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Vehicle-Grid Integration Analysis

Presentation to VGI Working Group

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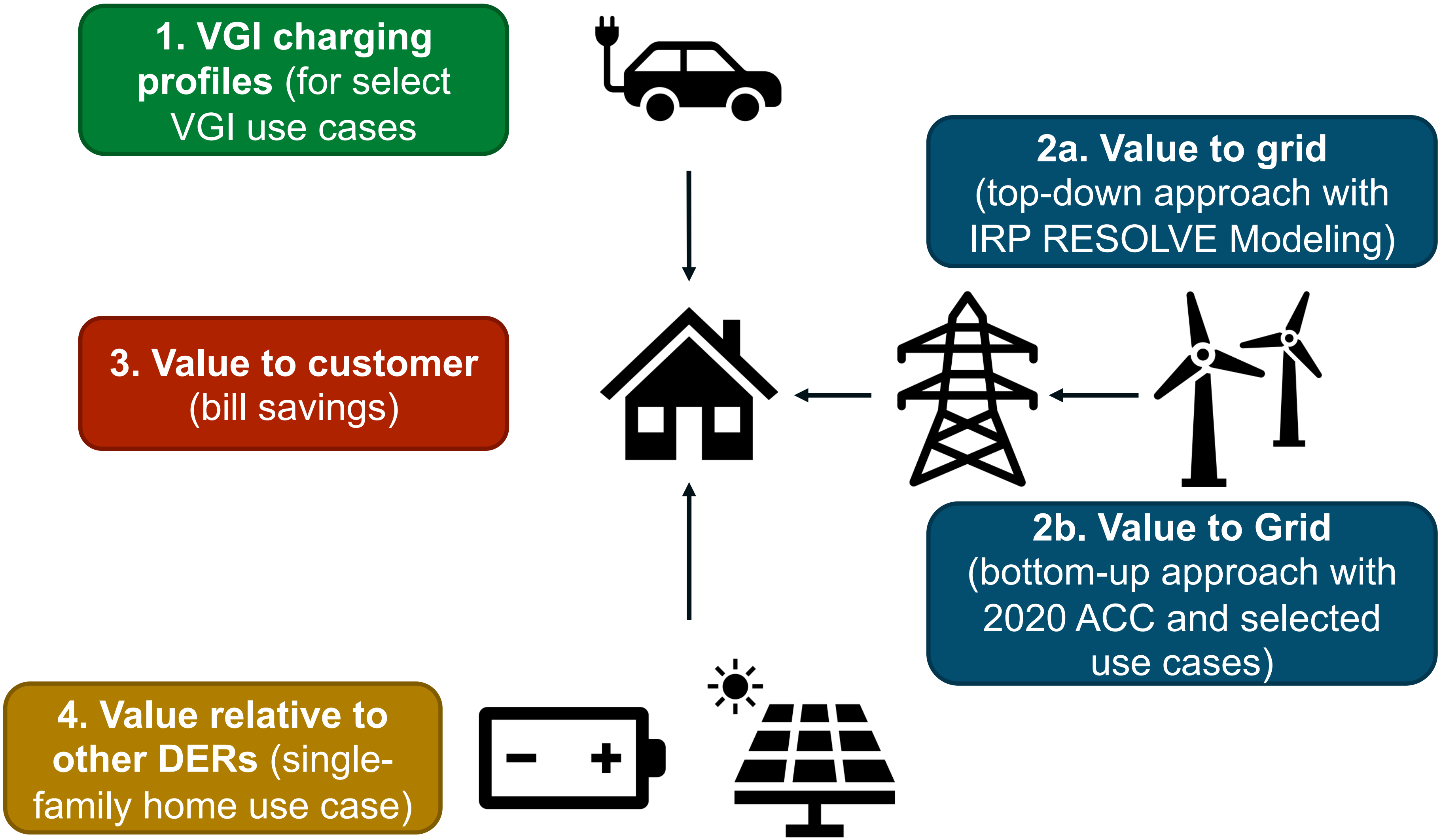
Contents

Background

+ **E3 is currently working with the CPUC to support the Integrated Resource Plan (IRP) proceeding**
+ **E3's work for the IRP includes various analyses of electric vehicle load shapes and costs and benefits**
+ **In order to support the VGI working group, E3 and the CPUC decided to leverage relevant parts of E3's EV analysis for the IRP**
    - E3's current work for IRP is focusing on LDVs, so this analysis is similarly focused on LDV use cases

Overview of analysis



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1. VGI charging profiles

Selected VGI use cases

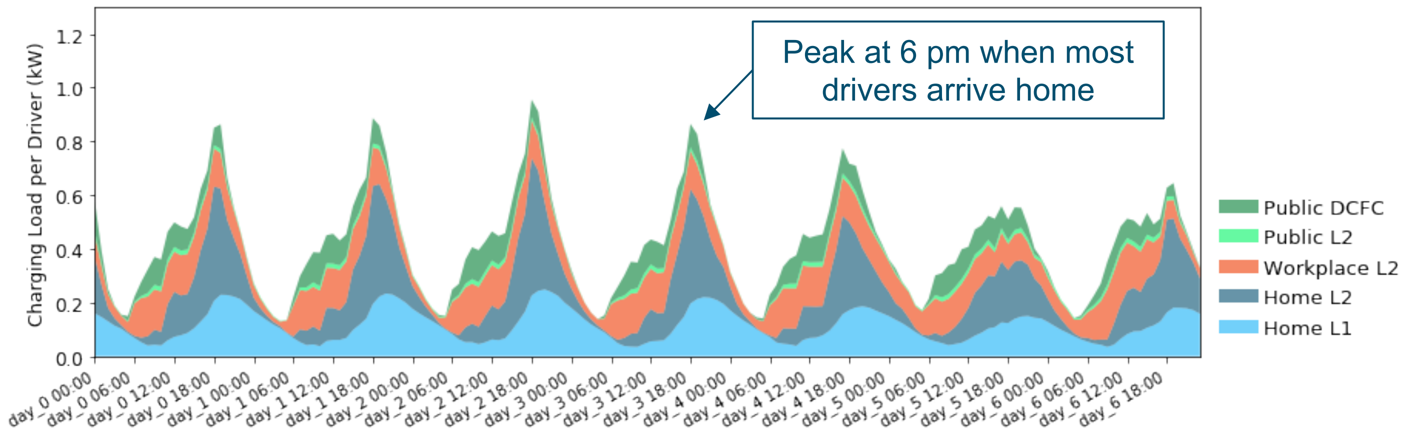
+ **E3 selected four of the VGI working group's use cases to model:**
  1. Residential Single-Family Home – Customer Bill Management
  2. Commercial Workplace – Customer Bill Management
  3. Residential Single-Family Home – CAISO Market Participation
  4. Transit Bus – Bill Management

+ **The current work being done for IRP is focusing on LDVs, which is why 3 of the 4 use cases are for LDVs**
  - E3 plans to do further analysis on MD/HD in the next round of analysis

Residential and workplace bill management (VGI use cases #1 and #2)

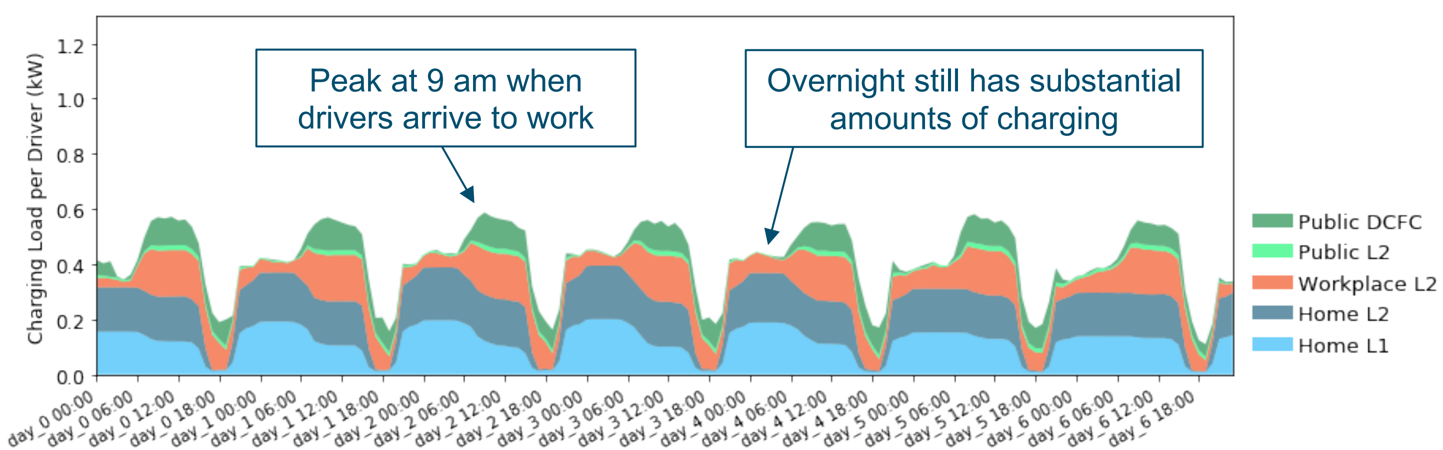
Unmanaged charging (2025, summer, one week)

Peak load = 0.957 kW



Managed charging w/ VGI (2025, summer, one week)

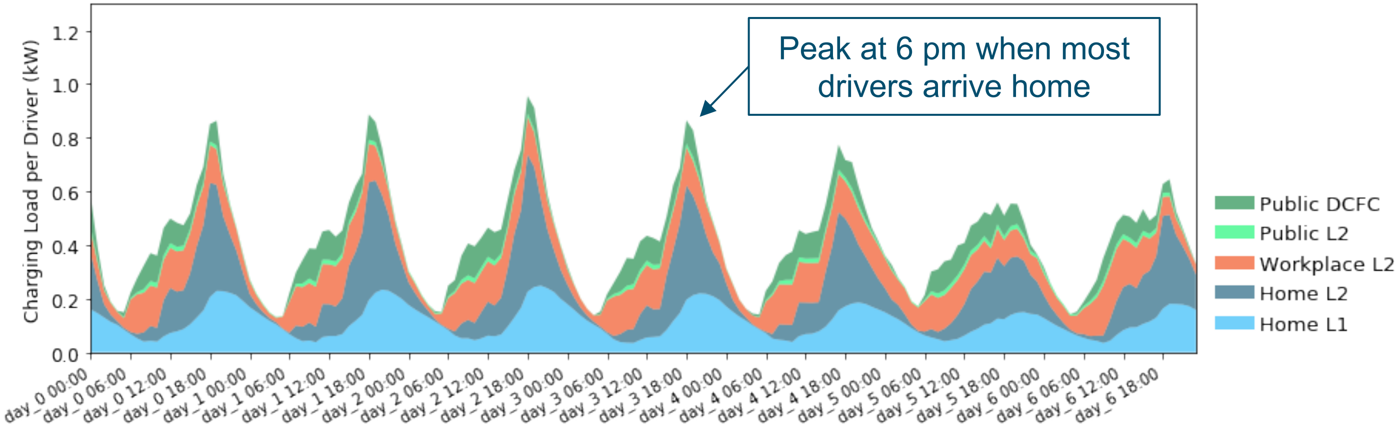
Peak load = 0.587 kW



Residential CAISO market participation (VGI use case #3)

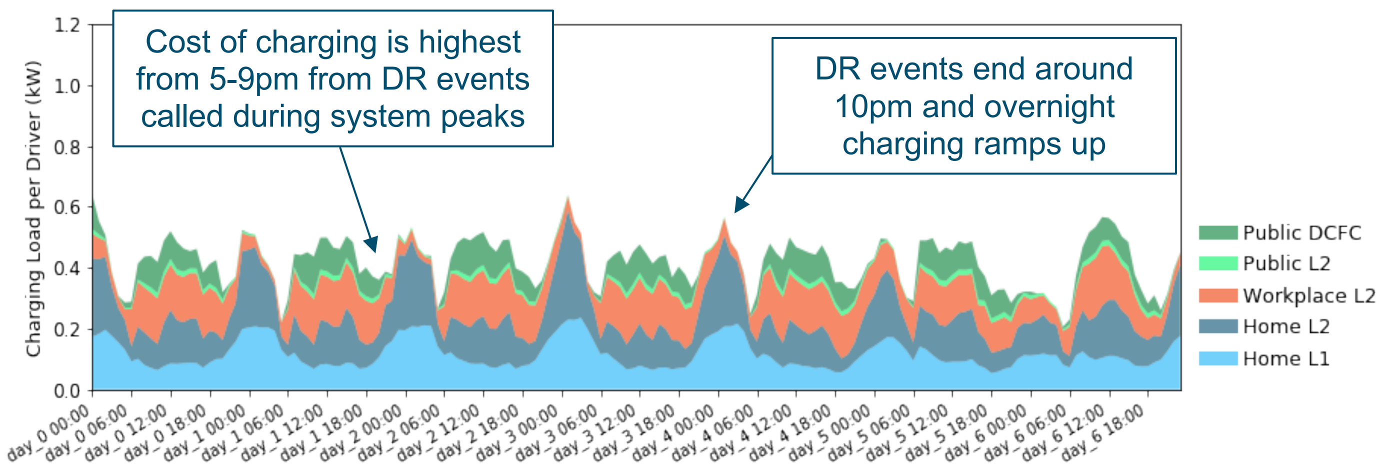
Peak load = 0.957 kW

Unmanaged charging (2025, summer, one week)



Peak load = 0.639 kW

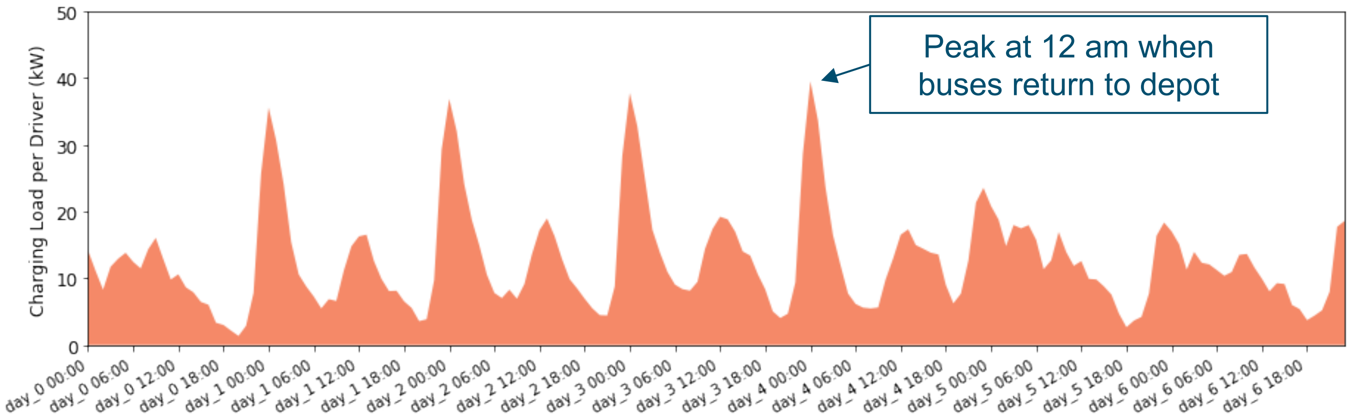
Managed charging (2025, summer, one week)



Transit bus bill management (VGI use case #4)

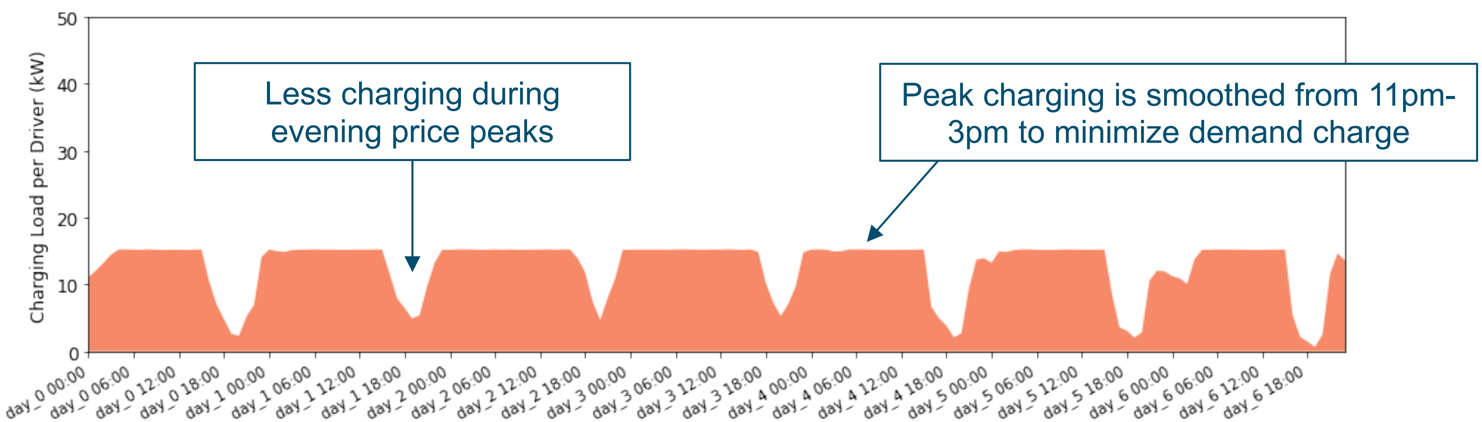
Unmanaged charging (2025, summer, one week)

Peak load = 39.5 kW



Managed charging w/ VGI (2025, summer, one week)

Peak load = 15.3 kW



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2a. Value to the grid: IRP system cost approach

Methodology

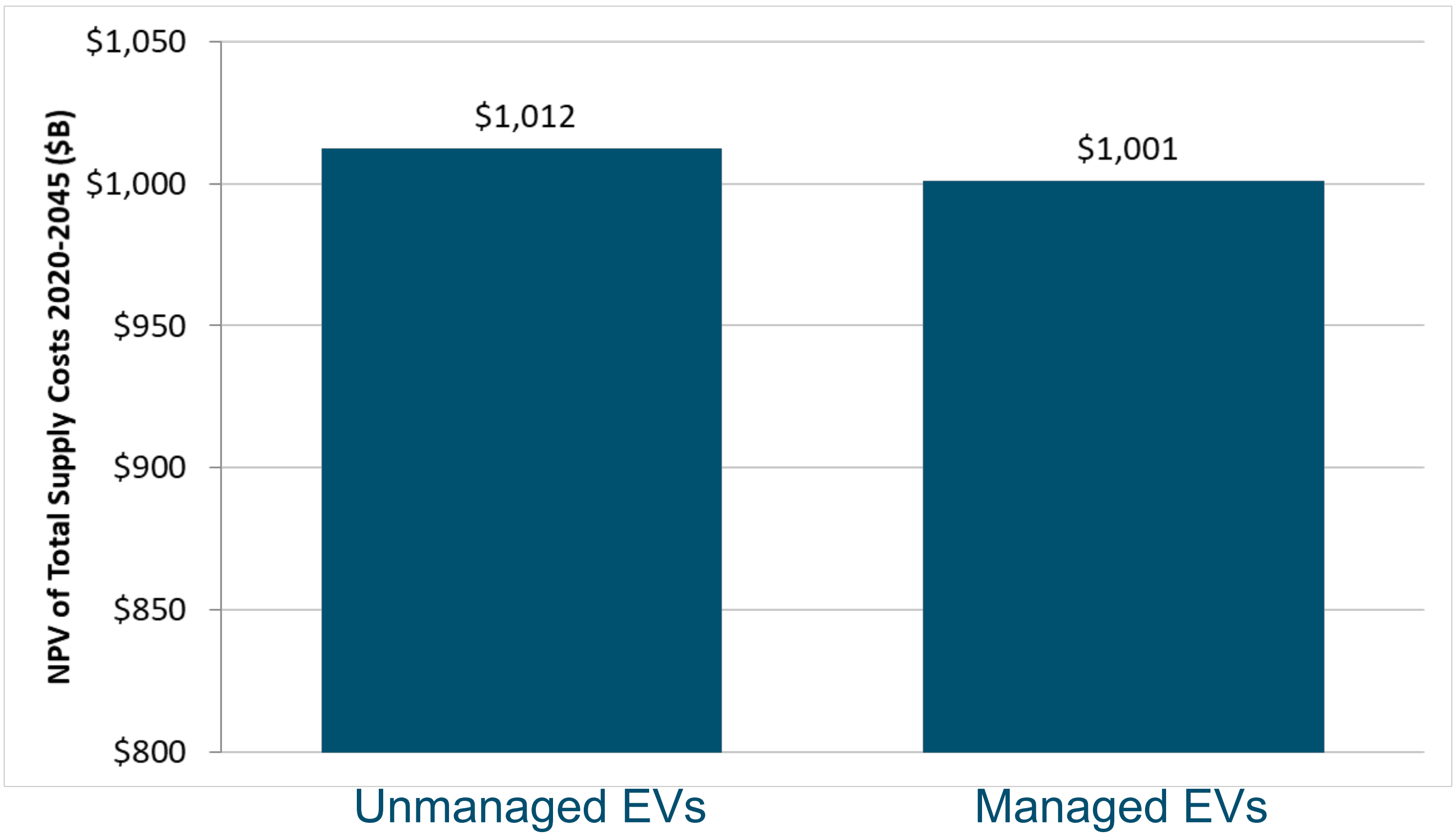
E3 followed a three-step methodology to evaluate the impact of managed charging on system electricity supply costs

1. **Use the CPUC IRP Reference System Plan (RSP) RESOLVE run as a "Base Case" to calculate the total system costs (with unmanaged EV charging)**
2. **Based on travel pattern data and corresponding charging shapes, generate two flexible load parameters:**
   - Amount of load that can be shifted per day (MWh)
   - Amount of flexible load that can be shifted into a single hour (%)
3. **Using the RSP as a base case, run RESOLVE with additional flexible load parameters, and compare the new total system costs to see benefit of managed charging**

RESOLVE runs should be viewed as an "upper bound" on the benefits of EV charging, as it simulates a world where EV drivers will perfectly optimize their charging as much as possible to reduce system costs

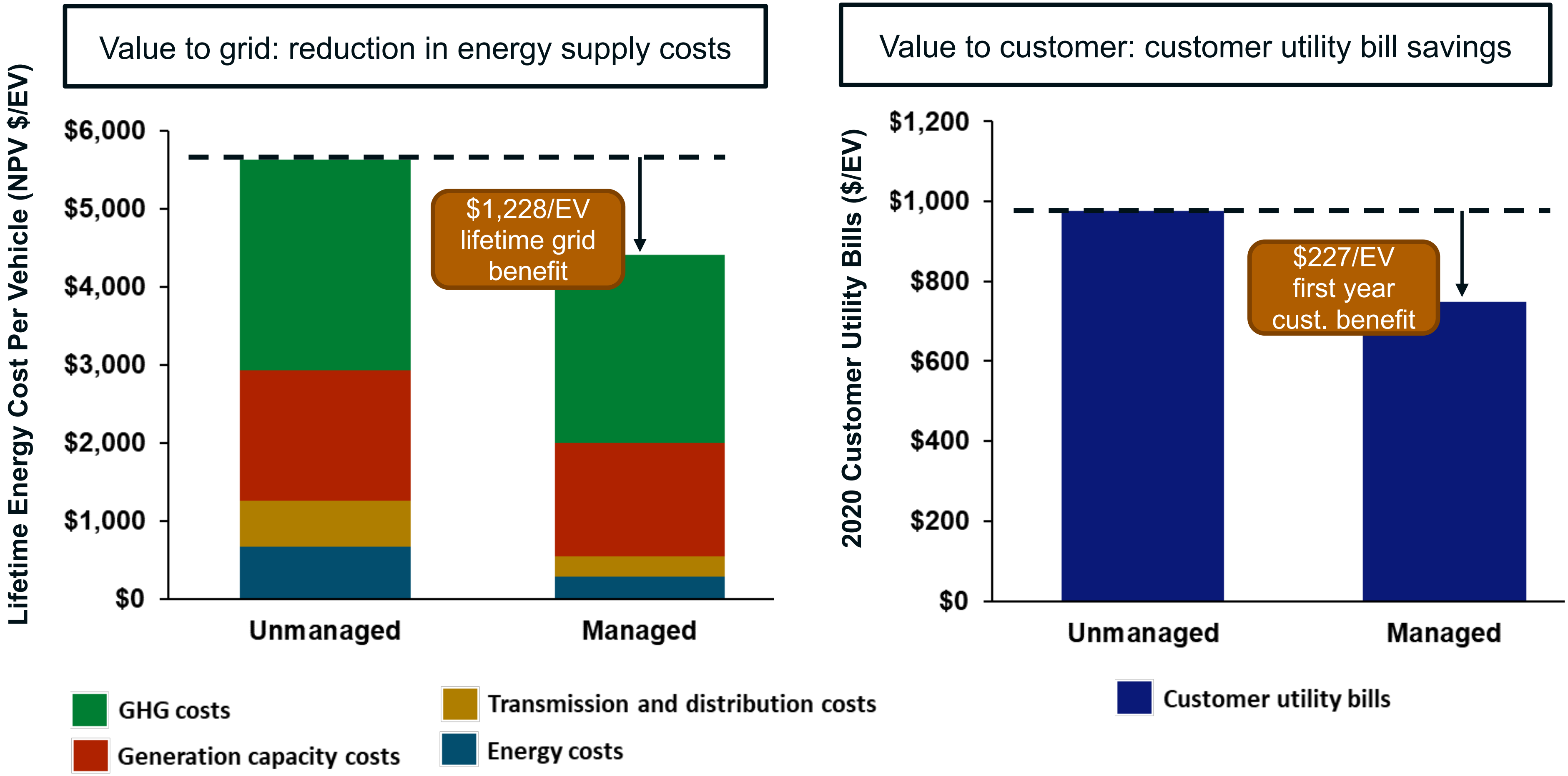
RESOLVE Results

Reduction in energy supply costs from managed charging (2020-2045, NPV):	$11.2 B
System benefit per EV (2020-2045, NPV $/EV):	$1,368



2b. Value to the grid, and 3. Value to customer VGI use case approach

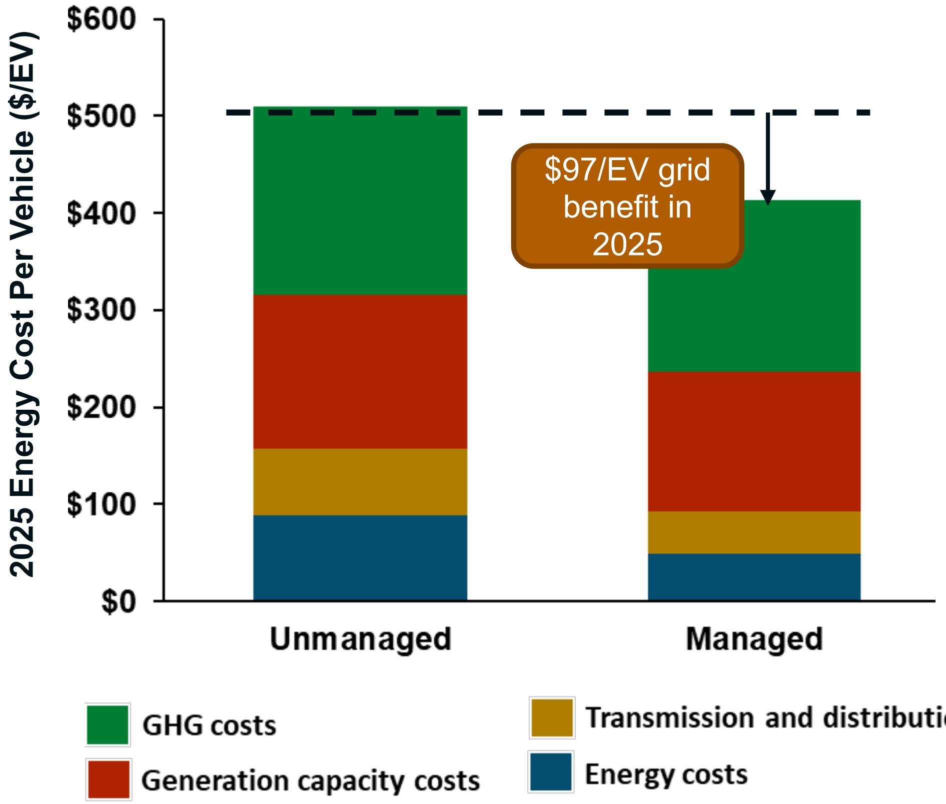
Residential and workplace bill management (VGI use cases #1 and #2)



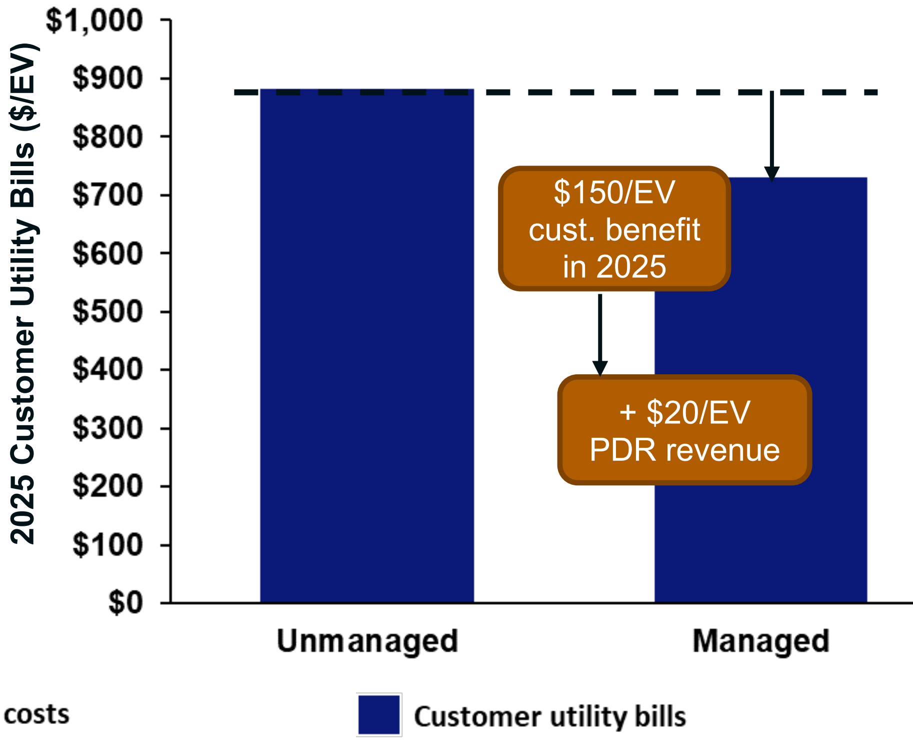
- Lifetime EV energy supply costs based on 2020 CPUC Avoided Cost Calculator outputs
- Customer utility bills shown for 2020 only since rates change over time
- Majority of VGI benefit comes from residential bill management (VGI use case #1)

Residential CAISO market participation (VGI use case #3)

Value to grid: reduction in energy supply costs

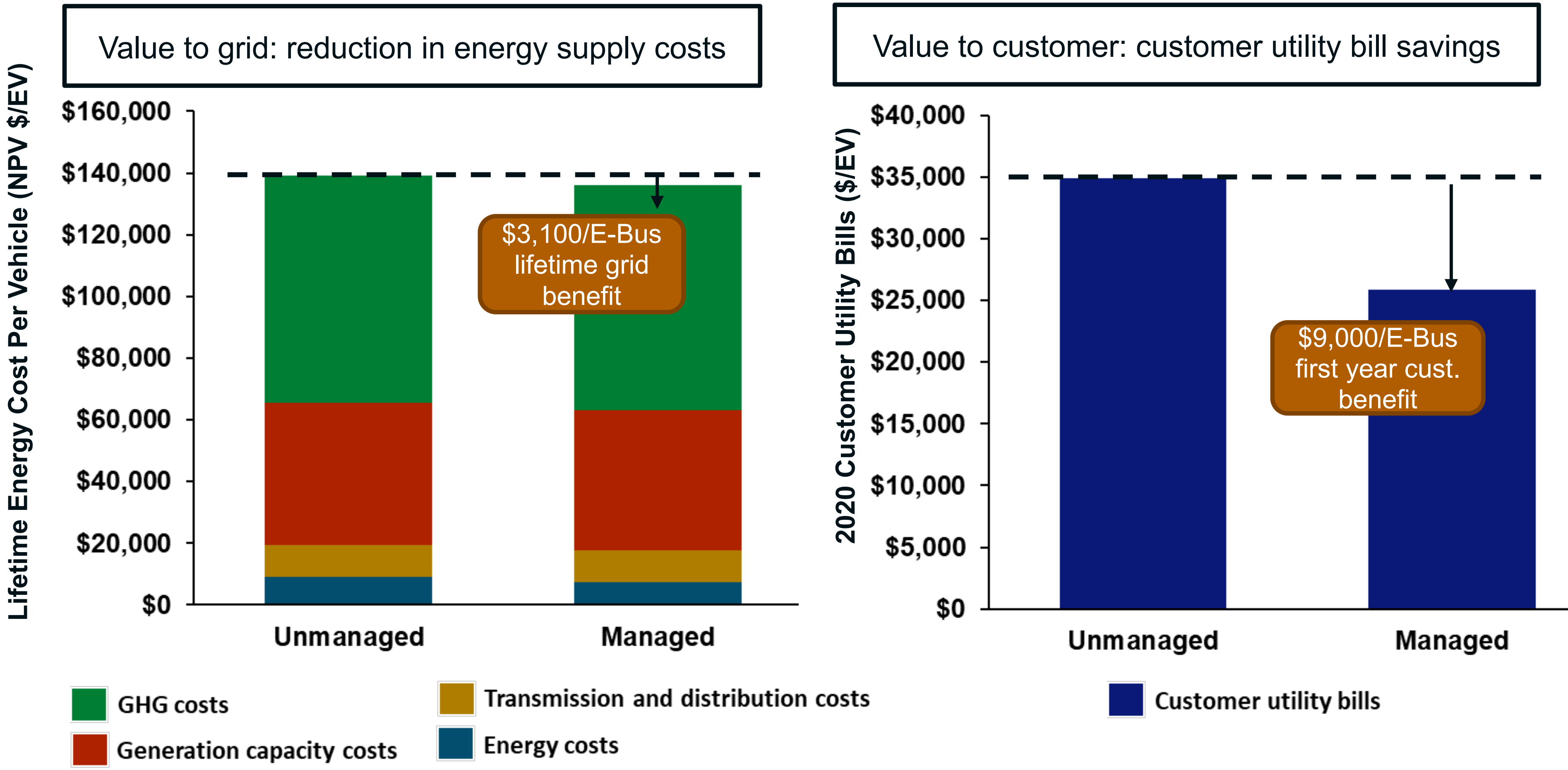


Value to customer: customer utility bill savings



- The residential CAISO market participation analysis used 2025 forecast market prices, so both energy supply costs and customer utility bills are shown for 2025 only
- Customers receive bill savings benefits, as well as revenue from DR programs

Transit bus bill management (VGI use case #4)



+ **Transit bus use case based on TOU rate response and demand charge mitigation, resulting in large customer bill savings compared to unmanaged**

Key takeaways from cost-benefit assessment

- **Managed charging results in significant grid cost reductions and customer bill savings, compared to unmanaged charging**
- **Additional alignment between grid costs and utility rates will continue to increase grid benefits**
  - VGI use cases #1, #2, and #4 were all based on customer bill management (response to TOU rates and to demand charges)
  - More dynamic or direct utility signals could significantly reduce the generation and T&D costs, and reduce GHG even further for even greater benefits
- **Customer bill savings for these load shapes will change over time as utility rates change**
- **Analysis does not include any VGI technology or implementation costs – more research on this is needed**

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4. DER comparison (single-family home use case)

Methodology

+ **Customer bill savings on TOU rates were modeled using E3's RESTORE, which uses perfect foresight linear optimization to reduce customer bills**
+ **The model used a baseline home with an EV, plus four DER scenarios:**

Baseline:

Single-family home:
6,700 kWh/year
2kW peak load

Unmanaged EV:
92 kWh battery (300 mi)
6.6 kW EVSE

DER Scenarios:

Managed charging
TOU rate response

Storage
5 kW / 13.5 kWh

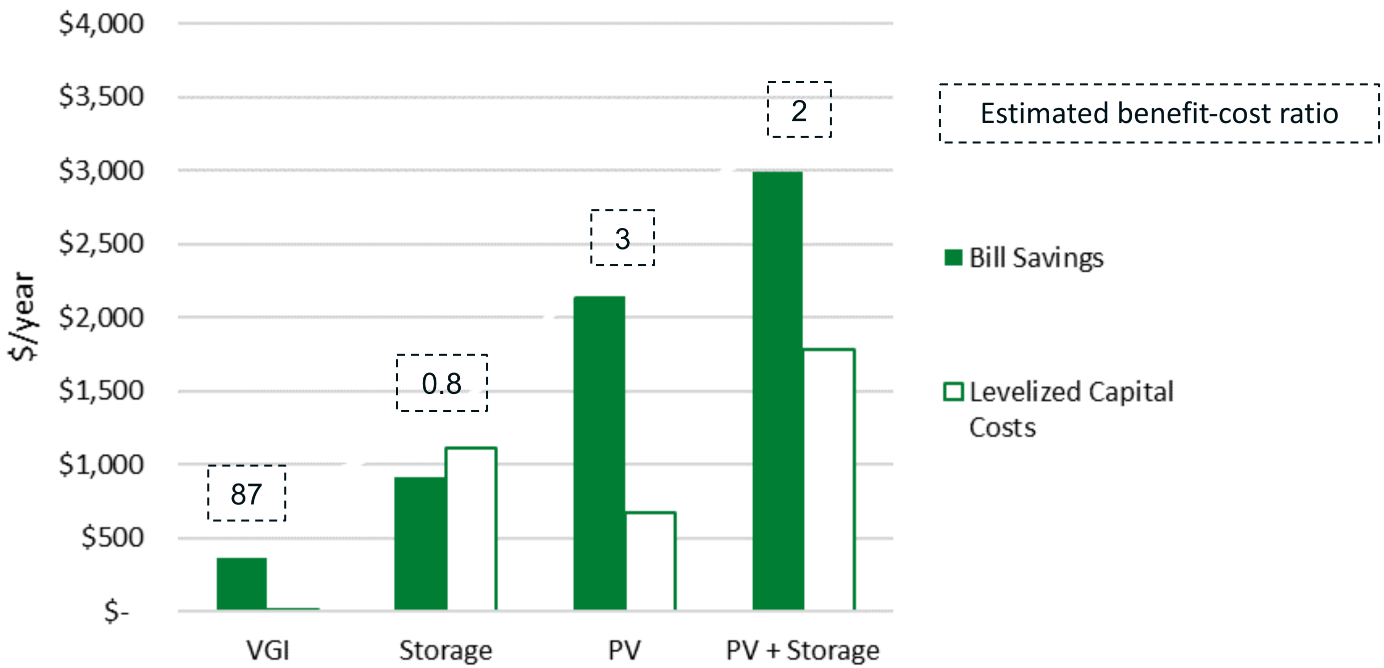
Solar PV
5.5 kW

Solar + Storage

+ **Research question: What are the customer bill savings of using VGI, versus other DERs, for a home with an EV?**

Annual bill savings across DERs

Annual bill savings versus levelized capital costs for different DERs



+ Key takeaways:

- Gross bill savings are highest with PV + storage
- PV has the highest net customer savings
- VGI has the highest estimated customer benefit/cost ratio, but **additional research is needed on VGI costs**
- Analysis was performed for a single-family home use case **– results for other use cases may differ**

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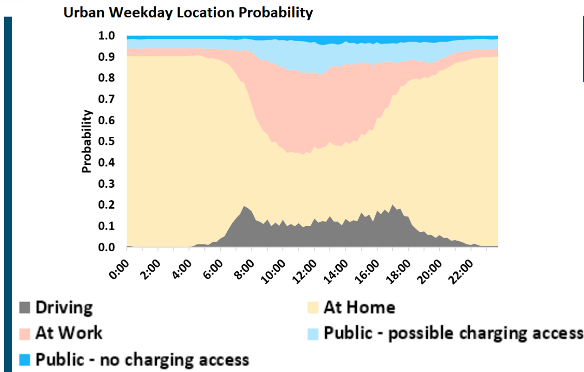
Appendices

Models used

- **VGI use case load shapes:**
  - E3's **EV Load Shape Tool**, which uses real-world trip data to simulate charging profiles based on each simulated driver's needs
- **Value to grid:**
  - Top-down approach used the **RESOLVE** model, which is a resource optimization model used for California's Integrated Resource Plan (IRP) proceeding
  - Bottom-up approach used E3's **EV Grid** model, which performs cost-benefit assessments based on EV adoption and load shapes
- **Value to customer:**
  - E3's **EV Grid** cost-benefit assessment model
- **DER comparison:**
  - E3's **RESTORE** model, which optimizes customer-side DER technologies to reduce customer electricity bills

Load shape and CBA methodology

1. Driving Profiles

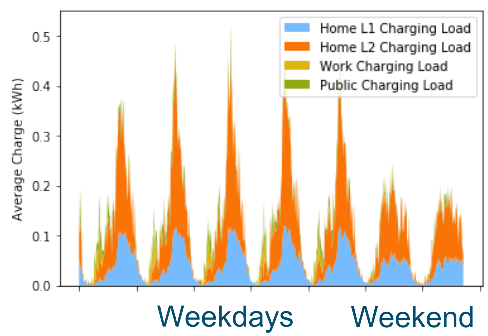


Markov Chain Monte Carlo Method

Inputs
- Vehicle and driver trip data (National Household Travel Survey)
- Vehicle VMT

Outputs
- Anonymized 15 min driving profiles

2. Charging Profiles

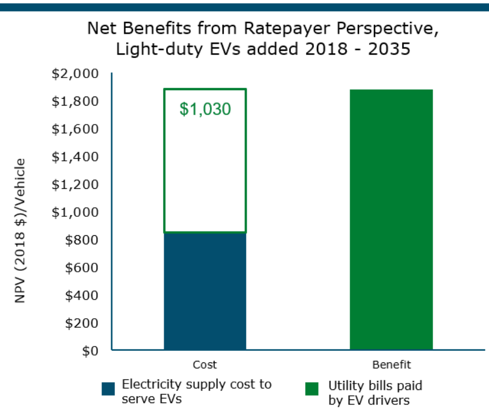


EV Load Shape Tool

Inputs
- Driving profiles
- Demographic data
- Vehicle & charger characteristics
- Rates & VGI

Outputs
- Normalized charging load shapes (unmanaged and managed)

3. Cost Benefit Analysis (CBA)



EV Grid CBA Tool

Inputs
- EV adoption forecasts
- System costs & emissions
- Charger & vehicles costs

Outputs
- Electricity supply costs
- Customer utility bills
- Net emissions impacts
- Peak load Impacts
- Standard cost tests

EV inputs and parameters

2025 charger & vehicle parameters

Parameters	Values
Battery size (kWh)	BEV150: 33.75 kWh; BEV400: 92 kWh; PHEV25: 5.625 kWh; PHEV60: 13.5 kWh
Charger power (kW)	L1: 1.4kW; L2: 6.6 kW; DCFC:150 kW

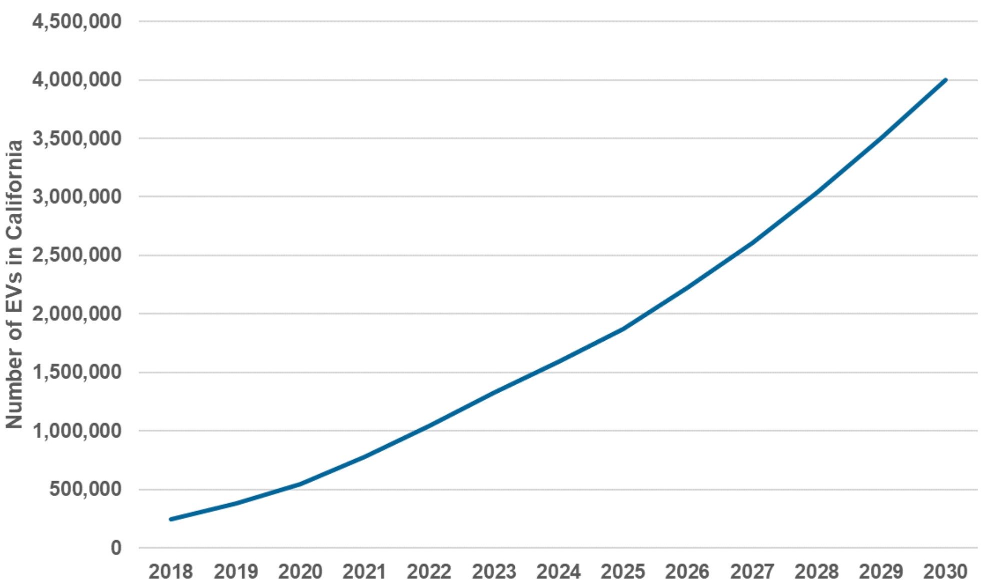
Source: NREL Charging Infrastructure Projections for California; CARB midterm review

2025 EV:EVSE ratios

Charge type	Work	Public
L1	23.7	n/a
L2	23.7	39.7
DCFC	n/a	118.8

Source: E3 calculations based on EVI Pro Lite

EV adoption trajectory



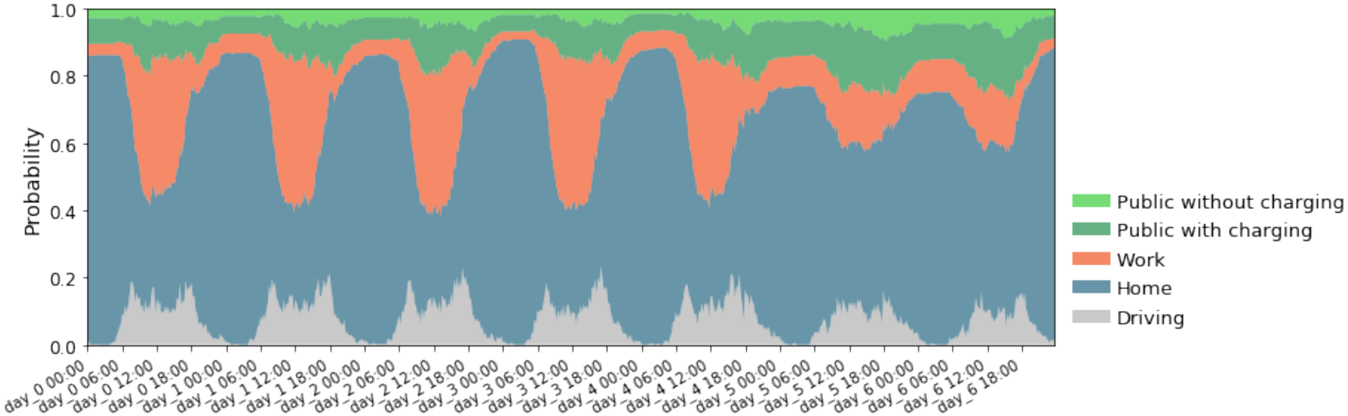
Source: E3 PATHWAYS model, Reference case

Rates used for bill management cases

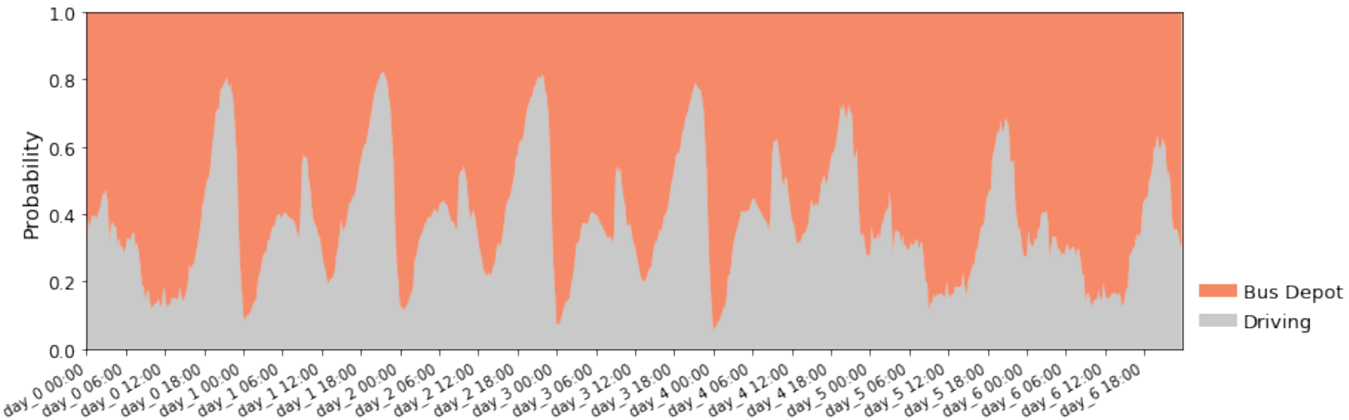
	Residential L1 / L2			Workplace L2				Public	
	PG&E	SCE	SDG&E	PG&E	SCE	SDG&E	Free	All IOUs	All IOUs
Rate name	EV-2A-TOU	TOU-D-PRIME-NEM2	EV-TOU-5-NEM2	A-10-TOU Secondary	TOU-GS-2-D-NEM2 From 2 kV to 50 kV	AL-TOU Secondary	Free	Public L2	Public DCFC
Demand charge?	No	No	No	Yes	Yes	Yes	No	No	No
EV-specific?	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Seasonal rate?	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
# of TOU periods?	3	3	3	3	3	3	-	-	-
Summer peak rate ($/kWh)	$0.234	$0.238	$0.315	$0.176	$0.095	$0.120	$0.00	$0.35	$0.40
Summer off-peak rate ($/kWh)	$0.008	$0.056	$0.101	$0.093	$0.056	$0.075	$0.00	$0.35	$0.40
% of drivers on rate	49%	45%	6%	37%	34%	4%	25%	100%	100%

2025 driving profiles

Light-duty driving profile (summer, one week)



Transit bus driving profile (2025, summer, one week)



+ **Driving profile charts show probability of vehicle being at each location type**

Unmanaged charging methodology

- **In an unmanaged case, drivers are still likely to select charging locations based on charging prices**
  - For example, public charging often tends to be the most expensive, so we would expect drivers with access to residential or workplace charging to typically choose to charge at home or work instead of public
- **Therefore, the unmanaged case considers the average charging rate at each location to determine locational preferences**
  - Since there are no time-varying rates, the time that an EV charges is not affected
  - i.e. charging is done immediately after a driver plugs in at a location

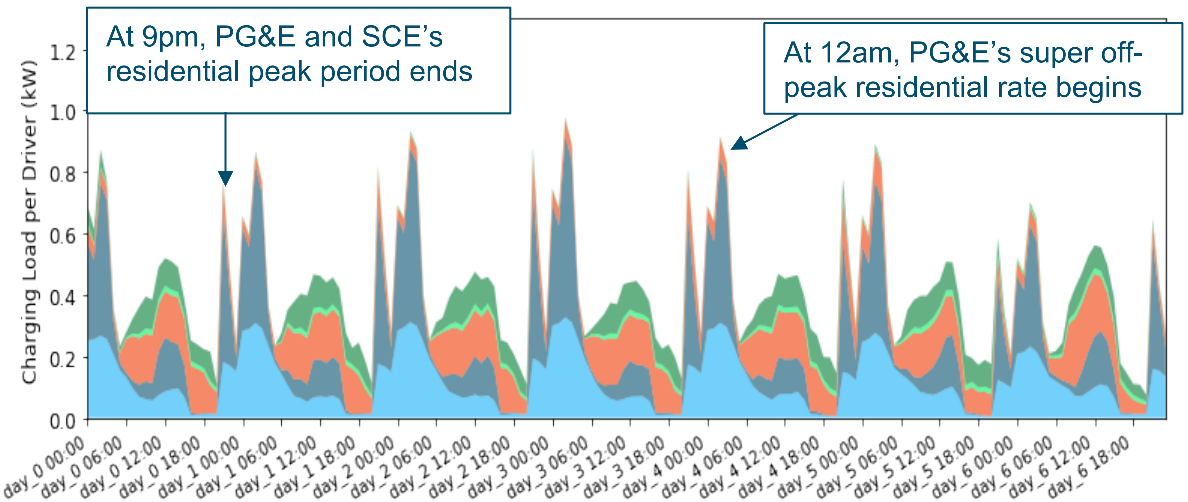
Managed charging methodology

+ The timing of charging, in addition to location of charging, is optimized based on a designated time-varying parameter (often price)
+ The proportion of drivers on each rate are assigned for each charger type and location:
  - **Residential L1 and L2**: the proportion of drivers charging on each utility's residential rate equal each utility's proportion of total EVs (from CPUC Load Research Report)
    - For example, 49% of CA EVs are in PG&E territory, so 49% of home L2 charging is on PG&E's residential EV rate
  - **Workplace L2**: assume 25% of workplace charging is free in 2025 and the remaining 75% is similarly based on the proportion of EV drivers in each utility
  - **Public L2 and DCFC**: all public charging uses average public L2 and DCFC charging rates, respectively
+ Managed charging can be done with or without VGI/aggregator involvement
  - **"No VGI"** represents drivers all responding immediately to lower rates
    - This causes sharp peaks at times when off-peak TOU periods begin
  - **"With VGI"** represents aggregator involvement to smooth responses to lower prices
    - Charging sessions are spread out more evenly over off-peak TOU periods

Managed load flattening

- Initial managed charging profiles based on TOU rates show large peaks when off-peak period begins
- E3's model assumes an aggregator or other VGI involvement is used to flatten charging start times within the TOU periods
  - Still allows drivers to meet their charging needs
  - Mitigates peaks resulting from off-peak period start times

Managed: initial results



Managed: with technology or aggregator flattening