Finding a Place to Plug:

A Review of Factors Influencing Optimal Electric Vehicle Charger Locations

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Abstract

This paper explores the factors that should be considered when selecting a new location to place an Electric Vehicle (EV) charger. To increase the confidence in EV driving ranges and encourage the adoption of EVs the supporting infrastructure will have to rise to meet demand. Charging stations need to be optimized to account for driver preferences with regards to location and rate of charge. Variables such as proximity to trafficked routes and short wait times can attract drivers looking to recharge. The implementation of renewable energy to power EV charging can reduce the strain on the grid and lower energy costs while enticing drivers to use ‘greener’ stations. By understanding common characteristics of EVs drivers and identifying populations with these same traits’, stakeholders can target potential markets for successful projects. Using major findings of current EV studies and a dataset of existing EV locations in Tucson, Arizona, it is possible to determine that the stated research supports the existing data.

Keywords: Electric Vehicles, EV Charging, Renewables

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Introduction

The lack of supporting charging infrastructure to plug-in electric vehicles minimizes the benefits to the consumer, environment, and local economy. The increased adoption of electric and plug-in hybrid vehicles considerably decreases the consumption of fossil fuels, which has a positive effect on air quality (Fotouhi et. al, 2019). As more drivers are purchasing electric vehicles (EVs), governments and utilities should be finding ways to capitalize on the needs of the consumers and provide the necessary infrastructure to support them. Factors such as rate of charge, electricity costs and grid limitations all impact the potential profits of a charging station. Compounded by the number of dispensers a station might have, there are high costs associated with starting and maintaining a charging station.

The concerns of potential and current EV drivers tend to center around the remaining battery and the availability of their next charge (Fotouhi et. al, 2019). The accessibility of the next electrical dispenser is not as readily available as a gas station. For those looking to invest in the infrastructure to solve this issue, the effectiveness of an electric charging station needs to make economic sense. The owner will need to acquire and dispense cheap electricity to enough paying EV owners to get a return on their investment. Potential charging locations need to be located near where the drivers are, or where they are going. Utilities have strict limits on amounts of energy you can pull from the grid and expensive demand charges during the times of day that consumers would likely use the equipment. A potential way to offset these costs is using battery storage options or connecting a charging installation to a photovoltaic array (McPhail, 2014). Another consideration is proximity to frequently traveled roads and the availability of charging infrastructure.

While some developers and business owners might be motivated to install electric vehicle supply equipment (EVSE) solely because of the environmental benefits or public perception, the return on investment is a stronger metric that will drive continued development. A highly trafficked charging location with frequent use by EV owners has the greatest potential of generating enough revenue to offset the initial and ongoing expenses (Chao et al., 2017). Chargers should be situated in areas visited by EV owners to maximize usage. It is possible to predict optimal locations by analyzing the shared factors.

As infrastructure continues to develop, other less evident location factors will need to be explored to determine the factors that make a potential location more favorable than another. The purpose of this paper is to encourage and promote investment into in studies of factors influencing charging infrastructure by illustrating the potential financial and environmental benefits to both the drivers and stakeholders. It does so by answering the following questions: Where can charging stations be located to be mutually beneficial to drivers and the stakeholders that will be funding them? Can the utilization of renewable energy sources encourage EV adoption by lowering the financial costs, reducing strain on the grid, and further improving the environmental benefit of EVs compared to fossil fuel powered vehicles? The audience of such a study would be for business owners, developers, and small governments who are interested in installing chargers but who might be skeptical about the feasibility of introducing these systems.

This paper will cover how EVs differ from traditional cars and how different chargers are categorized. In the literature review, results of previous studies will be reviewed to find common themes between studies. Certain locations are better suited for specific chargers based on the charging level installed. Factors influencing locations are based on common driving routes, preferences of drivers, and reasons for that charging session. Exploring driver demographics and charging habits can provide insight into how to attract EV drivers. Taking the major findings from the literature review and a dataset of existing chargers located within Arizona, it is possible to deeper analyze the findings in the literature review.

Traditional Combustion Cars and Electric Vehicles

To highlight the benefits of electric vehicles compared to traditional combustion cars it is important to understand the terminology. Traditional cars run using petroleum (gas) in a combustion engine. Gas is a nonrenewable resource and when burned releases harmful gases and chemicals into the atmosphere. Electric vehicles do not burn anything rather they use stored electric energy in the form of a battery to propel the car. The battery capacity of an EV is comparable to the size of a gas tank in a traditional car; the larger the capacity, the further the car can go between charges/refuels. Similar to the ‘mile per gallon’ metric of traditional cars, EVs have efficiency ratings as well that vary from car to car.

The important metrics to understand is that a kilowatt (kW) describes the rate of energy flowing. A kilowatt-hour (kWh) is a quantity of electricity. A common comparison used to explain electric energy terminology is in terms of water. If a hose is running, the rate at which the water is flowing would be measured in gallons per minute, or kW if electricity, and the amount of water would be measured in gallons, or kWh in electricity (Nelder 2019). Applying this example to EVs, the amount of time it takes a charger to charge a car is dependent on the kW (rate) the charger can dispense and the amount of energy the battery can hold (measured in kWh).

How does this relate to dollars and cents? When refueling a traditional car at a gas station, the refueling cost is determined by the tank size of the car and price per gallon. With EVs the cost of recharging is driven by the battery size and price per kWh. Like fuel prices, the price of electricity also fluctuates. Traditionally there are peak times during busy hours of the day and ‘off-peak' hours during the night when energy is cheaper. The same amount of energy might cost less depending on the time of day. Tucson Electric Power (TEP) is the utility serving Tucson, Arizona. According to their website on-peak hours for businesses are between 2-8 PM in the summer and 6—10 AM and 5—9 PM in the winter (the remaining hours are 'off-peak). By opting into this plan businesses can save 4 cents per kWh in the summer and 1 cent per kWh in the winter. (SGS TOU 2021). This is a way to incentivize business owners to shift energy usage to off-peak hours. The addition of renewable energy sources or external batteries can also help with demand charges. For new and proposed charging stations, it is also important to note that many utilities limit the amount of energy pulled from the grid (at a time/per day) (Bhatti et al, 2016). It is in the best interest of the utility, the EV driver, and the station owner that most energy consumed is during these off-peak times.

Figure 1 below is an image of the type of charging infrastructure studied in this paper. This is an example of just one type of electric vehicle supply equipment (EVSE). This specific charger can dispense energy from two separate connectors. There are multiple connector handles and cables as there currently is no standardized connector that all EV cars use.

Figure 1, EV Charger. Used with permission from Power Electronics USA, Inc.

The next section will address differences in chargers and how they are classified.

Charging Levels

The amount of power dispensed and the rate at which it can be dispensed are the most notable factors differentiating EV charging levels. In a study by Cave and De Young in association with the National Aeronautics Space Administration (NASA), they provide the below table that explains the differences between the charging levels.

	Level 1	Level 2	Level 3 (fast charging)
Power Supply	120 V @ 12-20 amps	240 V @ 30-80 amps	up to 600 V (DC) or 480 V (AC) @ 100 amps
Energy Use Charateristics	1-1.5 kW/hr	3-7 kW/hr	75-100 kW/hr
EV Range Boost	2-5 miles/hr	8-20 miles/hr	60-80 miles (< 30 minutes)
Bottom Line	Widely available, low cost ($10 to $1000). Ideal solution to provide EV owners with more range , and to gain experience in workplace charging.	Widely available, moderate cost ($500 to $6000). Many 3rd party equipment and service provideers. Ideal solution tto provide EV owners substantial boost in range in less time.	Limited availability, high cost (>$15,000 + installation). As of late 2012, this solution is not practical for most workplace charging sites.

Table 1 EV Charging Levels

Level 1 charging is typically associated with residential charging where the EV owner can slowly charge overnight. These chargers are typically the cheapest to install and operate as they can connect to most existing 120 Volt outlets. Besides the residential home, other locations that can benefit from Level 1 chargers are hotels, housing complexes or office buildings where employees can leave their car charging for long periods.

Level 2 and 3 charging are typically located in more commercial areas and are capable of higher power delivery rates and shorter charging times (Cave and De Young, 2014). Level 2 chargers are also an attractive option for developers who might not know if their facility necessitates the substantial investment that comes along with the Level 3 chargers. Chargers that fall into the level 2 category will need a dedicated 240V outlet (like a dryer or oven outlet in the home) and may be slightly more expensive to install. These chargers would be ideal for locations where people might spend anywhere from thirty minutes to a couple of hours away from their car, e.g., shopping centers or restaurants. Level 3 chargers are the fastest of the three and have high costs associated with hardware, install fees, and electricity usage. These chargers are also known as ‘DC (Direct Current) fast chargers.’ With level 3 charging, DC power is supplied straight from the EVSE to the battery. These chargers are commonplace at highway gas stations as the EV driver’s goal is to recharge quickly and be on their way to their destination.

Literature Review

A baseline understanding of Electric Vehicles and the characteristics that make up an EV owner will aid in understanding the optimal locations for infrastructure.

Placement of Different Chargers

Chao, Yih-Fang and Gupta (2017) developed a simulation of EV charging locations in the San Pedro district of Los Angeles, California. Using a combination of geographic and demographic data they found that optimal locations for future EV charging stations strongly correlate to the traffic heat map of the area. The traffic heat map is a map showing which roads and intersections are the most frequently used. The studied district includes many residential and commercial areas and the roadways that connect them. They separated providers into three categories based upon the charging level each would offer (provider 1 provides chargers at level 1, etc.) They found that Level 1 EVSE had a higher demand than level 2 or 3 charging stations. Optimal locations for the level 1 and 2 chargers were in highly trafficked commercial areas. This could be due to level 1 chargers being significantly slower and needing more locations. Slower chargers need more time to charge the EV battery. Therefore, more chargers are needed at lower levels to accommodate cars utilizing the chargers for longer. It is more beneficial for providers 1 and 2 (Level 1 and 2 chargers) to have a higher quantity of locations spread evenly across an area. On the other hand, the level 3 provider is more likely to place fewer chargers at some 'hot' locations (Chao et al., 2017). The best locations for level 3 chargers are near highways, especially highway intersections. DC fast chargers can recharge a car much quicker than level 1 or 2 chargers. In the same amount of time, it takes for a level 1 or level 2 charger to completely recharge one vehicle, a DC fast charger could charge multiple cars in the same timeframe.

Additionally, Chao et al. (2017) found that "due to product differentiation, [different charging levels] significantly soften the price competition so that they do not need to spatially separate from each other to further relax competition." In other words, it is preferred to cluster charging stations of different levels near highly trafficked areas as different level chargers fulfill different customer needs. Instead of prioritizing being the sole charger within a given radius, it is more beneficial to diversify the charging levels offered. EVSE with different charging levels installed in the same location do not compete for the same users. (Chao et. al, 2017). Stakeholders should balance increasing new EVSE locations to maximize coverage with providing charging level options for divers.

Shukla, Verma, and Kumar (2019) build on this idea by optimizing ideal sizes of EVSE based on distribution network constraints and charging demand. This study specifically looks at DC fast-charging stations as this type of EVSE pulls the most power from the localized grid. The energy needed to power these fast chargers is highly variable based on the demand of EV users. As lower-level chargers pull a smaller amount of energy over a longer time frame, multiple chargers running simultaneously do not stress the grid. Comparatively, DC fast chargers can dispense fifty times more kWh than a level 1 charger so a high quantity of dispensers at a site can cause a strain on the grid if not balanced properly. But, if EV drivers underutilize these chargers, the owner risks financial strain. For a charging station to be useful and profitable, it should have minimal idle time not connected to an EV. However, if a charging station is too popular and EV users need to wait to charge their vehicle, they might not use the station due to the inconvenience of waiting. Drivers are willing to wait an average of 10 minutes to start charging their vehicle (Shukla, 2019). This underlines the need to balance between the high productivity of a charging station and reduced wait times for users (Shukla et al., 2019). Another valuable finding is that the optimal location of a charging station is not static. As new EVSE continues to be installed and more area is within the service radius of existing chargers, ideal locations will shift to fill gaps (Shukla, 2019). When siting EVSE, many outside factors are contributing to the popularity and potential profitability of a charger.

Range Anxiety

Over the past 100 years, society has developed a network of roadways dotted with gasoline stations to aid in the mobility and confidence of car owners to drive long distances. However, as EVs are relatively new, the lack of supporting infrastructure is one of the main concerns facing potential EV buyers. Guo et al. (2018) found stations should be located based on the drivers' 'range anxiety.' The authors describe range anxiety as "(…) the concern that the driving range of EV may not be sufficient to reach its destination and is a major psychological obstacle to customers' purchasing intentions" (Guo et al., 2018). The worry that their car battery will not be sufficient to get the user to their destination (and that there will not be adequate infrastructure to support charging) is a substantial worry consumers' have about switching to EVs. The remaining charge needed to trigger a driver's range anxiety depends on the individual driver. This is comparable to traditional driver's preferences on how empty they let their gas tank get before filling up. In the same way that combustion cars have different sized gas tanks and different fuel economies, EVs have different battery capacities and kWh usage per mile.

Factoring into this range anxiety is the deviation tolerance that users must stray from their preferred route to reach a charging station (Guo et al., 2018). Applying the findings to a map of a Chinese province indicated the best locations to place new charging infrastructure. To minimize the inconvenience of driving off route by minimizing the distance needed to reach the charger, the researchers found that advantageous locations could be separated into three categories. The first category of stations that made up over half of the proposed locations were places at, or near, highway intersections. The second type identified were along typical driver routes between neighboring cities or points of interest. These were classified as origin-destination routes. The last category of ideal proposed locations are along roadways to remote cities within the geographic area of the study. Potential EVSE locations should use these categories as a framework.

One way to lessen the effects of range anxiety is by increasing the EV's battery capacity and increasing the reliability of the range predictions based on the percentage of the battery remaining. Increases in battery technology will lead to long drive ranges and fewer charging sessions needed, therefore fewer chargers. Unfortunately, these developments take time and are dependent on the car companies. The best way to increase adoption on a smaller scale is to carefully consider the multiple factors contributing to range anxiety like driver preferences in regard to distance convenience and range concerns.

Charging and Renewables

One way to offset some of the costs of owning and maintaining a charging station is by using renewable energy to power the chargers. In a 2016 paper, researchers looked at the willingness of consumers to pay additional money for energy coming from renewable sources. With data from a previously collected survey of California residents and their survey, the researchers found that the utilization of renewable energy is highly valued among EV drivers (Nienhueser, 2016). The referenced study of California drivers found that out of 1400 EV drivers, "39% of the participants had a photovoltaic (PV) solar system on their home, with another 17% planning on installing PVs in the next year" (Nienhueser, 2016). These figures show that compared to the general public, EV drivers place an increased importance on the utilization of renewable energy to recharge electric vehicles.

The primary metric evaluated in this paper was the "willingness to pay" of EV drivers. Out of 188 responses they found that: "At 66%, the majority of participants prefer that the EVSE offer renewable energy with every charge, while 19% prefer renewable energy be provided as an option, 14% like these options equally and 0.5% prefer the chargers not offer renewable energy" (Nienhueser, 2016). Typically, EV drivers charge their cars at home. However, this study asked participants if knowing that charging stations outside the home were powered by renewable energy would increase their willingness to pay for charging sessions. Nienhueser (2016) found that if renewable sources powered a given charging station, participants would increase the amount of outside the home charging sessions per month.

Not only do EV drivers prefer to use EVSE with renewables, but they are also willing to pay more for the energy consumed. While there are higher upfront costs associated with renewable coupled EV charging stations, these costs are not so high that they cannot be recouped. Amortized over multiple charging sessions by multiple users, this additional cost is not a deterrent. While these results come from a survey instead of studied behavior, it shows promise that marginally higher costs for kilowatt-hour charging are not a deterrent and could possibly be an incentive for some users.

Societal Factors Leading to Increased EV Adoption

Increased EV adoption is not just reliant on the EVs themselves; there are induvial and societal factors that form driver's opinions and their likelihood to purchase an EV. Drivers' opinions and community demographics can be studied to determine locations where new EVSE will have a higher chance at success. Stakeholders should place value on research into a potential areas' opinion on EVs as it can indicate if investment in this emerging technology will be beneficial.

The data collected in the study 'Impacts of renewables and socioeconomic factors on electric vehicle demands' examines the number of EV sales in 14 different countries between 2010 and 2015. The analysis was done on data originally gathered by the International Energy Agency (IEA). Countries included in this review are: USA, China, Germany, UK, France, Canada, Sweden, Norway, Italy, Spain, Portugal, Japan, South Korea and New Zealand. This specific study also included independent variables from the World Bank and Organization for Economic Cooperation and Development. The sales volume of EVs served as the dependent variable. They compared the countries' sales amount per 100,000 people to 7 variables: renewables, gas prices, charger-density, education, population density, GDP per capita, and urbanization. The researchers used an econometric model to analyze the results. While GDP and urbanization did not have apparent impacts, the other five variables did. Researchers concluded that locating future charging stations near highly populated areas with college-educated adults would increase demand for EVs (Li et al., 2017). In a study of Hawaiian EV driver characteristics, "A zipcode with a $10,000 higher median income is associated with 8% more registered EVs, and a 1000 person increase in the population with a Bachelor's degree or higher is associated with 19% more registered EVs" (Wee et al., 2020). By placing EVSE in communities with a higher population of college-educated adults with higher incomes, stakeholders can predict higher EVSE demand.

Li et al. (2017) concluded that: "when a country can increase one percent of renewable share in total electricity, it may sell 6% more EVs per 100 thousand people." Possible reasons for the increased interest in EVs are that "Consumers with environment awareness want electricity with renewables," and renewable energy can decrease the consumer's energy costs. The potential to use the EV battery as an energy storage system gives the consumer an option to 'sell' the stored energy back to the utility during peak usage times. This allows the utility to offset some of the unpredictability with renewable energy sources and lower grid demand during peak times. The customer can benefit as well. The consumer is incentivized to sell back the power at peak times and charge during cheaper 'off-peak' times. Currently, there are technical limitations to this concept but the potential for this type of power-sharing is very attractive for utilities and their customers.

Determining How Charging Stations Are Used

Sadeghianpourhamami, Refa, Stobbe and Develder (2018) published a study analyzing the relationship between drivers and their charging habits. The data used in their analysis is from charging sessions in the Netherlands between December 2014 and December 2015. The researchers were able to categorize three groups of drivers using these public stations, those who are charging: near home, near work, and those who 'park to charge' (Sadeghianpourhamami, 2018). The researchers examined data points of individual chargers over a year and categorized them based on the shared characteristics they had. Figure 2 shows a graph of their findings. To better understand how to read the graph, imagine a user that starts charging their EV at 6 PM (18:00) and disconnects the charger at 6 AM (06:00). To find where this data point would lie on the graph below, find 18:00 on the X-axis as this is the time the user starts charging. On the Y-axis is the time the user would disconnect (06:00). This specific user's charging session falls directly in the middle of the pink-colored block, or users that 'charge near home.' Users that charge near home have charging spans that start in the evening and may last overnight. Customers whose habits indicate they charge near work typically use the stations between the morning and evening. According to their assumptions, the largest group of users fall into the 'park to charge' category—62.86% of the total data points (Sadeghianpourhamami, 2018). They hypothesize these are users who do not use these stations due to proximity to work or home but solely because their car battery is low. This conclusion is further supported by the shorter charge and idle times when compared to the other two categories.

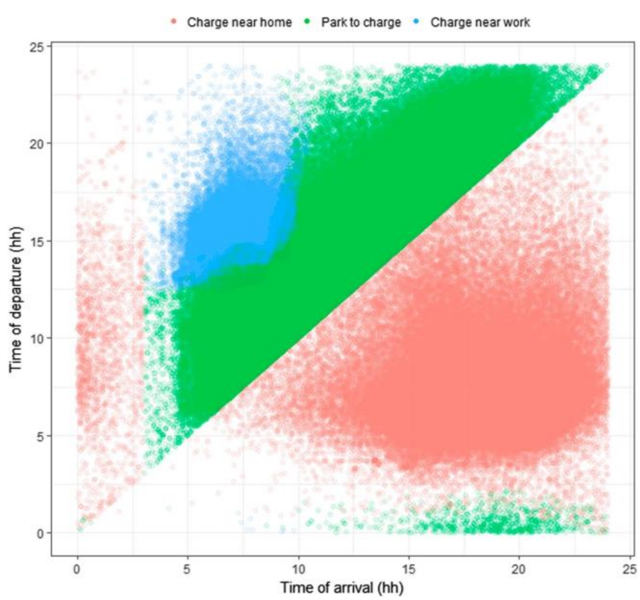


Figure 2, Showing reproduced graph of charging Sessions (Sadeghianpourhamami, 2018).

There are a couple of notable variables when looking at how these behaviors might differ from the US. In Europe, fewer people have access to private garages or dedicated parking spots and might not have the option to ‘charge at home.’ EV users have higher access to personal EV chargers making ‘charging near home’ a less prevalent category in the US. Commute lengths are generally longer in the US, which allows for greater depletion of the EV battery. This could lead to an increase in ‘charge near work’ users.

Methodology

Simply knowing the ideal characteristics to site successful EVSE locations does not mean these factors have been applied when selecting a location. The studies in the literature review, in theory, should apply to the dataset of existing EVSE locations. The data extrapolated from these sources aims to explain if the findings of the reviewed studies are corroborated with the actual locations of existing EVSE. The data collection method utilized is a combination of the above literature review and a second-hand data set. The United States Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy records the number of charging stations across the United States. The common factors between the observed locations and the previous findings are explored and validated in the next section.

Data Application and Discussion

As of April 2021, there are a total of 744 public charging stations with 1,864 possible charging ports available across the state of Arizona (*Electric Vehicle Charging Station Locations* 2021). The dataset of existing EVSE locations within Arizona is shown in figure 3. The green dots denote a location with either Level 2 chargers or DC fast chargers. Existing and proposed EVSE should be in areas where there are EV drivers, or areas these drivers want to go. The categories found by Guo et al. (2018) can group sites based upon the ‘need’ they fulfill for the driver. A large number of sites within city limits can be categorized as locations that help drivers recharge during normal origin-destination trips. The clusters of sites shown in and around the largest cities—the Phoenix metro area and Tucson fit this category.

Beyond the expected locations in the city, the remaining locations tend to be located along the state’s major roadways. This is not surprising as the Guo paper indicates the optimal charging stations are located at highway intersections and along familiar routes. These frequently traveled roads make a network of charging stations through the interstates that traverse the state. These locations help to connect remote areas and lessen range anxiety of long road trips. Locations are good markers of progress towards widespread adoption of EVs and a widespread infrastructure to support it.

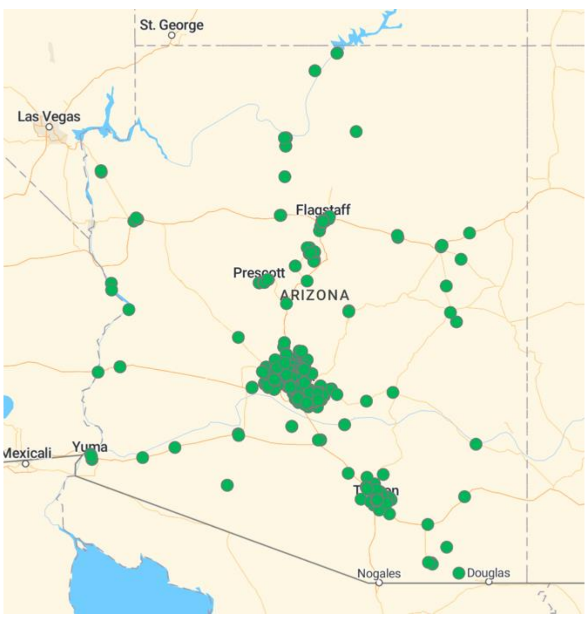


Figure 3 Locations of EV Chargers in Arizona

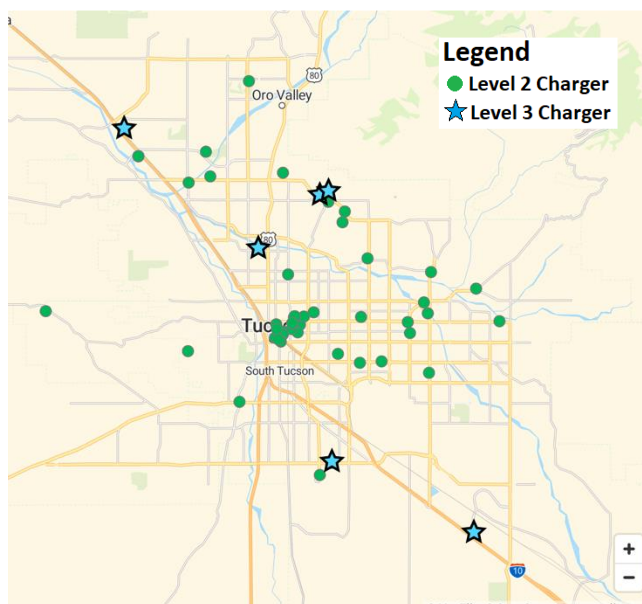
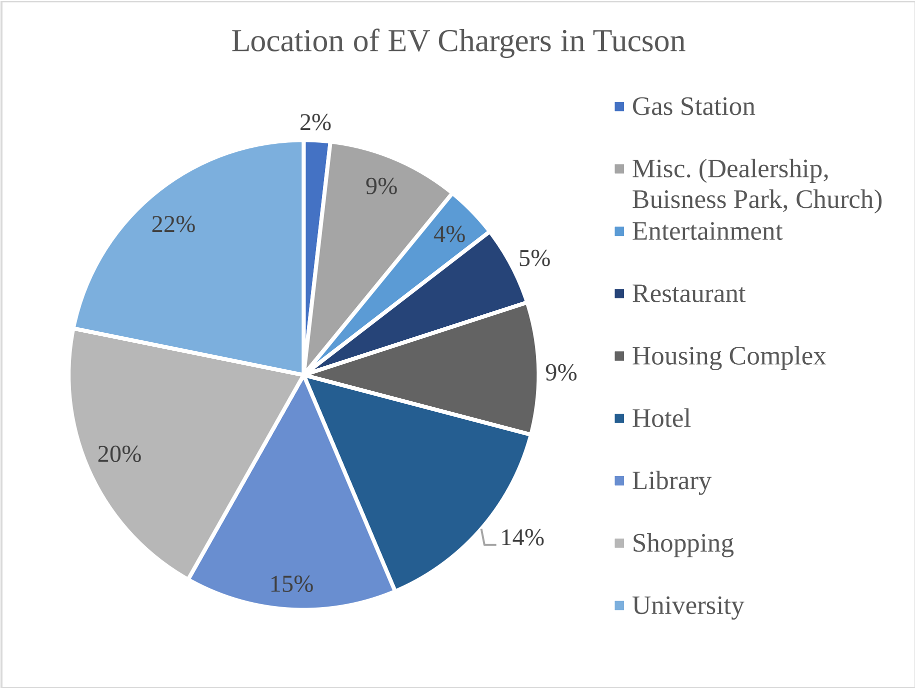


Figure 4 Locations of EV Chargers in Tucson, Arizona (DOE 2021)

Looking at Tucson specifically, there are 55 charging stations listed as open to the public, see Figure 4. These indicate 55 separate locations of EV chargers; this does not consider the number of dispensers at each location. The locations of the Tucson chargers were identified and put into categories using the same dataset from the DOE. The locations were put into nine different categories: University, Shopping, Library, Hotel, Housing Complex, Restaurant, Entertainment, Gas Station, and Miscellaneous. The percentage of locations that fall into each category is shown in Figure 5.

Figure 5



Graph of dataset from the DOE showing the percentage of EV charger locations in each category.

The type of charger installed at a given location can indicate the reason an EV driver might use that specific location. Level 2 chargers are slower and cheaper to install and maintain. Reiterating Cave and De Young (2014) results, these chargers have been installed at locations where the user is looking to 'top off' their battery. Level 2 chargers in Tucson are in commercial areas or locations where drivers are likely to spend 30 minutes to a couple of hours. Hotels and housing complexes like apartments are great for level 2 chargers as the user would be able to charge at a slower rate overnight while energy costs are low. The spread of level 2 chargers around Tucson is a good example of the conclusions in the study by Chao (2017).

The congregation of chargers in the center of Tucson corresponds to the chargers located within the University of Arizona and downtown Tucson. The largest category of EV chargers in this dataset (22%) was associated with the University of Arizona locations. This can indicate a couple of things about EV ownership in Tucson. Applying the conclusion that Li et al. (2019) found regarding college-educated adults, increasing charging infrastructure among a college-educated population will lead to higher EV demand and adoption. A higher percentage of college-educated adults results in higher EV registrations (Wee et al., 2020). Chargers located on the University campus are likely to serve students and faculty and encourage continued expansion of EVSE.

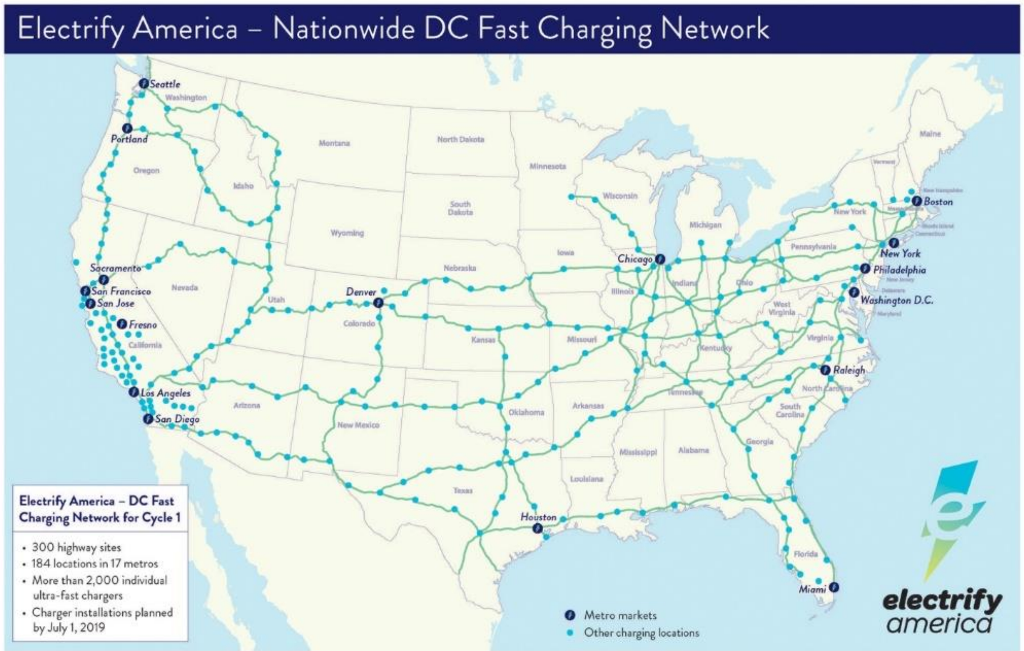
Out of the 55 different locations within Tucson, there were only six locations that had DC fast chargers. In figure 4 these 6 locations are marked with a blue star. Half of these sites were categorized as located within ‘Shopping’ centers. The other three locations were categorized as located at a dealership, a restaurant, and a gas station. The three most Northern DC fast charger locations are the locations categorized as ‘Shopping.’ The two stars located next to each other indicate two different DC fast chargers in the same shopping complex but owned by different charging networks.

Demographic data can be help explain some of the visible trends. The area of Tucson where the two DC fast chargers are located is called Catalina Foothills. This area of Tucson is known for being wealthier than the surrounding areas of Tucson. However, the area labeled as South Tucson is one of the poorest areas of Tucson. Applying the demographic trends found in Wee et al. (2020) income and education are factors that can greatly affect the adoption of EVs and the need for supporting infrastructure. The percentage of people with a bachelor's degree or higher is 67.8% for Catalina Foothills, 27.4% for Tucson and 5.4% for South Tucson (U.S. Census Bureau, 2019).

According to data from census.gov, Catalina Foothills has a median household income of $92,929 and a percentage of people in poverty of just 5.8%. In comparison, Tucson has a median household income that is less than half of Catalina Foothills at $43,425 and a percentage of people living in poverty at 22.5%. The median household income is $24,967 and the percent of people living in poverty is 43.7% (U.S. Census Bureau, 2019). South Tucson is located at the junction of Interstate-10 and Interstate-19. Highway intersections should be an attractive place to install EV chargers however, there are no EVSE currently installed in South Tucson. The population characteristics in the comparatively wealthy Catalina Foothills, compared to the poorer South Tucson, can partly explain the contrast of EVSE. This shows the demographics of an area can significantly influence decisions even in an otherwise attractive location. However, there are incentive programs offered by some utilities that encourage businesses in lower income areas to install EVSE. For example, TEP in Tucson offers the 'Smart EV Charging Program' that offers 75-85% rebates depending on the level installed (Smart EV Charging Program 2021). By offering these programs more EVSE can be installed in areas that might not typically be a candidate for investment.

Corroborating the conclusions detailed earlier in Guo et al., the locations in the Northwest (shopping center) and South East (gas station) of Tucson are situated on the Interstate running through Tucson. Electrify America is one of the largest manufacturers of EVSE in the United States. They are currently planning a network of future DC charging stations along the country's interstates and major cities; see Figure 6. DC Fast Chargers are more expensive per unit and have higher costs to install. Locating these chargers near highways and shopping centers is optimal for drivers to benefit based on charging needs and proximity on routes that value quick charges. Greater amounts of drivers, charging at locations is beneficial to stakeholders to recoup costs. The proximity of DC fast chargers to highly trafficked roads, lessens range anxiety by giving EV drivers higher confidence that supporting EVSE will be on their driving routes.

Figure 6



Map of the US Showing locations of planned DC Fast Chargers. From Electrify America

To have the greatest impact, ultimately, charging stations need to be close to or on the way to locations drivers are already going. The results show an overlap of common characteristics of optimal EVSE locations. Different charging levels have different optimal location characteristics based upon drivers' needs and stakeholder's financial goals. Level 1 and level 2 chargers with cheaper energy and installation costs can be implemented more widely for frequent use by EV drivers.

Conclusion

This paper aims to answer the following questions: is it was possible to install chargers in locations that are beneficial for drivers and owners? Can the use of renewable energy to charge EVs further help the environment by lowering costs and promoting additional EV users. Drivers concerns and expectations play a large role in the adoption of these systems. Drivers need to have the confidence in electric vehicle's themselves and the supporting infrastructure that will make it possible to recharge in public if needed. The problem for potential providers is finding locations to install charging stations. There is a myriad of variables that should be considered when choosing a location. Using the data studied earlier in this paper, we can hypothesize that installing EV chargers in highly trafficked commercial areas will see large amounts of users. New infrastructure should be in destinations that EV drivers are already going to. EVSE must balance the desire for high utilization of chargers with low wait times for users. Investors will want attract 'park to charge drivers' as they will not only maximize usage of the chargers but also have the greatest impact on the surrounding businesses. While it is possible to estimate where future charging stations would have the most benefits, currently installers have prioritized the wealthier and more educated communities. These areas are more likely to have higher EV registrations. As EV adoption grows and user demographics expand, less apparent locations will need to be reviewed to meet demands of a wider userbase.

Investing in new electric vehicle charging infrastructure can be expensive and hard to finance. It is important that the investors know that they will be able to recoup the costs of their investment. It has been shown that increases in renewable sources of energy, will also increase the amount of EVs on the road (Li et. al, 2017). With more electric cars on the road drivers will need more options to charge their cars. Renewable energy coupled EV charging stations can attract EV users who normally might charge at home while still profiting by selling energy at a higher rate. Incorporating renewable sources of energy or using external batteries to offset or lower electricity costs is mutually beneficial to the energy provider and the EV owner. With thoughtful consideration to external factors, it is possible to find an optimal location for future EV chargers, which can provide both economic and environmental benefits to a community willing to invest.

Limitations

Limitations of this work include using mixed datasets from Europe and the United States and applying that to US drivers' behaviors. This is generalized for the Arizona environment and assumes some environmental factors based on the author's knowledge of Arizona.

Further Recommendations

Recommendations for continued research would be to look at commercial programs more in-depth. Additionally, a cost-benefit analysis on the incentive programs that Utilities offer could document ways to offset costs. Potential EV charging locations is highly dependent on geographic and socioeconomic factors. These can vary widely from city to city and zip code to zip code. A more in-depth review of cost analysis for different areas and different renewable energy strategies would be helpful.

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