COMPACT GROWTH AND SMART CITY DEVELOPMENT: THE UNSUSTAINABILITY
OF URBAN SPRAWL

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Abstract

As cities become more populated, are municipal governments struggling to manage the influx of demand in the realm of power usage and city resources regarding critical infrastructure and energy management? Contemporary research centers on a prevailing view of the benefits of the compact growth smart city model over the outdated urban sprawl model regarding energy and environmental sustainability. In this study, data was collected and analyzed to provide meaningful insights for city planners and government leaders to weigh the costs and benefits of adopting the compact growth model of urban development in lieu of the urban sprawl model of expansion. Through collecting municipal data of high population cities in America, regressions were run to examine how density has an effect upon various factors supporting a city's operational efficiency. The results of this study indicate that the urban sprawl model, popularized during the 20th century, is less sustainable than the compact growth model of smart city development, especially with increasing populations. Furthermore, future urban development plans can employ the compact growth model of smart city development to maximize infrastructure and improve energy efficiency. This paper will delve into the contention that urban areas will need to adopt the compact growth model for sustainable operations.

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1. Introduction

Understanding how compact growth effects energy usage is critical for municipal leaders as they debate choices in urban development. The transformation of municipalities towards a smart city, compact growth model is a 21st century paradigm shift in urban planning that may be a necessity in sustaining growth. The United Nations Department of Economic Affairs projects that 68% of the world's population will live in cities by 2050.[1] This begs the question of how governments are expecting to prepare for this looming influx and what current steps they are taking to keep cities running efficiently? In this research, we will delve into the following questions:

- What are some of the factors that comprise an efficient city?

- What policy transformations can spark planning towards the predicted paradigm shift?

- What energy management aspects can support public and private enterprises to focus on initiating change in a sustainable, environmentally conscious manner?

The cities examined are limited to the 75 cities chosen by the American Council for an Energy Efficient Economy's (ACEEE) 2019 city clean energy scorecard.[2] The council has a scoring system which ranks each city based on the criteria below:

1. Local government score – How the city is managing smart city growth through renewable programs and development projects.

2. Community-wide initiatives score – How the city is implementing programs to grow the community in a renewable, sustainable way.

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[1] United Nations – Department of Economic and Social Affairs. "World Urbanization Prospects". Pg. xix. 2018. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf
[2] American Council for an Energy Efficient Economy. "City Clean Energy Scorecard". 2019. https://aceee.org/local-policy/city-scorecard

3. Building score – How efficiently buildings are operating through the lens of energy consumption, network management, infrastructural analysis, and sustainment of habitation.

4. Energy and Water score – How efficient are the commodity programs in the city and how they are supporting the population. This expands from government operations of water management to utility organizations providing services to the people.

5. Transportation score – How efficiently are the public transit programs operating and supporting the city.

In this paper we will examine how city density plays an integral role in a city's likelihood of high operational efficiency and sustainability. The five dependent variables (DV) of focus will be ACEEE score, residential electricity usage per capita; greenhouse gas emissions per capita; automobile independence; and ridership of the urban public transportation systems. In this research, regressions will be run to see how density as the sole independent variable (IV) effects not only the scoring provided by the council, but additionally how density effects the aforementioned four aspects of a smart city. Through linear regressions, correlational insights will be gained between density and the five dependent variables which may support to prove a causal relationship.

This paper supports the contention that there are strong correlations between density and urban operational efficiency. By choosing the smart city compact growth model for urban expansion, density of a city does increases, but so does the means to sustainably handle the growth with smart city designs. With respect to energy management, a portion of this research will conclude with a path forward for utilities and power producers. By initiating grid modernization and centralizing management systems to track, manage, assess, and maintain assets and operations, energy providers can optimize service for consumers. This research will

suggest that through the transformative shift towards smart city compact development, cities will become more operationally efficient and environmentally sustainable.

2. Literature Review

With respect to urban density, research shows that denser cities are on average more efficient operationally than sprawled developments. For instance, Boston with an energy efficiency score of #1 nationally as per the American Council for Energy Efficiency Economy in 2019[3] with a density of 13,861 citizens per square mile[4] outperforms #50 Oklahoma City with a 2019 density of 1,092 per square mile.[5] And this statement holds true across most top tier cities compared to lower tier ones. Those which are denser are almost always more efficient than those which are sprawled.[6]

The article "Energy Efficient Urban Form" by Julian Marshall alludes on the energy impacts sprawled cities may have upon the world. If not managed correctly, as urban infrastructure struggles to handle population growth, the energy wastes could be unprecedented and output negative externalities impacting our environment. The United Nations 2019 Urbanization Report suggests that as global population increases, so does the congregation of communities in cities as opposed to suburban areas. And with this, urban planners have been and continue to expand city limits and propagate sprawl. Julian Marshall promotes the argument that as sprawl increases, so will the number of cars on the road with more intricate highway systems

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[3] American Council for an Energy Efficient Economy. "City Clean Energy Scorecard". 2019. https://aceee.org/local-policy/city-scorecard.
[4] Open Data Network. "Data for: Boston, MA". 2017. https://www.opendatanetwork.com/entity/1600000US2507000/Boston_MA/geographic.population.density?year=2017
[5] Open Data Network. "Data for: Oklahoma City, OK". 2017. https://www.opendatanetwork.com/entity/0500000US40109/Oklahoma_County_OK/geographic.population.density?year=2017
[6] Open Data Network. "Data for: Oklahoma City, OK". 2017. https://www.opendatanetwork.com/entity/0500000US40109/Oklahoma_County_OK/geographic.population.density?year=2017

thereby manifesting encroaching congestion issues. With the choice to sprawl, automobile dependence will become a looming threat to the efforts of sustainability and decongestion. "[Sprawl] encompasses many aspects of land use, including leapfrog development, segregated land use, and automobile dependence".[7] Given the forecast of urban sprawl on climate change and environmental impacts, the end-results yields prominent negative externalities.

The urban sprawl model of the 20th century has led to an increase in environmental degradation and a decrease in sustainability. Marshall suggests, "[if] done well, reducing sprawl can improve the quality of life while reducing emissions. Successful approaches likely differ among cities….".[8] Thus a goal for municipal leaders to consider should be a need to reduce urban sprawl and promote dense urban developments. As stated above, cities may differ in their ways of transforming to accommodate the influx of people. But what can remain the same is the foundational architecture for urban growth. Choosing the methodology of compact urban development is step in the right direction and to that point, following the approach of Boston and New York City, lower tier cities in terms of operational efficiency can learn about the model and apply the lessons learned from these projects to their own.

An estimation by the Open Data Network indicates Oklahoma City's population density is increasing by 1.32% per year.[9] To manage this more efficiently than sprawling further, an inner-city development plan to combat population growth could be implemented to manage the growing density and therefore demand. In the realm of energy conservation and efficiency, a

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[7] Marshall, Julian D. "ENERGY-EFFICIENT
Urban Form". Page 3134. 2008. https://pubs.acs.org/doi/pdf/10.1021/es087047l
[8] Marshall, Julian D. "ENERGY-EFFICIENT
Urban Form". Page 3136. 2008. https://pubs.acs.org/doi/pdf/10.1021/es087047l
[9] Open Data Network. "Data for: Oklahoma City, OK". 2017.
https://www.opendatanetwork.com/entity/0500000US40109/Oklahoma_County_OK/geographic.population.density
?year=2017

study by Nallithiga Ramakrishna entitled "Contradictions Of Sustainable Urban Development: The Choice Of Compact City Development Approach", states that in a smart city, urban form, spatial characteristics, and social functions are the three pillars of what constitute its success. The pillars and their sub-points can be found below:

"Urban form:

    (i)   High dense settlements

    (ii)   Less dependence on automobiles (! high density)

    (iii)   Clear boundary from surrounding areas;

Spatial characteristics:

    (i)   Mixed land use

    (ii)   Diversity of life (! mixed-land use)

    (iii)   Clear identity;

Social functions:

    (i)   Social fairness (! high dense settlements)

    (ii)   Self-sufficiency of daily life

    (iii)   Independence of government (clear boundary)."[10]

The compact growth smart city model focuses on inwards growth to satisfy the pillars above. With respect to the first pillar of urban form, the denser cities thrive with a paramount decrease in Greenhouse Gas Emissions (GGE) due to automobile independence as per point two. With pillar two of spatial characteristics, mixed land usage enables city expansion in historically

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[10] Nallithiga, Ramakrishan. "Contradictions Of Sustainable Urban Development: The Choice Of Compact City Development Approach". Pg. 56. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2251825

marginalized neighborhoods. With pillar three of social functions, the empowerments to the constituents enable an iterative, agile urban ecosystem for growth and engagement.

In the aforementioned pillar one of urban form, in lieu of private automobiles, the compact growth model advocates a well-developed public transportation system. Through compact growth, there is an increase in developing communities in the inner city to manage the population increase. With municipal incentives to stay in the city, migration to the suburbs may be less likely if city policies change to adapt to the increase of habitants. New communities can be nurtured and interconnected to the urban transportation network for ease of access and reliability. With this requirement of compact growth comes the necessity of Transit-oriented-Developments (ToDs).

In these ToDs, urban planners would enable the newly constructed communities to thrive by promoting a growth strategy towards connecting the development to the already existing metropolitan transit network. Through expansions of critical infrastructure such as tighter, more compact building developments, higher, more versatile architectural designs, and cleaner, more sustainable building operations, governments can pursue ToDs to engage their urban strategies inwards – rather than outwards -- for community growth. The centralization of all newly proposed urban developments around the transit system would satisfy the ease of access requirement for all Areas-of-Change (AoC) communities without disruption and destabilization. In this respect, there would be a massive shift towards automobile independence.

Todd Litman wrote in his study entitled "Can Smart Growth Policies Conserve Energy And Reduce Emissions?" that compact urban living generates "20% - 40% less vehicle travel per capita".[11] In Litman's study, Portland, Oregon was analyzed before the ToDs were created and

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[11] Litman, Todd. "Can Smart Growth Policies Conserve
Energy And Reduce Emissions?". May 2011. https://www.vtpi.org/REQJ.pdf

afterwards to understand the influence it had upon the community. His analysis centered around two systems: The "Good transit & mixed travel land use" system representing the ToD implemented community and "Good transit only" representing the city before the ToD. His research concluded that ToDs outputted far less reliance on automobiles in the community and promoted the means of walking and use of public transit systems. Employing facets of compact growth in Portland, urban planners created a community where walking and public transit would satisfy requests far more than ever before. Walkability in the post-ToD community increased by approximately 20% and use of public transit by an approximate 15%. This system was a beachhead program and supports the contention that smart growth is around developing inwards, not outwards. With more ToDs in larger communities, these numbers could increase substantially.

Additionally, with the compact growth model enabling ToDs, overall energy usage per capita would decrease substantially. Without the suburban framework of private automobiles and larger private land ownership, the smaller, more confined living areas with a vaster public transit system would consume substantially far less electricity than the average suburban household. Litman argues that in a comparison of suburban to urban home energy use per year, one could find a decrease by as much as 50 million British Thermal Units (BTUs).[12]

A critical consideration to add involves the economic development and sustainability of the urban system. An argument can be made that smart growth may conflict with economic development by destabilizing the community. This, however, may not be accurate according to Karen Danielson's work "Retracting Suburbia: Smart Growth and the Future of Housing". She

[12] Litman, Todd. "Can Smart Growth Policies Conserve Energy And Reduce Emissions?". Page 6. May 2011. https://www.vtpi.org/REQJ.pdf

provides findings around compact growth that are supportive of economic development and flourishment through exhaustive financial savings across the community especially through the infrastructural lens.[13] Danielson argues the economic growth of compact cities thrive in part due to changes in the transportation network. Through increased use in the public service system, the urban network transforms for the better. Through these developments, all community members are enabled to travel without downsides of congestive traffic and costly automobile accruals.

Prompted by the question of how urban municipalities are governing their current urban sprawl dilemmas and preparing for an influx of the populous, an analysis of the United States' most representative cities can provide insights into trends, correlations, and forecasts with regard to urban planning, smart growth, and energy management. What are the lessons learned from top tier cities and how can they be applied to lower-tier ones? Is the compact growth model the sustainable model of the future, and are denser cities more efficient with a high level of statistical significance? The data analysis conducted outlines some of the sections of what constitutes a smart city and provides extrapolations around whether the compact growth model is needed for the 21st century's urban development marvels.

3. Data Analysis

From analyzing the American Council's chosen 75 cities, best practices of the compact growth model can be applied to suggest how to better manage the future of American cities. Part of this analysis is contributed by data provided by the American Council of an Energy-Efficient Economy (ACEEE) energy scorecard of 2019, providing insights into the most representative cities in America.

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[13] Karen A. Danielson et. al." Retracting Suburbia: Smart Growth and the Future of Housing". 1999.http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.513.7110&rep=rep1&type=pdf

In the data analysis below, assessments for ranks #1 to ranks #75 are introduced through linear regression analyses to extrapolate insights around urban growth. In tandem with the ACEEE factors, the analyses in this research focuses upon the aforementioned four pillars of what constitute a smart city. They are as follows:

1) Residential Electricity Usage Per Capita (MWh)

2) Environmental Consideration – GHG Emissions (per metric ton)

3) Automobile Independence -- Percentage of urban population that does not have a vehicle registered to their home address

4) Public Transportation Utilization– Number of riders daily that utilize the public transportation system.

With respect to these criteria, assessments can be made around the current state of each city to support the contention that there may be causality between density and city standing. With density being the independent variable, the outputs will bring light to the relation between how changes in urban density effect the overall operation of the city and its strides towards becoming smarter in the future. The outputs of this quantitative analysis prove a strong correlation between increasing the density of a city and the city's operational efficiency and energy sustainability.

3.1 American Council for an Energy Efficient Economy

The American Council for an Energy Efficient Economy runs analyses per state based on government programs and current operational capacities. Through discovery efforts, the council ranks each city based on its initiative for a smart city future operation. Below, a regression was run to show how the two variables are related to support the contention that as density increases,

urban operational efficiency follows. Table 1 below indicates the regression between density and ACEEE score.

**Table 1: Regression of Density and ACEEE Energy Scorecard**

	ACEEEEnergyScore
Density	0.00234***
	(5.74)
Constant	22.50***
	(7.98)
N	75
Beta	0.5575607
Multiple R	0.526349454
R Square	0.277043748
t statistics in parentheses	
* p<0.05	** p<0.01 *** p<0.001

From the regression above, the results support the claim that density has a positive relationship to city efficiency. As density increases by one person per square mile, the ACEEE energy score increases by .00234 as per the IV to DV table relationship. This means that for every increase of 1000 people per square mile of land, the ACEEE score ranking increases by 2. Given this output, the extrapolation is that the likelihood of a city earning a higher ACEEE score is related to how dense the city is. With a range of -1 to 1, the standardized beta (beta) signifies a moderate-positive regression-coefficient of .558 proving a moderate correlational relationship. Additionally, with a t-score of 5.74, a P value less than 0.001, and an R-squared of .277, this

regression is evidence fueling the contention that density has a strong correlational relationship to operational efficiency.

The line best fits plot below in Graph 1 further illustrates the relationship between density and ACEEE score. The individual (X, Y) points were plotted with density as the independent variable, on the X axis and ACEEE score on the Y.

Graph 1: Density to ACEEE Score
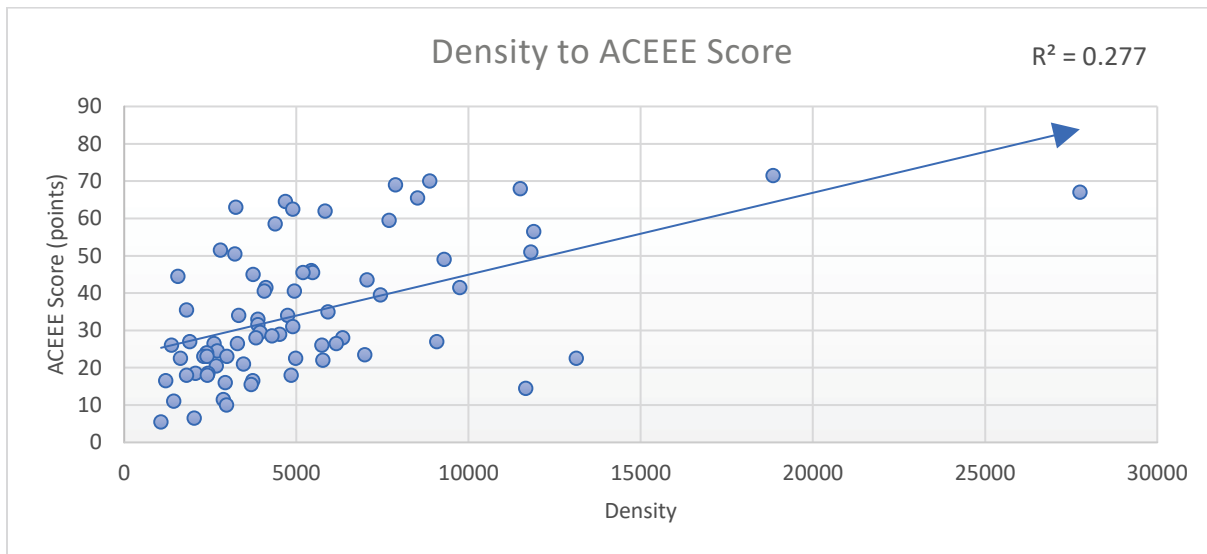
Through the regression, the line fit plot illustrates a trend line between the IV and DV. With an R-squared of .277, one can infer that this trend line shows a moderate correlational relationship between the two variables signifying that as density increases, the cluster of cities increase as well. With statistical significance, one can find more likely than not a positive relation between the two variables.

3.2 Residential Electricity Usage Per Capita

Using data from the U.S Department of Energy's State and Local Energy Data portal[14], extracts of urban residential electricity usage per capita can be introduced as a factor into

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[14] U.S. Department of Energy. "State and Local Energy Data". https://www.eere.energy.gov/sled/#/

determining how city density can be correlated to smart growth and operational efficiency. By examining density and running a regression against city electricity usage per capita per resident -- on average --, the following data in Table 2 is returned.

Table 2: Regression of Density and Residential Energy Use Per Capita (MWh)

	ResidentialElectricityUsage	
Density	-0.000150***	
	(-5.31)	
Constant	4.359***	
	(22.30)	
N	75	
Beta	-0.528	
Multiple R	0.513179488	
R-Squared	0.263353187	
t statistics in parentheses		
*p<0.05	** p<0.01	*** p<0.001

In the regression above, the coefficient for an increase of density by one person per square mile would output a decrease in the city's residential electricity energy usage per capita by .000150. To put into perspective, with an increase of city density by 1000, city electricity usage would decrease per capita by .15MWh. The coefficient is statistically significant with a t-score of -5.31 and an R-squared output of .263. There is a moderate-negative correlation between density and city electricity usage per capita as per the beta of -.528. This promotes the contention

that as density increases, city electricity usage per capita per resident decreases almost always. In

Graph 2 below, find the illustration of the regression ran showing as density increases, there is a

substantial decrease of residential electricity usage, especially after the 5000 people per square

mile cutoff point.

Graph 2: Density to Residential Electricity Usage (Per Capita)
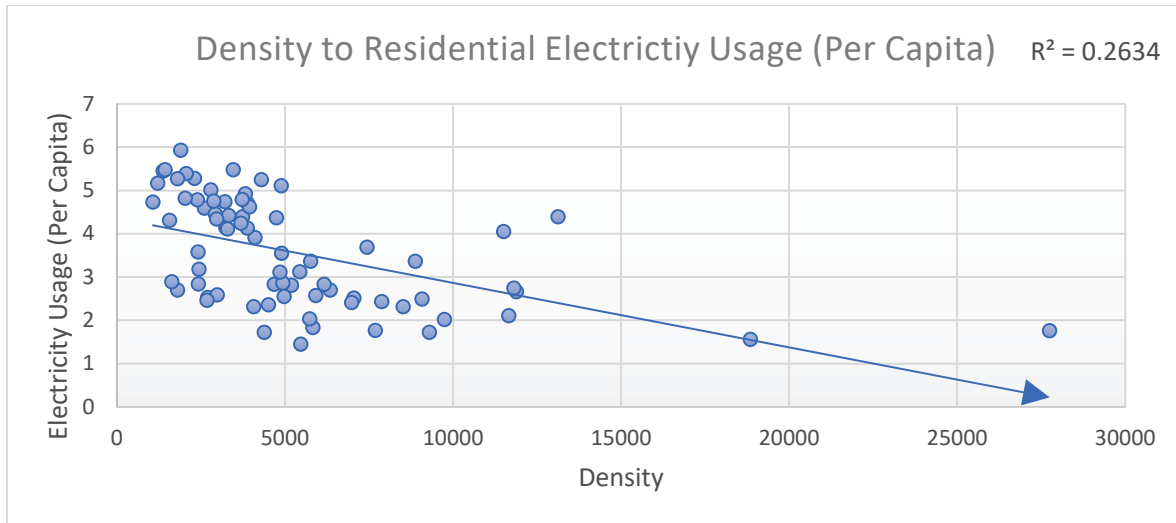
3.3 Environmental Consideration – GHG Emissions

      With respect to smart city growth, consideration of the compact growth model could be

made to evaluate the future state of energy generation, energy management, and emission

reductions. The Department of Energy's State and Local Data portal have critical data that can be

used to assess how density can have an effect on a city's global emissions[15]. By examining GHG

emissions per capita and density, a linear regression can provide insights into the relationship

between the two variables. The results are in Table 3.

[15] U.S. Department of Energy. "State and Local Energy Data". https://www.eere.energy.gov/sled/#/

Table 3: Regression of Density and GHG Emissions Per Metric Ton Per Capita

	GHGEmissions	
Density	-0.000481***	
	(-4.01)	
Constant	15.90***	
	(19.19)	
N	75	
Beta	-0.424943	
Multiple R	0.409603922	
R Squared	0.167775373	
t statistics in parentheses		
* p<0.05	** p<0.01	*** p<0.001

The regression shows that as density increases by one person per square mile, GHG emissions decrease by .000481 metric tons. To put this output into perspective, for every increase of density by 1000, greenhouse gas emissions would be expected to decrease by .481 metric tons. In the dataset of cities, the average GHG emission nationally was 13.3 metric tons per capita per person. Given this insight, an increase of density could greatly spark cities into becoming more environmentally sustainable. There is statistical significance of this regression with a t-score of -4.01, P value less than 0.001, and R-squared at .168. The beta of -.425 provides evidence that there is a moderate-negative correlation between density and emissions meaning

that almost always, as density increases, GHG emissions decrease. In Graph 3 below, the line fits graph of the regression can be found.

Graph 3: Density to GHG Emissions
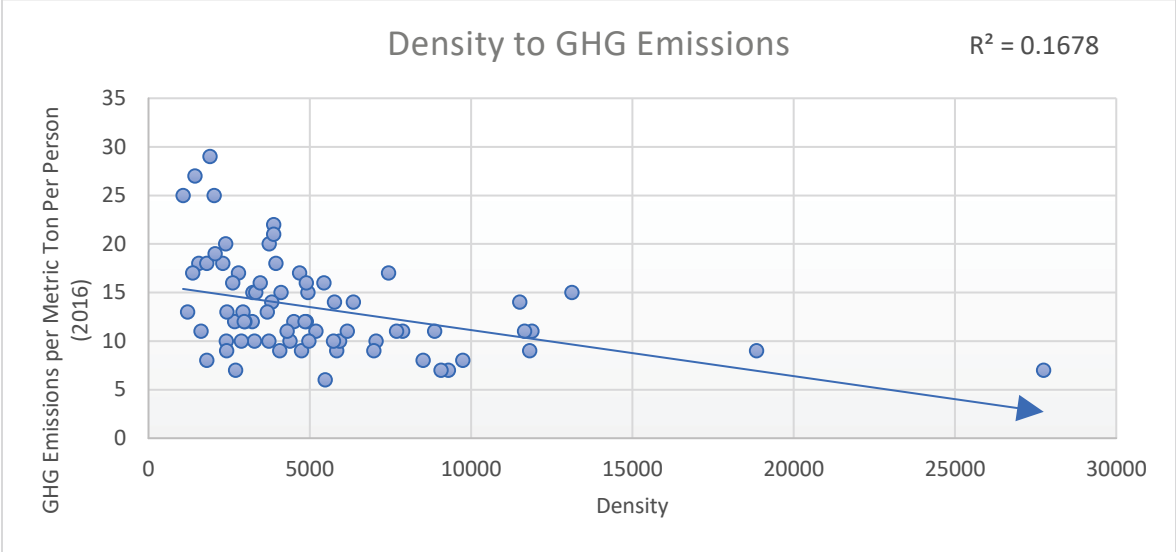
As seen in Graph 3, the trendline shows as density increases, emissions decrease. The cluster of cities are between the 3000 – 6000 density zone. Once over that threshold, the emissions decrease critically, however, one can see that a cluster of cities with emissions under the trend line are around the low-density zone. This shows that although there is a correlation, there is further researched needed to be conducted to see why particular cities don't follow this framework.

Overall, by increasing density, cities can promote a smart growth model of stronger public transportation programs discouraging private automobile use which can greatly reduce the GHG emissions recorded. With ToD communities pursued in smart city growth, compact developments can promote a dense ecosystem with public transit efficiency supporting the commute without the need of a personal vehicle.

Questions to consider are as follows: what percentage of all GHG emissions are a result of automobiles per city? And how does density influence the city's inclination to have personal vehicles per household? Do we see cities like New York City and Boston equally as likely to have cars as Reno and Oklahoma City? Find below the regression analysis between density and households without vehicle ownership in the next section.

3.4 Automobile Independence

The Environmental Protection Agency (EPA) in 2017 published statistics for GHG emissions per sector. In 2017, the transportation sector generated 29% of national GHG emissions.[16] Of that approximate one-third, 59% of the emissions were from light-duty vehicles. Those type of vehicles are the most commonly purchased by each household, such as the Toyota Prius or Honda Civic. How does this statistic look with regard to a distribution across the different types of cities, compact and sprawled? Gathering data from a publishing in 2016 by Governing entitled "Vehicle Ownership in U.S. Cities Data and Map", a regression became possible to find the relationship that density has with households that do not account for ownership of vehicles.[17] The variable introduced represents the percentage of households within the city that have no vehicle registered to the household address. With this DV, one can analyze how an increase in density influences the likelihood of a household to not own a car and perhaps not need one.

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[16] Environmental Protect Agency. "Fast Facts on Transportation Greenhouse Gas Emissions". 2017.
https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

[17] Governing. "Vehicle Ownership in U.S. Cities Data and Map". 2016. https://www.governing.com/gov-data/car-ownership-numbers-of-vehicles-by-city-map.html

Table 4: Regression of Density and Automobile Independence

	Automobile Independence	
Density	0.00179***	
	(10.61)	
Constant	5.252***	
	(4.51)	
N	75	
Beta	0.7788897	
Multiple R	0.778889654	
R Squared	0.606669093	
t statistics in parentheses		
* p<0.05	** p<0.01	*** p<0.001

From the regression above, with an increase in density comes an increase in percentage of households to not own a car. To put data into perspective, an increase of density by 1000 outputs a 1.8% decrease in urban car ownership. With a t-value of 10.61, P value less than 0.001, and R-squared at .61, this regression is statistically significant representing that with an increase in density, the need of owning a car decreases. The beta of .779 proves that there is a strong-positive relationship between city density and households without a car. And with fewer cars owned inner city, there may be decreases of congestion, decreases of automotive accidents, and increases of environmental sustainability are a few of the many positive outputs this regression indicates could be possible. Find Graph 4 below illustrating the regression.

Graph 4: Density to Automobile Independence

Density to Automobile Independence $R^2 = 0.594$
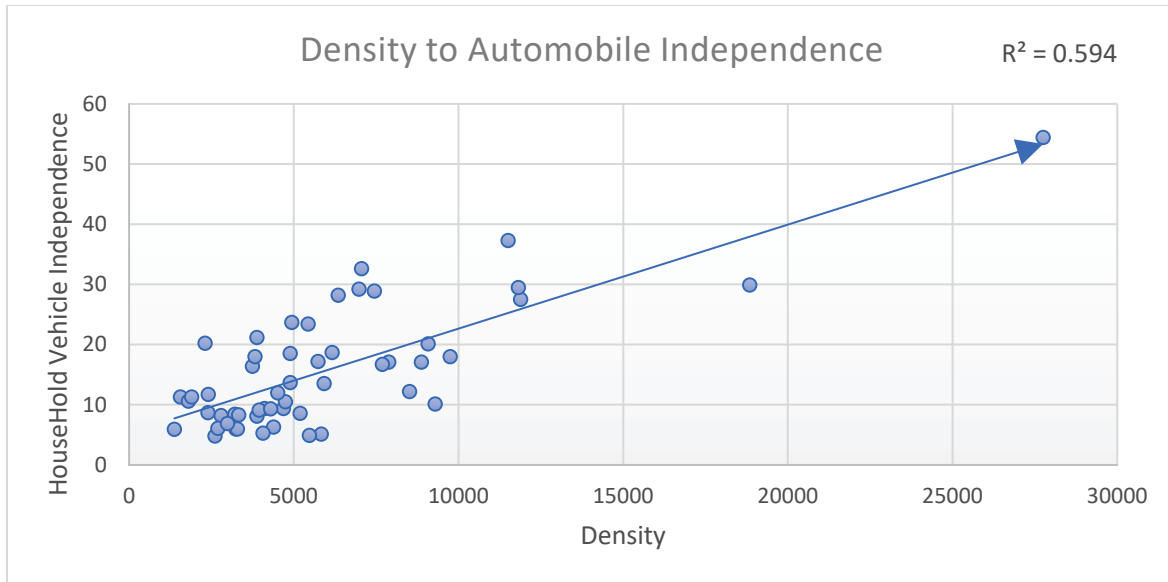
One can note that the cluster of cars are under the 5000-density mark. Once over that threshold, one can predict a greater likelihood of vehicle independence. In New York City with a density of 27,751 exhibits a strong vehicle independence percentage of 54%. One may possibly infer that an effective public transit network contributes to this automobile independence. The NYC Subway system is ranked #1 in North America by ARCADIS' Sustainable Cities Mobility Index.[18] Perhaps with an increase of density, the utilization of public transportation networks increases. Find in the next section the linear regression run between density and public transit utilization.

3.5 Public Transportation Utilization

Through the lens of public transportation use, a smart city compact growth development model could enable cities to create a more sustainable transportation network. With smart growth, as population increases, and urban development infills, the need of a car decreases as public transportation usage increase. The data for this regression was collected from the

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[18] ARCADIS. "Sustainable Cities Mobility Index". 2017. https://www.arcadis.com/en/global/our-perspectives/sustainable-cities-mobility-index-2017/?utm_source=PR&utm_medium=10302017&utm_campaign=SCMI2017&utm_content=global

American Public Transportation Association's 2019 ridership report.[19] Through the regression, the data proves that density plays a significant role in public transportation ridership. Constituents gravitate towards the path of convenience, therefore, if the network is efficient, ridership will increase. If the public transportation system can provide what a car normally would, car reliance would decrease substantially. In the regression below in Table 5, find the outputs of how density affects public transportation ridership daily.

Table 5: Regression of Density and Public Transportation (Weekday Average)

	PublicTransitUsePerWeekday	
Density	341.5***	
	(4.07)	
Constant	-1133640.8	
	(-1.79)	
N	54	
Beta	0.491313	
Multiple R	0.491312972	
R Squared	0.241388437	
t statistics in parentheses		
* p<0.05	** p<0.01	*** p<0.001

In this regression, the data of public transportation ridership was unavailable for all cities. 17 cities were removed from the analysis as the American Public Transportation Association has not reported on their averages for the 2019FY. 54 cities were assessed.

The regression shows that as density increases by one person per square mile, an increase of public transportation ridership daily increases by 331.5. This means that if density were to

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[19] American Public Transportation Association. "Transit Ridership Report. Second Quarter 2019". https://www.apta.com/wp-content/uploads/2019-Q2-Ridership-APTA.pdf

increase by 1000, daily ridership would increase by 331,500 people in capable cities. If this were

to happen, a consideration would be how the current system could manage such an influx. What

would the city need to do to deal with such a dramatic increase? With a t value of 4.07, P less

than 0.001, and an R-squared of .241, this regression holds true to prove a statistical significance

between density and public transportation use. With a beta of .49, this output shows a moderate-

positive correlational relationship between public transit usage and density.

If we compare top tier cities of public transportation use like New York City to lower tier

cities of automobile dependence like Charlotte, North Carolina, we can apply this regression to

real world numbers and see how a shift in density could greatly affect the city if the urban

infrastructure could enable said change. In New York City with a density of 27,751 people per

square mile, the number of daily riders of the MTA is 11,484,500.[20] In Charlotte, North

Carolina, the density is 2,930.993 people per square mile and their CATS public transit ridership

is 71,300.[21] The output can also be related to the likelihood of owning a car in that city. In NYC,

54.4% of households do not own a car.[22] In Charlotte, that number is 6%.[23] As density increases,

we can see a large growth of public transportation ridership. In Graph 5 below, find the

illustration indicating how as density increases, public transportation ridership follows. The

cluster of riders are under the density of 5000, however when density increases above that

threshold, we see this cluster begin to move upwards critically. The trend line has a sharp nature

to it having it move upwards after reaching the precipice point of ridership around 4,000 daily

users.

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[20] American Public Transportation Association. "Transit Ridership Report. Second Quarter 2019". Pg. 26.
https://www.apta.com/wp-content/uploads/2019-Q2-Ridership-APTA.pdf
[21] Ibid. Pg. 24.
[22] Governing. "Vehicle Ownership in U.S. Cities Data and Map". https://www.governing.com/gov-data/car-ownership-numbers-of-vehicles-by-city-map.html
[23] Ibid.

Graph 5: Density to Public Transportation Use (Daily Average)

Density to Public Transportation Use Daily (Average)   R² = 0.2414

Y-axis: Ridership of Transportation System (average weekday)

X-axis: Density
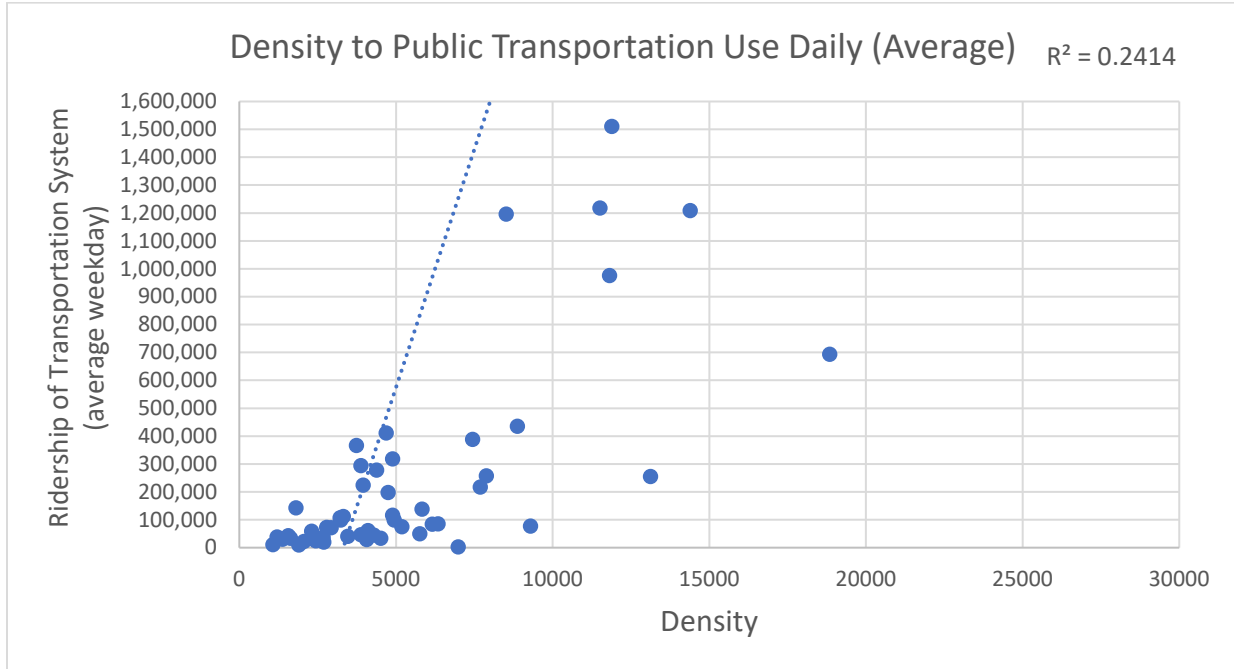
4. Energy Management

Considering the findings from the quantitative analyses conducted in this research, real-world applications can be postulated around how sectors may undergo paradigm shifts to transform and meet future demand. In particular, with the compact growth model pitched, one could presume that as density increases, there would be significant transformations of the current service network to satisfy the increased demand. In cases of urban growth, utilities and power producers could expect to face unprecedented levels of demand. Questions such as how the transmission and distribution critical infrastructure networks will handle the increase of demand is paramount for utilities and power producers to investigate. Predictably, the compact growth method may create a greater need for additions to the distribution critical infrastructure network. How will expansive means be introduced to the energy system to combat the problem of increased demand inner-city whilst maintaining the current network distribution assets?

Currently, utilities are undergoing grid modernization efforts to effectively update their power systems to handle the demand of the 21st century. These efforts are fueled by utilities and power producers investing in 21st century technologies and software's to manage the changes of the power system. Included -- but not limited to -- are the following initiatives encompassing the modernization effort as stated by the Department of Energy:

1) "Resilience Modeling

2) Energy Storage and System Flexibility

3) Advanced Sensors and Data Analytics

4) Institutional Support and Analysis

5) Cybersecurity and Physical Security

6) Generation"[24]

The Department of Energy created the Grid Modernization Institute (GMI) to join efforts with the Office of Electricity Delivery and Energy Reliability, the Office of Energy Efficiency and Renewable Energy, and the Office of Energy Policy and Systems Analysis to "[develop] new architectural concepts, tools, and technologies that measure, analyze, predict, protect, and control the grid of the future…that allow for more rapid development and widespread adoption of these tools and technologies".[25] With respect to the six pain points above of utilities and power producers, justifications around the grid modernization effort expands as far as to implement artificial intelligence programs to support, sustain, and pursue foundational security protocols in effort to protect the critical infrastructure network susceptible to malevolent cracks

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[24] Department of Energy. "About the Grid Modernization Initiative". https://www.energy.gov/grid-modernization-initiative-0/about-grid-modernization-initiative
[25] Ibid.

and hacks. The modernization initiative would promote the integration of Software as a Service (SaaS) platforms to centralize and mobilize the utility and power production sector's fleet of both physical and cyber resources. This could transform corporations through adoptions of Enterprise Asset Management and Work Management systems to strengthen resilience and promote proactive attempts at combating the world's ever-growing demand. If the compact urban development method is pursued, critical shifts of utility consumption will be present and the necessity for 21st century solutions will be more critical to adopt than ever before.

Considering the data from the regressions run, electricity demand may decrease per capita meaning that although the network must grow as customers increase, the overall use per capita may decrease. The data from this research outputs critical insights around what the positive externalities may be from a compact growth urban development method adopted and with those benefits comes the transformation utilities and power producers must undergo. For that reason, amongst many others, the grid modernization initiative is critical to the future of energy management, especially with the consideration of cities becoming denser.

5. Conclusion

When considering the future of urban planning, the dilemma that must be solved to pursue sustainable, environmentally conscious means of urban growth is whether to follow the path paved during the 20th century and to sprawl, or to change strategies and augment methods to grow inwards. Considering the path of smart city development through the compact growth model, one may see the exhaustive efforts of utilizing available technologies to enhance system operation. If municipal leaders introduce smart technology to their urban system forming an interconnected network to support the density changes in the city, improved urban function holistically could happen. As demand of service increases for both the public and private sector,

one would notice a shift in the infrastructural networks to meet such demand. For this reason -- of the many -- the local economy could thrive.

The lessons learned from this paper can be applied to governments, public policy planners, and energy professionals, to name a few. Analyzing the outputs of this research, following a compact growth development model of inwards expansion and density growth can output positive externalities with regard to energy management and emission control. Creating an infrastructure strongly supported by the public transportation system can output decreased traffic congestion, decreased energy usage/fuel consumption, and decreased greenhouse gas emissions as extrapolated in this paper. One of many operational exemplars in highly dense cities is the public utilization of their urban transportation system and substantial decrease in electricity usage per capita. In this research, significant regression coefficients, R-squareds, t-statistics, and variable coefficients all support the contention that there may be causality between an increase of density and an increase of urban efficiency.

What has been found in this research may support the argument to replace the urban sprawl model with compact growth. Urban sprawl may not be the most sustainable model to pursue especially with urban population growth rising. The statistics around increased density prove to lower electricity usage per capita; lower greenhouse gas emissions per capita; lower vehicle ownership per household; and increase public transportation usage. This could provide ample reason to shift the current path of planning and development towards compact growth outputting significant positive externalities supporting a more sustainable and environmentally friendly future state.

Data Source for Quantitative Analysis

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Appendix

The data collected to fuel this research primarily was sourced through the United States Census Bureau. City population and land area was collected and used to calculate density by dividing the two data points. The collected data for population information per city was from the "City and Town Population Totals: 2010 – 2018" publishing by the bureau.[26] The data for land area was taken from the "Population, Housing Units, Area, and Density: 2010 - United States -- County by State; and for Puerto Rico more information 2010 Census Summary File 1" table published by the bureau as well.[27]

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[26] United States Census Bureau. "City and Town Population Totals: 2010-2018". 2018.
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Master of Science in Government Analytics   01/2018 – 12/2019
- Concentration in Public Management

New York University School of Engineering   **New York, NY**
Bachelor of Science in Business and Technology Management   09/2013 – 08/2016
- Concentration in courses focused on innovation strategy and entrepreneurship

Technical Institute of America   **New York, NY**
CompTIA A+   07/2015 – 09/2015
- Specialization in computer network security

St. Mary's University   **San Antonio, TX**
Computer Science Major   08/2012 – 05/2013
- Focus on network security and cyber analytics

PROFESSIONAL EXPERIENCE

National Grid – Gas Business Enablement   **Waltham, MA**
Product Analyst, Asset Management   01/2017 – Present
- Dedicated SCRUM Master for Asset Investment Planning and Asset Risk Management
- Management of JIRA, Confluence, and Jira Align platforms under the Scaled Agile Framework
- Manage weekly SCRUM ceremonies
- Representation of development effort and scope expectations for program-wide communications

Come Join The Band!   **New York, NY**
Operations and Marketing Manager   10/2015 – 07/2016
- Began a marketing campaign expanding the Come Join The Band! program to other regions of New York.
- Created an organized, seamless system for the program connecting all employees and clients to the online database
- Managed monthly newsletter to clients compiling the media of the month
- Pitched marketing tactics and strategies directly to co-founder for expansion goal by year end

LingPerfect Translations   **New York, NY**
Assistant Vendor Manager   06/2014 – 08/2014
- Supported LingPerfect with client outreach alongside technical support through SalesForce (Market Research),
- Helped generate over 100 new clients through ProZ postings and personalized emailing.
- Reached out to Fortune 500 companies to fulfill their translation needs (Intel, Boeing et al).

CERTIFICATIONS

- Scaled Agile Framework Product Owner/Product Manager (POPM) certified