THE IMPACT OF SPRAWL ON TRANSPORTATION ENERGY CONSUMPTION AND TRANSPORTATION CARBON FOOTPRINT IN LARGE U.S. CITIES

by

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To my mother

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ABSTRACT

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Today, climate change and energy shortage are major concerns among scientists, politicians, and economists. For decades in the U.S., emphasis has been placed on improving energy efficiency through technological advances. However, most of these technologies are in the initial phases of development, while energy consumption continues to increase at a rapid pace. In order to solve this dilemma, there is a need to develop a faster and more effective approach for controlling the rates of energy consumption and demand.

Transportation consumes more energy than other energy-dependent activities, such as those in the industrial, residential, and commercial sectors of the economy. In addition, the transportation sector produces the highest level emissions in comparison to the other energy-dependent activities. Because of this problem, it is important that more studies examine the problem of energy consumption and emissions within the transportation sector. Cities are the main producers of transportation emissions and energy use. Many researchers have considered spatial form of contemporary urban regions as a source of environmental problems. Therefore the goal of this study is to examine the relationship between urban sprawl, transportation energy consumption and the carbon footprint. The impact of sprawl on transportation energy consumption has been investigated using some urban areas in the U.S. as case studies. However, there is not a comprehensive study employing reliable data among metropolitan statistical areas (MSAs) across the U.S.

To provide a better analysis, this dissertation examined the statistical strength between different urban forms, transportation energy consumption and carbon footprint among 73 MSAs in the U.S., using ordinary least square (OLS). The study found that a significant relationship between urban sprawl and transportation energy consumption and carbon footprint. Nevertheless, there are still more important factors that influence the transportation energy consumption and carbon footprint than urban sprawl.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Nowadays climate change and the energy crisis are two of the main concerns for the world's economists and environmentalists. Population growth, a preference for urban living, unrest in the Middle-east and increase demand for fossil fuels in India and China, are some of the factors creating this concern. (Attarian, 2002; Hallock, Tharakan, Hall, Jefferson & Wu, 2004).

Climate change results from natural factors, such as oceanic circulation & volcanic eruption, and human activities. (Climate Change Challenge, n.d.). An increase in atmospheric concentration of CO_2 due to emissions from fossil fuel combustion, is one of these anthropogenic factors that cause global warming. This phenomenon is creating potentially irreversible and disastrous consequences for health, coupled with rising sea levels, loss of glaciers and rising temperature. (Intergovernmental Panel on Climate Change [IPCC], 2007; Steinfield et al, 2006; Williamson, 2009). Emissions of CO_2 have increased by about 35% since the beginning of the Industrial Age when communities started burning fossil fuels. During the 20th century, emission levels rapidly increased, to a rate of approximately 3 percent per year. (Figure1.1). In 2005, carbon emissions from the combustion (burning) of fossil fuels totaled 7.9 billion tons (Florence, 2006).

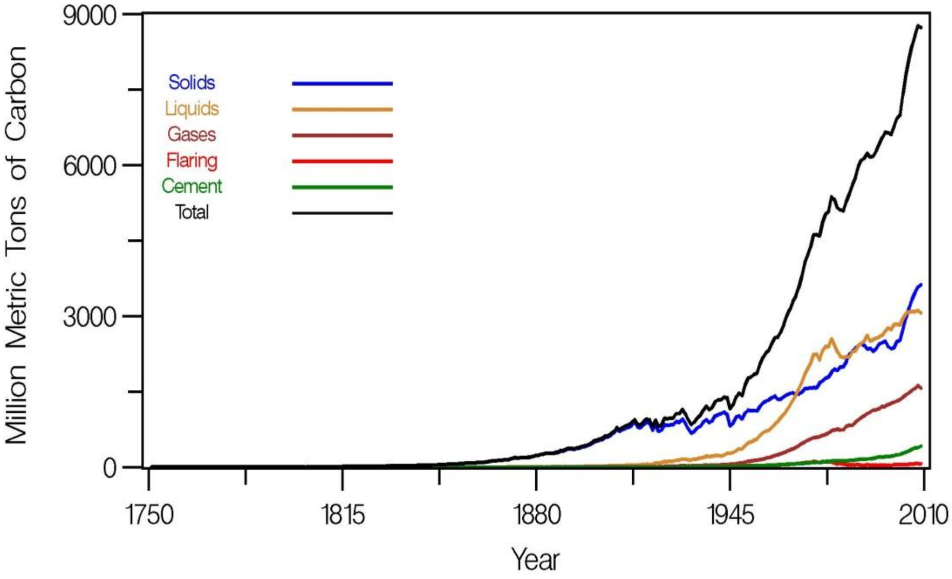

Figure 1.1 Global carbon dioxide emissions from fossil fuel burning, 1751–2006.
Source: Anders, Boden and Marland (2009)

The main source of anthropogenic carbon emissions are urbanized areas which emit nearly 78 percent of human generated CO_2. (O'Meara, 1999; United Nations [UN], 2006). Currently half of the global population lives in cities and this number will increase to 60 percent by 2025. In the U.S., the scenario is worse; by 2050, about 360 million people (80 percent of population) will reside in urban areas. (U.S. Census Bureau, 2008). This figure is concerning in light of the fact that 5 percent of the world's population live in the U.S., yet the U.S. consumes 20 percent of the total world energy. (Energy Information Administration [EIA], 2011). In addition, the U.S. also consumes 22.5 percent of the world's petroleum and produces 25 percent of the global carbon emissions. (Florence, 2006, Transportation Energy Data Book, 2010). According to the Energy Information Administration (EIA, 2007), about 34 percent of the total U.S. GHG emissions originates from the transportation sector (Figure 1.2), and 95 percent of the GHG emitted from motorized transportation sources is CO_2 (Liu & Shen, 2011).

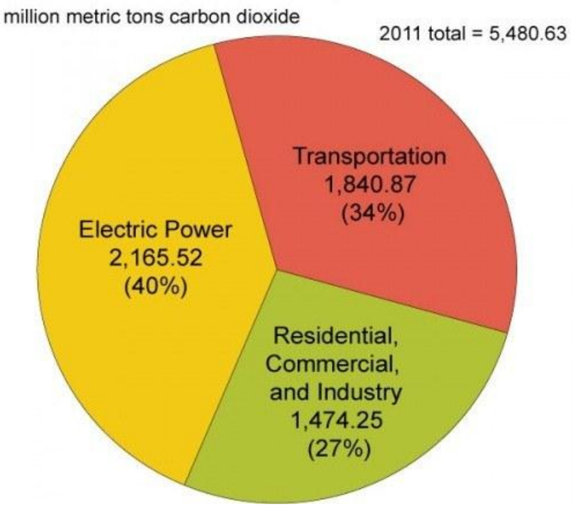

Figure 1.2 U.S. energy related carbon dioxide emissions by sector (Source: EIA, 2011)

Transportation sector consumes 28 percent of total U.S. energy (EIA, 2011, Figure 1.3), and 86 percent of the energy consumption in 2011 was from fossil fuels. (Figure 1.4, Appendix c).

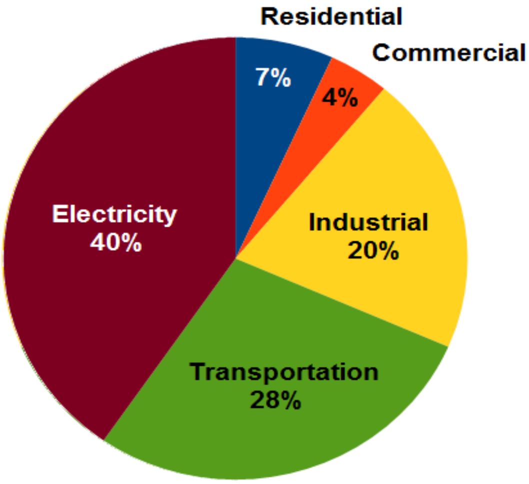

Figure 1.3 U.S. energy consumption by sector (Source: EIA, 2011)

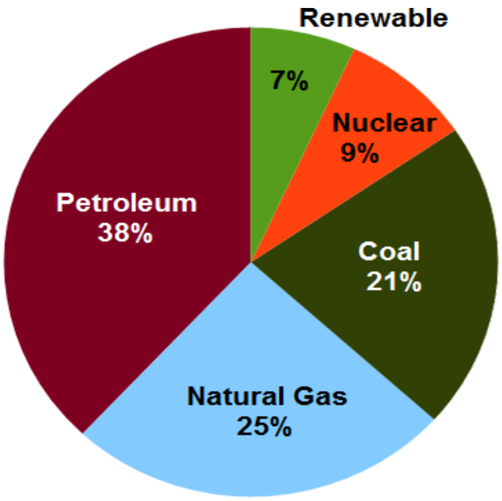

Figure 1.4 U.S. energy consumption by source (Source: EIA, 2011)

To prevent energy shortage, some policymakers recommend increasing the use of alternative energy however these kinds of energy resources are in the early stages of development. (Williamson, 2009). Another suggestion is efficient technologies, although increasing demand for vehicles, might jeopardize the effect of these technologies.

Several researchers have considered the sprawling spatial form of contemporary cities as a source of environmental problems. (Alberti et al., 2003; Beatley & Manning, 1997; Environmental Protection Agency [EPA], 2001; Newman & Kenworthy, 1989). Although cities and transportation have a great role in the U.S. energy related carbon emissions, most studies have investigated the relationship between city design and vehicle miles traveled (VMT) that increase tailpipe emissions. However, only a few studies have quantified the impact of urban form on energy use and related emissions. These papers mostly used case studies which makes generalization of findings inapplicable. This dissertation is the first to study the impact of urban form on transportation carbon footprint and energy use in major metropolitan statistical areas (MSA) in the U.S. by using different sprawl indices. The results will support policymakers who include sustainable policies in their decisions to choose the best and fastest solutions to develop sustainable cities.

1.2 Purpose of Research

This study will explore the impact of urban sprawl on per-capita transportation energy consumption and carbon footprint in large metropolitan statistical areas (MSAs) in the U.S.

1.3 Research Questions

1. Does urban sprawl increase transportation energy consumption?
2. Does urban sprawl increase transportation carbon footprint?
3. Do component sprawl indices predict better variation on transportation energy consumption?
4. Do component sprawl indices predict better variation on transportation carbon footprint?

Answers to these questions, could find a link between urban sprawl, energy consumption and carbon footprint.

1.4 Significance of the Dissertation

This study attempts to provide empirical support for the role of smart growth in attaining sustainability in future energy consumption and reducing carbon footprint. If the research finds a relationship between urban sprawl, transportation energy consumption and carbon footprint in MSAs in the U.S., the results and policy recommendations could potentially be applied in metropolitan areas outside the U.S.

1.5 Structure of the Dissertation

The dissertation is organized in four chapters. The first chapter contains the introduction and problem definition. In chapter 2, the literature review discusses the background and studies have done on this topic. In chapter 3, methodology employed in the study, source of data, hypotheses and regression equations will be presented. In chapter 4, the results will be presented, and chapter 5 is the conclusion and limitations of study. Chapter 5 also offers recommendations for policymakers and future research. More details about data, regression equations analysis and results can be found in the appendices.

Until now a comprehensive study investigating the impact of sprawl on transportation energy consumption and carbon emissions on entire the U.S. has been lacking. The differences between this study and other studies are listed below:

1. This study covers 73 MSAs in the U.S. while a majority of previous studies were case studies.
2. It uses different sprawl indices to explore the impact of sprawl cities on transportation energy consumption and carbon footprint.
3. The data for transportation energy consumption and carbon footprint that is used in this study is not based on surveys that only cover a small group of households. It is derived from a work done by Southworth et al (2008).
4. The transportation energy consumption and carbon footprint in this study is per capita. In other studies, usually total energy or emissions were investigated. For that reason, population was always considered in the regression models as a control variable.

CHAPTER 2

LITERATURE REVIEW

The environmental impact of urban form has been explored extensively. The next section reviews literature that covers interest of this dissertation (emissions and energy consumption). The literature review consists of three sections:

2.1) Definition and history of urban sprawl

2.2) Literature review related to research questions

2.3) Methods of measuring sprawl.

2.1 Definition and History of Urban Sprawl

In order to understand the form of contemporary cities, a brief history of urban form in the U.S. will be reviewed:

2.1.1 Urban Form

"Urban form is defined as a spatial configuration of fixed elements within an urban area. This includes the spatial patterns of land uses and their densities as well as the spatial design of transport and communication infrastructure." (Anderson, Kanargoglou, & Miller, 1996). Different values, design techniques, transportation technologies, energy supply and governmental policies are some of factors that have changed urban form during years. (Crawford, 2005). Different urban forms cause different environmental consequences. (Camagni, Gibelli, & Rigamonti, 2002; Holden, 2004).

In the U.S., pre-industrial cities had characteristics of compact cities: walkable, mixed land use and high density. Industrialization motivated people to migrate to cities to work in factories. This process was enabled by low-cost transportation modes. After a while**,** population growth, in addition to other factors like high rate of crime, pollution, the advent of electronic communication and higher incomes, caused suburbanization in the late of nineteenth century.

After World War II, factors such as federal housing programs, mass produced-housing and cars, racial segregation and new highways, increased the rate of suburbanization. In some cities like Atlanta, Dallas, Houston, and Phoenix, the local government supported suburbanization because they did not want low income people living in their highly productive, pleasant communities. (Glaeser, 2011; Sarzynski, 2006; Jackson, 1985; Geddes, 1997; Anas, Arnott, & Small, 1998; Boustan & Margo, 2011; Levy, 2009).

2.1.2 Urban Sprawl

Today, urban sprawl is defined by decentralized land use pattern with low population densities, low employment density, and auto-oriented design schemes. Urban sprawl is the dominant development pattern in the U.S. and is considered a significant factor escalating energy consumption and climate change. (Burchfield, Overman, Puga, & Turner, 2006; Sarzynski, 2006; Ewing, Pendall, & Chen, 2002). Scientists and researchers have found some advantages and disadvantages for urban sprawl. According to Burchell et al. (2005) some of advantages include:

1. People can have less expensive and bigger houses
2. The public schools have better quality because of low-density neighborhoods
3. Low crime rates
4. Less congestion
5. Stronger citizen participation because of smaller government units

The critics of sprawl believe sprawl has more disadvantages than its benefits:

1. Low aesthetic value (Burchell et al, 2002);
2. Increase of Infrastructure costs (Burchfield, Overman, Puga, & Turner, 2006);
3. High risk of flooding (Adelmann, 1998; Pennsylvania 21st Century Environment Commission [PTCEC], 1999);
4. Fragmentation of ecosystems (Margules & Meyers, 1992);

5. High dependency on private motor vehicles (Colby, 2006);
6. Health problems because of less physical activity (Frumkin, Frank, & Jackson, 2004; Lopez, 2004);
7. Loss of wildlife habitat (Hulsey, 1996); and
8. Racial segregation (Boustan & Margo, 2011)

The next section reviews studies that have investigated some of the negative impacts of urban sprawl.

2.2 Literature Review Related to Research Questions

2.2.1 Impact of Urban Sprawl on Air Quality:

Only a few studies have investigated the environmental impacts of urban form by using sprawl indices. One of these studies was done by Stone, (2008). Stone explored the impact of urban sprawl on 8-hour national ambient air quality standard for ozone (O_3) concentration in 45 MSAs in the U.S. over 13 years period by integrating Ewing sprawl index. The study controlled for population size, average ozone season temperatures, and regional emissions of nitrogen oxides and volatile organic compounds. The results showed that urban areas with higher sprawl numbers have a greater number of ozone exceedance days.

In a similar study, "*Urban Form and Air Quality in Large U.S. Metropolitan and Megapolitan Areas*", Bereitschaft (2011) investigated the impact of urban sprawl on 6 pollutants (O_3, VOCs, NO_x, CO_2, PM_{10}, and $PM_{2.5}$). Bereitschaft used sprawl indices that quantified urban sprawl and derived spatial metrics from remotely sensed images. After controlling for confounding variables and running regression analysis, Bereitschaft found that urban form has a measurable impact on both emissions and concentration of air pollutants. Urban areas that were more sprawling had higher concentration or emission of air pollutants.

2.2.2. Impact of Urban Sprawl on Transportation Emission

In another study, Stone, Mednick, Holloway and Spak (2009) compared smart growth development patterns to vehicle fleet hybridization in decreasing mobile source CO_2. By integration of a vehicle travel activity modeling framework, Stone et al (2009) modeled CO_2 emissions associated with alternative land development and technology change scenarios over a 50-year period (2000_2050) across 11 major metropolitan areas of the U.S. Midwestern region. The results suggest that compact growth and high levels of urban densification could achieve CO_2 emissions reductions equivalent to the hybridization of the light duty vehicle fleet (Stone, Mednick, Holloway, & Spak, 2009).

Furthermore, Bart (2010) evaluated a relationship between transportation CO_2 emissions and urban land-use in European Union (EU) countries between 1990 and 2000. Using regression analysis and controlling population and gross domestic product (GDP), he found that there is a strong correlation between transport CO_2 emissions and the increase of artificial land area. Based on this result, Bart (2010) recommended that EU should consider policies that emphasize reducing urban sprawl to decrease CO_2 emissions.

Passenger-vehicles are the largest source of transportation greenhouse gases (GHG) emission. (U.S. Department of Transportation, n.d.). Hankey and Marshall (2010) studied the impact of urban form on passenger-vehicles GHG emission under six different scenarios of urban form, for high and low sprawl U.S. urban growth. The study used the Monte Carlo approach and employed three vehicles and fuel-technology scenarios and found that comprehensive compact development can reduce U.S. 2000-2020 cumulative emissions by up to 15-20 percent. Hankey and Marshall (2010) recommended that for vehicle GHG mitigation, three types of approaches should be considered: making more-efficient vehicles, lower-GHG fuels, and reduce vehicle miles traveled.

2.2.3. Impact of Urban Sprawl on Transportation Energy Use

One of the most cited studies on the impact of urban sprawl on the use of energy for transportation was done by Newman and Kenworthy (1989). The research examined gasoline consumption in 32 cities around the world. Based on the results, the analysis found that urban population density is most important factor for reducing transportation energy consumption. This finding indicates that policymakers in the urban field should be planning for denser cities. Nevertheless the study was criticized by some scholars like Gomez-Ibanez (1991) that criticized the study for lack of control for variables such as fuel price and income and lack of complete multivariate analysis, and Kirwan (1992) who believed that socio-economic factors are more important than urban morphology. Another critic was Allaire (2007). In his dissertation, Allaire concluded that better economic situation and higher standards of living are the main reasons of suburbanization that cause more energy consumption by transportation.

Brownstown & Golob (2009) completed a similar study in the U.S. examining the impact of residential density on vehicle usage and fuel consumption. They controlled socio-economic variables and used weighted estimation methodology. Their data was obtained from 2001 National Household Travel Survey (NHTS). They compared two households that were equal in all aspects except density; results showed that the household in denser area consumed more gallons of fuel.

In a study investigating "*Urban Form, transportation emissions and energy consumption of commuters in the Netherlands*", Susilo and Stead (2008) used the Dutch National Travel survey data to explore the influence of different types of urban form on transportation emissions and energy consumption. The results showed that over a 10 year period, transportation CO_2 emissions and energy consumption in a less urbanized area was higher than denser urban areas. They also found other factors influence the amount of transportation CO_2 emissions and energy consumption more than urban form and built environment variables. They concluded that the effect of urban form on transportation energy consumption and CO_2 emissions is not as great as the socio-economic variables.

In the next section, sprawl indices that will be used for this research study and the methods used for calculating the indices will be reviewed.

2.3 Methods of Measuring Sprawl

There have been several attempts by scientists to quantify sprawl in order to understand it better, prove its advantages, and assist policymakers in their decisions. Some of the sprawl indices applied in this dissertation will be reviewed in this section.

Many of sprawl indices are based on density, such as El Nasser and Overberg sprawl index (2001).They measured the percentage of metropolitan population that lives in urban areas for 1990 and 1999 in 271 MSAs. They gave scores of 1 to the least sprawling city and 271 to most sprawling city, and then added the score for two years for every city. Ocala in Florida had the highest score 563 while Laredo in Texas, was least sprawl city with score 26. Most sprawling MSAs were located in the South including: Nashville, (TN); Austin, (TX) and Atlanta, (GA). The least sprawling MSAs were in the West, like: San Francisco, (CA); San Diego, (CA) and Los Angeles, (CA). Nasser and Overberg concluded that natural features like oceans and mountains that constrain MSAs like Los Angeles are the main reasons that control sprawl.

Lopez and Hynes (2003) developed an index based on the residential density. They divided population by land area for 1990 and 2000. The area of every MSA, were sorted into three categories: high-density tracts (more than 3,500 persons per square mile), low-density tracts (200-3500 persons per square mile), and rural tracts (less than 200 persons per square mile). The rural tracts were removed from the analysis. A sprawl index score was calculated for every MSA by this formula:

$SIi = \{[(S\% - D\%)/100) + 1]\} * 50$, *where:*

SIi: sprawl index for MSA

D%i= percentage of population in high-density tracts

S%i= percentage of population in low-density tracts

They calculated the sprawl index score for 330 MSAs. A 100 indicated the most sprawling MSA and a 0 indicated the least sprawl MSA. Thirteen of the MSAs located in south of the U.S., had the highest score, 100. A majority of the least sprawl MSAs were located in the West. By comparing scores for two years, 1990 and 2000, they found out that the sprawl increased in that time period.

Burchfield et al. (2006) developed a sprawl index for 40 MSAs by using remote-sensing data to track the evolution of land use on a grid of 8.7 billion 30 × 30 meter cells. They measured sprawl as the amount of undeveloped land surrounding an average urban dwelling. The results showed that extent of sprawl remained unchanged between 1976 and 1992, although it varied dramatically across metropolitan areas. The top 5 most sprawling MSAs were: Atlanta, GA; Greensboro, NC; Washington-Baltimore, VA/MD; Pittsburgh, PA and Rochester, NY. In contrast with other works, Dallas, TX; Phoenix, AZ and Memphis, TN all located in the south, were among the least sprawling MSAs. Miami, FL was the least sprawl of the MSAs. They concluded that moderate climate, lack of good public transportation, access to ground water, and unincorporated lands on the urban periphery are some of the reasons that increase sprawl.

Galster et al, (2001) considered sprawl as a multi-dimensional structure. They measured sprawl by incorporating six measures of urban form including: density, concentration, clustering, centrality, nuclearity and proximity. Galster et al used GIS and 1990 U.S. Census block data, for 13 large U.S. urban areas (not MSAs). The study found that most sprawling city was Atlanta, GA in the south with a score of -4.11. The city with the least sprawl was New York, (NY) in the east with a score of 8.9. After Atlanta; Miami, FL was second in rank. Los Angeles, CA, was among the least sprawl urban areas, due to its natural constraint. The majority of least sprawl cities were located in the northeast.

Custinger , Galster, Wolman, Hanson, and Towns (2005), expanded Galster et al.'s (2001) work and measure sprawl for 50 MSAs. They refined urban area to extended urban area and used all of the dimensions of Galster et al's work, and obtained seven factors: housing unit density, job density, nuclearity, mixed use of jobs to housing units, mixed use of housing units to jobs, housing unit and job centrality and housing unit and job proximity. Yin (2008) believed that these seven factors are not in conformity with the conceptual dimensions of sprawl identified by literature.

Ewing et al, (2002), developed Galster et al's (2001) work further, by using a multi-variable sprawl index based on 4 measures: density, land use mix, street accessibility and degree of centering. (Appendix D). For density, they combined 7 variables: Gross population density of urban lands and in persons per square mile, percentage of population living at low and high densities, estimated density at the center of the MSA, weighted average lot size and weighted density of all population centers within a metro area.

Mix factor was made up of 6 variables representing the relative balance between jobs and population, the diversity of land uses within subareas of a region, and accessibility of residential uses to nonresidential uses at different locations. The street factor was made up of 3 factors: Average block length, average block size and percentage of small blocks.

Six variables became components of center factor. Coefficient of variation of population density, density gradient, and percentage of metropolitan population less than 3 miles and more than 10 miles from the central business district (CBD), the percentage of population relating to centers, and ratio of the density of population centers to the highest density center.

Ewing et al (2002) applied principal component analysis to extract these 4 factors (density, mix, centers and street factor) from a large number of correlated variables and standardized them on scales with a mean of 100 and standard deviation of 25 to make all values positive and comparable. The final sprawl score was calculated by averaging the 4 sprawl factors. This sprawl index has been widely used in many studies. They calculated the sprawl score for 83 MSAs with population of more than half million. Nearly 150 million Americans were living in these MSAs in 2000. The results showed that Riverside, CA, in the west, was the most sprawling city and many southern cities, like: Atlanta, GA; Greenville-Spartanburg, SC; Knoxville, TN and Columbia, SC were among the most sprawl cities. The least sprawling MSAs were New York City, NY; Jersey City, NJ and Providence, RI. For Ewing et al sprawl index, lower scores show more sprawl urban areas but in other sprawl indices be used in this research study, higher scores, show more sprawl.

A review of the literature has shown that some studies found a direct link between density and energy consumption and carbon emission. Other projects have found alternate variables that were more significant in explaining this phenomenon. In next chapter methodology will be discussed.

CHAPTER 3

METHODOLOGY

This Chapter provides details on the research hypotheses, study area, data collection, variables, and regression equations used to examine the relationship between urban sprawl and transportation energy consumption and carbon footprint among 73 MSAs in the U.S.

3.1 Hypotheses

The hypotheses underlying this research study are as follows:

H0: MSAs that have higher levels of sprawl, (according to sprawl indices measured by different scholars) will not show higher per capita transportation energy consumption.

H1: MSAs that have higher levels of sprawl, (according to sprawl indices measured by different scholars) will show higher per capita transportation energy consumption.

H0: MSAs with higher levels of sprawl will not have a higher per capita transportation carbon footprint.

H2: MSAs with higher levels of sprawl will have a higher per capita transportation carbon footprint.

H0: Composite sprawl indices, that show urban sprawl as a multidimensional phenomenon, will not have a higher degree of correlation with levels of transportation energy consumption than sprawl indices that only use density to measure level of sprawl.

H3: Composite sprawl indices, that show urban sprawl as a multidimensional phenomenon, will have a higher degree of correlation with levels of transportation energy consumption than sprawl indices that only use density to measure level of sprawl.

H0: Composite sprawl indices, that show urban sprawl as a multidimensional phenomenon, will have a higher degree of correlation with levels of transportation carbon footprint than sprawl indices that only use density to measure level of sprawl.

H4: Composite sprawl indices, that show urban sprawl as a multidimensional phenomenon, will have a higher degree of correlation with levels of transportation carbon footprint than sprawl indices that only use density to measure level of sprawl.

3.2 Study Area

Because of data constraints, 73 MSAs were chosen for this study. According to the Office of Management and Budget ([OMB] 2008), an MSA contains "at least one urbanized area of 50,000 or more population, plus adjacent territory that has a high degree of social and economic integration with the core as measured by commuting ties." If 25% of commuters in outlying counties travel to a central county, then that county will be included in an MSA (Bereitschaft, 2011; OMB, 2008). Approximately 170 million people were living in these 73 MSAs in 2005. The selection of the 73 MSAs was based on the MSAs that two studies had in common. First, Ewing et al.'s (2002) work measured sprawl index for 83 MSAs. All of these 83 MSAs have a population greater than 500,000 and are nearly homogeneous. Second, Southworth et al.'s (2008) study calculated transportation energy use and carbon footprint for 100 MSAs. Of the MSAs in the two studies, 73 were in common: 15 MSAs from the Northeast region, 18 from the West, 25 from the South, and 15 from the Midwest (Census divisions).

3.3 Variables

The dependent variables are: transportation energy consumption and transportation carbon foot print.

The independent variables fall in two categories: 1. Urban sprawl indices—Four sprawl indices will be used in this study. The reason for choosing these sprawl indices is that they represent sprawl levels that were calculated for a number of MSAs in the United States. This enables comparison. Three of these sprawl indices are based on density; these include the indices of El Nasser and Overberg (2001), Lopez and Hynes (2003), and Burchfield et al.

(2006). The last one measures both density and contiguity. The Ewing et al. (2002) index is multidimensional and includes density, land-use mix, centering, and accessibility. As mentioned in the literature review, for each of these 4 criteria Ewing et al. provided a score and also provided an overall score for each MSA. Land-use patterns change slowly over time, and sprawl is a slow moving phenomenon, associated with decades-long development patterns. It is reasonable to assume that the most sprawling cities in 2000 were still the most sprawling cities in 2005 (or close to it) (R. Ewing, personal communication, April 19, 2012; B. Stone, personal communication, April 19, 2012). 2. Control variables—Confounding variables were chosen on the basis of strong theoretical or empirical correlations with dependent variables. Many variables influence transportation energy consumption and carbon footprint, but on this correlation basis 5 control variables were finally chosen: age, median family income, congestion index, mean travel time to work, and household median vehicle. Other control variables were also considered and their data collected, but they were not used in the analysis because (a) statistical constraints like multicollinearity and a large number of variables might bias regression results and degrees of freedom; (b) they had less logic or literature support; and (c) they lacked data in some cases. Finally, the five variables, which are considered to have a more distorting impact, were controlled for.

Regression analysis was run multiple times by different control variables and with all variables to ensure that any distorting impact was controlled. The process will be described in detail in the next chapter.

3.3.1 Control Variables

Age—Some studies, such as the one by Liddle (2011), found a positive relationship between young adults (20–34 years old) and vehicle miles traveled (VMT). The reason for this is that the majority of workers and drivers are in this age group, and normally young adults drive more. More VMT means more transportation energy consumption and carbon emissions. This variable should be controlled.

Median family income—Brazil and Purvis (2009), Brownstone and Golob (2009), Burchell et al. (2002), Fulton, Noland, Meszler, and Thomas (2000), Hu, Jones, Reuscher, Schmoyer, and Truett (2000), and Noland (2001) found that income has an impact on VMT: the higher the income, the higher VMT will be.

Congestion index—As congestion increases, travel time will increase, and that increases CO_2 emission and energy consumption. Su (2011) in his research study on U.S. urban areas showed that households in more congested areas consume more gasoline. Figliozzi (2011), in his study "*The Impacts of Congestion on Time-Definitive Urban Freight Distribution Networks CO2 Emission Levels: Results from a Case Study in Portland, Oregon*", showed that the impact of congestion on vehicle emission is significant but needs more research before it can be predicted.

Mean travel time to work—In some urban areas, normally suburbs, people drive more to get to their office. This variable should be controlled so as not to distort the effects of urban sprawl on energy consumption and carbon emissions.

Household median vehicle—More cars result in more driving, more emissions, and more fuel consumption.

3.4 Data Resource

Data for this research study was drawn from different resources. The data regarding transportation energy consumption and transportation carbon footprint for 2005 was obtained from a working paper by Southworth et al. (2008): "*The Transportation Energy and Carbon Footprints of the 100 Largest U.S. Metropolitan Areas"*. In this work, Southworth et al. set down the steps for calculating the transportation energy consumption and transportation carbon footprint for auto and truck travel activities in each metro area:

1. Estimate the daily vehicle miles of travel (DVMT).

2. Convert the DVMT estimates to gallons of fuel consumed, broken down by major fuel types—gasoline, petro-diesel, and liquefied petroleum gas.

3. Convert the fuel consumption into (a) its equivalent energy content (British thermal units) and (b) its equivalent carbon content, to produce a rough estimate of the carbon footprint created by this vehicular travel.

4. Multiply by 365 to get annual totals.

Data for 4 of the control variables (percentage of population in the age category 25–34, median family income, mean travel time to work, and household median vehicle) were collected from the U.S. Census Bureau (2009) and the American Factfinder website. The website classifies the U.S. Census data into categories for easier use. The congestion index came from Shrank, Lomax, and Eisele's (2011) work. For calculation procedure see appendix F.

3.5 Statistical Test

In this study, ordinary least squares (OLS) regression models were run on the Statistical Program for Social Sciences (SPSS) software to study the dependence of transportation energy consumption and transportation carbon emissions on sprawl. For evaluating the model output, significant variables from literature that were supported theoretically and empirically were added. Ten regression equations were run for the 4 research questions.

3.5.1. Regression Models

As discussed earlier, for the purpose of this research 4 hypotheses were formulated:

H1: MSAs that have higher levels of sprawl will show higher per capita transportation energy consumption.

For this hypothesis, the model regressed transportation energy consumption on the Ewing et al. (2002) sprawl components and confounding variables.

H2: MSAs that have higher levels of sprawl will show a higher per capita transportation carbon footprint.

This model regressed transportation carbon footprint on the Ewing et al. (2002) sprawl components while controlling confounding variables.

H3: The Ewing et al. (2002) composite sprawl index that uses multiple dimensions of urban forms to measure sprawl will have a higher degree of correlation with levels of transportation energy consumption than other sprawl indices that use only density to measure level of sprawl.

H4: The Ewing et al. (2002) composite sprawl index that uses multiple dimensions of urban forms to measure sprawl will have a higher degree of correlation with levels of transportation carbon footprint than other sprawl indices that use only density to measure level of sprawl.

These two hypotheses try to prove that density is not the only measure of sprawl and sprawl is a multidimensional phenomenon. The models regressed transportation energy consumption and carbon footprint on different sprawl indices to show which one better predicts transportation energy consumption and carbon footprint. The rest of this chapter will present the variables tested in the regression models in relation to the aforementioned hypothesis.

H1: MSAs that have higher levels of sprawl (according to sprawl indices) will show higher per-capita transportation energy consumption.

Transportation Energy Consumption Model

$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots\ldots\ldots + \beta_9X_9 + e$

Where:

Y = Transportation energy consumption (2005, million BTU per capita);
X_1= Age (25-34) (2005, percent);
X_2= Median household vehicle (2005, number);
X_3= Median family income (2005, thousand dollars);
X_4= Congestion index (2005);
X_5= Mean travel time to work (2005, minutes);

X_6 = Density factor (2000);
X_7= Mix factor (2000);
X= Streets factor (2000); and
X_9= Centers factor (2000)

H2: MSAs that have higher levels of sprawl, will show higher per-capita transportation carbon footprint.

Transportation Carbon Footprint Model

$Y = ß_0 + ß_1X_1 + ß_2X_2 + \ldots\ldots\ldots\ldots\ldots. + ß_9X_9+e$

Where:

Y = Transportation carbon footprint (2005, thousand metric ton per capita);

X_1= Age (25-34) (2005, percent);

X_2= Median household vehicle (2005, number);

X_3= Median family income (2005, thousand dollars);

X_4= Congestion index (2005);

X_5= Mean travel time to work (2005, minute);

X_6 = Density factor (2000);

X_7= Mix factor (2000);

X_8 = Streets factor (2000); and

X_9= Centers factor (2000)

H3: Ewing et al sprawl index that is a composite sprawl index and use multiple dimensions of urban forms to measure sprawl index will have higher degree of correlation with levels of transportation energy consumption than other sprawl indices that only use density to measure level of sprawl.

Transportation Energy Consumption Model

$Y = ß_0 + ß_1X_1 + ß_2X_2 +\ldots\ldots\ldots\ldots\ldots + ß_6X_6 +e$

Where:

Y = transportation energy consumption (2005, million BTU per capita);

X_1= Age (25-34) (2005, percent);

X_2= Median household vehicle (2005, number);

X_3= Median family income (2005, thousand dollars);

X_4= Congestion index (2005);

X_5= Mean travel time to work (2005, minute);

X_6 = Sprawl index: Ewing et al. (2002) or
Lopez and Hynes (2003) or
El Nasser and Overberg (2001) or
Burchfield et al (2006)

H4: Ewing et al sprawl index that is a composite sprawl index and use multiple dimensions of urban forms to measure sprawl index will have higher degree of correlation with levels of transportation carbon footprint than other sprawl indices that only use density to measure level of sprawl.

Transportation Carbon Footprint Model

$Y = ß_0 + ß_1X_1 + ß_2X_2 + \ldots\ldots\ldots\ldots\ldots + ß_6X_6 + e$

Where:

Y = Transportation carbon emission (2005, thousand metric ton);

X_1= Age (25-34) (2005, percent);

X_2= Median household vehicle (2005, number);

X_3= Median family income (2005, thousand dollars);

X_4= Congestion index (2005);

X_5= Mean travel time to work (2005, minute);

X_6 = Sprawl index: Ewing et al. (2002) or
Lopez and Hynes (2003) or
El Nasser and Overberg (2001) or
Burchfield et al (2006)

CHAPTER 4

RESULTS

This chapter presents the descriptive analysis, describes the regression models and estimates the significance of the independent variables.

4.1. Descriptive Analysis

Table 4.1 provides the descriptive statistics of the variables. For descriptive statistics for all control variables, see appendix A.

Table 4. 1 Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age (25-34) (percent)	73	10.44	17.48	13.54	1.43
MFI (thousand dollars)	73	38.60	93.90	62.18	10.32
MTT (minute)	73	18.00	34.20	24.78	3.21
CI	73	.55	1.57	1.05	.20
DF	73	71.22	180.69	96.90	18.03
MF	73	39.48	144.27	98.73	23.94
CF	73	41.42	167.29	102.50	22.58
SCF	73	37.23	138.56	96.82	23.47
EI	73	11.79	151.92	98.29	23.95
LI	73	6.72	94.17	52.87	19.48
NI	62	55.00	474.00	224.69	109.31
BI	39	20.73	57.70	38.54	8.44
TCF (thousand metric ton per capita)	73	.83	2.01	1.39	.28
TEC (million BTU per capita)	73	31.54	107.96	71.17	15.65

Note: BI, Burchfield et al. (2006) index; CF, centeredness factor; CI, congestion index; DF, density factor; EI, Ewing et al. (2002) index; LI, Lopez and Hynes (2003) index; MF, mix factor; MFI, median family income; MTT, mean travel time to work; NI, El Nasser and Overberg (2001) index; SCF, street connectivity factor; TCF, transportation carbon footprint; TEC, transportation energy consumption.

Appendix A gives some information about MSAs. The MSAs with the most transportation energy consumption in Southworth et al.'s (2008) work are in the South; for transportation carbon emissions the pattern is similar. As can be seen in appendix A, the most sprawling MSAs are in the South and the least sprawling are in the East. The majority of the top 10 MSAs with the least transportation energy consumption and smallest carbon footprint are in the East. MSAs in New York State that are the least sprawling have the least transportation energy consumption and smallest carbon footprint.

4.2. Pearson Correlation

The Pearson correlations for the variables used in the analysis for research question 1 are given in Tables 4.2–4.4. The results show that there is a moderate correlation between sprawl indices, urban forms, and transportation energy consumption and carbon footprint. It suggests that the increase in urban sprawl is associated with the increase in transportation energy consumption and carbon footprint, and this association is higher with carbon footprint.

Table 4-2: Pearson Correlations Among All Variables

		Age (25-34)	Median Family Income (1000)	Mean travel time to work	Congest-ion Index 2005	Transportation carbon footprint 2005 (per capita)	Transportation Energy Consumption 2005 (per capita)	Density Factor	Mix Factor	Centered-ness Factor	Street Connectivity Factor	Ewing Index	Lopez & Hynes Index	Nasser & Overburg Index	Burchfield et al Index
Age (25-34)	Pearson Correlation	1													
	Sig. (2-tailed)														
	N	73													
Median Family Income (1000)	Pearson Correlation	.036	1												
	Sig. (2-tailed)	.762													
	N	73	73												

Table 4-2 - continued

Mean travel time to work	Pearson Correlation	.099	.272*	1											
	Sig. (2-tailed)	.405	.020												
	N	73	73	73											
Congestion Index (2005)	Pearson Correlation	.398**	.255*	.635**	1										
	Sig. (2-tailed)	.000	.029	.000											
	N	73	73	73	73										
Transportation carbon footprint 2005 (per capita)	Pearson Correlation	.229	-.235*	-.327**	-.163	1									
	Sig. (2-tailed)	.051	.045	.005	.169										
	N	73	73	73	73	73									
Transportation Energy Consumption 2005 (per capita)	Pearson Correlation	.345**	-.180	-.181	-.019	.856**	1								
	Sig. (2-tailed)	.003	.127	.125	.876	.000									
	N	73	73	73	73	73	73								

Table 4-2 - continued

Density Factor	Pearson Correlation	.036	.209	.559**	.542**	-.585**	-.472**	1							
	Sig. (2-tailed)	.760	.077	.000	.000	.000	.000								
	N	73	73	73	73	73	73	73							
	Sig. (2-tailed)	.065	.128	.879	.751	.000	.005	.001							
	N	73	73	73	73	73	73	73	73						
Centeredness Factor	Pearson Correlation	-.166	-.051	-.309**	-.496**	-.180	-.279*	-.079	.146	1					
	Sig. (2-tailed)	.160	.670	.008	.000	.128	.017	.509	.219						
	N	73	73	73	73	73	73	73	73	73					
Street Connectivity Factor	Pearson Correlation	.091	.042	.409**	.506**	-.340**	-.210	.618**	.222	-.057	1				
	Sig. (2-tailed)	.444	.727	.000	.000	.003	.075	.000	.059	.634					
	N	73	73	73	73	73	73	73	73	73	73				
Ewing Index	Pearson Correlation	-.111	.035	-.004	-.021	-.487**	-.454**	.461**	.607**	.607**	.584**	1			
	Sig. (2-tailed)	.351	.767	.975	.861	.000	.000	.000	.000	.000	.000				
	N	73	73	73	73	73	73	73	73	73	73	73			

Table 4-2 - continued

Lopez & Hynes Index	Pearson Correlation	-.111	-.126	-.366**	-.558**	.541**	.437**	-.839**	-.440**	.137	-.600**	-.448**	1		
	Sig. (2-tailed)	.351	.287	.001	.000	.000	.000	.000	.000	.250	.000	.000			
	N	73	73	73	73	73	73	73	73	73	73	73	73		
	Sig. (2-tailed)	.954	.858	.146	.005	.000	.003	.000	.000	.886	.000	.000	.000		
	N	62	62	62	62	62	62	62	62	62	62	62	62	62	
Burchfield et al Index	Pearson Correlation	-.182	.214	-.065	-.331*	-.013	-.100	-.392*	-.366*	.034	-.358*	-.336*	.581**	.561**	1
	Sig. (2-tailed)	.267	.192	.693	.040	.935	.546	.014	.022	.838	.025	.036	.000	.000	
	N	39	39	39	39	39	39	39	39	39	39	39	39	37	39

Table 4-3: Pearson Correlations Among Control Variables and Dependent Variables

		Transportation Energy Consumption 2005 (per capita)	Transportation carbon footprint 2005 (per capita)	Median Family Income (1000)	Household median vehicle	Mean travel time to work	Congestion Index (2005)	Age (25-34)
Transportation Energy Consumption 2005 (per capita)	Pearson Correlation	1	.856**	-.180	.444**	-.181	-.019	.345**
	Sig. (2-tailed)		.000	.127	.000	.125	.876	.003
	N	73	73	73	73	73	73	73
Transportation carbon footprint 2005 (per capita)	Pearson Correlation	.856**	1	-.235*	.435**	-.327**	-.163	.229
	Sig. (2-tailed)	.000		.045	.000	.005	.169	.051
	N	73	73	73	73	73	73	73
Median Family Income(1000)	Pearson Correlation	-.180	-.235*	1	-.227	.272*	.255*	.036
	Sig. (2-tailed)	.127	.045		.053	.020	.029	.762
	N	73	73	73	73	73	73	73
Household median vehicle	Pearson Correlation	.444**	.435**	-.227	1	-.482**	-.021	.440**
	Sig. (2-tailed)	.000	.000	.053		.000	.863	.000
	N	73	73	73	73	73	73	73

Table 4-3 - continued

Mean travel time to work	Pearson Correlation	-.181	-.327**	.272*	-.482**	1	.635**	.099
	Sig. (2-tailed)	.125	.005	.020	.000		.000	.405
	N	73	73	73	73	73	73	73
Congestion Index (2005)	Pearson Correlation	-.019	-.163	.255*	-.021	.635**	1	.398**
	Sig. (2-tailed)	.876	.169	.029	.863	.000		.000
	N	73	73	73	73	73	73	73
Age (25-34)	Pearson Correlation	.345**	.229	.036	.440**	.099	.398**	1
	Sig. (2-tailed)	.003	.051	.762	.000	.405	.000	
	N	73	73	73	73	73	73	73

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4-4: Pearson Correlation Between Among Urban Sprawl Indices

		Density Factor	Mix Factor	Centeredness Factor	Street Connectivity Factor	Ewing Index	Lopez & Hynes Index	Nasser & Overburg Index	Burchfield et al Index
Density Factor	Pearson Correlation	1	$.379^{**}$	-.079	$.618^{**}$	$.461^{**}$	$-.839^{**}$	$-.630^{**}$	$-.392^{*}$
	Sig. (2-tailed)		.001	.509	.000	.000	.000	.000	.014
	N	73	73	73	73	73	73	62	39
Mix Factor	Pearson Correlation	$.379^{**}$	1	.146	.222	$.607^{**}$	$-.440^{**}$	$-.510^{**}$	$-.366^{*}$
	Sig. (2-tailed)	.001		.219	.059	.000	.000	.000	.022
	N	73	73	73	73	73	73	62	39
Centeredness Factor	Pearson Correlation	-.079	.146	1	-.057	$.607^{**}$	.137	-.019	.034
	Sig. (2-tailed)	.509	.219		.634	.000	.250	.886	.838
	N	73	73	73	73	73	73	62	39
Street Connectivity Factor	Pearson Correlation	$.618^{**}$	.222	-.057	1	$.584^{**}$	$-.600^{**}$	$-.563^{**}$	$-.358^{*}$
	Sig. (2-tailed)	.000	.059	.634		.000	.000	.000	.025
	N	73	73	73	73	73	73	62	39
Ewing Index	Pearson Correlation	$.461^{**}$	$.607^{**}$	$.607^{**}$	$.584^{**}$	1	$-.448^{**}$	$-.589^{**}$	$-.336^{*}$
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.036
	N	73	73	73	73	73	73	62	39
Lopez & Hynes Index	Pearson Correlation	$-.839^{**}$	$-.440^{**}$	.137	$-.600^{**}$	$-.448^{**}$	1	$.770^{**}$	$.581^{**}$
	Sig. (2-tailed)	.000	.000	.250	.000	.000		.000	.000
	N	73	73	73	73	73	73	62	39

Table 4-4 - continued

Nasser & Overburg Index	Pearson Correlation	-.630**	-.510**	-.019	-.563**	-.589**	.770**	1	.561**
	Sig. (2-tailed)	.000	.000	.886	.000	.000	.000		.000
	N	62	62	62	62	62	62	62	37
Burchfield et al Index	Pearson Correlation	-.392*	-.366*	.034	-.358*	-.336*	.581**	.561**	1
	Sig. (2-tailed)	.014	.022	.838	.025	.036	.000	.000	
	N	39	39	39	39	39	39	37	39

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.3. Statistical Tests for Research Question 1

In this section, regression analysis assesses the direction and strength of the relationship between urban form and transportation energy consumption and carbon footprint.

Research Question 1: Does MSAs that have higher levels of sprawl will show higher per-capita transportation energy consumption?

Table 4.5 shows the Analysis of Variance (ANOVA) and the significance of the model. The model is significant at .01 level (99 percent levels). The F value is less than .01, which means that the independent variables show a significant relationship with the transportation energy consumption and reliably predict the variation in per capita transportation energy consumption in 2005.

In Table 4.5 the coefficient of determination, the R^2 value is .438. Forty there percent of the variation in the dependent variable is explained uniquely or jointly by the independent variables. Adjusted R^2 adjusts the values of R^2 to the number of independent variables which in this model is .438. What is considered high R^2 varies in different fields; for example, in some areas of the social and biological sciences, an R^2 of .50 or .60 is considered high. (Smith, 2010).

The first regression model assesses the strength of the association between transportation energy consumption and 4 components of the Ewing et al. (2002) sprawl index. Table 4.6 shows the model Summary. Table 4.5 shows the coefficients and their corresponding significance values.

A significant negative association was found between density, centeredness, and transportation energy consumption. A significant positive association was found between age (25-34) and transportation energy consumption. Also, there is a negative relation between population density and energy consumption. Density is significant at .01 level (99 percent levels). One unit increase in density will decrease the transportation energy consumption by .431 million BTU. The estimated rate of change of the conditional mean of transportation energy consumption with respect to density, holding the other independent variables constant is between 0.58 and -.282 units (.431 ± .149). The confidence intervals provide a range of values within which, with a 99% level of confidence, the estimated coefficient in “B” lies. Another interpretations can be used: the standard deviation for density is 18.03. A single standard deviation increase in density, is associated with .497 standrad deviation decrease in transportation energy consumption or 8.96 (18.03 * .497) decrease in transportation energy consumption.

Centeredness is significant at .05 level (95 percent levels). One unit increase in centeredness will decrease transportation energy consumption by .184 units. A single standard deviation increase in centeredness is associated with a 6 (22.58 * .266) standard deviation decrease in transportation energy consumption. Age is significant at .05 level. One percent increase in age group (25-34), will increase transportation energy consumption by 3.25 million BTU. One standard deviation increase in percentage of age group (25-34) will increase transportation energy consumption by 4.2 (1.43 * .297). For other independent variables, no statistically significant linear dependence of the mean of Y on X was detected. The model tested for normality, auto-correlation, multicollinearity, outlier and heteroscedasticity. The model shows no auto-correlation, multicollinearity outlier and heteroscedasticity and is normally distributed. (Appendix E)

The Durbin-Watson value, close to 2, shows no auto-correlation. The value of VIF is less than 10, indicating no multicollinearity. If the leverage value is close to 1, it shows an outlier; in this case the Leverage value indicates no outlier. Another method for finding the outlier is using the Cook’s distance. If its value is more than 4/n, there is outlier. Here the value is less than 4/73, showing that there is no outlier.

Research Question 1: Does MSAs that have higher levels of sprawl will show higher per-capita transportation energy consumption?

Table 4.5 ANOVA – Regression Model 1

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	7726.222	9	858.469	5.447	.000
	Residual	9928.727	63	157.599		
	Total	17654.948	72			

a. Predictors: (Constant), Street Connectivity Factor, Median Family Income (1000), Centeredness Factor, 25-34, Mix Factor, Household median vehicle, mean travel time to work, Density Factor, Congestion Index 2005

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.6 Model Summary – Regression Model 1

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.662	.438	.357	12.55384	2.108

a. Predictors: (Constant), Street Connectivity Factor, Median Family Income(1000), Centeredness Factor, 25-34, Mix Factor, Household median vehicle, mean travel time to work, Density Factor, Congestion Index 2005

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.7 Coefficients and Significance - Regression Equation 1

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	90.212	29.843		3.023	.004
	Age (25-34)	3.255	1.395	.297	2.334	.023
	Median Family Income	-.131	.158	-.086	-.827	.411
	Household median vehicle	1.903	8.026	.038	.237	.813
	Mean travel time to work	.028	.774	.006	.036	.972
	Congestion Index 2005	-1.372	13.769	-.018	-.100	.921
	Density Factor	-.431	.149	-.497	-2.903	.005
	Mix Factor	-.022	.075	-.033	-.289	.773
	Centers Factor	-.184	.082	-.266	-2.254	.028
	Streets Factor	.051	.089	.077	.579	.565

4.4. Statistical Tests for Research Question 2

The second regression model assesses the strength of the association between the transportation carbon footprint and the four components of the Ewing et al.'s (2002) sprawl index. Research Question 2: Does MSAs that have higher levels of sprawl will show higher per-capita transportation carbon footprint?

Table 4.6 shows the model is significant at the .05 level and the .01 level. R^2, as Table 4.7 shows, is .478. This means that 47.8 percent of the variation in the transportation carbon footprint explained by the independent variables. The Adjusted R^2 value is .403.

Table 4.8 shows the coefficients. Only density factor is significant at .01 levels. One unit increase in density will decrease the transportation carbon footprint .007 units (thousands metric ton here). A single standard deviation increase in density is associated with 8.49 (18.03 * .471) thousand metric ton decreases in the transportation carbon footprint. This means a denser urban area results in less carbon footprint. Control variables were not significant in the carbon footprint model. Forty eight percent variations in the transportation carbon footprint are predicted by the Ewing et al sprawl components. The model shows no auto-correlation, multicollinearity, outlier and heteroscedasticity.

Research Question 2: Does MSAs that have higher levels of sprawl will show higher per-capita transportation carbon footprint?

Table 4.8 ANOVA **-** Regression Model 2

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2.768	9	.308	6.402	.000
	Residual	3.027	63	.048		
	Total	5.795	72			

a. Predictors: (Constant), Mix Factor, mean travel time to work, 25-34, Median Family Income(1000), Centeredness Factor, Street Connectivity Factor, Household median vehicle, Density Factor, Congestion Index 2005

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.9 Model Summary – Regression Model 2

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.691	.478	.403	.21919	2.079

a. Predictors: (Constant), Mix Factor, mean travel time to work, 25-34, Median Family Income(1000), Centeredness Factor, Street Connectivity Factor, Household median vehicle, Density Factor, Congestion Index 2005
b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.10 Coefficients and Significance - Regression Model 2

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.440	.521		4.683	.000
	Age (25-34)	.035	.024	.175	1.425	.159
	Median Family Income	-.003	.003	-.098	-.979	.331
	Household median vehicle	.009	.140	.010	.066	.947
	Congestion Index 2005	.078	.240	.055	.325	.746
	Mean travel time to work	-.013	.014	-.143	-.931	.356
	Density Factor	-.007	.003	-.471	-2.857	.006
	Mix Factor	-.002	.001	-.149	-1.341	.185
	Centers Factor	-.002	.001	-.187	-1.645	.105
	Streets Factor	-7.636E-5	.002	-.006	-.049	.961

Dependent Variable: Transportation carbon footprint 2005 (per capita)

4.5. Statistical Tests for Research Question 3

In the next set of regression models, the relationship between urban sprawl and per capita transportation energy consumption in 2005 will be explored. In each regression model the independent variables included one of the 4 sprawl indices and the 5 control variables. Because there is a high potential for multicollinearity between these sprawl indices, they will be run separately:

In the first model, the Ewing et al. (2002) sprawl index is examined. Table 4.9 shows the model is significant at the .05 and .01 level. R^2 as Table 4.10 shows is .382. This means that 38.2 percent of the variation in the transportation carbon footprint explained by the independent variables. The Adjusted R^2 value is .326.

Table 4.11 shows the coefficients. The Ewing et al index is significant at the .01 level. A one unit increase in Ewing et al sprawl index will decrease transportation energy consumption by .250 million BTU, or one standard deviation increase in the Ewing sprawl index, will decrease transportation energy consumption by 9.12 (.382 * 23.9). (Smaller scores in the Ewing sprawl index, show higher sprawl.) Household median vehicle and age are significant at .1 levels. This regression model, predicts only 38.2 percent variations in dependent variable. The model shows no auto-correlation, multicollinearity, outlier and heteroscedasticity.

Research Question 3: Does Ewing et al sprawl index that is a composite sprawl index have a higher degree of correlation with levels of transportation energy consumption than other sprawl indices that only use density to measure level of sprawl?

Table 4.11 ANOVA - Regression Model 3

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6748.080	6	1124.680	6.806	.000
	Residual	10906.869	66	165.256		
	Total	17654.948	72			

a. Predictors: (Constant), Ewing Index , mean travel time to work, 25-34, Median Family Income(1000), Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.12 Model Summary – Regression Model 3

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.618	.382	.326	12.85518	2.169

a. Predictors: (Constant), Household median vehicle, Congestion Index 2005, Ewing Index , Median Family Income(1000), 25-34, mean travel time to work

b. Dependent Variable: Transportation Energy Consumption 2005(per capita

Table 4.13 Coefficients and Significance - Regression Model 3

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	54.801	26.875		2.039	.045
	Age (25-34)	2.548	1.334	.233	1.911	.060
	Median Family Income	-.145	.156	-.096	-.929	.356
	Household median vehicle	12.251	7.126	.244	1.719	.090
	Congestion Index 2005	-6.531	11.312	-.084	-.577	.566
	Mean travel time to work	-.043	.778	-.009	-.055	.956
	Ewing Index	-.250	.065	-.382	-3.851	.000

Dependent Variable: Transportation Energy Consumption 2005(per capita)

In second model, the Lopez and Hynes (2003) index is significant at the .01 level, and it predicts 42 percent variation, more than the Ewing et al. (2002) sprawl index. One unit increase in Lopez and Hynes sprawl index, will increase transportation energy consumption by .428 million BTU. One standard deviation increases in the Lopez sprawl index increases transportation energy consumption by (19.4 * .532) 10.32 million BTU. The model shows no auto-correlation, multicollinearity, outlier and heteroscedasity. Other than Lopez and Hynes sprawl index, only Age (25-34) is significant at .05 level. One unit increase in this variable will increase the transportation energy consumption by 2.57 units.

Table 4.14 ANOVA - Regression Model 3

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7409.100	6	1234.850	7.954	.000
	Residual	10245.849	66	155.240		
	Total	17654.948	72			

a. Predictors: (Constant), Lopez & Hynes Index, 25-34, Median Family Income (1000), mean travel time to work, Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.15 Model Summary – Regression Model 3

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.648	.420	.367	12.45954	2.227

a. Predictors: (Constant), Lopez & Hynes Index, 25-34, Median Family Income (1000), mean travel time to work, Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.16 Coefficients and Significance - Regression Model 3

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
1	(Constant)	-5.151	24.287		-.212	.833
	Age (25-34)	2.577	1.293	.235	1.993	.050
	Median Family Income	-.202	.152	-.133	-1.328	.189
	Household median vehicle	8.706	7.057	.173	1.234	.222
	Congestion Index 2005	19.920	12.777	.256	1.559	.124
	Mean travel time to work	-.258	.760	-.053	-.339	.736
	Lopez & Hynes Index	.428	.096	.532	4.477	.000

Dependent Variable: Transportation Energy Consumption 2005(per capita)

The El Nasser and Overberg (2001) index is significant at the .05 level and predicts 34.7 percent variation in transportation energy consumption. One unit increase in El Nasser and Overberg index will increase transportation energy consumption by .53 million BTU and one standard deviation increase in this index is equal to 39.02 (.357 * 109.3) increase in transportation energy consumption. The model shows no auto-correlation, multicollinearity, outlier and heteroscedasticity. As shown in Table 4. 17, only one other variable, number of household median vehicle is significant at .1 level (90 percent levels).

Table 4.17 ANOVA - Regression Model 3

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5601.376	6	933.563	4.873	.000
	Residual	10536.539	55	191.573		
	Total	16137.915	61			

a. Predictors: (Constant), El Nasser & Overberg Index, 25-34, mean travel time to work, Median Family Income (1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.18 Model Summary – Regression Model 3

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.589	.347	.276	13.84101	2.304

a. Predictors: (Constant), El Nasser & Overberg Index, 25-34, mean travel time to work, Median Family Income (1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.19 Coefficients and Significance - Regression Model 3

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.453	29.984		.249	.805
	Age (25-34)	1.410	1.785	.124	.790	.433
	Median Family Income	-.050	.237	-.028	-.209	.835
	Household median vehicle	17.297	9.430	.335	1.834	.072
	Congestion Index 2005	9.917	14.054	.122	.706	.483
	Mean travel time to work	-.321	.908	-.064	-.353	.725
	El Nasser & Overberg Index	.053	.018	.357	2.983	.004

Dependent Variable: Transportation Energy Consumption 2005(per capita)

In the last model for question 3, the Burchfield et al index is not significant and cannot predict variation in transportation energy consumption.

Table 4.20 ANOVA - Regression Model 3

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2502.303	6	417.050	2.903	.022
	Residual	4597.117	32	143.660		
	Total	7099.420	38			

a. Predictors: (Constant), Burchfield et al Index, mean travel time to work, 25-34, Median Family Income(1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation Energy Consumption 2005(per capita)

Table 4.21 Model Summary – Regression Model 3

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.594	0.352	0.231	11.98582	1.701

a. Predictors: (Constant), Burchfield et al Index, mean travel time to work, 25-34, Median Family Income(1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation Energy Consumption 2005(per capita

Table 4.22 Coefficients and Significance - Regression Model 3

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	33.273	34.583		.962	.343
Age (25-34)	3.742	1.976	.412	1.894	.067
Median Family Income(1000)	-.090	.243	-.063	-.372	.713
Household median vehicle	9.286	10.536	.226	.881	.385
Congestion Index 2005	-6.948	14.167	-.105	-.490	.627
Mean travel time to work	-.637	1.028	-.146	-.619	.540
Burchfield et al Index	-.056	.259	-.035	-.216	.830

Dependent Variable: Transportation Energy Consumption 2005(per capita)

4.6 Statistical Tests for Research Question 4

In next set of regression models, the relationship between urban sprawl and per-capita transportation carbon footprint, in 2005 will be explored. In each regression model, the independent variables included one of 4 sprawl indices and 5 control variables:

In the first model, the Ewing et al. (2001) sprawl index will be examined, this index is significant at the 0.01 level, one unit increase in Ewing et al sprawl index, will decrease transportation carbon footprint 0.005 thousands metric ton. One standard deviation increase in the Ewing sprawl index, will decrease transportation carbon footprint by 10.39 (0.435*23.9) thousands metric ton. This model shows sprawl has greater impact on the transportation carbon footprint than control variables; the model predicts 42.3 percent of variation.

Research question 4: Does the Ewing sprawl index that is a composite sprawl index have a higher degree of correlation with levels of transportation carbon footprint than other sprawl indices that only use density to measure level of sprawl?

Table 4.23 ANOVA - Regression Model 4

Sum of Squares	df	Mean Square	F	Sig.
2.453	6	.409	8.073	.000
3.342	66	.051		
5.795	72			

a. Predictors: (Constant), Ewing Index , mean travel time to work, 25-34, Median Family Income(1000), Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.24 Model Summary – Regression Model 4

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.651	.423	.371	.22503	2.014

a. Predictors: (Constant), Ewing Index , mean travel time to work, 25-34, Median Family Income(1000), Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.25 Coefficients and Significance - Regression Model 4

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.862	.470		3.958	.000
	Age (25-34)	.032	.023	.163	1.388	.170
	Median Family Income(1000)	-.003	.003	-.115	-1.157	.251
	Household median vehicle	.159	.125	.175	1.276	.206
	Congestion Index 2005	-.137	.198	-.097	-.690	.493
	Mean travel time to work	-.015	.014	-.168	-1.087	.281
	Ewing Index	-.005	.001	-.435	-4.541	.000

Dependent Variable: Transportation carbon footprint 2005 (per capita)

In the second model, the Lopez and Hynes (2003) index is significant at the 0.01 level and it predicts 46.6 percent of variations, more than the Ewing sprawl index. One unit increase in Lopez and Hynes index increases transportation carbon footprint by .009 thousand metric tons. One standard deviation increase in the Lopez sprawl index increases transportation carbon emission by 11.62 (19.4 * .599). Surprisingly, none of the control variables are significant at the .05 or the .01 level in this model. Congestion index is significant at .1 level.

Table 4.26 ANOVA - Regression Model 4

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2.702	6	.450	9.606	.000
	Residual	3.094	66	.047		
	Total	5.795	72			

a. Predictors: (Constant), Lopez & Hynes Index, 25-34, Median Family Income(1000), mean travel time to work, Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.27 Model Summary – Regression Model 4

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.683	.466	.418	.21650	2.072

a. Predictors: (Constant), Lopez & Hynes Index, 25-34, Median Family Income(1000), mean travel time to work, Household median vehicle, Congestion Index 2005

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.28 Coefficients and Significance - Regression Model 4

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	.629	.422		1.491	.141
Age (25-34)	.033	.022	.166	1.470	.146
Median Family Income(1000)	-.004	.003	-.157	-1.637	.106
Household median vehicle	.088	.123	.097	.720	.474
Congestion Index 2005	.402	.222	.285	1.809	.075
Mean travel time to work	-.019	.013	-.216	-1.446	.153
Lopez & Hynes Index	.009	.002	.599	5.252	.000

Dependent Variable: Transportation carbon footprint 2005 (per capita)

The El Nasser and Overberg (2001) index is significant at the .01 level and predicts 46.6 percent variation in transportation carbon footprint and control variables. One unit increase in El Nasser and Overberg index is equal to .001 thousand metric ton increase in transportation carbon footprint. One increase in its standard deviation is equal to 54.32 (0.497 * 109.31) standard deviation increase in transportation carbon footprint. Also mean travel time to work is significant at .1 level.

Table 4.29 ANOVA - Regression Model 4

Model	Sum of Squares	Df	Mean Square	F	Sig.
1 Regression	2.411	6	.402	7.855	.000
Residual	2.814	55	.051		
Total	5.225	61			

a. Predictors: (Constant), El Nasser & Overberg Index, 25-34, mean travel time to work, Median Family Income(1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.30 Model Summary – Regression Model 4

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.679	.461	.403	.22618	2.024

a. Predictors: (Constant), El Nasser & Overberg Index, 25-34, mean travel time to work, Median Family Income(1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.31 Coefficients and Significance - Regression Model 4

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.020	.490		2.081	.042
Age (25-34)	.008	.029	.038	.268	.790
Median Family Income	-.002	.004	-.052	-.436	.665
Household median vehicle	.216	.154	.233	1.402	.167
Congestion Index 2005	.255	.230	.174	1.111	.271
Mean travel time to work	-.025	.015	-.277	-1.683	.098
El Nasser & Overberg Index	.001	.000	.497	4.575	.000

Dependent Variable: Transportation carbon footprint 2005 (per capita)

The Burchfield et al. (2006) index is not significant and cannot predict variation in transportation carbon footprint.

Table 4.32 ANOVA - Regression Model 4

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.754	6	.126	2.795	.027
	Residual	1.439	32	.045		
	Total	2.193	38			

a. Predictors: (Constant), Burchfield et al Index, mean travel time to work, 25-34, Median Family Income(1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.33 Model Summary – Regression Model 4

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.586	.344	.221	.21205	1.943

a. Predictors: (Constant), Burchfield et al Index, mean travel time to work, 25-34, Median Family Income(1000), Congestion Index 2005, Household median vehicle

b. Dependent Variable: Transportation carbon footprint 2005 (per capita)

Table 4.34 Coefficients and Significance - Regression Model 4

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.682	.612		1.114	.273
	Age (25-34)	.040	.035	.253	1.154	.257
	Median Family Income(1000)	.000	.004	-.005	-.029	.977
	Household median vehicle	.275	.186	.380	1.477	.150
	Congestion Index 2005	-.194	.251	-.166	-.775	.444
	Mean travel time to work	-.008	.018	-.101	-.425	.674
	Burchfield et al Index	.000	.005	.007	.044	.965

Table 4.35 and 4.36 show the summary of results. Density factor, centers factor and age are significant in the first model. In the second model, only density is significant. The third and fourth models show Lopez & Overberg index has higher degree of association with transportation energy consumption and carbon footprint than other sprawl indices.

Table 4.35 Summary of Results for Model 1 and 2

		Transportation energy	Transportation carbon
Density Factor	Unstandardized B	-.431	-.007
	Standardized B	-.497	-.471
	Sig	.005	.006
Mix Factor	Unstandardized B	-.289	-.002
	Standardized B	-.033	-.149
	Sig	.773	.185
Street Factor	Unstandardized B	.051	-7.6E-5
	Standardized B	-.266	-.187
	Sig	.565	.961
Centered Factor	Unstandardized B	-.184	-.002
	Standardized B	.077	-.006
	Sig	.028	.105

Table 4.36 Summary of Results for Third and Fourth Models

		Transportation energy	Transportation carbon
Ewing et al	Unstandardized B	-.25	-.005
	Standardized B	-.382	-.435
	Sig	.000	.000
	R Square	.382	.423
	Adj R Square	.326	.371
Lopez & Hynes	Unstandardized B	.428	.009
	Standardized B	.532	.599
	Sig	.000	.000
	R Square	.42	.466
	Adj R Square	.367	.418
Nasser & Overberg	Unstandardized B	.53	.001
	Standardized B	.357	.497
	Sig	.004	.000
	R Square	.347	.461
	Adj R Square	.276	.403
Burchfield	Unstandardized B	-.058	.000
	Standardized B	-.035	.007
	Sig	.830	.965
	R Square	.352	.344
	Adj R Square	.358	.271

CHAPTER 5

CONCLUSION

The objective of this research was to assess the impact of urban sprawl on per capita transportation energy consumption and transportation carbon footprint (2005) of 73 MSAs in the U.S. This chapter reports the research findings and discusses implications that were identified from comparing data in each study.

5.1. Summary of Results

The previous chapter evaluated and tested the following 4 research questions:

Research Question 1: Do MSAs that have higher levels of sprawl will show higher per-capita transportation energy consumption?

Research Question 2: Do MSAs that have higher levels of sprawl, will show higher per-capita transportation carbon footprint?

Research Question 3: Does the Ewing et al sprawl index that is a composite sprawl index and use multiple dimensions of urban forms to measure sprawl index will have higher degree of correlation with levels of transportation energy consumption than other sprawl indices that only use density to measure level of sprawl?

Research Question 4: Does the Ewing et al sprawl index that is a composite sprawl index and use multiple dimensions of urban forms to measure sprawl index will have higher degree of correlation with levels of transportation carbon footprint than other sprawl indices that only use density to measure level of sprawl?

5.1.1. Research Question 1

In the first regression model, 3 variables were significant: density at the .01 level and centeredness and age (25-34) at the .05 level. Density and centeredness had negative correlations with transportation energy consumption; indicate that as urban area become denser and centeredness increases less transportation energy will be consumed. Another significant variable was age category (25-34). If the proportion of young people (25–34) in an urban area increases, transportation energy consumption will increase. Metropolitan centers are places in the city that activities are concentrated. Technical literature, associates sprawl cities with lack of centers (Ewing, 2002). In Ewing's work, 6 variables, made centers factor:

1. "Coefficient of population density variation across census tracts (standard deviation divided by mean density);
2. Density gradient (rate of decline of density with distance from the center of the metro area);
3. Percentage of metropolitan population less than 3 miles from central business district (CBD);
4. Percentage of metropolitan population more than 10 miles from the CBD;
5. Percentage of the metropolitan population relating to centers or sub centers within the same MSA or PMSA; and
6. Ratio of the weighted density of population centers within the same MSA or PMSA to the highest density center to which metro relates."

Then as density, density gradient, and percentage of population close to CBD increase; the transportation energy consumption will decrease.

The results support the idea that as concentration increases around central business districts, the transportation energy consumption decreases. Hiramatsu (2010) in his dissertation suggested that with more sub centers and CBDs in sprawl cities, residents would be able to complete most of their activities near these sub centers. This would decrease the vehicle usage, but not as much as it would be in a very compact, high density city with a single center.

5.1.2. Research Question 2

In the regression model for this research question, density was the only significant factor in predicting transportation carbon footprint. A negative significant correlation was found between density and transportation carbon footprint, indicating that denser urban areas have less carbon emissions. The second null hypothesis was rejected. One reason that the centers factor was not significant in this model was the methodology used to calculate transportation carbon footprint. The type of fuel might be another reason. It is also possible that in some MSAs, lower carbon emitting fuels were used.

5.1.3. Research Question 3

In this set of regression models, 3 of 4 sprawl indices were significant: the Ewing et al. (2002) composite sprawl index, the Lopez and Hynes index and the Nasser and Overberg index. The Lopez and Hynes's index show a higher degree of correlation with transportation energy consumption than the Ewing et al sprawl index and Nasser and Overberg's sprawl index. Considering standard deviation, one standard deviation increase in the Lopez and Hynes index will increase transportation energy consumption more than two other indices. The third hypothesis was not proven.

5.1.4. Research Question 4

In this set of regression models, 3 of 4 sprawl indices were significant. The Ewing et al. (2002) sprawl index, the Lopez and Hynes (2003) index, and the El Nasser and Overberg (2001) index were significant at the .01 level. The Lopez and Hynes index and the El Nasser and Overberg index predicted 46% of variation in transportation carbon footprint. The Ewing et al. index predicted 42 percent of variation, the B coefficient of the Lopez and Hynes index was .009, higher than with the Ewing et al.'s index, which was .005, and for the El Nasser and Overberg index it was 0.001. A one standard deviation increase in the Lopez and Hynes index increased the transportation carbon footprint by .17 thousand metric tons. For the Ewing et al.

index, this value was 0.11, and for the El Nasser and Overberg index it was 0.109 thousand metric tons. This hypothesis was not proven.

The Burchfield et al. (2006) sprawl index was not significant for any of the research questions. One reason might have been that it was applied to 40 MSAs, which reduces the statistical power of the regression models. Another issue is the data used in this index is from 1992 (Bereitschaft, 2011).

The third and fourth hypotheses were not proven. It shows that density has more impact on transportation energy consumption than other factors. In the first research question, density was the most important factor, and in the second research question, density was the only significant factor among 4 components. That in the third and fourth research questions the Lopez and Hynes (2003) sprawl index (measured on density) was more significant than the Ewing et al. (2002) sprawl index is not surprising. To summarize, 3 of the 4 sprawl indices indicated a significant rise in transportation energy consumption of 5.32–57.9 million BTU for one standard deviation increase in urban sprawl. The three sprawl indices also indicated a significant rise in transportation carbon footprint of between .109 and .17 thousand metric tons. The results did not support the third and fourth research questions, which asked whether composite sprawl indices will have a higher degree of association with levels of transportation energy consumption and carbon footprint than indices using only density. However, it shows that density is the most important factor.

The results of this research confirm some of the findings and significant variables that were identified in the literature review. Among the control variables, only age was significant at the .05 and .01 levels, because of the high percentage of young people as a working group and the behavioral characteristics of young people, who normally drive more. Household median vehicle was significant at the .1 level in research question 3 for the Ewing et al. (2002) index and the El Nasser and Overberg (2001) index equations. It shows that as the number of vehicles increase, transportation energy consumption increases. In research question 4, the congestion index was significant at the .1 level for the Lopez and Hynes (2003) index, meaning that as congestion increases the transportation carbon footprint increases. Mean travel time to work was significant at the .1 level for the El Nasser and Overberg index, which shows that as travel time increases, the transportation carbon footprint increases. Most of the regression models predicted nearly half of the variation. The other half can depend on many other variables, such as driving behavior, road type, length of the road network, existing capacity of road network, vehicle type, weight of vehicles, transit availability, and level of accessibility on VMT and many other variables that are not measurable. The equations were run also with different control variables than these 5 control variables, but the R^2 value was not improved.

5.2 Limitations

There are several limitations in this study:

1. The results are limited because all the important controls were not included based on lack of data and time.
2. This research study has used secondary data from a working paper by Southworth et al (2008): "*The transportation energy and carbon footprints of the 100 largest U.S. metropolitan areas*". Caution is advisable in interpreting or making inference from the results of the study because of the secondary data. This data was used because it was the only data that has calculated transportation energy consumption and carbon footprint for 100 MSAS in the U.S. To be able to generalize the results of this research study, an original data may have provided different results.
3. Statistical significance is not stressed because of the relatively small sample size, 73 urban areas only within the U.S., which makes generalization difficult.
4. The El Nasser & Overberg index had 10 missing values and the Burchfield et al index was calculated for 40 MSAs which make comparison of the results difficult.
5. There is no agreement on measuring sprawl.

5.3 Policy Implications

The findings of this study, support the idea that urban sprawl is associated with higher transportation energy consumption and carbon footprint. Among the 4 components of urban sprawl, density had the strongest negative correlation, with the dependent variable. This indicates that an increase in density will result in less transportation energy consumption and carbon footprint. The results can be used as evidence for policymakers to support more compact cities. Smart growth is one of the urban planning policies that can be used to provide a more sustainable urban area. It encourages compact, transit-oriented, walkable, bicycle-friendly land use and supports infill development of abandoned areas and redevelopment of already built areas. (Anderson & Tregoning, 1998, Porter 2002). One of the strategies used in smart growth is urban growth boundaries (UGB). UGB is a governmental decision to stop supporting areas beyond a specific area with public infrastructure services like water and sewer services. (Kolakowski, Machemer & Hamlin, 2000).

Another strategy is new urbanism which Congress for the New Urbanism (2001) indicated its goal is providing a healthy urban development by reintegrating traditional elements of neighborhoods with modern neighborhoods in which affordable homes are available for all, schools are in walking distance, commuting time is less and where there are multiple transportation options available (as cited in Ferriter, 2008).

New urbanism encompasses principles like transit-oriented development (TOD). That is another strategy to encourage the development around public transportation. Some of the benefits of TOD include “reduced household driving, walkable communities, increased transit ridership and fare revenue, improved access to jobs and economic opportunity for low-income people and working families, and expanded mobility choices that reduce dependence on the automobile. “(Reconnecting America, 2012).

Some suggestions that can result in less transportation energy consumption and carbon emissions and going toward a more sustainable urban living are as follows:

1. Giving government incentives for redevelopment of built areas;
2. Increasing taxes for abandoned lands or reinvesting in them;
3. Decreasing the horizontal expansion of cities;
4. Maximizing the energy efficiency of vehicles;
5. Implementing anti-congestion policies in compact cities to encourage people to live there;
6. Providing effective public transportation;
7. Supporting technological innovations, such as the electric car;
8. Applying intelligent transportation systems;
9. Educating society about the environmental problems of sprawling cities;
10. Using other kind of fuels, such as biofuels, and making them cheaper than fossil fuels or subsidizing them;
11. Switching to natural gas or shale gas;
12. Practicing eco-driving;
13. Supporting smart growth strategies; and
14. Imbibing the right to live in a healthy environment into the right to life under countries constitution and force governments to take actions for a sustainable and healthy environment. (Ahmadi & Ahmadi, 2011).

5.4. Recommendations and Future Research

Improvements can be made to the study by replicating and modifying it:

1. Replicating the study for longer periods, such as a decade to be able to compare the differences that were caused based on different policies;
2. Extending the geographic scope of the investigation by replicating the study for other U.S. MSAs and counties, or other countries to determine whether the results are similar or not. Larger and newer dataset would make generalization easier;
3. Using other sprawl indices or a more accurate method for calculating sprawl index;

4. Replicating the study with another source of data;
5. Controlling other variables, such as travel (driving) behavior, type of roads, length of the road network, and existing capacity of the road network;
6. Using onboard automobile emissions measurement methods to improve the quality of the data;
7. Updating sprawl indices for recent years.
8. Comparing the impact of sprawl on residential and transportation energy consumption and emissions.

APPENDIX A

DESCRIPTIVE TABLES

Descriptive Statistics of Control Variables

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Age (25-34)	73	10.44	17.48	13.5486	1.43046	.183	.281	-.080	.555
Median Family Income(1000)	73	38.60	93.90	62.1888	10.32296	.877	.281	1.361	.555
Household median vehicle	73	.70	2.50	1.9103	.31191	-.869	.281	1.872	.555
Mean travel time to work	73	18.00	34.20	24.7863	3.21806	.579	.281	.540	.555
Congestion Index 2005	73	.55	1.57	1.0589	.20147	.130	.281	-.285	.555
Valid N (listwise)	73								

Descriptive Statistics of Sprawl Indices and Its Components

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Density Factor	73	71.22	180.69	96.9030	18.03844	2.092	.281	6.657	.555
Mix Factor	73	39.48	144.27	98.7370	23.94556	-.454	.281	-.181	.555
Centeredness Factor	73	41.42	167.29	102.5023	22.58729	-.012	.281	.721	.555
Street Connectivity Factor	73	37.23	138.56	96.8256	23.47858	-.049	.281	-.596	.555
Ewing Index	73	11.79	151.92	98.2940	23.95091	-.780	.281	1.657	.555
Lopez & Hynes Index	73	6.72	94.17	52.8747	19.48730	-.143	.281	-.238	.555
Nasser & Overburg Index	62	55.00	474.00	224.6935	109.31914	.429	.304	-.314	.599
Burchfield et al Index	39	20.73	57.70	38.5497	8.44189	.315	.378	-.287	.741
Valid N (listwise)	37								

Descriptive Statistics of Dependent Variables

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Transportation carbon footprint 2005 (per capita)	73	.83	2.01	1.3901	.28370	.244	.281	-.697	.555
Transportation Energy Consumption 2005 (per capita)	73	31.54	107.96	71.1773	15.65911	.145	.281	-.284	.555
Valid N (listwise)	73								

Top 10 Least Transportation Energy Consumption MSAs by Southworth et al (2008) Calculation

MSA	Region	Score
Syracuse-NY	NE	31.54
Newark-NY	NE	42.42
Honolulu-HI	W	43.67
Rochester-NY	NE	48.79
El Paso-TX	S	50.01
Buffalo-NY	NE	50.35
Philadelphia-PA	NE	52.38
Las Vegas-NV	W	53.01
Boston--Lawrence--Salem--Lowell--Brockton, MA	NE	53.33
Portland-OR	W	54.25

Top 10 Most Transportation Energy Consumption MSAs by Southworth et al (2008) Calculation

MSA	Region	Score
Dallas- Fort worth- Arlington	S	107.96
Toledo-OH	MW	102.28
Little Rock-AR	S	102.24
Jacksonville-FL	S	97.56
Riverside-CA	W	96.6
Knoxville-TN	S	95.81
Oklahoma City-OK	S	94.54
Colombia-SC	S	90.83
Birmingham-AL	S	90.04
Raleigh-NC	S	89.59

Top 10 Least Transportation Carbon Footprint MSAs by Southworth et al (2008) Calculation

MSA	Region	Score
New York- NY	NE	0.825
Honolulu-HI	W	0.847
Rochester-NY	NE	0.95
Buffalo-NY	NE	0.982
Los Angeles-CA	W	1.022
Philadelphia-PA	NE	1.023
Boston--Lawrence--Salem--Lowell--Brockton, MA	S	1.028
Las Vegas-NV	W	1.032
Portland-OR	W	1.053
Cleveland-OH	MW	1.072

Top 10 Most Transportation Carbon Footprint MSAs by Southworth et al (2008) Calculation

MSA	Region	Score
Toledo-OH	MW	2.005
Little Rock-AR	S	1.999
Jacksonville-FL	S	1.902
Riverside-CA	W	1.885
Knoxville-TN	S	1.867
Oklahoma-OK	S	1.846
Columbia-SC	S	1.771
Birmingham-AL	S	1.756
Raleigh--Durham-NC	S	1.754
Indianapolis-IN	MW	1.732

Top 10 Most Sprawling MSAs by Sprawl Index

MSA	Region	Score
Ewing et al. (2003) Index		
Greensboro--Winston-Salem--High Point, NC	S	46.78
Raleigh-Durham-Cary, NC	S	54.2
Atlanta-Sandy Springs-Gainesville, GA-AL	S	57.66
Greenville-Spartanburg-Anderson, SC	S	58.56
Knoxville-Sevierville-La Follette, TN	S	68.68
Rochester, NY	NE	77.93
Dallas-Fort Worth, TX	S	78.26
Detroit-Warren-Flint, MI	MW	79.47
Syracuse-Auburn, NY	NE	80.27
Little Rock-North Little Rock-Pine Bluff, AR	S	82.27

MSA	Region	Score
Lopez and Hynes Index (2003) index		
Greenville-Spartanburg-Anderson, SC	S	98.76
Chattanooga-Cleveland-Athens, TN-GA	S	95.86
Knoxville-Sevierville-La Follette, TN	S	94.17
Greensboro--Winston-Salem--High Point, NC	S	91.77
Lafayette-Acadiana, LA	S	91.6
Charlotte-Gastonia-Salisbury, NC-SC	S	88.06
McAllen-Edinburg-Pharr, TX	S	87.31
Columbia-Newberry, SC	S	87.02
Little Rock-North Little Rock-Pine Bluff, AR	S	85.93
Charleston-North Charleston, SC	S	85.64

MSA	Region	Score
Nasser and Overburg (2001) - USA Today Index		
Nashville-Davidson--Murfreesboro--Columbia, TN	S	478
Little Rock-North Little Rock-Pine Bluff, AR	S	474
Knoxville-Sevierville-La Follette, TN	S	464
Portland-Lewiston-South Portland, ME	NE	457
Charlotte-Gastonia-Salisbury, NC-SC	S	454
Fort Wayne-Huntington-Auburn, IN	MW	452
Lexington-Fayette-Frankfort-Richmond, KY	MW	446
Greensboro-Winston-Salem-High Point	S	437
Mobile-Daphne-Fairhope, AL	S	433
Austin-Round Rock, TX	S	413

MSA	Region	Score
Burchfield et al. (2006) Index		
Phoenix-Mesa-Scottsdale, AZ	W	57.7
Atlanta-Sandy Springs-Gainesville, GA-AL	S	55.6
Greensboro--Winston-Salem--High Point, NC	S	52.9
Charlotte-Gastonia-Salisbury, NC-SC	S	52.7
Washington-Baltimore-Northern Virginia, DC-MD-VA-WV	NE	49.8
Richmond, VA	S	48.8
Boston-Worcester-Manchester, MA-NH	NE	47.6
San Francisco--San-Jose--Oakland, CA	W	46.9
San Antonio, TX	S	45.6
Pittsburgh-New Castle, PA	NE	44.9

Source: Breitschaft (2011)

Top 10 Least Sprawling MSAs by Sprawl Index

MSA	Region	Score
Ewing et al. (2003) Index		
New York-Newark-Bridgeport, NY-NJ-CT-PA	NE	177.78
Providence-New Bedford-Fall River, RI-MA	NE	153.71
San Francisco-San-Jose-Oakland, CA	W	146.83
Omaha-Council Bluffs-Fremont, NE-IA	MW	128.35
Boston-Worcester-Manchester, MA-NH	NE	126.93
Portland-Vancouver-Beaverton, OR-WA	W	126.12
Miami-Fort Lauderdale-Miami Beach, FL	S	125.68
New Orleans-Metairie-Bogalusa, LA	S	125.39
Denver-Aurora-Boulder, CO	W	125.22
Albuquerque, NM	W	124.45

MSA	Region	Score
Lopez and Hynes Index (2003) index		
New York-Newark-Bridgeport, NY-NJ-CT-PA	NE	6.72
Los Angeles-Long Beach-Riverside, CA	W	10.61
San Diego-Carlsbad-San Marcos, CA	W	14.89
Miami-Fort Lauderdale-Miami Beach, FL	S	15.73
Stockton, CA	W	21.52
Las Vegas-Paradise-Pahrump, NV	W	25.54
San Antonio, TX	S	26.85
Chicago-Naperville-Michigan City, IL-IN-WI	MW	30.71
Philadelphia-Camden-Vineland, PA-NJ-DE-MD	NE	31.46
Denver-Aurora-Boulder, CO	W	32.9

MSA	Region	Score
Nasser and Overburg (2001) - USA Today Index		
Colorado Springs, CO	W	55
Sacramento--Arden-Arcade--Truckee, CA-NV	W	60
San Diego-Carlsbad-San Marcos, CA	W	62
San Antonio, TX	S	66
Miami-Fort Lauderdale-Miami Beach, FL	S	69
Omaha-Council Bluffs-Fremont, NE-IA	MW	77
Los Angeles-Long Beach-Riverside, CA	W	78
New York-Newark-Bridgeport, NY-NJ-CT-PA	NE	82
Norfolk-Virginia Beach-Newport News, VA-NC	S	94
El Paso, TX	S	97

MSA	Region	Score
Burchfield et al. (2006) Index		
Miami-Fort Lauderdale-Miami Beach, FL	S	21.7
Memphis, TN-MS-AR	S	27.4
Philadelphia-Camden-Vineland, PA-NJ-DE-MD	NE	27.5
Dallas-Fort Worth, TX	S	28.1
Denver-Aurora-Boulder, CO	W	28.6
New York-Newark-Bridgeport, NY-NJ-CT-PA	NE	28.8
San Diego-Carlsbad-San Marcos, CA	W	30.5
Chicago-Naperville-Michigan City, IL-IN-WI	MW	31.7
Sacramento--Arden-Arcade--Truckee, CA-NV	W	31.9
Minneapolis-St. Paul-St. Cloud, MN-WI	MW	32.1

Source: Breitschaft (2011)

APPENDIX B

ENERGY CONSUMPTION

AND

CARBON EMISSIONS TABLES

U. S. Consumption of Total Energy by End-Use Sector 1973-2011 (Quadrillion Btu)

Year	Transportation	Percentage transportation of Total	Industrial	Commercial	Residential	Total[a]
1973	18.6	24.6%	32.6	9.5	14.9	75.7
1974	18.1	24.5%	31.8	9.4	14.7	74.0
1975	18.2	25.4%	29.4	9.5	14.8	72.0
1976	19.1	25.1%	31.4	10.1	15.4	76.0
1977	19.8	25.4%	32.3	10.2	15.7	78.0
1978	20.6	25.8%	32.7	10.5	16.1	80.0
1979	20.5	25.3%	33.9	10.6	15.8	80.9
1980	19.7	25.2%	32.0	10.6	15.8	78.1
1981	19.5	25.6%	30.7	10.6	15.3	76.1
1982	19.1	26.1%	27.6	10.9	15.5	73.1
1983	19.2	26.3%	27.4	10.9	15.4	73.0
1984	19.7	25.7%	29.6	11.4	16.0	76.7
1985	20.1	26.3%	28.8	11.5	16.0	76.4
1986	20.8	27.1%	28.3	11.6	16.0	76.7
1987	21.5	27.2%	28.4	11.9	16.3	79.1
1988	22.3	27.0%	30.7	12.6	17.1	82.7
1989	22.5	26.5%	31.3	13.2	17.8	84.8
1990	22.4	26.5%	31.8	13.3	16.9	84.5
1991	22.1	26.2%	31.4	13.4	17.4	84.4
1992	22.4	26.1%	32.6	13.4	17.4	85.8
1993	22.8	26.1%	32.6	13.8	18.2	87.4
1994	23.4	26.3%	33.5	14.1	18.1	89.1
1995	23.8	26.2%	34.0	14.7	18.5	91.0
1996	24.4	26.0%	34.9	15.2	19.5	94.0
1997	24.8	26.2%	35.2	15.7	19.0	94.6
1998	25.3	26.8%	34.8	16.0	19.0	95.0
1999	25.9	26.8%	34.8	16.4	19.6	96.7
2000	26.5	26.9%	34.7	17.2	20.4	98.8
2001	26.3	27.3%	32.7	17.1	20.0	96.2
2002	26.8	27.5%	32.7	17.3	20.8	97.6
2003	27.0	27.6%	32.5	17.3	21.1	98.0
2004	27.9	27.8%	33.5	17.7	21.1	100.2
2005	28.4	28.3%	32.4	17.9	21.6	100.3
2006	28.8	28.9%	32.4	17.7	20.7	99.6
2007	29.1	28.7%	32.4	18.3	21.6	101.3
2008	28.0	28.2%	31.3	18.4	21.6	99.3
2009	27.1	28.6%	28.5	17.9	21.1	94.5
2010	27.5	28.1%	30.4	18.1	21.8	97.7
2011	27.1	27.8%	30.7	18.1	21.7	97.5
	Average annual percentage change					
1973–2011	1.0%		-0.2%	1.7%	1.0%	0.7%
2001–2011	0.3%		-0.6%	0.5%	0.6%	-0.1%

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review,* March 2012, Washington, DC. (Additional resources: www.eia.doe.gov)

1973 and 2011 (Percentage)

Energy Source	Transportation 1973	Transportation 2011	Residential 1973	Residential 2011	Commercial 1973	Commercial 2011
Petroleum[a]	95.8	92.8	18.8	5.3	16.8	3.8
Natural gas[b]	4.0	2.7	33.4	22.3	27.8	17.8
Coal	0.0	0.0	0.6	0.0	1.7	0.3
Renewable	0.0	4.2	2.4	2.6	0.1	0.7
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0
Electricity[c]	0.2	0.3	44.8	69.8	53.7	77.4
Total	100.00	100.00	100.00	100.00	100.00	100.00

Energy Source	Industrial 1973	Industrial 2011	Electric Utilities 1973	Electric Utilities 2011
Petroleum[a]	27.8	26.3	17.8	1.0
Natural gas[b]	31.8	27.1	19.0	19.6
Coal	12.4	5.4	43.9	46.0
Renewable	3.7	7.5	14.4	12.5
Nuclear	0.0	0.0	4.6	20.9
Electricity[c]	24.2	33.7	0.2	0.3
Total	100.00	100.00	100.00	100.00

Source:
U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, March 2012, Washington, DC (Additional resources: www.eia.doe.gov)
Note: Numbers may not add due to rounding.

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[a] In transportation, the petroleum category contains some blending agents which are not petroleum.

[b] Includes supplemental gaseous fuels. Transportation sector includes pipeline fuel and natural gas vehicle

[c] Includes electrical system energy losses

World Carbon Dioxide Emissions, 1990 and 2008

	1990		2008	
	Million metric tons	Percent of emissions from oil use	Million metric tons	Percent of emissions from oil use
United States	4,989	44%	5,838	42%
Canada	471	48%	595	48%
Mexico	302	77%	493	66%
OECD[a] Europe	4,149	45%	4,345	48%
OECD Asia	243	59%	522	39%
Japan	1,054	65%	1,215	47%
Australia/New Zealand	298	38%	464	33%
Russia	2,393	33%	1,663	20%
Non-OECD Europe	1,853	32%	1,169	25%
China	2,293	15%	6,801	15%
India	573	28%	1,462	25%
Non-OECD Asia	811	57%	1,838	48%
Middle East	704	70%	1,581	57%
Africa	659	46%	1,078	41%
Central & South America	695	76%	1,128	71%
Total World	21,488	42%	30,190	37%

Source:
U.S. Department of Energy, Energy Information Administration, *International Energy Outlook 2011*, Washington, DC, September 2011 (Additional resources: www.eia.doe.gov)

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[a] OECD is the Organization for Economic Cooperation and Development.

Total U.S. Greenhouse Gas Emissions by End-Use Sector
2010 (Million metric tons carbon dioxide equivalent[a])

	Carbon dioxide	Methane	Nitrous oxide	Hydroflurocarbons, perflurocarbons,	Total greenhouse gas emissions
Residential	1,190.0	3.7	9.3	23.5	1,226.5
Commercial	1,002.9	126.9	13.5	27.6	1,170.9
Agricultural	82.6	207.2	231.1	0.1	521.0
Industrial	1,625.9	327.2	33.0	32.9	2,019.0
Transportation	1,759.5	1.6	19.0	58.4	1,838.5
Transportation share of total	31.1%	0.2%	6.2%	41.0%	27.1%
Total greenhouse gas	5,660.9	666.6	305.9	142.5	6,775.9

Source:
U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2010*. EPA 430-R-12-001, April 2012. (Additional resources: http://www.epa.gov/climatechange/emissions/usinventoryreport.html)

Note: Totals may not sum due to rounding.

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[a] Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured by its estimated Global Warming Potential.

U.S. Carbon Emissions from Fossil Fuel Consumption by End-Use Sector, 1990–2010[a]
(Million metric tons of carbon dioxide)

	End use sector				Transportation percentage	CO_2 from all sectors
	Residential	Commercial	Industrial			
1990	931.4	757.0	1,533.1	1,489.0	31.6%	4,710.5
2005	1,214.7	1,027.2	1,553.3	1,901.3	33.4%	5,696.5
2006	1,152.4	1,007.6	1,560.2	1,882.6	33.6%	5,602.8
2007	1,205.2	1,047.7	1,559.8	1,899.0	33.2%	5,711.7
2008	1,192.2	1,041.1	1,503.8	1,794.5	32.4%	5,531.6
2009	1,125.5	978.0	1,328.6	1,732.4	33.5%	5,164.5
2010	1,183.7	997.1	1,415.4	1,750.0	32.7%	5,346.2
	Average annual percentage change					
1990–2010	1.2%	1.4%	-0.4%	0.8%		0.6%
2005–2010	-0.5%	-0.6%	-1.8%	-1.6%		-1.3%

Source:
U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2010*. EPA 430-R-12-001, April 2012. (Additional resources: http://www.epa.gov/climatechange/emissions/usinventoryreport.html)

[a] Includes energy from petroleum, coal, and natural gas. Electric utility emissions are distributed across consumption sectors.

Transportation Greenhouse Gas Emissions by Mode, 1990 and 2010 (Million metric tons of carbon dioxide equivalent)

	Carbon dioxide	Methane	Nitrous oxide
1990			
Highway total	1,190.5	4.2	40.4
Cars, light trucks, motorcycles	952.2	4.0	39.6
Medium & heavy trucks and buses	238.3	0.2	0.8
Water	44.5	0.0	0.6
Air	179.3	0.2	1.7
Rail	38.5	0.1	0.3
Pipeline	36.0	0.0	0.0
Other	0.0	0.2	0.9
Total[a]	1,489.0	4.7	43.9
	2010		
Highway total	1,482.5	1.4	16.6
Cars, light trucks, motorcycles	1,077.2	1.3	15.6
Medium & heavy trucks and buses	405.3	0.1	1.0
Water	42.6	0.0	0.6
Air	142.4	0.1	1.3
Rail	43.5	0.1	0.3
Pipeline	38.8	0.0	0.0
Other	0.0	0.3	1.6
Total[a]	1,750.0	1.9	20.4
Percent change 1990–2010			
Highway total	24.5%	-66.7%	-58.9%
Cars, light trucks, motorcycles	13.1%	-67.5%	-60.6%
Medium & heavy trucks and buses	70.1%	-50.0%	25.0%
Water	-4.3%	0.0%	0.0%
Air	-20.6%	-50.0%	-23.5%
Rail	13.0%	0.0%	0.0%
Pipeline	7.8%	0.0%	0.0%
Other	0.0%	0.0%	77.8%
Total[a]	17.5%	-59.6%	-53.5%

Source:
U.S. Environmental Protection Agency, *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*,

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Note: Emissions from U.S. Territories, International bunker fuels, and military bunker fuels are not included. [a] The sums of subcategories may not equal due to rounding.

APPENDIX C

EWING SPRAWL INDEX METHODOLOGY

Ewing’s methodology for measuring sprawl index and its components:

Seven variables constitute the density factor developed for this study:

1. Gross population density in persons per square mile
2. Percentage of population living at densities less than 1500 persons per square mile, a low suburban density
3. Percentage of population living at densities greater than 12500 persons per square mile, an urban density that begins to be transit-supportive
4. Estimated density at the center of the metro area
5. Gross population density of urban lands
6. Weighted average lot size in square feet for single family dwellings
7. Weighted density of all population centers within a metro area

For mix factor, Ewing’s study used 3 types of mixed-use measures, the first type shows relative balance between jobs and population, the second type shows diversity of land uses within subareas of a region and the third type represents the accessibility of residential uses to nonresidential uses at different locations within a region:

1. Percentage of residents with businesses or institutions within-block of their homes
2. Percentage of residents with satisfactory neighborhood shopping within 1 mile
3. Percentage of residents with a public elementary school within 1 mile
4. Job-resident balance
5. Population-serving job-resident balance
6. Population-serving job mix

Six variables became components of center factor:

1. Coefficient of variation of population density across census tracts (standard deviation divided by mean density)
2. Density gradient (rate of decline of density with distance from the center of the metro area)

3. Percentage of metropolitan population less than 3 miles from the CBD
4. Percentage of metropolitan population more than 10 miles from the CBD
5. Percentage of the metropolitan population relating to centers or sub centers within the same MSA or PMSA
6. Ratio of the weighted density of population centers within the same MSA or PMSA to the highest density center to which a metro relates

Street factor was made up of 3 factors:

1. Approximate average block length in the urbanized portion of the metro
2. Average block size in square miles (excluding blocks > 1 square mile)
3. Percentage of small blocks (< 0.01 square mile)”.

Source: Ewing et al (2002)

APPENDIX D

CONGESTION INDEX CALCULATION

Tim Lomax in his 2011 urban mobility report, has suggested the following steps to calculate the congestion performance measures for each urban roadway section.

1. Obtain HPMS (HIGHWAY PERFORMNG MONITORING SYSTEM) traffic volume data by road section
2. Match the HPMS road network sections with the traffic speed dataset road sections
3. Estimate traffic volumes for each hour time interval from the daily volume data
4. Calculate average travel speed and total delay for each hour interval
5. Establish free-flow (i.e., low volume) travel speed
6. Calculate congestion performance measures
7. Additional steps when volume data had no speed data match."

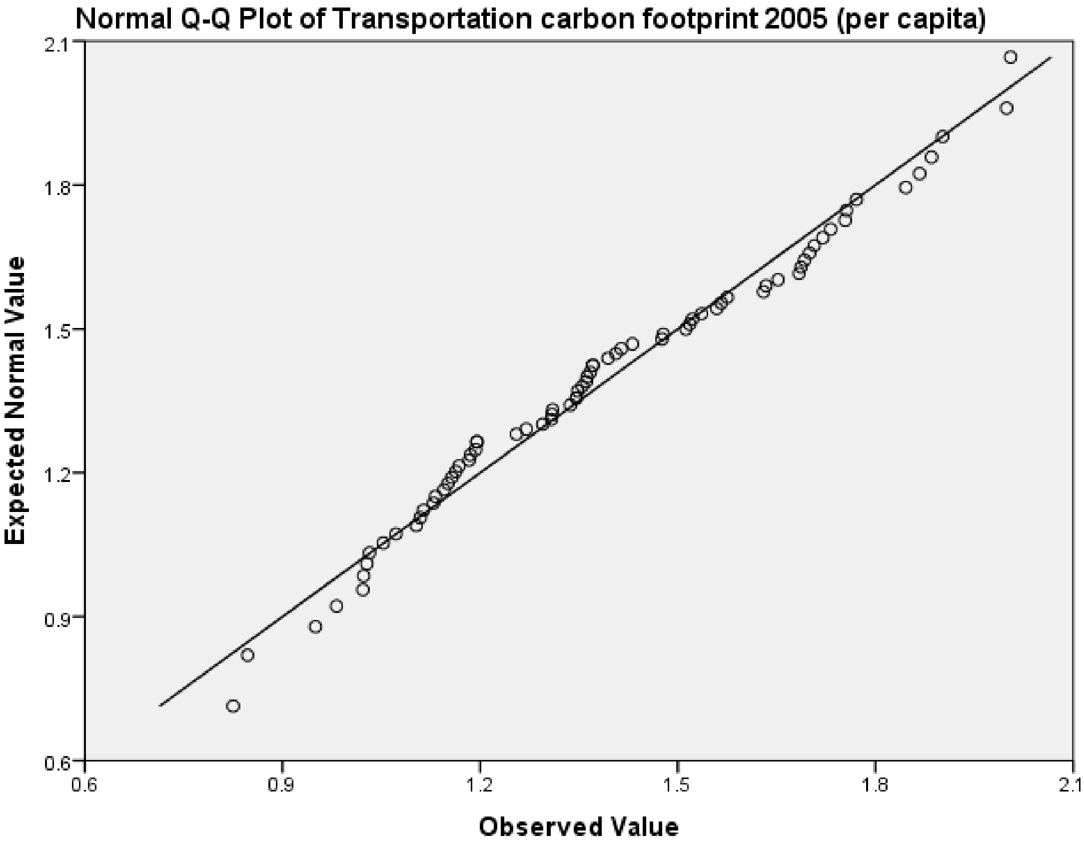
For complete process see: http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2011-appx-a.pdf

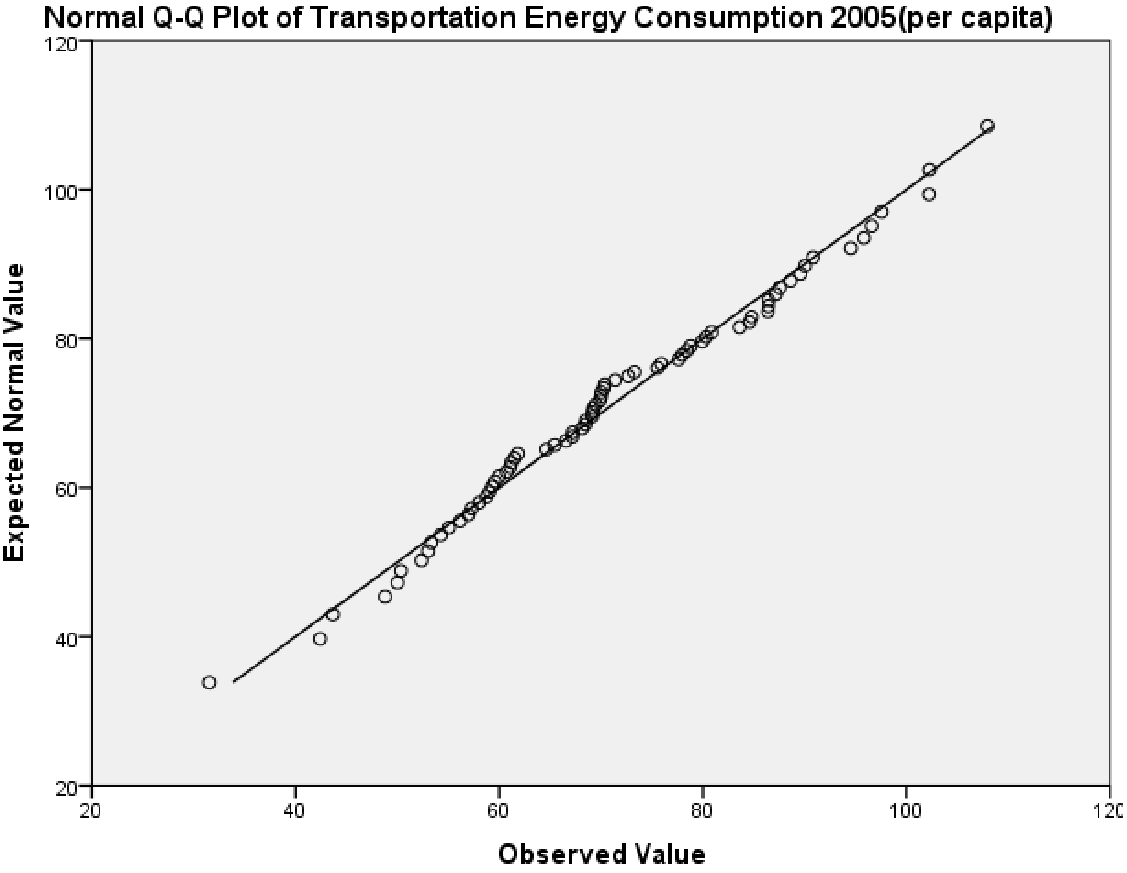
(2011 Urban Mobility Report Methodology http://mobility.tamu.edu/ums/congestion-data/ A-3)

Source: Lomax, T. (2011).

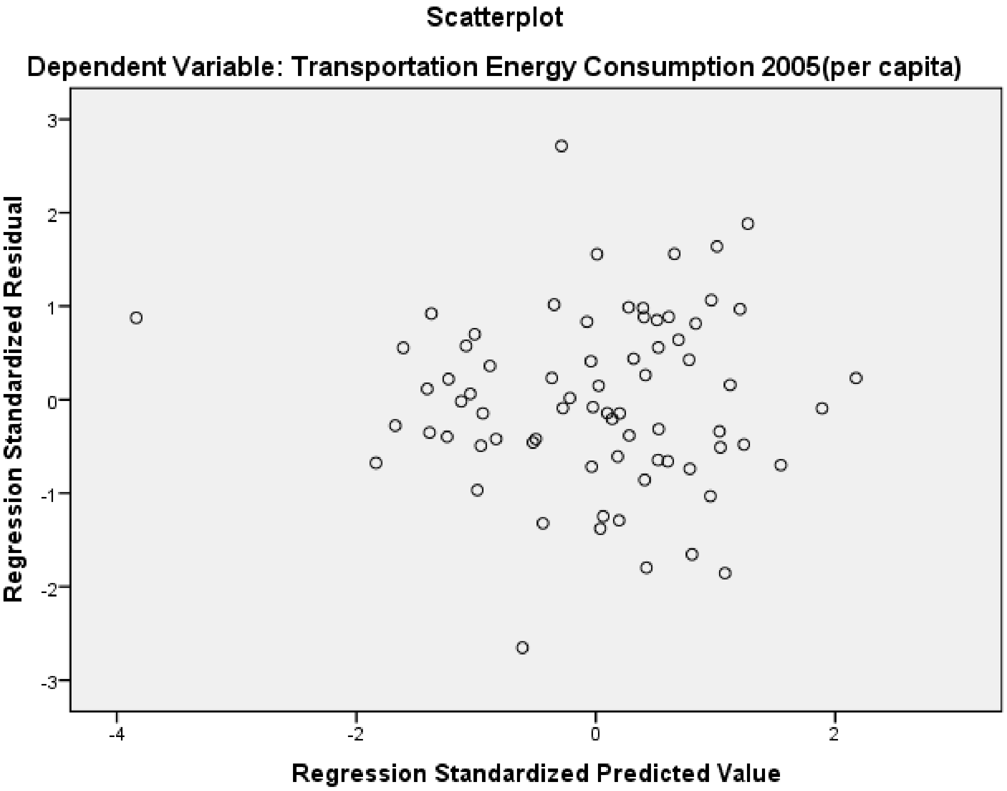
APPENDIX E

GRAPHS

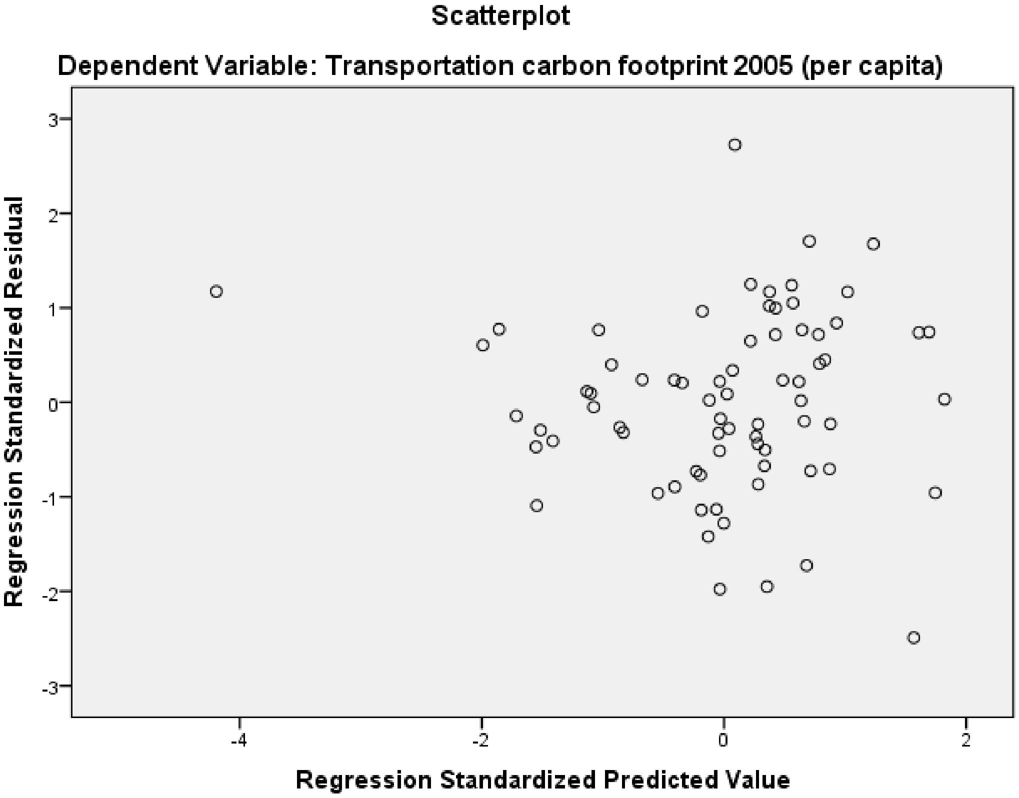

Normal Q-Q Plot of Transportation carbon footprint 2005 (per capita)
Expected Normal Value
2.1
1.8
1.5
1.2
0.9
0.6
0.6
0.9
1.2
1.5
1.8
2.1
Observed Value


Normal Q-Q Plot of Transportation Energy Consumption 2005(per capita)
Expected Normal Value
Observed Value
120
100
80
60
40
20
20
40
60
80
100
120

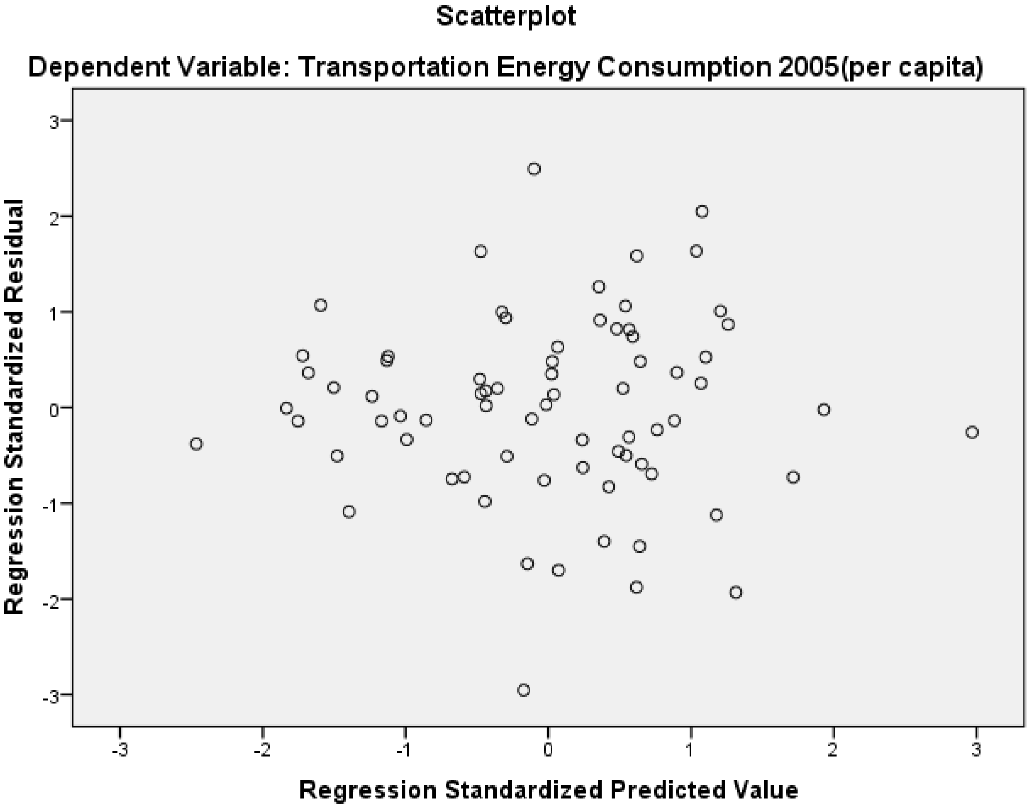
Test of heteroscedasticity: Research question 1



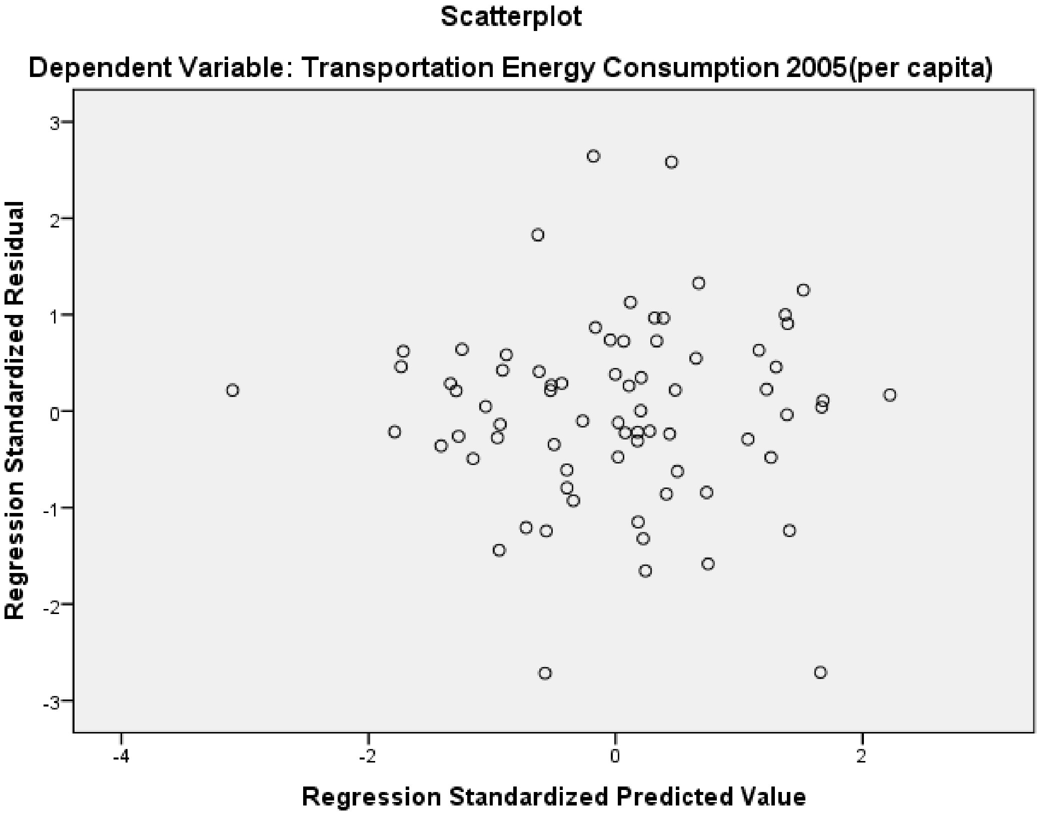
Test of heteroscedasticity: Research question 2



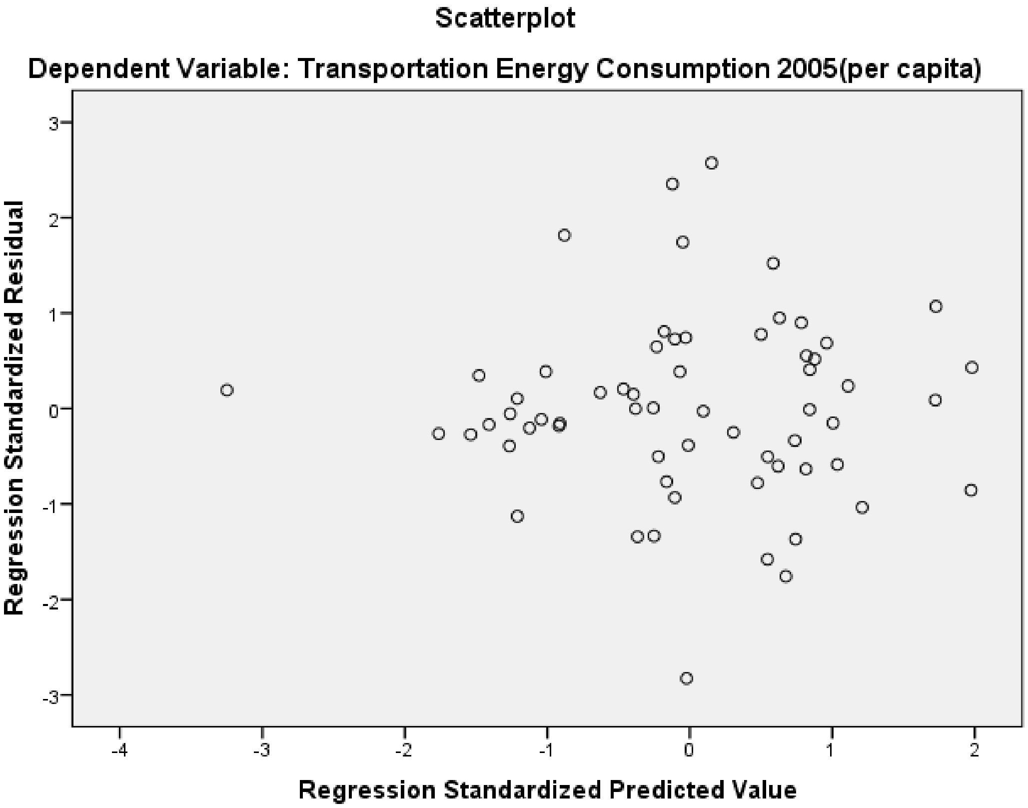
Test of heteroscedasticity: Research question 3, Ewing et al sprawl index



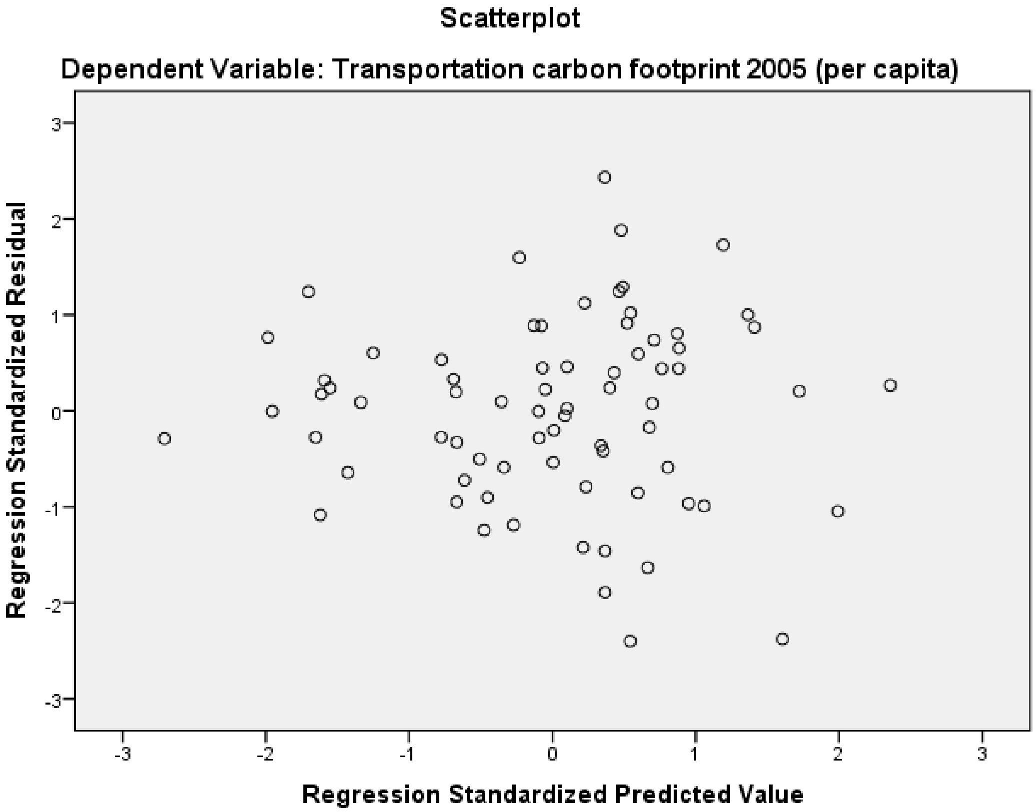
Test of heteroscedasticity: Research question 3, Lopez and Hynes sprawl index



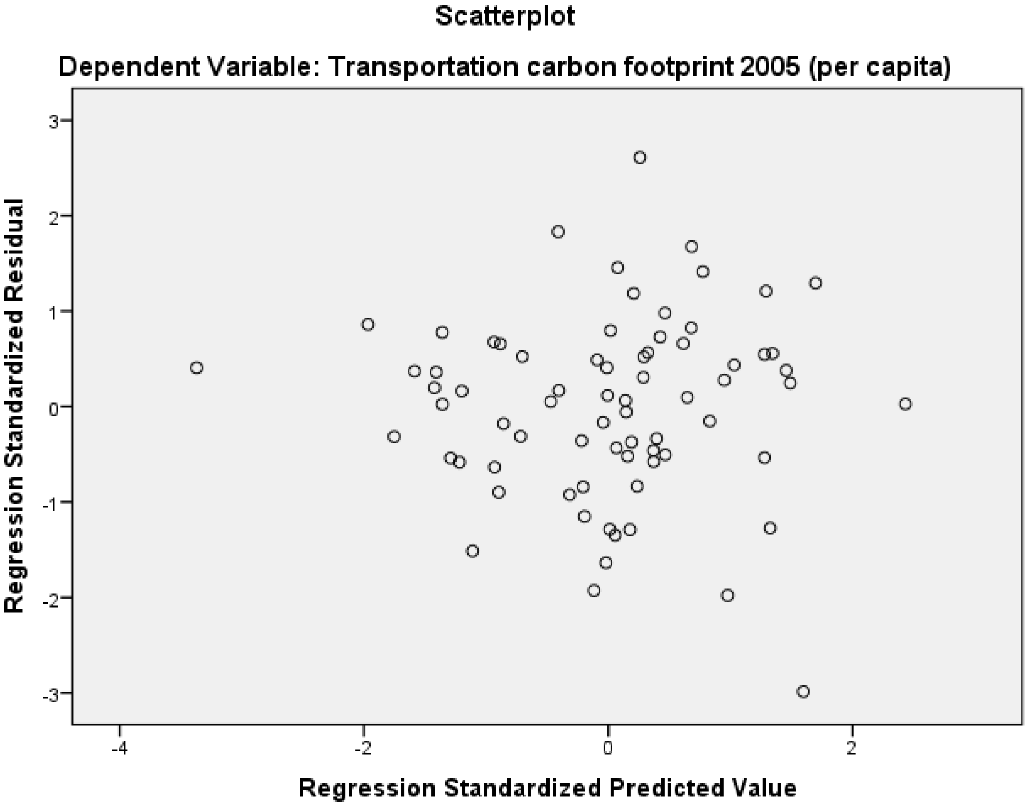
Test of heteroscedasticity: Research question 3, Nasser and Overberg sprawl index



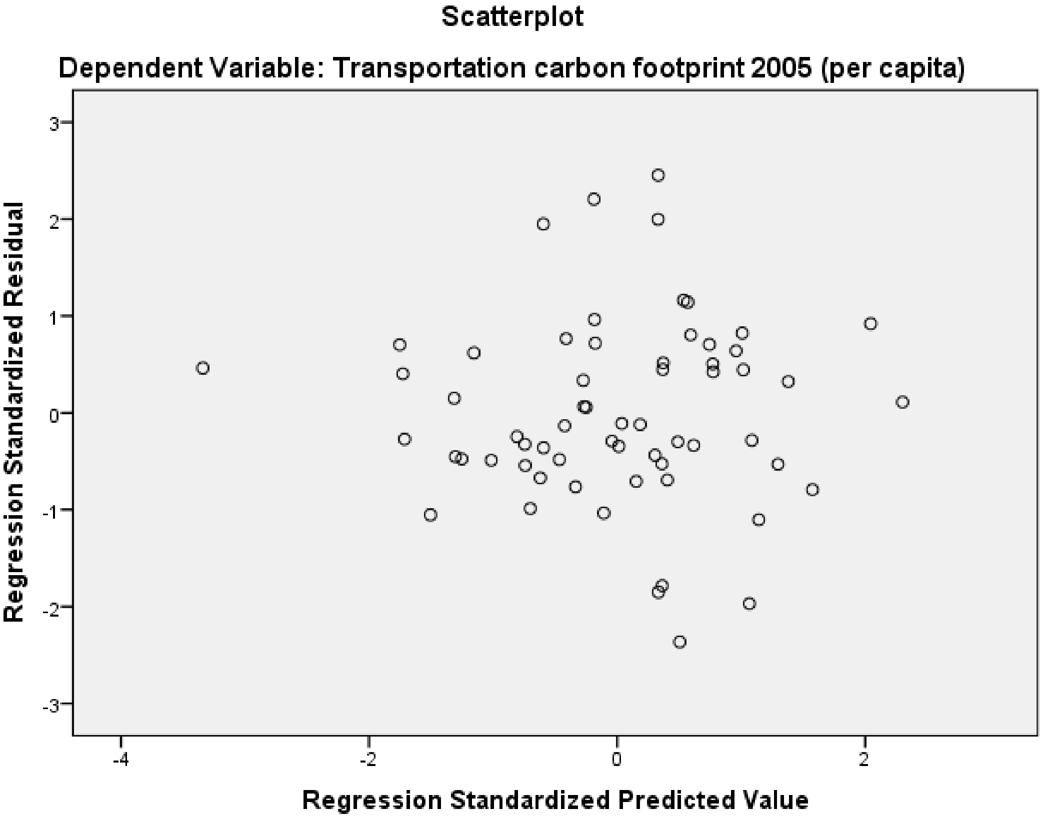
Test of heteroscedasticity: Research question 4, Ewing et al sprawl index



Test of heteroscedasticity: Research question 4, Lopez and Hynes sprawl index



Test of heteroscedasticity: Research question 4, Nasser and Overberg sprawl index



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Leila Ahmadi acquired her PhD in Environmental Science from the University of Texas. She is the managing director of an environmental company. She is interested in many environmental topics and has done research on environmental education, sustainability, waste management, environmental law and regulations, environmental economy, environmental planning, and air pollution. She has participated at international conferences and has presented her research on environmental issues. She has also published several papers in international journals. She plans to continue her work and research in the environmental field.