Predicting Battery Electric Vehicle Ownership in the United States Based on Demographic and Spatial Characteristics



By
Timothy Cornett

Department of Environmental Science
Allegheny College
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Christopher Shaffer	4/26/2016		4/26/16
Chris Shaffer	**Date**	**Dr. Ian Carbone**	**Date**

Pledge

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Abstract:

The United States transportation sector contributes significantly to climate change, producing 33.7 percent of global greenhouse gas (GHG) emissions from typical internal combustion engine vehicles. Battery electric vehicles (BEVs) emit zero tailpipe emissions and therefore offer the opportunity to reduce GHG emissions while fulfilling the transportation needs of the United States. This study performs a geographic information system (GIS)-based multi-criteria site suitability analysis of the Unites States to predict BEV ownership using a number of spatial variables. These variables include charge station density, median household income, percentage of commuters who commute by car, gas prices, and congestion levels. These variables were individually ranked by suitability and prioritized in accordance with their importance in determining BEV ownership. Suitable and moderately suitable areas encompass 18.1 percent (665,881 square miles) of the United States. Suitable areas were concentrated around major metropolitan areas, specifically the Northeast Megalopolis (stretching from Washington, DC to Boston, MA), San Francisco, Los Angeles, and Chicago. As BEVs are an emerging market, vehicle manufacturers may use these data to market and distribute BEVs to appropriate dealerships across the United States more effectively. Increased ownership of BEVs will reduce GHG emissions and anthropogenic climate change.

Introduction:

The United States is well known for its "American Dream," a notion that evokes an image of a beautiful suburban home surrounded by a white picket fence. America's infrastructure and society reflect this suburban lifestyle that many Americans have come to expect. The nation's sprawling suburban landscape, however, could not be possible without cars and trucks to move people, goods, and services.

86 percent of Americans commute to work by car; of these, 76.1 percent drive alone (Florida, 2011; U.S. Census Bureau, 2014). The National Household Travel Survey has found that as household income levels rise the number of vehicles per household and the percentage of commuters rise as well (Federal Highway Administration, 2009). Unfortunately, the typical vehicle is propelled by an internal combustion engine and burns fuels such as gasoline or diesel for power. While petroleum fuels are an incredibly effective energy source given their energy density, burning these fuels can release gases such as carbon dioxide (CO2), hydrocarbons, carbon monoxide, nitrogen oxides, and water vapor. Increased CO2 concentrations resulting from human activity is the leading cause of climate change due to increased radiative forcing. Radiative forcing is the difference of sunlight absorbed by the earth and the energy radiated back into space. Gasoline releases the highest concentrations of CO2 and is accountable for 85 percent of the increased radiative forcing effect compared to other greenhouse gases (GHG) (EPA, 2006). Emissions from internal combustion engine vehicles (ICEVs) would not be a significant problem if the transportation sector were small; however, this is not the case. In 2013, the U.S. transportation sector consumed 27 percent of the world's total energy and produced 33.7 percent of its total greenhouse gas emissions (EIA, 2014).

ICEVs also are highly inefficient, with only 15 percent of the total fuel energy combusted contributing to moving a vehicle and its occupants. During combustion, approximately 40 to 70 percent of the fuel's energy is lost as thermal energy in the engine cooling system and exhaust system (Tie & Tan, 2013). This waste heat directly contributes to global climate change and warming, in addition to the impact of CO2 emissions on radiative forcing (Chau & Chan, 2007). Unlike ICEVs, battery electric vehicles (BEVs) produce no tailpipe emissions. BEVs replace the typical vehicle's drivetrain (e.g., engine, transmission, gas tank) with an electric motor and battery. These vehicles look and perform similarly to ICEVs; however, instead of refueling them at a gas station, one plugs them into an electric outlet.

The absence of tailpipe emissions suggests that BEVs do not contribute to global warming; unfortunately, this is untrue. Instead, the emissions are offset to electricity production, which is currently being researched by the Union of Concerned scientists. In a 2012 report (updated in 2014), Anair and Mahmassani examined the emissions of energy production in the electrical grid associated with BEVs compared to the emission levels of hybrid electric vehicles (HEVs) and ICEVs. The authors found that more than 60 percent of the U.S. population lives in an area where BEVs produce fewer global warming emissions than even the most efficient hybrid. The entire U.S. population lives in an area where BEVs produce fewer emissions than the most efficient gasoline-powered compact car (Anair & Mahmassani, 2012; Anair, 2014). Yuksel and Michalek performed a spatial analysis to examine regional temperature's effect on driving range, average daily driving in different cities, and electrical grid emissions. One notable result was that BEV emissions vary by as much as 22 percent due to temperature variation within a region (Yuksel & Michalek, 2015). The study attributed this finding to the fact that extreme temperatures often require in-cabin heating or cooling, both of which draw significant amount of

power from the battery system. Similarly, extreme temperatures reduce battery capacity, thus limiting driving range. While this study examined the effectiveness of battery electric vehicles based on a region's climate, it did not consider the population living in those regions and how their lifestyle might impact the effectiveness of BEVs.

In recent years, the market for hybrid electric vehicles (HEVs) and electric vehicles (EVs) has grown in the United States. As of January 2015, there are currently 49 HEV, 9 plug-in hybrid electric vehicle (PHEV), and 13 BEV models for sale in the consumer market. In 2013, EV and PHEV sales accounted for 1.2 percent of total passenger sales, double that from the previous year (Argonne National Laboratory Transportation Technology R&D Center, 2014). While data on battery electric vehicle sales by state do not yet exist, these national figures suggest that American consumers are rapidly adopting electric vehicles as a mode of transportation at a much higher rate than HEVs (Argonne National Laboratory Transportation Technology R&D Center, 2014).

While BEVs are far less expensive to refuel, their starting price greatly exceeds that of a typical ICEV. The cheapest new BEV in the American market, the Mitsubishi i-MieV, starts at $23,845 and is nearly twice as expensive as the cheapest new ICEV, the Nissan Versa 1.6S, which starts at $12,815 (Edelstein, 2015; Gold, 2015). Studies have analyzed incentives provided to boost EV growth. Jenn and colleagues (2013) examined the effect of the Energy Policy Act of 2005, the intent of which was to incentive HEV purchases. They found that the legislation only increased hybrid sales between 3 percent and 20 percent (depending on vehicle model) and that the incentives were only effective when there was a high monetary reward (Jenn et al., 2013). Currently, there is a $2,500 federal tax credit for all BEV and PHEV purchases that can increase up to $7,500, depending on the battery size. This incentive, however, extends only to the first

quarter million electric vehicles sold in the United States and will likely be minimized or eliminated once this quota is reached. At the state level, incentives include rebates and tax credits for vehicles and their charging infrastructure, as well as access to HOV (high occupancy vehicle) lanes and free parking in certain municipalities (Zivin et al., 2014). Research has found that these state incentives positively correlate to market sales and distribution across the nation (Jin et al., 2014). By decreasing the cost to consumers through economies of scale and tax incentives, it is likely that the growth in BEV and PHEV sales will continue throughout the nation so long as the supporting infrastructure (such as charge stations) develops at a similar rate.

A study in Seattle, WA examined residential vehicle Global Positioning System (GPS) data to determine whether BEVs could meet the needs of the average household. The study demonstrated that a BEV with a 100-mile range could satisfy the needs of 50 percent of one-vehicle households and 80 percent of two-vehicle households (Khan & Kockelman, 2012). This study was conducted under the stipulation that vehicles were charged once a day (at home, overnight). Analysis by the U.S. Department of Energy has found that the greatest barriers to BEV adoption are the vehicle's limited driving range and lengthy refueling time, both of which are associated with "range anxiety." Of the nine electric vehicles with the greatest driving range under $45,000, the mean range is 82 miles on a single charge (Schaal, 2015). To mitigate this limited range, further improvements to the charging infrastructure grid and battery technology are needed. Charging stations are becoming more common across the United States, with nearly 9,300 public stations available as of April 2015 (U.S. Department of Energy, 2015). These findings suggest that BEVs are most suitable for urban and suburban drivers who travel short distances consistently, for example, daily commuters.

Current data indicate a massively growing demand for electric vehicles in the United States, a trend that will likely continue as BEVs become more efficient and cost effective. Research has been conducted in the U.S. on the emissions associated with these vehicles and how adequately BEVs meet household needs. Until this analysis, however, no study has examined where battery electric vehicle ownership is most suitable. Environmental science explores how to integrate more sustainable behavior and technologies into everyday life. In the case of battery electric vehicles, well-established technologies exist that can significantly reduce the environmental impact associated with transportation. While the market for electric vehicles is growing, their monetary purchase costs are still notably higher compared to conventional automobiles. Research needs to be conducted to examine which American consumers can afford to purchase a BEV and where they live, as these factors will impact the likely distribution of and use of these vehicles.

This study utilizes spatial analysis to predict the regions within the United States where battery electric vehicle ownership is likely to be most prevalent based on demographic data and regional factors (e.g., public charge stations, gas prices, congestion levels). The resulting map (Figure 8) will aid vehicle manufacturers and dealerships in better targeting likely consumers.

Methods:

A vector-based overlay allows one to maintain raw data's accuracy and extent of influence while also evaluating their relevant importance to other variables. Unique variables cannot be compared because of their unique measures and values. For example, the price of gas cannot be compared to the density of electric charge stations. For this reason, each variable in this analysis was converted to a standardized scale of suitability rankings on a scale 1 to 5. On this scale, highly suitable areas are given higher values and less suitable areas are given lower values. This common scale allows variables to be compared and combined into an overall suitability map.

Based on findings from an extensive literature review, a number of variables were identified that contribute to BEV ownership in the United States. Five variables were selected to predict the likelihood of BEV ownership. These five variables—median household income, percentage of commuters using a vehicle, public BEV charge station density, state gas prices, and congestion levels—are identified in the following text for their suitability in predicting BEV ownership.

TABLE 1 Data sources.

Data Variable	**Source**	**Date Created**
Electric Charging Stations	U.S. Department of Energy	February 16, 2016
State Gas Prices	Energy Information Administration	2015
TIGER/Line (Demographics)	U.S. Census Bureau	2013
Congestion	Texas A&M Transportation Institute; U.S. Census Bureau	2014

Median Household Income:

Demographic data were obtained from the U.S. Census Bureau's American Community Survey 5-year estimates 2009-2013. These survey results were created from a random sample of 3.5 million addresses in the United States. This source was selected because it is the most recent that can be applied to small geographic areas. Census blocks were selected to represent the following data because they are the smallest units of area that can accurately represent changing demographics across cityscapes. Census blocks can encompass small areas such as individual blocks and neighborhoods and can also expand across vast areas such as the Midwest. Census tracts and county data, on the other hand, are too large to display detailed differences in demographics. For example, Monroe County, New York encompasses the city of Rochester as well as the surrounding suburbs, which have a much higher household income. Census blocks show these distinct distributions of wealth. The data were obtained in two forms: American Community 5-year estimate geodatabases (which organized the resultant data) and 2013 TIGER/Line shapefiles which defined block group boundaries. The geodatabase files were joined to the TIGER/Line shapefiles and then ranked.

These data provided a critical variable for this analysis: median household income level, which can be used to predict whether a household can afford a BEV. This variable was selected instead of mean household income to eliminate the effect of skewed income levels. Extreme incomes (usually on the higher side of the curve) can pull the average income up which misrepresents the overall dataset. Financial planners generally advise that one spends no more than 10 percent of one's monthly income when paying for a new vehicle. Using the prices of the top BEVs[1] currently on the market and the average four-year loan and interest rate (4.3 percent), it is possible to determine the yearly household income level necessary to afford BEVs across a

[1] Defined as those BEV models under $45,000 with the highest driving range.

range of prices (Table 2) (Edelstein, 2015; Sante, 2016; Schaal, 2015). Median household income levels were divided based on these estimated yearly income levels into four ranked groups (Table 3). These ranked values were then displayed on a map to show the suitability across the United States based on income level (Figure 3).

TABLE 2 Yearly household income levels necessary to afford BEVs.

	Vehicle	**Cost**	**Monthly Payment**	**Yearly Income**
Minimum	Mitsubishi Mi-ev	$23,845.00	$511.41	$61,369.20
Average*	Average BEV	$32,816.66	$727.42	$87,290.40
Maximum*	BMW i3	$43,350.00	$981.02	$117,722.40
Maximum	Tesla Model S	$75,000.00	$1,743.04	$209,164.80

* excluding Tesla

TABLE 3 Median household income ranked classes.

Median Household Income	**Rank**	**Suitability**
$250,001 – $117,723	5	High
$117,722 – $87,291	4	Moderately High
$87,290 – $61,370	3	Medium
$61,369 – $2,888	1	Low

Percentage of Commuters Using a Vehicle:

Census data also provided the percentage of workers in each block group who commute using a vehicle. It is important to distinguish areas that have a high percentage of commuters using alternative forms of transportation like public buses or trains (e.g., New York City) from those that have a high percentage of commuters driving (e.g., Los Angeles) and are thus likely to have more potential BEV buyers. Within the attribute dataset, the percentage of commuters driving was calculated by comparing the number of workers who commute using a vehicle to the

total number of workers who commute to their place of work. These data were then divided into ranked values using a Jenks classification method (Table 4). These ranked values were displayed on a map to show the suitability across the United States based on percentage of commuters by car (Figure 2).

TABLE 4 Ranked classes for vehicle commuter percentage.

Percentage of Commuters Using a Vehicle	**Rank**	**Suitability**
100.0% – 93.4%	5	High
93.3% – 84.1%	4	Moderately High
84.0% – 69.7%	3	Medium
69.6% – 41.3%	2	Moderately Low
41.2% – 0	1	Low

Charge Station Density:

The U.S. Department of Energy's Alternative Fuels Data Center provides updated spatial data on alternative fueling stations across the United States. The number of public and private electric vehicle charging stations grows daily as communities shift towards providing more renewable infrastructure. This growth in infrastructure can be attributed to public interest in supporting the use electric vehicles within a community. Both supporting infrastructure and public interest are strong indicators of BEV ownership. Public electric vehicle charge locations are recorded in latitude and longitude and when plotted on the globe, relative density can be easily visually assessed. A kernel density tool was utilized to quantify the relative density of these charge station across the United States. These densities were broken into groups using a Jenks classification method and ranked to best match the differences in density across the region

(Table 5). These ranked values were then displayed on a map to show the suitability across the United States based on public BEV charge station density (Figure 4).

TABLE 5 Ranked classes for charge station density.

Charge Station Density	Rank	Suitability
0.0218 – 0.0094	5	High
0.0094 – 0.0058	4	Moderately High
0.0057 – 0.0034	3	Medium
0.0033 – 0.0012	2	Moderately Low
0.0011 – 0.0000	1	Low

State Gas Prices:

The cost of gasoline is another factor that drives consumers to seek alternative modes of transportation. Within the ICEV market, there is close competition to maximize fuel efficiency to bolster vehicle appeal to the consumer. Even the most efficient ICEV, however, cannot compare to the high efficiency and low running costs of a BEV. Gas prices vary widely across the United States—the product of state taxes, which can increase the price of gas by as much as 20 percent. Distribution and refining, additional components of the supply chain, can further influence prices by nearly 30 percent (Dilallo, 2015). Areas surrounding the Gulf Coast, for example, are located in close proximity to the source of crude oil that is locally refined to gasoline; therefore, these regions have lower overall gas prices. Gas prices in the West Coast and Northeast, on the other hand, are subject to greater pipeline tariffs. The U.S. Energy Information Administration has kept records on average yearly state gas prices for the past 30 years. After averaging the cost of gasoline to the consumer over the past 5 years, these data can be joined to a state map layer to overlay and accurately rank this data (Table 6). These ranked values were then displayed on a

map to show the suitability across the United States based on the 5-year average gas prices to the consumer (Figure 5).

TABLE 6 Ranked classes for 5-year gas prices.

Average Price of Gas	**Rank**	**Suitability**
$2.81 – $2.53	5	High
$2.52 – $2.35	4	Moderately High
$2.34 – $2.27	3	Medium
$2.26 – $1.78	2	Moderately Low
$1.77 – $1.74	1	Low

Traffic Congestion:

The final variable considered in this analysis accounts for a small, but important, influence on BEV development in the United States. Cities with high levels of traffic congestion (e.g., Boston, Los Angeles) typically have long commute times during which, more fuel is consumed by vehicle idling. BEVs consume similar amounts of fuel (electricity) over the same distance, no matter the speed or time spent idle, making them a more environmentally friendly alternative for consumers in areas with heavy congestion. Texas A&M Transportation Institute (2015) has evaluated Urban Mobility and Congestion Statistics generated from data from 471 urban centers across the United States between 1982 and 2014. These cities, along with their associated congestion data, were geocoded as points and then merged with a city boundaries layer so that the results of this analysis could be displayed over the relative city limits to which they apply. As most commuters tend to travel from outside city limits, a buffer was applied based on population level to extend the congestion values over a more representative area (Figure 1).

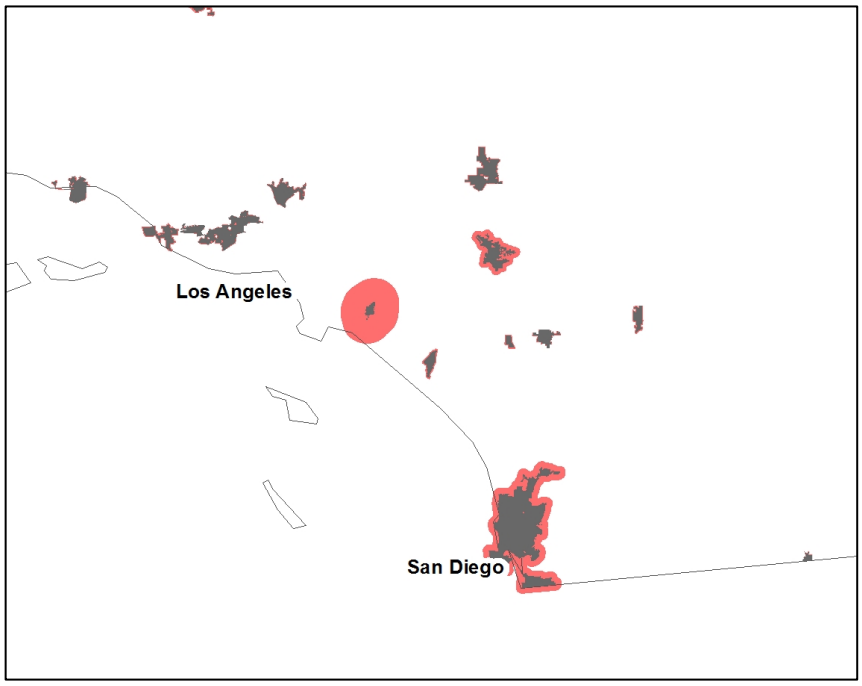


FIGURE 1 City limit expansion based on population.
NOTE: The initial boundaries are in dark grey and the population-based buffered boundaries are shown in light red.

The data were then divided into groups using Jenks classification method based on the average annual hours of delay per vehicle commuter and ranked (Table 7). These ranked values were then displayed on a map to show the suitability across the United States based on ranks of the annual hours of delay per vehicle commuter (Figure 6).

TABLE 7 Ranked classes for annual delay per vehicle commuter.

Annual Delay per Vehicle Commuter (Hour)	**Rank**	**Suitability**
82 – 54	5	High
53 – 36	4	Moderately High
35 – 22	3	Medium
21 – 13	2	Moderately Low
12 – 1	1	Low
No Data	0	

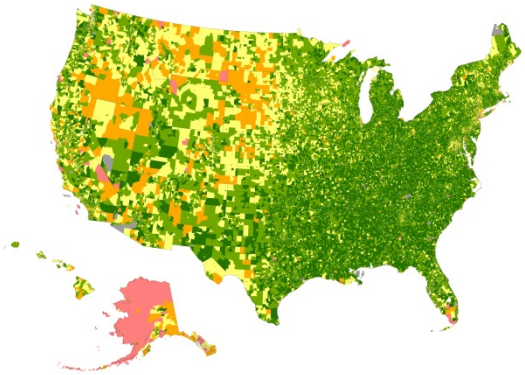


FIGURE 2 Vehicle commuter percentage.

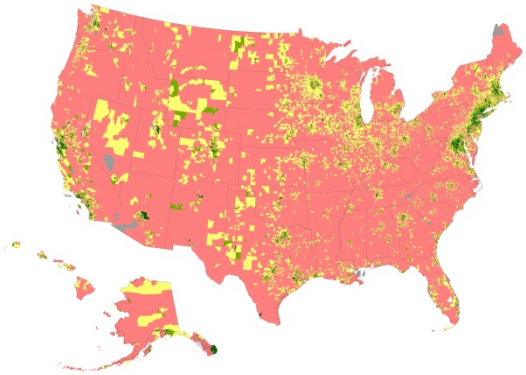


FIGURE 3 Median household income.

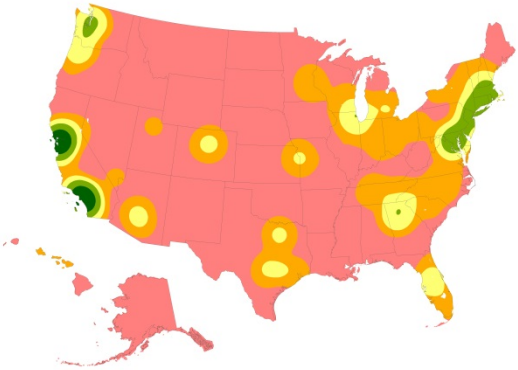


FIGURE 4 Public charge station density.

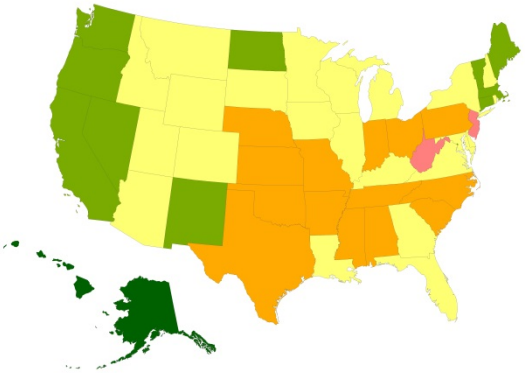


FIGURE 5 5-year gas price.

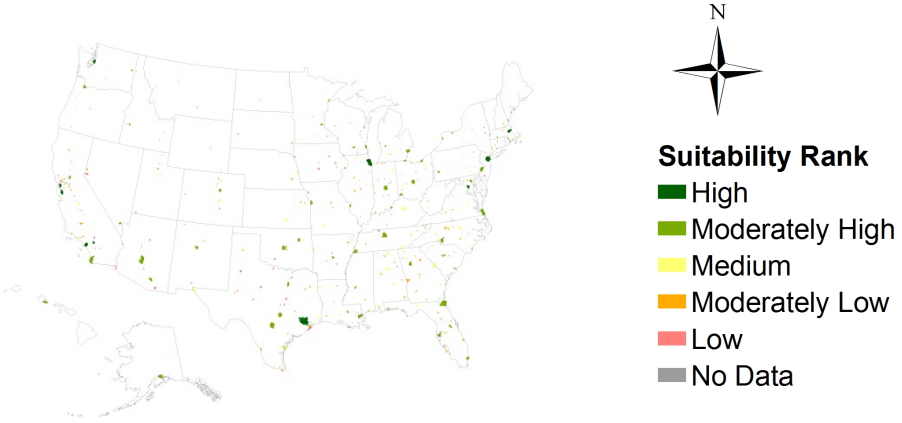


FIGURE 6 City congestion level.

Overlay:

The spatial variables were combined to create a map that effectively displays the predicted relative development of BEV ownership in the United States. These five variables were combined into a common dataset by overlaying the individual map layers as shown in Figures 2-6. Within the dataset, new polygons were created from overlapping polygons (see Figure 7). For example, many census blocks were broken up by charge station density boundaries. Each polygon still contains all original suitability rankings associated with that area.

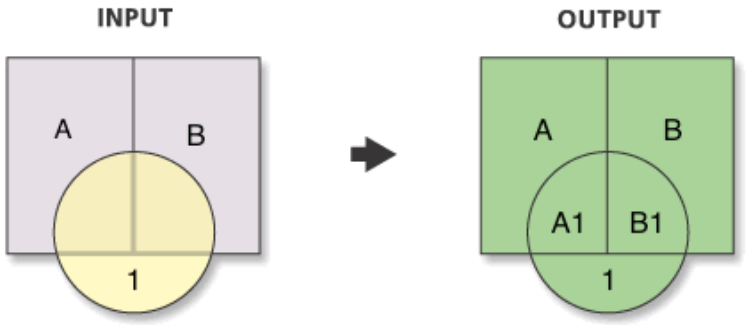


FIGURE 7 Map overlay showing how datasets are combined.
SOURCE: ESRI Resources

Based on results from the previously described literature review, certain variables are more important than others in predicting BEV ownership. Median household income is a definitive limiting factor; as a result, it was given greater weight in the calculation of the overall suitability. Charge station density and percentage of commuters via car were also assigned high importance when predicting the likelihood of vehicle ownership because they are indicative of regions where there are more drivers as well as preexisting infrastructure for and interest in BEVs. Weighted values define how much each variable impacts the final suitability rank (Table 8).

TABLE 8 Weighted importance of variables.

Variable	Weight (%)
Median Household Income	30
Percentage of Commuters via Car	20
Charge Station Density	30
Cost of Gas	15
Annual Delay per Commuter	5

Results:

The results of this analysis provide a relative ranking for BEV suitability in the United States based on demographic and spatial characteristics. The resulting study region is made up of 3,678,238.50 square miles of ranked suitability values.[2] The results of the weighted analysis broken into suitability ranks are presented in Table 9. This analysis produced 157,483 square miles (4.3 percent) of the highest suitability class in the study region; 508,398 square miles (13.8 percent) of moderately high suitable area; 1,530,703 square miles (41.6 percent) of moderately suitable area; 1,397,674 square miles (38.0 percent) of moderately low suitable area; and 83,981 square miles (2.3 percent) of low suitable area in the United States.

TABLE 9 Resulting values from weighted overlay

Weighted Overlay Value	Suitability
4.85 – 2.96	High
2.95 – 2.36	Moderately High
2.35 – 1.76	Medium
1.75 – 1.16	Moderately Low
1.16 – 0.50	Low

[2] Note: this is not the exact size of the United States as some variables were missing data for certain regions.

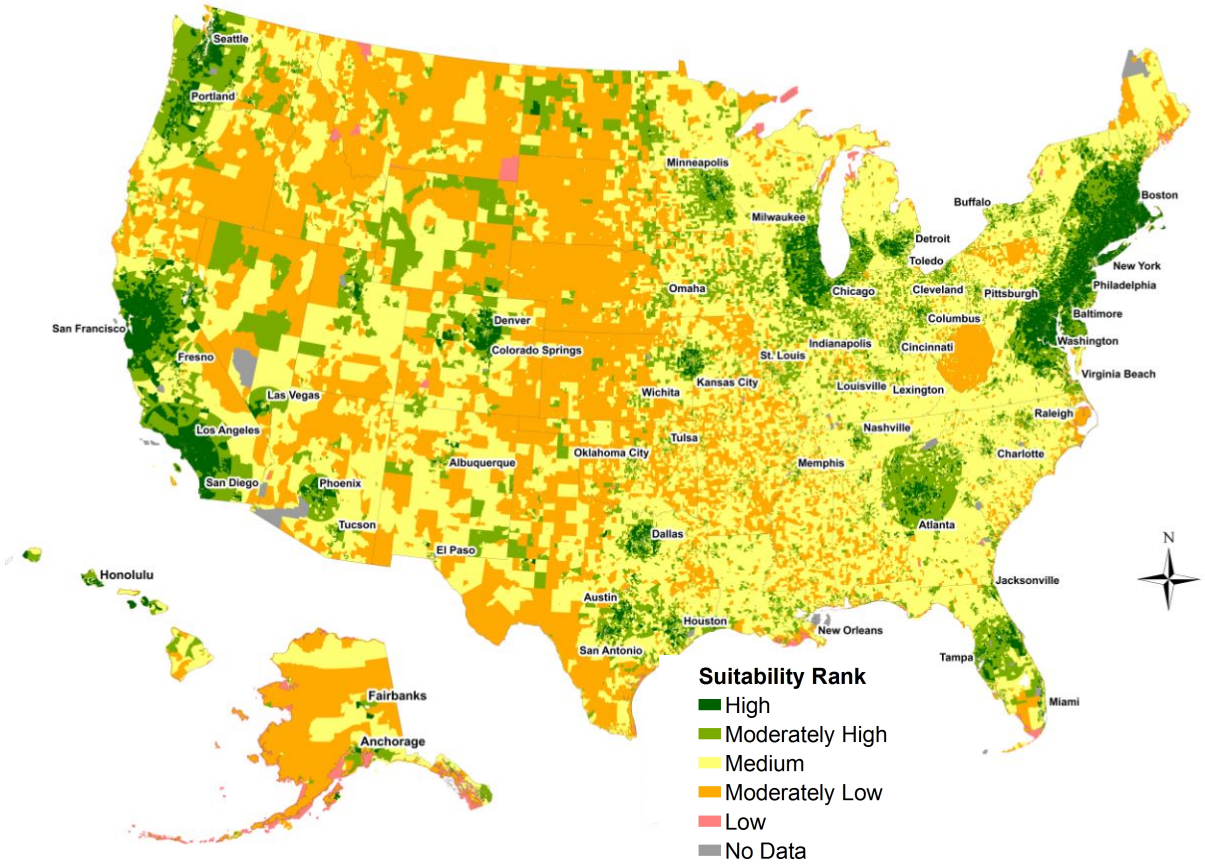


FIGURE 8 Final suitability results based on weighted analysis.

Figure 8 depicts multiple areas of high suitability. The Northeast megalopolis, which stretches from Washington, DC to Boston, MA, represents the largest grouping of high suitability area on the East Coast. This area displays moderately high to high suitability ranks with slightly lower values centering on the major cities and higher suitability surrounding the metropolitan areas. Within the Northeast, West Virginia is notable in that it is an area of contiguous low suitability. Along the West Coast, San Francisco and Los Angeles are other large areas of high suitability, with continuous areas of high suitability within and surrounding the metropolitan areas. Seattle and Portland also display moderately high to high suitability ranks, though not to the magnitude of Los Angeles and San Francisco. The Chicago and Milwaukee area in the Northeast also demonstrates fairly high suitability with lower suitability values within

the metropolitan city limits. The Atlanta and Tampa areas both display moderately high suitability ranks with some high suitability within the metropolitan area. In general, the Midwest displays lower suitability values.

Discussion:

This discussion focuses on those regions with the greatest extent of highly suitable ranks; the Northeast megalopolis, Los Angeles and San Francisco, and the Chicago-Milwaukee area. The Portland-Seattle region, Atlanta, and Tampa areas were excluded because they scored mostly moderately suitable ranks. The Northeast megalopolis of the United States is the most extensive suitable region in this analysis (Figure 9). This highly suitable region, which extends from Virginia to Maine, represents a large portion of the American population and has excellent potential for BEV ownership. One in eight Americans resides in these cities (Table 10). This region also is the wealthiest in the country, encompassing 37 counties with a median household income of at least $75,000. Additionally, public electric vehicle charging stations are abundant and these cities have high congestion levels and a fairly high percentage of commuters. While gas prices varies dramatically across the region, this factor does not dramatically influence this region's suitability.

TABLE 10 Population levels for the Northeast megalopolis.

City	**Population**
Greater Boston	4.6 million
NY-NJ Metropolitan	20.1 million
Greater Philadelphia	6.5 million
Baltimore/Washington, DC	9.3 million
Region Total	**40.5 million**
U.S. Population	**318.9 million**
Percent U.S. Population	12.70%

SOURCE: U.S. Census Bureau, 2015.

The Northeast megalopolis demonstrates the suburbanization phenomenon that dramatically impacts BEV ownership suitability. New York City, Baltimore, and Philadelphia demonstrate this effect to a greater degree than Washington, DC and Boston. The centers of the former three cities are moderately suitable (a final weighted rank of 3) and suitability increases as distance from the city center increases. Low-income citizens tend to live closer to the city center and make use of public transportation rather than vehicles. These three cities also have well established public transportation systems. Higher income residents, on the other hand, are more likely to be able to afford to live further outside the city as well as a vehicle to commute.

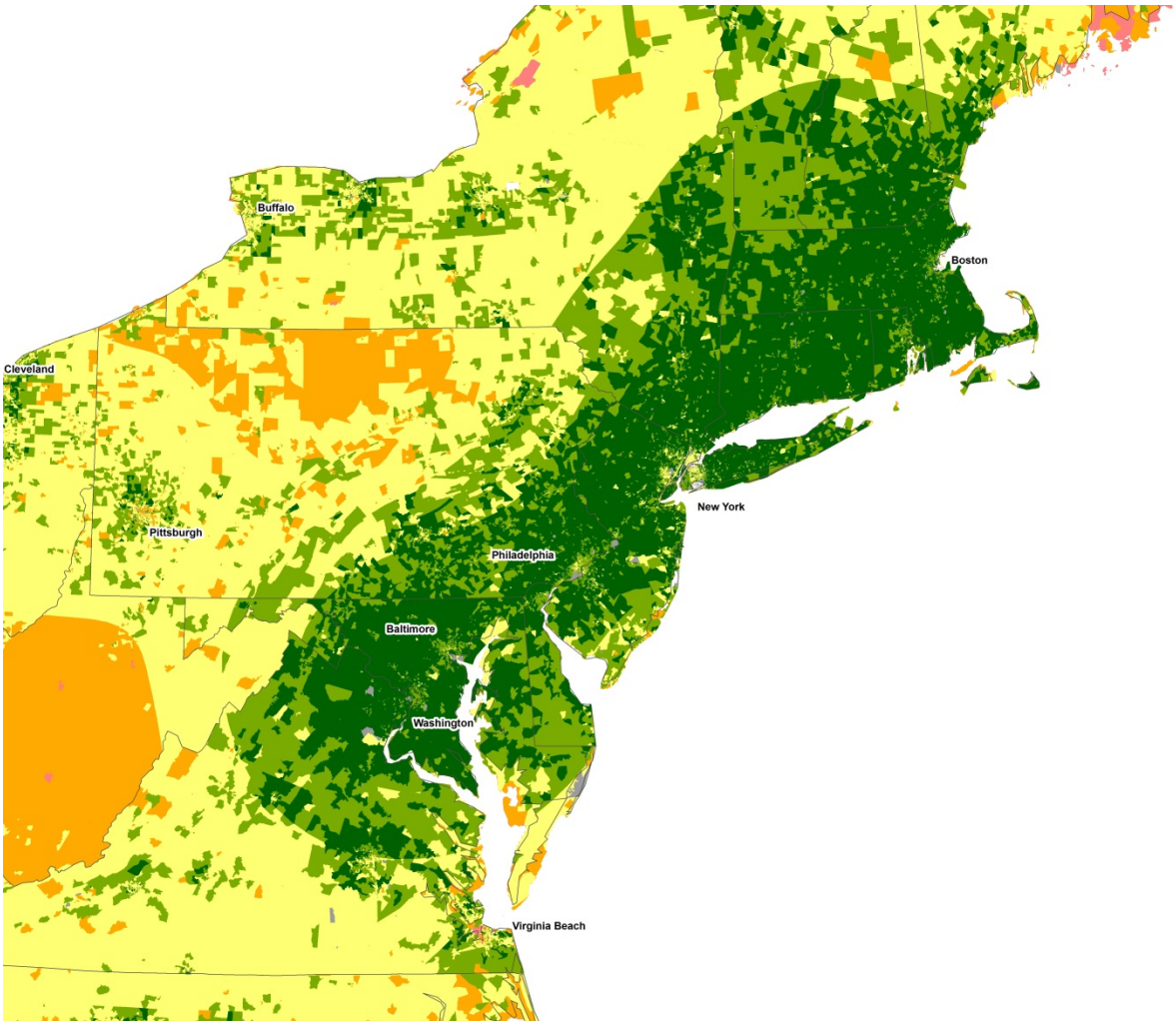


FIGURE 9 Northeast megalopolis suitability levels.

Within California, there are two highly suitable metropolitan areas (Figure 10). Los Angeles and San Francisco are the largest cities on the West Coast (Table 11). These cities demonstrate a higher level of urban sprawl compared to those on the East Coast. Los Angeles has an extensive network of freeways that extends in all directions to connect its suburbs. Both cities also are environmentally friendly, with high gas taxes and prices and numerous public BEV changing stations. Within the United States, Los Angeles and San Francisco are the only areas that rank high in electric charge station density (Figure 4). In comparison, the Northeast megalopolis and Seattle only rank moderately high. Los Angeles and San Francisco also experience high levels of traffic congestion and have a fairly high number of vehicle commuters.

Los Angeles and San Francisco have moderate to high levels of suitable household income, which, while not equal to that of the Northeast megalopolis, is high enough that nearly all block groups within these regions can afford a BEV.

TABLE 11 Population levels for Los Angeles and San Francisco.

City	**Population**
Greater Los Angeles	18.6 million
Greater San Francisco	7.1 million
Region Total	**25.7 million**
U.S. Population	**318.9 million**
Percent U.S. Population	8.06%

SOURCE: U.S. Census Bureau, 2015.

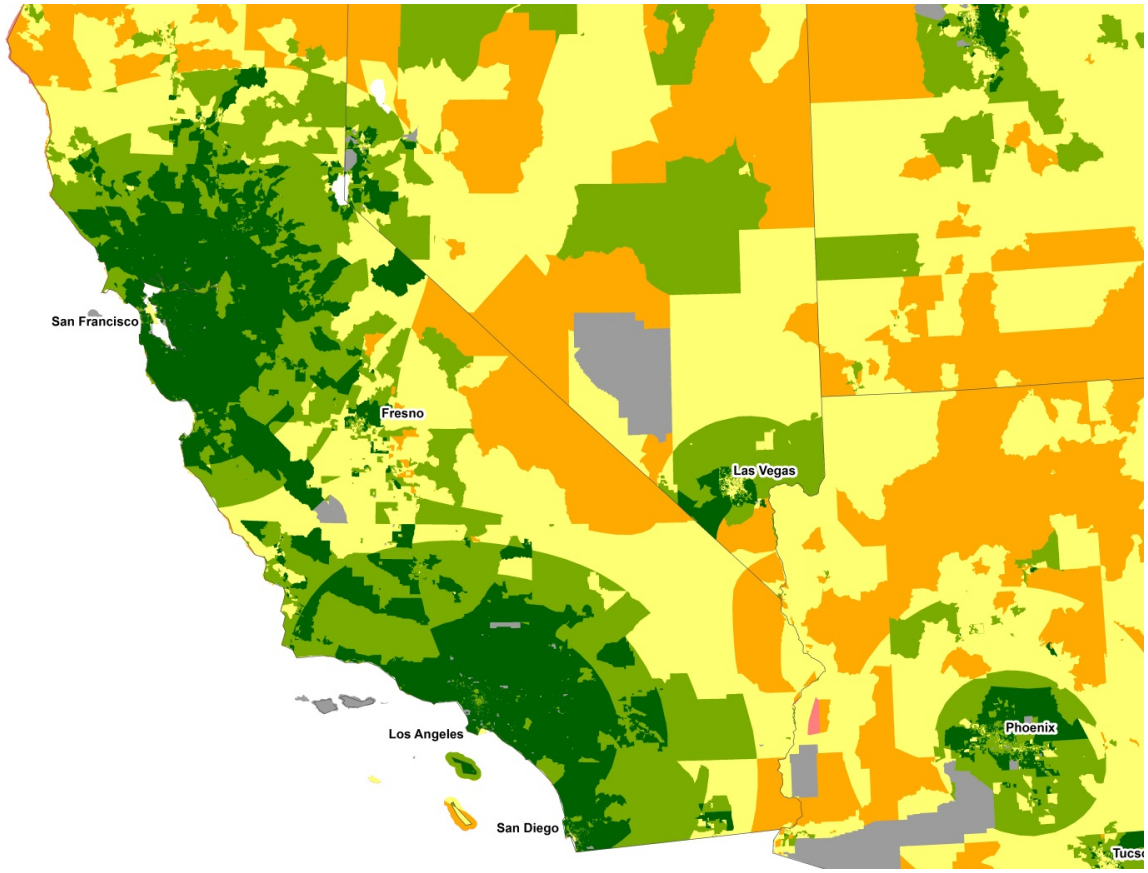


FIGURE 10 Suitability levels for Los Angeles and San Francisco.

A large area of suitability also appears around the Chicago-Milwaukee area (Figure 11), the combined population of which is 11.7 million (Table 12). The region demonstrates similar characteristics to that of the Northeast megalopolis but to a lesser degree. The area demonstrates suburban sprawl surrounding the Chicago and Milwaukee cityscape. Both inner cities rank low in household income whereas the surrounding areas rank moderately high. The region also is characterized by moderately high levels of vehicle commuters and traffic congestion. It ranks moderate to moderately high for BEV charge station density and moderate for gas prices.

TABLE 12 Population Levels for Chicago and Milwaukee.

City	**Population**
Greater Chicago	9.73 million
Greater Milwaukee	2.0 million
Region Total	**11.7 million**
U.S. Population	**318.9 million**
Percent U.S. Population	3.67%

SOURCE: U.S. Census Bureau, 2015.

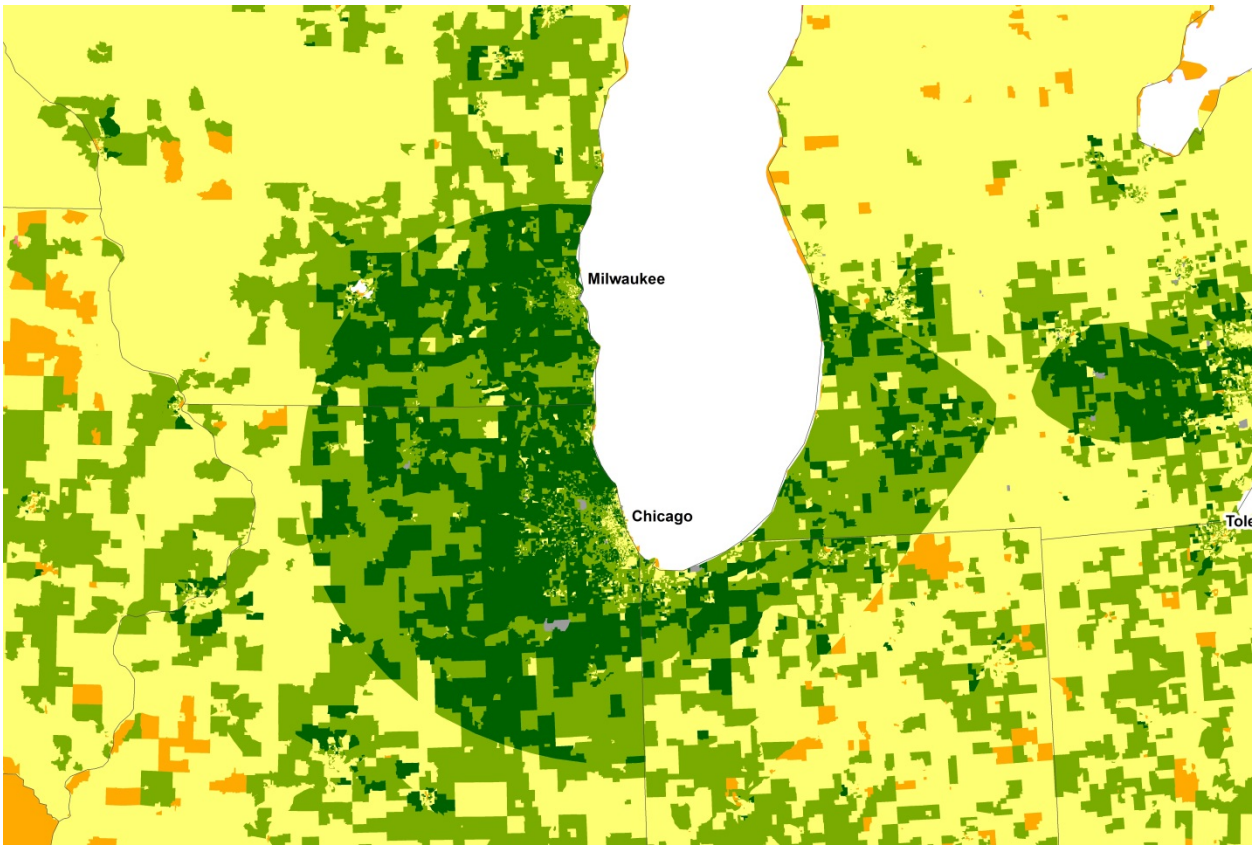


FIGURE 11 Suitability levels for Milwaukee and Chicago.

West Virginia is notable in that it includes the most contiguous area of low suitability arising from this analysis (Figure 12). The entire western half of the state ranks moderately low in suitability, despite being situated among three major areas of fairly high suitability: the Northeast megalopolis, Chicago, and Atlanta. West Virginia lacks major cities around which any substantial populations or industry can centralize (Texas A&M Transportation Institute, 2015). This is associated with lower income levels and a lack of BEV charge stations. The moderately high suitability of vehicle commuters is effectively cancelled out by the low suitability of all other variables. For example, West Virginia does not tax gas; therefore, the state has extremely low gas prices.

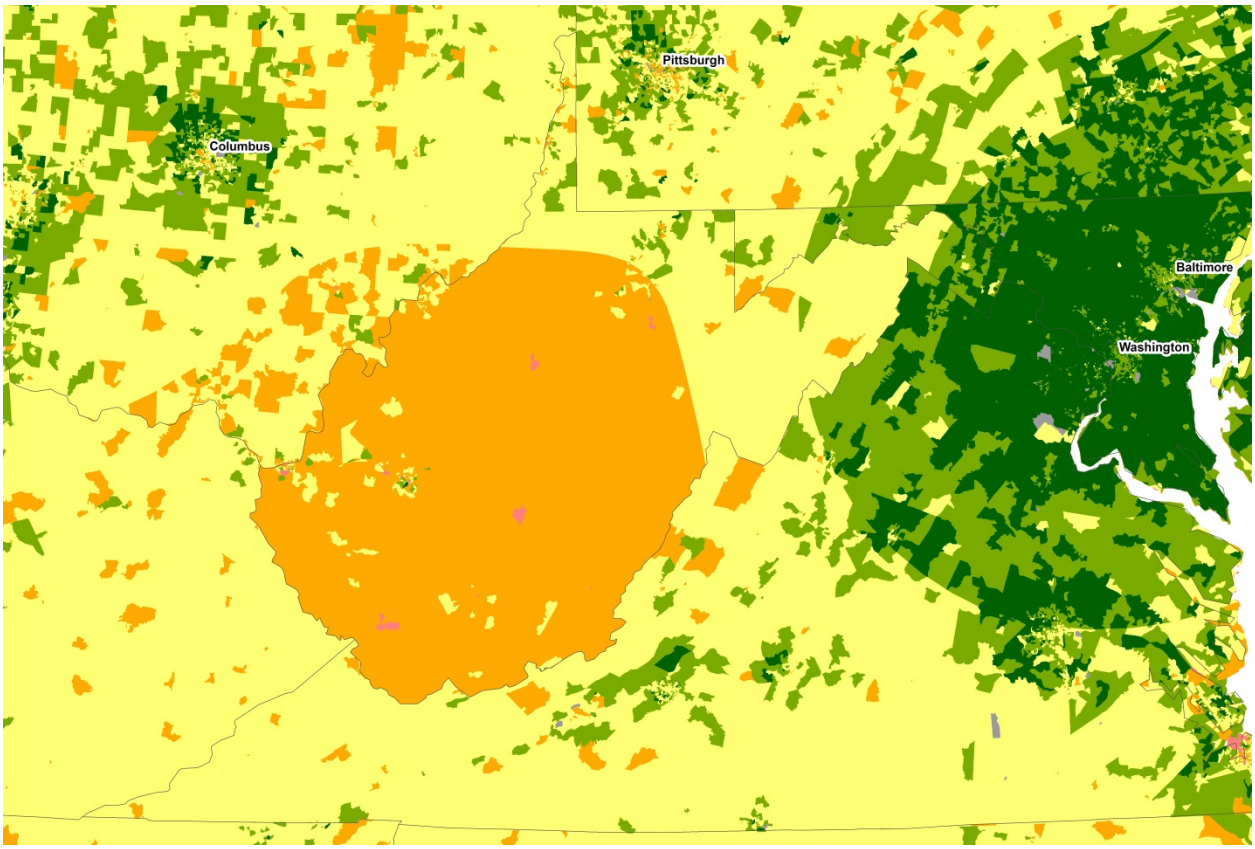


FIGURE 12 Suitability levels for West Virginia.

TABLE 13 Selected regions for comparison.

	Northeast megalopolis	**Los Angeles**	**San Francisco**	**Chicago-Milwaukee**
Area (mi^2)	46,609	12,626	15,423	8,504
Population Density (pop/mi^2)	868.9	1,473.1	460.4	1,375.8
Average Median Income	$75,341	$67,328	$78,160	$63,296
Average Percent Car Commuter	71	86	81	80
Charge Stations per mi^2	0.040	0.093	0.084	0.045

SOURCE: U.S. Census Bureau, 2015.

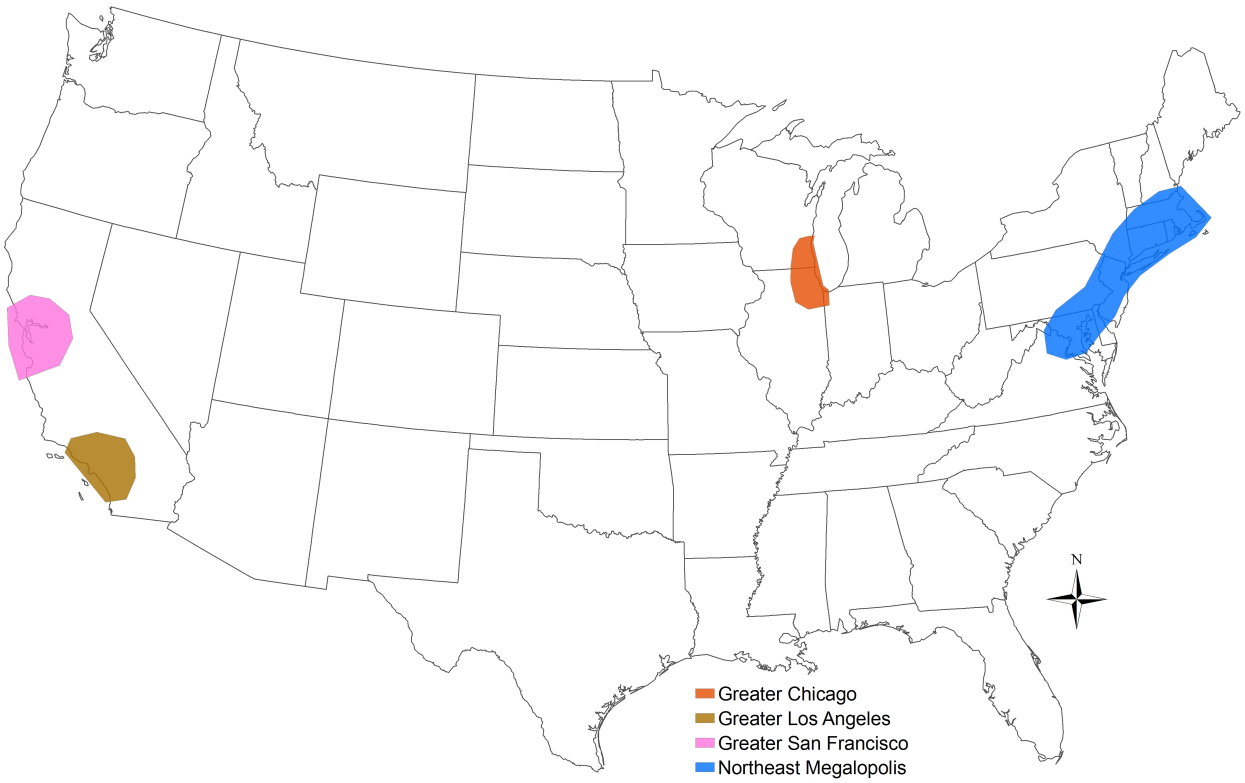


FIGURE 13 Boundaries for the suitable regions.

By approximating the extent of these four regions (Figure 13), it is possible to effectively compare these regions based on some of the unique variables. Even though the Northeast megalopolis is characterized by the greatest area and overall population, it demonstrates relatively low population density. Los Angeles and Chicago, on the other hand, demonstrate a much higher population density for their given boundaries due to the nature of their population distribution. San Francisco and the Northeast megalopolis have the highest median household income. Of the 3,144 counties that make up the United States, the Northeast megalopolis includes 37 of the nation's 75 wealthiest counties (Badger, 2013). Los Angeles has the largest portion of commuters who commute by vehicle. The Northeast megalopolis has a much lower percent of commuters who commute by vehicle likely due to the well-developed and frequently utilized public transportation systems. Finally, Los Angeles and San Francisco have much higher BEV charge station densities compared to cities on the East Coast. Combined, the two cities

have 2,460 public BEV charging stations. California is well known for its environmental initiatives and a culture that favors environmentally friendly behavior.

Based on these figures, Los Angeles and San Francisco are optimal locations for the automotive industry to pursue marketing BEVs. These areas demonstrate high population density, income levels, commuter levels, and charge station densities. The preexisting infrastructure for BEVs offers an effective selling point to the large number of potential consumers. Although Chicago has a higher population density and percentage of commuters using a vehicle, Chicago does not have as much potential as a BEV market given its relatively low income level. Table 13 suggests that the Northeast megalopolis is a promising region with the potential for further infrastructure growth and increased interest in these vehicles. The region's population density is fairly low; however, this reflects the great expanse covered by megalopolis. Targeting any of the Northeast's metropolitan areas as a growing market for BEVs would likely be profitable for the automotive industry.

Battery electric vehicles are an emerging market in the United States. Since 2013, BEV and PHEV sales rates have doubled (Argonne National Laboratory Transportation Technology R&D Center, 2014). New electric vehicles (e.g., Tesla Model 3, Chevy Bolt) are released and old versions (e.g., Nissan Leaf, Chevy Volt) are redesigned on almost a monthly basis. American consumers are rapidly adopting electric vehicles. Those regions with consumers most likely to purchase these vehicles are identified in this analysis. Industry can make use of these results to target the most suitable markets for BEV ownership. Vehicle manufacturers can utilize these data to optimize the distribution of BEVs to dealerships, so that BEVs are sent to those areas where consumers can feasibly own these vehicles. Selling BEVs at dealerships in West Virginia, for example, would be extremely unwise because the state lacks supporting infrastructure for these

vehicles and income data suggest the median household cannot afford a new vehicle at the price point of a BEV. These data can also be used when marketing these vehicles with targeted advertising on a local level.

These results could be refined further for these purposes by obtaining existing BEV and HEV sales for the United States, by location. There are a number of mechanisms by which one could obtain these data: on a state-by-state basis from the Department of Motor Vehicles or from dealership sales across the nation.

A similar analysis was conducted for the state of Texas at a similar scale of census tracts (Bansal, Kockelman, & Wang, 2015). Rather than predicting ownership rates based on demographics, however, these researchers correlated demographic variables with existing registered vehicles. The authors found that as household income, resident education level, and proportion of male residents increased, ownership rates for fuel-efficient vehicles rose in turn. Bansal and colleagues findings are thus consistent with this analysis, which found that higher income households surrounding major cities are more suitable for BEV ownership.

The clustering of a highly suitable area around major cities is spatially correlated to local government incentives and marketing, demographics, and land use patterns (Kodjak, 2012). The associated clustering may also be a result of public exposure to BEVs; for example, potential consumers may see BEVs in their neighbors' driveways or on the road (Axsen & Kurani, 2011). The high population density of cities (and therefore greater exposure) as well as the unique appearance of BEVs in contrast to ICEVs further magnify this effect. These results also are consistent with Keith, Sterman, and Strubens' finding that regional clusters of high suitability demonstrate preexisting strong adoption rates for HEVs (2012).

One of the main reasons BEVs are increasing in popularity is that they serve as a more environmentally friendly alternative to ICEVs and HEVs. Los Angeles and San Francisco are ideal locations for BEVs based on the results from this analysis and the CO2 emissions associated with BEV usage in these areas and the relatively low CO2 emissions associated with this region (100 g/mi). The Northeast megalopolis' CO2 emissions are less favorable (180 to 210 g/mi) but better than those of Chicago and Milwaukee (180 g/mi to 340 g/mi) (Yuksel & Michalek, 2015).

Conclusion:

This study used demographic and spatial data to predict BEV ownership across the United States. The analysis combined median household income, percentage of commuters who travel by car, public charge station density, average gas prices, and city congestion levels to generate a suitability map for the United States. These results demonstrate that major metropolitan areas are the most apt for BEV adoption based on these characteristics. In particular, the Northeast megalopolis and California represent the areas of greatest potential for future BEV adoption.

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