How Electric Vehicle Use Types Impact Utilities' Load Shapes
All EV Charging Loads Are Not the Same

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ABSTRACT

This paper will cover different electric vehicle (EV) types and uses in California, and the charging loads associated with light-, medium-, and heavy-duty EVs.

Light-Duty EVs. A combination of policies and promotional activities sets the California EV market apart from the rest of the US. The principal policy driver responsible is California's Zero Emission Vehicle (ZEV) regulation that requires an increasing share of EVs and other zero emission fuel type vehicles be sold annually through 2025. The second prong of ZEV is the infrastructure to support these vehicles. Currently ZEV has pushed California to have over 50% of all 2017 EV sales in the US and to have the highest per capita EV market share of any state (Kane, 2018).

Medium- and Heavy-Duty EVs. Unlike light-duty EVs, the growth in medium- and heavy-duty EVs (MHDEVs) is determined chiefly by economic growth. Additionally, many types of MHDEVs use different charger types than do light-duty EVs so that they may need additional infrastructure resources.

Effects on electrical loads. The increase of EVs across all duty types will have a profound effect on the increased need for electricity for California. But there are multiple effects on the hourly load shape. Time-of-Use rates and an increase in municipalities and commercial firms incorporating green vehicles in their bus and delivery fleets all have variable effects on the load shapes for charging battery-powered EVs. The EV charging load shapes, how they impact the grid, and how they can be used in forecasting will be discussed in this paper.

Introduction

ADM developed commercial and residential end-use load profiles for the California Energy Commission including load profiles for electric vehicles (EVs). These load profiles were developed based on vehicle size classifications into light-, medium-, and heavy-duty EVs. Each classification has a unique charging load profile. EVs use a variety of charger types.

Charger Types

Fossil fuel vehicles require a specific type of fuel. Most run on regular grade gasoline, but some require premium gasoline or diesel or ethanol and some are flexible-fuel vehicles. Similarly, not all EVs charge on the same voltage and some can use multiple voltages. To satisfy those differences, not all EV charging stations are the same. The make and model of an EV requires a defined voltage to charge the battery system. The common voltages are 120 AC (alternate current), 240 AC, and 480 DC (direct current) voltage. These are generally referred to as Level 1, Level 2, and DC chargers respectively. A level 1 (also known as a Type 1) charger supplies 120 AC through a special cord from a dedicated outlet. The typical charging time may run from 8 to 12 hours for a completely depleted battery. A level 2 (also known as a Type 2) charger supplies 240 AC through a charging station on a dedicated circuit. The typical charging time may run from 4 to 6 hours for a completely depleted battery. Level 3 chargers come in two types, CHAdeMO (CHArge de MOve is a trade name and is also known as DC fast charging) and Tesla

Superchargers. Level 3 chargers output 480 DC and can typically provide a half charge in 20 minutes. Most EV chargers can be programmed to specify the time or conditions the charging will occur.

Light-Duty

Light-duty are automobiles including sedans, sports cars, sports utility vehicles, and pickup trucks. These vehicles may be used by individuals (or families), private corporations, or government agencies. Each type of vehicle ownership and use may have a characteristic load profile. The vehicles are generally not restricted to using a single charging station and may be able to use multiple types of charging stations. In this paper we focus on the source of the light-duty EV charging, which is the charging station. We also only subdivide these into two location classifications: residential and commercial. The data for the residential chargers are all Level 2 located at single family residences. Commercial charging stations include public and private access locations. Over 22,500 vehicles are represented in the data presented here.

Medium-Duty

In this paper, medium-duty EVs are represented by data from one van manufacturer. They have supplied data for ten electric vans across five small fleets of one to four vehicles. These are shuttle vans such as those used by airports and hotels. The vans have a capacity of 14 riders. The vans use Level 2 and CHAdeMO charging stations.

Heavy-Duty

The heavy-duty EVs in this paper are represented by full-sized public transportation buses. These are fleet vehicles from one municipality in southern California. Charging stations are located at a transfer station where riders switch buses. The charging connection is made via an overhead coupling to the top of the bus in a designated parking space. It uses DC fast charging. Charging must be rapid since the buses are at the transfer station for a limited time, typically from 1 to 15 minutes. This paper has data from one public transit system with fourteen electric buses currently in the fleet. The buses have a capacity of 40 riders.

The Future

Two transit systems in southern California have plans to replace their fossil fuel buses with electric buses so that by the year 2030, 100 percent of their fleets will be all electric (Foothill Transit, 2016). That is only 11 years away. The power generation and grid need to be ready for these and many more EVs of all types that will be added to the roadways. The California Air Resources Board (CARB) has incentives for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP).[1] This is to incentivize zero emission and low NO_X engines to accelerate the purchase of cleaner, more efficient trucks and buses in California. In January 2018, the governor of California issued Executive Order B-48-18 calling for 1.5 million zero-emission vehicles (ZEVs) by 2025 and 5 million ZEVs by 2030, and the installation of 250,000 EV charging stations, including 10,000 direct current fast chargers, by 2025 (CEC, 2018). In November 2018, FedEx announced it will be adding 1,000 electric delivery vehicles to its fleet in California (FedEx 2018).

[1] The HVIP incentivizes large electric battery buses up to $175,000. www.californiahvip.org

Data Collection

Most of the data collected on energy charging profiles comes from EV charging stations rather than recording and collecting data from onboard individual EVs. The exception in this case is for the medium-duty shuttle vans. Each make of charging system collects information the manufacturer deems important. Charging stations record some universally common data fields such as energy use, charge start and end times, and some basics about the vehicle being charged.

Data was obtained from the following sources:

- Light Duty: The data is from one charging station manufacturer. Data from the light-duty vehicle charging stations were obtained for 30 days randomly selected throughout 2017.
- Medium Duty: The medium-duty vehicle manufacturer obtains data directly from the vehicles through remote connections to the onboard system controller. Two weeks of data were obtained for the medium- and heavy-duty electric vehicle (MHDEV) charging during the month of September 2018.
- Heavy Duty: The data is from one charging station manufacturer. The heavy-duty EV manufacturer makes charging stations unique for their vehicles. Two weeks of data were obtained for the medium- and heavy-duty electric vehicle (MHDEV) charging during the month of September 2018.

The number of charging data points are identified in Table 1. The light-duty residential chargers had one driver using each charging station, while over 22,100 drivers used the 1,849 light-duty commercial charging stations.

Table 1. Charging Data Sources

Vehicle Type	Charging Stations	Vehicles
Light-duty Residential	498	-
Light-duty Commercial	1849	-
Medium-duty	-	10*
Heavy-duty	2**	-

** All were shuttle vans., ** The two charging stations charged 14 buses throughout the day.*

All the single family residential chargers were Type 2. No data was obtained from Tesla chargers, although Tesla cars were charged on stations for which data was obtained. The light-duty commercial charging stations came in Type 1, 2, and 3 chargers. They were distributed in a variety of location categories as shown in Table 2. Seventy percent of these chargers were at the workplace.

Table 2. Percent of Light-Duty Commercial Charging Stations by Location Category and Charger Type

Location Category	Type 1, %	Type 2, %	Type 3, %	Total, %
Workplace	0.02%	68.89%	1.26%	70.17%
Municipal	0.22%	9.00%	0.00%	9.22%
Retail	0.00%	5.79%	0.43%	6.22%
Education	0.02%	3.54%	0.00%	3.56%
Parking	0.01%	3.01%	0.00%	3.02%
Multifamily	0.00%	2.56%	0.00%	2.56%
Healthcare	0.00%	1.67%	0.00%	1.67%
Hospitality	0.01%	1.43%	0.04%	1.48%
Government (Fed, State)	0.00%	1.18%	0.03%	1.22%
Fleet	0.00%	0.89%	0.00%	0.89%
Total	0.28%	97.95%	1.77%	100.00%

The make and model were available for most of the light-duty EVs charged. Table 3 presents the EV auto makers as a percent of the available charging data separated by single family residential locations and commercial locations. Chevrolet and Nissan were the top two EV auto makers represented in the data.

Table 3. Percent of Charges Made at Residential and Commercial Locations by Auto Maker

Auto Maker	Charging at Single Family Residences, %	Charging at Commercial Locations, %
Audi	2.7%	1.1%
BMW	14.6%	7.7%
Chevrolet	30.7%	21.8%
Fiat	4.8%	6.8%
Ford	5.4%	8.5%
Honda	1.1%	0.7%
Hyundai	1.3%	0.5%
Kia	1.2%	0.9%
Mercedes-Benz	4.7%	1.4%
Nissan	12.1%	21.2%
Tesla	2.4%	8.1%
Toyota	5.8%	5.8%
Volkswagen	10.4%	6.7%
Other Makers	2.7%	8.6%
All Makers	100.0%	100.0%

Hourly load profiles were generated from raw data. Individual charging sessions were divided into hourly blocks from the start to end charge times, and the energy use was evenly distributed across the hourly blocks based on the amount of time charging took place within each hour. This approach assumes charging energy is constant with time throughout a charging session. In reality charging energy transfers fastest when the battery is first plugged in and the energy transfer rate decreases with time. If the rate of decline with time is known then other approaches could have been taken by assuming a charge curve. That charging curve is dependent on other factors not always available such as state of charge at the beginning and end of the charging, charger voltage, battery capacity, and battery temperature. The individual charging sessions were then averaged to develop the load profiles presented in the next section.

Results

Hourly load profiles for EVs were developed for average weekdays and weekend days. In the process, other characteristics of the charging were also identified. These are included in Table 4. The average charging time for most vehicles was over two hours. The heavy-duty city buses used fast chargers and were an exception at less than five minutes per charge, on average. This is because the charging station for the buses is at a transfer station where the buses drop off passengers and load new passengers throughout the day. This is evident in the high number of charging sessions that occur each day at a station for the buses. The other types of vehicles show approximately one charge per day. The average energy per charging session ranges from 9.4 to 30.5 kWh. The average energy per day is shown in the last column of the table.

Table 4. Average Charging Characteristics

Vehicle Type	Average charging time	Average charges per day	Average kWh per charge	Average kWh per day
Light-duty Residential	2.18 hours	0.80 / station	9.44	7.56 / station
Light-duty Commercial	2.38 hours	1.35 / station	9.93	13.41 / station
Medium-duty vans	2.14 hours	1.50 / van	30.57	45.97 / van
Heavy-duty buses	4.3 minutes	48.0 / station	18.75	900.6 / station

Level 1 chargers take more time to charge a battery than Level 2 chargers, and Level 2 chargers take more time to charge a battery than Level 3 chargers. The medium duty shuttle vans (all the same make) were sometimes charged using Level 2 chargers and sometimes CHAdeMo (Level 3) chargers. Figure 1 shows a scatter plot of charging time versus charging energy for the two types of chargers. The Level 3 chargers delivered energy to the batteries at a rate approximately five times faster (thus the term, DC fast charging).

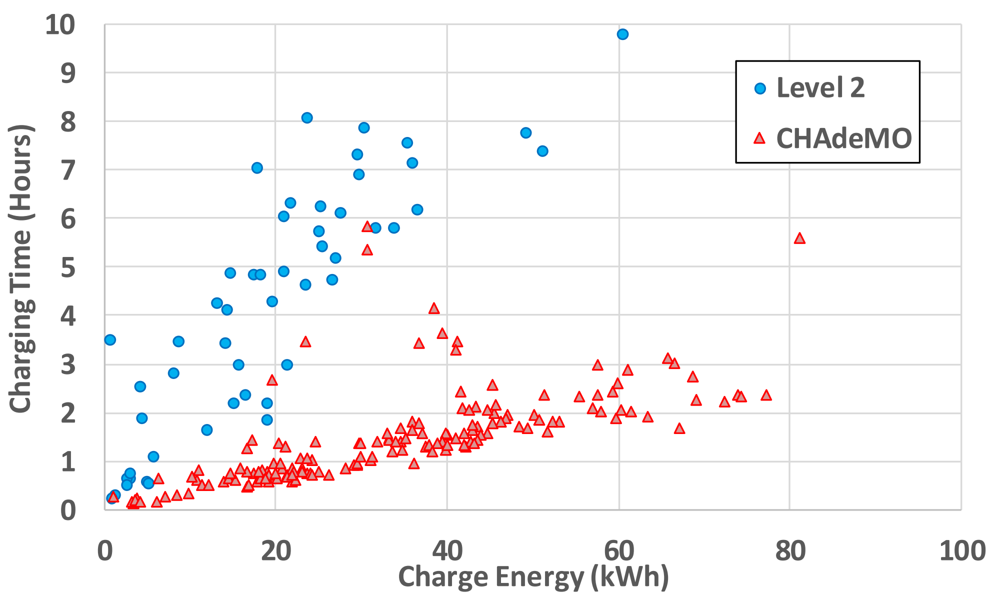

Figure 1. Medium Duty Shuttle Van Charging Time versus Charge Energy for Two Types of Chargers

The hourly load profiles for residential EVs shown in Figure 2 is what is typically expected for vehicles that are driven home, parked in the garage, and charged overnight when the electric rates are lowest, with time of use pricing. EV charging profiles for light-duty residential charging is good for the utilities based on current off-peak period definitions.

The hourly load profiles for charging stations used by light-duty commercial EVs is shown in Figure 3. These are most heavily used during the day by people who work or shoppers. The mid-morning peak represents the commuters who go to work and park their car in an EV charging space and recharge the car for the evening commute home. The overall load profile is advantageous to the optimal use of solar photovoltaic (PV) electricity generation as the use of the chargers coincides with the power generated during daylight hours. These provide a great source of energy utilization for the solar industry.

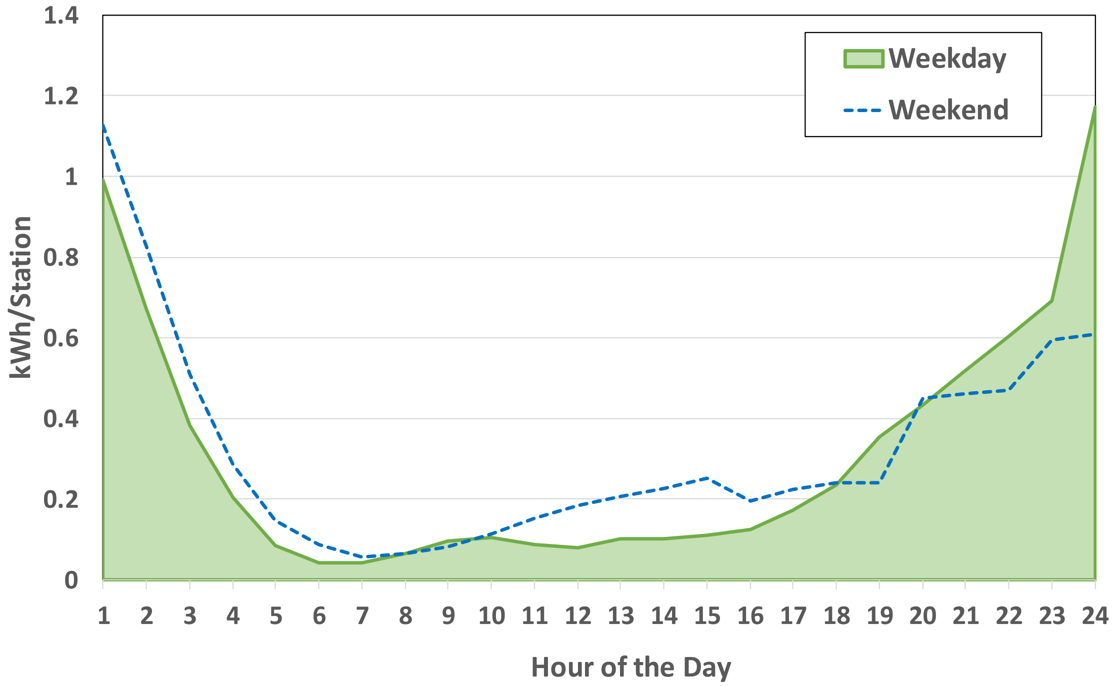

Figure 2. Average Daily Residential Light-Duty Vehicle Charging Load Profile

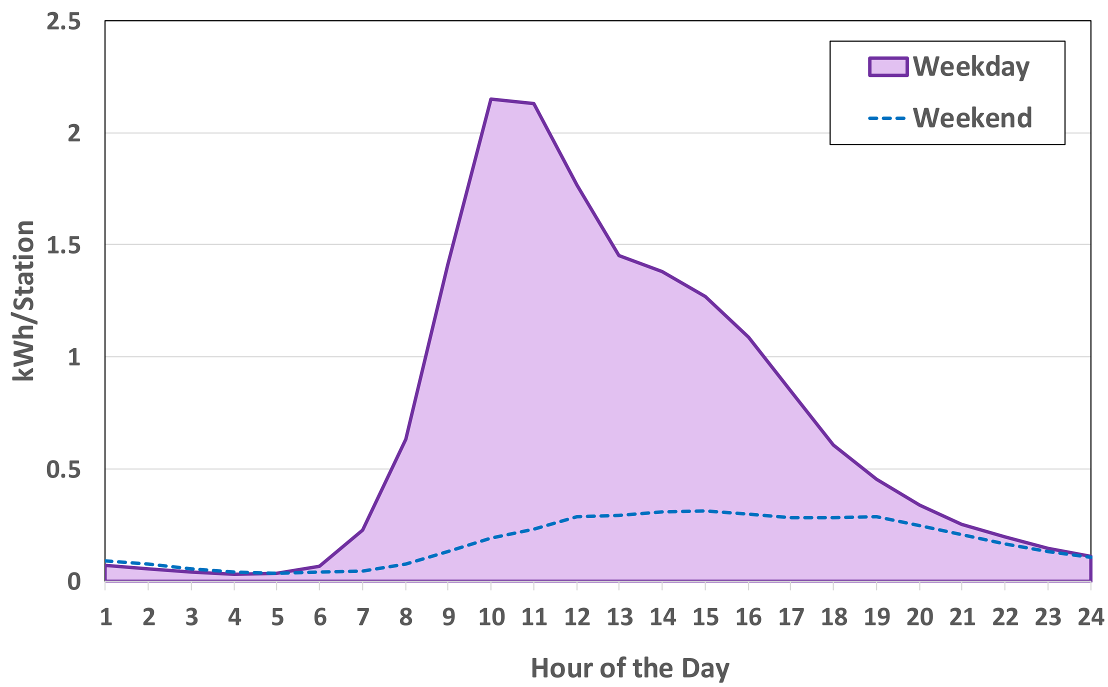

Figure 3. Average Daily Commercial Light-Duty Vehicle Charging Station Load Profile

The hourly load profile for the medium-duty shuttle vans is more erratic as shown in Figure 4. The load profile is active throughout the day and night. The vans are cycled out of active use while being charged, which requires coordination of vehicles within small fleets. This profile is expected to smooth out if more data was obtained.

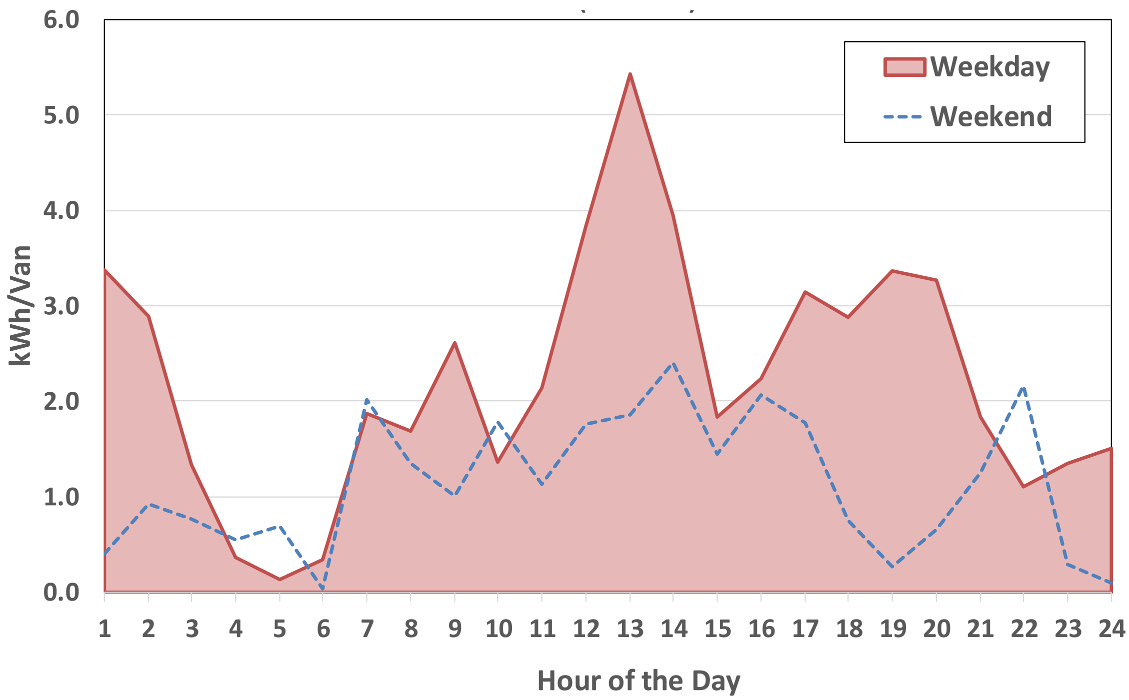

Figure 4. Average Daily Medium-Duty EV Charging Load Profile

The hourly load profiles for the heavy-duty buses is significant throughout the day and evening as shown in Figure 5. These vehicles can use energy generated during the day by solar PV systems, but also require other sources throughout the evening.

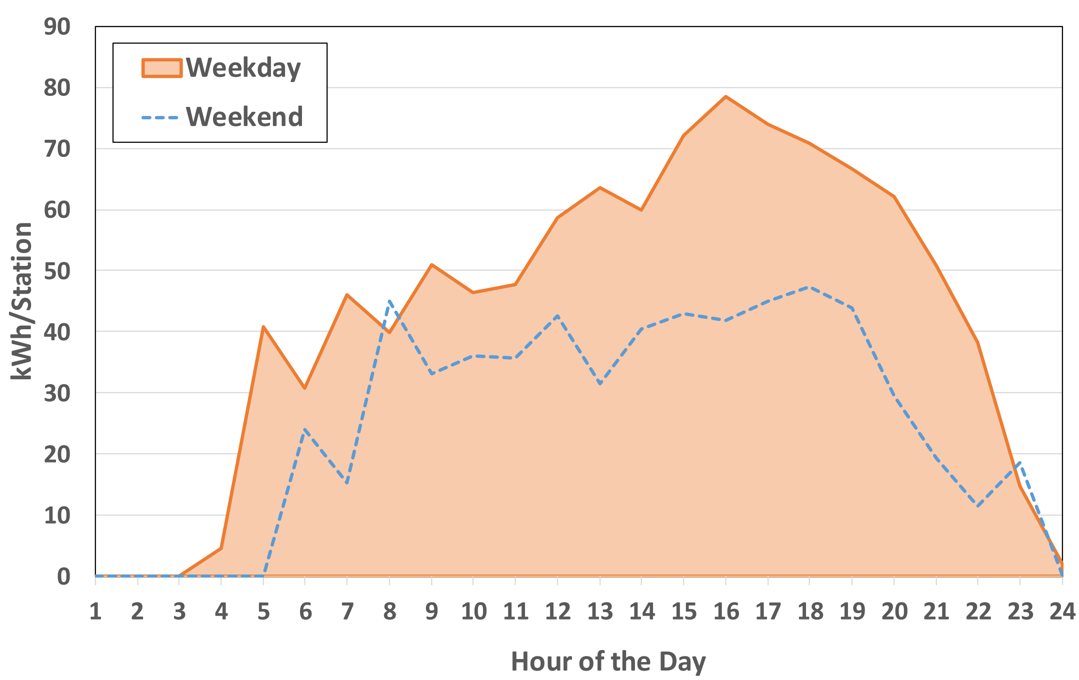

Figure 5. Average Daily Heavy-Duty EV Charging Load Profile

Public and commercial placement of EV chargers and charging of MHDEVs contribute to peak period loads as currently defined by the utilities. Opportunities for peak period reduction programs for these chargers can help the utilities and the grid.

Conclusions

The single family residential EV charging profile is currently good for the utilities since the majority of the charging load occurs at night during off-peak periods. At the present, California utilities should encourage the use of residential EV charging at home during the off-peak period. In contrast, the light-duty commercial EV charging is occurring during the mid-day hours and encompasses the peak period. That is because the majority (70%) are from workplace charging of EVs. At the present this adds stress to the grid, but in the future as solar PV becomes a more predominant power source, these batteries can be used as an effective method to store the excess power generated (CPUC, 2015). Medium and heavy duty EVs could also be used in the future to utilize the excess power generated from solar PV.

As charging technology has advanced, charging times have decreased. Thus, the decreasing time it takes to fully charge provides more opportunities to selectively charge at the optimum time for the user. For example, EVs can be plugged into a charging station which can be programmed to charge during the lowest rate based on the next time the vehicle will be needed or based on signal inputs from the utility.

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