Electric Vehicles & Charging Stations:
Los Angeles County's Roads Readiness for California's Transportation Electrification

by

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A Thesis Presented to the
FACULTY OF THE USC DORNSIFE COLLEGE OF LETTERS, ARTS, AND SCIENCES
University of Southern California
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

August 2022

To my future grandchildren

Acknowledgements

I would like to thank my advisor and committee chair, Professor Jennifer M. Bernstein; my other committee members, Professors Jennifer N. Swift and An-Min Wu; and Professors Darren M. Ruddell and Vanessa Griffith Osborne for guiding and supporting me in this process. Thank you to the US Federal and State governments for providing the data to make this research possible. Finally, thank you to the California government and all its members for their commitment to improving the State's traffic network and leading the way in electric vehicle adoption.

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List of Abbreviations

AADT	annual average daily traffic
ACS	American Community Survey
AFDC	Alternative Fuels Data Center
CARTA	Chattanooga Area Regional Transportation Authority
D	Decision
DEM	digital elevation model
DOE	US Department of Energy
EO	Executive Order
EPA	United States Environmental Protection Agency
EU	European Union
EV	electric vehicle
EVCO	electric vehicle charging outlet
E-VRP	Electric Vehicle Routing Problem
GHG	greenhouse gas
GIS	geographic information software
GO-Biz	California Governor's Office of Business and Economic Development
GPS	global positioning system
HEV	hybrid electric vehicle
HHS	US Department of Health and Human Services
LA	Los Angeles
LADOT	City of Los Angeles Department of Transportation
NASA	The National Aeronautics and Space Administration

PHF	peak hour factor
PSO	particle swarm optimization
SSI	Spatial Sciences Institute
TEN-T	Trans-European Transport Network
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
US	United States of America
USC	University of Southern California
ZEV	zero-emission vehicle

Abstract

With the rising threat of climate change, the State of California committed itself to have all vehicles sold within its borders to have zero emissions by 2035. The State dubbed this strategic plan "Transportation Electrification," which includes Senate Bill No. 100 California Renewables Portfolio Standard Program and Executive Order (EO.) B-48-18. California is in need to implement proper infrastructure to accommodate the influx of electric vehicles (EVs) on its roads to accomplish this goal. This project uses geospatial analysis approaches to determine the readiness of the Los Angeles County region in support of a 100% EV-owning driving population. Criteria for identifying a location's readiness were based on the California Governor's Office of Business and Economic Development's (GO-Biz's) and the US Department of Health and Human Services' (HHS's) public programs, and related studies. This project used the following criteria when evaluating locations' support of EV drivers: (1) population distribution, (2) traffic, (3) proximity to other charging stations, and (4) governing body. By conducting a geospatial analysis (i.e., "summarize within" and "hotspot analysis"), the result indicated that most Los Angeles County areas, especially cities/communities in the Santa Clarita and Antelope Valleys, lack sufficient charging stations to support the State's vehicle electrification goals. Particularly underserved populations are the County's unincorporated areas (e.g., Malibu Bowl, Monte Nido) and areas with a high population density (i.e. the Cities of Maywood, Huntington Park, and Cudahy). Ultimately, this project identified locations' readiness for an EV driving population, which will lead to proper EV infrastructure development that reach the State's carbon emission goal and granting easier EV-charging access to Los Angeles County residents and visitors.

Chapter 1 Introduction

When looking out the window at the traffic passing by, one may overlook the amount of time, planning, and evolution a road and its users have gone through. Traffic systems have evolved for thousands of years in an effort to accommodate changing landscapes and different modes of transportation. Over the 21st century, humans have acquired a vast array of technologies, including quantum computers, renewable energy sources, and rapid communication. All these technologies allow humans to work together to face the pressing issues of their times, including the widely discussed threat of climate change. To address this threat, the State of California committed itself and its residents to adopt the usage of electric vehicles (EVs) by 2030 (The 100 Percent Clean Energy Act of 2018; De León 2018). This moment in human history is transformational, as the shift in technology and infrastructure is not simply dependent on efficiency; instead, humankind must act to combat increased environmental precarity caused by climate change.

Like many governments worldwide, California adopted several *100% zero-emission* actions to address climate change. In 2018, the Californian Governor signed Senate Bill No. 100 California Renewables Portfolio Standard Program: emissions of greenhouse gases (The 100 Percent Clean Energy Act of 2018; De León 2018). This law includes displacing the State's fossil fuel consumption, reducing air pollution, promoting electric service retail rate, and improving the State's electric grid. This act was further built upon by Executive Order (EO.) B-48-18 (Brown 2018). This group of policies and orders became collectively known as "Transportation Electrification" (California 2021b).

To achieve its goal of an all zero-emission vehicle (ZEV) roadway, the State employed many strategies, which include the following (California 2021b):

- Decision (D.)19-08-026—authorizes the spending of over $107 million on medium- and heavy-vehicle charging infrastructure installation.
- D.19-09-006—places priority on low-income residential areas.
- D.19-10-055—implements a new subscription-based EV rate design for commercial and industrial customers (according to the decision, this strategy will encourage customers to charge their vehicles during an off-peak time).

Though climate-related laws and incentives in California increase annually, some relevant highlights include the following (Newsom 2020):

- All new passenger cars/trucks and drayage trucks must be ZEVs by 2035.
- Medium- and heavy-duty vehicles must be ZEVs by 2040 (when possible).
- All ZEV markets must provide bold accessibility to all Californians.

As of 2021, California has an estimated 22,000 charging stations for the 655,000 EVs registered in the state. Los Angeles County houses 3,209 of California's charging stations (398 of which are free). While California and Los Angeles County are certainly making headway in the EV accommodation front, there is nowhere near the total number of charging stations needed to accommodate a traffic grid composed entirely of EVs. According to Environment California (Brandt 2020), the State will need about one charging station for every five EVs on the road; therefore, California will need to build about 1.2 million more charging stations, and Los Angeles County (specifically) will need about 324,000 more charging stations (Brandt 2020; California Energy Commission 2021a).

Aside from the amount of EV Charging stations needed, they also need to be distributed appropriately with respect to an area's population. The US Department of Energy (DOE 2021) measures its EV charging stations based on the distance an average EV can drive on a single charge, namely 250 miles. Thus, according to the State, 250 mi. is an appropriate distance for the placement of EV charging stations. But there is an obvious problem with this projection. While 250 mi. may be a reasonable distance for a long-distance driver, 250 mi. is not appropriate for residents. If each EV charging station were 250 mi. from another, a resident would potentially have to travel 125 mi to charge her vehicle. This issue is not incidental; it has been well-documented that the distance between charging stations can act as a discouragement when drivers consider whether or not to adopt EVs (Melaina, Bremson, and Solo 2013; Kang, Feinberg, Papalambros 2015). In an attempt to address this, the company EVgo Inc. locates charging stations in "places where customers want to be and where there are sufficient amenities" (e.g., malls, grocery stores, theaters; Chiland 2021). However, even these placements near amenities will not be sufficient in assuring drivers that they will be able to charge their vehicles while they go about their day.

California, and Los Angeles County in particular, are aware of their gaps in EV accommodation. This awareness is why in October 2020 the State and County governments announced their partnership with the City of Los Angeles to implement the LADOT (City of Los Angeles Department of Transportation) Transit Bus Rollout Plan. While not aimed at personal vehicles, this plan aims to charge a fleet of electric busses at one of the largest solar-powered EV charging stations in the United States (Wood 2021; LADOT Transit 2020). Another example is Culver City-based Envoy Technologies Inc., which worked with Culver City's property owners to build charging stations at residential complexes and commercial buildings. The Los Angeles Department of Water and Power offers a rebate of $4,000 for multi-family property owners with a charger on-site, with an additional $750 for every additional charging port (Chiland 2021). On April 20, 2021, the Los Angeles County Board of Supervisors committed to tripling the number of EV charging stations (60,000 additional stations) in the county by 2025. The Board cited county facilities, rights-of-way, parks, and libraries as possible sites for EV charging stations (City News Service 2021). Overall, there is no “silver bullet” for vehicle electrification but rather a suite of initiatives that will work in tandem to achieve statewide goals.

Based on the regulations California has committed to entail extensive planning and coordination, this project aimed to address how California’s Los Angeles County will accommodate a massive increase in the number of ZEVs, with a specific focus on location and access to EV charging stations. The California policies outlined above are official regulations, but they mainly advocate for EV usage.

1.1. What the General Driver Needs

As any driver knows, vehicles require fuel, and most current fueling stations in California do not accommodate EVs. Thus, Californians need to rectify the lack of EV charging stations. Vehicles can be charged within the owner’s home, which benefits the State government and drivers alike. However, drivers also need access to charging stations outside their homes, such as in the case of long-distance travel or extensive travel within a particular area. For this reason, this analysis is tailored to address the needs of this population, namely those who for whatever reason, must charge their vehicles at locations other than their personal residence.

Within this study, the specific needs are defined as the charging stations’ proximity to the residents’ respective households and the charging stations’ proximity to roadways. The driver requires a charging station a reasonable distance from her place of residence, instead of driving several miles to charge her vehicle (i.e., her primary mode of personal transportation). Moreover, the driver will need to have charging stations in locations close to roadways in the event of traveling long distances especially in areas without significant major developed urban areas (to avoid the driver becoming stranded).

1.2. Different Types of Vehicles

Another factor often overlooked by researchers (further detailed in Chapter 2) is that vehicles require different amounts of energy. Though most vehicles on the road are of the personal-passenger variety, there are also larger vehicles (e.g., trucks, trailers, buses). The State of California has committed to transitioning larger vehicles into EVs; thus, they too will need accommodation. Generally, larger EVs do not have the same charging plugin as the standard personal-passenger EV. Moreover, hypothetically, if the larger EVs did share the same plugin as their smaller counterparts, they would require far longer charging wait times (due to having a larger battery and requiring more energy; McGrath 2021).

At the opposite end of the spectrum, smaller vehicles (e.g., electric bikes, motorcycles) need varying degrees of accommodations (i.e., different charging ports, smaller battery charge). If the government offer incentives to drive smaller vehicles, the zero emissions goal is more likely to be met. However, isolating the needs of smaller vehicles versus larger vehicles is beyond the scope of this project.

1.3. Equity

Not all drivers have access to the charging stations at home. For example, people living in multi-family housing will likely have more cars than their housing unit will fit; therefore, they will rely more heavily on public EV charging stations. Another varying factor of drivers is the natural environments they live in. In the Los Angeles County area the more inland region has a shrubland-desert, which can be particularly hot on the summer days and cold on the winter nights. Without public charging stations in areas with a low level of human infrastructure, drivers traveling between urban areas can become endangered if they are stranded in hazardous weather; thus, different types of charging needs. California residents without a home charging location rely on public and private charging stations outside the home (Gardiner 2021; Sullivan and Taylor 2021). Thus, an increase in public access to charging stations is critical in addressing the needs of different populations as they adopt EVs.

1.4. Motivation

As the Californian government aims to champion the adoption of EVs among its residents and visiting drivers, charging stations need further dispersant in California to accommodate the vision the Californian government is arguing for. Therefore, funding for charging station development is needed, which will likely need government sponsorship due to the measure originating from a government source (i.e., the State Government). However, the governments needed to implement the EV charging stations' development and management will likely be California's government subsidiaries (e.g., county, city) given the project's scope and ambitious nature.

1.4.1. Innovation & Efficiency

The first motivation for this study was the power of innovation and efficiency. When an individual adopts an EV, she utilizes technologically advanced energy storage capabilities. This type of technology opens a new transportation market and encourages competition within a newly forming industry and demand (i.e., green technology). Moreover, the ability to charge one's personal vehicle in a home or parking garage will provide the customer greater convenience in automobile maintenance. By adopting EV technology in the California, the Golden State can act as a leader for technological innovation within the United States.

1.4.2. Opportunity for Restructuring

The second motivation behind this project is the opportunity for the placement of EV charging stations to enable the State to restructure its roadways in the name of furthering equity. Because the State will require its buses and taxi services to adopt a zero-emissions policy, it forces public agencies to rethink how they operate their public vehicle services and place bus stops in more accessible location to underserved populations. This restructuring is fundamental to the issue of equity—with more accessible modes of transportation, disenfranchised populations will have increased opportunities.

Further, restructuring the EV market will grant easier access. Many individuals wish to own an EV but lack the funds to do so or do not live in an area that supports EV operation. According to Hsu and Fingerman (2021), Black-Hispanic majority census blocks are likely to have low levels of EV charging stations compared the their respective surrounding areas. This market change can potentially lead to innovations within the home and power grid (i.e., where and how the energy is generated) such as though home-generated electricity (e.g., solar panels, wind turbines, and solar water heaters).

1.4.3. Climate Change

The final motivation may be the most obvious—the most critical issue facing Earth today is climate change. With the rise of temperatures, there is more significant seasonal variation, change in precipitation patterns (i.e., more significant flooding in some areas and higher droughts in others), and increasingly frequent environmental disasters (e.g., hurricanes, Derechos, wildfires, ice storms, heat waves; Hardy 2003). Humanity must act swiftly and effectively to curb climate change. This is not a process that one person or entity can perform alone.

Humanity is not doing all it can to ameliorate climate change (Esty and Moffa 2012). Protecting flora and fauna are noble causes, but from an anthropocentric perspective, humanity is also making its environment inhospitable for itself.

Carbon emissions from burning fossil fuels, which is how traditional vehicles are fueled, are a large contributor to climate change. According to the United States Environmental Protection Agency (EPA; 2020), highways vehicles are responsible for about 1.6 billion tons of greenhouse gasses (GHGs) each year, which would be about 6–9 tons of GHGs for each vehicle. Moreover, the number of collective GHGs released by vehicles increases each year. Therefore, the public should be aware of how they are (collectively) directly responsible for a factor of climate change. More importantly, residents should be provided with the necessary infrastructure to make pro-environmental decisions. Through such initiatives as the 100% EV mandate, it will spur action on climate change beyond what is capable on the individual level.

1.5. Area of Study

The study area of this project is Los Angeles County, California (see Figure 1). However, though San Clemente Island and Santa Catalina Island are officially a part of Los Angeles County, the islands will not be a part of this study due to personal commercial automobiles not being a major part of the islands' roadways and the islands' lack of terrestrial roadways connecting to the Los Angeles County mainland. For the duration of this analysis, the Los Angeles County mainland will simply be referred to as "Los Angeles County."

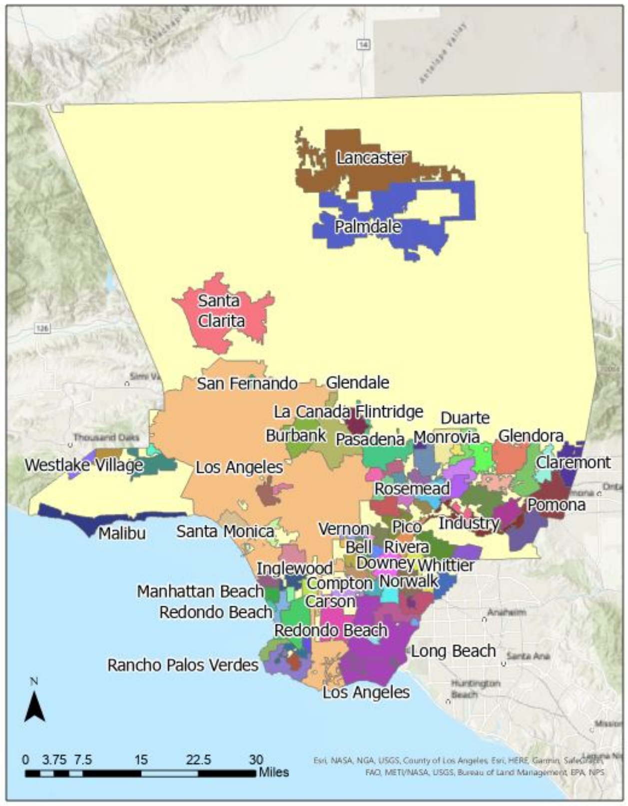

Figure 1: Mainland Los Angeles County, California

The geography of Los Angeles County is unique. The county covers 4,058 mi^2 (10,510 km^2), which includes multiple ecological environments: ocean and coast, inland valley, lower mountain, and higher mountain. The county's biome is Mediterranean (Pitt 2021).

Another noteworthy fact of Los Angeles County is in its population characteristics: the county is one of the most racially and ethnically diverse counties in the United States. According to Los Angeles County's (2021) 2020 Census, the County is about 48% Hispanic/Latino, 25.6% White, 15% Asian, 7.9% Black/African, and 1.6% Native. The average household income is about $30,654, which is below the national average ($67,521) and a living wage in Los Angeles County ($40,248) (Los Angeles County 2021).

As of 2021, Los Angeles County consists of 88 cities, with the County Seat of Government in its largest city, the City of Los Angeles. The US Census (2018) estimates Los Angeles County's population to be about 10,014,009, which would place its density at about 2,100 individuals per mi^2 (810 km^2). Not only does Los Angeles County (2021) house the states largest population, it is also the largest county by population in the United States, harboring a population larger than 40 individual US states.

Los Angeles County's incorporated history began long before California's statehood. The county gained official recognition by the US Federal Government during California's acquisition of statehood in 1950 (Pitt 2021). The City of Los Angeles is the County's oldest city. Having been established in 1771 under Spanish rule, it has since grown into the metropolitan city it is today with a population of 3,898,747 (as of 2020; US Census Bureau 2021b).

Los Angeles County's infrastructure has one of the most extensive and complex traffic ways in the country, with 515 mi (828.81 km) of freeways/expressways alone. In the 1920s, the City of Los Angeles and neighboring cities developed the Los Angeles Railway which was the most extensive trolley system in the world at the time. In 1944, the railway's owner, Henry E. Huntington, sold the Los Angeles Railway to the National City Lines (which held Firestone Tire, Standard Oil of California, and General Motors as investors). The National City Lines proceeded to rip out the LA railways to monopolize surface transportation (i.e., personal vehicle use). The lack of a suitable form of public transportation forced Southern Californian cities to build extensive roadways, which slowly became wider to accommodate its ever-growing population (O'Toole 2013). Los Angeles County's problematic history developing public transportation and eco-friendly transportation makes California's adoption of ZEVs all the more important for its residents.

1.6. Research Objectives

Based on the commitment of the California Government (i.e., the California State Legislature, California Office of Governor), the State of California will need to prepare its vehicle infrastructure to support an EV adoption, to have every driver in the State drive an EV. Therefore, an EV charging station will need to be in place for the drivers' charging of their EVs. The goal of this project is to take the California Government's commitment to determine if the current EV charging stations in place supports a population that all drive EVs. By using geographic information systems (GIS), this project will analyze the State's readiness for transportation electrification in Los Angeles County.

Specifically, the primary objective of this project is to identify areas within Los Angeles County that do not have a sufficient number of EV charging stations using the number of EV charging stations, the number of households and the placement of roadways. With the State Government's fast approaching self-given date of 2035, in which the government commits to having an all EV populated traffic network; areas will need to be identified across California in need of more public charging stations to accommodate such a dramatic shift in transportation technology.

This project will investigate how many EV charging stations are in the study area in comparison to the area's population and how far behind each area is in providing for the pubic with EV chargers. To accomplish this task, this project will involve the analysis of the population and the number of households on a census-block level and calculating the number of EV charging stations in a 1-mile radius within each census block. Furthermore, the roadways' placement will also be accounted for, in which how many EV charging stations are within a 1-mile radius of road segment for the drivers of the areas.

1.7. Criteria for Evaluating EV Charging Sites

To evaluate the current locations of EV charging stations and areas in need of more EV charging stations in the Los Angeles County regions, criteria were selected based on previous studies. The California Governor's Office of Business and Economic Development (GO-Biz 2019) established criteria when building EV Charging stations: location, available space, permitting, electric capacity and its service's location, and property ownership. GO-Biz set their criteria based on the input of federal, state, and local agencies/industry and nonprofit EV charging station experts. In their guidebook, the State Office argues for different entities (e.g., public bodies, private businesses, charitable organizations) to establish EV charging stations in addressing the accessibility of different vehicles, how to obtain proper permitting, and where to find suitable construction contractors. However, despite all the criteria that the GO-Biz lists for considering building an EV charging station, it is built primarily with the needs of business in mind. It is critical to remember that this phenomenon- that businesses do not have the same motivation as government entities- will be a point of contention as EVs are adopted. Businesses are motivated by profit, while government entities are typically motivated by managing and serving the public. These conflicts will need to be anticipated.

Criteria were decided upon using the GO-Biz's criteria for EV charging stations, the HHS's public programs, and a number of research projects described in Chapter 2. This project used the following criteria when evaluating suitable EV charging sites:

1. Population Distribution
2. Roadway Distribution
3. Proximity to Other Charging Station
4. Governing Body

Using the criteria stated above, this analysis identifies readiness for California's Transportation Electrification based on the number and distribution of EV charging stations in Los Angeles County, though the methods and resources can apply to other regions in California and other states.

Chapter 2 Related Work

A plethora of studies received publication regarding examining traffic efficiency and EV adoption (Roy and Law 2022; Huang, Kanaroglou, and Zhang 2016; Wang 2022). The studies like Perera, Hewage, and Sadiq (2020); Huang, Kanaroglou, and Zhang (2016); and Kang, Kan, and Lin (2021) described in the sections below examine at the following: (1) how to determine the distribution of EV charging stations, (2) approaches to analysis of EV site selection, namely the “summarize within” and “hotspot analysis” techniques, or (3) differentiating between high and low traffic roadways. In addition to the GO-Biz’s (California Governor’s Office of Business and Economic Development’s) criteria and the HHS’s (US Department of Health and Human Services’) public programs, this project looked at the existing academic research as to the appropriate criteria to include when evaluating locations’ readiness for EV charging station accessibility.

2.1. Establishment of Criteria

Using the studies described below, the project established the following criteria when analyzing the EV charging stations already in place within Los Angeles County. The following sections are divided by the criterion that contributed to the analysis (i.e., population, roadway, EV proximity to each other, governing body). However, please note, each study used multiple criteria when performing its own analysis.

2.1.1. EVs and the population

Given that transportation planning is inherently tied to population distribution, the population criterion appeared in the following studies. Perera, Hewage, and Sadiq (2020) studied recharging infrastructure in urban communities and considered the demand for EV infrastructure by population numbers and distribution. In Roy's and Law's (2022) examination of EV charging station placement disparities, the authors considered the population distribution (along with the population's various characteristics; e.g., density, socioeconomic status). Based on the findings of these studies, it was determined that the population factor is imperative for any study of human infrastructure.

2.1.2. EVs and the roadways

Naturally, any EV charging station should have proximity to the transportation network built for private motor vehicles. Therefore, when analyzing transportation, one cannot separate the vehicle from the roadway network. For example, Huang, Kanaroglou, and Zhang (2016) studied charging stations' placement along the roadways to "relieve EV drivers' range anxiety" (Huang, Kanaroglou, and Zhang 2016, 1) regarding a lack of EV charging stations throughout the roadways of Greater Toronto and Hamilton Area and Downtown Toronto. In Wang's (2022) study of identifying EV charging stations in the Lingang area (of Shanghai, China), Wang used the Shanghainese roadway data to conduct her hotspot analysis of charging station site selection properly. Using the roadway data, the authors studied how many charging stations were within the direct-administered municipality. Thus, roadways were deemed to be core to successful studies analyzing EV charging stations readiness.

2.1.3. EV charging stations' relation to each other

In the following studies on charging stations, the results found clustering in specific areas using a suite of approaches to cluster analysis. Wang's (2022) hotspot analysis study was based on this principle. She identified specific locations suitable for EV charging stations based on clustering in various locations. Kang, Kan, and Lin (2021) studied the patterns of charging station cluttering (e.g., non-urban central areas clustering, ring-like clustering, high-densities patterns with short-distance), which is reshaping the landscape in Beijing, China. Similarly, in the study of Jia, Liu, and Wan (2018), the authors used clustering to analyze EV charging placement. Essentially, EV analysis using different statistical approaches to visualizing and analyzing clustering is essential to perform this type of spatial analysis.

2.1.4. Governing Body

When studying the placement of EV charging stations based on a policy implemented by the California Legislature, one will have to account for how these different actors operate and the subsequent implications of legislative policy. All studies regarding EV implementation described above accounted for the type of governing body. Studies like those of Roy and Law (2022); Wang (2022); and Kang, Kan, and Lin (2021) found the type of government in their respective study areas relevant. However, unlike the previous criteria listed (i.e., population, roadway, and other charging station relations), the type of government body criterion is more secondary in the analysis. Thus while discussed during the course of this project, it will not take center focus.

2.2. Spatial Optimization

Spatial optimization means identifying the most effective way to analyze objects, resources, and networks in a defined space in respect to set goals (Tong and Murray 2012). In short, spatial optimization can help explain a complex spatial landscape. One obvious application of spatial optimization is the political boundaries within a space (e.g., country, state, city). Spatial optimization can also determine where to district specific infrastructure (e.g., business, residential, recreational/park districts), account for ecological/environmental management, maintain water resources, and plan for appropriate transportation routes (Cao, Li, and Church 2020).

The more specific method, suitability analysis, is needed to aggregate the numerous variables that go into locating EV charging stations. Guo and Zhao (2015) conducted a study to locate optimal sites for EV charging stations in Beijing, China, utilizing a fuzzy method called Fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), which the authors accounted for the following criteria in identifying suitable sites for EV charging stations:

- the environment (e.g., vegetation/water destruction, waste discharge)
- the economy (e.g., construction cost, annual operation cost, investment payback period)
- the society (e.g., traffic convenience, service capability, impact on people's lives)

Utilizing the Fuzzy TOPSIS method and the three criteria, Guo and Zhao (2015) produced a map identifying four ideal sites for EV charging stations in Beijing: Fengtai district, Changping district, Daxing district, and Chaoyang district.

In another suitability study, Hosseini and Sarder (2019) developed a Bayesian network model to select optimal sites for EV charging stations in Tehran, Iran. Hosseini and Sarder (2019) used Guo's and Zhao's (2015) environmental, economic, and social criteria, and the former added the fourth criterion of technical (i.e., power outage/failure frequency). Using this model, Hosseini and Sarder (2019) identified Tehran's Districts 2, 7, 11, and 22 as ideal EV charging station sites.

Caparros-Midwood, Barr, and Dawson (2017) utilized spatial optimization methods (i.e., suitability analysis) in their study on climate risk and sustainability in Greater London, United Kingdom. The authors had numerous objectives: minimizing heat, flooding, travel costs, and urban sprawl; maximizing brownfield development; and preventing unnecessary urban development. The authors utilized algorithms, including ones for flood risk assessment and to measure accessibility in areas' new development, to process their data through a geographic information system (GIS) to address their defined objectives. The resulting maps highlighted problem areas with respect to the authors' six objectives. Caparros-Midwood, Barr, and Dawson (2017) took their study further by producing a comparison of the Greater London districts and evaluated the extent of planning needed for each district.

Suitability analysis is particularly important with respect to transportation networks. Church and Cova (2000) studied the capacity of a transportation network in the event of an evacuation emergency. The authors created a ratio between the roads' bulk capacity (i.e., the maximum number of vehicles a single lane could hold) based on number of lanes, dubbed the "bulk lane demand" (Church and Cova 2020, 324). They used this ratio to process data on the roads in Santa Barbara, California, and identified the city's vulnerable roads in the event of an evacuation. The authors suggested emergency lanes or routes for these vulnerable areas on the map but ultimately argued that it is the responsibility of the Fire Department and homeowner associations. Though Church and Cova (2000) do not specifically look into EV adoption, their methods of roads' bulk capacity are useful in identifying the capacity required for a particular roadway.

In the late 1990s and early 2000s, car manufacturers introduced the hybrid EV (e.g. Toyota Prius, Honda Insight, Mazda Demio) to the consumer market. Given the EV's initial high price and lack of public fueling sources, individuals of a higher than average economic income (i.e., above an annual $69,560 as of 2019) are more likely to adopt the technology when compared to their lower-income counterparts (Bauer, Hsu, and Lutsey 2021). Therefore, charging stations were primarily located in higher-economic areas (Gardiner 2021). Given the haphazard beginnings of charging station distribution, researches and charging station operators recognized that there needed to be a more systematic approach to EV charging stations given their inevitable rise (California 2021b).

Another factor in identifying appropriate EV charging stations, as discussed briefly in Chapter 1, is amenities. Drivers need amenities to occupy themselves during their EVs' charging due to the necessary wait time. Chen (2017) produced maps that depicted the EV charging stations' distribution with respect to amenities using data from the Alternative Fuels Data Center, Caltrans, and National Geographic, and processing that data with ArcMap, ArcCatalog, ArcGlobe, and ArcScene. Chen (2017) selected McDonald's and Starbucks as commercial establishments that should be located near EV charging stations. The study showed that the EV charging stations are generally not located near the selected amenities (i.e., McDonald's and Starbucks); however, due to Starbucks's high level of distribution, it faired better in proximity. Whether McDonald's and Starbucks are appropriate proxies, the premise of the study is sound. Simply, drivers are more likely to adopt EVs if they are not inconvenienced and, thus, amenities should be of concern.

Given their necessity, there has not been an easy way for EV drivers to find charging stations to date. Developers have utilized GIS to assist EV drivers in locating EV charging stations along their route. A typical personal global positioning system (GPS) will produce a route based on the shortest travel time, but EV drivers must account for EV charging stations' infrequent placements (Altaweel 2016). EV Explorer, developed by the Plug-in Hybrid & Electric Vehicle Research Center (of the Institute of Transportation Studies at UC Davis; PH&EV Research Center 2014), accounts for EV charging stations to assist a driver in trip planning. The Centre of Advanced Research in Electrified Transportation built upon this project and also accounted for vehicle charging rates (i.e., how fast a vehicle will take to charge) at each station. Altaweel (2016) argues that the simple existence of these applications demonstrates that governments should build more EV charging stations. The author further argues that government agencies can utilize census data, infrastructure/construction costs, power supply, and traffic patterns within a particle swarm optimization (PSO) to identify the most efficient locations. While Altaweel (2016) suggests the inclusion of these criteria, the author does not include them in the analysis. This research demonstrates the necessity for using census data in this type of project.

In a related project, Zhang and Iman (2017) created a hot spot map to identify suitable locations for EV charging stations in the Wasatch Front, Utah. The researchers created a list of factors (e.g., elevation, employment estimates, population estimates, airports) that contribute to a suitable EV charging station location and then "scored" the locations accordingly. The authors produced several maps that present the best-suited spots for EV charging stations, which differed by giving their calculations' stability factors different weights. A similar type of hot spot analysis was utilized in this project, using Zhang's and Iman's factors combined with the unique criteria listed in Chapter 1). This method will be further elaborated on in Chapter 3.

2.3. Other Factors

Given the premise of this analysis (i.e., analyzing the introduction of relatively-new technology/ infrastructure), other past studies were incorporated into the research and method development process. The following section describes the research essential to understanding EVs, their charging stations, organizational implementation, management, and critique of such technology.

2.3.1. Other Countries' and International Organizations' EV Transition

Countries and organizations outside of the United States have conducted their own studies and research regarding EVs and EV charging stations. Merkisz (2019) studied the development of electric and hydrogen vehicles in Poland. The European Union (EU) has committed to reducing carbon emissions within its member states. However, the wealthy EU states (e.g., Italy, Portugal) are outpacing the more modest states, like Poland. Merkisz's data presents Poland as having minimal infrastructure for EVs, and therefore, its residents are discouraged from buying such vehicles. Merkisz suggests several strategies to encourage the Polish to invest in EVs, including the EU investing in Polish EV charging stations and gradually introducing hybrid vehicles.

The EU committed to introducing one million EVs to Poland by 2030 (Gis, Bednarski, and Orliński 2019). However, the authors argue that with rapid change to the infrastructure of Poland (and similar economic countries) must be planned and organized. In their study, Gis, Bednarski, and Orliński focused specifically on the Trans-European Transport Network (TEN-T) as a case study. By calculating the routes' length, the distance between charging stations, and the demand for EVs, the authors conclude that the stations should be included off the TEN-T's main route and have fast-loading points. The quantitative data suggested that the charging stations should have a distance of about 110 km between them and prepare to have a daily average energy consumption of 115.632 GWh. Gis, Bednarski, and Orliński identify two traits, namely distance and energy consumption, which all entities should be aware of when preparing for EV infrastructure (such as maximum distance and expected energy consumption).

2.3.2. Types of Charging Stations

There is a lack of studies regarding *non*-passenger vehicles (i.e., trucks, bikes/motorcycles). This following section discusses some of the relatively few studies that address issues that arise with vehicles that require more or less energy than the standard passenger vehicle. Liimatainen, van Vliet, and Aplyn (2019) expressed concern over the energy consumption and lack of power among electric-powered trucks. The authors used Switzerland and Finland as their study areas to develop a methodology to estimate electric trucks' potential energy consumption. Liimatainen, van Vliet, and Aplyn calculated the trucks' weight, travel time, and diesel consumption, which showed that a 100% adoption of electric trucks would increase the countries' annual electricity consumption by 1–3%, but would reduce the trucks' collective carbon emissions.

Ding, Batta, and Kwon (2015) explored the limited battery capacity and lack of charging facilities along the routes of large trucks. The authors developed a series of mathematical equations, utilizing the Electric Vehicle Routing Problem (E-VRP) model, which can improve travel distances between charging stations for trucks. The authors stated that the locations and capacities of the charging stations would need to be developed in a future study.

On the opposite end of the size spectrum, there are electric bikes and motorcycles. These vehicles do not have the same concern as larger vehicles in the sense that they require very little energy, have a longer battery life, and can typically charge at the same stations as electric passenger vehicles. One should focus on accommodating such vehicles because they are preferable in increasing energy efficiency and reducing traffic congestion. According to Wikstrøm and Böcker (2020), e-bikes play a vital part in sustainable transportation. The authors selected Bærum, Norway, as the study area as it is near 100% renewable electricity production and has a high percentage of bike and pedestrian ways. Wikstrøm and Böcker found that individuals changes their transportation habits based on their circumstances. An individual will use a car if she is carrying goods or people, needing overnight parking, or experiencing hazardous weather (e.g., rain, snow, heavy wind); thus, a full electric bike adoption is highly unlikely. Wikstrøm and Böcker argue that these issues can be partially addressed if cycle infrastructure and cargo bikes were more widely available.

The easiest way for a government entity to change a commuter's way of traveling is through public vehicles (i.e., buses, taxicabs, railway transit). Public entities have direct control over public transportation when compared to private transportation. However, since taxicabs are passenger vehicles (addressed in Section 2.1) and railways are usually electric, the following paragraphs will focus exclusively on buses.

Since buses are either government-owned or government-contracted, making buses electric is a relatively easy shift compared to the private vehicles discussed above. Al-Ogaili et al. (2020) investigated the energy consumption of electric buses, using Malaysia as a case study. According to Al-Ogaili et al., Malaysia is the second-largest per capita GHG emitter globally, leading to the Malaysian government committing 2,000 electric buses and EVs on Malaysian roads by 2030. By aggregating data from the Malaysian bus network, regional requirements, digital elevation model (DEM) data (acquired from the National Aeronautics and Space Administration; NASA), and power grid data, Al-Ogaili et al. produced a series of models of the Malaysian electric bus network.

In a similar study, Sun et al. (2021) researched the fuel consumption of diesel and electric buses in Chattanooga, Tennessee. By acquiring data from the Chattanooga Area Regional Transportation Authority (CARTA) and on-board sensors, then running them through mathematical formulas, Sun et al. produced graphs and maps illustrating the CARTA buses' traits, namely engine speed, acceleration, road grade, ambient temperature, and vehicle-specific power. According to Sun et al., the diesel and electric buses showed very little difference in performance (i.e., speed, engine demand, road grade); however, electric cars have a higher fuel-saving rate than their diesel counterparts. This relatively minor difference in electric bus energy consumption further cements the argument that the adoption of electric vehicles will have a more profound impact that the adoption of electric busses.

Wenz et al. (2021) analyzed the most efficient route for electric buses using Cuenca, Ecuador, as their area of study. The authors chose Cuenca for its mountainous geography and high population. By accounting for the electric buses' state of charge, roads quality and shape (e.g., width and curve), and the number of expected passengers, Wenz et al. produced a map of bus routes and rated the routes by their performance (e.g., comfort of ride, adherence to scheduled stops, distance per charge). With their method, the authors identified the top three streets that should transition to EV's first and proceeded to rank the remaining streets by priority.

2.3.3. Equity & Accessibility

To further complicate the matter of EV adoption, not all households have equal access to EVs and the needed charging stations. The wealthy are the most likely demographic to purchase EVs and, yet, low-income communities are disproportionately affected by air pollution and climate change (e.g., urban heat island effect, air quality, natural disaster recovery; Canepa, Hardman, and Tal 2019). Using data from the US Census Bureau, the California Clean Vehicle Rebate Project, DMV registrar, PH&EV Center, and the Department of Energy's Alternative Fuels Data Center; Canepa, Hardman, and Tal (2019) conducted a spatial analysis of EV ownership in California. According to the authors, disadvantaged communities have fewer EV charging stations than their non-disadvantaged counterparts, but the disadvantaged communities' charging stations, while limited, have a higher charge capacity. Nevertheless, the average income for a house with an EV was $153,175 in a non-disadvantaged community and $135,102 in a disadvantaged community. These finding reveal that the EV drivers living in disadvantaged communities are higher income when compared to their neighbors, further illustrating the divide between EV and non-EV owners.

To address these issues of disparity, Governor Brown signed the “Greenhouse gases: investment plan: disadvantaged communities” in 2016 in the hopes of accommodating concerns about lower-income communities. The goal was to provide lower-income communities access to the EV market and encouraging said community to willingly purchase EVs. Hsu and Fingerman (2021) took sociodemographic data from the 2016 American Community Survey (ACS) and the US Census Bureau, along with EV charging station data from the Alternative Fuels Data Center, to calculate the current distribution of public EV charging stations and the placement of new charging stations. According to Hsu and Fingerman (2021), an EV charging station is most likely to be built next to a freeway, and multi-unit dwelling residents are far more likely to depend on public charging stations. Furthermore, Black-Hispanic majority census blocks are the least likely locations for EV charging stations’ locations regardless of proximity to freeways or economic status.

Azarova et al. (2020) offer solutions to inequity in EV adoption. Using Austria as their study area, Azarova et al. conducted a survey regarding residents’ EV ownership status (i.e., own, plan to buy, not interested), barriers to EV adoption, and household demographics (e.g., homeownership, living space size, number of residents, number of vehicles). They proceeded to take this data and process it using the multinomial logistic model. Like the studies discussed above, Azarova et al. identified EV charging station locations best suited for the public.

However, what differentiates Azarova et al. from the other studies (described above) is their suggestions of accommodations for the lower-income communities, such as communal owned charging stations, semi-public charging stations, and scheduled charging times.

In 2014, California approved the Charge Ahead California Initiative, which provided incentives for car-sharing services that utilized clean transportation options, including EVs. Mitra (2021) researched the impact of the initiative using data from the California Household Travel Survey and the US Department of Housing and Urban Development and several land-use-entropy-index formulas. Mitra found that lower-income households are less mobile than their higher-income counterparts, with the two groups largely spatially distinct from one another. Furthermore, the car-sharing program had a higher effect on lower-income groups by increasing their mobility and accessibility to public services. Moreover, one-way car sharing (e.g., Zipcars) became an excellent substitute for the lack of public transportation in lower-income neighborhoods.

Mitra (2021) expressed concern about the ability of lower-income communities to access the EV market. Nemoto et al. hoped that the introduction of EVs (along with self-driving vehicles) would increase the mobility of EU residents. The researchers used four European cities as their study area: Geneva, Switzerland; Lyon, France; Copenhagen, Denmark; and Luxembourg City, Luxembourg. After an extensive literature review, Nemoto et al. found that EV sharing improved accessibility, affordability, environmental friendliness, and mobility efficiency for the four cities' respective residents.

2.3.4. Energy Sources

Despite all the benefits of EVs in reducing emissions, EVs are only as environmentally friendly as their energy source. Schelly and Price (2014) studied the United States and each state's adoption of renewable energy. The authors visualized the states' renewables portfolio by compiling the 50 states' respective policies, production, and consumption in a vector map. For the sake of this project, this review of Schelly's and Price's findings focus on their results regarding California. Despite ranking first in energy consumption, California also ranks highest in provisions for solar-related technology and increased renewable energy generation despite public policy. The State ranks second in solar development, only after Arizona. Furthermore, California is one of two states (the other being Hawaii) committed to having an above 33% renewable energy source by 2020. However, as of 2021, California has not quite met its 33% renewable energy goal, but is close at 32% (California 2021a). In short, any initiative looking to reduce fossil fuel consumption cannot claim EV adoption to be the sole solution because the electricity the EVs consume potentially originates from fossil fuels.

Like Schelly and Price (2014), Hafez and Bhattacharya (2017) expressed concern about traditional energy sources and identified various alternatives. By comparing the energy supply between diesel, solar, and diesel-solar, Hafez and Bhattacharya found that diesel-solar provided the most economical and logistically efficient energy for a (hypothetical) metropolitan city. This deviates from an exclusively solar energy plan, which has zero carbon footprint. This finding should raise particular concern for California, which wishes to exclusively transition to more energy-efficient vehicles.

Zheng and Weng (2019) conducted a similar study regarding the disproportionately high-energy consumption in Los Angeles County, California. Zheng and Weng ominously note that 50% of building energy consumption is for heating and cooling, the latter of which climate change is exacerbating. While most of Zheng's and Weng's study consists of retrofitting buidings in Los Angeles County to be more energy efficient, the authors' study is of particular interest with regards to Zheng's and Weng's findings. According to Zheng and Weng (2019), only 29% of California's energy is consumed through renewable sources, with a majority of energy (77.6%) coming from natural gas (31.8%), petroleum (28%), and coal (17.8%).

In a study strikingly similar to this analysis's topic and concerns, Huang et al. (2019) utilized GIS to identify optimal charging stations in Hong Kong. Huang et al. accounted for the population's distribution and density, rooftop locations (for installing photovoltaic panels), and the electrical grid. Using GIS, the authors created buffers around green energy sources and identified areas based on the number of charging stations they could accommodate. Additionally, Huang et al. located areas where charging stations could be built (e.g., commercial districts, unoccupied land). The authors' techniques of buffering, rooftop coverage, and population distribution were replicated in this project.

Chapter 3 Methods

The goal of this project is to identify locations' readiness for the population's EV charging station use. Based on review of previously published literature and analyses described in Chapter 2, the project focused on four criteria—population distribution, roadway locations, proximity to other charging stations, and political governing body—for evaluating EV charging stations readiness. The unit of spatial analysis was by census block. All analysis conducted in this project used Microsoft Excel for non-spatial data handling and ArcGIS Pro (version 2.9.1) for spatial analysis and visualization.

A more straightforward method for performing this analysis would be incorporating a spatial database and importing the data. However, this project was conducted with the resources generally available to government agencies, which are typically constrained by budget leading to a lag in adopting the most recent software/applications produced (Kahn 2020). Moreover, according to the US Census Bureau (2021a, 2-2), "Due to the wide use of Esri products by [the Bureau's] partners in the Geographic Information System (GIS) community, and ubiquitous use of the shapefile format as a medium for GIS data exchange, the Census Bureau provides data in shapefile format." Therefore, the methods focus on use of the shapefile data format and the GIS software Ersi ArcGIS Pro to conduct the analysis.

3.1. Research Design

As previously stated, this project's primary goal was to examine the Los Angeles County area's population and EV charging stations distribution and determine where new EV charging stations do not adequately accommodate the surrounding population. This project was separated into two primary analysis components: The analysis on households' relation to EV charging stations and the analysis on traffic roadways' relation to EV charging stations (see Workflow in Figure 2).

In both analyses, the data was first gathered and prepared in shapefile format compatible with ArcGIS Pro. Moreover, the shapefiles were converted into vector formats (i.e., points, polylines) that made them compatible with the 'Summarize Within (Analysis)' tool.

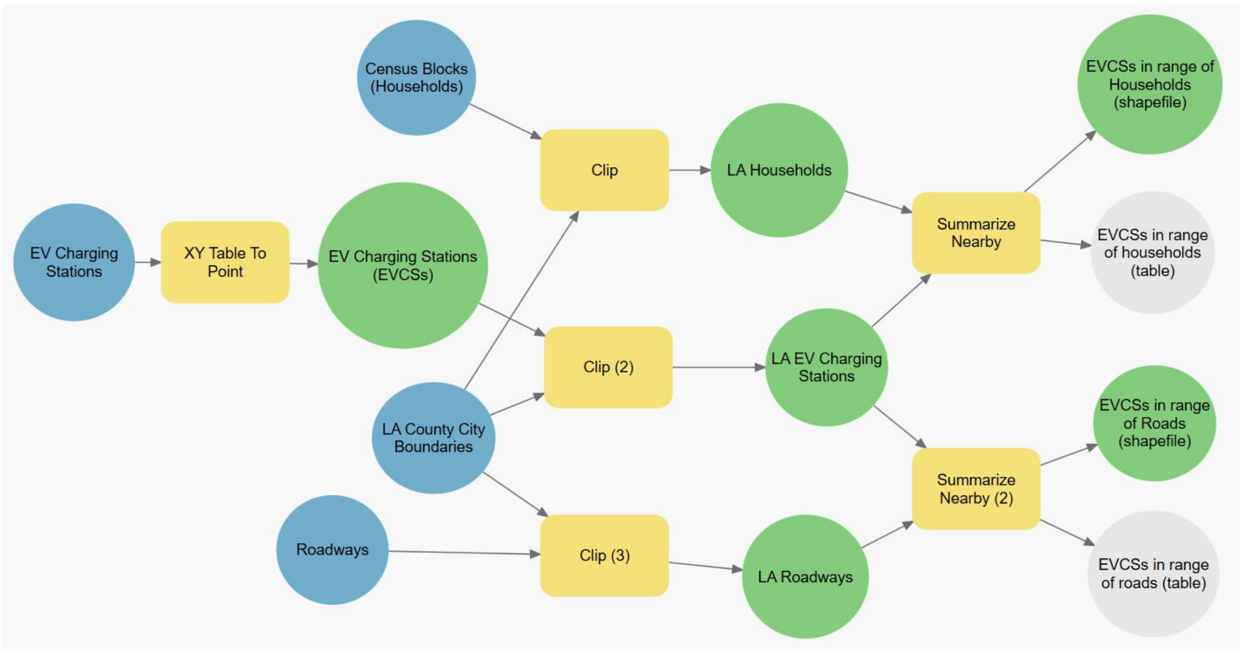

Figure 2. Image of Analysis Workflow (prepared using ArcGIS Pro's ModelBuilder).

3.2. Data Requirements & Data Sources

A variety of data describing Los Angeles County's population, roads, and infrastructure was needed to conduct this analysis. This study gathered data regarding political boundaries from the California State Geoportal (2020), EV charging station locations from the Alternative Fuels Data Center (AFDC 2021) and County of Los Angeles (2021b), population data from the US Census Bureau (2021c), and road line data from the California State Geoportal (2020) (see Table 1).

Table 1. Summary of the data required for analysis.

Dataset	Scale	Precision	Source	Publication Date	Last Update
City Boundaries	≈1:2,500,000	≤ 1 km	California State Geoportal	March 6, 2015	March 18, 2022
Traffic/Roadways	≈1:2,500,000	≤ 1 m	California State Geoportal	June 1, 2019	Jan. 15, 2021
LA [EV] Charging Station Locations	≈1:35,000,000	≤ 1 mm	US Department of Energy	July 18, 2012	March 1, 2022
California [EV] Charging Station Locations	≈1:2,500,000	≤ 1 km	US Department of Energy	July 18, 2012	March 1, 2022
Population Traits (e.g., density, income)	≈1:2,500,000	≤ 30 kg	US Census Bureau	Oct. 7, 2021	Dec. 16, 2021

3.2.1. EV charging stations

The most important data needed for this study was the data describing the distribution of EV charging stations. They were acquired from the County of Los Angeles (2021b), which utilized the US Department of Energy (AFDC 2021) generated data. The data contained every EV charging stations' location in Los Angeles County as of August 29, 2019. The data contained a table listing the EV charging stations' name (if applicable), address, number of outlets, longitude, and latitude. This data was essential in all parts of the analysis due to its use in both the population and roadway analysis.

3.2.2. Population data

The Los Angeles County data was used to analyze and visualize the county's physical characteristics and demographic makeup (e.g., census boundaries, number of households, population, government body; census blocks acted as the data's smallest spatial unit). The boundaries for Los Angeles County were used to extract the specific spatial information from the census shapefiles for the study of Los Angeles County (County of Los Angeles 2016a). While the political boundaries are generally well defined, privacy concerns mean that the demographic data is generalized. Adjustments were needed regarding the population's data (i.e., formatted in polygon shapefile format for ArcGIS Pro to read) to achieve the most accurate results for the Los Angeles County residents (US Census Bureau 2021c). The census blocks with a population of zero (0) indicated that no people were living in the area; thus, they were eliminated from the analysis.

3.2.3. Road data

Road data includes a roadway's shape and length. This data was accessed through a government body's (i.e., State of California, County of Los Angeles) data portal. Because the government has formal naming conventions and guidelines for their data format, most of the data acquired from the city and other government-run data portals are compatible with each other, which provides for ease of analysis.

One limitation of the data was a lack of information on the road sections' maximum volume and peak hours. Though this data can be acquired via larger LA city data portals (e.g., Los Angeles, Long Beach, Santa Clarita), smaller cities often depend on the county to offer spatial information to the public. Moreover, Los Angeles County consists of 88 cities, which proved to be too cumbersome to calculate for every road volume within the scope of this project. Therefore, this analysis acknowledges that traffic volume and peak hour are important topics to study, but they require a study on a larger scale than a county level.

3.3. Analysis Procedure

To conduct this study, the procedure was broken up into three phases:

1. Obtaining and preparing EV charging station Data
2. Preparing and analyzing the populations' access to EV charging stations
3. Preparing and analyzing traffic ways' proximity to EV charging stations

The EV charging station data prepared in the 1st phase was used in the 2nd and 3rd phases.

3.3.1. Obtaining and preparing EV charging station data

Los Angeles County's EV charging station data were accessed using the California Energy Commission's open data portal. The data needed processing to be visualized in ArcGIS Pro.

First, the table was imported. Next, the 'XY Point Data' tool gave the charging stations coordinates. The California Energy Commission's longitude and latitude were ideal coordinates to use in an XY grid representing the globe. Therefore, the California EV charging station table was placed into the 'XY Point Data' tool, the longitude data were set as the x-coordinates, and the latitude data were set as the y-coordinates. With the information provided, the 'XY Point Data' tool produced a point shapefile containing all the EV charging station data originally provided in California Energy Commission's data table.

The EV charging station data was clipped to Los Angeles County. This required having data on the county's boundaries. After placing this county boundary data into ArcGIS Pro, the software's 'Clip (Analysis)' tool was utilized. In the tool's settings, the EV charging station point shapefile was set as the "input feature," and the Los Angeles County polygon shapefile was set as the "clip feature." A point shapefile containing only Los Angeles County's 1356 total EV charging station was produced when the tool reached completion. The smaller shapefile made the following phases' processing time much shorter.

3.3.2. Populations' access to EV charging stations—Data Preparation

Like the EV charging station data, the California census block data possessed more information than this study needed, and processing census block shapefiles on a state-wide level would have been far too cumbersome. For that reason, the 'Clip (Analysis)' tool was utilized once again. The census block polygon shapefile was set as the "input feature," and the Los Angeles County polygon shapefile was set as the "clip feature."

The data preparation's final step involved identifying the census blocks' respective centroids. The purpose of finding the centroid was to avoid presenting any misleading data. Though called "blocks," census blocks vary in footprint and many have branching appendages. Moreover, using the entire polygon for calculation will create data that suggests that a person has free movement within her assigned census block.

When examining the census blocks, one will note the variance in size. Because census blocks are based on population size and the US population is not distributed evenly across the county, the census blocks have a vast difference in area and shape. Therefore, when producing a buffer for the census blocks to measure the number of EV charging stations within a 1-mile radius, the analysis will likely produce skewed results based on the census block's size. A larger census block will have a greater opportunity to encompass an EV charging station within its 1-mile radius compared to a census block an eighth of its size.

To ensure all the census block data shapes possess the same length and width, the centroids were used to give a general location for all the individuals living in the census block. To find the polygons' centroids, ArcGIS Pro's 'Centroid (Polygon)' tool was used in conjunction with the census block polygon shapefile. The analysis converted the polygons into points to ensure all census blocks had the same length and width measurements (i.e., a length of zero units and a width of zero units), which allows one to avoid larger census blocks appearing to have greater access to EV charging stations on account of its larger footprint. The tool then produced a point shapefile representing each census block's centroid.

This proved to be problematic. Due to the size of the census block centroid shapefiles, ArcGIS Pro had difficulty processing the needed calculation. After much deliberation, the solution was to split the census block centroid point shapefile using the 'Duplicate Feature' tool. The second half of the points (based on Object ID) were duplicated into another shapefile, and the original shapefile's second half of points were deleted. Then, two shapefiles represented two halves of the LA census block centroids. The data was then ready for analysis.

3.3.3. Populations' access to EV charging stations—Data Analysis

Populations can be understood using the census variables of individual or household. This study measured population by household because not every individual household member needs to drive or does not have the ability to drive (e.g., children, elderly, disabled persons). The EV charging stations were measured by the number of charging ports (Electric vehicle charging station outlets; EVCOs) a station has available (California Energy Commission 2021b).

The 'Summarize Within (Analysis)' tool was used to identify the number of EV charging ports within a 1-mile radius of the census block centroid. The 1-mile radius was based on the appropriate 15–20 minute distance (about 1 mile for an average person) between residents and amenities (Liese et al. 2007) and the appropriate 1-mile distance between residents and public transportation (LA Metro 2022). With the 'Summarize Within (Analysis)' tool, the analysis looked at the census block centroids, created a 1-mile buffer, calculated the number of EV charging stations within the buffer, and presented a sum of the number of charging outlets within the given buffer. This process was repeated for the second half of census block centroids.

Once the calculations for both census block centroid shapefiles were completed, the calculations' results needed to be placed back into the census block polygon shapefile for proper visualization. The 'Add Join (Data Management)' tool was used to perform this task to join both halves of data to the single census block polygon shapefile, with the join based on Object ID. The 'Symbology' tool was then used to present the data in visual form, showing the number of EV charging station ports within a 1-mile radius for each census block.

Because not all census blocks have the same number of households and vary to a small degree in population, the data required a normalization based on the census block's household total. A new field (column) was created in the census block's attribute table using the calculation of the following: (number of households) ÷ (number of EV charging ports). This created a more accurate map displaying a ratio of the number of households in the census block for every EV charging port within a 1-mile area. If an area had zero EV charging ports in the area, an undefined/null value occurred (division by zero); this undefined value proved helpful in identifying areas in need of any charging stations.

When examining the analysis's results, the data produced a bimodal distribution, making the map hard for a reader to interpret. Many census blocks did not have any EV charging stations within a 1-mile radius compared to those with over 20 EV charging stations within their respective 1-mile radii. Therefore, a map with an equal interval classification would produce results appearing practically binary (despite the data having variation). Thus, the map produced in this analysis utilized a quantile classification to ensure one may observe the variation in households' distance from charging stations.

3.3.4. Roadways' relation to EV charging stations—Data Preparation

The third phase of this analysis analyzed the roadways' relationship with EV charging stations. Because people are not confined within their assigned census block, this analysis used roads to account for the commuter population. This factor is fundamental in areas between long stretches of empty areas between human-populated areas.

The roadway data was found on the California State Geoportal (2020). Compared to the population data, the roadway data needed less preparation. As with the data in previous phases, the 'Clip (Analysis)' tool was used to isolate the roadways within Los Angeles County's borders. The roadway polyline shapefile was set as the "input feature," and the Los Angeles County polygon shapefile was set as the "clip feature."

Under usual circumstances, this step involves segmenting the roads into small, more manageable polylines. Otherwise roadways could cover the entire footprint of the county (e.g., interstate highways), producing inaccurate results. The results could show that a highway has access to a suitable amount of EV charging stations, but the charging stations could all be clustered on a far end of the highway, making it unreasonable for people living on the other end of the roadway to travel to. Thus, roads of more considerable length need to be segmented into smaller polylines. The California State Geoportal (2020) already segments its roadway polylines into smaller objects, but one should be aware of this issue if desiring to replicate these methods because not all regions are pre-segmented for the analyst.

Unlike the census polygons, the roadway polylines did not need to have their centroids calculated. The polylines' length averaged to be less than a mile long, and an individual on a roadway is not in a fixed position like an individual residing in her living quarters. Consequently, calculating the centroids of the roadways would be largely superfluous.

The next part of preparing the data was to split the roadway polyline shapefile into two to expedite the software processing time. In the same manner as the census household shapefile, the roadway shapefile was separated using the 'Duplicate Feature' tool, except this time, two new features were created. Using Object ID, the first half of the lines were duplicated into one polyline shapefile, and the second half of polylines were duplicated into another shapefile.

3.3.5. Roadways' relation to EV charging stations—Data Analysis

Similar to the census data, the 'Summarize Within (Analysis)' tool was used to calculate the number of EV charging stations within a 1-mile radius of the roadway segment. In this case, the 1-mile radius was chosen to retain consistency with the household data. The roadway polyline shapefile and the EV charging station point shapefile were placed into the 'Summarize Within (Analysis)' tool, which created a 1-mile buffer around the roadway segments and calculated the total number of EV charging station ports in the given area. The 'Symbology' tool was used to visualize the results.

3.3.6. Governing bodies' relation to EV charging stations

The analysis used the census data provided by the US Census Bureau (2021c) and the Alternative Fuels Data Center (AFDC 2021), which calculated statistics regarding cities' household totals, the number of charging stations, and the number of charging stations per household. This part of the analysis utilized the summary of the total charging stations in each city (produced in the population analysis; see Section 3.3.3) and placed the data into Microsoft Excel. The analysis produced a summary of the charging stations by city using the same ratio used in the population analysis [i.e., (number of households) ÷ (number of EV charging ports)].

Chapter 4 Results

The process described in Chapter 3 produced extensive results regarding the population and roadway accessibility to EV charging stations. This chapter is divided into three sections based on the results. Namely, the results of individual methods define the drivers by their residence location, roadway placement, and governing body statistics.

4.1. Population share of EV charging station results

The population and EV charging station results (see Figure 3) depict a map illustrating the varying ratios of EV charging stations to households in the Los Angeles County area.

In theory, an EV charging station should be present where there are people present, and conversely, an EV charging station would not be in an area without people present. However, the results also illustrate the relationship (i.e., ratio) between total households present and total EV charging station outlets (EVCOs) in the area. Furthermore, there are areas with a sizable population without EV charging stations. Upon normalizing the data based on the total number of household within the census block, these results become more apparent.

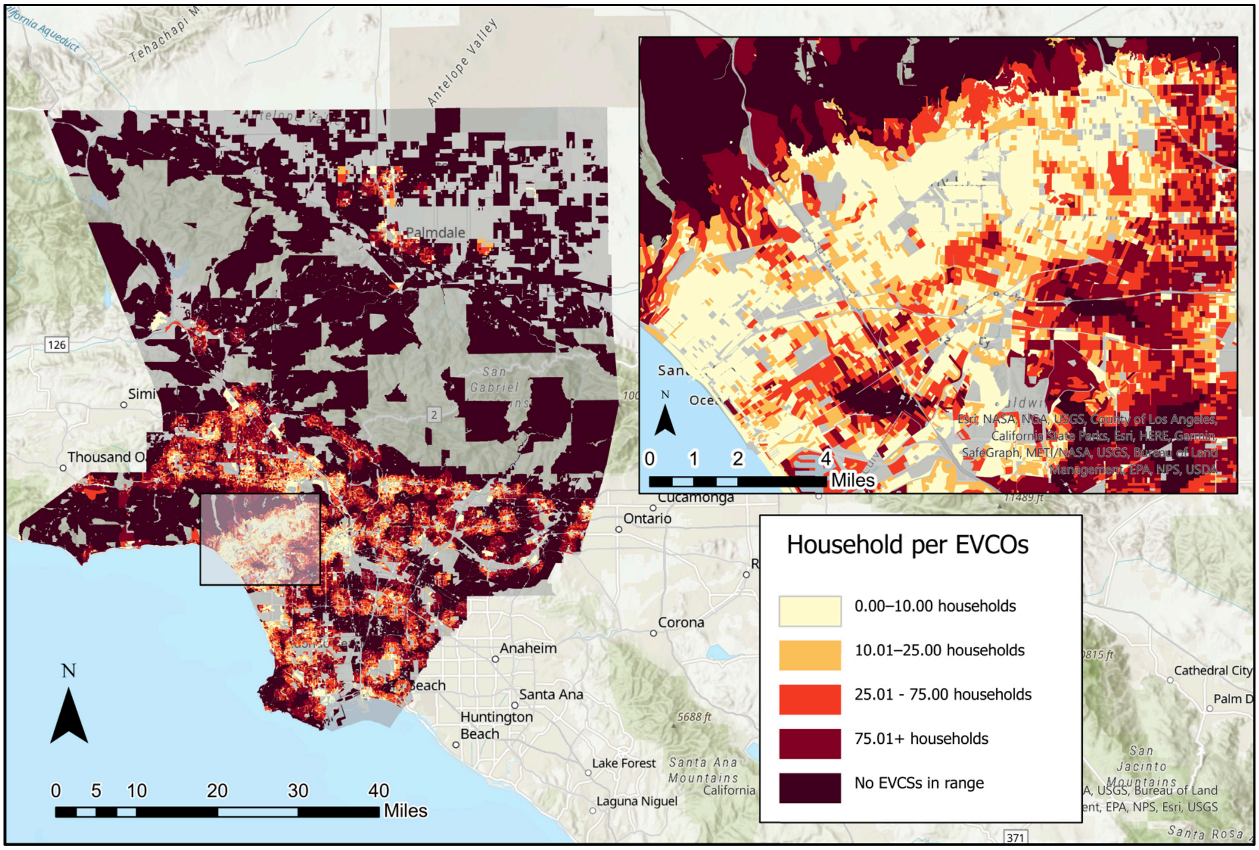

Figure 3: The number of household per EV charging station outlet (EVCO)

The EV charging stations are primarily concentrated in the contiguous Los Angeles County regions (i.e., Central Los Angeles, Gateway Cities, San Fernando Valley, San Gabriel Valley, South Bay), particularly in the general area of Santa Monica, Beverly Hills, and West Hollywood. The further inland into the contiguous Los Angeles County region, the less frequent the EV charging stations' presence becomes. The Santa Monica Mountain cities (e.g., Agoura Hills, Calabasas, Malibu) present a far less EV charging station presence (with and without normalization). The most notable area without EV charging stations is the unincorporated area between Malibu and the northern Santa Monica Mountain cities. However, one should note that the unincorporated area houses residents (census blocks without any residents have been removed from the calculations and the final presented map).

There are two minor locations outside of the contiguous Los Angeles County regions that appear to have a sizable EV charging station presence, which correlates with a municipal presence. The first location is the City of Santa Clarita, with most of its EV charging stations in its western portion and various charging stations distributed eastward. However, the charging stations' presence is not reasonably accessible across the city's entire residential areas (i.e., northern Santa Clarita).

The second location outside of the contiguous Los Angeles County regions that appear to have a sizable EV charging stations presence are the twin cities of Lancaster and Palmdale. Similar to the City of Santa Clarita, the twin cities have their EV charging stations concentrated in their western portion, while the cities' eastern portion has no EV charging stations.

Beyond the Los Angeles County's proper city boundaries, there are no areas with any EV charging stations present in the Santa Clarita Valley's and the Antelope Valley's unincorporated areas despite having a residential population. Furthermore, despite all of the areas described above having an EV charging station presence, none have a fair number of public charging stations. The results suggest there is relationship between the population's distribution and EV charging stations' placement.

4.2. Roadways and EV charging station results

The results of the roadways and EV charging stations (see Figure 4) look similar to the population and EV charging station results (see Section 4.1) in some areas and have more information in other areas (i.e., the areas within census blocks without a residential population). Like the population map, the clustering of EV charging station accessibility is in the contiguous

Los Angeles County regions, sparse placement in the Santa Monica Mountain cities, and smaller clustering in the City of Santa Clarita and the twin cities of Lancaster and Palmdale. However, unlike the population map, when analyzing EV charging station accessibility based on roadways, the area of EV charging station accessibility became larger. These results are due to how the accessibility was calculated in this part of the study.

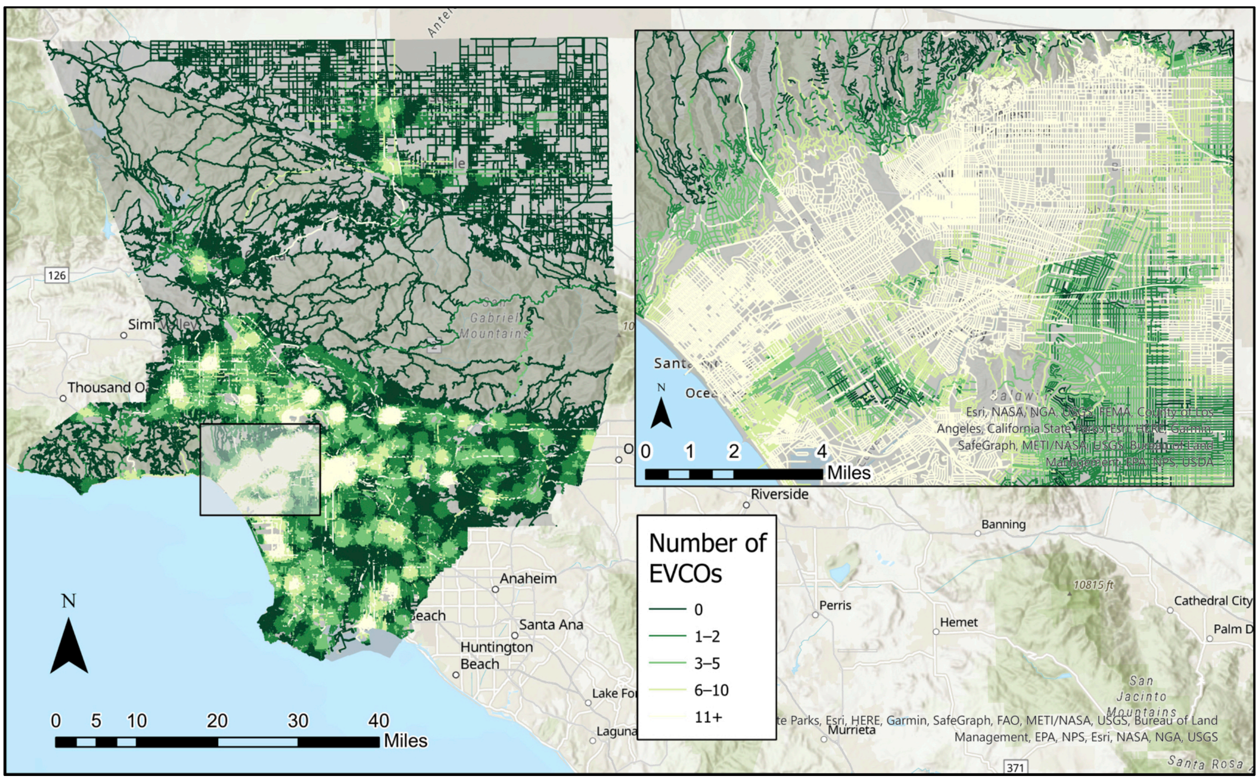

Figure 4: The number of EV charging stations per 1-mile radius of roadway segments

The population was calculated using points to represent the average location of a household in a census block. Roadways were calculated using polylines to represent the length and placement of the roadway segments. Therefore, the results present greater EV charging station accessibility when using roadways due to the polylines’ lengths.

Another difference between the two methodologies is the areas without a residential population. These results present a lack of any EV charging station presence and no reasonable EV charging station access from any major roadway. The stretch of land between the Antelope Valley and the San Fernando Valley was largely unaccounted for in the population analysis but can be viewed in the roadway analysis.

Finally, like the population results, none of the areas present a suitable amount of EV charging stations for their driving population in the roadway results. The areas' shortcomings are presented as a more prominent issue in the roadway results due to the roadway driver population being larger than the residential population.

4.3. Governing bodies and EV charging station results

Finally, the analysis produced the following statistics through the spatial analysis performed in ArcGIS Pro and Microsoft Excel. The top 10 cities with the most charging stations per household are the following (in ranking order): Industry, Vernon, Irwindale, El Segundo, Westlake Village, Beverly Hills, Signal Hill, Culver City, Commerce, and Santa Monica (see Table 2). Moreover, the analysis produced data of cities without any charging stations in the area (in alphabetical order): Artesia, Avalon, Bell, Bell Gardens, Bellflower, Bradbury, Cudahy, Hidden Hills, Huntington Park, La Habra Heights, La Puente, La Verne, Lawndale, Lomita, Palos Verdes Estates, Paramount, Rolling Hills, San Gabriel, San Marino, and Sierra Madre (see Table 3; see Appendix A for full list of Los Angeles County charging stations by city).

Table 2. Top 10 cities with the most EV charging stations per Household in Los Angeles County.

Rank	City Name	Total EV Charging Station	2020 Population	2020 Total Households	Household per EVCO
1	Industry	14	589	173	12
2	Vernon	2	266	89	45
3	Irwindale	3	1,652	470	157
4	El Segundo	27	17,251	7,492	277
5	Westlake Village	6	8,026	3,440	573
6	Beverly Hills	27	32,845	16,334	605
7	Signal Hill	7	11,812	4,735	676
8	Culver City	26	40,862	17,902	689
9	Commerce	5	12,710	3,614	723
10	Santa Monica	59	93,025	52,353	887

Table 3. Cities with zero EV charging station in Los Angeles County.

City Name	Total EV Charging Station	2020 Population	2020 Total Households
Artesia	0	16,384	4,744
Avalon	0	3,431	2,192
Bell	0	33,592	9,475
Bell Gardens	0	39,496	10,189
Bellflower	0	79,316	25,252
Bradbury	0	935	360
Cudahy	0	22,805	5,855
Hidden Hills	0	1,727	635
Huntington Park	0	54,881	15,492
La Habra Heights	0	5,687	2,022
La Puente	0	37,966	9,899
La Verne	0	31,304	12,206
Lawndale	0	31,690	10,243
Lomita	0	20,935	8,596
Palos Verdes Estates	0	13,337	5,283
Paramount	0	53,469	14,787
Rolling Hills	0	1,740	702
San Gabriel	0	39,494	13,432
San Marino	0	12,507	4,479
Sierra Madre	0	11,280	5,100

Chapter 5 Discussion and Conclusion

This project investigated the placement of existing EV charging stations in the State of California based on the EV driver's residence, local roadways, EV charging station proximity, and governing body. The analysis results identified areas with appropriate amounts of EV charging stations for their respective population and commuters. Furthermore, the analysis illustrated areas that require more EV infrastructure. The California state government can use this research results to appropriately prepare the state for the shift of increased EV use in the near future.

5.1. Discussion

The first major finding of this study was the uneven distribution of EV charging stations within the Los Angeles County area. When looking at the map created from the analysis of the EV charging stations, they appeared to be clustered in specific regions across Los Angeles County, particularly in the contiguous Los Angeles County regions, the City of Santa Clarita, and the twin cities of Lancaster and Palmdale. This particular trend is noteworthy because it gives the residents of these areas access to EV charging stations but only in a high concentration of a particular area. One may argue that this creates areas marked by extremes (i.e., high concentration, low concentration) in relation to the number of EV charging stations and the areas the charging station provides service for. This factor alone points to the issues that will arise in the future when more drivers adopt EVs: the clustering will lead to higher traffic in those particular areas.

It would be advantageous to perform this entire analysis using a spatial database in a future study. Using a spatial database would cut down on the data processing time and allow bigger datasets that could cover a much broader scale to be analyzed. This method would benefit areas with a more extensive physical footprint than Los Angeles County (e.g., larger counties, state level, country level). However, as stated in Chapter 1, this analysis utilized the technology most US government agencies have access to (e.g., ArcGIS Pro, shapefiles) to ensure such entities could readily repeat this study and its methods at the present time.

Given that this is an analysis of technology (i.e., electric vehicles, charging stations), the technology will likely improve in the decades to come. Given the rapid advancement in renewable energy and transportation technology, in the future, one must look into the current status of EV charging station distribution, how long an EV takes to receive a full charge, and how far an EV can travel on a given charge. These three factors will likely affect a future study's methods and results for the following reasons. First, a greater EV charging station distribution will lessen the concern regarding California's transportation electrification. Second, a faster EV charging time will lessen the number of charging station outlets needed in a given area. Third, better EV mileage will widen the distance of EV charging stations needed in desolate areas.

5.1.1. Relation to population

When looking at the relationship between EV charging stations, they are predictably located where the population is denser, while large swaths of desolate land have little to no charging stations. This issue can be due to many reasons, but given that most EV charging stations are built by private companies, they are located in areas deemed to be more profitable. This trait is particularly noticeable in the Santa Clarita and Lancaster-Palmdale areas, where the charging stations are clustered in their respective downtowns.

Theoretically, if EV charging stations were clustered in specific areas, they should be clustered in commercial areas. This gives the drivers something to do while waiting for their respective vehicles to charge. That said, not everyone lives close to commercial areas. This finding leads to an observation discussed in previous studies like Chen's 2017 study regarding

McDonald's and Starbucks's proximity to EV charging stations. According to Chen (2017), drivers should preferably have activities at their disposal while they wait for their EVs to charge at the charging stations (see Chapter 2 for further detail). Based on the findings in the analysis, EV charging stations are presumably clustered in areas that occupy the EV driver (e.g., shopping centers, theaters, business district complexes). A future study could identify the commercial areas in Los Angeles County, the average traffic they experience in a day, and how many vehicles they can accommodate. Collecting information on each city's commercial area and daily/annual traffic would be an intensive task, one beyond the scope of this project.

5.1.2. Lack of placement in unincorporated areas

The area's incorporated status (i.e., unincorporated versus an official city) has the most significant correlation with the areas with zero EV charging stations. Areas outside the official city boundaries lack EV charging stations. This correlation could be due to a multitude of reasons, such as the resources and investment the presiding governments have in the areas, but further research will be needed to have a confirmed quantitative reason.

This disparity between city and unincorporated areas raises concerns about when EVs become mandatory on California roadways. For one, residents of unincorporated areas will likely have to petition Los Angeles County if the infrastructure is not built soon. And if this infrastructure is not built rapidly, the residents and government officials residing in unincorporated areas can make the argument to the California State government that the adoption of a mandatory EV policy should be prolonged. This of course runs counter to the State of California's carbon emissions reduction goals.

5.1.3. Complete lack of EV charging stations in areas without residents

A significant concern of the findings is the areas without any EV charging stations. As stated in Chapter 1, the presence or absence of charging stations in a particular area is a major concern among Americans when considering EV adoption (Melaina, Bremson, and Solo 2013; Kang, Feinberg, Papalambros 2015). The absence of charging stations may lead to one not wishing to travel far from her home. Moreover, an absence of charging stations between metropolitan areas and places of residence will likely cleave the further-living residents' access metropolitan business districts.

However, the placement of EV charging stations for private-use vehicles in these unincorporated areas does not necessarily have to be the answer to California's EV adoption plan. Investment in electric public transportation may be a complimentary option for the state and county governments in unincorporated areas. However, dependence on public transportation may be a culture shock for many Southern Californians accustomed to using private vehicles.

5.1.4. The edge effect

For the analysis to commence, boundaries needed to be made for measurement purposes (i.e., the edge effect). First, one should note that when measuring the EV charging stations with a 1-mile radius, the individual is fully capable of traveling across the 1-mile radius. As stated in Chapter 1, the 1-mile radius was decided based on the appropriate distance between residents and amenities defined by municipal agencies (Liese et al. 2007; LA Metro 2022). Second, when looking at the EV charging stations by city boundary, the cities' residents (especially near a city's edge) are fully capable of crossing the boundaries for work and services. The EV charging station outlets within each city were measured to quantify each Los Angeles County city's EV charging station infrastructure and households.

5.1.5. Speculations

One piece of data that would improve the analysis would be to better understand where drivers are traveling. The non-residential areas between cities are certainly of concern, but the stark lack of EV charging stations in these areas should be further studied on a larger scale. To conduct this type of study, one would need to look at the traffic volume of the roads between cities to calculate how many EV charging stations are designed to accommodate the drivers on the road. This study area includes areas north and west of the Lancaster-Palmdale area, and, thus, commuters from Ventura and Kern County must be considered. Moreover, tourists are major consumers of EV charging stations' services and would ideally be considered in further research in these areas.

Another topic that was not fully examined was the cities' respective budgets and capital. Naturally, governments with more funding have more extensive resources to implement the infrastructure for a shift in the transportation network. This factor is of particular concern for the State government, as a financially-challenged city will not be able to fully fund/contract the building of EV stations no matter how much they would like to make the stations available to the public. Future studies will need to look into each local government's resources (e.g., budget, workforce/agency on staff, average and range of residents' economic status).

5.1.6. Individual cities and regions

Each region must be examined individually when implementing new EV infrastructure. The methods used in the analysis could be used in future analyses of individual cities. For example, one may look at the City of Industry, which has a low residential population (440 residents; the second smallest Californian city by population; City of Industry 2017b) but a high workforce population (68,000 employees; City of Industry 2017a). This peculiarity of the city will need to have more in-depth research before the placement of new EV charging stations beyond the residential population distribution and the frequency of roadway use.

Another unique type of region are those with less EV infrastructure than cities. In the case of the Santa Monica Mountains, there are multiple neighborhoods not affiliated with a city (e.g., Malibu Vista, El Nido, Monte Nido). These areas without a local city government and with a dependency on the county's infrastructure will need to be addressed (and based on the literature review, these have not historically been well studied).

Other areas in need of EV charging stations are tourist destinations that do not necessarily have a high population, if any population. Examples include state parks, cultural sites, and entertainment sites (e.g., theme parks, concert halls). Another case are the areas between major cities—more specifically, the area between Los Angeles, California, and Las Vegas, Nevada. The 270-mile stretch between the two cities does not have a consistent residential population. Therefore, the same type of analysis used to determine EV locations is different. Furthermore, this roadway bisects the Mojave Desert, which can reach temperatures of 103°F (39.44°C) during the summer months (Britannica 2021). A stranded driver in the desert may face fatal circumstances. When making location decisions, the state should consider increasing the number of fueling stations in areas.

5.2. Conclusion

This study looked into the current distribution of EV charging stations in relation to the residential population, roadways, proximity to each other, and governing bodies. Its purpose was to reveal the area readiness for EV charging station use to prepare for the Californian government's action to transition California's vehicles to 100% electric in an effort to combat climate change. By looking into the population distributions, one can see those in need of charging stations for their future EVs and how much congestion will occur for lack of infrastructure. In particular, the residents of the Santa Monica Mountains area (e.g., Beverly Hills, Malibu, Santa Monica, Topanga) are in need of more EV charging stations to better accommodate their population. Furthermore, areas like the cities of Santa Clarita, Lancaster, and Palmdale have EV charging station within parts of their respective city boundaries, but they do not have enough evenly distributed to service their populations. By looking at the roadways, one can account for those residing outside of the immediate area that require a fueling station during the drivers' travel times.

A few key studies influenced the project. For one, Altaweel (2016) demonstrated that EV drivers need knowledge of EV charging stations' location before driving; therefore, he identified census data and traffic infrastructure needed for a study, which were incorporated into this project's analysis. Second, this project utilized Chen's (2017) method to calculate the distance between amenities and EV charging stations but replaced the amenities with residential units. Furthermore, Zhang's and Iman's (2017) hotspot methods to locate EV charging stations in the Wasatch Front were used to identify EV charging stations in Los Angeles County.

By using the EV charging stations' location shapefiles supplied by the California Government and the census block information provided by the US Census Bureau, the analysis calculated the average distance between the average resident in each census block. Additionally, road segments' proximity to the EV charging station was mapped using roadway placement and charging station locations. The analysis was primarily performed with Esri's ArcGIS Pro, with additional assistance from Microsoft Excel, to reflect the government's resources.

The analysis resulted in two key maps depicting a residential areas' and roadways' accessibility to EV charging stations across Los Angeles County's network. As described in Chapter 4, clusters of EV charging stations were mainly in the contiguous region of Los Angeles

County, with two outlying clusters in the City of Santa Clarita and the twin cities of Lancaster and Palmdale. By adjusting the census blocks' number of EV charging stations through a per capita (based on household total) measurement, the final map depicted the number of stations per household. Though the results presented unique concerns in each region, of particular concern are areas with a residential population in unincorporated areas. The map also presented an issue in the areas further away from commercial areas (i.e., parks, non-developed areas).

By using the methods here, the State of California and its local governments can better prepare for their shift to a 100% EV traffic network through *transportation electrification*. Furthermore, other municipalities can better use the methods described in the project to understand their population's access to EV charging stations. By supplying the public with the proper resources for a comfortable transition, the State of California will be one step closer to addressing climate change.

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Appendix A Total Charging Stations in Los Angeles County by City

City Name	Total EV Charging Station	2020 Population	2020 Total Households	Household per EVC
Agoura Hills	3	20,291	7,619	2,540
Alhambra	7	82,903	31,475	4,496
Arcadia	6	56,574	20,472	3,412
Artesia	0	16,384	4,744	NA
Avalon	0	3,431	2,192	NA
Azusa	6	49,938	15,287	2,548
Baldwin Park	7	72,065	18,168	2,595
Bell	0	33,592	9,475	NA
Bell Gardens	0	39,496	10,189	NA
Bellflower	0	79,316	25,252	NA
Beverly Hills	27	32,845	16,334	605
Bradbury	0	935	360	NA
Burbank	30	107,337	45,615	1,521
Calabasas	6	23,241	9,290	1,548
Carson	11	95,471	27,669	2,515
Cerritos	10	49,528	16,353	1,635
Claremont	10	37,265	12,754	1,275
Commerce	5	12,710	3,614	723
Compton	1	95,687	24,722	24,722
Covina	3	51,344	17,498	5,833
Cudahy	0	22,805	5,855	NA
Culver City	26	40,862	17,902	689
Diamond Bar	4	55,054	18,814	4,704
Downey	20	114,350	36,091	1,805
Duarte	4	21,664	7,645	1,911
El Monte	11	109,260	29,846	2,713
El Segundo	27	17,251	7,492	277
Gardena	5	60,966	22,364	4,473
Glendale	23	196,488	80,170	3,486
Glendora	3	52,502	18,636	6,212
Hawaiian Gardens	2	14,138	3,803	1,902
Hawthorne	7	87,964	31,517	4,502
Hermosa Beach	3	19,708	10,024	3,341
Hidden Hills	0	1,727	635	NA
Huntington Park	0	54,881	15,492	NA
Industry	14	589	173	12
Inglewood	3	107,864	39,471	13,157
Irwindale	3	1,652	470	157
La Canada Flintridge	2	20,564	7,114	3,557
La Habra Heights	0	5,687	2,022	NA
La Mirada	5	48,025	15,455	3,091

City Name	Total EV Charging Station	2020 Population	2020 Total Households	Household per EVC
La Puente	0	37,966	9,899	NA
La Verne	0	31,304	12,206	NA
Lakewood	5	82,514	27,934	5,587
Lancaster	19	173,512	55,140	2,902
Lawndale	0	31,690	10,243	NA
Lomita	0	20,935	8,596	NA
Long Beach	60	466,861	179,575	2,993
Los Angeles	618	3,899,439	1,496,754	2,422
Lynwood	4	67,316	15,865	3,966
Malibu	7	10,513	6,491	927
Manhattan Beach	8	35,541	15,002	1,875
Maywood	1	25,115	6,690	6,690
Monrovia	4	37,990	15,261	3,815
Montebello	4	62,656	20,314	5,079
Monterey Park	3	61,126	21,559	7,186
Norwalk	4	102,794	28,473	7,118
Palmdale	18	169,386	49,668	2,759
Palos Verdes Estates	0	13,337	5,283	NA
Paramount	0	53,469	14,787	NA
Pasadena	34	138,753	61,663	1,814
Pico Rivera	1	62,116	17,366	17,366
Pomona	6	151,702	43,343	7,224
Rancho Palos Verdes	2	42,287	16,509	8,255
Redondo Beach	8	71,633	31,011	3,876
Rolling Hills	0	1,740	702	NA
Rolling Hills Estates	3	8,259	3,205	1,068
Rosemead	11	51,101	14,865	1,351
San Dimas	5	34,848	13,018	2,604
San Fernando	6	23,904	6,494	1,082
San Gabriel	0	39,494	13,432	NA
San Marino	0	12,507	4,479	NA
Santa Clarita	15	228,655	78,581	5,239
Santa Fe Springs	5	19,259	6,013	1,203
Santa Monica	59	93,025	52,353	887
Sierra Madre	0	11,280	5,100	NA
Signal Hill	7	11,812	4,735	676
South El Monte	1	19,627	5,072	5,072
South Gate	3	92,676	25,073	8,358
South Pasadena	1	26,912	11,135	11,135
Temple City	1	36,624	12,264	12,264
Torrance	28	147,060	58,776	2,099
Vernon	2	266	89	45
Walnut	2	28,405	9,160	4,580
West Covina	8	109,232	34,728	4,341
West Hollywood	26	35,918	25,919	997
Westlake Village	6	8,026	3,440	573
Whittier	2	87,299	29,952	14,976

Appendix B Assembly Bill No. 1550 CHAPTER 369 (Summary)

Assembly Bill No. 1550
CHAPTER 369
An act to amend Section 39713 of the Health and Safety Code, relating to greenhouse gases.
[Approved by Governor September 14, 2016. Filed with Secretary of State September 14, 2016.]
Chapter 6 LEGISLATIVE COUNSEL'S DIGEST
AB 1550, Gomez. Greenhouse gases: investment plan: disadvantaged communities.
The California Global Warming Solutions Act of 2006 designates the State Air Resources Board as the state agency charged with monitoring and regulating sources of emissions of greenhouse gases. The act authorizes the state board to include the use of market-based compliance mechanisms. Existing law requires all moneys, except for fines and penalties, collected by the state board as part of a market-based compliance mechanism to be deposited in the Greenhouse Gas Reduction Fund and to be available upon appropriation. Existing law requires the Department of Finance, in consultation with the state board and any other relevant state agency, to develop, as specified, a 3-year investment plan for the moneys deposited in the fund. Existing law requires the investment plan to allocate a minimum of 25% of the available moneys in the fund to projects that provide benefits to disadvantaged communities, as defined, and a minimum of 10% to projects located in those disadvantaged communities. Existing law authorizes the allocation of 10% for projects located in disadvantaged communities to be used for projects included in the minimum allocation of 25% for projects that provide benefits to disadvantaged communities.
This bill would instead require the investment plan to allocate (1) a minimum of 25% of the available moneys in the fund to projects located within, and benefiting individuals living in, disadvantaged communities, (2) an additional minimum of 5% to projects that benefit low-income households or to projects located within, and benefiting individuals living in, low-income communities located anywhere in the state, and (3) an additional minimum of 5% either to projects that benefit low-income households that are outside of, but within a $^1/_2$ mile of, disadvantaged communities, or to projects located within the boundaries of, and benefiting individuals living in, low-income communities that are outside of, but within a $^1/_2$ mile of, disadvantaged communities.
The bill would become operative only if AB 1613 of the 2015–16 Regular Session is enacted and becomes effective on or before January 1, 2017.
Vote: majority Appropriation: no Fiscal Committee: yes Local Program: no

Source: Gomez 2016

Appendix C Senate Bill No. 100 CHAPTER 312 (Summary)

Senate Bill No. 100
CHAPTER 312
An act to amend Sections 399.11, 399.15, and 399.30 of, and to add Section 454.53 to, the Public Utilities Code, relating to energy.
[Approved by Governor September 10, 2018. Filed with Secretary of State September 10, 2018.]
SB 100, De León. California Renewables Portfolio Standard Program: emissions of greenhouse gases.
(1) Under existing law, the Public Utilities Commission (PUC) has regulatory authority over public utilities, including electrical corporations, while local publicly owned electric utilities, as defined, are under the direction of their governing boards. The California Renewables Portfolio Standard Program requires the PUC to establish a renewables portfolio standard requiring all retail sellers, as defined, to procure a minimum quantity of electricity products from eligible renewable energy resources, as defined, so that the total kilowatthours of those products sold to their retail end-use customers achieve 25% of retail sales by December 31, 2016, 33% by December 31, 2020, 40% by December 31, 2024, 45% by December 31, 2027, and 50% by December 31, 2030. The program additionally requires each local publicly owned electric utility, as defined, to procure a minimum quantity of electricity products from eligible renewable energy resources to achieve the procurement requirements established by the program. The Legislature has found and declared that its intent in implementing the program is to attain, among other targets for sale of eligible renewable resources, the target of 50% of total retail sales of electricity by December 31, 2030.
This bill would revise the above-described legislative findings and declarations to state that the goal of the program is to achieve that 50% renewable resources target by December 31, 2026, and to achieve a 60% target by December 31, 2030. The bill would require that retail sellers and local publicly owned electric utilities procure a minimum quantity of electricity products from eligible renewable energy resources so that the total kilowatthours of those products sold to their retail end-use customers achieve 44% of retail sales by December 31, 2024, 52% by December 31, 2027, and 60% by December 31, 2030.
Under existing law, a local publicly owned electric utility is not required to procure more than a specified minimum quantity of eligible renewable energy resources under the program if it receives more than 50% of its retail sales from hydroelectric generation, as specified.
This bill would revise those provisions, limit the applicability of this exception to large hydroelectric generation, and reduce that threshold to 40%.
(2) Existing law establishes the California Environmental Protection Agency, establishes the State Air Resources Board within the agency as the entity with responsibility for control of emissions from motor vehicles, and designates the state board as the air pollution control agency for all purposes set forth in federal law. The California Global Warming Solutions Act of 2006 establishes the state board as the state agency charged with monitoring and regulating sources of emissions of greenhouse gases that cause global warming.
The Warren-Alquist State Energy Resources Conservation and Development Act establishes the State Energy Resources Conservation and Development Commission (Energy Commission) and requires it to conduct an ongoing assessment of the opportunities and constraints presented by all forms of energy, to encourage the balanced use of all sources of energy to meet the state's needs, and to seek to avoid possible undesirable consequences of reliance on a single source of energy.
This bill would state that it is the policy of the state that eligible renewable energy resources and zero-carbon resources supply 100% of retail sales of electricity to California end-use customers and 100% of electricity procured to serve all state agencies by December 31, 2045. The bill would require that the achievement of this policy for California not increase carbon emissions elsewhere in the western grid and that the achievement not allow resource shuffling. The bill would require the PUC and the Energy Commission, in consultation with the state board, to take steps to ensure that a transition to a zero-carbon electric system for the State of California does not cause or contribute to greenhouse gas emissions increases elsewhere in the western grid. The bill would require the PUC, Energy Commission, state board, and all other state agencies to incorporate that policy into all relevant planning. The bill would require the PUC, Energy Commission, state board, and all other state agencies to ensure actions taken in furtherance of these purposes achieve specified objectives. The bill would require the PUC, Energy Commission, and state board to utilize programs authorized under existing statutes to achieve that policy and, as part

of a public process, issue a joint report to the Legislature by January 1, 2021, and every 4 years thereafter, that includes specified information relating to the implementation of the policy.
(3) Under existing law, a violation of the Public Utilities Act or any order, decision, rule, direction, demand, or requirement of the PUC is a crime.
Because certain of the provisions of this bill would be a part of the act and because a violation of an order or decision of the PUC implementing its requirements would be a crime, the bill would impose a state-mandated local program. By expanding the requirements placed upon a local publicly owned electric utility, the bill would impose a state-mandated local program.
The California Constitution requires the state to reimburse local agencies and school districts for certain costs mandated by the state. Statutory provisions establish procedures for making that reimbursement.
This bill would provide that no reimbursement is required by this act for specified reasons.
Vote: majority   Appropriation: no   Fiscal Committee: yes   Local Program: yes

Source: De León 2018

Appendix D EXECUTIVE ORDER B-48-18

WHEREAS California is the largest market in the United States for zero-emission vehicles and approximately half of all zero-emission vehicles in the nation are sold in this state; and
WHEREAS California increased the number of zero-emission vehicles in the state by 1300 percent in six years—growing from 25,000 in 2012 to more than 350,000 today— and zero-emission vehicles now account for approximately 5 percent of all new car sales in California; and
WHEREAS the transportation sector still emits 50 percent of California's total greenhouse gas emissions and 80 percent of the smog-forming oxides of nitrogen; and
WHEREAS California's 2017 Climate Change Scoping Plan—which charts the path for meeting the state's greenhouse gas emissions and air quality goals—calls for major increases in zero-emission vehicles on the roads; and
WHEREAS Executive Order B-16-12 called for 1.5 million zero-emission vehicles on California roads by 2025; and
WHEREAS California's eight-year, $2.5 billion investment plan will help achieve the requirements of Executive Order B-16-12 by 2025 by funding more zero-emission infrastructure and continuing vehicle rebates for consumers; and
WHEREAS California can exceed its existing 2025 zero-emission vehicle goals by increasing the availability of charging and refueling stations and other zero-emission vehicle infrastructure; and
WHEREAS further boosting California's zero-emission vehicle market will strengthen the economy, improve air quality and public health, lower fuel costs for drivers and reduce the state's dependence on fossil fuels; and
WHEREAS California must continue to attract and encourage significant investments in zero-emission vehicles and infrastructure from utilities, car manufacturers and vehicle charging and re-fueling companies.
NOW, THEREFORE, I, Edmund G. Brown Jr., Governor of the State of California, do hereby issue the following orders to become effective immediately:
IT IS HEREBY ORDERED that all State entities 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.
IT IS FURTHER ORDERED that all State entities work with the private sector 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.
IT IS FURTHER ORDERED that all State entities continue to partner with regional and local governments to streamline zero-emission vehicle infrastructure installation processes wherever possible. As part of this effort, the Governor's Office of Business and Economic Development shall publish a Plug-in Charging Station Development Guidebook and update the 2015 Hydrogen Station Permitting Guidebook. IT IS FURTHER ORDERED that all State entities, in carrying out programs under their authorities, shall collaborate with stakeholders to implement this order, including but not limited to taking the following actions:

- Update the 2016 Zero-Emission Vehicle Action plan to help expand private investment in zero-emission vehicle infrastructure, particularly in low income and disadvantaged communities.
- Recommend actions that boost zero-emission vehicle infrastructure to strengthen the economy and create jobs in the State of California.
- Recommend ways to expand zero-emission vehicle infrastructure through the Low Carbon Fuel Standard Program.
- Support and recommend policies and actions that make it easier for people to install electric vehicle chargers in their homes and businesses.
- Ensure electric vehicle charging and hydrogen fueling are affordable and more accessible to all drivers.

This Order is not intended to, and does not, create any rights or benefits, substantive or procedural, enforceable at law or in equity, against the State of California, its agencies, departments, entities, officers, employees, or any other person.
I FURTHER DIRECT that as soon as hereafter possible, this Order be filed in the Office of the Secretary of State and that widespread publicity and notice be given to this Order.
IN WITNESS WHEREOF I have hereunto set my hand and caused the Great Seal of the State of California to be affixed this 26th day of January, 2018.

Source: Brown 2018