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# Identification of potential locations of electric vehicle supply equipment

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## HIGHLIGHTS

- Electric vehicle charging demand is identified as a function of time and place.
- Public charging usage rates are modeled by investigating US travel survey data.
- Minimum power requirement for electric vehicle supply equipment is identified.
- Time of peak-usage for charging stations is identified.

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## ABSTRACT

Proper placement of electric vehicle supply equipment (charging stations) requires an understanding of vehicle usage patterns. Using data from the National Household Travel Survey on vehicle mileage and destination patterns, analyses were performed to determine electric vehicles' charging needs, as a function of battery size and state of charge. This paper compares electric vehicle charging needs with Department of Energy electric vehicle charging data from real-world charging infrastructure. By combining the electric vehicles charging needs with charging data from real-world applications, locations with high electric vehicle charging likelihood are identified.



## 1. Introduction

Vehicle owners have become accustomed to long ranges on their gasoline vehicles, as well as the convenience and speed of refueling at public gas stations. With the advent of electric vehicles (EVs), a paradigm shift is needed regarding vehicle travel patterns and refueling infrastructure. The ability to operate a vehicle on electricity introduces the need for charging stations, or “electric vehicle supply equipment (EVSE)”, either at home, in public, or both. Identifying the location of EVSE is important to the economic viability of the charging infrastructure and the general adoption of electric vehicles. Predicting the usage at public charging locations is not trivial. In contrast to the placement of gasoline stations which are widely distributed along highways, at major intersections, and around busy streets, the locations for public EVSE for EVs will be significantly different due to the fact that EVs can be charged at home, and the charging time for an EV is significantly longer than a gasoline vehicle. The need for charging an EV battery at a given location is dependent on several factors, such as:

- Incoming state of charge of the battery
- Dwell time spent at the charging location
- Distance to next charging event
- Battery size
- Driver charging preference

The challenge for EVSE is in identifying where to put the charging station, how many should be installed, and what power requirements the charging station should have. Ideally, the location of charging stations should be placed in those areas that will receive the greatest usage, with only as many stations as are needed to meet the demand. The power of the charging station should be selected to provide the optimum charging profile at the lowest cost. For example, an AC Level 1 charging station is as simple as an

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extension cord plugged in to a 120 V AC socket, with about 15 A current rating. This EVSE is the least expensive, but only provides about 1–2 kW, or 2–5 miles of range per hour of charge. In order to supply 10 miles of range, the vehicle must be plugged in for at least 2 h. Faster charging can be achieved with AC Level 2 (3–20 kW, 10–60 miles of range per hour of charge), but with the additional cost of installing high current circuits (13–80 amps with 240 V AC supply). Although the SAE J1772 Standard defines AC Level 2 charging up to 20 kW, in practice Level 2 charging is limited to less than 10 kW, due to the fact that EVs will use an on-board charger (3.6 or 7.2 kW) that will convert AC power to the DC power required for charging the battery. At these power levels, most circuits for a single Level 2 EVSE will require 240 V AC at 30 A. If vehicles are available with higher power on-board chargers, then the EVSE supply circuits will need to be adapted accordingly. Thus, the recharging rates will depend on the rating of the circuit delivering power to the charging station, as well as the power rating of the vehicle's on-board AC/DC converter. In general, the purpose of Level 1 and 2 AC EVSE is to provide a safe and reliable mechanism of delivering AC power to the vehicle.

The fastest EV charging is achieved using DC fast chargers, which deliver a high rate of charge directly to the vehicle's battery, bypassing the on-board charger. This approach requires a high-power AC/DC converter that is external to the vehicle. This AC/DC converter typically operates on 480 V AC, and can deliver as much as 50 kW, resulting in recharging rates up to 150 miles of range per hour of charge. Due to the high power and the AC/DC converter, DC-fast chargers cost the most of any EVSE, but provide the fastest recharge rates. With the greater infrastructure cost, identifying proper charging locations becomes even more important.

Several reports have discussed EVSE placement, and optimizing the location based on electric vehicle adoption rates and modeled energy consumption rates [1–4]. In order to more accurately capture vehicle energy consumption, transportation surveys, such as the Metropolitan Travel Survey Archive [5] or the National Household Travel Survey (NHTS) [6], may be employed to determine typical driving patterns. The NHTS data has been used in several reports relating to electric vehicles [7–11]. Several reports on EVSE placement have made use of the NHTS data to predict usage rates at different locations. For example, Sears et al. identified sites with 1–2 h dwell times, assuming that vehicles would not charge during dwell times less than an hour [7]. Saxena et al. modeled energy consumption of EVs based on the NHTS travel patterns to predict end of life battery limits [8]. These studies determining the location of EVSE have often been based on average daily usage rates, but do not typically take into account the variation in usage frequency as a function of time of day. Furthermore, charging preferences of the vehicle driver are not included.

The purpose of this paper is to explore the data contained within the National Household Travel Survey to understand vehicle travel behavior as a function of both destination as well as time in order to predict EVSE usage patterns. Furthermore, the preference to charging is included to determine the fraction of vehicles most likely to charge at a given site and time of day. Once vehicle travel behavior is quantified with respect to the various destinations and total miles traveled, and once driver charging preferences are understood, the task to identify potential locations for EV recharging may be simplified.

## 2. Methods

### 2.1. Distribution of SOC at recharge

Electric vehicle recharge data was obtained from the EV Project, a DOE-sponsored project between 2011 and 2013 [12]. Within this project, the charging behavior was monitored for several thousand Nissan Leaf and Chevrolet Volt drivers. The state of charge (SOC) at the beginning of charge at “away from home” charging stations was provided by Idaho National Laboratory for all “away from home” charging events between January 2011 and December 2013. This data was used to determine the probability of recharging as a function of state of charge for Nissan Leaf and Chevrolet drivers, as shown in Fig. 1.

These charts demonstrate that the probability of recharging will increase as the SOC decreases. For example, between 80 and 90% SOC, there is less than a 10% probability that a Nissan Leaf will recharge. However, when the SOC drops to 20–30%, there is greater than 90% probability that the vehicle will recharge. It can also be seen that the SOC at recharge for the Volt is shifted to lower values than the Leaf. This is likely due to the presence of the gasoline range extender on-board the vehicle.

Although this recharge data is from real-world charging events, it is recognized that it does not represent a true probability, since this data was influenced by EVSE availability as well as driver preferences. For example, some drivers may delay charging at a public station if they are close to home. On the other hand, some drivers may experience strong range anxiety and recharge more frequently than would be needed. Notwithstanding the limitations on this data, it was employed to provide a starting point. Future efforts could refine this data to more accurately reflect driver behavior.

### 2.2. Travel pattern analysis

Daily vehicle travel patterns were obtained by analysis of the National Household Travel Survey (NHTS) from 2009 [6]. The survey was conducted by the US Department of Transportation Federal Highway Administration between March 2008 and April 2009, and travel days were assigned to over 150,000 households, representing

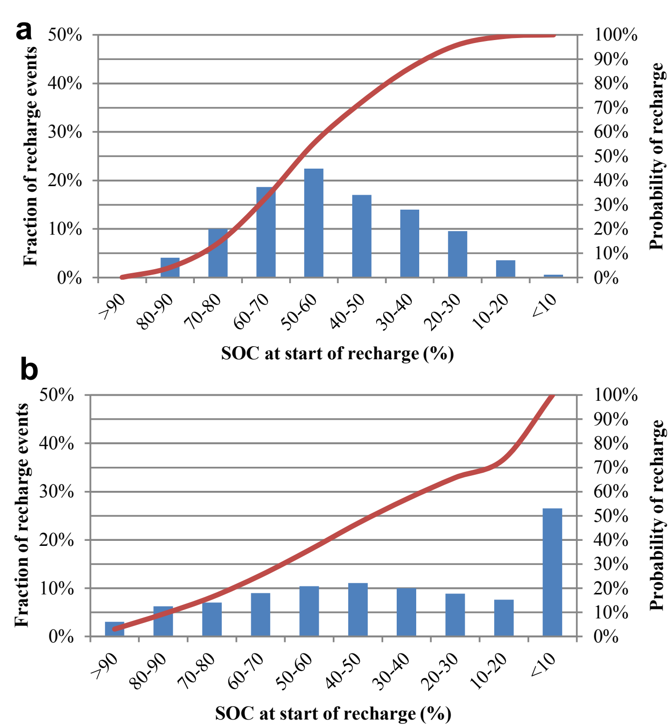


**Fig. 1.** Fraction and probability of recharge as a function of SOC at start of recharge for Nissan Leafs and Chevrolet Volts. Data provided by Idaho National Laboratory.