Electric Vehicles Charging Infrastructure Integration Into The Electric Grid Considering The Net Benefits To Consumers

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Abstract—**The Electric Vehicle (EV) market is one of the most rapidly changing and fastest growing high-tech sectors in the United States. The relatively small number of large-scale public vehicle-charging stations makes recharging electric vehicles problematic, if not impossible at times. This study aims at addressing "How to properly integrate EV charging infrastructure into the electricity system and deliver net benefits to the consumers?" To answer the research question, we have built a prototype of Geographic Decision Support Systems (GDSS), which is an elegant, interesting, and novel solution, to demonstrate how an interactive, computer-based system can assist in decision-making considering the net benefits to consumers and the potential benefits to the grid. The proposed solution provides evidence that GIS can play an integral role in the problem domain.**

Keywords-dispatchable grid resource; battery range; V2G technology

I. INTRODUCTION

The Electric Vehicle (EV) market is one of the most rapidly changing and fastest growing high-tech sectors in the United States. According to some recent estimates from the United States Department of Energy's Clean Cities program [1], the U.S. has approximately 482,000 EVs, 14,000 public charging stations, and 36,000 charging outlets. The U.S. market currently has over 20 electric vehicle models from 12 manufacturers. To increase the adoption and use of plug-in electric vehicles, President Obama announced the "EV Everywhere Challenge" in 2012 as a part of the Energy Department's Clean Energy Grand Challenges. It aims "to make electric vehicles more affordable and convenient to own and drive than today's gasoline-powered vehicles within the next 10 years." [2]. Similarly, a Bloomberg New Energy Finance report [3] suggests that the sale of electric vehicles will hit almost 90 times the equivalent figure for 2015 by 2040. The report also highlights that, by year 2022, electric vehicles will cost the same as their gasoline-driven equivalents, the point from where the sale of EVs will takeoff. California's target is to have 1.5 million EVs on the road by 2025, which is more than 600% increase over the roughly 200,000 EVs it has today [4]. According to Trabish [5], EV sales have already outperformed infrastructure growth, which is a problem that is expected to increase with the skyward trend of the EV sales.

The relatively small number of large-scale public vehicle-charging stations makes recharging electric vehicles problematic, if not impossible at times. Supporting California's target to have 1.5 million EVs on the road by 2025, a rapid expansion of charging infrastructure (between 150,000 and 750,000 non-home charging stations) is needed [6]. Faster adoption of EVs will require flexibility in charging. Various analyses suggest that more charging stations are necessary to accommodate consumer demand for convenient electric vehicle recharging but the question is where these charging stations should be located. Decisions on making more charging stations are not as simple as simply opening more stations. The reason is that an electric charge depends on and impacts the overall electric grid in a region. Charging an electric vehicle is, in some instances, the equivalent of adding three houses to the grid and the electric grid is not ready for these stratospheric spikes in power demand [7]. Utilities need to keep a close eye on the grid constraints as they plan EV charging stations infrastructure in order to avoid grid reliability problems, power outages, and other unplanned costs that might occur due to peak demand influences and the grid overload. According to SDG&E calculations, if California's targets by 2025 (1.5 million EVs) are all gotten charged during peak times, it could add almost 10,000 MW of new peak load to the existing 64,000 MW load on California's grid [6].

An additional point is that deploying networks of EV charging stations can stabilize and bring benefits to the grid in locations where there is excess power. Looking at possible benefits and the new electricity grid of the future, EV charging can absorb mid-day solar over-generation and alleviate wind curtailment at night. Charging EVs when non-dispatchable assets like solar and wind generators are producing more energy than the electricity system can help flatten out the duck curve of demand and reduce the extent to which supply suddenly escalates. All of these characteristics reduce system costs, benefit ratepayers, and improve the profitability of generators [6].

Considering the grid capacity constraints, implications of EV charging if it is not appropriately incorporated into the electricity system, and the potential benefits of infrastructure planning, this paper addresses the research question: "How to properly integrate EV charging infrastructure into the electricity system and deliver net benefits to the consumers?" Previous literature showed insufficient attempts by researchers to provide solutions that can assist in decision-making with respect to this research question. The existing research was developed bearing in mind only the net benefits to EV owners while neglecting the electric circuit capacity constraints and the impact of the EV charging infrastructure on the electric grid.

The objective of this research is to build a Geographic Decision Support Systems (GDSS) prototype, which is an elegant, interesting, and novel solution to assist in the placement of electric vehicles charging stations. The goal is to demonstrate an interactive, computer-based system to assist in decision-making considering the net benefits to consumers and the potential benefits to the grid.

This research paper is based on the process steps in Takeda, et. al.'s design cycle to create the artifact/solution [8]. This cycle has five main steps, which are the awareness of the problem, suggestion, development, evaluation, and conclusion. The awareness of the problem phase has been indicated as mentioned above in the introduction and problem definition section. The suggestion phase is the decisions that have been made to develop the prototype to assist in the placement of electric vehicles public charging stations. In Section 2, we indicated the steps taken to develop and create the prototype considering some factors that will impact decision-making; in Section 3, we analyzed the prototype and wrote our findings; in Section 4, we explained the evaluation section of the paper; in Section 5 and 6, we highlighted the limitations, future work, and conclusion.

II. ARTIFACT: GDSS PROTOTYPE

This study proposes a GDSS solution to assist in the placement of EV public charging stations as shown in Figure 1. A GDSS model can aid in EV charging stations location choices and provide actionable information for utilities, state-level decision-makers, and other stakeholders who are concerned about the EV integration as a dispatchable grid resource (a resource for which its power output can be adjusted, turned on or off at the request of the power grid operators). Though a GDSS can provide a solution to address the placement of all types (levels) of EV public charging infrastructure, we chose to only focus on level 2 EV public charging stations as we are building the prototype for illustration purposes.

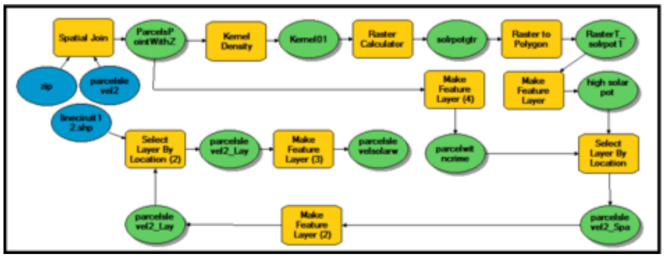


Figure 1. GDSS Prototype For Placement Of Electric Vehicle Charging Stations

The factors that we have considered and used are safety, number of EV in the area, exploiting excess power, grid capacity, convenience, and accessibility. We identified these factors as follows:

1) Security: safety assessment based crime rate [9].
2) Number of EV in the area: total count of vehicles that can be plugged into an electric power source to charge the battery, which is the sum of battery electric vehicles (BEVs) and Plug-In Hybrid electric vehicles (PHEVs) [10].
3) Exploiting excess power: locations with potential excess solar and/or wind generation [11]).
4) Grid capacity: Load capacity of electric circuits determined by the maximum load a circuit can handle safely without overheating. The minimum requirement of Load capacity is 12 kilovolts modern circuit ([11]; [12]).
5) Convenience: Anything that saves or simplifies work, adds to one's ease or comfort, which is short distance and comfortable place to spend time. For example, destination location for work and/or home ([13]; [14]).
6) Accessibility: the maximum and the minimum distance that EV owners are willing to walk from and to charging station. The maximum walk is 0.5 mile [9].

A. Data Selection and Acquisition

1) Crime Index Data: LA County Portal is the data source for the 2016 crime index data. The LA County crime index database is available at [15].
2) Parking Lot boundaries Data: LA County GIS Data Portal is the data source for 2014 dataset which contains the boundaries of the parking lots in the County of LA 5000 square feet and larger for commercial, industrial, and government properties. The database is available at [16].
3) Southern California Edison (SCE)'s Distributed Energy Resources interconnection Map (DERiM) Capacity Analysis Data: SCE's DERiM includes power electric lines and the capacity analysis in

kilowatts by circuit line. The data is retrieved from DERiM web map at [17].

4) Solar Parcel Data: LA County is the data source for the solar parcel data. The link to LA County solar parcel database is available at [18]. LA County solar map provides key data elements such as: total roof area and area suitable for solar, potential solar system size, solar potential annual output, and potential cost savings.

B. *Data Preparation Steps*

1) Data was extracted and loaded into ArcMap to show four map layers. The first layer showed LA county solar data by parcel while the other layers showed the crime index, SCE electric circuit capacity by circuit line and the targeted parking lots.
2) The targeted parking lot types were suggested by researchers as shown in Table 1 to meet the specification of the convenience factor for level 2 EV public charging stations. Similarly, walking distance from the potential targeted locations were set to 500 feet to meet the requirement of the accessibility factor.
3) According to Sultan et al. [19], the solar rooftop's potential electricity output was calculated for each parcel by multiplying the rooftop's solar panel area, the solar panel yield, the annual average solar radiation on tilted panels (constant for LA county, equal to 2018.45), and the solar system's performance ratio which is the coefficient for losses (used default value = 0.75). Two fields were added in ArcMap attribute table to perform these calculations. Considering the V2G technology/exploiting excess power factor, these calculations are required to predict areas with potential solar excess generation assuming maximum adoption of solar rooftops in LA County.
4) Considering the Grid Capacity requirement, locations not meeting the 12 kilovolts minimum circuit capacity constraints were excluded.
5) Using ArcMap model builder tool, a model was constructed to spatially join all map layers and provide an output map layer showing the potential locations for level 2 EV public charging stations.

TABLE 1. LA COUNTY TARGETED PARKING LOTS FOR LEVEL 2 EV PUBLIC CHARGING STATIONS

Use Description	Count
Athletic & Amusement Facilities	247
Colleges, Universities (Private)	170
Commercial	4970
Department Stores	298
Golf Courses	153
Government Parcel	7551
Hospitals	460
Hotel & Motels	1317
Industrial	5698
Institutional	37
Office Buildings	7989
Parking Lots (Commercial Use Properties)	11598
Parking Lots (Industrial Use Properties)	1424
Professional Buildings	2895
Recreational	11
Restaurants, Cocktail Lounges	4238
Rivers & Lakes	6
Schools (Private)	1096
Shopping Centers (Neighborhood, community)	3110
Shopping Centers (Regional)	610
Supermarkets	566
Theaters	67

III. ANALYSIS AND FINDINGS

According to Esri [20], "the Kernel Density tool calculates a magnitude-per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline." In this case, Kernel Density Estimation (KDE) is used to estimate the probability density function of solar excess generation. KDE statistics is given as:

$$\int_h^1 (x) = \frac{1}{n}\sum_{i=1}^{n} k_h\,(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} k\,(\frac{x - x_i}{h})$$

Where (x1, x2… xn) is an independent and identically distributed sample drawn from some distribution with an unknown density f, K (•) is the kernel (a non-negative function that integrates to one and has mean zero) and h > 0 is a smoothing parameter called the bandwidth. KDE statistics estimates the shape of this function f.

Assuming the maximum adoption of solar rooftops in LA County, analysis indicates there are several dense areas where solar excess generation is estimated as shown in Figure 2.

Figure 2. Areas With Projected Solar Excess Generation

The excess solar generation dense spots appeared, as shown in Figures 2 and 3, in areas such as Lawndale, Hawthorne, Inglewood, Gardena, Downey, Norwalk, Cerritos, and Paramount. It is important to note that the dense spots (red areas) imply higher statistically significant excess solar generation. In addition, Figure 4 shows locations with excess solar generation along with SCE DERiM circuits line and substations (blue squares).

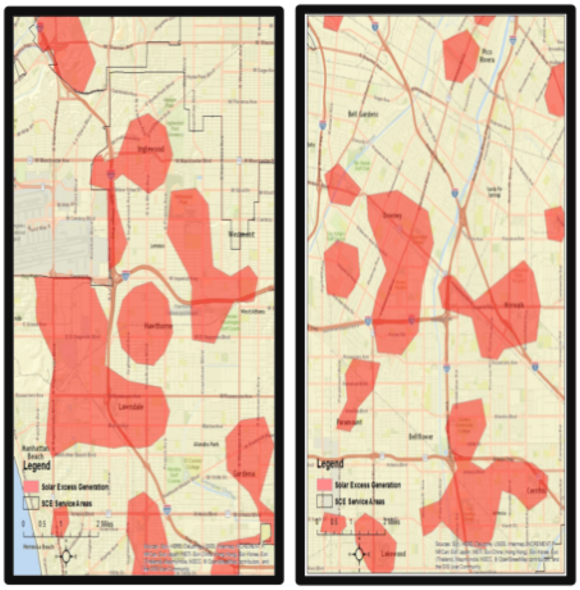


Figure 3. Areas With Forecasted Solar Excess Generation

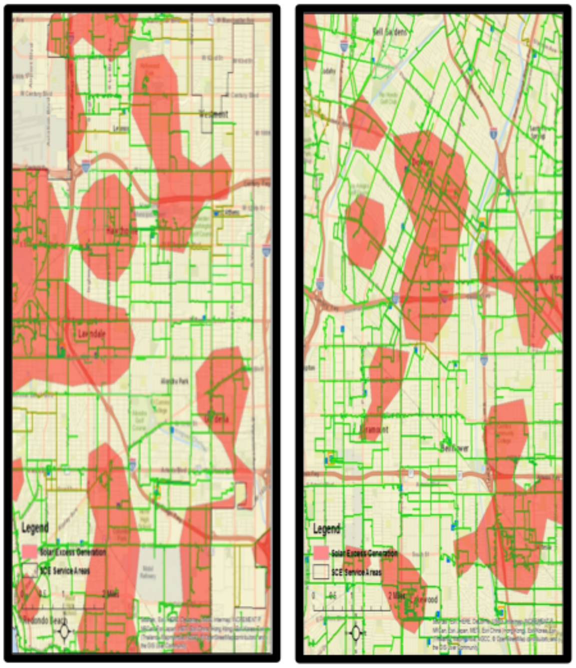
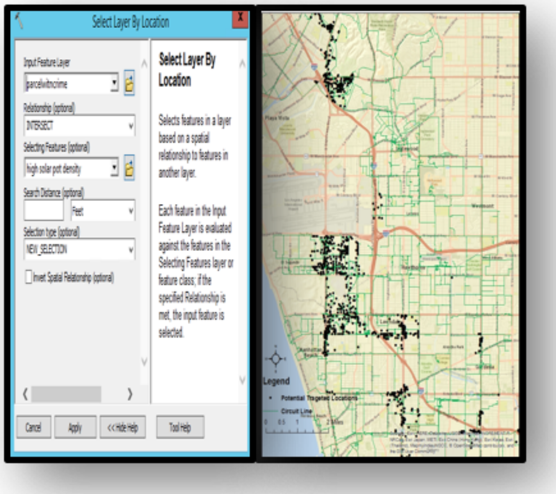


Figure 4. Locations Along With SCE DERiM Circuits Line and Substations

The crime Index layer was joined with the excess solar generation layer. Then, Select *Layer By Location* tool was used to intersect the two layers in order to show only safe zip codes areas with excess solar generation as shown in Figure 5. It is important to note that crime index for less than 93 per zip code were not considered safe area for level 2 EV stations installation. Considering the electric circuit current hosting capacity with 12 kilovolts as minimum circuit capacity constraints and the potential targeted areas yielded from the previous steps, locations where the level 2 charging stations might be installed were shown as in Figure 6.


Select Layer By Location

Input Feature Layer: parcelwitnocrime

Relationship (optional): INTERSECT

Selecting Features (optional): high solar pot density

Search Distance (optional): Feet

Selection type (optional): NEW_SELECTION

☐ Invert Spatial Relationship (optional)

Select Layer By Location

Selects features in a layer based on a spatial relationship to features in another layer.

Each feature in the Input Feature Layer is evaluated against the features in the Selecting Features layer or feature class; if the specified Relationship is met, the input feature is selected.

Figure 5. Safe Zip Codes Targeted Areas
With The 12 Kilovolts Minimum Circuit Capacity Constraints

Figure 6. Optimal Locations For Placement
Of Level 2 EV Public Charging Stations

IV. EVALUATION

The project team applied a qualitative interview method to evaluate the prototype using socio-technical technique to assess the following metrics: propriety and utility. The researchers evaluated the different values held by the different stakeholders by sending the following three interview questions via email: (1) Do you agree with the factors' definitions on page 2, please explain why? (2) Do you see the potential solution offered by the GDSS prototype (shown in Figure 7)? (3) What changes would you recommend for improvement? In this case, both EV drivers' and utility executives' perspectives were part of the evaluation process to ensure that their unique stances were understood.

Feedback was solicited from participants who were previously involved in the awareness of the problem phase and gathering the requirements. Two participants responded with positive feedback and they highlighted the potential offered by the proposed solution. According to Jim Horstman, a utility industry consultant, the artifact is useful and he agreed with the factors' definitions. However, Horstman pointed out that there is an overlap of some factors such as the accessibility and convenience. In spite of the factors' overlap, the actual analysis would not change.

V. LIMITATIONS AND FUTURE WORK

Public charging infrastructure can thus be prioritized in locations with sufficient circuit capacity, potential excess renewable power, low crime index, convenience and accessibility factors of the EV drivers/owners. However, a limitation of the GDSS prototype proposed in this paper is that it offers a solution to address the placement of level 2 stations only. Thus, a prototype to address the placement of level 3 stations is not offered in this case.

Due to time and data availability constraints, the prototype illustrated the optimal locations for placement of level 2 EV public charging stations considering the convenience, accessibility, security, V2G technology/exploiting excess power, and grid capacity factors. We did not address the travel time, battery range, and the number of EV factors of the decision-making framework.

Another limitation is in the evaluation phase. It is important to recognize that the time constraint imposed limitations on the evaluation and what these limitations are. The project team did not have the time to complete the evaluation phase and address the interviewees' comments after the solution delivery. The researchers did not have an opportunity to perform further iterations to improve the prototype. The project team need to get and address the interviewees' suggestions to move to the next phase of the research.

The utility and novelty of the solution is important to emphasize as the driving factors for this project. By developing a GDSS prototype for decision making that previously did not exist, a great amount of time is reduced for both the developers who are interested in finding the optimal locations and the utility companies who are interested in integrating the EV charging infrastructure into the electricity system in ways that deliver net benefits to utility customers, shareholders, vehicle owners, and society at large. It is important to realize that this prototype is only meant to serve as a good starting point for the illustration of how EV charging demand can be managed geographically to minimize potential increases to overall electric system costs while still meeting customers' needs.

In future DSR cycles, the project team will address all of the suggestions from interviewees after they collect the remaining feedback from them. The project team will evaluate the GDSS prototype many times through multiple iterations to improve its utility. The next iteration will offer a custom tool for developers/utilities, so that they are better able to evaluate the results. The prototype will run on a public server to give the research participants access to the application.

Moreover, the project team will add quantitative methods in the evaluation such as System Usability Scale (SUS) and cognitive walkthrough. The usability of this prototype will increase since both methods measure the usability of any application. The SUS and cognitive walkthrough will be administered to all research participants. In this case, the evaluation will involve more participants who will be given access to the application to ensure the validity of the evaluation results.

As part of future work, multiple tools can be developed for the purpose of building an interactive, computer-based system where developers/utilities are allowed to configure their own criteria for decision-making.

VI. CONCLUSION

This study aimed at addressing "How to properly integrate EV charging infrastructure into the electricity system and deliver net benefits to the consumers?" To answer the research question, we have built a prototype of Geographic Decision Support Systems (GDSS). Our proposal was developed bearing in mind not only the net benefits to EV owners but also the electric circuit capacity constraints and the impact of the EV charging infrastructure on the electric grid.

From this research, we conclude that EV charging demand can be managed geographically to minimize potential increases to overall electric system costs while still meeting customers' needs. Our solution provides evidence that GIS can play an integral role in the problem resolution. If additional funds and data are made available, a custom GDSS solution can be developed to allow EV charging developers to configure their own criteria for decision-making.

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