Spatial Analysis to Identify the Need for Additional EV Charging

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***Abstract*—Los Angeles County's electric-vehicle (EV) charging-station infrastructure is growing rapidly due to increased environmental awareness. Implementing city-wide infrastructure is costly, and funding is limited. Spatial analysis can offer useful insights by visualizing existing EV charging-station infrastructure along with several other factors to determine where and how many EV charging stations are needed. Uneven EV charging-station availability complicates consumers' decisions to switch to driving EV. This analysis examines the uneven distribution of EV charging stations, the demand for more charging stations, and the EV-to-charger ratio to fill in the spatial discrepancies with charging stations in Los Angeles County.**

Keywords—Electric vehicles; charging stations; Spatial analysis; environmental awareness.

I. INTRODUCTION

For most EV drivers, switching to driving EVs has not been simple. However, the difficulties drivers face are not uniform, primarily due to affluence, population, and unequally distributed charging stations throughout Los Angeles County. To help spread EV driving, our analysis report suggests distributing more charging stations, preferably quick and vehicle-brand-neutral charging stations, in areas with spatial disparities, particularly in lower-income communities and areas where EV ownership is high in comparison to EV-charging-station availability. This would help smooth the transition for new EV drivers and reduce range anxiety. The same goal should also be applied to other communities. This is an important study because Los Angeles is among the top cities in California making the switch to EVs.

California has rapidly increased the number of zero-emission vehicles in the state, 1,300% in six years and from 25,000 in 2012 to more than 350,000 today. California continues to lead this trend as it has the highest EV penetration in the country, 40% of all EVs in the United States. To promote EV use and combat the lack of EV charger availability, California enacted Executive Order B-48-18. The order calls for "all State entities [to] work with the private sector and all appropriate levels of government to put at least 5 million zero-emission vehicles on California roads by 2030" and "all appropriate levels of government to spur the construction and installation of 200 hydrogen fueling stations and 250,000 zero-emission vehicle chargers, including 10,000 direct current fast chargers, by 2025" [1].

The Biden-Harris Electric Vehicle Charging Action Plan was created to push American leadership on using such clean cars as EVs. President Biden set an EV market share goal of 50% in the United States by 2030 and further explained the issue with the current EV charging network of over 100,000 public chargers as they operate "with different plug types, payment options, data availability, and hardware hookups." The Bipartisan Infrastructure Law "includes $5 billion in formula funding for states with a goal to build a national charging network" and "provides $2.5 billion for communities and corridors through a competitive grant program that will support innovative approaches and ensure that charger deployment meets Administration priorities such as supporting rural charging, improving local air quality and increasing EV charging access in disadvantaged communities." Moving forward, using the EV Charging Action Plan will establish a more uniform approach to EV charger accessibility while providing greater convenience for customers and offering increased confidence for the industry, which should promote the use of EVs in return [2].

In Los Angeles, the EV-to-charger ratio is currently 5.6. By 2030, this ratio is expected to grow to 37.4 as the EV industry is projected to grow immensely. Under the Biden administrations Plan for EV Infrastructure, the ratio goal is 18.7. Our research provides a means to reach this goal.

The paper is structured as follows. Section II reviews the literature on this topic. Section III presents the problem. Section IV presents the data. Section V presents the system used and the methodology. Section VI discusses the results and Section VII discusses the project's limitations. Section VIII concludes.

II. LITERATURE REVIEW

One factor we analyzed is charger locations in lower income communities. Identifying and prioritizing EV planning and extending the economic and environmental benefits to those who need them most is vital, with the focus on places with lower incomes and high environmental pollutants. Bui et al. [3] presents a figure showing the west side of Los Angeles with more cumulative EV registrations than the northeast and south. After adding our EV-ownership data, the gaps clearly represented EV ownership disparities. Peer-to-Peer Car Charging (P2C2) offers a scalable method for charging EVs that reduces the requirement for complex charging infrastructure. The idea is to work with a cloud-based control system to coordinate EVs so that they can share chargers while enroute. This would reduce the barriers and limitations consumers face in transitioning to EVs without having more local EV charging stations [4].

In contrast, our proposal is to carefully place more fast-charging stations. We start by outlining the three tiers of equipment used to recharge battery EVs. To help in the deployment of the variety of vehicles being offered, all three levels of charging infrastructure, from basic, low-cost Level 1 to DC fast chargers, should be built. “DC fast chargers will be important to drivers who need to quickly recharge their depleted batteries. Using fast chargers, most vehicles will recharge up to 80 percent of capacity in a ½ hour or less” [5]. This will help reduce range anxiety. A study in Ireland conducted a sensitivity analysis and discovered that the overall EV cost is highly sensitive to the daily availability of EV charging and the number of charging stations [6]. As an alternative to using big data, [7] used a forecasting model to calculate the demand for charging electric vehicles. The report used a decision tree for classification, a relational analysis to find influential elements, and cluster analysis to categorize traffic patterns [7]. This proposal would enable system engineers to foresee the need for EV charging based on historical traffic and weather data. Abo-Khalil et al. [8] evaluated the impact of random factors connected to vehicles’ prior driving distances and the time at which they connected to the electrical grid to adjust the capacity of charging stations. Another issue is that neighborhoods in different counties of California with a large Black or Hispanic populations have less access to public EV chargers. The results from [8] show that the distance off the highway or freeway is negatively correlated with charging-station density. Los Angeles County was not included in Chih-Wei and Fingerman’s analysis [9]. In Orange County, [10] created a machine-learning framework to investigate spatial discrepancies in EV-charging-station deployments using a predictive methodology. “The first was to pinpoint the crucial socioeconomic variables, and the second was to use these elements plus ground truth information from current charging station placements to estimate future EV charging station density using machine learning techniques at various spatial scales and compare their predictive performance to determine the best spatial resolution.” Optimally sited charging stations are required for long-distance demand in heavily traveled areas like Los Angeles and New York. He et al. [11] analyzed long-distance travel data using spatial analysis and an algorithm demonstrating that a 100-mile range is required to prevent problems. Our study will determine the quantity and placement of fast charging stations for various scenarios, better planning, and more environmentally friendly transportation.

In the past, analyses have assessed the economic benefits of newly built public charging stations. These analyses have considered charging revenues and costs, land-rental costs, and investment costs. Charging revenues and costs are calculated based on electricity price, the cost of the selected electric vehicle supply equipment, and charging demand covered by the public charging station [12]. A common question in these studies is how much charging infrastructure is needed in each area and where charging infrastructure should be built. These question is crucial because these decisions are associated with large investments and have a long-term influence on adapting electric mobility [13]. We set out to answer them in our research. Careful studies have also been undertaken to identify the communities that EV charging station implementation tends to overlook. However, the measurement of “underserved” communities shifts according to the type of research and, therefore, could have many definitions. Zhou et al. [14], for example, looked at communities that experience high transportation energy costs, and high exposure to pollutants, which lead to public health issues and limited access to clean and reliable transportation. These factors were used to categorize underserved community needs. One point is certain: Lower-income EV drivers are more likely to rely on public charging [15], in large part because private EV charging stations are limited to homeowners. However, it is critical to implement a steady plan for EV infrastructure that not only supports current EV owners’ needs, but is able to accommodate future EV owners. EV ownership requires access to both public- and home-charging infrastructure so that they can feel confident in transitioning to EV ownership without fear that their driving behavior will be curtailed due to refueling limitations [16].

As society moves towards using EVs, suppliers must work to meet consumer needs and demands. To sustain EV commuting, a well-running and coordinated electric-charger infrastructure must meet the charging demand. Aside from an influx of EV owners, we should also expect more EV owners to use public charging stations because charging a single EV can increase household electricity consumption by 50% [7]. As public-charger demand grows, these stations will become essential and must have availability to build consumer confidence in their greater adoption [17]. An additional 10–20% EV market penetration would increase the daily peak electricity demand by 17.9–35.8% [18]. Such high electricity peaks may cause outages and other issues. High EV penetration and the resulting losses in the network would consequently impose more complexity on the solution of the EV-charger application problem [19]. To solve these issues, calculated maps are needed indicating the optimal city areas where charging stations could be placed according to specific scoring levels (which, of course, depend on the weighting factors). Space limitations and the maximum acceptable distance from the electricity network must also be considered before choosing new EV charger locations [20].

Zhou et al. [6] investigated the relationships between income and affluence levels and the tendency to acquire an EV in Ireland and examined the private EV-household-charger population’s characteristics using a regression model and spatial analysis. The Ireland study used information on EV household chargers rather than EV ownership due to data limitations. “The results indicate that 1) urban areas are more likely to see higher concentrations of EV ownership, 2) an income and equity gap exists …. This finding is very important because it suggests that lower-income categories may have a financial barrier to shifting to EVs” [21].

It is very common to use ArcGIS tools to identify suitable locations to install EV charging stations. For example, [22] suggested installing DC fast-charging stations at public libraries and parks within 0.5 miles of major freeways based on the GIS data [23], and Chen suggested setting EV charging stations close to McDonald’s and

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Starbucks using geospatial datasets [24]. While the development of EV charging stations is in progress, several studies have noted that the accessibility of charging stations is one of the barriers to the adoption of EVs, especially for people with low incomes and those who live in multifamily housing [25]. The distribution of EV charging stations was uneven [26]. In some cities, the location of EV charging stations was not determined by population density, but by people's income [27], and it has caused the issue of inequitable access to EV charging stations. When the government is involved in developing EV charging stations, it becomes essential to "distribute the benefits of facilities to all stakeholders" [28].

Our underlying theory is that EV charging stations are unevenly distributed throughout the city of Los Angeles. It is commonly seen throughout past research that affluent areas tend to be better equipped with EV infrastructure. Although previous analysis assessed EV-charging-station placement, we took a distinct approach because our research analyzes several factors, including current EV stations, area median income, EVs per Zip Code, and population. Previous research only analyzes one or two of these factors. We decided to combine these factors in addition to calculating a current need based on the EV-to-charger ratio, allowing us a better understanding of where and how many EV chargers need to be placed moving forward.

Our fundamental approach is to analyze the correlation between EV-charger distribution, area income, and EV ownership in each area. This will help determine where and how many EV charging stations are needed to meet the current administration's goal.

III. Problem Definition

California has the most EVs in the country, 40% of all EVs in the United States. The problem is our current EV infrastructure is unevenly distributed and will fail to meet the needs and demands of future EV drivers. Since the recent legislature, [1] and [2] have been enacted, we expect an influx of EV drivers, and therefore, more EV chargers must be readily available to meet the public's demand.

Currently, Los Angeles County still has areas with minimal to no EV-charging availability, although the area has EV owners. To promote EV use and combat limited EV-charger availability, we must determine what areas need EV chargers based on income, population, and demand. The goal is to identify areas where the population owns EVs and has insufficient or no EV chargers. With our analysis, we set out to learn how many and where additional EV charging stations are needed based on the ratio of EV ownership to EV charging station. We investigate how and if EV charger placement is disproportionately affected by income, population, or current EV ownership. Finally, we calculate an EV-to-charger ratio for each Los Angeles Zip Code to identify specific needs, aiming for a goal of 18.7 EVs per charging station.

IV. Data Selection and Acquisition

For our analysis, we used data from the National Renewable Energy Laboratory's developer network to identify alternative fuel stations in the city of Los Angeles. We also used data from the California Department of Motor Vehicles that identifies vehicle ownership by Zip Code and fuel type [29]. Two datasets: *City Boundaries* and *Zip Codes*, came from Los Angeles GeoHub [30] [31]. Lastly, we used area median-income shapefile data from Los Angeles Mayor Eric Garcetti's GeoHub site and total estimates from the Los Angeles Almanac.

Alternative fuel-station data, vehicle ownership data, and Los Angeles Almanac data were downloaded as csv files. *City Boundaries* and *Zip Codes* were imported to ArcGIS as shapefiles. A shapefile was initially used for area median income. A second source of median-income data was located and manually converted to a csv file.

To begin our analysis, we had to solve problems with our data sets. First, our vehicle-ownership file did not contain unique identifiers, so we added these manually before importing the data into ArcGIS. Second, the same data set only contained a Zip Code as a location identifier rather than latitude and longitude; therefore, to map the vehicle ownership detail within each Zip Code on the map, we ran the ArcGIS geocode function to assign coordinates to each Zip Code. In order to perform our OLS analysis, we needed a summary of EV data, a summary of EV-charger data, and area median-income data in one file. Since our initial area median-income data was only a shapefile, we located another source of detailed income data by Zip Code and manually created a csv table containing all three elements.

V. System and Methodology

We chose ArcGIS Pro, version 3.0, to perform our analysis because it provides intuitive tools that would aid in visualizing and manipulating our data to reveal patterns or correlations with EV-charger placement and other factors.

To evaluate the current distribution of EV charging stations in Los Angeles County, we created a map with three layers: EV charging stations, city boundaries, and Zip Codes. Density analysis shows the concentration or clustering of points or lines on a map. To get a whole picture of the distribution of EV charging stations in Los Angeles County, we used Kernel Density. This tool "calculates a magnitude-per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline" [23]. We performed kernel density analysis on the data of EV charging stations in Los Angeles County and evaluated how these charging stations were distributed in the whole county area.

In addition to kernel density analysis, mean center, median center, and directional distribution (standard deviational ellipse) are common useful spatial statistics methods to measure geographic distributions. "Standard deviational ellipse has long served as a versatile GIS tool for delineating the geographic distribution of concerned features" [32]. Kemtec and Knez used standard deviational ellipse with other spatial statistics tools, such as mean and median center, to evaluate the location of EV charging stations in Slovenia [26]. We used mean center to identify the geographic center of EV charging stations in Los Angeles County. Median center helped us locate "the point that minimizes Euclidean distance" to all EV charging

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stations in Los Angeles County [33]. Directional distribution (standard deviational ellipse) helped us find the central tendency, dispersion, and directional trends of EV charging stations in Los Angeles County.

Summarize Within, a statistics tool in ArcGIS, very effectively allows users to "overlay a polygon layer with another layer to summarize [and] calculate attribute field statistics about the features within the polygons" [23]. We used this tool to investigate the locations of EV charging stations in each city and each area by Zip Code. For insight into the number of EV charging stations in each city, we set the city boundaries as Input Polygons and set EV charging stations as Input Summary Features, and then calculated the total EV charging stations in each city. Similarly, we calculated the total EV charging stations in each area based on Zip Codes.

We then calculated EV-to-charger ratios within each Zip Code using Summarize Within within Zip Code boundary polygons. We partially joined the summarized tables containing the EV-ownership detail and EV-charger detail and added a field that divided the sum of EV ownership by the sum of EV charging stations. For the purpose of identifying critical null values in Zip Codes where EV ownership is high and there are no EV charging stations, we manually assigned a −1 value to distinguish these areas in our visualization. We added another field to calculate the number of EV stations needed to bring the currently calculated ratio up or down to 18.7. With this newly created table, we performed a Hot Spot analysis to identify concentrations of high and low EV charger placement. Additionally, we used Optimized Outlier Analysis to identify areas of high and low EV charger placement, as well as to identify areas of high and low EV charger concentration. Finally, we created a manual table containing summarized data per Zip Code for EV ownership, EV-charger placement, and area median income. With this, we use OLS to find correlations between EV-charger placement and area median income or EV ownership.

VI. Results/Discussion

Figure 1 presents a map of Los Angeles County that displays EV charging stations and population density. The map was created to show disparities between areas with high and low population access to EV chargers.

Figure 2 presents a close-up group showing high-population to high-EV-charger density in Los Angeles County based on Figure 1. Areas with "high population density" are areas with a population of 22,000 or more and are shown as orange to yellow shades on the map.

Figure 3 is a close-up group that displays low-population to low-EV-charger density in Los Angeles County based on Figure 1. Areas with "low population density" are areas with a population of 22,000 or less and are shown as purple to black shades on the map.

These two figures show disparities between areas with high population access to EV chargers and low population access to EV chargers. The average distance from EV charger to EV charger in an area with high population density is 0.341 miles. The same average distance in areas with low population density is 0.913 miles. This shows an accessibility disparity, proving that areas with higher populations have more access to EV chargers. This is an issue because high population density does not necessarily point to EV-charger use.

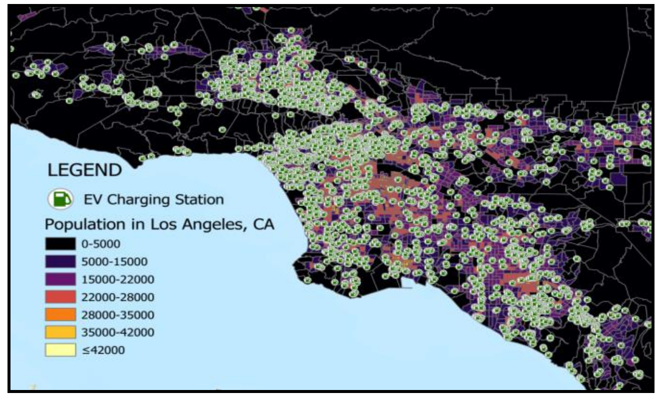

Figure 1. Los Angeles County EV-to-charger ratios and populations.

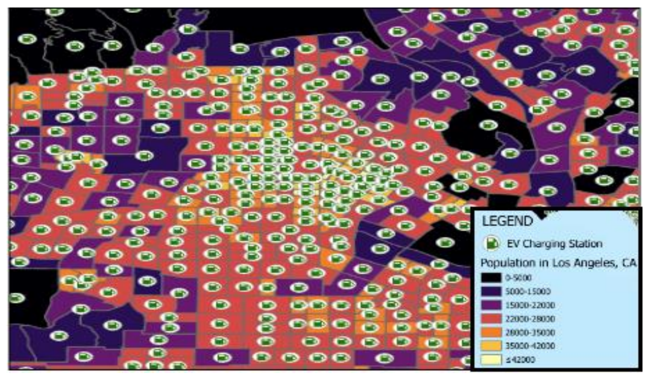

Figure 2. High-population to high-EV-charger density in Los Angeles.

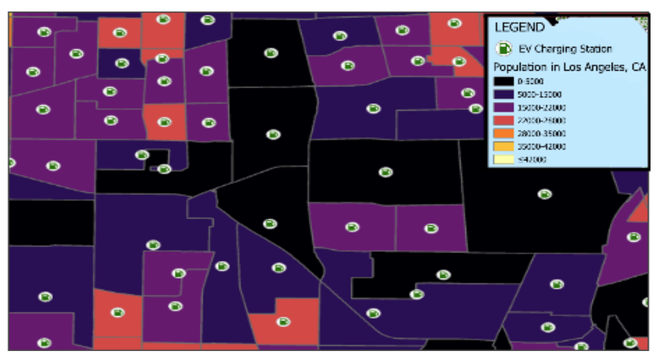

Figure 3. Low-population to low-EV-charger density in Los Angeles.

The kernel density of EV charging stations in Los Angeles County (Figure 4) shows the highest densities of EV charging stations are in Downtown Los Angeles; others are in Pasadena, Hollywood, Beverly Hills, Santa Monica, Los Angeles International Airport, and Long Beach. The western regions of Los Angeles County have more charging stations than the eastern regions.

Figure 5 shows that the mean and median centers of EV charging stations are located near Downtown Los Angeles, and the standard deviational ellipse shows the first standard deviation area: Around 68% of EV charging stations are in this ellipse.

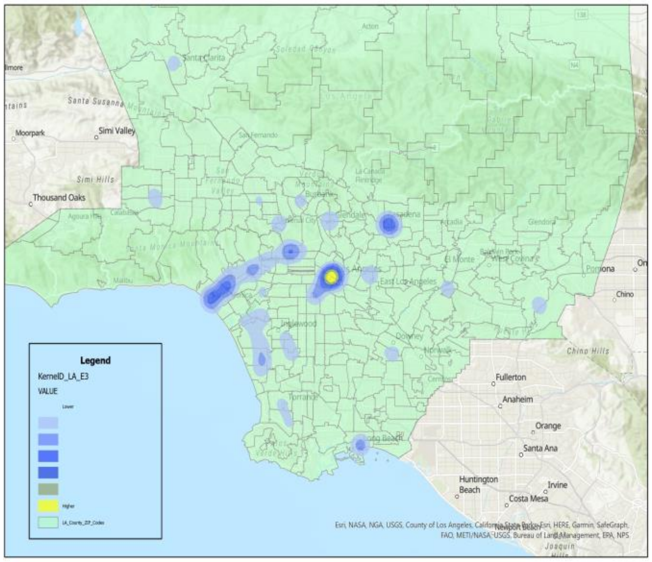

Figure 4. Kernel density of EV charging stations in Los Angeles County.

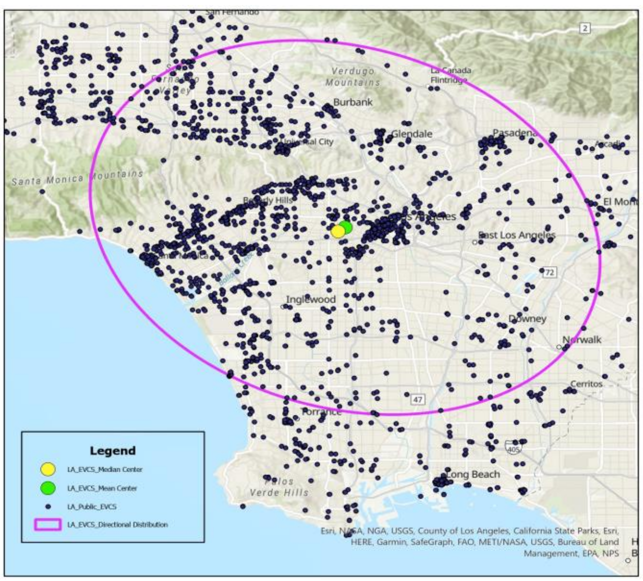

Figure 5. Mean center, median center, and directional distribution of EV charging stations in Los Angeles County.

As the distribution of EV charging stations in each city shows (Figure 6), most EV charging stations are in the city of Los Angeles, the red area. The bar chart (Figure 7) shows a total of 3,028 chargers there, which accounts for 34% of the county's total EV charging stations.

The distribution of EV charging stations in the area by Zip Code (Figure 8) shows how they are located in each Zip Code. The area in red (light yellow) indicates more (fewer) charging stations. Table I lists the top 10 areas by the number of charging stations, and it clearly shows that most of these areas are from the top four cities in which most EV charging stations are located, Los Angeles, Santa Monica, Long Beach, and Pasadena.

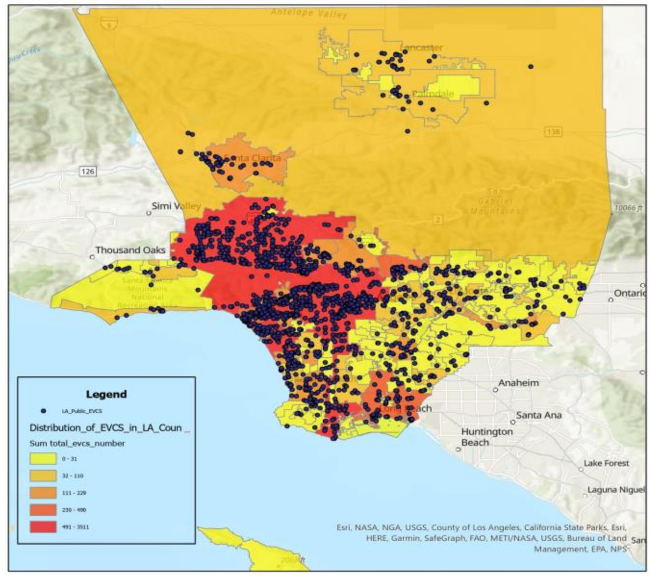

Figure 6. Distribution of EV charging stations in each city.

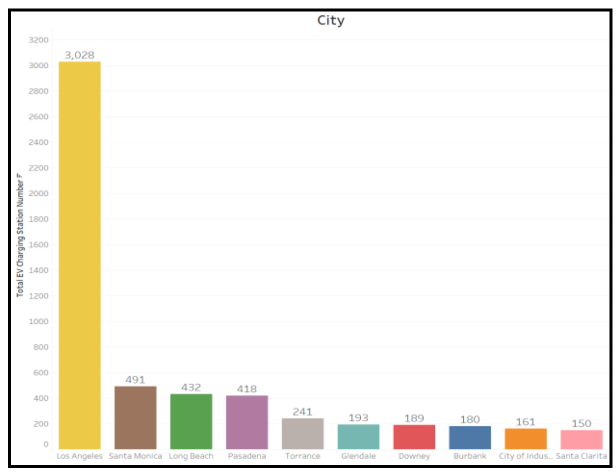

Figure 7. Top 10 cities by the number of total EV charging stations.

TABLE I. TOP 10 ZIP CODE AREAS BY THE NUMBER OF EV CHARGERS

	Zip Code	City	Number of EV Charging Stations
1	90012	Los Angeles	351
2	90045	Los Angeles	200
3	90802	Long Beach	193
4	90404	Santa Monica	191
5	91355	Santa Clarita	185
6	90028	Los Angeles	175
7	90007	Los Angeles	162
8	90401	Santa Monica	143
9	90245	El Segundo	143
10	91125	Pasadena	139

Our analysis found an uneven distribution of EV charging stations in Los Angeles County. Most charging stations are located in the western region of the county, concentrated in Downtown Los Angeles. This finding

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suggests that the accessibility of EV charging stations varies by area. People living around Downtown Los Angeles have more convenient access to charging stations.

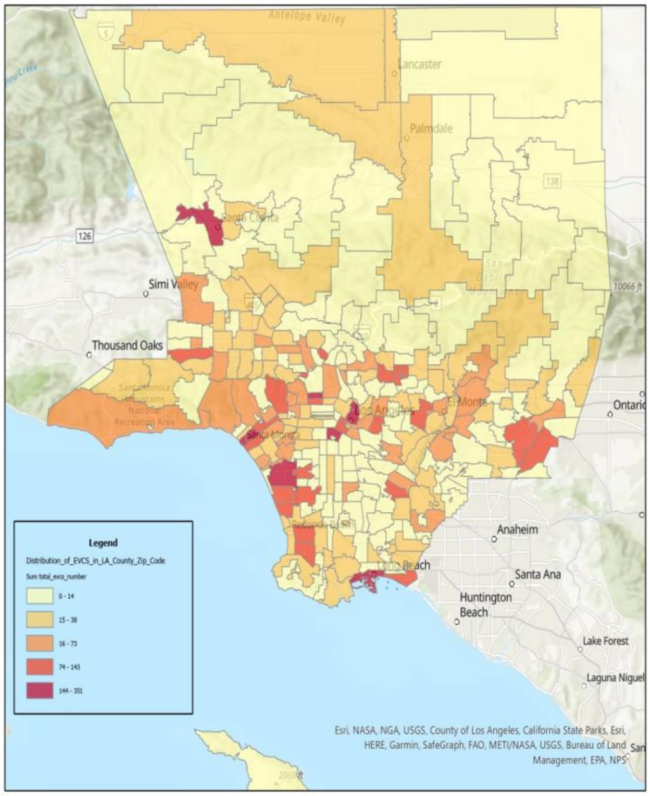

Figure 8. Distribution of EV Charging Stations in the Area by Zip Code.

OLS of the manually created table contains the sum of EV charging stations as a dependent variable and the sum of EV ownership and area median income as explanatory variables. Results R^2 multiple of 8% explained no correlation among these variables in Los Angeles County (Figure 9).

To complete the following analysis, we calculated the EV-to-charger ratio by dividing the sum of EV ownership within each Zip Code by the sum of EV charging stations to determine a ratio within each Zip Code (Table II). By doing so, we will identify specific Zip Codes where the ratio is null, indicating EVs but no charging stations, or Zip Codes where the EV-to-charger ratio is high and in need of additional stations to bring the ratio down to the current administrations' goal of 18.7.

TABLE II. SAMPLE DATA OF LOS ANGELES COUNTY EV OWNERSHIP TO EV CHARGING STATION RATIO CALCULATIONS

Zip Code	Sum of Electric Vehicles	Sum of EV charging stations	EV to charging station Ratio
90059	36	5	7.2
91301	180	5	36.0
91775	*335*	*0*	*−1**
91801	345	9	38.3
90007	68	65	1.0

*Indicates placeholder number not actual calculation

A hot/cold spot analysis of EV charger locations that only includes areas where the ratio is greater than 18.7 as proposed by the current administration (Figure 10) shows a higher concentration of EV chargers in northwest Zip Codes from Los Angeles city center and low concentrations in Zip Code South East of the Los Angeles city center.

Figure 9. OLS analysis of Los Angeles EV charging station placement using AMI and vehicle ownership as explanatory variables.

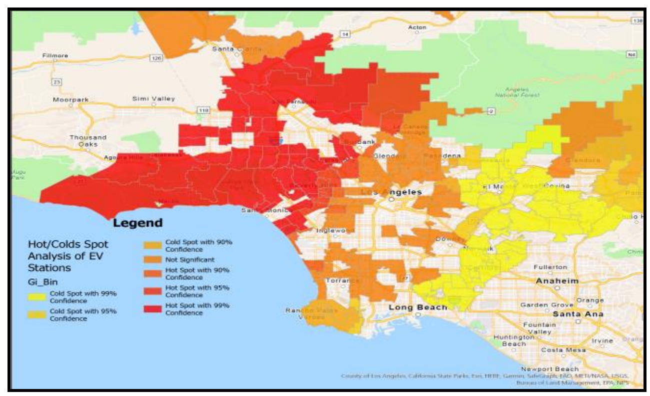

Figure 10. Hot/cold spot analysis of EV chargers within areas of Los Angeles with calculated EV-to-charger ratio greater than 18.7.

An optimized-outlier analysis of EV charger locations that only includes areas where the EV-to-charger ratio is greater than 18.7 as proposed by the current presidential administration (Figure 11) highlights areas of urgent need for EV charging stations in light blue and red. Light blue highlights output features with clusters of low sums of EV chargers, and red highlights output features with high outliers within a cluster of low sums of EV-charger values.

A visualization of the EV-to-charger ratio in all areas broken out by Zip Code (Figure 12) indicates that the majority of Los Angeles Zip Codes falls significantly far above the proposed ratio of 18.7. This means there are more than 18.7 EVs per charger in these Zip Code, which could lead to availability issues.

Upon identifying areas in need of more EV chargers, we identified how many EV charges are needed within each Zip Code in areas where the EV-to-charger ratio is greater than 18.7 (Figure 13).

Figure 14 presents an identified area in need of more EV chargers to display the specific locations of existing EV chargers. Our calculation shows that these sample areas in

Los Angeles require between 19 to 24 new EV chargers to bring the current EV-to-charger ratio down to 18.7 and ensure availability.

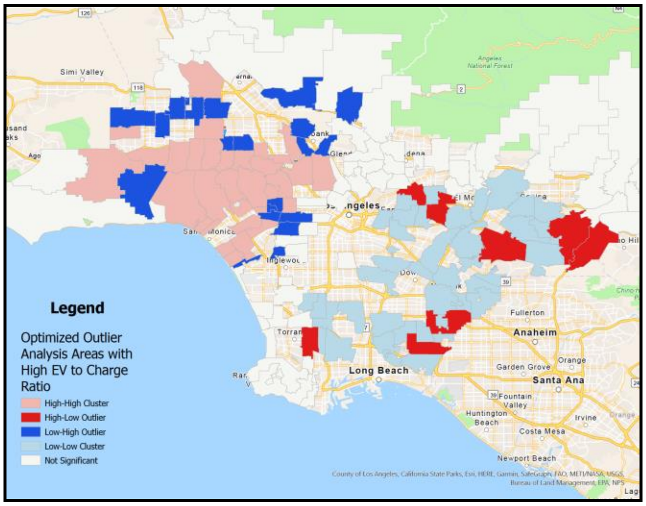

Figure 11. Optimized outlier analysis of EV chargers in areas of Los Angeles with calculated EV-to-charger ratios greater than 18.7.

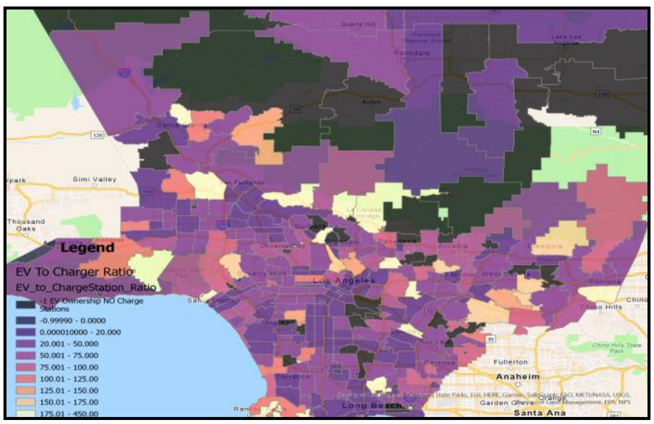

Figure 12. Los Angeles County EV-to-charger ratio all areas.

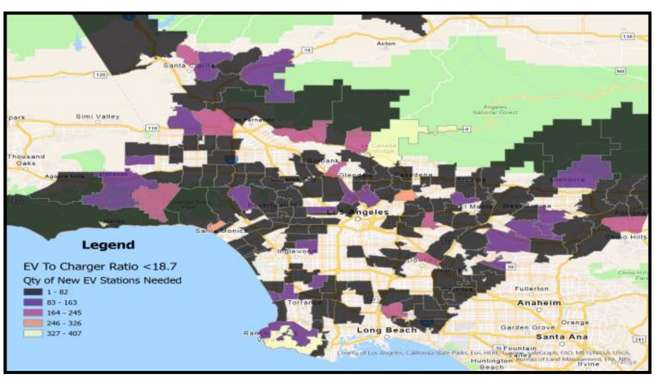

Figure 13. Quantity of new EV charging stations needed within areas of calculated ratio greater than 18.7 in Los Angeles County.

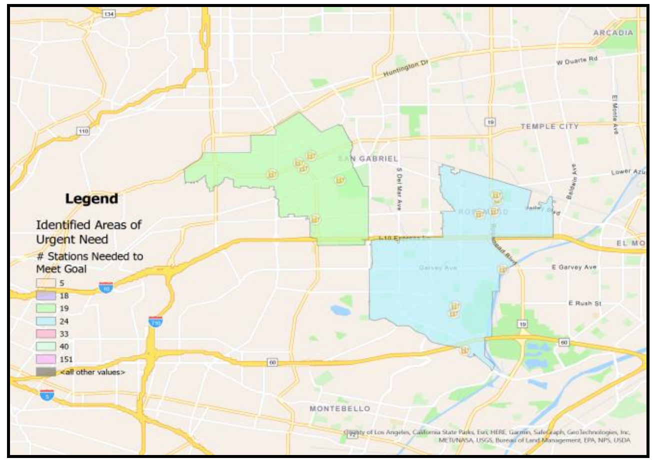

Figure 14. Sample area in Los Angeles County with identified quantity of new EV charging stations needed to meet goal ratio of 18.7.

VII. PROJECT LIMITATIONS

With access to more detailed spatial data, our analysis could be more in depth. For example, access to privately owned EV charger providers, such as Tesla, EVgo, and ChargePoint, would allow us to analyze their trend, peak time, charge frequency, and public reviews to correlate public preferences and determine the need for higher quality and more reliable charger placements. Using a dataset within ArcGIS pro that does not contain latitude and longitude limits the analysis. Since vehicle ownership data is personal and private, our dataset was limited to quantities per Zip Code and therefore the rest of our analysis was modeled around Zip Code analysis. Exact location data would have provided exact walking distances and charger accessibility.

VIII. CONCLUSION

Our analysis was able to determine by visual observation that areas in Los Angeles with high populations tend to have more EV chargers. Kernel-density, spatial, hot-spot, and outlier analysis confirmed that the distribution of EV chargers in Los Angeles County is uneven: Areas north and west of Los Angeles city center have higher concentrations of EV chargers, while areas east and south of the city center have significantly lower concentrations. Most EV chargers are located in the city of Los Angeles, especially in Downtown Los Angeles. Such an uneven distribution of EV chargers would cause inequitable access issues for people living and working in other areas.

Upon categorizing each Zip Code by EV-to-charger ratio, we specifically identified areas where additional EV chargers are needed and, more importantly, determined how many EV chargers would be required within each Zip Code. For Los Angeles to become fully electric by 2035, investment in EV infrastructure will require the implementation of many new EV chargers to support current and future EV drivers. Ensuring that the EV-to-charger ratio is lowered and remains low will ensure that drivers are able to access EV chargers when they need them.

Some possible extensions of this work are modeling EV penetration in different population areas and examining the distribution of vehicle-brand-neutral charging stations. Also, studies could examine the effects of encouraging low-income drivers to use EVs: Upfront costs for the drivers, the ecological impact of recycling batteries and mining the resources to make more batteries. Finally, more private data should be available at all granularities to improve on studies like this.

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