EVI Pro

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Alternative Fuels Data Center: Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite Assumptions and Methodology
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Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite Assumptions and Methodology

EVI-Pro Lite uses the following assumptions and methodology to provide a simple way to estimate potential need for electric vehicle charging infrastructure and how it affects charging load profiles. For more information, see these sections below:

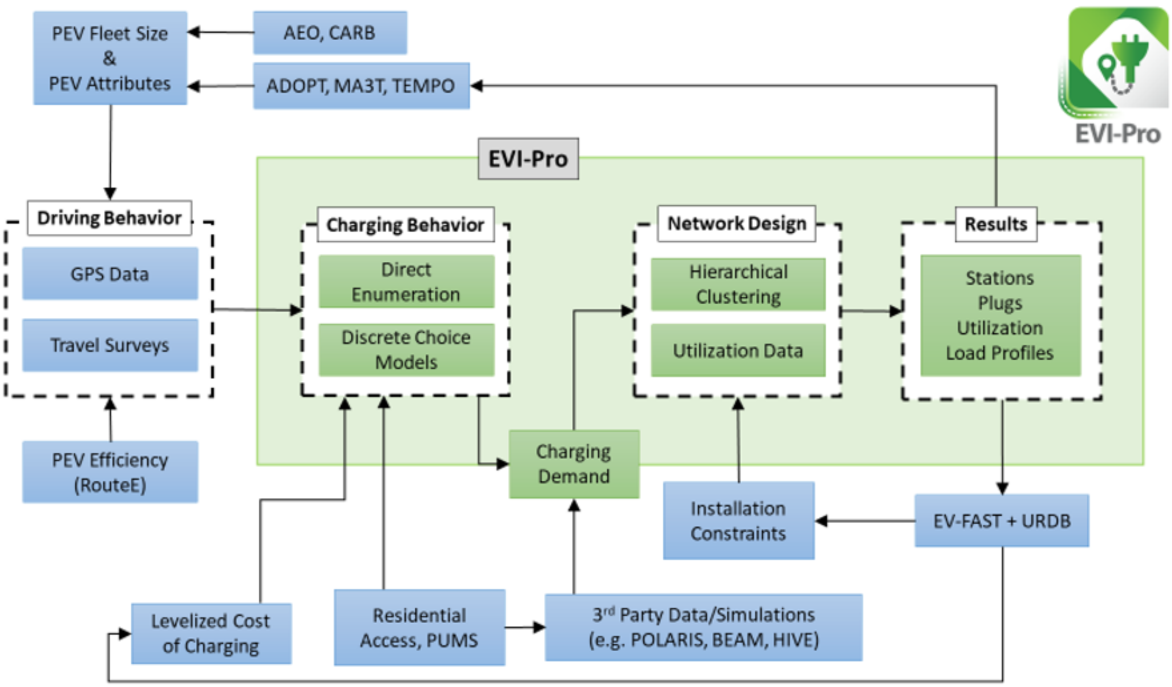
Introduction

EVI-Pro Lite is a simplified version of the Electric Vehicle Infrastructure Projection Tool (EVI-Pro). Assumptions in EVI-Pro Lite are consistent with a 2017 EVI-Pro analysis investigating charging infrastructure requirements at the national-level*(PDF)* which relied on advanced PEV simulations using millions of miles of real-world daily driving schedules sourced from large public and commercial travel data sets (additional regional analyses have been conducted in Massachusetts*(PDF)*, Columbus*(PDF)*, California*(PDF)*, and Maryland*(PDF)*). Charging at non-residential stations is simulated on an as-necessary basis such that consumers are able to maximize electric vehicle miles traveled (eVMT). It is assumed that future PEVs will be driven in a manner consistent with present day gasoline vehicles (e.g., 70% of daily driving under 40 miles and 95% under 100 miles). Technical considerations are made for the spatial density of PEVs, ambient temperature effects on electric driving range, and frequency of long-distance driving days.

1. EVI-Pro Methodology

EVI-Pro uses real-world travel data from mass market consumers to estimate future requirements for residential, workplace, and public charging under a variety of scenarios. Outputs of the model include: anticipating spatial/temporal consumer demand for charging accounting for the impact of SUD and MUD residency, weekday/weekend travel behavior, and regional differences in travel behavior and vehicle adoption. A graphical representation of the input/output relationships in EVI-Pro is shown below, including the primary processing steps in the model:

1. Conducting individual PEV driving/charging simulations over real-world 24-hour driving days
2. Spatial-temporal post processing of individual charging events to derive ratios of charging plugs to PEVs
3. Scaling said ratios per a PEV stock goal or projection



Graphical representation of inputs/outputs and data flow in EVI-Pro.

EVI-Pro uses a “bottom-up” approach to estimate PEV charging requirements with the fundamental element of 24-hour daily driving schedules from real-world vehicles. While these driving schedules are typically sourced from gasoline vehicles, EVI-Pro simulates each driving day as though it were attempted in a PEV. By applying real-world travel data from gasoline vehicles to simulated PEVs, EVI-Pro attempts to estimate charging solutions that enable future PEVs to serve as a direct replacement for the gasoline vehicles that represent the present-day majority of the light-duty vehicle fleet.

Charging solutions to complete individual days of driving are estimated by identifying charging opportunities that are consumer-oriented for both convenience and cost. Convenience is achieved by simulating charging events as only occurring during dwell times present in the original travel data. The EVI-Pro method implies that the mainstream PEV drivers will have a low tolerance for altering travel behavior on a regular basis to accommodate charging their vehicle. When the price of charging is equivalent for two or more locations EVI-Pro assumes that consumers prefer to charge at locations with long dwell times. This approach implies a greater energy transfer per charging event and helps to minimize the number of charging events per day. Simulated consumers in EVI-Pro are modeled as being economically efficient, preferring to charge their vehicles at locations that help minimize charging costs. Simulated consumers are provided with charging cost information and the energy needed to complete their next trip, so each simulated PEV driver can decide whether or not a charging event is needed at their current location. Once feasible charging solutions are identified, the model further iterates through driving/charging events until the battery state of charge (SOC) at the start and end of the simulated day are consistent.

In addition to the objective of minimizing cost, simulated consumers are also subject to constraints on battery state of charge. For each simulated driving day in EVI-Pro, BEVs are required to maintain battery state of charge above a pre-defined level, defined as a reasonable proxy for minimizing range anxiety.

Since PHEVs can operate with a depleted battery in charge sustaining mode, EVI-Pro does not place a constraint on the minimum allowable state of charge for PHEVs, but instead attempts to maximize electric vehicle miles traveled (eVMT) and minimize gasoline consumption.

While the individual driving and charging simulations determine the number of vehicles that utilize each charger type, the amount of infrastructure required to satisfy charging demand is dependent on the spatial-temporal coincidence of charging. For example, consider a fixed number of charging events at public L2 chargers. If these charging events happen at the same location and are uniformly distributed throughout the day, a minimal amount of infrastructure can meet the demand (corresponding to the high utilization of a small number of chargers). Conversely, if the same number of charging events occur in isolated locations all at the same time a much larger amount of infrastructure is required (corresponding to the low utilization of a large number of chargers). EVI-Pro calculates spatial-temporal coincidence of simulated charging events by geographically aggregating charging sessions and allocating sufficient charging capacity (plugs) to prevent queuing at each individual charging locations (stations).

1.1 Daily Driving Schedules

Global positioning system travel trajectories for the Columbus area from commercial traffic/mapping provider INRIX were used as the input data set to the EVI-Pro model. Results from the Columbus model were harmonized with PEV/EVSE ratios from a California model (based on the 2012 California Household Travel Survey) and a Massachusetts model (based on the 2011 Massachusetts Travel Survey).

1.2 Simulated PEV Attributes

The vehicle attributes specified in EVI-Pro include the electric range (miles), vehicle drive efficiency (watthours-per-mile), minimum range tolerance (miles), onboard charger efficiency, and maximum AC charging power. Vehicle energy consumption, which is the main driver of charging requirements, is computed based on highly resolved speed profiles for each different model type and accounts for temperature effects on fuel economy.

Modeled PEVs	PHEV20	PHEV50	BEV100	BEV250
Nominal Electric Drivinge Range, mi	20	50	100	250
Sedan Nominal Efficiency, Wh/mi (excludes charger effic.)	325	325	325	325
SUV Nominal Efficiency, Wh/mi (excludes charger effic.)	450	450	450	450
Minimum Range Tolerance, mi	0	0	20	20
Onboard Charger Efficiency	90%	90%	90%	90%
Maximum AC Charging Power, kW	3.6	3.6	7.2	11.5
Maximum DC Charging Power, kW	0	0	50	150

1.3 Simulated Infrastructure Attributes

Charging infrastructure is segmented by location type as home (single-unit or multi-unit dwelling), workplace, and public (any destination not classified as either a home or work destination). For each location type, up to three charging power levels are available (L1, L2, DCFC). For all simulated charging opportunities, a minimum dwell time for the driver to consider plugging in (at all location types, including home) is also be specified (minimum dwell time of 2 hours for L1/L2 opportunities, 30 minutes for DCFC opportunities), though simulated consumers may not plug in at every opportunity depending on their daily charging needs.

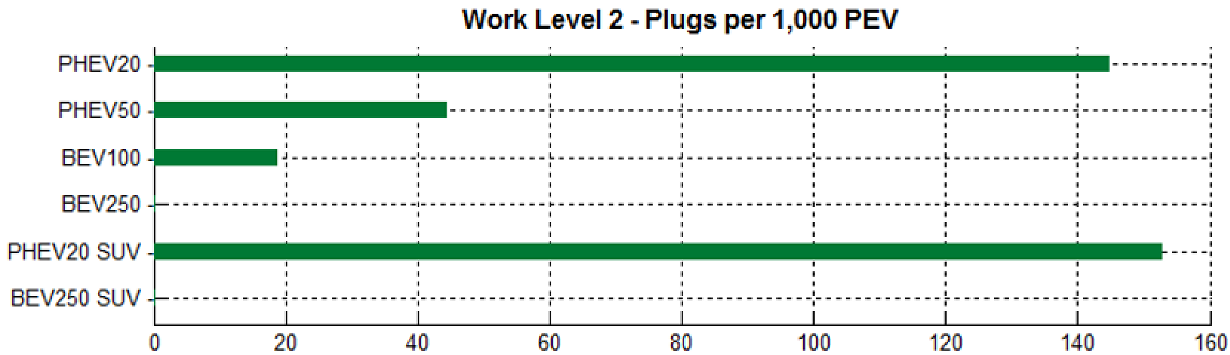
Consumer charging preferences are implemented in EVI-Pro to simulate selection of charging opportunities for individual travel days. EVI-Pro Lite considers a baseline scenario where residential charging is preferred by consumers (if available) with workplace charging, public L2 charging, and DCFC charging used to fill gaps in daily charging needs (in that order).

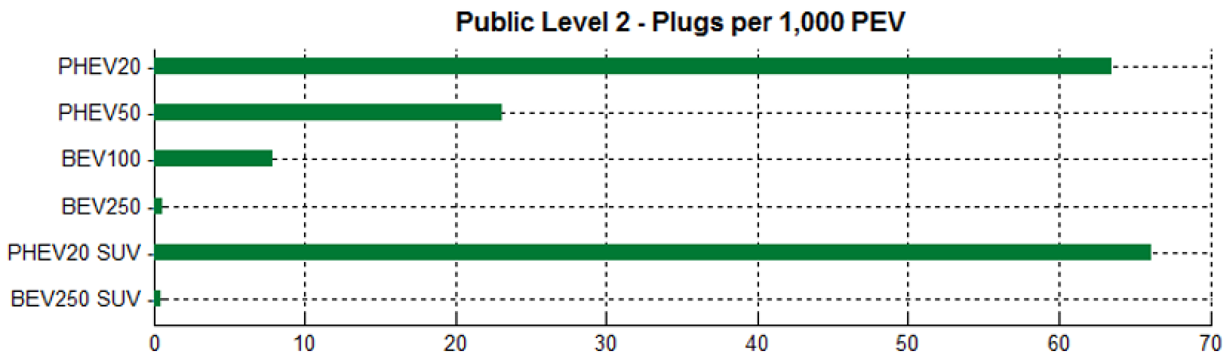
Several scenarios are simulated for each consumer to cover a broad range of possible charging options and capture their impact on PEV charging, infrastructure requirements, and resulting electric load. A matrix of all charging options considered is shown below. The effective DCFC charge rate is adjusted for temperature effects as well as charge duration, assuming that charging power tapers as battery state of charge approaches high levels.

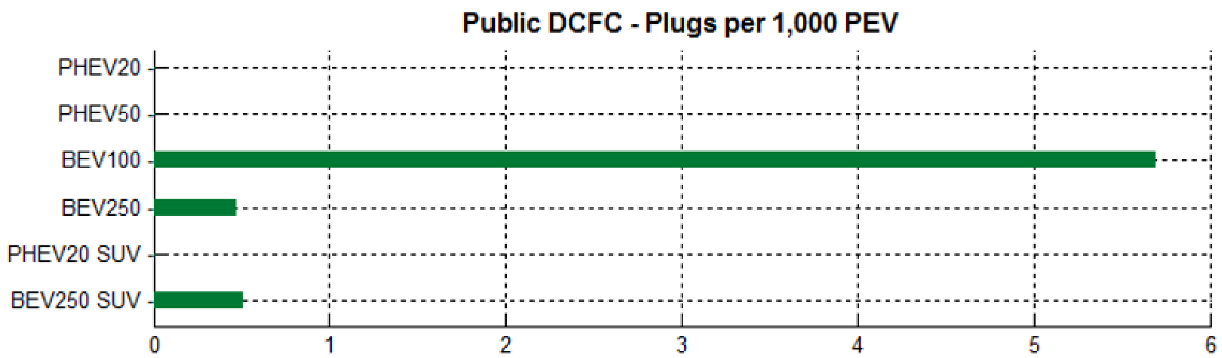
Location	Level	Power	Comment
Home	L1	1.4 kW	N/A
Home	L2	7.2 kW	BEV250 assumes 11.5 kW to enable full overnight charge
Work	L2	6.2 kW	PHEV on-board charger limits max. power to 3.6 kW in model
Public	L2	6.2 kW	PHEV on-board charger limits max. power to 3.6 kW in model
Public	DCFC	150 kW	BEVs only; charge rate tapers at high state of charge; BEV100 limited to 50 kW max

2 EVI-Pro Lite: Charging Infrastructure

Global positioning system travel trajectories for the Columbus area from commercial traffic/mapping provider INRIX were used as the input data set to the EVI-Pro model (Wood et al. 2018). Results from the Columbus model were harmonized with PEV/EVSE ratios from the California model (based on the 2012 California Household Travel Survey) and Massachusetts model (based on the 2011 Massachusetts Travel Survey). This process yields a nominal set of EVSE/PEV ratios for each charger location and power level. The below shows the nominal EVSE/PEV ratios in terms of plugs per 1,000 PEVs for work L2, public L2, and public DCFC infrastructure. These estimates assume a home-dominant charging pattern in which consumers have access to home charging and prefer to do most charging at home owing to their electricity rate structures and the perceived level of convenience.







Nominal non-residential EVSE/PEV ratios (home dominant charging behavior).

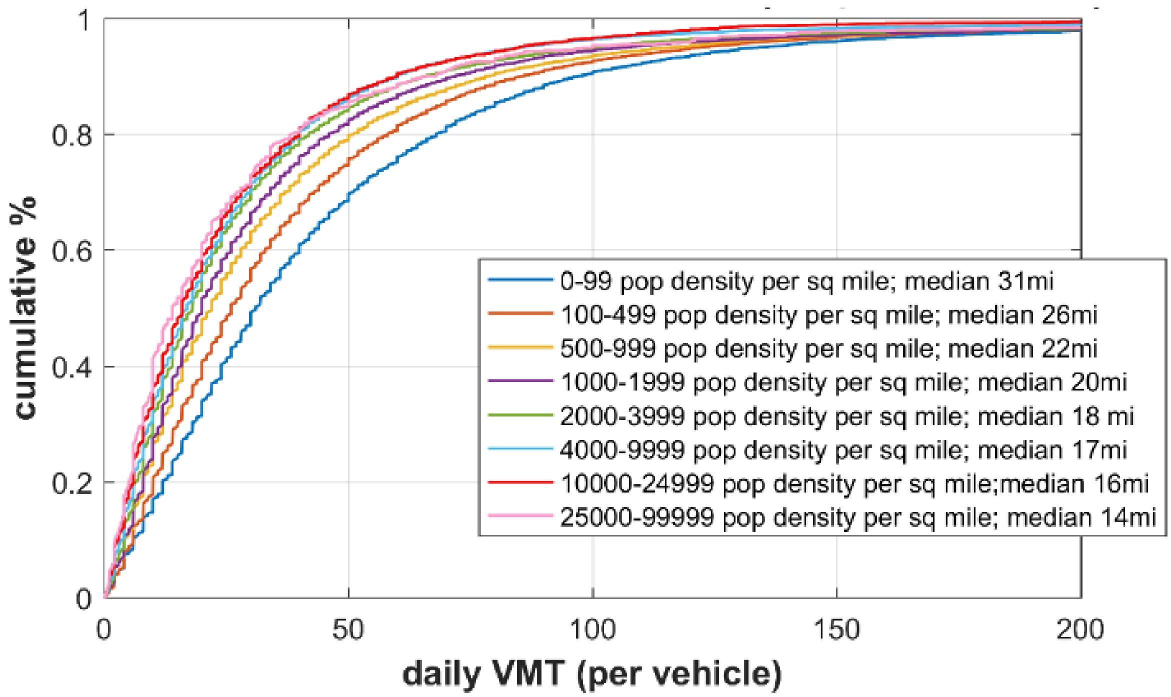
The nominal set of EVSE/PEV ratios is adjusted within EVI-Pro Lite to account for the unique characteristics of all U.S. geographies based on population density, PEV concentration, and ambient temperature. Infrastructure estimates within EVI-Pro Lite will be enabled at various geographies, including state, county, urbanized area, and Census incorporated place levels (excluding geographies with population less than 50,000).

2.1 EVSE/PEV Adjustment Factors to Account for Local Conditions

The nominal set of EVSE/PEV ratios derived from EVI-Pro Lite is adjusted to account for the unique characteristics of all geographies based on population density, PEV concentration, and ambient temperature.

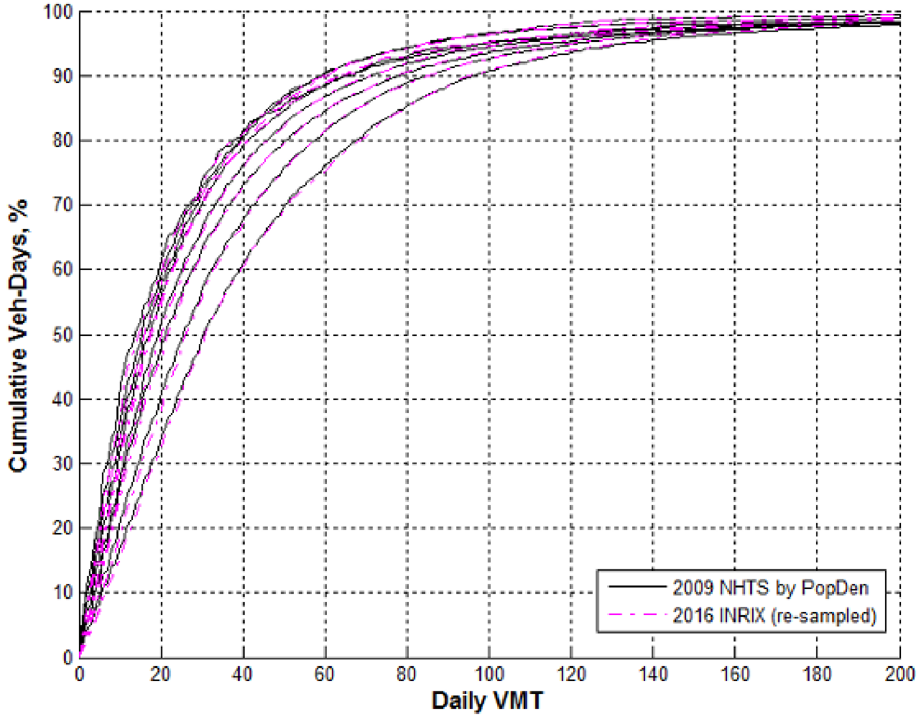
2.1.1 Population Density as a Surrogate for Local Distributions of Daily Vehicle Miles Traveled

As population density increases in a region, the average VMT per vehicle decreases, and thus less EVSE capacity is required. Daily VMT data from the 2009 NHTS are used to quantify this relationship and develop a population density adjustment factor. The below figure shows the daily VMT cumulative distribution functions by population density. Median VMT ranges from 14 miles per day in the most densely populated areas to 31 miles per day in the most sparsely populated areas.



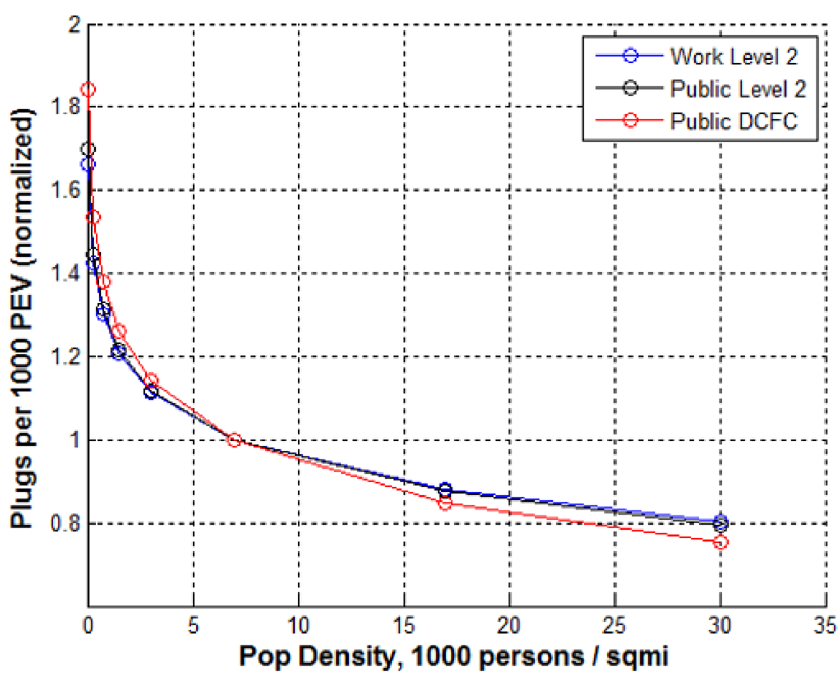
Daily VMT cumulative distribution functions by population density, from the 2009 NHTS.

The INRIX travel data are resampled to mimic the NHTS daily VMT distributions (see below figure). For example, for each U.S. urban area with 2,000–3,999 people per square mile, the INRIX data are sampled so that vehicles modeled have the same VMT distribution as NHTS vehicles from the 2,000–3,999 density bin, and so forth.



Mimicking NHTS daily VMT cumulative distribution functions by population density by resampling INRIX travel data.

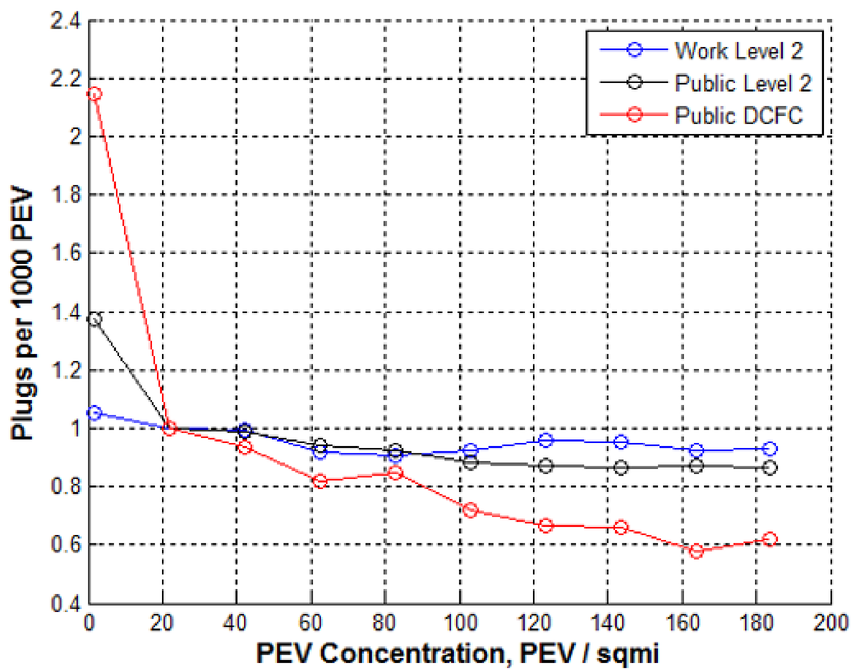
EVI-Pro computed the EVSE/PEV ratio for each population density distribution from the resampled INRIX data to generate the adjustment factor shown below. These adjustment factors are used with EVI-Pro Lite to customize infrastructure estimates to local geographies.



Adjustment factor: non-residential EVSE/PEV ratio as a function of population density.

2.1.2 PEV Concentration Adjustments

Similarly, an adjustment factor based on PEV concentration is generated by running EVI-Pro simulations at various PEV concentrations. Plug requirements are lower at higher PEV concentrations (see below figure) due to the greater opportunity for efficient infrastructure sharing. These adjustments are directly incorporated into EVI-Pro Lite.



Adjustment factor: non-residential EVSE/PEV ratio as a function of PEV concentration.

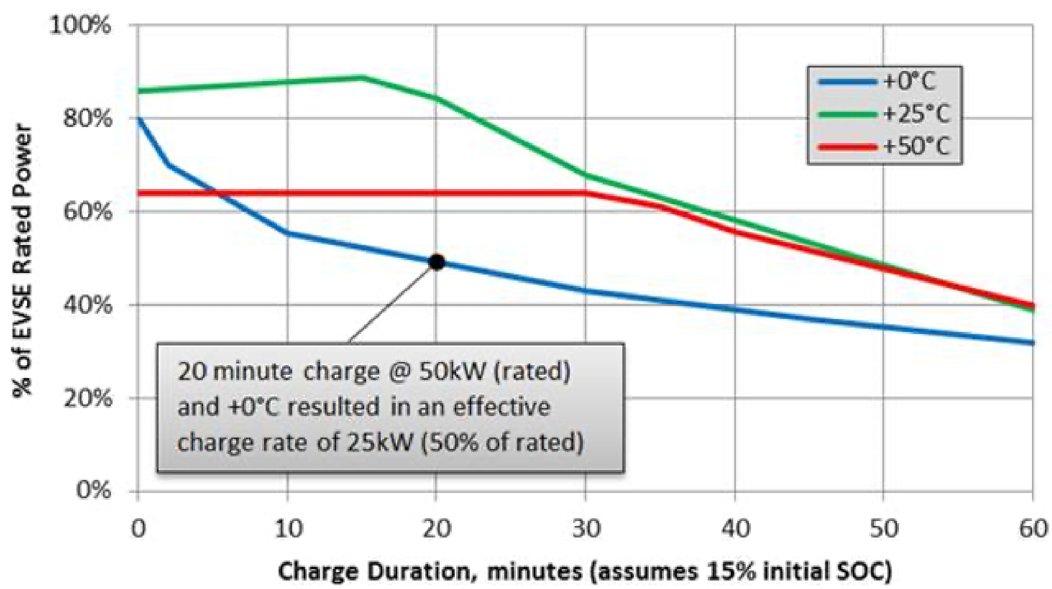
2.1.3 Ambient Temperature Adjustments

Ambient temperature affects battery charge and discharge rates, and the temperature adjustments applied account for both impacts. Using EVI-Pro, non-uniform discharge rates are applied to driving events depending on trip average speed and ambient temperature, based on the measured effects of temperature on Nissan Leafs (Yuksel and Michalek 2014) over simulated drive cycles (Neubauer and Wood 2013). The below figure shows the modeled relative battery discharge rates as a function of ambient temperature and trip average speed: very hot and very cold temperatures drain the battery more quickly at any speed.

Trip Avg Speed, mph	Ambient Temperature, °C												
	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
2.5	203%	193%	186%	178%	167%	154%	141%	132%	129%	136%	153%	180%	213%
7.5	177%	168%	162%	155%	146%	135%	123%	115%	113%	119%	134%	157%	186%
12.5	163%	155%	149%	143%	134%	124%	114%	106%	104%	109%	123%	145%	171%
17.5	146%	139%	134%	128%	121%	111%	102%	95%	93%	98%	110%	130%	153%
22.5	135%	128%	123%	118%	111%	102%	94%	88%	86%	90%	102%	120%	141%
27.5	132%	125%	120%	115%	108%	100%	92%	85%	84%	88%	99%	117%	138%
32.5	135%	128%	123%	118%	111%	102%	94%	88%	86%	90%	102%	120%	141%
37.5	141%	134%	129%	124%	116%	107%	98%	92%	90%	94%	106%	125%	147%
42.5	147%	139%	134%	129%	121%	111%	102%	95%	93%	98%	111%	130%	154%
47.5	155%	147%	142%	136%	128%	118%	108%	101%	99%	104%	117%	138%	163%
52.5	164%	156%	150%	144%	135%	125%	114%	107%	104%	110%	124%	146%	172%
57.5	168%	159%	154%	147%	139%	128%	117%	109%	107%	113%	127%	149%	176%
62.5	182%	172%	166%	159%	150%	138%	126%	118%	115%	121%	137%	161%	190%

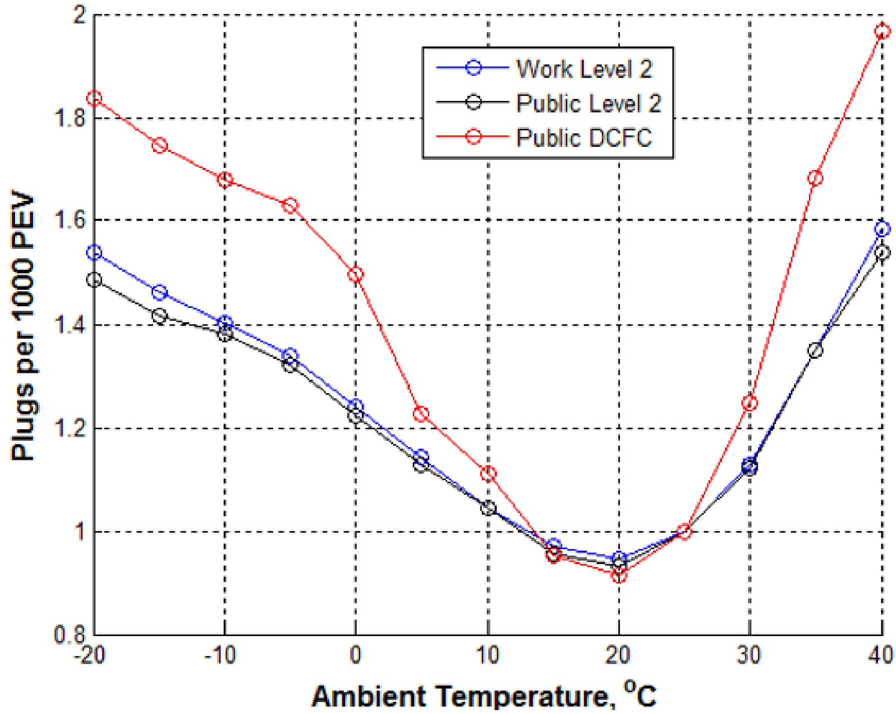
EVI-Pro Driving Discharge Model: Relative Battery Discharge Rates as a Function of Ambient Temperature and Average Trip Speed

EVI-Pro also adjusts DCFC charge rates for battery temperature and charge duration, based on INL's testing of a Nissan Leaf (INL 2016). Again, temperature has a major impact, for example, reducing the 20-minute effective DCFC charge rate from over 80% of rated power at a battery temperature of 25°C to 50% of rated power at 0°C.



EVI-Pro DCFC effective charge rate model: percentage of EVSE rated power delivered as a function of charge duration and battery temperature.

These ambient temperature adjustments are applied across EVI-Pro simulations at multiple ambient temperatures to derive the temperature adjustment factors shown below, which are directly applied within EVI-Pro Lite.



Adjustment factor: non-residential EVSE/PEV ratio as a function of ambient temperature.

3 EVI-Pro Lite: Charging Load Profiles

Load profiles for EVI-Pro Lite have been developed by parameterizing EVI-Pro over a large design space and synthesizing composition charging load profiles using weighted sampling.

Within the user interface for EVI-Pro Lite, users are first required to select an urbanized area (organized by state) and target PEV fleet size for analysis. Based on the user's geographic selection, load profile inputs for average daily miles traveled per vehicle and average ambient temperature are automatically populated, with the option to edit. Automatically populated values for average daily miles traveled per vehicle are selected based on the population density of the given urbanized area using the above correlation derived from the 2009 NHTS. The ambient temperature value is populated using Typical Meteorological Year data for the nearest weather station. Additional reference information is provided for projected size of future PEV fleets based on national electric vehicle stock projections from the U.S. Energy Information Administration. National estimates are disaggregated to urbanized areas based on existing hybrid, plug-in hybrid, and all-electric vehicle registrations provided from IHS Markit's Polk light-duty vehicle registration database.

3.1 Parameterizing EVI-Pro Simulations

EVI-Pro has been parameterized for simulation of nearly 50,000 real-world travel days from the 2012 California Household Travel Survey across 14 unique ambient temperatures (-20°C to 40°C), 8 representative PEV types (PHEV20, PHEV50, BEV100, BEV250 with sedan and SUV variants for both), and 36 combinations of charging behavior and technology types (including varying home/work charging power and availability, and home or work as the preferred charging location).

The resulting product is a database of over 200 million unique simulated charging events. Each simulated charging event is described in the database based on simulated vehicle ID, arrival and departure time at the charging location, start and end time for the charge event, destination type (home, work, or public), charge level (L1, L2, or DCFC), and energy dispensed during the charging event (expressed in kWh).

3.2 Synthesizing Charging Load Profiles

The database of simulated charging events was subjected to weighted sampling using a design space of over 13,000 unique combinations of vehicle and infrastructure technology, driving and charging behavior, and ambient conditions. For each of the 13,000 combinations, individual simulated charging events are sampled according to a user specified weighting scheme and a composite charging load profile is generated and archived. Input and output parameters for this sampling methodology are described in the below table.

Data Label	Description	Units	Type	Allowed Values
Input Variables				
temp_c	Average Ambient TemperatureAverage ambient temp. that the fleet is driving in. This impacts vehicle and charger efficiency.	oC	Integer	-20-10010203040
fleet_size	Fleet SizeTotal number of light duty plug-in electric vehicles (PEVs) that are modeled.	vehicles	Integer	1,00010,00050,000
mean_dvmt	Average Daily Vehicle Miles TraveledAverage daily vehicle miles traveled (DVTM) for all vehicles in the fleet.	Miles per weekday	Integer	253545
pev_dist	Electric Vehicle Type DistributionDistribution of PEV technology type for hte fleet. Each option corresponds to a % distribution of PHEV20 / PHEV50 / BEV100 / BEV250: • BEV Dominant: 10 / 15	---	Character	BEV DominantPHEV DominantEqual

	/ 25 / 50 • PHEV Dominant: 25 / 50 / 10 / 15 • Equal: 15 / 35 / 15 / 35			
class_dist	Vehicle Class DistributionDistribution of PEV class for the fleet. Each option corresponds to a % distribution of Sedan / SUV: • Sedan Dominant: 80 / 20 • SUV Dominant: 20 / 80 • Equal: 50 / 50	---	Character	Sedan DominantSUV DominantEqual
pref_dist	Driver Home / Work Charging PreferenceDistribution of driver’s preferred charging location for the fleet. Each option corresponds to a % distribution of Prefer Home / Prefer Work: • Home100: 100 / 0 • Home80: 80 / 20 • Home60: 60 / 40	---	Character	Home100Home80Home60
home_access_dist	Home Charging Access DistributionDistribution of drivers that have access to home power for the fleet. Each option corresponds to a % distribution of Access / No Access: • HA100: 100 / 0 • HA75: 75 / 25 • HA50: 50 / 50	---	Character	HA100HA75HA50
home_power_dist	Home EV Charging Station Power DistributionDistribution of home charging power for those drivers that have access to home charging. Each option corresponds to a % distribution of L1 / L2: • MostL2: 20 / 80 •	---	Character	MostL2MostL1Equal

	Most L1: 80 / 20 • Equal: 50 / 50			
work_power_dist	Work EV Charging Station Power DistributionDistribution of workplace charger power across all drivers of the fleet. Each option corresponds to a % distribution of L1 / L2: • MostL2: 20 / 80 • Most L1: 80 / 20 • Equal: 50 / 50	---	Character	MostL2MostL1Equal
Output Variables				
day_of_week	Indicates if the kW load is associated with typical weekday or weekend trip types	---	Character	WeekdayWeekend
pev_type	Indicates which of the four different PEV technology types the kW load is associated with	---	Character	PHEV20PHEV50BEV100BEV250
class_type	Indicates which of the two different vehicle classes the kW load is associated with	---	Character	SedanSUV
dest_type	Indicates which of the three different destination types the kW load is associated with	---	Character	HomeWorkPublic
dest_chg_level	Indicates which of the three EV charger power levels the kW load is associated with	---	Character	L1L2L3

References

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