Transportation Electrification Impact Study (TEIS)

Vehicle Technologies Office Annual Merit Review - June 4, 2024

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Project ID #VAN061

NREL/PR-5400-89539

Overview

Timeline

- Project start date: Nov 2022
- Project end date: Sept 2025
- Percent complete: 60%

Budget

- Total project funding: $5.5M
    - DOE share: $5.1M
    - EPA share: $0.4M
- Funding for FY 2023: $4.3M
    - Includes $3.9M for TEIS
- Funding for FY 2024: $0.8M

Barriers

- Availability of EV charging infrastructure
- Financial viability of charging infrastructure owner/operators
- Grid planning to enable efficient infrastructure deployment

Partners

- Kevala
- U.S. Environmental Protection Agency
- U.S. Joint Office of Energy and Transportation
- California Energy Commission
- And others (see collaboration slide)

VTO Investments Position Labs to Inform Policy

- This presentation covers activity under the typical cycle and the TEIS "Sprint"
- The TEIS "Sprint" is an example of activating lab capabilities to inform policy decisions on a short, fixed timeline

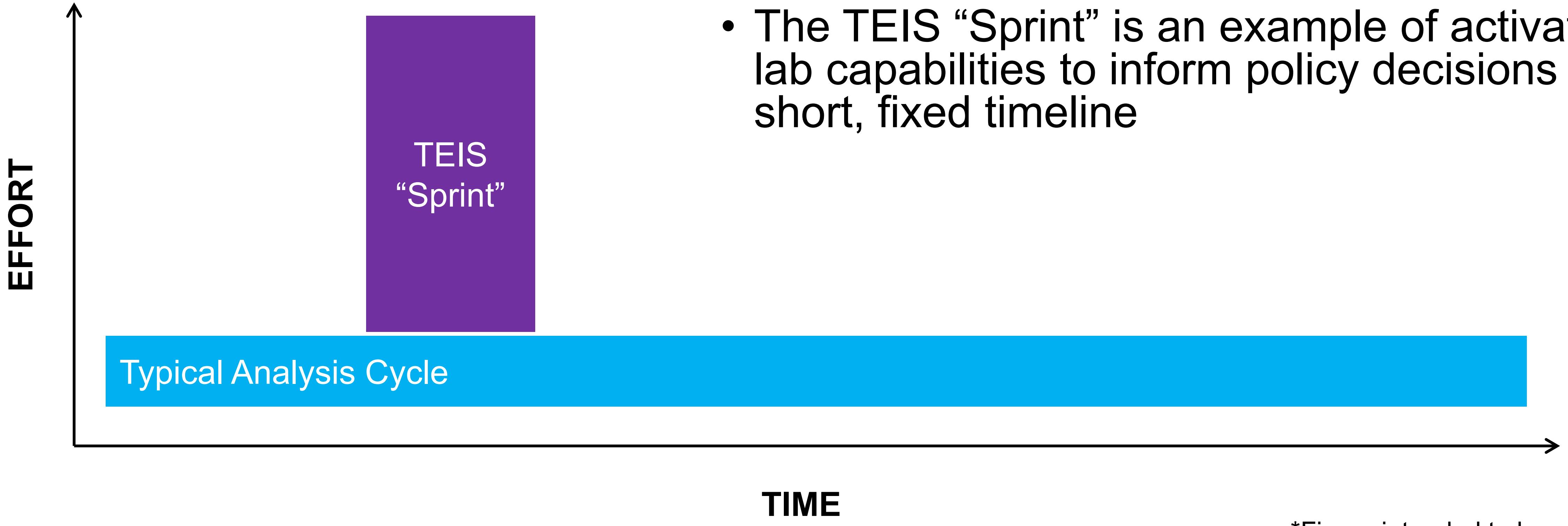

*Figure intended to be conceptual

Motivation

Relevance

- As EPA works to finalize historic GHG regulations for light-, medium-, and heavy-duty vehicles in March 2024, questions persist regarding the cost of requisite plug-in electric vehicle (PEV) charging infrastructure
- Charging infrastructure deployment costs are notoriously location-specific, with estimates requiring granular information on network design, potential charging flexibility, and grid readiness
- In August 2024, with support from EPA and DOE*, a team comprised of LBNL, NREL, and Kevala began collaborating on a multi-state charging infrastructure cost assessment including grid upgrades that considers potential impact of EPA policy and the mitigation potential of PEV load flexibility

EPA United States Environmental Protection Agency

MAIN MENU

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News Releases: Headquarters | Air and Radiation (OAR)

CONTACT US

Biden-Harris Administration Proposes Strongest-Ever Pollution Standards for Cars and Trucks to Accelerate Transition to a Clean-Transportation Future

Building on rapid advancements and investments in clean vehicle manufacturing, including investments in domestic manufacturing in the Inflation Reduction Act, EPA's proposed standards would deliver on President Biden's agenda to tackle the climate crisis

April 12, 2023

Contact Information

EPA Press Office (press@epa.gov)

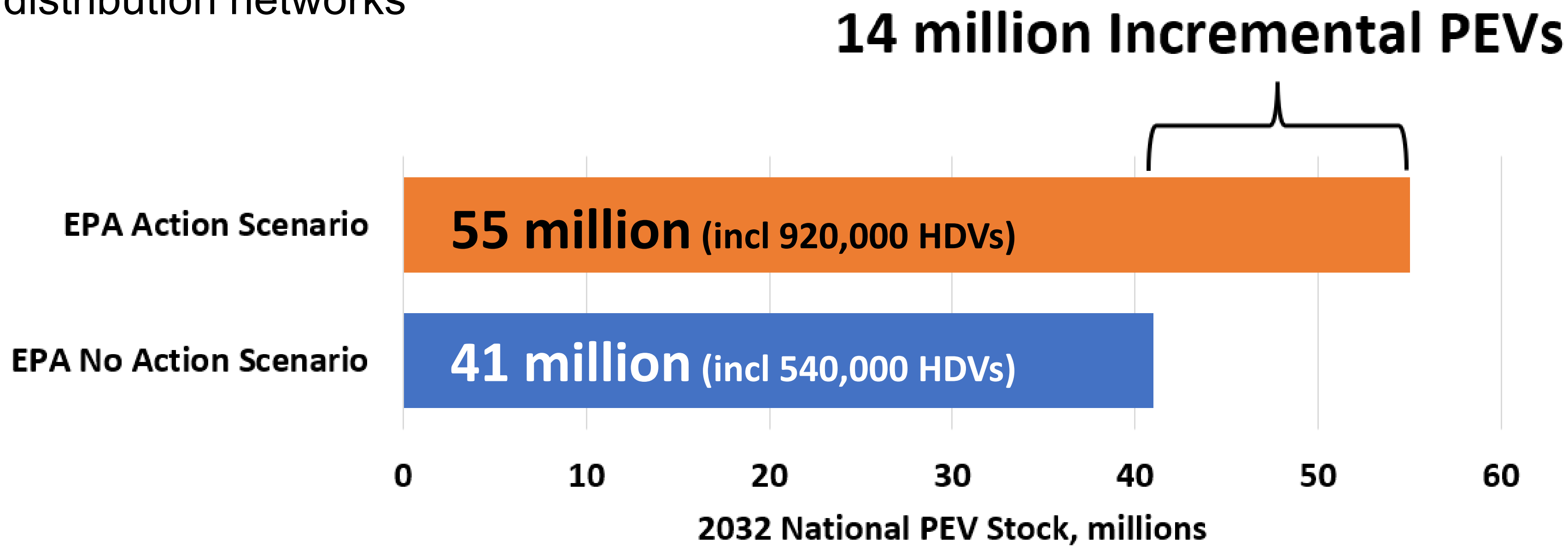
*OP, DAS-T, VTO, SA, JO, OE

Deliverables Aim to Inform Decision Makers

Milestone	Date	Status
NREL will supply LBNL with two L/M/HD ZEV adoption scenarios for selected years (e.g., 2027, 2032) and various modeling assumptions necessary for consistency across discrete L/M/HD ZEV simulations.	Oct 3, 2023	Complete
NREL will provide Kevala with EVI-X light-duty simulation results with quantified charging demand (load profiles) and network size in the unmanaged and mitigated cases for multiple scenarios with county-level resolution for the following states: CA, NY, IL, OK.	Oct 10, 2023	Complete
Evaluation of Kevala platform, analysis, and identification of future electrification impact use cases or projects.	Oct 10, 2023	Complete
NREL will provide DOE with simulated infrastructure capital cost estimates (excluding cost of grid upgrades and distributed energy resources) for multiple scenarios across the following states: CA, NY, IL, OK.	Oct 17, 2023	Complete
Kevala will provide NREL with draft capital cost and average retail rate estimates (inclusive of ZEV charging/refueling equipment, installation, and distribution grid upgrades) for ZEV infrastructure scenarios modeled in Task 4 and grid asset upgrade costs quantified in Task 5 for the forecast horizon.	Oct 17, 2023	Complete
Kevala will provide NREL with final capital cost and average retail rate estimates (inclusive of ZEV charging/refueling equipment, installation, and distribution grid upgrades) for ZEV infrastructure scenarios modeled in Task 4 and grid asset upgrade costs quantified in Task 5 for the forecast horizon.	Oct 31, 2023	Complete
NREL will use state-level capital cost estimates from Kevala to provide insights on national trends.	Oct 31, 2023	Complete
Draft report (jointly developed with LBNL, Kevala) delivered to DOE.	Nov 30, 2023	Complete
Final report (jointly developed with LBNL, Kevala) delivered to DOE.	Jan 31, 2024	Complete
NREL will provide DOE with documentation that a data license with Kevala has been executed, giving NREL access to Kevala's database of utility distribution topologies across multiple states.	Mar 31, 2024	Complete
NREL will assess Kevala's data to ascertain how it could be applied in longer-term to comprehensive analyses on distribution system evolution driven by end-use load growth from the buildings, industrial, and transportation sectors.	Jun 30, 2024	On track

Focus on "Incremental" Cost of Proposed Rulemaking

- This study focuses on the delta between the EPA **Action** and **No Action** scenarios
- **"Incremental"** is used to reflect the difference between EPA's policy scenarios, including differences in:
  - PEVs on the road (light-, medium-, and heavy-duty)
  - Charging network size (up to 1.5 MW per port)
  - Upgrades to local distribution networks

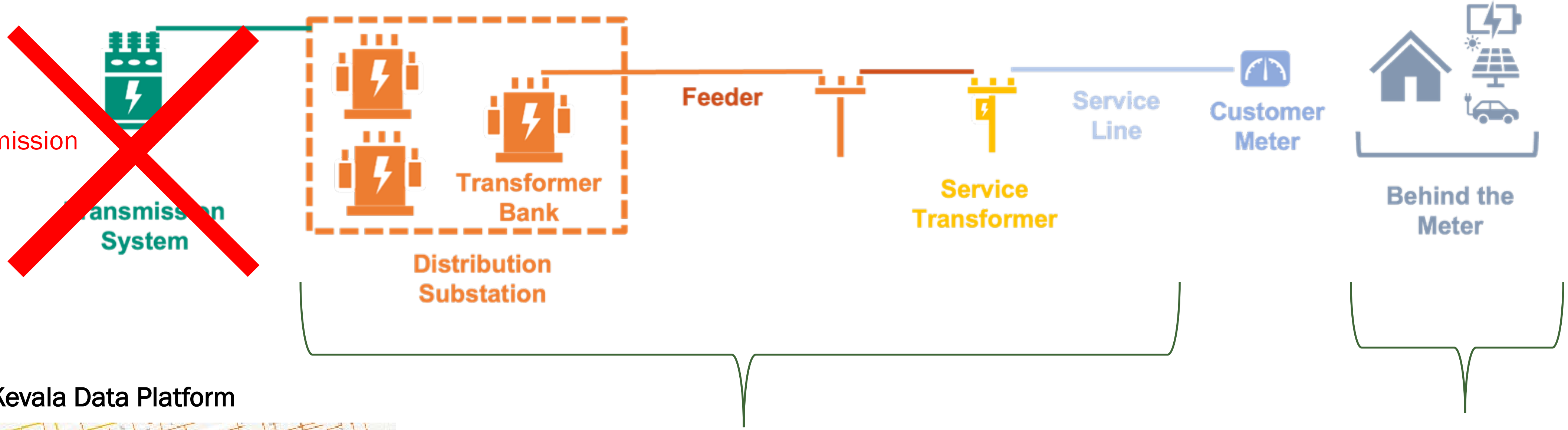


Out of Scope in this Study:

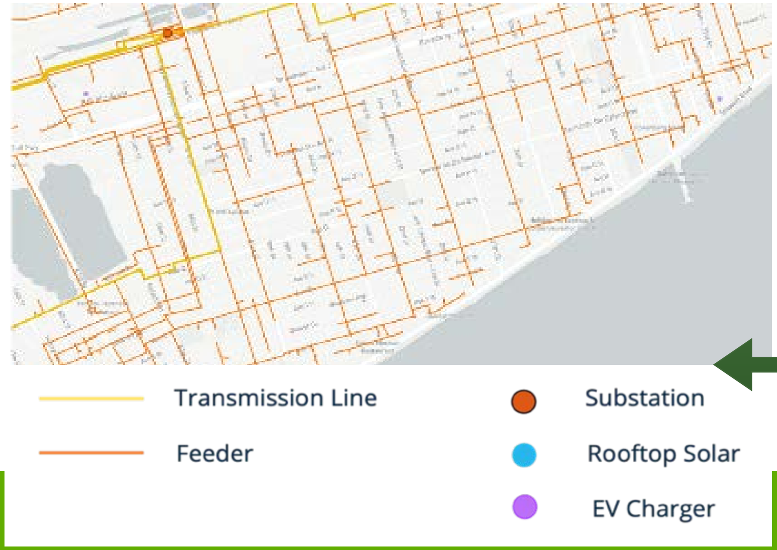
Absolute Costs

Scope of this Analysis

Generation & Transmission
Out of Scope



Snapshot of Kevala Data Platform



Distribution Grid

Includes: substations, feeders, and service transformers (aggregated by feeder)

Charging Infrastructure

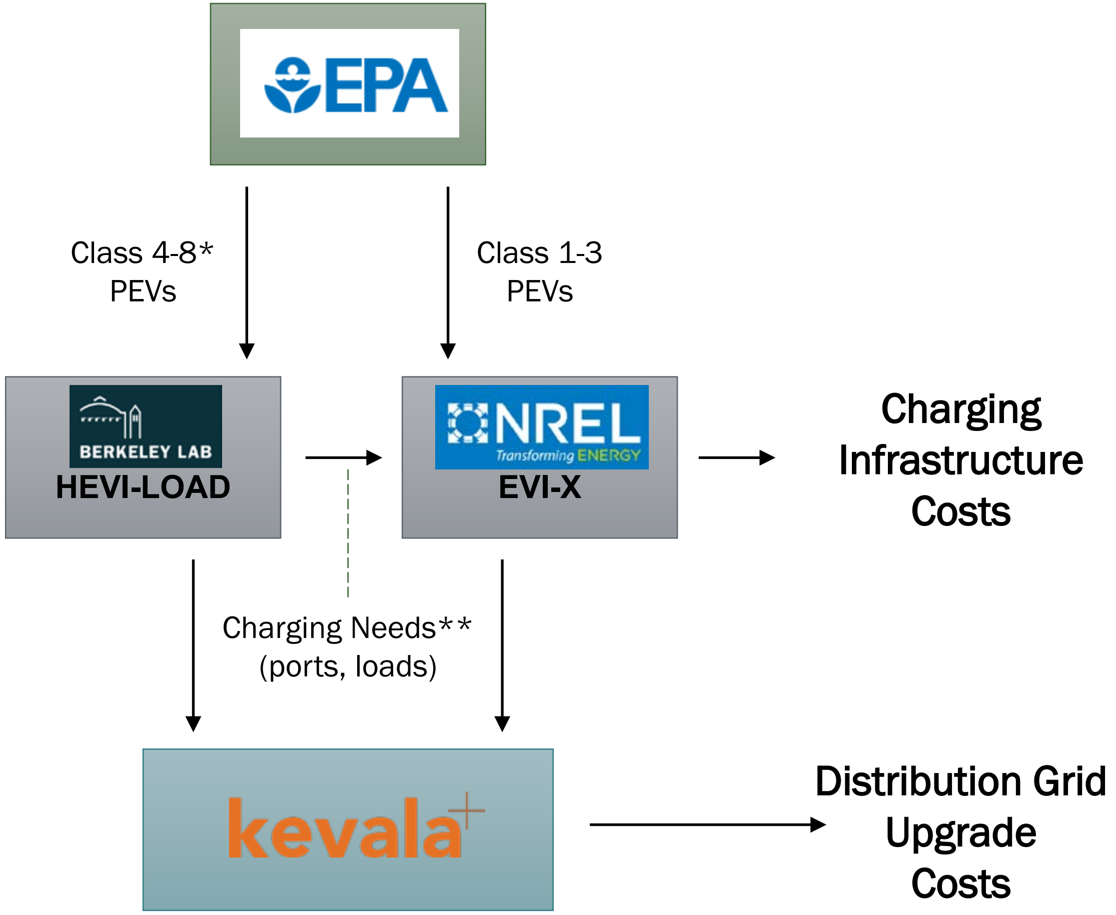
Includes: EVSE, labor, panel upgrades, conduit, wiring, and site prep/construction work (including trenching)

EVSE: Electric Vehicle Service Equipment

Study Design

Variable	Extent
Analysis Years	2027, 2032
EV Adoption Scenarios	Action, No-Action (based on EPA analysis)
Geographic Extent	5-States (CA, OK, IL, PA, NY)
Load Profiles	Managed, Unmanaged (multiple implementations)

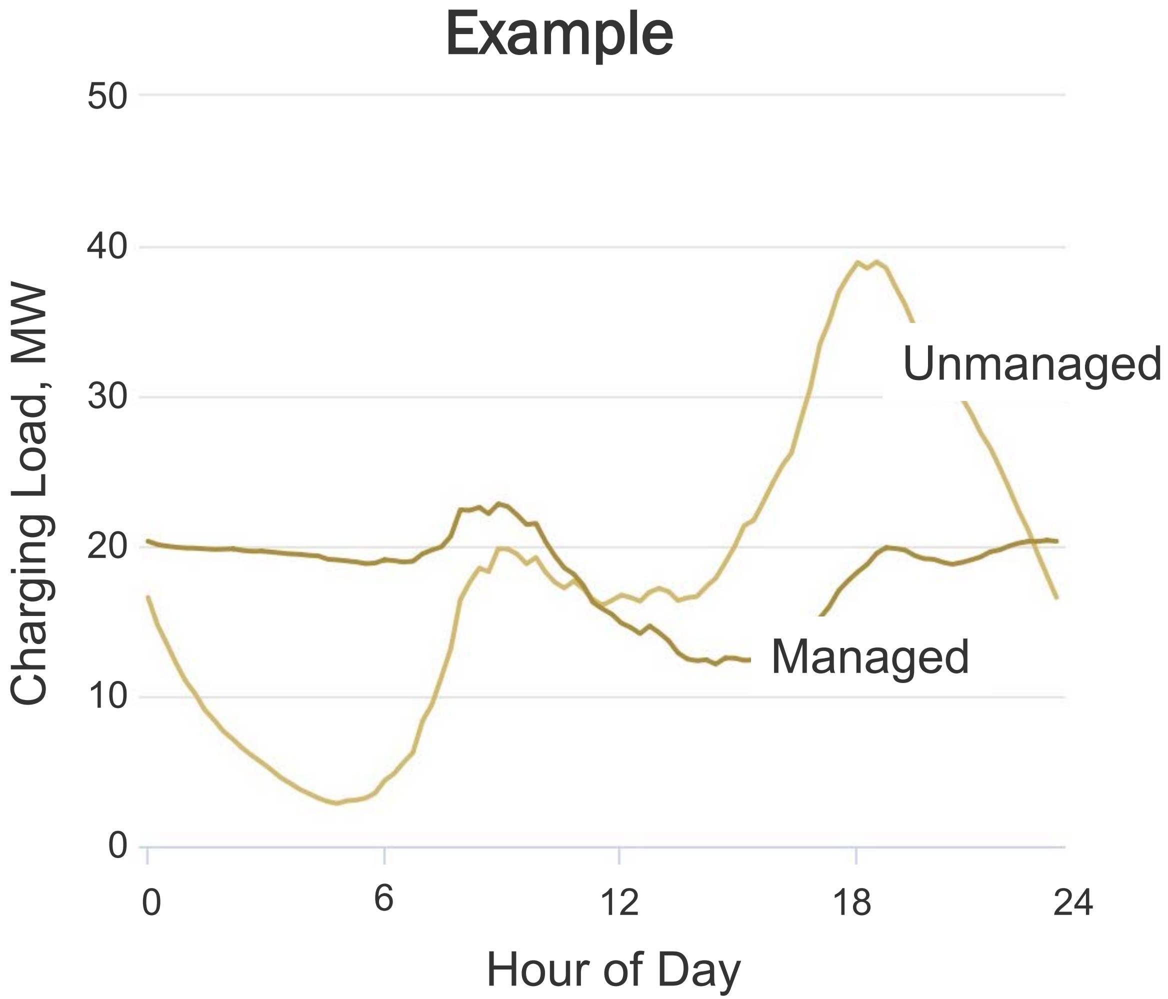
- Analysis years bookend EPA model year authority
- Selected states reflect diversity in urban/rural population, utility distribution grid composition, freight travel demands, and state EV policies.
- Load flexibility intended to demonstrate the value of VGI in deferring distribution costs
  - Only applies to long-duration charging opportunities (home and depot)



* Excluding school/transit buses, which are simulated by NREL.
** Data also being shared with EPA for production cost and capacity expansion modeling (occurring in parallel).

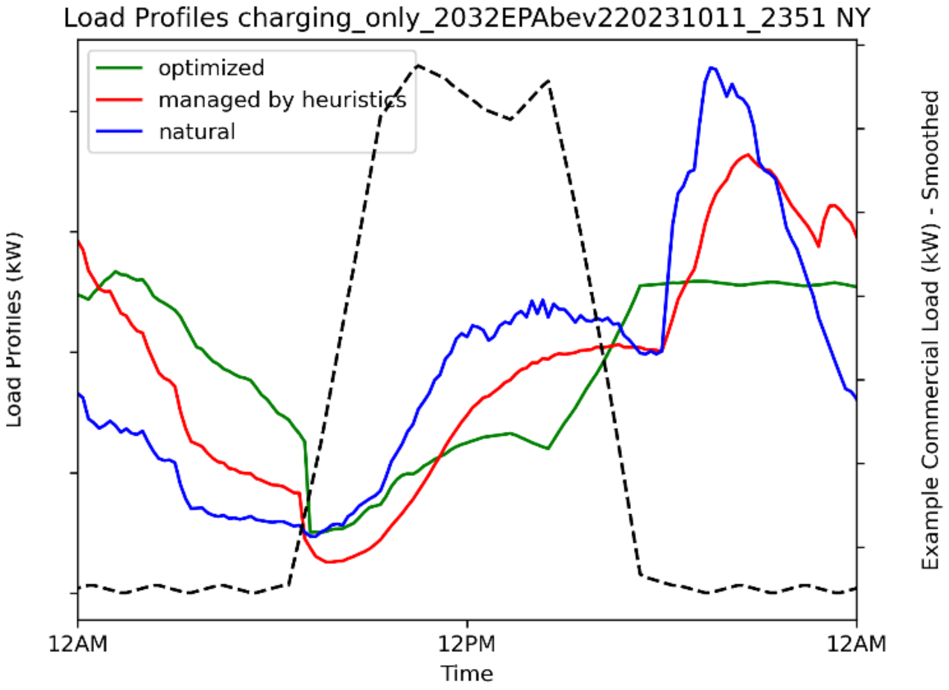
Managed Charging Scenario

- A managed charging scenario is developed to estimate the potential for distribution cost savings
  - Charge management only implemented at home/depot locations
  - Arrival/departure times are not adjusted to facilitate charge management
- "Capacity unaware" heuristic is implemented which produces a static profile that attempts to minimize the PEV charging peak
  - Implementation is ignorant to non-EV load
  - Further savings could be realized



Managed Charging Scenario

- For heavy-duty applications, heuristics-based vs optimization-based approaches to shift/flatten the load
- Heuristics-based methods
  - Objective: shift the to avoid the coincident peaks with the assumed commercial load
  - Method:
    - Extend the duration of sessions starting between 8AM and 11PM
    - Reduce the power of the selected sessions
    - Agnostic to the underlying circuit capacity and load shapes
- Optimization-based methods
  - Formulate an optimization problem (convex) to flatten the aggregated load curves
  - Consider an assumed baseload shape
  - Leverage a commercial solver with multi-thread implementation



Example managed load shapes by heuristics and optimization methods

Related Research Efforts

- This study (highlighted) is unique in the pursuit of distribution capacity expansion analysis with high spatial resolution across multiple states.
- To our knowledge, no other study includes a scope of this nature.
  - Many utilities are conducting detailed integrated distribution planning for their investment cycles that capture EV-driven grid upgrades and program costs for their service areas.

		Demand Side Variables					Supply Side Variables	
Project	Final Analysis Year	EV Adoption (class dependent)	EV Weight Classes	Charging Infrastructure Needs	Spatial Extent	Spatial Granularity	Generation Impacts	Distribution Approach
2030 NCN "50x30" (JOET)	2030	15% Stock (50% Sales)	LDV	Yes	National	County	No	NA
DECARB (DOE)	2050	80% Stock	L/M/HDV	No	National	County	Yes	Econometric Model
EVs on Bulk Power Systems (DOE)	2050	80% Stock	L/M/HDV	No	National	County	Yes	NA
EVs2Scale2030/eRoadMap (EPRI)	2030	15% Stock (50% Sales)	L/M/HDV	No	National	~0.28 mi^2 Cells	No	NA
EVs@Scale/FUSE (DOE)	2040	50% Stock	L/M/HDV	Yes	Virginia	Feeders	No	Power Flow of Existing System (~100 feeders)
Electrification Impact Study (CPUC)	2035	30% Stock	L/M/HDV	Yes	California	Parcels	No	Thermal Capacity Analysis of 9,000+ feeders in CA
Multi-State TEIS (DOE/EPA)	2032	20% Stock (67% Sales)	L/M/HDV	Yes	National	County --> Parcels	No*	Thermal Capacity Analysis of 30,000+ feeders across 5-states

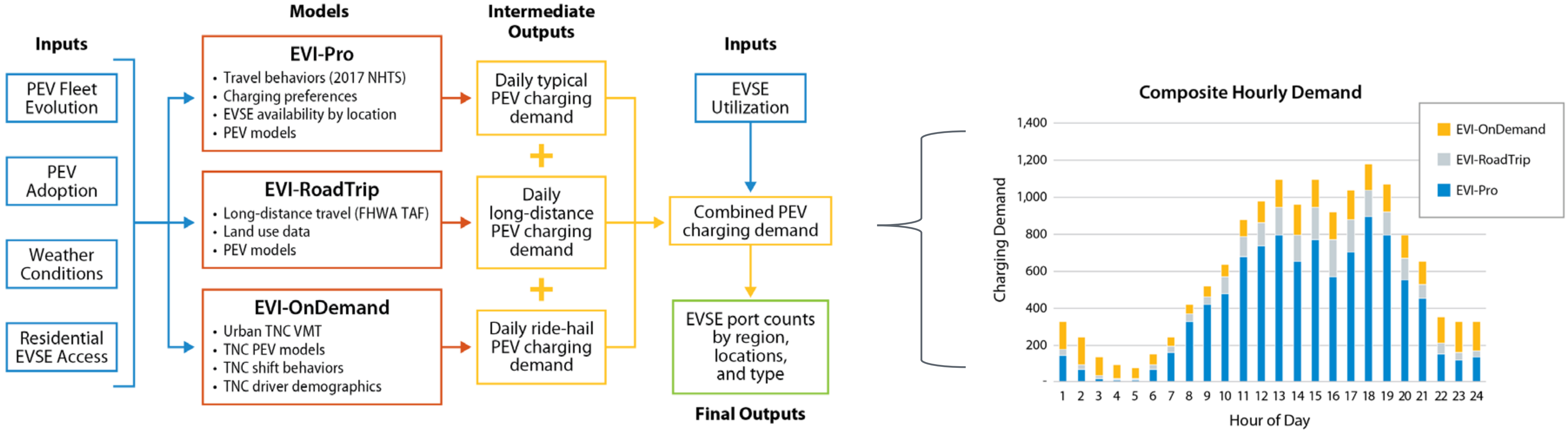
*EPA independently simulating generation capacity expansion

Multi-State TEIS Methodology: Light- & Medium-Duty PEVs (NREL)

Approach

National modeling framework standardizes inputs and combines outputs for each of the EVI-X demand models.

Captures regional differences in EV charging demands and port requirements due to differences in travel patterns, residential access, PEV adoption, vehicle type preferences, and weather conditions.



TEMPO + EVI-X: *Integrated Modeling Pipeline*

Approach

Inputs → *Feedback* →

Vehicle & Fuel Assumptions → **TEMPO**

Mobility Demand; Vehicle Sales; Stock; Energy Needs → **EVI-Pro**

Charging Infrastructure (EVI-Pro → TEMPO)

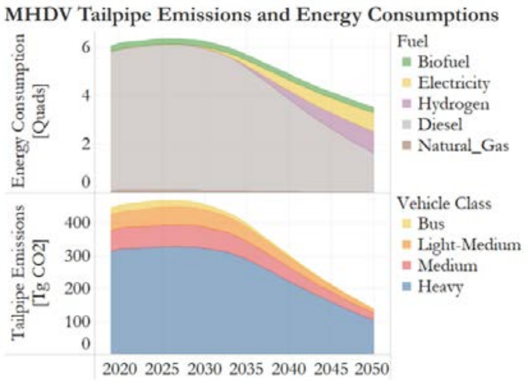
Charging Infrastructure; Spatiotemporal Load Profiles → **NREL Grid Modeling Library**

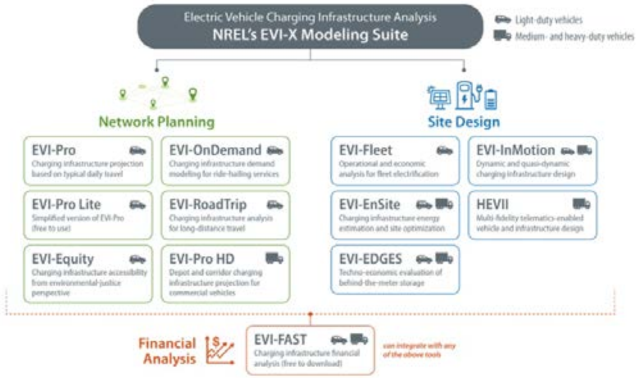
Grid Hosting Capacity (NREL Grid Modeling Library → EVI-Pro)

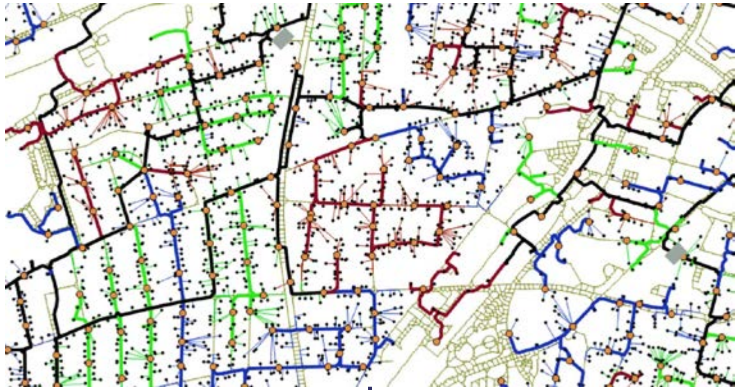
NREL Grid Modeling Library

dsgrid	RPM
ReEDS	SIIP
PLEXOS	Smart-DS

and more...







Electricity Costs, GHG Emissions, Generation/Distribution Capacity Expansion (NREL Grid Modeling Library → TEMPO)

Major Steps for EV Load & Infrastructure Forecasting

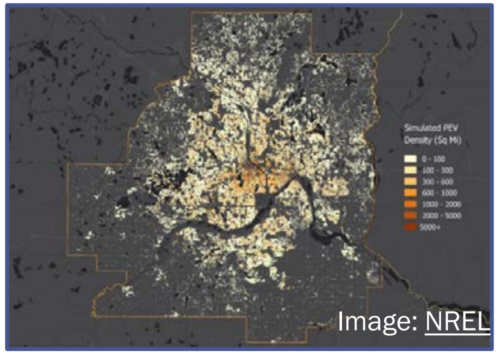


Image: NREL

When/Where/Which EVs are adopted

- Which regions, communities, households are likely to adopt EVs?
- What types of EVs will be adopted?
- How quickly will EVs be adopted?


Image: Wood et al.

How EVs are operated

- How do driving requirements vary by region or household?
- Where are EVs parked during the day?
- Do EV travel patterns differ from ICE vehicles?

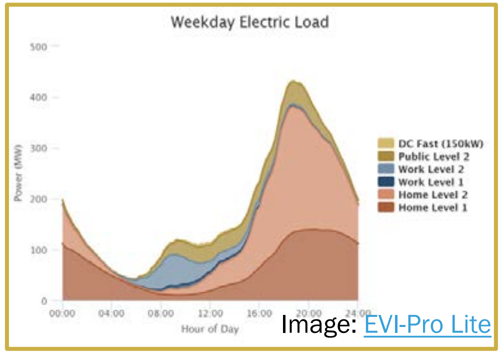


Image: EVI-Pro Lite

How EVs are charged

- Can EVs charge while at home, work, or in public?
- How do EV drivers prefer to charge, and will this change over time?
- Can EVs shift (in time) or modulate their loads?

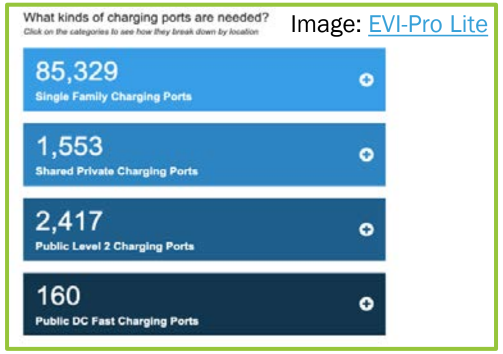


Image: EVI-Pro Lite

What charging infrastructure is required

- What are realistic utilization levels for charging stations?
- Which deployment strategies will EVSE operators take?
- Will EVSE operators employ ”idle” fees to incentivize throughput?

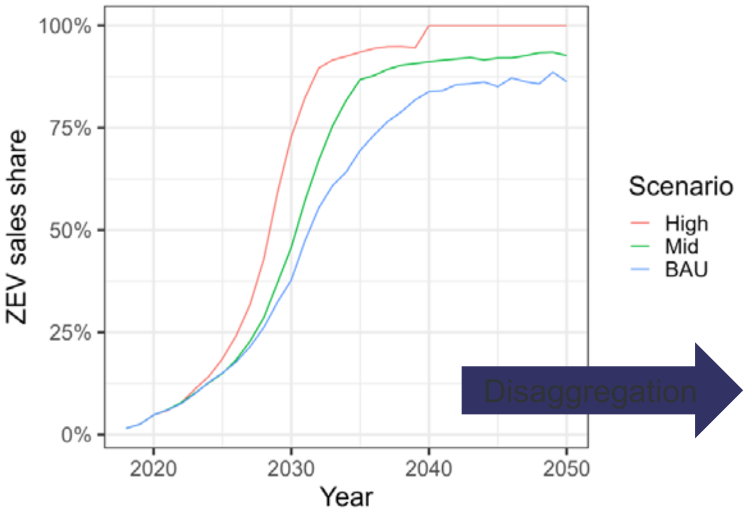
Modeling TEMPO LDV Scenarios in EVI-X

Accomplishments

In coordination with VAN050

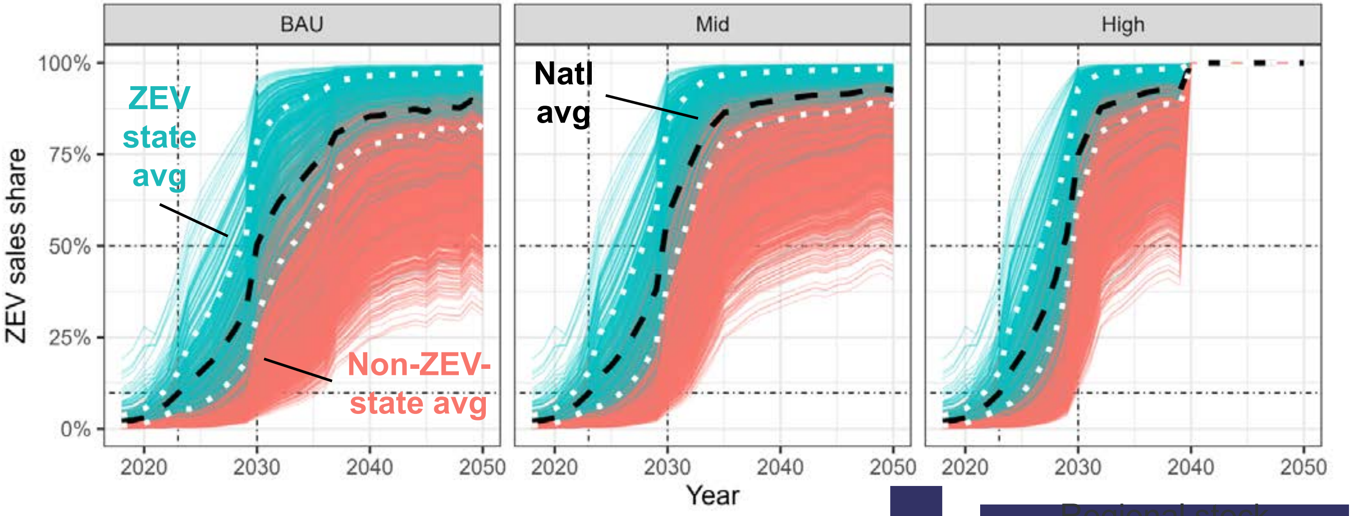
TEMPO develops scenario-specific county ZEV sales trajectories.

National ZEV sales shares



Disaggregation

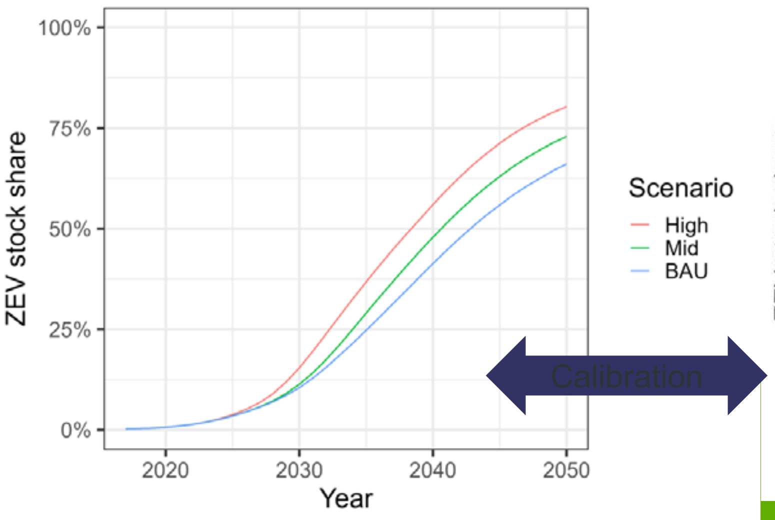
County-level ZEV sales shares



Regional stock turnover

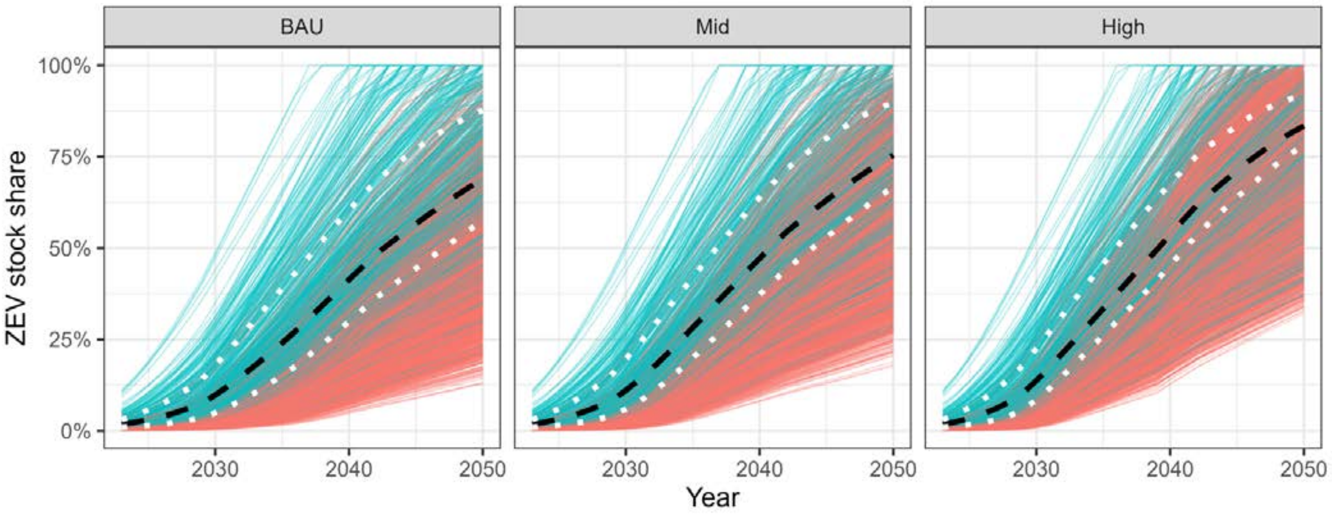
EVI-Pro simulates EV charging for EVs projected in each county

National ZEV stock shares



Calibration

County-level ZEV stock shares



"ZEV states" include CA, CO, CT, DE, ME, MD, MA, MN, NV, NJ, NM, NY, OR, RI, VT, VA, WA, DC, HI (as of 2023)

Modeling TEMPO M/HDV Scenarios in EVI-X

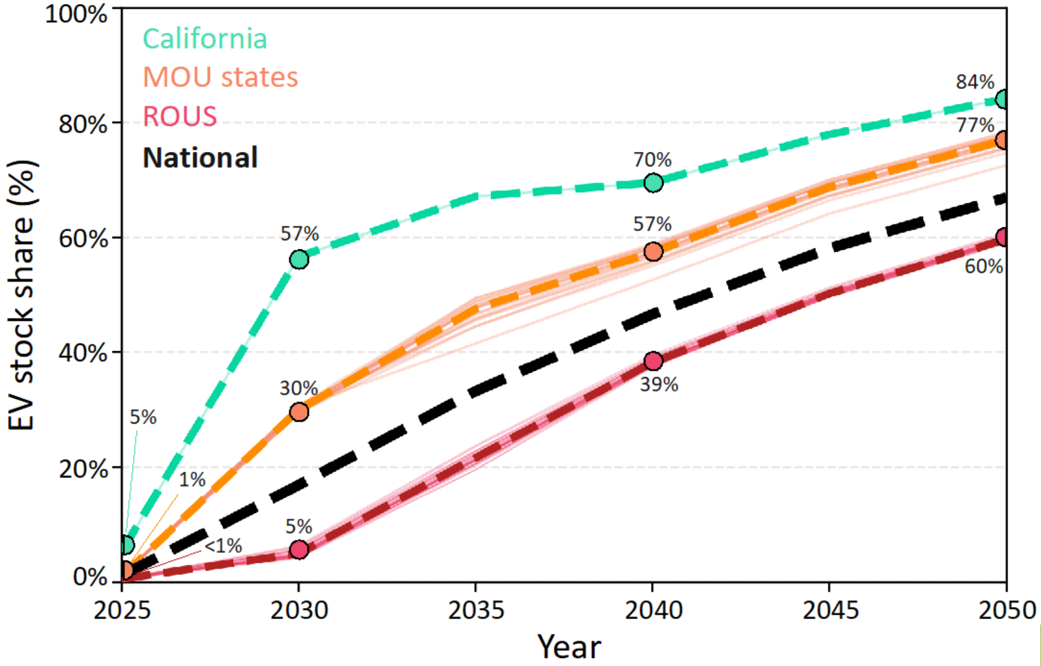
Accomplishments

In coordination with VAN050

TEMPO

TEMPO develops scenario-specific national ZEV sales trajectories that are disaggregated to the state-level based on VIUS registration shares by vehicle class and operating distance and state-level MHD electrification targets (CA, MOU, ROUS).

Medium- and Heavy-Duty EV Stock Shares by State Group



EVI-Pro

EVI-Pro takes these state-level EV stock projections and **simulates spatial and temporal charging demands** for a set of EVSE access and charge preference assumptions.

Top 10 Counties: 2030 MHD EV Demand

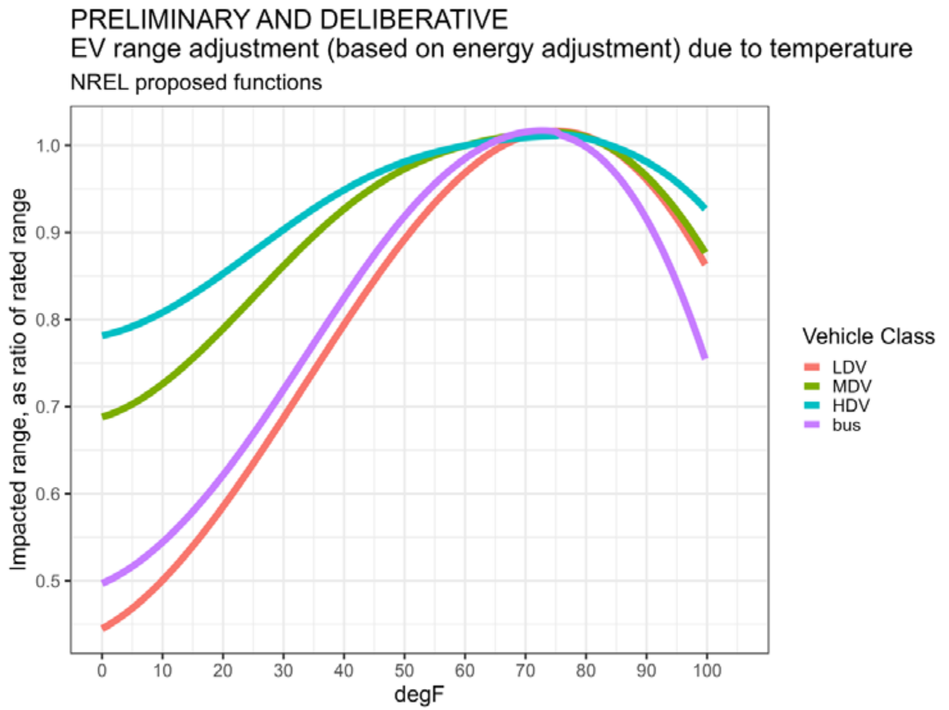
County Name	MHD EV Demand (TWh/yr)	Depot/Opp. (%)	En-route (%)
Los Angeles County, CA	3.1	79%	21%
San Bernardino County, CA	1.3	47%	53%
Riverside County, CA	1.0	72%	28%
San Diego County, CA	1.0	82%	18%
Kern County, CA	0.8	73%	27%
San Joaquin County, CA	0.6	85%	15%
Fresno County, CA	0.6	75%	25%
Sacramento County, CA	0.5	85%	15%
Contra Costa County, CA	0.3	87%	13%
Rockland County, NY	0.3	93%	7%
Top 10 counties:	9.5 (25% of U.S.)		

Top 10 Counties: 2050 MHD EV Demand

County Name	MHD EV Demand (TWh/yr)	Depot/Opp. (%)	En-route (%)
Los Angeles County, CA	5.7	70%	30%
San Bernardino County, CA	2.8	38%	62%
Riverside County, CA	1.7	59%	41%
Harris County, TX	1.6	85%	15%
San Diego County, CA	1.5	69%	31%
Cook County, IL	1.3	71%	29%
Middlesex County, NJ	1.2	76%	24%
Kern County, CA	1.2	54%	46%
Maricopa County, AZ	1.1	74%	26%
New Haven County, CT	1.0	82%	18%
Top 10 counties:	19.1 (8% of U.S.)		

TEMPO + EVI-X Harmonization Efforts

- **EV technology assumptions** aligned with Transport ATB & VTO/HFTO R&D Benefits analysis.
- **EV charging speed assumptions** aligned with DOE targets (*full charge in 15 min or less*).
- **Temp. impacts on EV efficiency** informed via on-road and lab-test data.
- **EVSE utilization** informed by real-world data and stated "breakeven" targets.
- **Charging losses** for AC L1, AC L2, and DC EVSE.
- **Travel data sources** for direct inputs and/or derived modeling assumptions.



Updated Temp <> EV efficiency Curves:

LDV: to follow most recent real-world data from Geotab (2023) and Recurrent Auto (2024). Comparisons are made against ANL (2023) and AAA (2019) lab tested data.

MHDV: Fit generalized patterns from HD-TRUCS (2023) and its source data (Basma et al. 2020).

Approach

Multi-State TEIS Methodology: Heavy-Duty PEVs (LBNL)

Travel Demand Modeling

↓

Agent-based Simulation

↓

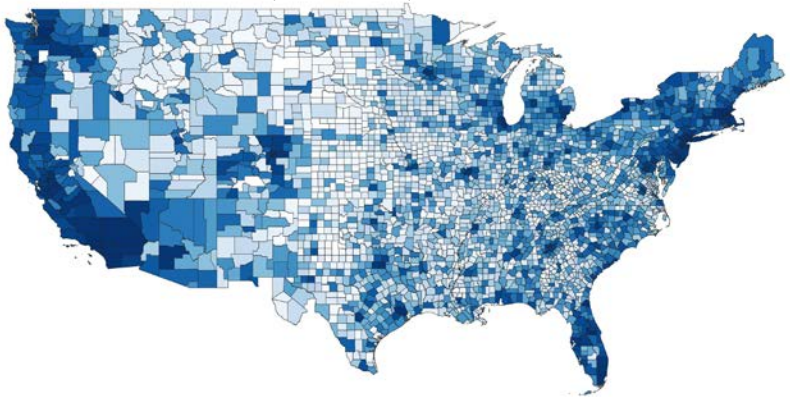
Infrastructure & Load Assessment

Truck travel demand at the national scale

Example truck routes for NY state

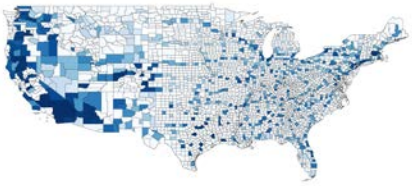
- Adoption scenario (EPA)
- NHTS/INRIX truck OD data
- Telematics data (FleetDNA)
- National Freight Network (FAF)
- Vehicle specifications
- Experian registration data
- Business census data
- Etc.

County level load projection



Depot charger needs

Public en-route charger needs



Truck volume for LA region

Truck volume for SF Bay Area region

Medium- and Heavy-Duty Electric Vehicle Load, Operations, and Deployment (HEVI-LOAD) Augmentation for National-Scale Infrastructure Assessment

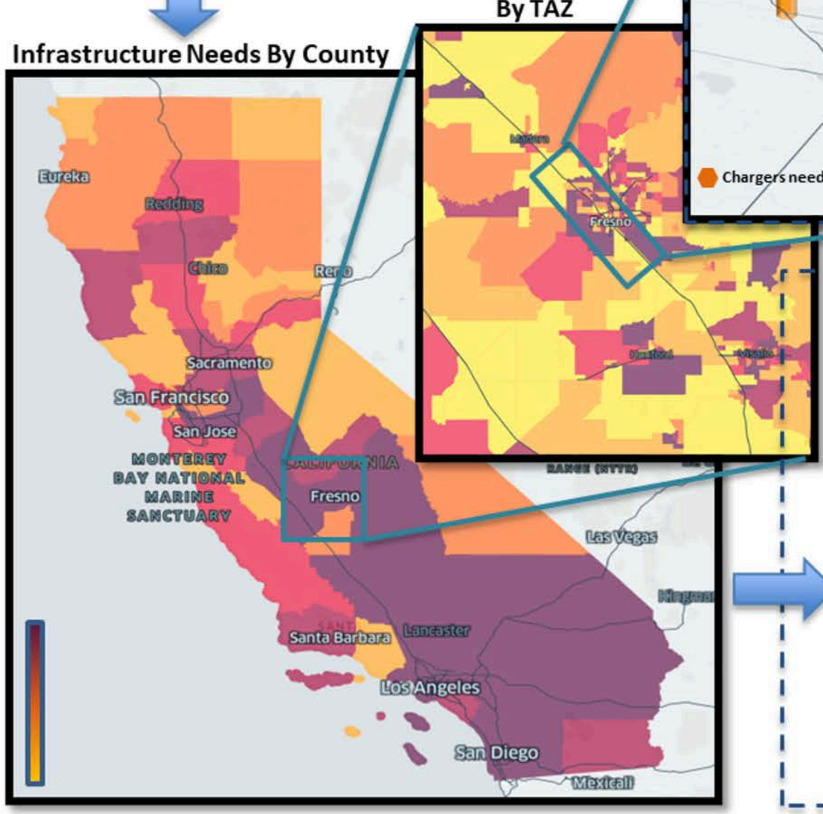
HEVI-LOAD Inputs

- MDHD travel demand (trips),
- parking and infra. location,
- truck GPS data,
- adoption scenarios,
- vehicle specifications, etc.

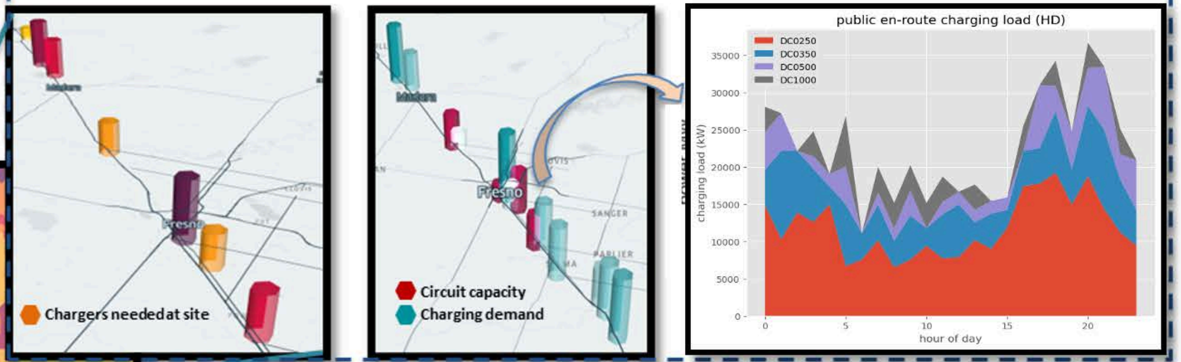
HEVI-LOAD Agent-Based Simulation

- Integrated driving-parking-refueling behavior modeling and simulation
- Smart/managed charging strategies

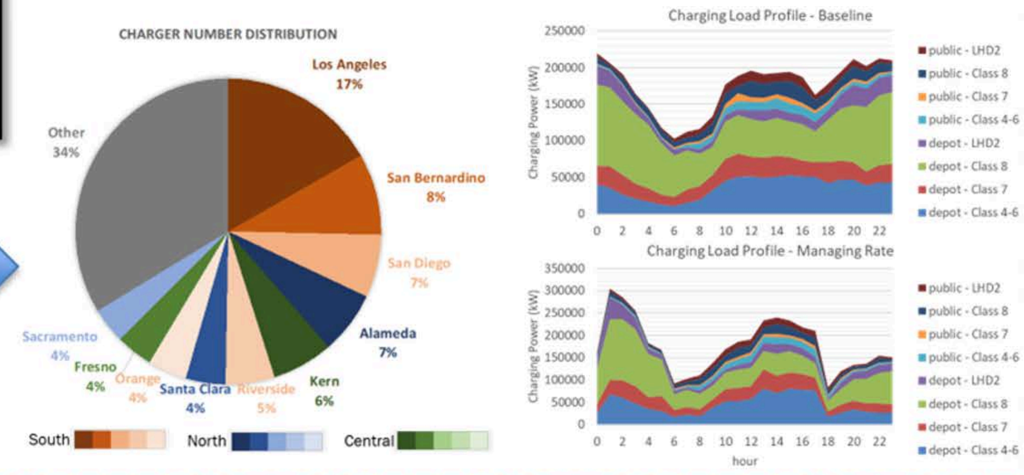
Infrastructure Needs By County



Infrastructure Assessment at the Site Level

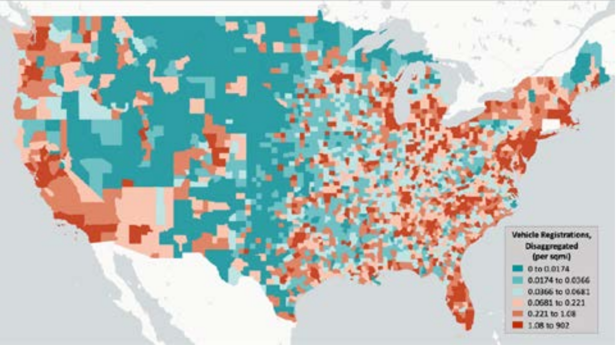


Infrastructure Assessment at the State and County Level

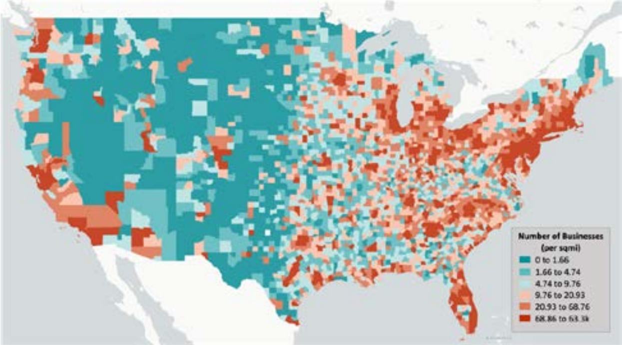


Trip and Travel Demand Modeling

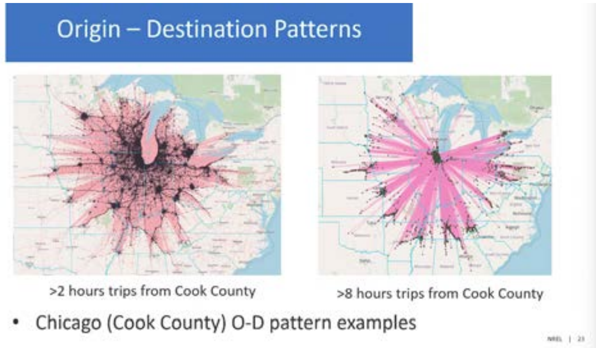
Vehicle Registration Data



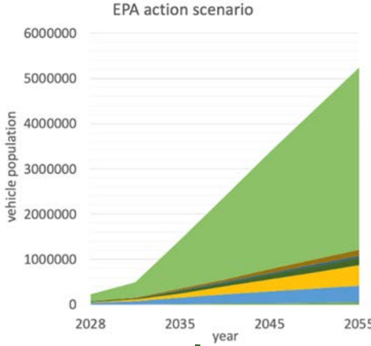
Business Census Data

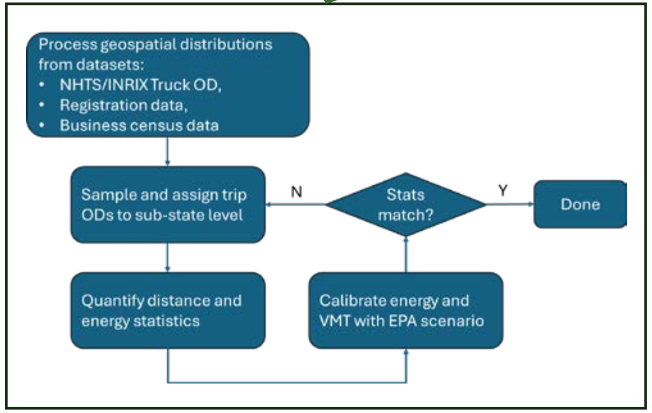


INRIX Truck OD Data

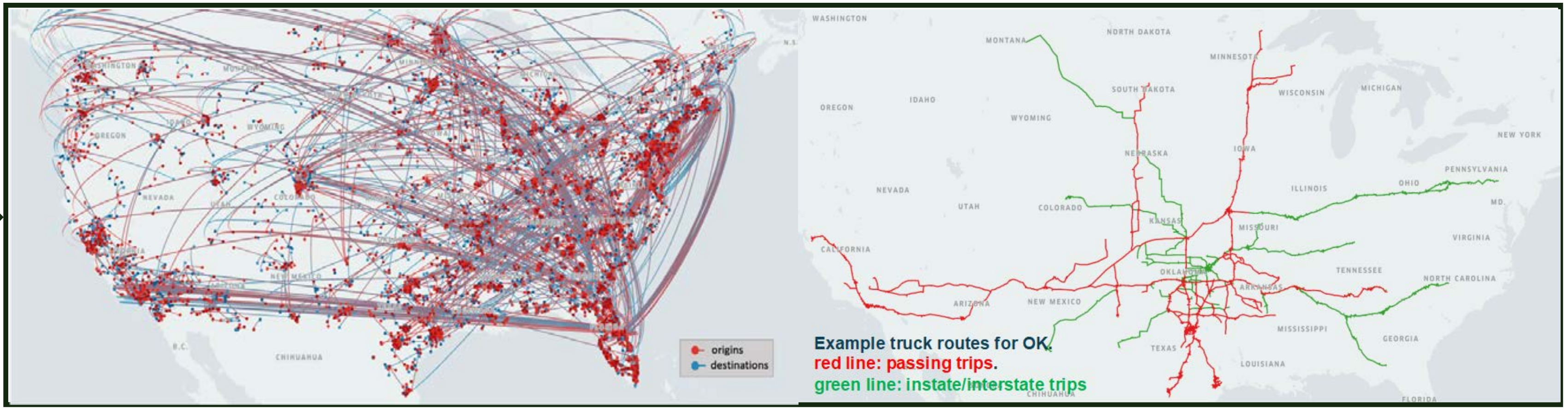


Adoption Scenario Data





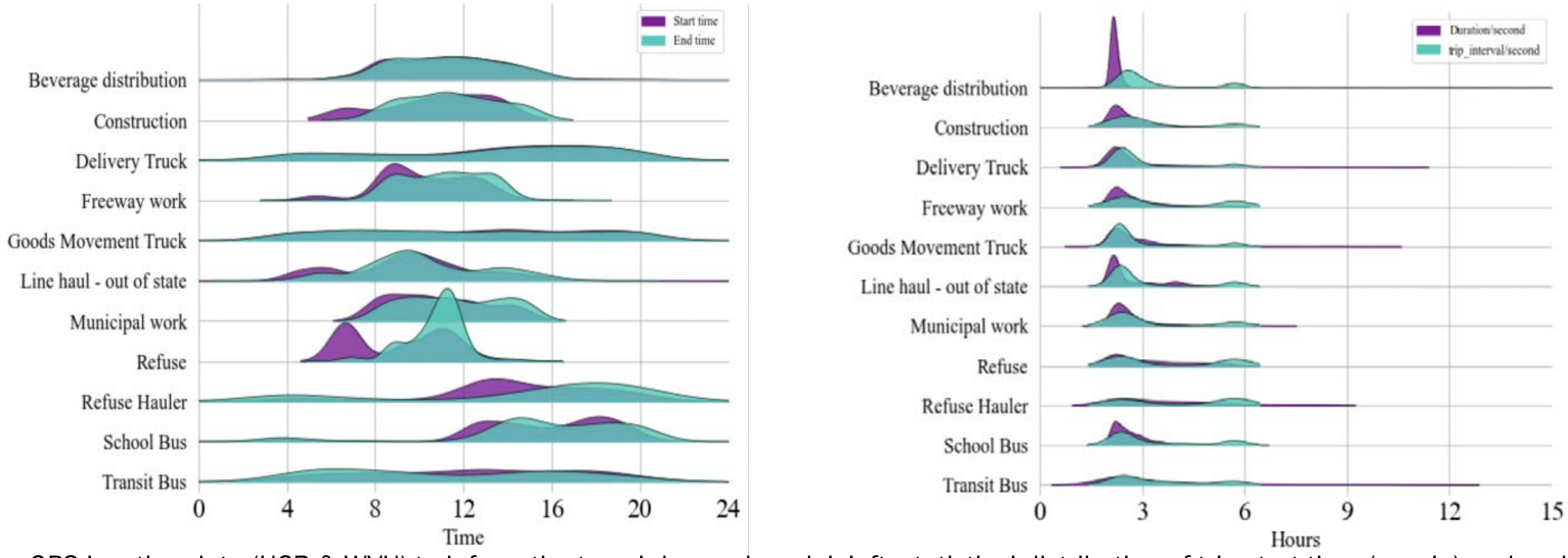
Simplified trip synthesis method



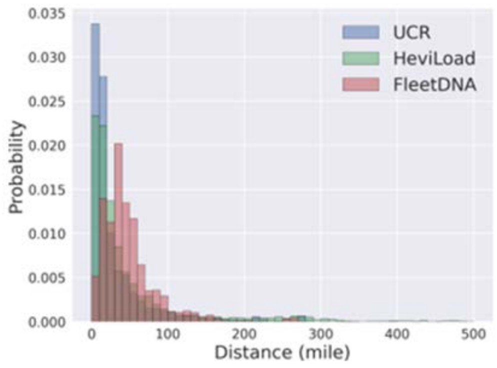
Example travel demand model with routes

Trip and Travel Demand Modeling

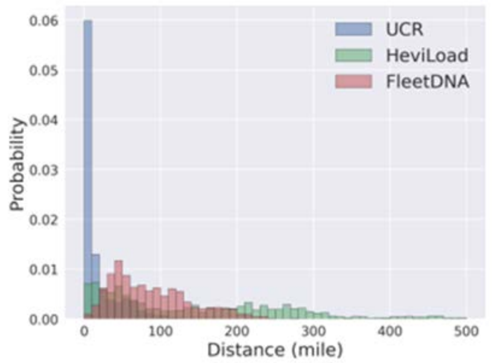
- Calibrate the travel demand models as inputs to HEVI-LOAD
- Characterize trip starting time and durations with real-world datasets (e.g., telematics data from UCR and NREL FleetDNA, etc.)
- Calibrate the trip distance and VMT statistics with the existing survey data



GPS location data (UCR & WVU) to inform the travel demand model, left: statistical distribution of trip start time (purple) and end time (green) for multiple applications, right: statistical distribution of trip duration (purple) and trip interval duration (green)



(a) Vocational heavy-duty

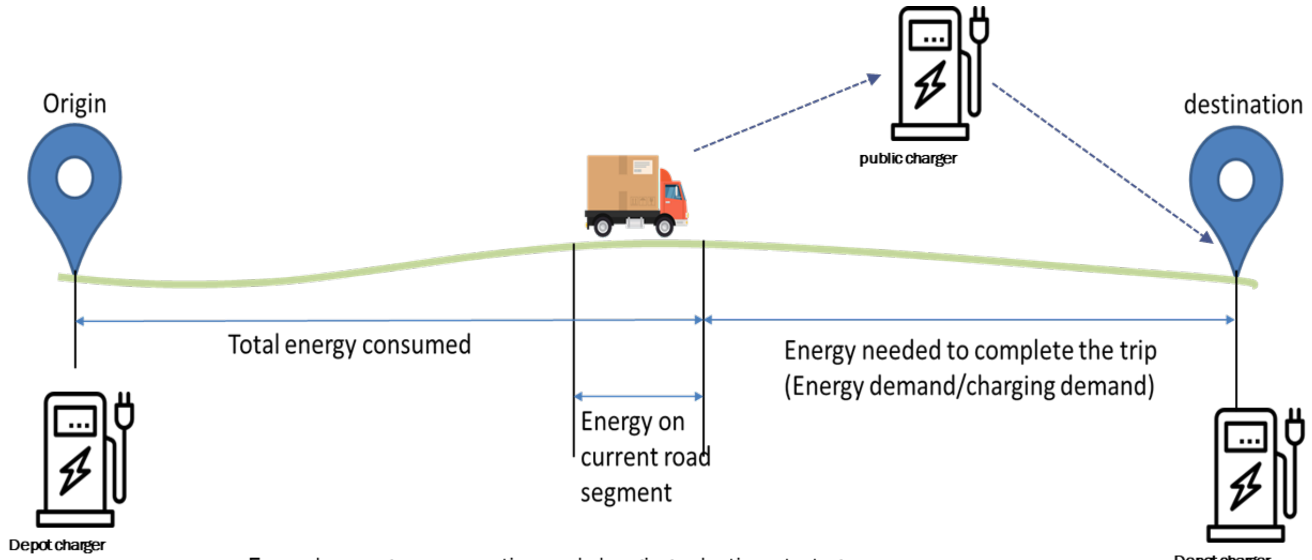


(b) Short-haul heavy-duty

Trip distance statistics used to inform the travel demand generation

En-Route Charger Selection Heuristics

- Simulate the entire driving-routing-parking-charging behavior chain within HEVI-LOAD
- Solve the charging plans for each trip (depot vs. public chargers) - select the enroute charger(s) with the shortest distance/travel time
- Jason's Law database was utilized for the initial public en-route charging locations

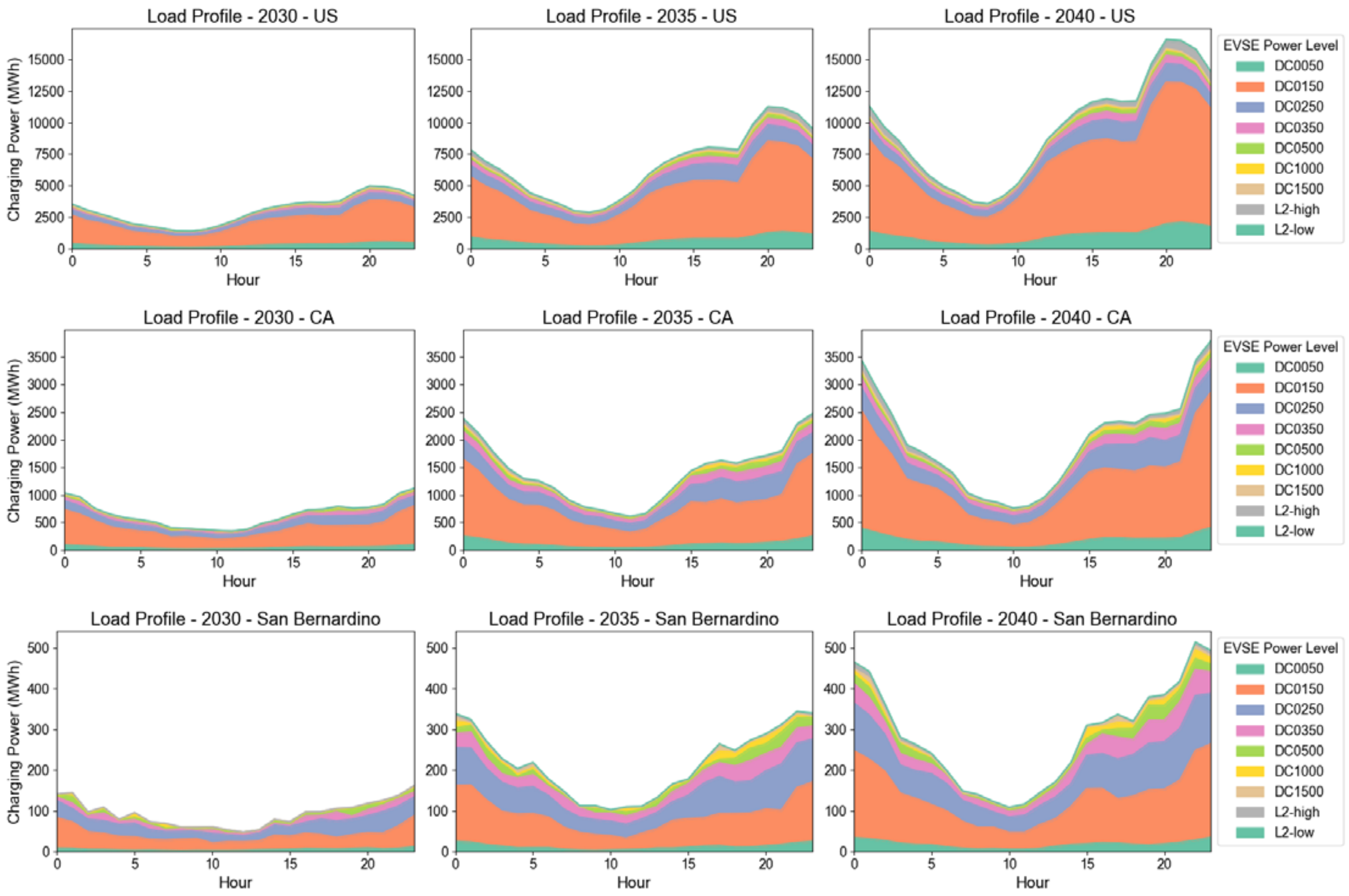


Example energy consumption and charging selection strategy

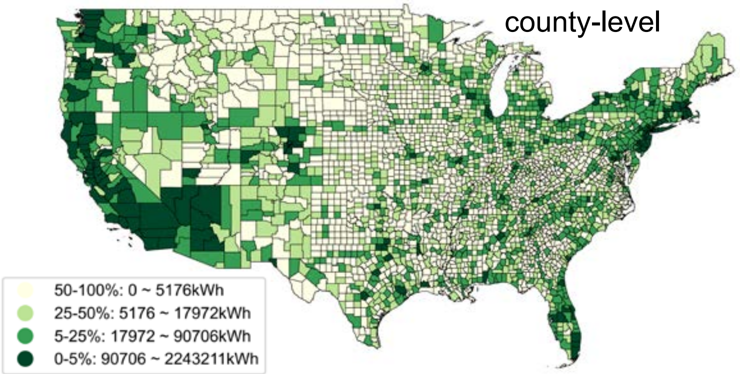
Truck parking locations along the freeway corridors

Charging Infrastructure and Load Profile Results

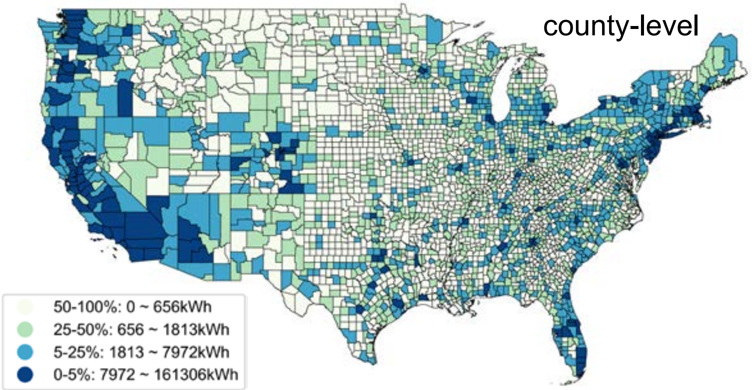
Hourly load profile by year



Aggregated daily load percentile



Aggregated peak load percentile



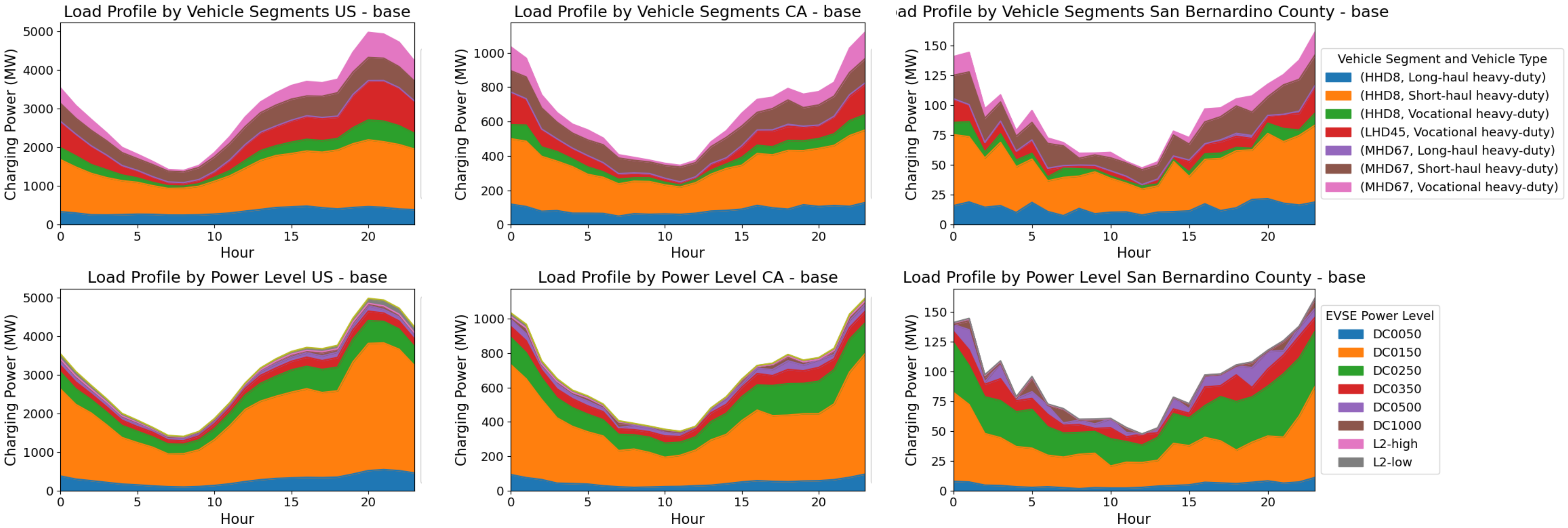
Hydrogen refueling demand

- No depot charging behaviors are assumed for Hydrogen fuel cell EVs
- Existing truck stops are assumed to be the initial candidate locations for hydrogen refueling
- Collaborate with NREL SERA team to determine the hydrogen simulation scenario (powertrain, infrastructure and station spacing and prioritization, etc.)
- Ongoing work to refine the scenarios and simulation

Simulated hydrogen refueling demand aggregated at the truck stops

Sensitivity Analysis

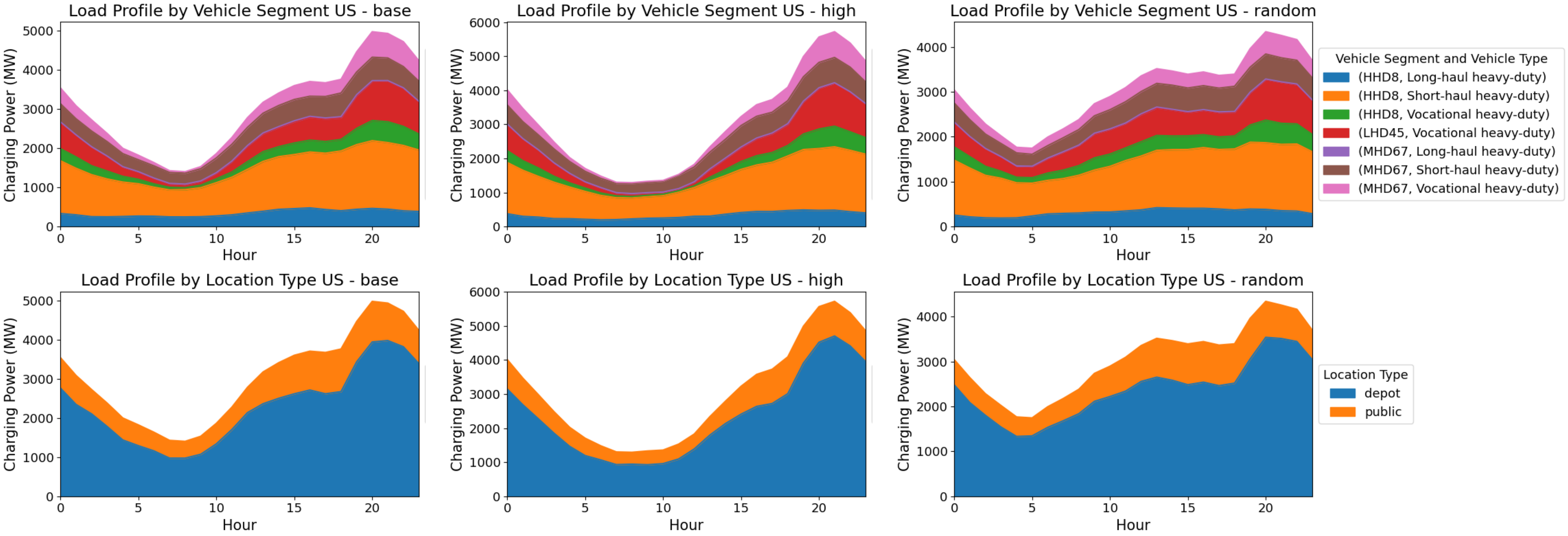
- Compare charging load results at different geospatial scales – national, state and county
- The level of smoothness tends to reduce as the geospatial granularity increases
- Energy demand by different vehicle types and charger types will also vary



Load profiles at U.S., CA and San Bernadino County (2030)

Sensitivity Analysis

- Compare charging load results with respect to different starting State of Charge (SOC) levels
- The overall load shape changes due to the updated charging behaviors
- Higher starting SOCs tend to shift the charging demand to later times and reduce the percentage of public charging demand



Sensitivity analysis of the trip starting SOC (2030)

Multi-State TEIS Methodology: Distribution Upgrades (Kevala)

Approach

Objective

Methodology / Tools

Parcel-Level Base Load and Existing PV

Residential | Commercial | Industrial | PV

ResStock | ComStock | Sunspot

Demand Modifier Forecast

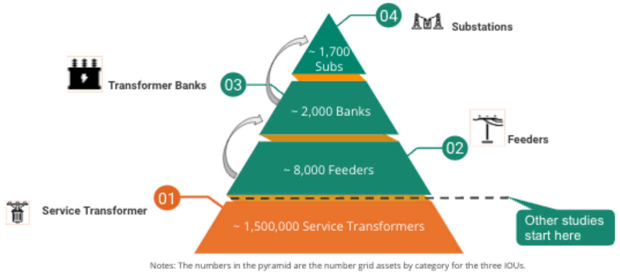
EV/EVSE | NREL Transforming ENERGY | BERKELEY LAB

Bottom-Up Propensity Adoption to Disaggregate County-Level EVI-X and HEVI-LOAD

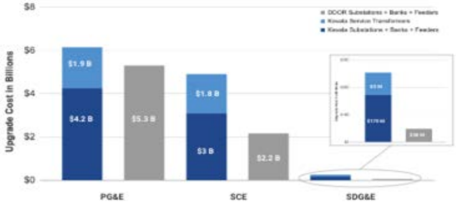
Size | Behavior | Adoption | Target

Kevala National Grid Data

Stepwise Grid Infrastructure Needs Assessment



Capacity Expansion Needs & Cost Estimates

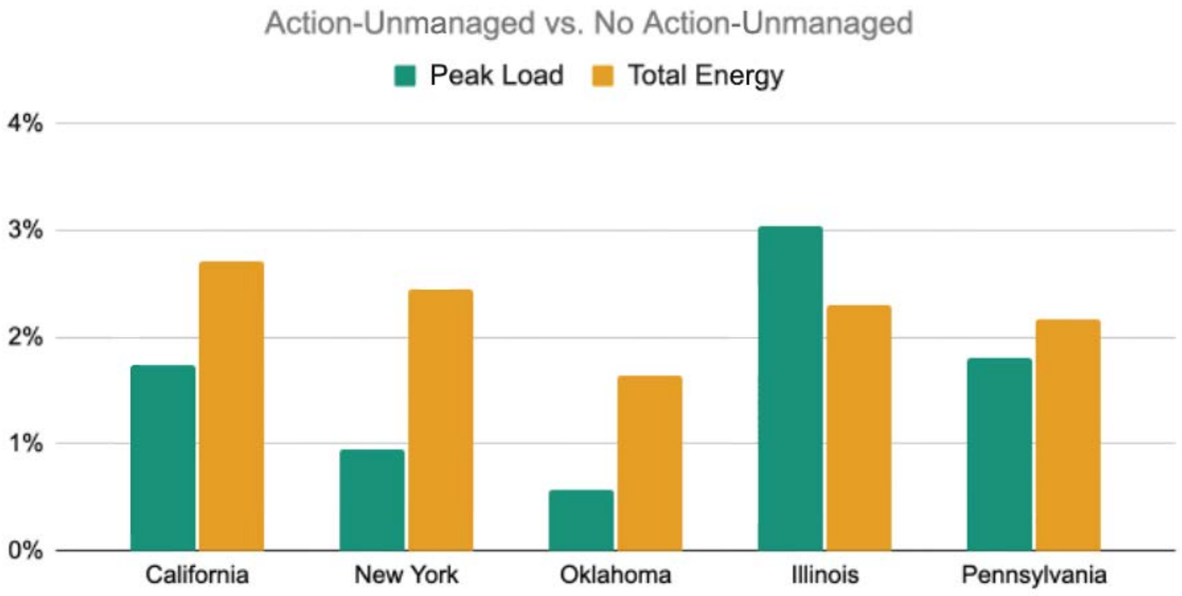


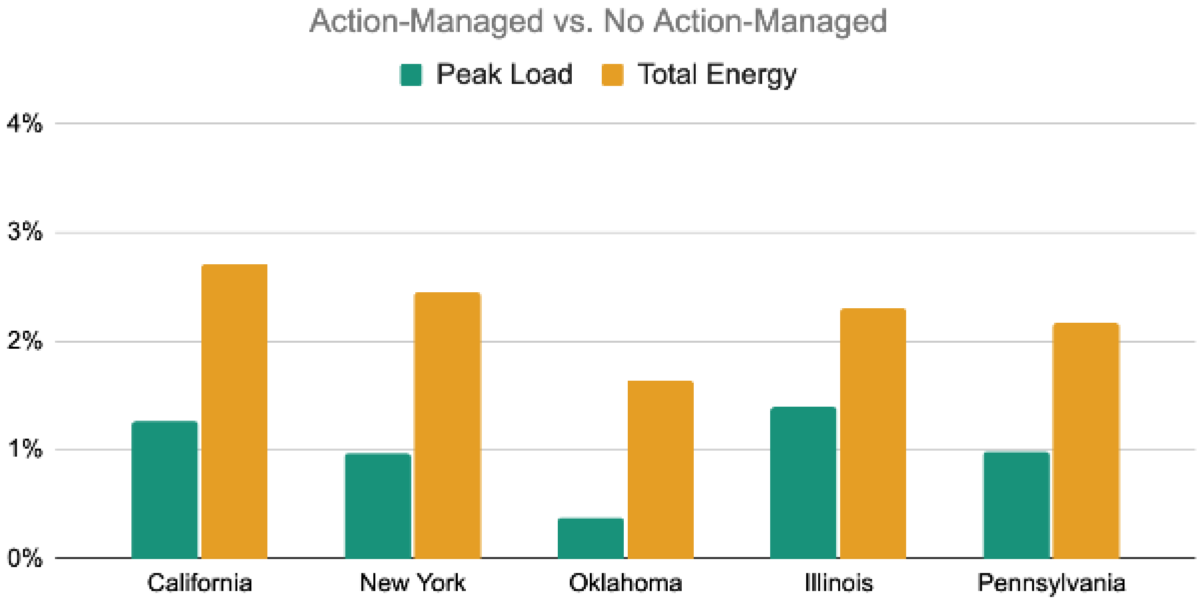
Unit Cost Assignment and Aggregation

$X + $Y + $Z

2032 Simulation Results (5-States)

- Total load is consistent across managed/unmanaged
  - 1.6% to 2.7% increase in total incremental load (as a result of Action)
- Managed scenario is more effective at reducing peaks
  - 0.6% to 3.0% increase in peak incremental load (unmanaged)
  - 0.4% to 1.4% increase in peak incremental load (managed)





2032 Simulation Results (5-States)

Five-State Scenarios (2032)	Action vs No Action	
	Unmanaged	Managed
Incremental PEV adoption (all weight classes)	3.9 million	
Incremental charging ports (all types)	2.3 million	
Incremental charging infrastructure capital investment	$9.7 billion	
Incremental substations	8	4
Incremental feeders	125	75
Incremental service transformers	30,000	21,000
Incremental distribution grid capital investment	$2.3 billion	$1.6 billion
Combined incremental infrastructure capital investment	$12.0 billion	$11.3 billion

Results are cumulative across 5-states

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3% Annual Increase (relative to No Action)

Managed charging (at homes and depots) decreases PEV peak by 30%. Substantial asset deferrals, cost savings.

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Based on NREL Annual Technology Baseline, fleetwide net benefits ($33 billion) are at least 2.5x greater than incremental infrastructure costs (excludes emission benefits)

Results are cumulative across 5-states

Additional Activities Under this Project

- Updating EVSE cost assumptions (with ANL/BNEF, JOET/McKinsey)
- Evaluating the Kevala platform for other projects (NREL)
- Synergy between LDV, MDV, and HDV charging
- Updating HDV activity data (multiple sources)
- Load flexibility scenarios, including “capacity aware”
- Coordinating hydrogen demand (HFTO)
- Analyzing cost-benefits in Integrated Planning Model (EPA)
- National extrapolation of 5-state results
- State variation in infrastructure costs
- Forthcoming national HEVI-LOAD study (LBNL)
- On-going supporting EVGridAssist

Responses to Previous Year Reviewer Comments

- This project was not reviewed in FY22.

Collaboration and Coordination with Other Institutions

- This project has benefited from engagement with the following organizations:
  - California Energy Commission
  - Edison Electric Institute
  - Electric Power Research Institute
  - Environmental Resources Management
  - Evgo
  - Kevala
  - General Motors
  - National Grid
  - New York State Department of Public Services
  - New York State Energy Research and Development Authority
  - Shell Recharge Solutions
  - Toyota Research Institute
  - Trillium
  - U.S. Department of Transportation
  - U.S. Environmental Protection Agency
  - U.S. Joint Office of Energy and Transportation

Remaining Challenges and Barriers

- Applied planning for distribution asset manufacturing ramp
- Options for maximizing ability to serve load in the near-term
- Quantify infrastructure needs stemming from IRA, state policy

Proposed Future Work

- **Develop pipeline** for generating county-level load profiles and associated infrastructure requirements using EVI-Pro for any national TEMPO run [In Progress]
- **Coordinate with EVs@Scale NextGen Load Profiles** project to update assumptions around ratio of “effective” to peak EV charging rates and temperature impacts on EVSE efficiency [Planned]
- **Increase the spatial resolution of EVI-X** for distribution-level planning & analysis [Planned]
- Better **incorporate feedbacks** from each model to inform/align assumptions (e.g., EVI-Pro charging mix informing TEMPO EV charging costs) [Future Opportunity]

Any proposed future work is subject to change based on funding levels

Conclusions

- Charging infrastructure and grid upgrade **investments that enable PEV adoption** offer significant environmental, health, and economic benefits, including consumer cost savings
  - Incremental cost of charging infrastructure ($12.0 billion investment across five states, between 2027 and 2032) was found to be at least two times smaller than the lifetime net benefits of vehicle electrification (including purchase price and fuel savings but excluding the value of avoided emissions).

- Incremental distribution grid investment to enable PEV charging ($2.3 billion across five states) was found to be approximately **3% of existing utility distribution system investments** (2027-2032).

- The potential for managed charging to defer distribution grid upgrades was found to be significant.
  - Managed charging was shown to decrease incremental distribution grid upgrade costs from $2.3 billion, to $1.6 billion across five states, over six years.
  - A reduction of this magnitude **alleviates the need for thousands of distribution assets** (including service transformers) across the 5-states under study.

Key Publications

- Wood, E., B. Borlaug, M. Moniot, D-Y Lee, Y. Ge, F. Yang, and Z. Liu. 2023. "The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure." NREL Technical Report 85654, June. https://www.nrel.gov/docs/fy23osti/85654.pdf.
- Wood, E., B. Borlaug, D-Y Lee, Y. Ge, and F. Yang. 2023. "Enhancing the EVI-X National Framework to Address Emerging Questions on Charging Infrastructure Deployment." Presented at the 2023 Vehicle Technologies Office Annual Merit Review. https://www.nrel.gov/docs/fy24osti/86030.pdf.
- Wood, E., D-Y Lee, L. Spath-Luhring, B. Borlaug, M. St. Louis-Sanchez, Y. Ge, and F. Yang. 2023. "EVI-X Updates and National Charging Assessment Report." Presented at the 2023 Vehicle Technologies Office Annual Merit Review, https://www.nrel.gov/docs/fy24osti/86417.pdf.
- Wood, E., Borlaug, B., McKenna, K., Keen, K., Liu, B., Sun, J., Narang, D., Kiboma, L., Wang, B., Hong, W., Giraldez, J., Moran, C., Everett, M., Horner T., Hodges, T., Crisostomo, N., and Walsh, P. 2024. "Multi-State Transportation Electrification Impact Study: Preparing the Grid for Light-, Medium-, and Heavy-Duty Electric Vehicles" DOE/EE-2818, https://www.energy.gov/policy/articles/new-multi-state-analysis-helps-guide-grid-planning-electric-vehicle-charging