and most densely populated cites: Boston, Los Angeles, New York, Philadelphia, San Francisco and Washington DC. Taken over all 100 metro areas

[9] Complete, sorted tables of all 100 metros are provided in the spreadsheets developed as part of this effort.

[10] Taking each of the 100 metro area results as one observation, metric tons per person was found to have a correlation coefficient of 0.743 against metric tons per $ Mill. GMP.

there is a correlation (R value) of 0.41 between metro area population size and total auto plus truck carbon per capita. There are exceptions at both ends of the spectrum however that warrant further analysis (see Section 4.2 below)

Table 7. Carbon per Million Dollars of Gross Metropolitan Product in 2005: 10 Highest and Lowest Metro Area Emitters

Top 10 Emitters per $ of 2005 GMP	*VMT /person*	*Fuel (gallons/ person)*	*Btu (million/ person)*	*Carbon (metric tons/person)*	*Carbon (metric tons/$ mill GMP)*
Bakersfield, CA	13,128.9	867.7	111.9	2.189	72.6
Riverside-San Bernardino-Ontario, CA	12,307.5	756.8	96.6	1.885	72.6
Stockton, CA	10,252.6	647.9	83.0	1.622	62.5
Fresno, CA	10,968.3	676.5	86.4	1.687	59.1
Palm Bay-Melbourne-Titusville, FL	12,008.4	710.0	90.2	1.759	58.3
Augusta-Richmond County, GA-SC	11,463.0	699.9	89.2	1.740	55.6
Youngstown-Warren-Boardman, OH-PA	9,735.5	622.2	79.8	1.559	55.2
Sarasota-Bradenton-Venice, FL	12,733.6	764.9	97.3	1.897	55.1
Jackson, MS	13,742.9	836.5	106.4	2.073	53.9
Toledo, OH	11,820.6	794.2	102.5	2.005	52.7
Bottom 10 Emitters per $ of 2005 GMP	*VMT /person*	*Fuel (gallons/ person)*	*Btu (million/ person)*	*Carbon (metric tons/person)*	*Carbon (metric tons/$ mill GMP)*
Seattle-Tacoma-Bellevue, WA	8,552.6	488.4	61.7	1.200	21.1
Los Angeles-Long Beach-Santa Ana, CA	7,672.2	419.8	52.6	1.022	20.9
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	7,088.8	414.9	52.5	1.023	20.1
Honolulu, HI	6,680.5	351.0	43.7	0.847	18.6
San Francisco-Oakland-Fremont, CA	8,779.8	489.1	61.5	1.195	18.5
Boston-Cambridge-Quincy, MA-NH	7,609.0	421.1	52.9	1.028	17.5
Washington-Arlington-Alexandria, DC-VA-MD-WV	8,643.6	474.9	59.6	1.157	17.5
San Jose-Sunnyvale-Santa Clara, CA	8,798.7	485.0	60.9	1.183	16.9
Bridgeport-Stamford-Norwalk, CT	8,560.2	486.3	61.3	1.193	14.8
New York-Northern New Jersey-Long Island, NY-NJ-PA	5,889.9	336.0	42.4	0.825	14.7

Figures 5 and 6 graph the per capita and per $GMP statistics ranked from highest to lowest across all of the 100 metro areas, again for the 2005 dataset. Figure 5 shows the range of annual carbon emitted per person and Figure 6 shows carbon emitted per $ million of GMP. In Section 4.2 below we provide a preliminary exploration of the factors that might produce such differences across metro areas, differences that appear to go beyond purely metro area specific data quality issues when evaluated as a set.

Some cautions: Note that the above estimates are based on sample-expanded VMT counts within each metro area, which includes the VMT from only that portion of the many trips which pass through an area. This includes many relatively low mpg combination truck trips, which typically pass through urbanized areas along Interstate routes. This, among other data quality issues, notably the method of designating "metropolitan" areas used by the Census Bureau, should be borne in mind when comparing results across metro areas. This is significant because the combination truck share varies a great deal across the 100 metro areas, from a low of 2.5% (Honolulu, HI) to high of 28.9% (Bakersfield, CA), and for an average metro area carbon contribution of 14.4%. Bakersfield, CA, Toledo, OH, Lexington, KY, Little Rock, AR, Indianapolis, IN and Harrisburg, PA top the list of high combination truck shares. Similarly, total truck

Figure 5. 2005 Carbon Emissions Ranked by Metro Area (metric tons/person)

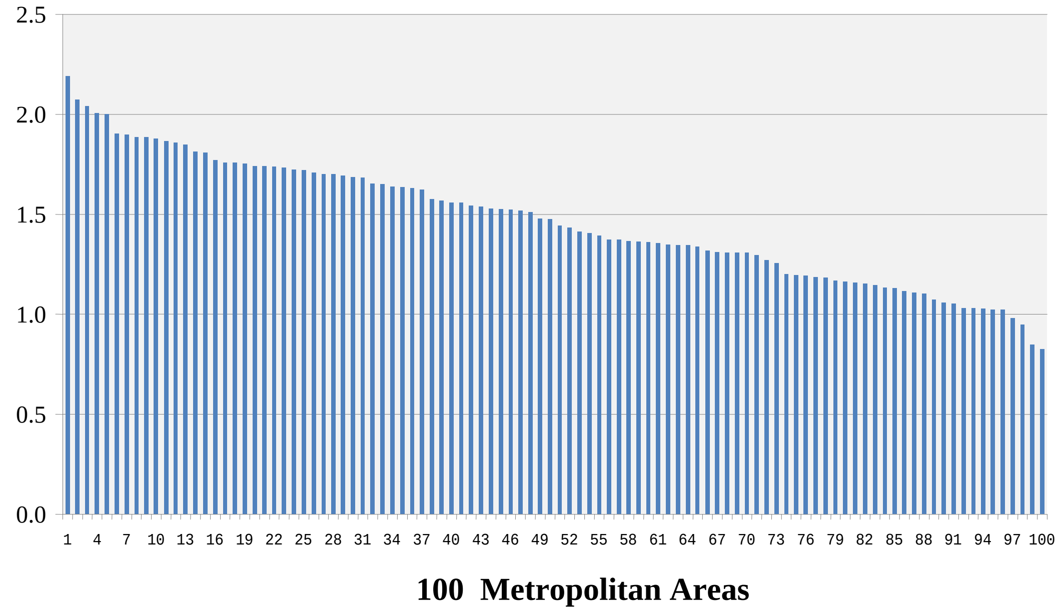
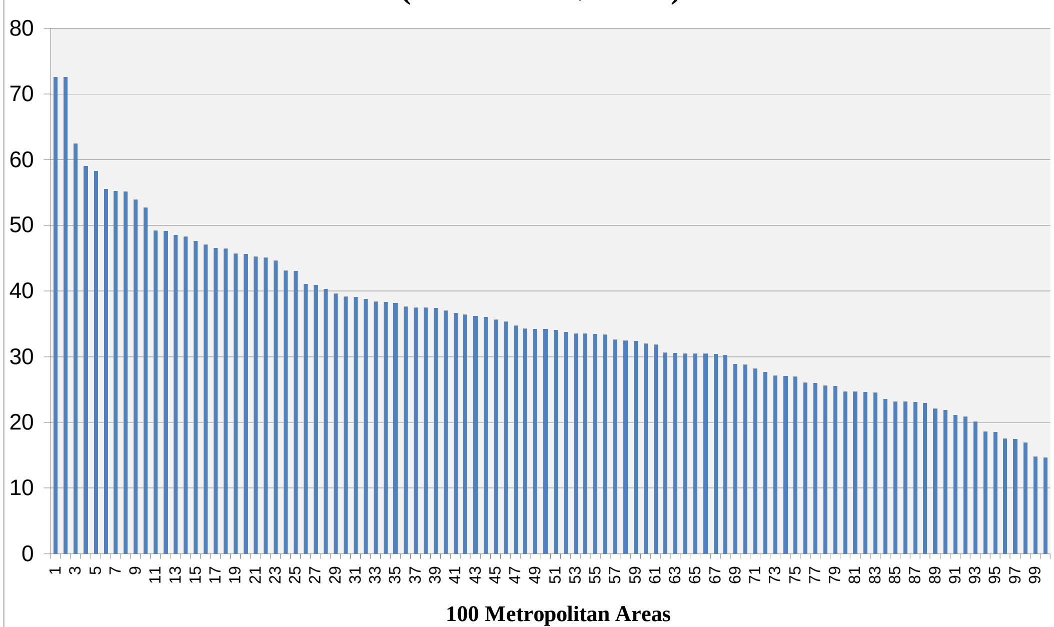


Figure 6. 2005 Carbon Emissions Ranked by Metro Area: (metric tons/$ GMP)



shares vary a good deal, from a low of 7.3% in Honolulu, HI to a high of 41.1% for Toledo, OH. For example, Bakersfield and Toledo both appear among the top ten metro area emitters per capita and per $GMP, while Honolulu appears among the lowest ten. Correlating total carbon per capita against trucking's share of carbon emissions in each metro area yields a positive R value of 0.64 (0.59 for combination trucks). Finally, some noticeable inconsistencies in the freight VMT data appear to exist between 2000 and 2005 for a number of metro areas, notably for Springfield, MA and Trenton, NJ, where freight VMT growth over the 5-year period is much too high and calls into question the data's ability to reflect the actual trend in these cases.

4.2 Carbon Emissions and Urban Form: Some Correlations

In looking for patterns in the differences in carbon emitted per capita and per dollar of GMP across metro areas a number of urban form variables were developed for 97 of the 100 metro areas (one or more data gaps meant that the metropolitan areas of Bridgeport CT, Honolulu HI, and Palm Bay, FL could not be included in the analysis). This analysis is focused here on the 2005 dataset. As noted by Ewing et al (2002), who carried out correlation analysis on aggregate metropolitan area-level data in their study of urban sprawl, such studies cannot establish cause-and-effect relationships. But where statistically significant relationships are found to exist between variables this establishes at least a necessary condition for causality, and one warranting further investigation. Even so, the size and direction of such statistical relationships must be put into proper context. One way to do this is to control for other "confounding" variables, including variables that may prevent a wrong diagnosis between a supposedly "dependent" and "explanatory" variable in some cases. The following statistical analysis therefore represents only an initial excursion into the potential quantitative impacts of urban form factors on carbon emissions from highway travel.

Based on the past literature linking travel, energy consumption and urban form, eighteen different urban form measures were developed, grouped under the following seven headings:

Metropolitan Density
Centrality [Absolute]
Centrality [Relative]
Concentration
Jobs-Housing Balance
Land Cover Mix
Mass Transit Effect

These measures, with the exception of the mass transit effect, were developed and provided to the study by the Brooking Institution, in consultation with the authors. The detailed derivation of each of the urban form measures applied is provided in Appendix C to this report. Among the measures developed, significant correlations were obtained for a subset of eight measures against a number of our carbon, energy and VMT activity per capita and per $GMP estimates. Table 8a shows these correlations for the per capita

Table 8a. Correlations Between Carbon, Btu and VMT per person statistics and Selected Urban Form Variables (N= 97)

	DENP	*DENH*	*DENJ*	*CENTJ10*	*CENTJ35*	*BALC*	*BALZ*	*Rail Transit Dummy*
DENP	1.0000							
DENH	0.9904	1.0000						
DENJ	0.9888	0.9819	1.0000					
CENTJ10	-0.3402	-0.3375	-0.3406	1.0000				
CENTJ35	0.3454	0.3353	0.3375	-0.8548	1.0000			
BALC	0.6116	0.5860	0.6590	-0.2980	0.2507	1.0000		
BALZ	-0.2182	-0.2013	-0.2511	0.0858	-0.1275	-0.0320	1.0000	
Rail Transit Dummy	0.4031	0.4000	0.4072	-0.4144	0.4839	0.2947	-0.2883	1.0000
Total carbon (metric tons/ person)	-0.4917	-0.4850	-0.4833	0.2136	-0.1575	-0.3753	0.0760	-0.3693
Auto carbon (metric tons/ person)	-0.3887	-0.3773	-0.3753	0.1658	-0.1149	-0.3038	0.0046	-0.3047
Total Truck carbon (metric tons/person)	-0.4976	-0.4980	-0.4969	0.2197	-0.1706	-0.3717	0.1408	-0.3590
SU Truck carbon (metric tons/ person)	-0.3857	-0.3659	-0.3970	0.2664	-0.1843	-0.3325	0.0876	-0.3052
Comb. Truck carbon (metric tons/person)	-0.4936	-0.5029	-0.4876	0.1747	-0.1457	-0.3487	0.1494	-0.3440
Total Btu (million/person)	-0.4907	-0.4839	-0.4822	0.2131	-0.1571	-0.3747	0.0746	-0.3688
Auto Btu (million/person)	-0.3887	-0.3773	-0.3753	0.1658	-0.1149	-0.3038	0.0046	-0.3047
Total Truck Btu (million/person)	-0.4977	-0.4980	-0.4970	0.2198	-0.1706	-0.3717	0.1403	-0.3591
SU Truck Btu (million/person)	-0.3864	-0.3669	-0.3977	0.2666	-0.1847	-0.3329	0.0864	-0.3056
Comb.Truck Btu (million/person)	-0.4936	-0.5029	-0.4876	0.1745	-0.1456	-0.3486	0.1494	-0.3440
Total VMT /person	-0.4332	-0.4234	-0.4233	0.1876	-0.1298	-0.3368	0.0331	-0.3323
Auto VMT /person	-0.3835	-0.3712	-0.3688	0.1716	-0.1300	-0.2841	0.0184	-0.3211
Total Truck VMT/person	-0.4630	-0.4628	-0.4687	0.2115	-0.1453	-0.3509	0.1238	-0.3305
SU Truck VMT /person	-0.3500	-0.3370	-0.3647	0.2335	-0.1418	-0.2846	0.0528	-0.2593
Comb.Truck VMT /person	-0.4763	-0.4855	-0.4747	0.1643	-0.1263	-0.3470	0.1569	-0.3333

Table 8b. Correlations Between Carbon, Btu and VMT per $GMP statistics and Selected Urban Form Variables (N= 97)

	DENP	*DENH*	*DENJ*	*CENTJ10*	*CENTJ35*	*BALC*	*BALZ*	*Rail Transit Dummy*
DENP	1.0000							
DENH	0.9904	1.0000						
DENJ	0.9888	0.9819	1.0000					
CENTJ10	-0.3402	-0.3375	-0.3406	1.0000				
CENTJ35	0.3454	0.3353	0.3375	-0.8548	1.0000			
BALC	0.6116	0.5860	0.6590	-0.2980	0.2507	1.0000		
BALZ	-0.2182	-0.2013	-0.2511	0.0858	-0.1275	-0.0320	1.0000	
Rail Transit Dummy	0.4031	0.4000	0.4072	-0.4144	0.4839	0.2947	-0.2883	1.0000
Total carbon (metric tons/$GMP)	-0.4635	-0.4638	-0.5126	0.2053	-0.1909	-0.4232	0.3588	-0.4667
Auto carbon/ (metric tons/ $GMP)	-0.4254	-0.4218	-0.4820	0.1922	-0.1880	-0.4180	0.3723	-0.4773
Total Truck carbon (metric tons/ $GMP)	-0.4580	-0.4638	-0.4899	0.1973	-0.1702	-0.3755	0.2925	-0.3905
SU Truck carbon (metric tons/ $GMP)	-0.3808	-0.3694	-0.4247	0.2526	-0.2008	-0.3639	0.2666	-0.3709
Comb.Truck carbon (metric tons/$GMP)	-0.4627	-0.4765	-0.4865	0.1564	-0.1432	-0.3542	0.2841	-0.3720
Total Btu/$GMP	-0.4631	-0.4633	-0.5124	0.2052	-0.1910	-0.4233	0.3591	-0.4671
Auto Btu/$GMP	-0.4254	-0.4218	-0.4820	0.1922	-0.1880	-0.4180	0.3723	-0.4773
Total Truck Btu/$GMP	-0.4580	-0.4638	-0.4899	0.1974	-0.1703	-0.3755	0.2921	-0.3905
SU Truck Btu/$GMP	-0.3812	-0.3700	-0.4250	0.2527	-0.2011	-0.3639	0.2656	-0.3709
Comb. Truck Btu/$GMP	-0.4627	-0.4764	-0.4865	0.1563	-0.1430	-0.3542	0.2841	-0.3720
Total VMT/$GMP	-0.4380	-0.4359	-0.4926	0.1978	-0.1871	-0.4192	0.3666	-0.4701
Auto VMT/$GMP	-0.4254	-0.4217	-0.4819	0.1923	-0.1882	-0.4177	0.3724	-0.4775
Total Truck VMT/$GMP	-0.4228	-0.4283	-0.4595	0.1912	-0.1531	-0.3540	0.2785	-0.3615
SU Truck VMT/ $GMP	-0.3506	-0.3450	-0.3953	0.2259	-0.1684	-0.3227	0.2338	-0.3283
Comb.Truck VMT/$GMP	-0.4406	-0.4543	-0.4678	0.1470	-0.1275	-0.3464	0.2880	-0.3546

The following definitions apply to each of the eight urban form measures included in these two tables.

carbon, Btu and VMT statistics. To recognize the effects that truck VMT, and in particular combination truck VMT and its generally lower mpg can have on the carbon estimates, results are shown separately for auto, total truck, single unit (SU) and combination (Comb.) truck as well as total (auto + truck) statistics. Table 8b shows the equivalent correlations between these same eight urban form variables and the carbon, Btu and VMT per $GMP statistics, again by vehicle class.

1. DENP: number of persons per acre of developable land area in the metro
2. DENH: number of housing units per acre of developable land area in the metro
3. DENJ: number of jobs per acre of developable land area in the metro
4. CENTJ10: share of metro area jobs within 3-10 mile ring of traditional CBD
5. CENTJ35: share of metro area jobs within 10-35 mile ring of traditional CBD
6. BALC: un-weighted average number of jobs per housing unit, by county
7. BALZ: weighted-average jobs-housing balance, by zip code area
8. Rail Transit Dummy: =1 if the metro area contains > 10 miles of rail transit; = 0 otherwise

As expected, each of the three measures for residential, housing and employment (job) density, themselves highly correlated, yield negative correlations with carbon, Btu and VMT per capita (first three columns of data, Table 7a) and per $GMP (first three columns of data Table 7b). These correlations (R values) range from -0.34 to -0.51 when looked at across all five vehicle classes. Total (auto plus truck) carbon emitted per capita exhibits correlations of -0.492, -0.485 and -0.483 on the average residential, housing and job density employment density measures respectively. Total carbon emitted per $ million of GMP in 2005 exhibits correlations of -0.483, -0.483, and -0.513 on these same three average, metro-area wide density measures. Auto carbon per capita correlations mirror these results but with lower R values around -0.38. Total truck-created carbon per capita correlations produce R values that are, in contrast, a little higher, at just below -0.50.

Figures 7 through 10 contain plots for four selected relationships between measures of urban density and carbon intensity. Figures 7 and 8 provide plots of persons per developable acre (DENP) against annual estimated metric tons of carbon per capita for total (auto plus truck) and for auto only travel respectively. Figures 9 and 10 provide plots of jobs per acre of developable land (DENJ) against the 2005 carbon emitted by trucks (SU plus combination trucks) per person and per emitted $ million of GMP respectively. While the shape of the relationships between carbon and urban density shown in these plots is expected, there is obviously a good deal of variability in the data at specific density levels, indicating the importance of other factors in carbon consumption.

From a number of measures of metro area centrality, varying from simple to comparatively complex indices, that were tried (see Appendix C) the two measures displaying by far the highest correlations with our standardized carbon, Btu and VMT statistics were simple measures of a) the share of jobs found within a 3 to 10 mile ring centered on the metro area's CBD (= CENTJ10) and b) the share of jobs found within a 10-35 mile ring each centered on the metro area's CBD (CENTJ35). Of these two indices, CENTJ10 is positively correlated with carbon, Btu and VMT per capita and per $GMP, with results in the range 0.15 to 0.27: while CENTJ35 is negatively correlated, with results in the range -0.12 to -0.20. The implication here is that more dispersed employment reduces VMT by, presumably, reducing trip distances within the metro area.

Figure 7. Carbon from auto and truck travel within metropolitan areas carbon in 2005 (metric tons/person)

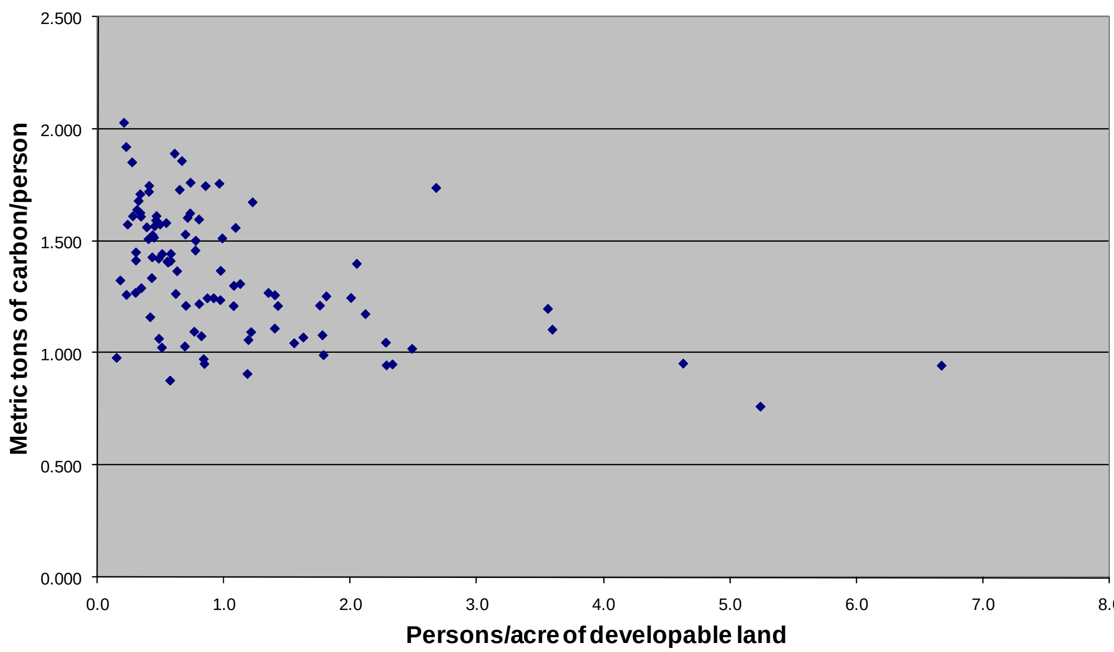


Figure 8. Carbon from auto travel in metropolitan areas in 2005 (metric tons/ person)

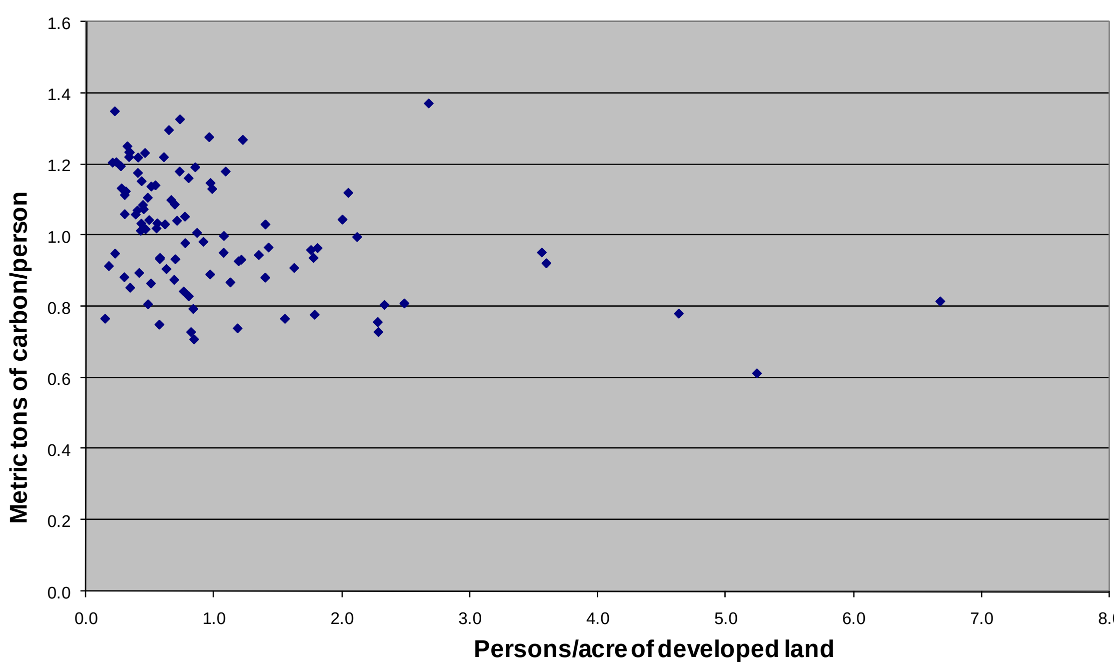


Figure 9. Carbon from truck travel within metropolitan areas in 2005 (metric tons/person)

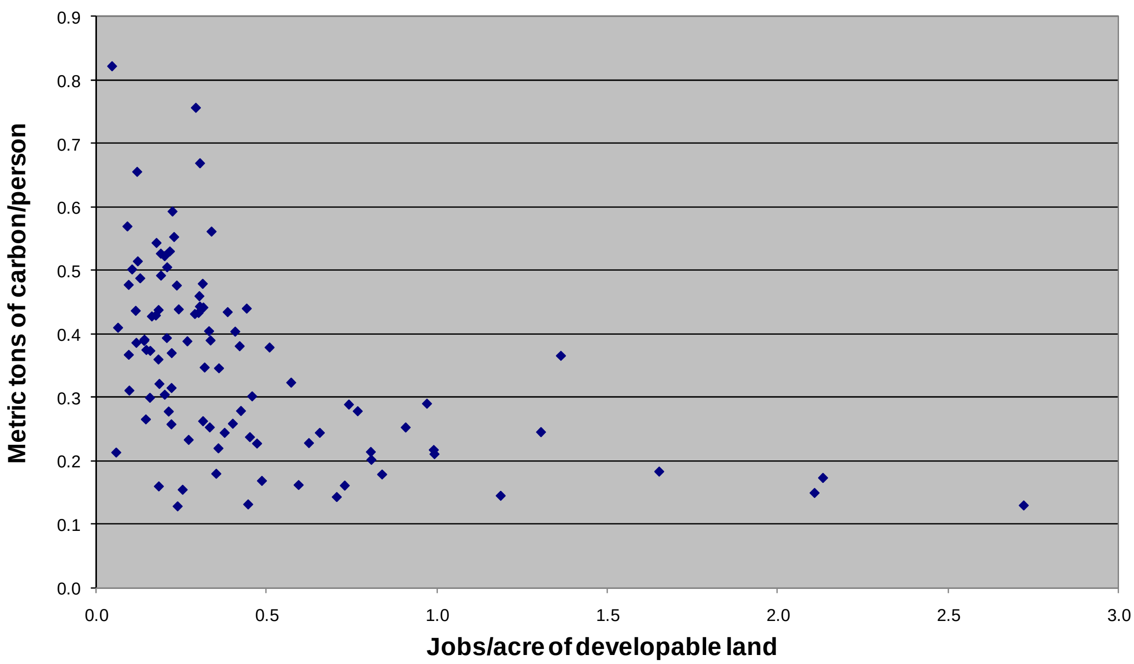
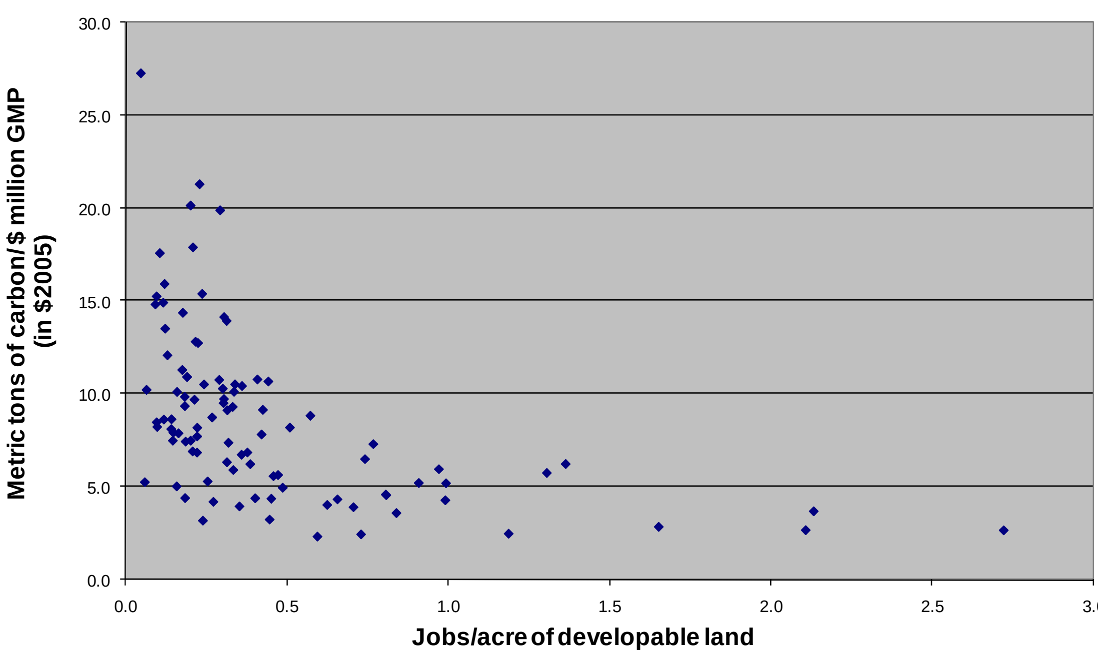


Figure 10. Carbon from truck travel within metropolitan areas in 2005 (metric tons/ $ million GMP)



This could apply to both auto and truck trips to some extent. Again, both of these centrality variables are highly (negatively) correlated with each other (-0.855).
And again, truck carbon per capita displays slightly higher R values, while auto carbon per capita displays slightly lower values than those for total (auto plus truck) carbon per capita produce.

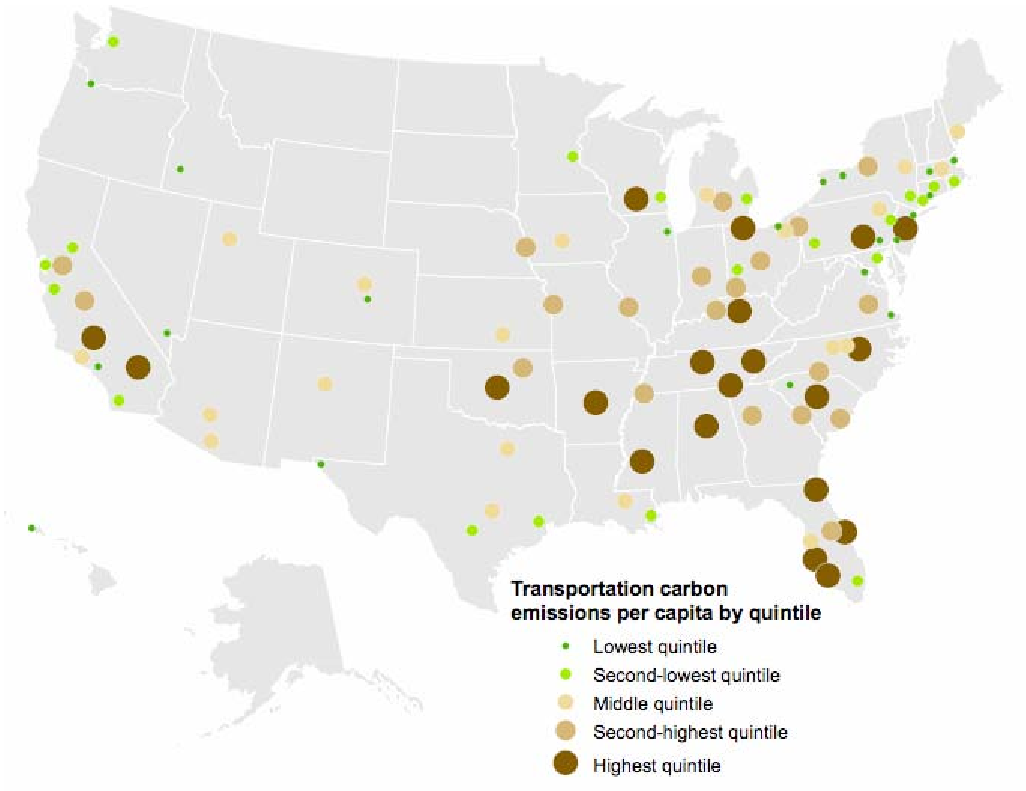
The two jobs-housing spatial imbalance variables, BALC and BALZ, in contrast, show very little correlation with each other (-0.032), indicating that they are measuring two very different phenomena, rather than two very different representations of the same thing. First, BALC, the un-weighted average number of jobs per housing unit by county (weighted provides little correlation) suggests a very broad match of jobs to housing across the entire metropolitan area. It provides negative correlations with all of our five per capita and per $GMP statistics, in the range -0.33 to -0.42, suggesting that a better regional balance offers some savings in VMT, Btu and carbon. The per $GMP correlations here are consistently around 0.04 higher than their per capita counterparts on the BALC measure. In contrast, the zip code area-based BALZ measure shows positive correlations in the range 0.28 to 0.36 across the set of per $GMP statistics. When examined against the carbon, Btu and VMT per person statistics, very little correlation is observed except for some mildly positive correlations involving combination truck and total truck (the latter strongly influenced by the former), in the range 0.14 to 0.15.

The influence of mass transit on highway based carbon footprints, energy consumption and VMT is captured in a very approximate manner by using a (0:1) dummy variable that indicates whether a metro area had at least 10 miles of rail transit (heavy rail, commuter rail or light rail) operating within its boundary in 2005. Thirty of the top 100 metros were identified as a primary regional base for such rail operations. While offering only a very rough approximation of the role of rail transit availability in reducing highway auto VMT, and no doubt also capturing something of both a metro area size and density effect, it exhibits the expected negative correlation with carbon, Btu and VMT per person and per $GMP, in the range -0.31 to -0.48, with the higher correlations associated with the per $GMP statistics.[11]

The influence of rail transit is also apparent in Figure 11, which provides a map of per capita metropolitan carbon footprints based on highway (auto and truck) transportation. The geographic distribution of the lowest carbon emitters shows a clustering in the Northeast where rail transit enjoys strong ridership. Large metropolitan areas on the West Coast and bordering the Great Lakes – home to many of the nation's oldest settlements, many of which have rail transit – also tend to have small transportation carbon footprints.

[11] Without the time or resources to compute actual rail, plus bus plus other transit services fuel consumption per metro area, this dummy variable is seen more as a rough indicator variable reflecting interest in the promotion of public mass transit in each metro area. The empirical results suggest that better variables could be found: or better yet transit carbon, Btu and VMT calculated and added to the auto and truck footprints reported here.

Figure 11. Map of metric tons of highway transportation carbon emissions per capita in 2005



5. Summary

5.1 Major Findings

Carbon footprints have been estimated for passenger automobile and commercial truck travel for each of the 100 largest metropolitan areas in the United States, for the years 2000 and 2005. The average carbon produced per person is estimated to have been just over 1.2 metric tons per year in 2005. This translates into an estimated 27.2 metric tons per million dollars of gross metropolitan product in 2005. Summed over all 100 metro areas the total carbon emitted by autos and trucks is estimated to be 253 million metric tons in 2005, up 8.8 percent since year 2000.

While we note that specific results for any single metropolitan area should be treated with caution, it does appear reasonable to draw the following conclusions for the top 100 metro areas as a set:

- Many of our largest metropolitan areas emit less carbon from auto and truck transportation on a per capita basis, and especially on a per dollar of GMP basis than smaller and non-metro areas.

- Carbon emissions per person and per dollar of GMP vary a good deal across metro areas. The highest area emitter on a per capita basis is 2.7 higher than the lowest emitter. On a per dollar of gross metropolitan product basis the highest area emitter is 4.9 times greater that the lowest emitter.

- A number of urban form variables as measured in this report correlate with the variability in both per capita and per dollar of GMP carbon intensities. A metro area's average density of population, housing and jobs correlates positively with lower carbon emissions. Centrality measures also show mild positive correlation with lower carbon, as does a broad county-based jobs-housing balance measure.

- Metros that act as the primary base for rail transit systems (which are also some of our largest and densest metros) were also found to have lower carbon per capita and per $GMP emissions than metros that don't operate such systems

- Correlations between urban form variables, the need to include other, including control variables, as well as the somewhat arbitrary nature of the metro area boundaries used in the analysis all make it difficult to further explain specific metro area footprints at this level of data aggregation. There is, however, sufficient statistical evidence to warrant more in-depth study of these relationships

- As might be expected, metro areas with a higher percentage of trucking activity (VMT) tend to have higher carbon footprints, especially if their annual vehicle miles of travel profile exhibits a larger than average share of combination truck miles of travel, a good deal of which may involve low mpg trips that either start and/or end outside the metro area's boundaries.

5.2 Some Caveats

The results presented in this report must be treated as approximate and descriptive in nature. The analysis was based on the use of readily available data sets, and in particular on the vehicle miles of travel data supplied by the nation's Highway Performance Monitoring System. The accuracy of the estimates is therefore dependent on this and the other data sources used. In particular, the accuracy of the final carbon estimates depends heavily on the following factors:

- the consistency across the various regions of the country in HPMS traffic count sampling, and the appropriateness of the spatial sampling design when used to factor HPMS traffic counts up to vmt totals on a metropolitan area basis.

- the consistency in Census Bureau defined metropolitan area boundary definitions for present study purposes (based on US county boundaries)
- the impacts of some urban area redefinitions within HPMS, between 2000 and 2005, and the subsequent use of these definitions in the urban-to-metro factoring process, as used in this study to obtain metro-based local vmt sub-totals
- the lack of empirical data on the split of local truck vmt into single-unit versus combination vehicle classes by metro area, and
- the lack of an exact match between the U.S. Vehicle Inventory and Use (VIUS) survey's truck classes, as used to estimate regional miles per gallon, and the truck classes used in HPMS, subsequently aggregated in this study into two broad truck classes.
- The use of VIUS supplied 2002 (rather than 2000 and 2005) data on average truck mpg by vehicle class and fuel category.

6. References

EIA, 2007a. *Annual Energy Outlook 2007*, Washington, DC: Energy Information Administration, DOE/EIA-0383(2007), February, Available at: http://www.eia.doe.gov/oiaf/aeo/

EIA., 2007b. *Alternatives to Traditional Transportation Fuels 2005*, Washington, DC: Energy Information Administration, November, available at: http://www.eia.doe.gov/cneaf/alternate/page/atftables/afvtrans_c1.xls

EIA, 2008. *Annual Energy Outlook 2008*, Washington, DC: Energy Information Administration, DOE/EIA-0383(2008), April, Available at: http://www.eia.doe.gov/oiaf/aeo/

FHWA, *Highway Statistics 2000 and 2005*. Federal Highway Administration. Available at: http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm

Gallivan, F., Ang-Olson, J., and Scroeer, W. 2008. *Innovations in State-led Action to Reduce Greenhouse Gas Emissions from Transportation: The State Climate Action Plan.* Paper presented at TRB Annual Meeting January 13-17, Washington DC.

ORNL, 2007. *Transportation Energy Data Book 26*: Oak Ridge National Laboratory. Oak Ridge, Tennessee.

U.S. EPA (2007) Chapter 2. Trends in US Greenhouse Gas Emissions. Greenhouse Gas Inventory Reports: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. United States Environmental Protection Agency. April 2007.

Appendix A

Methodology for Estimating the Energy and Carbon Footprints from Transportation Energy Consumption in the 100 Largest U.S. Metropolitan Areas

1. Introduction

This appendix describes how the annual vehicle miles of travel activity, gallons of fuel consumed, and associated annual energy and carbon contents of these fuels were estimated, for the nation's 100 largest metro areas, for calendar years 2000 and 2005. These energy and carbon "footprints" are made up of the two major components of carbon dioxide emissions from the transportation sector: automotive and truck traffic activity. A three step process was followed:

1) First, data was gathered and processed to produce estimates of the daily vehicle miles of travel (DVMT) within each metro area.

2) These DVMT estimates were then converted to gallons of fuel consumed, broken down by major fuel types: principally gasoline and petro-diesel but also liquefied petroleum gas (LPG) and other small percentage contributors involved in vehicle operations.

3) This fuel consumption was then in turn converted into a) its equivalent energy content, measured in British thermal units (Btu) and b) its equivalent carbon content, to produce a rough estimate of the carbon footprint created by each metro area's estimated auto and truck vehicular travel activity.

Finally, these representative daily results were multiplied by the number of days in a year to produce annual totals for calendar years 2000 and 2005. The following sections describe each of these steps in turn, listing the data sources and equations used, and noting the assumptions being made at each step. The empirical analysis was carried out using Microsoft Excel spreadsheet software.

2. Calculating Vehicle Miles of Travel

The calculations of the Vehicle-Miles Traveled (VMTs) for the top 100 metro areas are based on two data sources: 1) the Highway Performance Monitoring System (HPMS[12]), which is a national level highway information system maintained by the Federal Highway Administration (FHWA) and which includes data on the condition, performance, use, and operating characteristics of the Nation's highways, and 2) Highway Statistics[13], which is

[12] See http://www.fhwa.dot.gov/policy/ohpi/hpms/index.htm

[13] See http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm

also an FHWA publication, one that brings together data from the HPMS and other sources to produce annual statistical tabulations relating to national and state level highway activity and cost measures.

The HPMS database[14] was used to calculate daily VMT (DVMT) estimates for three types of highway vehicle: passenger vehicles (composed of autos and small trucks, including sports utility vehicles), single unit trucks, and (generally much larger) combination trucks. While these data are usually reported for FHWA designated urbanized areas (UAs), this present study re-processed the raw HPMS data records to capture sampled vehicle counts in those counties making up the study's designated 100 largest metropolitan areas. For the most part these metro areas are larger in geographic extent, and therefore also in driving population, than the UAs reported in Highway Statistics.

For each county (FIPS code) in the metro area the DVMTs were calculated for each road section included in the HPMS database as follows:

$$DVMT_{Total,\ section} = \textit{Section length} * AADT * \textit{Std. Expansion Factor}$$

The Standard Expansion Factor accounts for the fact that traffic counts are only collected on a part of (i.e. on *sections* of) the transportation network, and not for every roadway mile. The HPMS database contains a Standard Expansion Factor for each section. For single unit trucks and combination trucks the DVMTs for each section were then multiplied by their reported traffic share:

$$DVMT_{Single\ Unit,\ section} = DVMT_{Total,\ section} * \%\ \textit{Single Unit [Avg\_Single\_Unit]}$$
$$DVMT_{Combination,\ section} = DVMT_{Total,\ section} * \%\ \textit{Combination [Avg\_Combination]}$$
$$DVMT_{Car,\ section} = DVMT_{Total,\ section} - (DVMT_{Single\ Unit} + DVMT_{Combination})$$

To calculate the total DVMTs for a certain metro area ($DVMT_{METRO,\ TOTAL}$, $DVMT_{METRO,\ CAR}$, $DVMT_{METRO,\ SINGLE\ UNIT}$, $DVMT_{METRO,\ COMBINATION}$) the numbers were aggregated over all sections with a FIPS code in the metro area.

FHWA also supplied the project with separate estimates of "local" highway DVMT traffic for its UAs, for both 2000 and 2005. This is traffic that is not captured by HPMS traffic counters, but which takes place on the many miles of lowest capacity local roads that pass through, for example, many residential areas, and which are effectively "off the network" of collector, arterial, Interstate and other high volume roads captured by the survey data. Manual assignment of each UA to its appropriate metro area was then required, a process that frequently involved summing the local DVMT for a number of different UAs into a single metro area.

[14] The 2005 HPMS database was composed of 119,528 sampled data record. The 2000 HPMS sample contained 113,041 sampled data records

Since FHWA's urbanized areas do not correspond with our metro areas, it was necessary to adjust (typically, expand) these local DVMT estimates to fit our metro areas. To determine this factor we calculate the DVMTs for cars, single unit trucks, and combination trucks for the urbanized areas by using the HPMS database. (This also serves as a useful check on the accuracy of our computations). Next, the DVMTs for the metro areas ($DVMT_{METRO}$) are divided by the total DVMTs for the all of the urban areas falling within a metro area. A second assumption required was the percentage of local DVMT by truck (single unit, combination) type. Our default assumption is that 90 percent of the local trucks are single unit trucks and the other 10 percent are combination trucks. Thus, the local DVMTs for the metro areas are calculated as follows:

$$DVMT_{local,\,METRO,\,TOTAL} = DVMT_{local,\,URBAN} * (DVMT_{METRO,\,TOTAL} / DVMT_{URBAN})$$

$$DVMT_{local,\,METRO,\,CAR} = (DVMT_{METRO,\,CAR} / DVMT_{METRO,\,TOTAL}) * DVMT_{local,\,URBAN} * (DVMT_{METRO,\,TOTAL} / DVMT_{URBAN})$$

$$DVMT_{local,\,METRO,\,SINGLE\ UNIT} = ((DVMT_{METRO,\,SINGLE\ UNIT} + DVMT_{METRO,\,COMBINATION}) / DVMT_{METRO,\,TOTAL}) * DVMT_{local,\,URBAN} * (DVMT_{METRO,\,TOTAL} / DVMT_{URBAN}) * 0.9$$

$$DVMT_{local,\,METRO,\,COMBINATION} = ((DVMT_{METRO,\,SINGLE\ UNIT} + DVMT_{METRO,\,COMBINATION}) / DVMT_{METRO,\,TOTAL}) * DVMT_{local,\,URBAN} * (DVMT_{METRO,\,TOTAL} / DVMT_{URBAN}) * (1 - 0.9)$$

By adding the local DVMTs to the HPMS expanded, traffic count-based DVMTs, the total DVMTs and total annual VMT for each metro area were calculated.

3. Calculating Fuel Consumption

For the calculations of the fuel consumption three data sources were used. Oak Ridge National Laboratory's (ORNL) Transportation Energy Data Book[15] and FHWA's Highway Statistics Publications were used for the calculation of the average fuel consumption for cars. Data from the U.S. Census Bureau's 2002 Vehicle Inventory and Use Survey (VIUS)[16] was combined with data from FHWA's Highway Statistics publication for the calculation of the average fuel consumption for trucks.

Table A.1 in the Transportation Energy Data Book reports the following automobile fuel shares:

Auto Fuel Shares:	2000	2005
Gasoline	0.869	0.669
Gasohol	0.126	0.326
Diesel	0.005	0.005

[15] http://cta.ornl.gov/data/Index.shtml
[16] http://www.census.gov/svsd/www/tiusview.html

Highway Statistics reports the following average miles traveled per gallon of fuel consumed:

Year	Miles Per Gallon
2000	20.1
2005	19.7

These numbers have been used for all three fuel types and are assumed to apply nationwide. By doing this we do not capture differences in the fuel mix across regions. These differences we take to be comparatively small, especially when compared to other possible sources of variation in the available data. However, for trucks, which tend to vary more in fleet characteristics in different parts of the nation, a distinction in fuel efficiency by fuel type was made. The 2002 VIUS database was used here to calculate miles per gallon by fuel type and by state, for both single unit trucks (no trailer) and combination trucks (1 or more trailers).

To calculate the fuel shares for each state, and for both truck classes, the miles traveled using
each fuel type was divided by the total miles, i.e.

Share of Fuel Type X = Reported Truck Miles Using Fuel Type X / Total Reported Truck Miles

The VIUS database classifies fuel consumption in classes based on 2 mpg ranges (5-6.9 mpg, 7-8.9 mpg, etc.) To calculate the average miles traveled per gallon of fuel consumed, for each fuel type the share of miles per mpg class was multiplied by a middle of class mpg number. For example, 8 mpg was taken to represent the fuel efficiency of trucks operating in the 7 – 8.9 mpg range. These values were summed up over all mpg classes, so that:

Avg MPG Fuel Type X = ((Miles ‘mpg class 1’/Total miles fuel type X) Middle value ‘mpg class 1’) + ((Miles ‘mpg class 2’/Total miles fuel type X)* Middle value ‘mpg class 2’) + … etc.*

The VIUS data used was collected in calendar year 2002, while our study focuses on calendar years 2000 and 2005. Therefore adjustments were made to take into account the evidence for trucks becoming more efficient over that five year period. From the VIUS 2002 database a nationwide average mpg of 8.6 for single unit trucks and 6.1 for combination trucks was calculated. The Transportation Data Book (Edition 26, 2007) reports values of 7.4 mpg (for the year 2000) and 8.8 mpg (for the year 2005) for single trucks and values of 5.3 mpg (2000) and 5.9 mpg (2000) for combination trucks. For single unit trucks the values for average mpg were therefore multiplied by a factor 7.4/8.6 (2000) and 8.8/8.6 (2005). For combination trucks the factors 5.3/6.1 and 5.9/6.1 were used. This factor does not vary among different fuel types. Moreover, a similar adjustment factor for fuel type shares was not used as the fuel mix in the nation’s truck fleet was not reported to have changed significantly over this short time horizon.

By multiplying the total DVMTs per vehicle class by the fuel shares and dividing these values by the average mpg's *(which are state dependent for trucks),* the number of gallons of fuel consumed for each metro area was calculated.

4. Calculating Btu and Carbon

For the calculations of Btus and Carbon emissions published numbers for the heat and carbon content for different fuels has been used. For Gasohol the same values have been used as those for gasoline[17]. These numbers are:

Default Energy and Carbon Content Coefficients:

Heat Content for Fuels (Btu/gal)			
Gasoline	Diesel	Gasohol	LPG/Propane
125,000	138,700	120,900	91,300
Carbon Coefficients (Tg/QBtu)			
Gasoline	Diesel	Gasohol	LPG/Propane
19.34	19.95	19.34	16.99

By multiplying the total gallons of fuel consumed by the net heat content the total Btus for each metro area were calculated. Multiplying these numbers by the carbon coefficients (reported in Table 1 as Tg/QBtu, or Teragrams per Quadrillion Btu) gives the transportation carbon footprint for each metro area.

5. Checks for Reasonableness of Estimates

VMT Estimates: Given the approximate nature of the carbon and energy footprints derived, a number of checks on the reasonableness of the estimates produced were carried out. Of most concern is the validity of the spatial sampling of traffic sections within HPMS when aggregated to compute metropolitan area specific numbers. Of note, the metro areas used in this present study are also generally larger that the urbanized areas reported in HPMS and other US DOT publications. Since there is no other single source of VMT data available for all metro (or urbanized) areas in the nation we are for the foreseeable future limited to this dataset as our basis for VMT comparisons. As an initial check that the correct formulas were being used to compute metro area daily vehicle miles of travel (DVMT) totals, the same formulas were used to compute the urban area DVMTs reported in Highway Statistics. A second check compared the DVMT numbers produced for combination and single unit trucks with those supplied to the project by

[17] This approach was based on the description and carbon content numbers reported in the US Energy Information administration's (EIA) "ANNEX B. Methodology for Estimating the Carbon Content of Fossil Fuels" (2002), which reports gasohol as part of its average gasoline carbon content per Btu estimate. http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJQ62/$File/2003-final-inventory_annex_b.pdf

FHWA. Given a satisfactory match in each case the DVMT expansion formulas were then applied to the project's metro area sections. This included factoring FHWA's local highway DVMT statistics for urban areas up to metro area totals.

The following table summarizes the VMT totals derived and their relationship to annual vmt numbers published in Highway Statistics for 2000 and 2005:

Highway Statistics VMT data:	**Year 2000**	**Year 2005**
http://www.fhwa.dot.gov/ohim/hs00/xls/vm2r.xls		
US Total Annual VMT:	2,746,925,000,000	2,989,807,000,000
US Urban Total:	1,663,773,000,000	1,951,870,000,000
Urban VMT Share:	0.61	0.65
http://www.fhwa.dot.gov/ohim/hs00/xls/hm71r.xls		
DVMT (401 UAs in 2000)	3,982,873,000	4,845,312,000
Annual VMT (401 UAs in 2000)	1,453,748,645,000	1,768,538,880,000
UAs VMT Share	0.53	0.59
Data used in this study:		
Top 100 Metro DVMT	4,357,012,872	4,800,718,476
Top 100 Metro Annual VMT	1,590,309,698,354	1,752,262,243,632
100 Metro VMT Share	0.58	0.59

These numbers imply that the study is capturing much of the nation's traffic movement in urban areas and that this metro area traffic is in turn almost sixty percent of all vmt in the nation on an annual basis.

As a further check on the reasonableness of the metro area DVMT figures, the DVMT per capita in each metro area was compared with the DVMT per capita figures reported for urban areas in HPMS (Table 71). These results were found to produce general agreement between UAs and Census defined Metropolitan Areas where the two are similar geographically. Where the two areas differ significantly, however, these statistics show some significant differences, with metro area DVMT/capita in some cases much higher and in others much lower than the DVMT/capita results for urban areas. This results no doubt reflects the effects of urban development patterns and the generally less dense nature of settlement in more peripheral parts of the metro areas. These differences also, therefore, suggest using caution when trying to draw comparisons across metro areas on the basis of such a statistic: since the definition of metro area boundaries with respect to urban development patterns is not consistent across the set of metropolitan areas. It should be noted that the definition of some urban areas also changed in the HPMS/Highway Statistics dataset between 2000 and 2005, so that a significant number of metro area-to-urban area matches contained differently designated urban areas between the two years' of data[18].

Fuels, Btu and Carbon Content: Other government produced or reported estimates of Btus consumed and carbon emitted at the fully national level appear to be consistent with our findings. The US Department of Energy's Transportation Energy Data Book, Table 2.5 reports the following estimates of Btu content of highway fuels consumed for the nation as a whole in 2005 (ORNL, 2007):

The US DOE's Energy Information Administration (EIA) estimates that the United States produced 1,958.6 million metric tons of carbon dioxide annually from transportation sources in 2005 (up from 1,854.mmt in 2000). Multiplying by12/44 to get carbon content this translates into 534.3 million metric tons of carbon. Dividing by a US residential population of 295,885,897 in 2005 this represents an equivalent carbon emissions 1.8 tons per person. Of these emissions approximately 60.3% is attributed to motor gasoline, with approximately 14.4 % attributable to diesel fuelled trucks and autos (ORNL 2007: combining data from Tables 2.5 and 11.5). Adding one more adjustment factor, the vmt data presented above indicates that the metro area share of national vmt is roughly 58.6 percent. Putting these three figures together suggests carbon emissions of roughly 534.2*0.747*0.586 = 233.75 million metric tons of carbon from auto and truck transportation in our 100 metropolitan areas in 2005. The study's empirical analysis produces a figure of 234 mmt for 2005, which is very close to this estimate.

[18] Specific data problems of note: 1) the re-definition of the Miami, Florida county FIPS code, which is given as 12086 in the 2000 HPMS database, and subsequently re-defined to be FIPS code 12025 in the 2005 HPMS dataset; 2) the 2000 DVMT figures for Chattanooga, TN are identified as being unreliable in Highway Statistics 2000 (Table 72).

Appendix B
The Urban Form Measures Developed For This Study

1. Introduction

Sixteen different urban form measures were developed for use in the study. Based on a review of the urban form literature it was decided to develop one or more measures under the following headings:

Metropolitan Density
Centrality [Absolute]
Centrality [Relative]
Concentration
Jobs-Housing Balance
Urban Transit Effect

Each measure is described succinctly below, along with the sources of the data used to create it and references to specific technical works where these provided the original idea for trying a specific type of measure.

2. The Measures

Metropolitan Density

1. DENP: number of persons per acre of developable land area in the metro
2. DENH: number of housing units per acre of developable land area in the metro
3. DENJ: number of jobs per acre of developable land area in the metro

<u>Data Sources</u>: 2000 Census (persons, housing units); 2005 Population Estimates (persons, housing units); 2000 and 2005 County Business Patterns (jobs).

Centrality [Absolute]

4. CENTP3: share of metro population within 3 mile ring of CBD
5. CENTP10: share of metro population within 3-10 mile ring of CBD
6. CENTP35: share of metro population within 10-35 mile ring of CBD
7. CENTJ3: share of metro jobs within 3 mile ring of CBD
8. CENTJ10: share of metro jobs within 3-10 mile ring of CBD
9. CENTJ35: share of metro jobs within 10-35 mile ring of CBD

<u>Data Sources</u>: 2000 Census (population); 2000 Population Estimates (population); 2000 and 2005 Zip Business Patterns (jobs).

Centrality [Relative]

10. CENTPR: averaged difference between cumulative population in ring *n* (as percentage of total population) and the cumulative distance-weighted population in ring *n* (as percentage of total distance-weighted population). See Bento et al. (2005):
11. CENTJR: averaged difference between cumulative jobs in ring *n* (as percentage of total jobs) and the cumulative distance-weighted jobs in ring *n* (as percentage of total distance-weighted jobs) . See Bento et al. (2005):

Data Sources: 2000 Census (population); 2000 Population Estimates (population); 2000 and 2005 Zip Business Patterns (jobs).

Concentration

12. CONCPD: Concentration (delta) index for population
13. CONCJD: Concentration (delta) index for jobs

The concentration (delta) index measures the extent to which persons or jobs are evenly distributed across the metro area. It ranges from 0 to 1, with lower scores representing more concentration of persons or jobs across the metro.

Jobs-Housing Balance

14. BALC: un-weighted average number of jobs per housing unit (by county)

Data Sources: 2000 Census (housing units); 2005 Population Estimates (housing units); 2000 and 2005 County Business Patterns (jobs).

15. BALZ: weighted-average jobs-housing balance (by zip)

Source: Ewing et al. (http://smartgrowthamerica.org/sprawlindex/MeasuringSprawlTechnical.pdf) p.21 FN 21.

Urban Transit Effect

16. Rail Transit Dummy: =1 if metro area contains at least 10 miles of rail transit (Heavy Rail, Commuter Rail or Light Rail) service; = 0 Otherwise

Data Source: derived from data contained in the Federal Transit Administration's 2005 National Transit Data Base.

References

Bento, Antonio M., Maureen L. Cropper, Ahmed Mushfiq Mobarak, and Katja Vinha. "The Effects of Urban Spatial Structure on Travel Demand in the United States." *Review of Economics and Statistics* 87, no. 3 (2005): 466-78.

Cutsinger, Jackie, George Galster, Harold Wolman, Royce Hanson, and Douglas Towns. "Verifying the Multi-Dimensional Nature of Metropolitan Land Use: Advancing the Understanding and Measurement of Sprawl." *Journal of Urban Affairs* 27, no. 3 (2005): 235-59.

Ewing, Reid, Rolf Pendall, and Don Chen. "Measuring Sprawl and Its Impact: Volume I." Washington, DC: Smart Growth America, 2002.