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Evaluating the emissions benefits of investor-owned utility electric vehicle charging infrastructure programs in California

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Executive Summary

Three California IOU electric vehicle (EV) charging infrastructure programs were evaluated to assess emissions benefits associated with each program. Charging session data from 2017 to 2023 was analyzed in conjuction with Califoria electric grid hourly emissions rate to determine the observed emissions for each program. Three scenarios were devised to assess the emissions benefits of deploying multi-unit dwelling and workplace charging to inform program design and investment strategy. The study found that public, daytime charging delivers more emissions benefits compared residential, overnight charging.

Keywords: electric vehicle (EV), electric vehicle supply equipment (EVSE), emissions, utility, level 2

1 Background & Motivation

Decarbonizing California's economy is the critical task for the 20 years. State Bill (SB) 32 mandates 40% emissions reduction below 1990 levels by 2030 and Assembly Bill (AB) 1279 requires net zero carbon emissions by 2045 [1] [2]. The recent California Air Resources Board (CARB) 2022 Scoping Plan translates these goals into a comprehensive multi-sectoral strategy and goes further to increase the 2030 goal from 40% to 48% emissions redutions below 1990 levels [3]. Cementing the State's commitment, Governor Newsom's 2022 budget committed \$54 billion to climate change spending [4]. Despite California's lofy carbon reduction goals and billions of dollars committed to climate efforts, a recent study by Energy Innovation shows that the State will miss its orginial (40%) 2030 target by 20% [5]. Moreover, as of 2020, the State has only reduced 14% of required emissions and would need to cut 2.6% per year to meet SB 32 and 3.4% per year to meet CARB's new Scoping Plan target [5]. Successfully reaching California's emission reduction goals rests on extracting every percent of CO_2 equivalent (CO_2e) emission savings across the economy.

CARB's Scoping Plan identifies the key sectors in California to generate emissions reductions. At the top of list is the transportation sector, which accounts for 40% of (CO_2e) emissions [3]. CARB outlines several strategies reduce transportation emissions, namely transitioning from internal combustion engine (ICE) vehicles to zero emissions vehicles (ZEV). Importantly, EV CO_2e emissions are based on the type of electricity generation resource. Given two identical EVs, an EV charged on electricity from solar is 'cleaner' than an EV charged on coal, natural gas, or other fossil fuels. EVs can become 'cleaner' over time whereas ICE vehicles will produce an ever increasingly amount of CO_2e over their lifetime. The Scoping Plan recognizes this reality as it aims to reduce electric sector emissions by 30% and 85% compared to 2020 emissions by 2030 and 2045 respectively [3].

Until the State reaches its electric sector decarbonization goals, the carbon-free miles promised by EVs can not be fully attained, but emissions reductions can still be achieved my strategically matching charging with carbon-free electricity generation. California's electric grid experiences drastic shift in carbon intensity from nighttime to daytime hours as the renewable generation resources (e.g., solar, wind) come online and pour carbon-free electrons onto the grid. This shift in carbon intensity implies that the time an EV is charged will have a significant impact on the carbon intensity of the miles driven and by extent transportation sector emissions. When an EV is charged is generally dependent on where the charging station is located; broadly, an EV charger, or electric vehicle supply equipment (EVSE), located at home will charge an EV overnight and an EVSE located at a workplace or other public location (e.g., a parking garage) will charge at EV during the day. Given the temporal CO_2 emission impacts of charging, the strategic siting of of EV charging infrastructure can be a key tactic to reduce transportation sector emissions.

In this vein, the California Public Utilities Comission (CPUC) commissioned a University of California, Davis (UCD) research team at the Electric Vehicle Research Center along with other California-based research teams to study the emissions impact of investor-owned utility (IOU) EV charging infrastructure programs. In 2016, the CPUC approved $243M in IOU program spending to support light-duty EV charging infrastructure deployment across Pacific Gas & Electric's (PG&E) EV Charge Network, Southern California Edison's (SCE) Charge Ready (Pilot and Bridge) program, and San Diego Gas & Electric's (SDG&E) Power Your Drive Pilot [6]. Between August 2020 and December 2022, the CPUC approved another $531.7 million in additional funding for EV charging infrastructure, including $436 million from SCE, $52.5 million from PGE, and $43.5 million from SDGE, to deploy 42,622 chargers between Level 2 and Direct Current Fast Charging (DCFC) [6]. Utilities play a critical role in the electrification ecosystem and can market leaders for strategic EVSE deployment. This study focuses on EVSE installed through Pacific Gas & Electric's (PG&E) EV Charge Network, Southern California Edison's (SCE) Charge Ready (Pilot and Bridge) program, and San Diego Gas & Electric's (SDG&E) Power Your Drive Pilot at multi-unit dwellings (MUDs) and workplaces. The study aims to develop a more holistic and empirically based understanding of the emissions reduction impacts of EV charging infrastructure locations to inform program design and guide investment strategies.

2 Methods & Data

Establishing the emissions benefits of installing public EV charging infrastructure is a multi-step process, which requires an understanding of not only how public charging lead to changes in the electric vehicle adoption and use, but also the relationship between charging events and electricity grid emissions. To assess the emissions benefits, three scenarios were devised to capture an upper bound, a lower bound, and a baseline. By design, the upper bound scenario reflects the most emissions savings, the lower bound reflects the least emissions savings, and the modeled actual savings should fall somewhere in between. Table 1 describes each scenario in more detail.

Table 1: Emission Scenarios

Scenario	Description
All ICE	Reflects the emissions impacts of a hypothetical scenario where all kWh delivered by IOU-funded EVSE powered ICE vehicle miles traveled (VMT) compared to the observed emissions impacts from IOU-funded EVSE
Overnight charging	Reflects the emissions impacts of overnight charging compared to the observed emissions impacts from IOU-funded EVSE
Shift to Daytime Charging	Reflects the emissions impacts of workplace charging sessions in which a proportion of charging sessions serve a ICE to EV transition and a proportion replace charging overnight at home based on workplace EV charging deployment forecast from the UC Davis EVToolbox model

2.1 Data

To construct these scenarios, the study leveraged several data sources: (1) IOU charging session data for Level 2 EVSE installed at MUDs, workplaces, and other public locations from 2017 to early 2023, (2) hourly

CO_2 equivalent emissions for the California grid for 2019 to 2021 from Singularity Energy, (3) 2019 Tigerline Census Tract Data shapefiles from the United States Census Bureau, (4) the Department of Energy (DOE) Alternative Fuels Data Center (AFDC), and (5) estimated number of public EV chargers for 2022 using the University of California, Davis EV Toolbox (EVTB). Table 2 provides more detail for each data source.

Table 2: Study data sources and descriptions

Data Source	Description
IOU charging session interval	Per-IOU dataset provided by CPUC including EVSE ID, location, energy (kWh) per session, session start and end time for Level 2 EVSE
Singularity Energy [7]	Open-source dataset containing validated hourly emissions data by balancing authority for the United States from 2019 to 2021
United States Census Bureau, TIGER/Line Shapefiles [8]	Open source dataset containing geographic information for regions in the United States
Department of Energy, Alternative Fuels Data Center [9]	Public dataset collected by the DOE reporting various demographic information of public EV charging stations across the United States
University of California, Davis EV Toolbox [10]	Sophiscated modeling tool based on a multi-location charging choice model developed by the Electric Vehicle Research Center to enable higly granular spatial predictions of the number of EVs, number of commuters, number of charging events per day, and number of EV chargers

All data was cleaned, processed, and analzyed using R [11] [12] [13]. The IOU charging session data was first transformed from individual charging sessions that included a start time and end time to charging sessions by hour data to match the hourly emissions rate data in Singularity Energy's dataset. The consumed kilogram (kg) CO_2e per megawatt-hour (MWh) in the Singularity data set was used as the emissions factor because as it captures the additional CO_2e emitted by the electricity generation resource to account for transmission and distribution losses in the electrical grid. For the years (2017, 2018, 2023) not included in the Singularity Energy database, data from 2019 was scaled proportionally for 2017 and 2018 using the percentage difference in cumulative annual carbon emissions reported by the California Independent System Operator (CAISO) [14]. Data from 2022 was applied to 2023 as only January hourly emissions data was needed. This process produced an hourly emissions file for each IOU totaling 14,572,225 observations (obs) across ~39,500 hours (PGE: 1,795,160 obs; SDGE: 6,323,454 obs; SCE: 6,453,611 obs).

After generating an hourly emissions file, the EVSE locations were geocoded and intersected with the 2019 United States Census Bureau census tract shapes produced by the TIGER line package in R [15]. Lastly, the EVSE counts, kWh, and emissions were summarized and grouped by census tract and IOU. The AFDC data was similarly filtered for public charging, geocoded, and grouped by corresponding census tract. The IOU EVSE data and AFDC data were joined by census tract with the EVTB data to create a single file outlining the number of EV charging stations for each data source by census tract. The scenario parameters for the EVTB are shown in Table 3.

Table 3: UC Davis EV Toolbox parameters for Scenario 3 EV Toolbox EV charger estimates

Assumptions
Baseline year: 2021
50% of drivers commute
80% of EVs have a range greater than 220 miles
80% of EVs charger at home
Each public charging station experiences 0.6 charging sessions per day
Workplace charging fee

2.1.2 Data Processing & Gaps

Prior to joining the IOU charging session data with Singularity's dataset, the IOU data was filtered to remove incorrectly collected or reported data, and data that did not reflect real world conditions. Three filters were applied: (1) sessions delivering more than 150 kWh (no light duty EV on the market from 2017 – 2022 sold in California has a battery pack greater than 125 kWh), (2) sessions with power levels greater than 11.2 kW (all EVSE were stated to have 7.2 kWh power level, but a margin of error was included to account for stations that may have been upgraded from 40A circuit to a 60A circuit), and (3) sessions that delivered less than 0.05 kWh [16].

In addition to the data filters applied, the data provided to the research team contained multiple data omissions that are important to note. First, due to the structure of each IOU's program, site hosts had a choice between IOU ownership, or sponsorhip, of the installed EVSE or direct ownership. Due to this program design choice, only EVSE owned by each IOU are included in the dataset. Significantly, PG&E reported data for only 654 EVSE compared to 2,000 and 2,936 for SCE and SDGE, respectively, after the data filters were applied. Second, the geographic and demograhic attributes for SCE and SDG&E EVSE were reported in separate files from the charging session data. While joining the datasets, it was found that the number of EVSEs reported in the charging session file did not match the number of EVSE reported in the geographic and demographic file. Due to this error in data collection and reporting, only 1,179 EVSE of 2,000 EVSE and 2,711 EVSE of 2,936 EVSE for SCE and SDG&E, respectively, were included in the analysis.

2.2 Methods

The total emissions for each scenario were calculated individually with similar, but slightly different approaches. Table 4 outlines the variables used for each equation.

Table 4: Description of variables used in emissions calculations

Variable	Description
$IOU_i\ evse_{census\ tract}$	Number of EVSE per census tract for IOU *i*
$AFDC\ evse_{census\ tract}$	Number of EVSE per census tract from AFDC data set
$EV.tb\ evse_{census\ tract}$	Number of EVSE per census tract from EV Toolbox
EV Efficiency	Assumed efficiency of an EV in kWh per mile (3 kWh/ mile)
$Emissions\ Factor_{Gasoline}$	g CO_2 per gal gasoline (8,887 g CO_2e/ gal)
$Efficiency(mpg)_{CA\ Light\ Duty\ Fleet}$	California light duty ICE fuel economy (32 mpg)

For Scenario 1 were calculated with Equation (1) using 3 kWh/ mile as the average EV efficiency.

$$\left(\frac{Total\ kWh_{PGE} + Total\ kWh_{SCE} + Total\ kWh_{SDGE} * EV\ Efficiency}{Efficiency\ (mpg)_{CA\ Light\ Duty\ Fleet}}\right) * Emissions\ Factor_{Gasoline} \quad (1)$$

The total emissions for Scenario 2 were calculated with Equation (2) using the observed weighted average overnight emissions rate for each IOU as the emissions factor as shown in Table 5.

$$\begin{gathered} Total\ kWh_{PGE}\ * Weighted\ Avg\ IOU_{PGE} Emissions\ Rate_{\ CA\ Grid\ Overnight} + \\ Total\ kWh_{SCE}\ * Weighted\ Avg\ IOU_{SCE} Emissions\ Rate_{\ CA\ Grid\ Overnight} + \\ Total\ kWh_{SDGE}\ * Weighted\ Avg\ IOU_{SDGE} Emissions\ Rate_{\ CA\ Grid\ Overnight} \end{gathered} \quad (2)$$

Table 5: Overnight weighted average emissions factors

	Units	Factor
PGE Weighted Avg Nighttime Em. Rate	CO_2e g/ kWh	276.91
SCE Weighted Avg Nighttime Em. Rate	CO_2e g/ kWh	271.20
SDGE Weighted Avg Nighttime Em. Rate	CO_2e g/ kWh	272.86

The total emissions for Scenario 3 were calculated by combining the emissions impacts generated by a transition from ICE to EV, emissions impacts stimulated by shift charging from overnight to daytime, and the total non daytime, or non-workplace EVSE, emissions in the hourly emissions datasets. The non-daytime EVSE emissions were added to the sum in to order isolate the effect of public charging on emissions savings. Total emissions for ICE to EV were allocated to Equation (3) based on two sets of conditions, $EV.tb\ evse_{census\ tract} \geq AFDC\ evse_{census\ tract} + IOU_i\ evse_{census\ tract}$ or $EV.tb\ evse_{census\ tract} < AFDC\ evse_{census\ tract} + IOU_i\ evse_{census\ tract}$ and $EV.tb\ evse_{census\ tract} - AFDC\ evse_{census\ tract} > IOU_i\ evse_{census\ tract}$

$$\frac{IOU_i evse_{\ census\ trac} + (EV.tb\ evse_{\ census\ tract} - AFDC\ evse_{\ census\ tract})}{IOU_i evse_{\ census\ tract}} * \frac{IOU_i Total\ kWh_{\ census\ tract} * \frac{kWh}{mile}}{Efficiency\ (mpg)_{CA\ Light\ Duty\ Fleet}} * Emissions\ Factor_{Gasoline} \quad (3)$$

Total emissions for overnight to daytime charging shift were calculated with Equation (4) based on one set of conditions, $EV.tb\ evse_{census\ tract} < AFDC\ evse_{census\ tract} + IOU_i\ evse_{census\ tract}$ and $AFDC\ evse_{census\ tract} > EV.tb\ evse_{census\ tract}$ or $AFDC\ evse_{census\ tract} < EV.tb\ evse_{census\ tract}$ and $IOU_i\ evse_{census\ tract} < EV.tb\ evse_{census\ tract}$

$$\frac{(AFDC\ evse_{\ census\ tract} + IOU_i evse_{\ census\ tract}) - EV.tb\ evse_{\ census\ tract}}{IOU_i evse_{\ census\ tract}} * (IOU_i Total\ kWh_{\ census\ tract} * IOU_i Emissions\ Rate_{\ CA\ Grid\ Overnight}) \quad (4)$$

The same overnight emissions factors outlined Table 5 were used to calculate the total emissions in Equation (4). The emissions benefits for each scenario were calculated by taking the difference of the total emissions for each scenario and the total observed emissions from the hourly emissions data.

3 Results

The total Observed CO_2 emissions from IOU infrastructure programs was 6,360.67 mt and the total modeled emissions for 23,863.56 mt, 7,804.58 mt, and 16,334.75 mt for Scenarios 1, 2, and 3, respectively.

Table 6: Summary metrics for PG&E, SCE, and SDG&E hourly emissions & total emissions by scenario

IOU	Total kWh Delivered	Observed CO_2e emissions (mt)	Scenario: 1 All ICE (mt)	Scenario 2: Overnight charging (mt)	Scenario 3: Shift to Daytime Charging (mt)
PG&E	2,629,772.00	615.33	2,191.01	728.21	1,122.40
SCE	12,946,348.00	2,858.50	10,786.33	3,511.12	7,079.23
SDG&E	13,066,236.00	2,886.84	10,886.22	3,565.25	8,133.12
Total	28,642,356.00	6,360.67	23,863.56	7,804.58	16,334.75

Table 7: Total CO_2e emissions savings by scenario

IOU	Scenario 1: All ICE (mt)	Scenario 2: Overnight charging (mt)	Scenario 3: Shift to Daytime Charging (mt)
PG&E	1,575.68	112.88	507.07
SCE	7,927.83	652.62	4,220.73
SDG&E	7,999.38	678.41	5,246.28
Total	17,502.89	1,443.91	9,974.08

Subtracting the Observed CO_2e emisions from each scenario yields that emissions savings for each scenario. The most emissions savings (17,502.89 mt) are generated from transitioning ICE VMT to EV VMT where as the least emissions savings (1,443.91 mt) are generated from shifting all charging to overnight. Scenario 3 emissions savings (9,974.08) reflects the baseline emissions savings from the IOU programs.

Further analysis of the emissions allocations in Scenario 3 shows the total kWh and CO_2e emissions shifted for workplace EVSE. In total, 14.05% of kWh and 18.22% of CO_2e were shifted within Scenario 3, which implies an average of 1.29% of CO_2e emissions saved for every 1% of load shifted. Per IOU, shifting PG&E charging generates 277 g CO_2e saved per kWh, shifting SCE charging generates 271.2 g CO_2e saved per kWh, and shifting SDG&E generates 295.9 g CO_2e saved per kWh shifted.

Table 8: Total kWh delivered & shifted for workplace EVSE in Scenario 3

IOU	Total kWh Delivered	Total kWh Shifted	Percent kWh Shifted
PGE	846,498.35	39,277.86	4.64%
SCE	8,949,946.81	2,335,529.48	26.10%
SDGE	8,748,466.62	231,178.65	2.64%
Total	18,544,911.77	2,605,985.99	14.05%

Table 9: Total CO_2e emitted & shifted for workplace EVSE in Scenario 3

IOU	Total CO_2e Emissions (mt)	Total CO_2e Shifted (mt)	Percent CO_2e Shifted
PGE	178.59	10.88	6.09%
SCE	1,926.21	633.41	32.88%
SDGE	1,806.27	68.37	3.78%
Total	3,911.07	712.65	18.22%

4 Discussion

The results can be interpreted from two perspectives – future EV charging infrastructrure program design and existing charging infrastructure operation.

First, as anticipated, Scenario 1 delivered the highest emissions savings whereas Scenario 2 generated the least. Notably, shifting to daytime charging at workplaces in Scenario 3 yields nearly 6 times more emissions savings than strictly relying on overnight, at-home charging in Scenario 2. This suggests that EV charging infrastructure installed at workplaces can deliver greater emissions saving than installing EV charging infrastructure. As IOU or other entities consider EV infrastructure programs focusing on workplace charging deployment will yield greater reductions. However, it is important to recognize that while emissions reductions are critical they can only be achieved if drivers switch from ICE vehicles to EVs. Installing at-home charging is critical to provide equitable charging access to ensure all Californians can own EVs.

Second, in context of existing charging infrastructure operation, the results shows that shifting charging from overnight to daytime yields 1.29% CO_2e emission savings for each 1% kWh shifted. This finding suggests that emissions savings be extracted from existing EV charging infrastructure by adjusting the charging behaviors of drivers. For instance, an IOU could introduce a public charging tariff schedule that targets 1.29% CO_2e saved per kWh shifted by discounts the price per kWh compared to residential rate plans. Implicitly, this rate plan would include the IOU's social cost of carbon. Further analysis on this topic would be required to appropriately evaluate this hypothetical rate plan.

5 Conclusion

Despite California's lofty decarbonization goals, billions of dollars committed to climate efforts, and a comprehensive, multi-sector strategy, California is not on target to meet its 2030 target [5]. State agencies, IOUs, and other entities must double-down on extracting every percent of CO_2e emission from each program, project, and piece of infrastructure installed. While this effort must apply across sectors, the transportation sector, which accounts for 40% of California's emissions, is a prime area to enhance CO_2e reductions. Transitioning from ICE vehicles to EVs is the centerpiece for transportation related emissions reductions. However, EVs are only as 'clean' as the electricity that they use to charge. California's grid experiences drastic swings in carbon intensity from night to day as more renewables inject electrons into the grid. From an emissions reductions perspective, charging an EV during the day is more optimal than overnight. Generally, daytime charging occurs at workplaces and overnight charging happens at home. Until California can decarbonize its electric sector, the temporal dependency of carbon intensity will continue to impact transportation sector emissions reductions and require close attention to the siting of EV charging infrastructure.

The study evaluates EV charging infrastructure emissions impacts of Pacific Gas & Electric's (PG&E) EV Charge Network, Southern California Edison's (SCE) Charge Ready (Pilot and Bridge) program, and San Diego Gas & Electric's (SDG&E) Power Your Drive Pilot programs. Collectively, California IOUs have invested or have been authorized to invest nearly $775 million in EV charging infrastructure. Developing a holistic and empirically grounded program design and infrastructure investment approach centered on emissions reductions can maximize the impact of IOU funding. The study finds that workplace charging delivers more emissions savings than an at-home charging approach. Future EV charging infrastructure programs should prioritize workplace or daytime charging in program design and the investment strategy to enhance emissions reductions for the growing fleet of EVs in California. Current EV charging infrastructure infrastructure emissions reductions could be enhanced by designing rates to achieve a minimum amount of CO_2e saved compared overnight charging.

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