Environmental Impact of Sunbelt Growth: Investigating Trends in Household Carbon Dioxide Emissions

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Abstract

This paper reveals a significant positive association between average household carbon dioxide emissions and whether a city belongs to the Sunbelt, a region with warm climate extending across the southern US. Many Sunbelt cities are spatially defined by lower levels of population density and centralization. Data analysis gives insight on spatial and weather factors that could motivate the discrepancy in emissions—denser populations situated closer to city centers, cooler summers, and warmer winters are all associated with lower average household greenhouse gas production. From a policy perspective, quantifying the gap in carbon emissions between regions could enhance the accuracy of greenhouse gas projections into the future.

I. Introduction

Despite the heated, ongoing debate about global warming's projected costs, a general consensus within the scientific community recognizes that greenhouse gas emissions raise substantial risks of climate change. Climate change affects people's lives in multifaceted ways, most notably through interactions with water—severe droughts, floods, and sea-level rise.[1] To lessen the consequences of a shifting global environment, experts from a wide range of backgrounds have advocated large investments toward diminishing carbon footprints, with a greater burden of change landing on heavy producers like the United States. For instance, in 2006 the US produced one fifth of the world's overall carbon dioxide emissions. Since approximately 40% of US carbon dioxide emissions can be accounted for by automobiles and houses, policies that alter current patterns of transportation and urban expansion theoretically can have a tremendous impact on emissions. Within the US, the intensity of emissions varies considerably between cities and suburbs, and even between types of metropolitan areas. A better grasp of various economic determinants behind carbon dioxide emissions can change the light in which we view certain urban development decisions.

This paper delves into ways cities in the Sunbelt might differ from other US cities with respect to per household carbon dioxide emission levels. Specifically, what are some spatial and weather factors that could motivate heterogeneous emissions? For clarification, the Sunbelt is a region that extends across the southern US, distinguished by its warm climate with prolonged summers and relatively mild, fleeting winter seasons. Since the 1960s, the region has witnessed ample population growth due to mounting economic opportunities in the South, a swell in retired baby boomers, increased supply of housing from rapid new construction[2], and importantly, the introduction of air conditioning. In comparison with other US urban areas, Sunbelt cities are often characterized as sprawling, suburban metropolises.[3] Gasoline consumption plays a significant role in carbon emissions—therefore, at the household level, residents of dense cities have lower carbon footprints since they tend to drive less than those

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[1] Nicholas Stern, "The Economics of Climate Change" 1. "Greenhouse gas (GHG) emissions are externalities and represent the biggest market failure the world has seen."

[2] Edward L. Glaeser and Kristina Tobio, "The Rise of the Sunbelt" 35. "…our estimates suggest that faster housing supply growth in the South has been as big a factor as economic productivity in driving the rise of Sunbelt population."

[3] Becky M. Nicolaides, "Suburbia and the Sunbelt" 21

living in cities with greater urban sprawl.[4] This reality, combined with the fact that warm weather creates higher demand for electricity channeled toward air conditioning, prompts my hypothesis that urban areas located in the Sunbelt are associated with higher levels of per household carbon dioxide emissions. Yet it is important to note that tradeoffs exist; frequent driving could entail lower emissions from public transportation, and warm climate could imply decreased use of natural gas or other forms of energy for heating during wintertime. Different temperatures also may be associated with more or less efficient fuel use.

To assess the relationship between urban areas' carbon dioxide emissions and whether or not they belong to the Sunbelt region, I build a simple ordinary least squares (OLS) model using a sample size of 65 cities. The variable of interest, the Sunbelt city dummy, has a positive coefficient estimate that is statistically significant at the 0.05 level (p: 0.005), suggesting that there is indeed an association between a metropolitan area's quantity of carbon dioxide emissions and whether it is located in the Sunbelt. The patterns in these data seem to be in line with prior studies demonstrating population density and climate effects on carbon dioxide emissions. From a policy perspective—if we have knowledge about growth trends of different regions and can quantify the emissions disparities between these regions, we can improve the accuracy of greenhouse gas projections into the future.

II. Literature Survey

(1) *Urban development and greenhouse gas emissions*

Past studies have indicated that, although people living in areas with high population densities generally contribute less greenhouse gas production than those in other parts of the US, these cities' widespread suburbs effectively eliminate any climate benefits. For example, Jones and Kammen (2014) demonstrate that the mean carbon footprint of households in the heart of large, population-dense urban areas is about 50% below the nationwide average, while households residing in peripheral suburbs emit up to twice the average.[5] There is no clear solution to this conundrum; merely increasing population density in an area would be an unproductive approach for cutting greenhouse gas emissions. For instance, to reduce per

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[4] Conor K. Gately, Lucy R. Hutyra, and Ian Sue Wing, "Cities, traffic, and CO_2: A multidecadal assessment of trends, drivers, and scaling relationships" 2

[5] "Metropolitan areas look like carbon footprint hurricanes, with dark green, low-carbon urban cores surrounded by red, high-carbon suburbs." - Christopher M. Jones, Ph.D., in UC Berkeley interview

household emissions by 25% would require an impractical tenfold surge in population density within cities. Thus, Jones and Kammen call upon future research to create a more nuanced understanding of the various factors leading to this city-suburbs emissions gap.

Glaeser and Kahn (2009) look at spatial determinants of carbon dioxide emissions from a different angle, by endeavoring to quantify the marginal emissions linked to recent urban construction across the US. While they ultimately observe a weak relationship between marginal per household emissions and new construction, a few other relevant findings were encountered in the process. Through a series of ordinary least squares (OLS) regressions using carbon dioxide emissions as the dependent variable[6], their study reveals that emissions are positively associated with average summer temperature, negatively associated with average winter temperature, and negatively associated with city population and centralization (as proxied by the percentage of metropolitan statistical area (MSA) employment within five miles of the urban center). In particular, as this measure of centralization rises by 10%, annual household carbon dioxide emissions related to driving fall by 1,300 lb. Although other studies have previously shown that regional and national greenhouse gas production vary as a function of population and income (Holtz-Eakin and Selden, 1995; Auffhammer and Carson, 2008), Glaeser and Kahn distinguish their approach from existing literature by holding population and income constant to demonstrate that the spatial distribution of a population is a critical factor for carbon dioxide emissions.

(2) *Environmental externalities from residential spatial distributions*

Why would it be valuable in the first place to identify carbon dioxide emission patterns associated with various US cities? We can use a simple economic model to help illustrate the implications that these types of environmental externalities have on urban development (Glaeser and Kahn, 2008). Assume that there exists a set population of N identical individuals who have to select between different communities. Let $\hat{E}$ represent mean energy consumption across all people and $C(N\hat{E})$ refer to the costs of energy consumption that could be connected to climate change. To find the marginal cost of average energy consumption, we would take the first derivative of the term, yielding $NC'(N\hat{E})$. If the government essentially taxes greenhouse gas emissions at rates such that the tax entirely captures marginal social cost of energy consumption

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[6] Units: lb. of CO_2

(i.e., $t = NC'(N\hat{E})$), then individuals can fully internalize the negative environmental externalities accompanying their energy use. This tax will affect individual decisions about where or whether to move; thereby, we have reached a spatial equilibrium that is Pareto optimal.[7] If energy is suitably taxed, then the society would have no need for additional spatial policies to curb emissions.

Nevertheless, these tax conditions are unlikely to hold in a real economy—and an individual's choice of transferring to a specific location would consequently generate an environmental externality. Equation (1) encapsulates the magnitude of the negative externality associated with a person moving to community A instead of B. Now, let E_i^* reflect an individual's optimal energy consumption level in area i, which depends on the area's energy prices and emissions taxes:

$$(1) \qquad S_A = (E_A^* - E_B^*)(NC'\left(N\hat{E}\right) - t)$$

In equation (1) S refers to the size of the environmental externality of emissions, while E_A^* and E_B^* denote the expected energy consumption in locales A and B, respectively. When considering two potential communities, the externality from moving to A rather than B can be estimated by taking the difference in expected energy usage between the two places and multiplying by the difference between marginal social cost of carbon emissions (i.e., the optimal energy tax) and the current tax rate. As long as $NC'\left(N\hat{E}\right) > t$, or the marginal social cost exceeds the existing carbon tax, then individual incentives are incapable of producing a socially optimal spatial distribution. Hence, scrutinizing the divergence of carbon dioxide emissions between regions would provide estimates of $E_A^* - E_B^*$ and help determine the scale of externality, or the degree of sprawl-related inefficiency in residential choice patterns across cities.

(3) *Urban sprawl in the Sunbelt*

A glimpse of the northwest reaches of Phoenix, AZ, reveals innumerable miles of tract housing and strip malls, the landscape only to be interrupted by an occasional freeway onramp

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[7] Edward L. Glaeser and Matthew E. Kahn, "The Greenness of Cities: Carbon Dioxide Emissions and Urban Development" 6. (2008 NBER Working Paper)

or superstore. Although considered part of a metropolitan area, this district has all of the open space and banal accessories of a suburb. However, this scene is not unique to northwest Phoenix; numerous Sunbelt cities came of age just as suburbanization reached its prime in the post-World War II US, and accordingly, these cities have become spatially defined by urban sprawl. Lead developers of many Sunbelt cities intended to improve greatly upon the overcrowded eastern city model, and their new prototypes starkly contrasted the archetypal industrial city.[8] These planners searched for urban designs that capitalized on vast amounts of space, thus creating the concept of a suburban metropolis. As an example, the outskirts of Las Vegas, NV, have recently seen burgeoning residential development; notably, around 2010, about 13,000 homes were constructed by the very corporation that also planned the aforementioned community layouts on the fringe of Phoenix.[9]

Figure 1: Sunbelt urban sprawl—New housing developments on Las Vegas periphery

To create context for the historical environment in which Sunbelt cities started rapidly expanding, it is crucial to understand a greater nationwide movement. Regardless of region in the US, a fundamental theme of urban development during the 20th century involves movement toward suburbs, as urban centers struggled to retain employment opportunities and households.

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[8] Nicolaides, 22

[9] Christopher Gielen: The New York Times, “Sun Belt Sprawl” (Source of photo)

To illustrate, in 1950 only about 35% of the population within urbanized areas resided in suburbs, while the remaining 65% lived in central cities; by 1990 the circumstances had been reversed, with suburban populations at 65%.[10] To explain this trend, existing urban economics literature hones in on the roles of increased income and falling transportation costs as the main driving influences (Brueckner, 2001; Pickrell, 1999; Margo, 1992), while pinpointing assorted government zoning, tax, and expenditure policies, such as the New Deal's creation of the Federal Housing Administration (FHA) and school integration resulting in white flight, as secondary factors (Voith, 1999; Oates 1969). Within the "monocentric city model," metropolitan spatial structures evolve from the tradeoff between land rents and costs of transportation. In the model's equilibrium, city limits need lower land rents to counterweigh higher commuting costs.[11] As we go from the edge of a city to the metropolitan area's central business district (CBD), gradually increasing rents result in rising density gradients.

The urban economics literature built upon the monocentric city model explains the past century's growth in urban sprawl by focusing on the role of diminishing transportation costs. A new availability of automobiles, along with boosted public investment in road infrastructure, substantially lowered commuting costs. In particular, construction of arterial roads and widespread use of cars by households after the 1920s turned previously undeveloped land on city margins, too remote to be accessible by streetcar lines, into prime real estate. Additionally, the monocentric city model emphasizes the trend of rising household incomes as an important factor toward urban sprawl. Higher incomes could lead to declining urban densities since the income elasticity of demand for land and housing is fairly large in relation to the income elasticity of transportation.[12] Thus, in this model, as levels of average income rise, more and more households choose to locate in the periphery. On the whole, the monocentric city model motivates urban sprawl's occurrence through the joint effect of rising income and cheaper commuting. This new pattern of land conversion impacted the spatial development of the many Sunbelt cities that came of age during this nationwide transformation. In the following sections, I will delve into potential implications of Sunbelt cities' characteristics, including their degree of urban sprawl, on carbon dioxide emissions.

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[10] Thomas J. Nechyba and Randall P. Walsh, "Urban Sprawl" 180

[11] Richard F. Muth, *Cities and Housing: The Spatial Pattern of Urban Residential Land Use*

[12] Nechyba and Walsh, 182

III. Data

To study the extent of association between carbon dioxide emissions and Sunbelt cities, I use publically accessible data from 2000 provided by the US Census Bureau, US Climate Data, National Household Transportation Survey (NHTS), and Department of Energy. I focus on data from 2000 for two reasons: (1) in more recent years, the NHTS only published state-level rather than MSA-level metrics on gasoline consumption, which is a crucial variable in the analysis, and (2) the question of interest involves scrutinizing relative, not absolute, per household emissions across the US; although emissions and population numbers have changed over the years, broader relationships should remain fairly stable. Specifically, I pinpoint 65 US cities with detailed data available on household carbon dioxide emissions. An indicator variable tracks whether a given city belongs to the Sunbelt, which encompasses cities in most states situated in the southern region of the US—roughly below the 36th parallel north, latitude.[13] For the purposes of this analysis, California is treated separately from Sunbelt states because its city characteristics (e.g., population density and climate) differ significantly from traits of Sunbelt MSAs, and the central-northern expanse of California does not lie in the Sunbelt region. A second indicator variable that identifies whether a city is located in California helps isolate certain regional effects.

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[13] *Dictionary of American History* (2003). The SunBelt includes the states of Alabama, Arkansas, Arizona, Florida, Georgia, Louisiana, Mississippi, Nevada, New Mexico, North Carolina, South Carolina, Tennessee, and Texas, along with the southern part of California.

Table 1: US MSAs included in data ($n = 65$), Sunbelt cities in brown and CA cities in green

Akron, OH
Albany, NY
Baltimore, MD
Boston, MA
Buffalo, NY
Chicago, IL
Cincinnati, OH
Cleveland, OH
Columbus, OH
Dayton, OH
Denver, CO
Detroit, MI
Grand Rapids, MI
Hartford, CT
Indianapolis, IN
Kansas City, MO
Louisville, KY
Milwaukee, WI
Minneapolis, MN
New York, NY
Norfolk, VA
Oklahoma City, OK
Philadelphia, PA
Pittsburgh, PA
Portland, OR
Providence, RI
Richmond, VA
Rochester, NY
Salt Lake City, UT
Scranton, PA
Seattle, WA
St. Louis, MO
Syracuse, NY
Tacoma, WA
Tulsa, OK
Washington, DC
Fresno, CA
Los Angeles, CA
Riverside, CA
Sacramento, CA
San Diego, CA
San Francisco, CA
San Jose, CA
Albuquerque, NM
Atlanta, GA
Austin, TX
Birmingham, AL
Charlotte, NC
Dallas, TX
Fort Lauderdale, FL
Greensboro, NC
Greenville, SC
Houston, TX
Las Vegas, NV
Memphis, TN
Miami, FL
Nashville, TN
New Orleans, LA
Orlando, FL
Phoenix, AZ
Raleigh-Durham, NC
San Antonio, TX
Sarasota, FL
Tampa, FL
Tucson, AZ

For each of the 65 MSAs, I collect information on population size, median household income, and population-weighted density in year 2000 from the US Census Bureau. The weighted density calculates the density at which the average inhabitant lives in the MSA; this measure helps to roughly gauge the extent of a city's sprawl. Moreover, I take into account four principal sources of carbon dioxide emissions on an urban household level: private automobiles for within-city transport, public transit, residential electricity usage, and home heating (i.e., fuel oil and natural gas). Glaeser and Kahn (2009) translate energy consumption from driving and residential heating into carbon dioxide emissions estimates using simple conversion factors[14]; meanwhile, for public rail transportation and household electricity usage, the study transforms megawatt hours (MW h) of electricity into emissions by tapping into data about the rate of carbon dioxide emissions accompanying electricity production in different regions of the US. Therefore, for the four variables representing sources of urban carbon dioxide emissions, I use annual standardized household data published in the 2009 study. While Glaeser and Kahn (2009) approximate carbon emissions associated with recent construction in different locations, my research examines the existing relationship between emissions and city characteristics.

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[14] Glaeser and Kahn, 406. The NHTS estimates annual household gasoline consumption, relying on vehicle type information. Thereafter, the mean gasoline consumption for a standardized household (i.e., 2.62 members, income of $62,500—number based on average, not median income) living in a certain MSA can be predicted.

After aggregating the different sources of carbon dioxide emissions into an average household emissions estimate for an MSA, trends can be discerned across regions. In economic terms, the social cost of emissions can be predicted by multiplying a social cost figure of $43 per ton of carbon dioxide produced.[15] The estimates illustrate a wide range of per household carbon dioxide emissions costs—from approximately $2,015 annually in Memphis to $1,148 in San Diego. In the meantime, average household emissions in MSAs of the northeastern US typically sit between those values. While residents of these older, denser cities tend to drive less, they also live in a colder climate and require considerable amounts of residential heating, thus buffering the effect of lower automobile-related emissions.

Table 2: Summary Statistics– Population Density, Transportation & CO_2 Emissions

Type of City	Population Weighted Density	Emissions from Driving* (lb of CO2)	Emissions from Public Transport* (lb of CO2)	Carbon Dioxide Emissions Cost* ($/yr)
Sunbelt (n = 22)				
Mean	3,530	27,924	997	1,739
SD	*1,899*	*2,351*	*995*	*232*
California (n = 7)				
Mean	7,584	24,789	991	1,207
SD	*3,674*	*1,107*	*694*	*57*
Other (n = 36)				
Mean	4,817	26,367	1,662	1,622
SD	*4,937*	*2,410*	*1,632*	*238*

*Annual standardized household CO2 emissions or costs

Generally, the MSAs with the highest carbon dioxide emissions are almost all situated in the Sunbelt. While Memphis emits the absolute highest quantity among the 65 urban areas observed, the state of Texas is especially well represented among the locales that produce the greatest levels of emissions; Houston, Dallas, and Austin all lie among the ten cities with highest emissions. Meanwhile, among these top ten, Indianapolis and Minneapolis are the only ones located outside of the South. On the other extreme, six of the ten lowest emissions cities belong to California (i.e., San Diego, San Francisco, San Jose, Los Angeles, Sacramento, and Riverside). In terms of metropolitan sprawl and driving habits, there is a discernible negative relationship between population-weighted density and carbon dioxide emissions from driving. The

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[15] Synapse Energy Economics, Inc., "Carbon Dioxide Price Forecast" 1

association is seemingly nonlinear; for lower density cities, the same incremental increase in weighted density is correlated with a greater decline in driving-related emissions than in denser areas. This pattern seems logical in that a critical mass of residents may be needed to establish more extensive public transportation networks. Once these transit systems are instituted, the relative amounts of driving saved would increase less dramatically. Public transit releases carbon emissions as well, but most forms of public transportation are considerably more energy efficient per capita than if someone were to drive the same distances in private automobiles. As an example, in a year the New York City Transit system expends 14.8 billion megawatts of electricity and 42 million gallons of diesel fuel to send its riders on 2.6 billion subway trips.[16] On an individual level, the computations work out to approximately 0.9 pounds of carbon dioxide on average per trip—one tenth as much as the nine pounds emitted in an average private car trip.

Overall, although there is substantial variance in population densities within each region, inhabitants in Sunbelt cities tend on average to live at lower densities—a city characteristic associated with more driving and higher gasoline consumption. Meanwhile, metropolitan areas in California sit on the other end of the spectrum with both lower emissions and urban sprawl.

Figure 2: Relationship between driving-related CO_2 emissions and MSA density

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[16] Edward Glaeser, “The Benefits of Density” and Bill Bayne, “National Mass Transit ridership growth” (2013)

In terms of regional weather patterns, California's MSAs are quite fortunate to have a temperate climate. Mild temperatures yearlong combined with residents' propensity toward clean electricity production and energy-efficient home appliances (i.e., the "California factor") motivate the fact that California's standardized annual household electricity consumption of about 8.5 MWh is almost half the magnitude of average electricity use, 15.9 MWh, in Sunbelt cities.[17] Since weather can clarify much of the discrepancies in emissions across regions, I collect city-level data from US Climate Data, specifically looking at the average high temperature in July and average low in January. Across different parts of the US, these two months tend to have the highest and lowest temperatures of the year, respectively, and my rationale for selecting them is to potentially capture the need for air conditioning during the wintertime and residential heating during the summer.

Table 3: Summary Statistics– Seasonal Weather, Home Electricity Use & Heating Emissions

Type of City	July High Temperature (°F)	Electicity (MWh)	January Low Temperature (°F)	Emissions from Home Heating (lb of CO2)
Sunbelt (n = 22)				
Mean	93.0	15.9	39.0	5,003
SD	*4.8*	*2.4*	*10.2*	*2,941*
California (n = 7)				
Mean	83.6	8.5	44.0	6,745
SD	*11.0*	*1.2*	*4.9*	*521*
Other (n = 36)				
Mean	84.6	11.3	22.7	10,215
SD	*3.9*	*3.1*	*6.5*	*2,945*

Home electricity consumption and accompanying carbon dioxide emissions indeed rise with July temperatures. And in the case of heating-related natural gas and fuel oil consumption, there is a sharp negative correlation between the resulting emissions and January temperature; the colder it gets, the increased demand households have for heating. Although Sunbelt cities tend to be situated in warmer climates and thereby produce greater emissions from residential air conditioning, this effect is offset by their reduced need for heating in the winter. Furthermore, even though older dense metropolises have lower average household emissions from driving and air conditioning, if they are exceptionally cold, the effect from increased heating can surpass the other factors in importance. These circumstances could explain why Minneapolis is one of two

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[17] State of California Energy Commission, "Summary of Renewable Energy Installations," 8

northern areas among the top ten highest emissions cities. Additionally, urban sprawl can compound the effects of weather; people living in smaller, less dense Sunbelt cities not only face more humid summers, but also tend to own larger homes, which require more electricity to cool.[18]

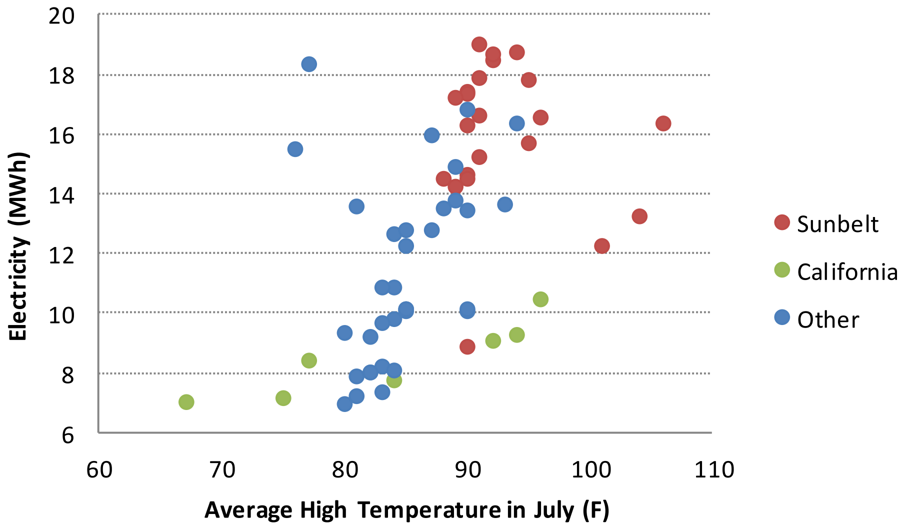

Figure 3: Relationship between electricity consumption and July average high temperature

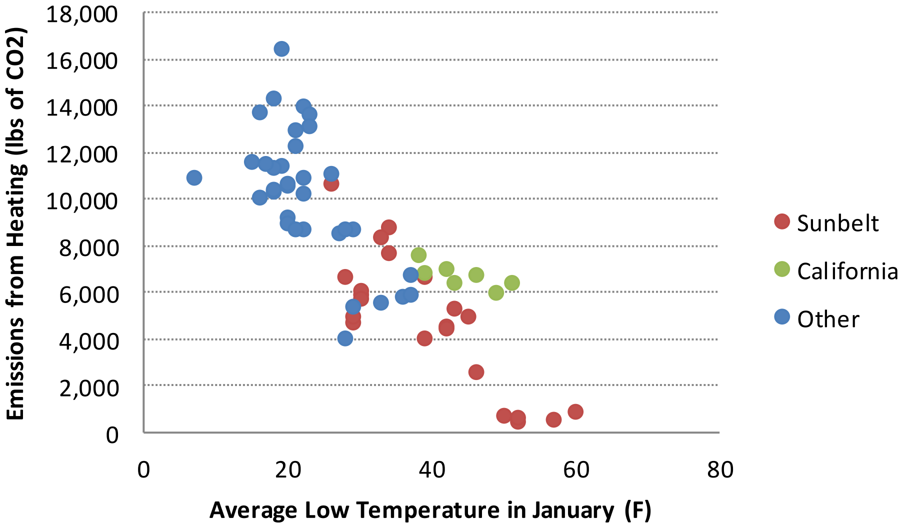

Figure 4: Relationship between heating-related CO_2 emissions and January low temperature

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[18] Edward Glaeser, *Triumph of the City*. "The average single-family detached home consumes 88 percent more electricity than the average apartment in a five-or-more-unit building."

IV. Methodology

To evaluate the association between metropolitan areas' carbon dioxide emissions and whether or not they belong to the Sunbelt region of the US, I construct a simple OLS model using a sample size of 65 observations:

$$(2) \qquad CO_2\ cost = \beta_0 + \beta_1 * Sunbelt + \beta_2 * Population + \beta_3 * Income + \varepsilon$$

…where the dependent variable is the annual cost of carbon dioxide emissions faced by an average standardized household; recall that this value is computed by multiplying emissions' social cost with the quantity of average urban household emissions aggregated over private automobile use, public transportation, electricity consumption, and residential heating. In the meantime, the independent variables of equation (2) include: an indicator variable designating whether a city is part of the Sunbelt (i.e., takes on the value of 1 if it is a Sunbelt city and 0 otherwise), population size, and median household income. To avoid issues of multicollinearity, I omit population-weighted density along with July and January temperatures from the model because I suspect that they are highly correlated with the Sunbelt dummy variable. In contrast, overall population (r: 0.077) and median income (r: -0.081) are relatively uncorrelated with whether or not MSAs belong to the Sunbelt.[19] Moreover, to avoid the dummy variable trap, I also avoid incorporating the indicator variable that represents whether or not a city is part of California. If both are included, the two variables would be highly correlated and contribute to multicollinearity in the model.

V. Results

Table 4 presents the OLS regression results of the various urban characteristics used to explain average household carbon dioxide emissions for different MSAs. The variable of interest, the Sunbelt city indicator, has a positive coefficient estimate that is statistically significant at the 0.05 level (p: 0.005), suggesting that there is an association between an urban area's magnitude of carbon dioxide emissions and whether or not it is situated in the Sunbelt or a different part of the US. The model gives an estimate for β_1, the Sunbelt dummy's coefficient, of 192.998. Therefore, controlling for population size and median household income, cities in the Sunbelt, on average, have average standardized household carbon dioxide emissions costs

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[19] In both cases, r represents the correlation between said variable and the Sunbelt indicator.

that are approximately $193 higher per year than in metropolitan areas located within other US regions. This Sunbelt-related difference in social cost of emissions is a considerable amount, ranging from 10.5% to 14.0% of a city's total average household emissions cost in a given year. The results provide convincing evidence that MSAs' quantities of carbon dioxide emissions are associated with whether they belong to the Sunbelt.

Table 4: Regression outcomes for a simple OLS model with CO_2 emissions cost as the dependent variable

	Coefficient	Standard Error	t statistic	P > |t|	95% Confidence Interval	
Sunbelt	192.998	66.191	2.920	0.005	60.641	325.355
Population	-1.4E-05	2.9E-05	-0.500	0.617	-7.2E-05	4.3E-05
Median HH Income	-0.009	0.004	-2.070	0.043	-0.017	-2.7E-04
Constant	1863.887	147.839	12.610	0.000	1568.265	2159.509

Number of obs: 65	
F(3, 61): 4.31	R-squared: 0.175
Prob > F: 0.008	Adj. R-squared: 0.134

Furthermore, although the data cannot conclude that there is a significant relationship between population and per capita carbon dioxide emissions costs (p: 0.617), there seems to be a statistically significant association between emissions and median household income (p: 0.043). The OLS model estimates β_3, the coefficient of median income, to be -0.009. While keeping all of the other covariates fixed, the annual household cost of carbon dioxide emissions decreases by $90 when a city's median household income rises by $10,000. The direction of this estimate is unexpected because we anticipate a positive relationship between carbon dioxide emissions and income. Intuitively, as household income grows, the family gains access to amenities such as vehicles or undergo increased willingness to use air conditioning or residential heating liberally.

Note that this model specification yields a low R^2 value of 0.175, thus exhibiting that this specific OLS regression model is more useful for identifying broad trends than predicting specific carbon dioxide emissions costs from the given factors. Provided the oftentimes noisy nature of macro level data on MSA characteristics (i.e., there are innumerable determinants of carbon dioxide emissions of a city), a relatively small R^2 value should not be viewed as a deterrent toward finding some information value regarding the associations between variables.

VI. Discussion

This paper reveals a significant positive association between the cost of carbon dioxide emissions and whether a city belongs to the Sunbelt (i.e., nationwide, MSAs in the Sunbelt tend to emit higher levels of carbon dioxide), hence corroborating earlier research on this significant environmental and urban planning issue. Exploratory data analysis gives insight on some spatial and weather factors that could motivate this discrepancy in emissions; denser populations situated closer to city centers, cooler summers, and warmer winters all correlate with lower average household greenhouse gas production. Since many Sunbelt cities had started rapidly expanding in the past century when the dominating patterns of land conversion involved suburbanization and sprawl, these cities have become spatially defined by lower degrees of population density and centralization.

Thereby, Sunbelt cities like Greenville, Charlotte, and Nashville were developed at low densities and have widely distributed employment (e.g., research and industrial parks such as Research Triangle Park near Raleigh have become common fixtures on Sunbelt city landscapes). Accordingly, these Sunbelt cities' residents consume the most gasoline per capita nationwide. Meanwhile, out of all the major MSAs in the US, the hot, sweltering cities of New Orleans, Houston, Memphis, and Orlando use the most electricity per household. In these locales, the long summer months are virtually intolerable without creating an artificial climate through air conditioning. On the whole, looking at aggregate carbon dioxide emissions—coastal California is undoubtedly the greenest area of the country, and the Deep South is by far the brownest, while older, denser metropolises in the Midwest and Northeast tend to remain between the extremes. The disparity between these two extremes is striking; a standardized household in Memphis produces 60% more carbon dioxide emissions than its counterpart living in San Francisco.

Since there are countless determinants of a city's average household carbon dioxide emissions, a main limitation to this study potentially involves omitted variable bias. Logically, simply knowing an urban area's region, total population size and median income is insufficient for determining its household levels of greenhouse gas production. Nonetheless, incorporating more of the variables available in the exploratory data analysis section of this paper would have created issues of multicollinearity. Additionally, although density is a standard measure for urban sprawl, it can only imperfectly capture the definition of sprawl[20]—therefore, it may be better to use density gradient, or the population density of a given area relative to the central business district, as a proxy. Another concern involves relying on the index weight of $43 per ton of carbon dioxide; since this measure sits within a large confidence interval, using it to convert aggregate carbon dioxide estimates into social cost may be imprecise and would not be a sound basis for proposing the size of a carbon tax, for instance. However, since our question of interest involves analyzing relative, not absolute, per household emissions across the US, broader relationships should remain fairly stable. For future research efforts, it may be worthwhile to expand the scope of this study from household energy use to a more encompassing measure that includes industry and agriculture. Particularly, quantifying MSAs' average carbon footprint associated with water use would be immensely relevant. Although California cities are relatively energy-efficient, simply delivering water to dry urban areas such as Los Angeles expends substantial quantities of energy.

From a policy perspective, quantifying the gap in carbon emissions between regions could enhance the accuracy of greenhouse gas projections into the future. For instance, if we know that the Sunbelt tends to produce higher average household emissions, then we can factor in the predicted growth rate of Sunbelt cities when forecasting the next decades' carbon dioxide emissions. The policy implications of these types of studies would not be limited to the US; similar regional analyses covering other countries of the world, such as China, are quickly emerging (Zheng et al., 2012). Moreover, illustrating the relationship between urban sprawl and carbon emissions can promote growing urban design movements such as New Urbanism, which supports walkable communities that comprise a variety of employment types and housing. Transit-oriented development (i.e., endorsing mixed-use residential and commercial areas designed to maximize people's access to public transportation) and similar urban planning concepts can rein in sprawl, thus leading the way toward smart growth and lowered human impact on the global climate.

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[20] Eric Eidlin, "What Density Doesn't Tell Us about Sprawl" 9

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