Optimal Siting of Charging Infrastructure for EV Ecosystem Partners: A Multi-constraint Approach integrated with Geospatial Analysis

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Abstract:

Electric mobility is one of the key drivers of the undergoing clean energy transition. As the primary enabler of sustainable transportation, electric mobility plays a critical role in achieving net-zero carbon emissions. The availability and optimal access to Electric Vehicle (EV) charging infrastructure plays a critical role in accelerating the EV adoption goals set by various countries and regions. Hence, the planning for the optimal location of EV charging station setup is crucial for various partners – Customers, Charge Point Operators (CPOs), Original Equipment Manufacturers (OEMs), and Utility grid operators in the EV ecosystem defined below:

- **Customers:** People who own and use EVs for transportation
- **Charge Point Operators (CPOs):** Entities that provide charging services to EV customers
- **Original Equipment Manufacturers (OEMs) :** Manufacturers of charging stations as well as EVs
- **Utility grid operator:** Entities that operate power grids and support EV charging stations

As urban areas deal with space shortages, and energy demands are rising exponentially, identifying suitable and appropriate locations for setting up charging stations is a challenge. Both supply side and demand side inputs are important to arrive at the optimal location of charging stations. The supply side input datasets include - EV fleet growth forecast from OEMs, current utilization rate and fleet availability from CPOs, and power grid constraints from Utility grid operators. Demand side input datasets include – EV travel patterns and customer behavior. These data sets will be processed and transformed into geospatial data layers to be overlaid on a base layer that represents the area of study. Supply-side constraints, relating to CPOs, Utility grid operators, and OEMs, include proximity to electric infrastructure and public space availability. The stakeholder constraints on the demand side include customer travel range and pattern which will be captured in the traffic density data layer. Accordingly, these inputs and constraints will be processed in a geographical information system (GIS) to determine the optimal location of EV charging stations in a particular region. A ranking-based framework scrutinizes suitable sites among the feasible ones and the rank is decided based on the total score obtained by each candidate site. The results of such analysis will ensure that the stations are optimally located near the customers, the Utility power grid is not overloaded, and the CPOs obtain maximum revenue from their charging business while the OEMs can plan their manufacturing output based on the demand pattern.

Introduction

Environmental concerns owing to the usage of fossil fuels have led to serious actions towards safeguarding the ecological and economic balance. Global greenhouse gas emissions due to energy usage and transportation have catapulted the shift towards sustainable alternatives in the form of the undergoing energy transition. Energy and power systems are moving towards cleaner Renewable Energy (RE) sources, both centralized utility-scale power plants and microgrids while energy efficiency and increasing consumer participation (in the form of prosumers) are gaining importance at the consumer end. Transportation is also moving away from fossil fuel-powered vehicles to their sustainable alternatives and electric mobility is emerging as the strongest amongst them. Electric Vehicles (EVs) have an all-electric drive train powered by a battery while gasoline-electric hybrids also exist. Having a robust EV charging infrastructure is the main requirement for establishing a comprehensive E-mobility ecosystem.

Random allocation of spots for installing EV charging stations is not a sustainable practice since demand growths are sporadic and the electricity distribution infrastructure also needs to be revamped accordingly. Moreover, **as cities expand and urbanization and commercialization grow exponentially, finding adequate space for installing the EV charging station system setup is the biggest challenge.** Hence, a more scientific approach is required to site public EV charging stations in an urban area which can also be treated as an optimization problem that needs to follow the various constraints relating to an urban setup. Many methods have been documented in the literature[1] for finding the optimal location of public EV charging stations in urban areas/cities for both intra-city and inter-city travel. Many of these approaches consider the problem from the point of view of an electrical power distribution network wherein the most appropriate node on the distribution network is identified to site EV charging stations. However, it has been found that practically, often the node suggested by the optimization problem solver turns out to be in a physical area where space for setting up a public EV charging station is not adequate. It is thus important to view the problem from a geospatial angle wherein the actual grounds-up approach can be adopted considering each aspect: land usage, traffic movement, electricity distribution infrastructure, proximity to road/highway network, and many such factors. **In this paper, a geospatial analysis has been described in the form of a framework approach that can be adopted to optimally site public EV charging stations in city areas considering multiple constraints relating to the key stakeholders or ecosystem partners in the E-mobility domain.**

Key Input Datasets

The key stakeholders in the E-mobility eco-system are namely:

1. Customers or EV owners having different purposes (residential for office commute, commercial, logistics, etc.)
2. Charge Point Operators (CPOs): Entities that install and operate the EV charging stations
3. Original Equipment Manufacturers (OEMs): For both EVs and EV chargers
4. Utility power grid operators

Apart from these, there are electric fleet operators too that are becoming important for intra-city passenger commute or inter-city travel as well as for logistics. However, from the point of view of the availability of datasets as important decision variables in the geospatial domain, the above four stakeholder categories hold good. Public EV charging stations are akin to diesel or gasoline refueling stations for Internal Combustion Engine (ICE) vehicles although the battery charging time or 'refueling' time is longer than that for the gas stations. However, battery swapping stations are also emerging as a smarter alternative wherein the exhausted vehicle battery is replaced by a fully charged one, there are compatibility and inter-operability issues with battery and vehicle brands. EV charging stations are characterized by charging power and voltage levels. For intra-city travel, AC or slow or level 1 chargers spread across the city's important points or junctions can support the travel needs for a limited distance within the periphery of the city. For such chargers, average output powers start from 3.3 kW upto 10 kW although in some countries, even 15 kW is considered as fast charger. For inter-city travel, fast or DC chargers are important as they can provide quicker charging times to fully charge batteries of vehicles that need to cover long distances on highways. Intra-city chargers placed at commercial places like shopping malls or cinema halls also provide revenue-earning avenues for CPOs through opportunity charging wherein customers can have their parked vehicles charged at competitive rates while shopping or grabbing a cup of coffee or watching a movie.

It is thus crucial to lay down a network of EV charging stations (fast or slow) that are strategically placed at important junctions of the city or at strategic points along the highway. To support the demand for the charging of vehicles which, in turn, is dictated by travel patterns and customer behavior, a strong and robust electricity supply infrastructure is necessary. Accordingly, input datasets both from the demand and supply sides are important to identify to create the geospatial layers. Numeric values in these datasets are translated or extracted into geospatial layers to perform the geospatial analysis for the siting of EV charging stations.

The important datasets from the supply side include the following:

- Existing EV charging stations in the city/region of study
- Electricity supply infrastructure/network
- Street and road network

The important datasets from the demand side include the following:

- Vehicle population density
- EV travel pattern/customer behavior

The datasets listed above need to be transformed into geospatial datasets for performing the analysis. The directly available geospatial datasets that are required for the analysis include:

- Land Use/Land Cover
- Population density
- Traffic density

Considering each stakeholder, datasets specific to them are:

- EV growth forecast numbers – available from OEMs
- Current EV fleet utilization rate – available from CPOs

Some policy and regulatory level information or data may also be useful to consider as an input variable for planning the optimal siting of EV charging stations using geospatial analysis.

EV Charging Station Siting Key Considerations

Public charging stations must cater to the charging demands based on the travel patterns and customer charging behavior and must be located optimally to serve the traffic at important junctions of the city for example near airports, major roadway points or at commercial centres. The key points to consider while optimally siting EV charging stations can be taken as constraints in the optimization problem having key inputs embedded in the form of decision variables. To understand customer behavior and capture it in the form of key decision variables or constraints, a survey can be performed in case digital records for a location are not available. Some of these data points include:

- Average time to stay
- Parking space availability
- Proximity to road/highway

Figure 1 shows the key datasets and the sources from where they can be collected. To highlight the relative importance of each of these parameters in deciding the location of an EV charging station, weights have been assigned to each variable as shown in Fig. 1. For example, proximity to the road or nearness to the electricity infrastructure must be relatively high while the average time to stay can be average medium or high to help rank the site as a potential EV charging station location. The weights assigned to each of such parameters based on domain-level judgement are accumulated in the optimization problem that is fed to the GIS solver engine. The flow is shown in the figure.

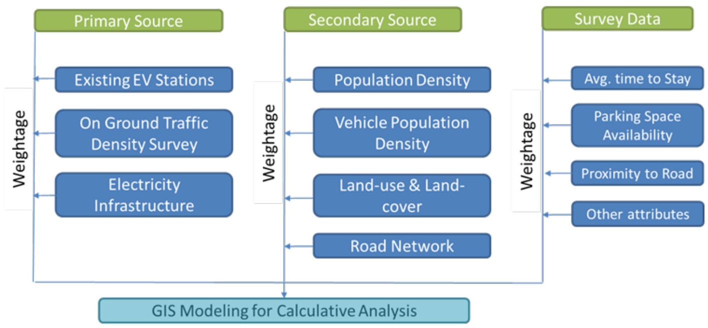

Fig: 1 – Datasets and their sources

For a site to become an optimal location for an EV charging station, some of the considerations that need to be taken into account are:

- Proximity to nearest electricity distribution sub-station/distribution transformer must be high
- Nearest electricity network infra must be strong and robust having enough capacity to support EV charging load
- Enough space for setting up the charging infrastructure must be available
- Density of vehicles passing through the site must be high

These high-level considerations can then be incorporated into a numeric framework which can be fed into a GIS analysis engine running the geo-spatial analysis to find out the most optimal EV charging station's location.

Methodology and Framework

There can be a number of potential sites in a city or a region where EV charging stations can be located. This site-suitability analysis can be carried out at a geospatial level in a GIS framework to optimally arrive at the best among the suitable candidate sites. The relative weights assigned to each of the important parameters can be used in the GIS optimization framework so that the actual geographical co-ordinates can be identified after the optimization problem has been solved considering the constraints and the decision variables (both having weights assigned) The result of the GIS analysis is a rank assigned for each site which is obtained based on a site-suitability score. The site-suitability score is generally arrived at based on the degree of match with the desired constraints as explained above – high proximity to electricity infrastructure, high space availability, etc.

Figure 2 shows the methodology of site-suitability analysis which considers the inputs and constraints related to all the four stakeholders: Users/EV customers, CPOs, OEMs and power grid operators.

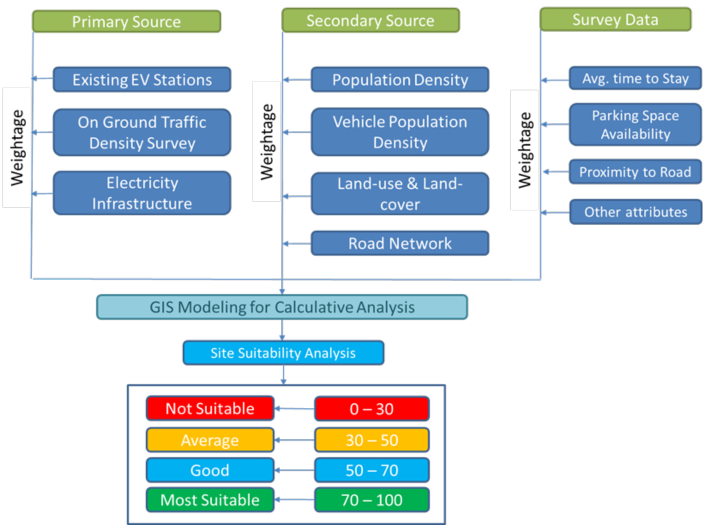

Fig: 2 – Site suitability analysis

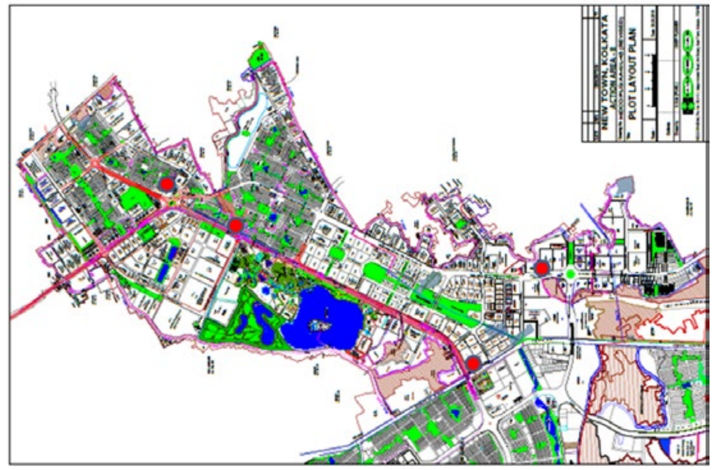

Fig: 4 –City area map showing four most suitable sites (in red)
Source: www.wbhidcoltd.com

Figure 3 shows a sample digital map form where multiple datasets in the geospatial domain can be extracted. These datasets and the survey datasets can be used together to run the geospatial location finding analysis based on the internal distance based optimization algorithm [2].

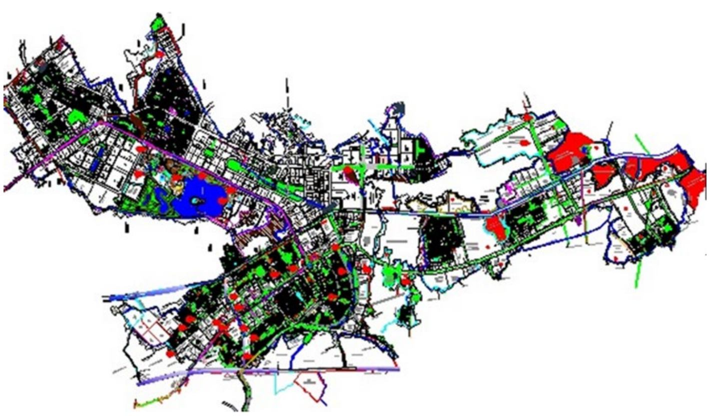

Fig: 3 –City area digital map for analysis
Source: www.wbhidcoltd.com

The various data layers that can be extracted from the above digital map include:

- Land Use/ Land Cover
- Points of Interest (landmarks in the city)
- Roads
- Building Footprints

Based on the ranking score obtained for each candidate site, the sites with the highest ranks can be considered as the most suitable locations for siting public EV charging stations. Figure 4 shows a sample map of the same region with the most suitable sites identified by the analysis engine as red colored spots.

Conclusion

In this paper, a multi-constraint framework using GIS analysis has been proposed to determine the optimal locations of public EV charging stations. The various key input datasets, both from the supply and demand side and different constraints have been identified and discussed. The methodology of transforming each of these datasets into geospatial data points and assigning weights to them in order of relative importance has been presented. The final step of obtaining scores to rank the potential candidate sites has been described. A sample illustrative digital map of a region of a city is shown with the optimal or most suitable sites identified. The key stakeholders in the E-mobility domain that are considered for this study are: Customers/EV users, OEMs, CPOs and utility-grid operators. From the point of view of locating public EV charging stations in urban areas, these are the important entities to consider. As the e-mobility landscape evolves, more players will emerge.

References

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