



Managing Increased Electric Vehicle Shares on Bulk Power Systems

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**Presenter*

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Project ID # VAN054

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

Project start date: 11/14/22

Project end date: 12/31/25

Percent complete: 75%

**as of 03/22/2025*

Budget

Total project funding: \$1,400,000

DOE share: 100%

FY 2024 funding: \$500,000

FY 2025 funding: \$400,000

Barriers Addressed

- Electricity demand growth from electric vehicle (EV) charging
 - **Electricity demand growth from EV charging is uncertain**, particularly for medium- and heavy-duty (M/HD) vehicles, yet **projections are critical for power system planning**.
- System-level costs/benefits of EV managed charging (EVMC)
 - **Managed charging** of EVs can reduce grid capacity needs and operational costs, but the **extent of these benefits and how they compare to costs is unclear**.
- Co-evolution of the bulk power system, EV adoption, EV supply equipment (EVSE) networks, and EVMC

Partners (Advisors)

- Atlas Public Policy
- Boston University
- California ISO
- California Public Utility Commission
- Camus Energy
- Carnegie Mellon University
- ChargePoint
- Daimler Truck North America
- Dallas-Fort Worth Clean Cities
- FlexCharging
- Ford
- Karlsruhe Institute of Technology
- National Grid
- North Carolina A&T State University
- New Jersey Clean Cities
- PG&E
- PJM
- Smart Electric Power Alliance
- Tennessee Clean Fuels

Project Relevance

Motivation

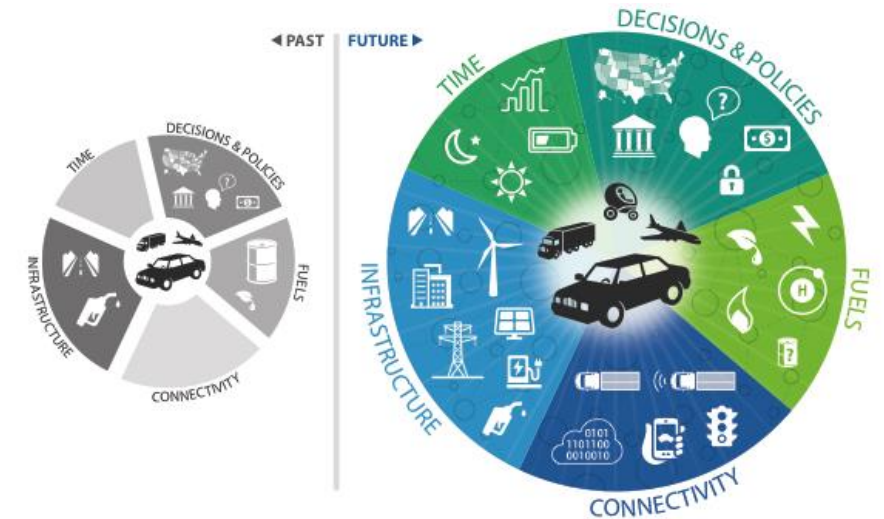
Transportation electrification, other load growth, and the integration of **many power sector technologies**—the convergence of these trends presents a complex planning problem requiring **realistic, region-specific modeling and analysis** to ensure the power system can support new loads quickly and affordably.

Objectives

- Simulate **evolution of the U.S. bulk power system** (through 2050) to accommodate large-scale EV charging (**innovative transportation technology**) across all on-road vehicle segments.
- Assess the **opportunity and value of demand-side flexibility** (i.e., “smart” charging) for **reducing energy costs** and grid capacity needs (**increased energy security**) compared to the costs of managing EV charging loads.
- Study how the buildout of **EV infrastructure impacts demand-side flexibility and grid system costs**.

Impact

- Improved understanding of **anticipated challenges and least-cost solutions for managing load growth from EV charging** on the U.S. bulk power system through 2050.
- **EV load data sets** (for both unmanaged and managed charging scenarios) and **supply curves for EV managed charging** made publicly available, and key findings described in a series of **publications**.



Muratori et al., 2020, “Future integrated mobility-energy systems: a modeling perspective,” *Renewable Sustainable Energy Rev.* <https://doi.org/10.1016/j.rser.2019.109541>

Technical Approach

Details

National (CONUS), 2025-2050

Hourly annual loads (8760) for counties and/or ReEDS grid regions (balancing authorities)

EVMC: Grid-managed load profiles

Reference: Unmanaged load profiles (no EVMC)

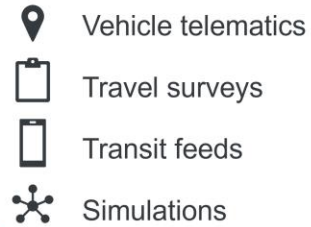
Modeling Framework

EV Demands

EV Adoption



Travel Data



Charging Sims



EVMC Resource Potential

Aggregate EV Flex

Develop MW-scale EVMC resources that can:

- Delay charging by... (mid-term)
- Decreasing charging and (short-term)
- Increasing charging (short-term)

Supply Curves

\$/MW for different types of EVMC:

- Time-of-use (TOU) rates
- Real-time pricing (RTP)
- Direct load control (DLC)
- Demand response (DR)

Enablement Costs

- Communications
- Software
- Program operations
- Marketing
- Customer incentives

Grid Investment

System buildout, operations, costs, and emissions for each scenario, considering:

- Generation
- Transmission
- Utility-scale storage
- EVMC

Outcomes

- Costs and emissions** for different EV adoption, EVSE buildout, and EVMC strategies
- Hourly annual (8760) EV load profiles** for each scenario (2025-2050)

EV Load Profiles –
Baseline &
Flexibility
(within-session
& within-week)

Core Models



TEMPO

TEMPO is an all-inclusive transport demand model used to develop long-term scenarios of EV adoption, vehicle use, and within-week charging flexibility.



EVI-Pro

EVI-Pro models realistic EV charging behaviors and within-session charging flexibility for all on-road vehicles. It estimates charging network requirements and associated costs for each scenario.



dsgrid

dsgrid-flex bridges the transport and power sector models, transforming vehicle-level load profiles into grid-model ready, storage-like EVMC resources.



ReEDS

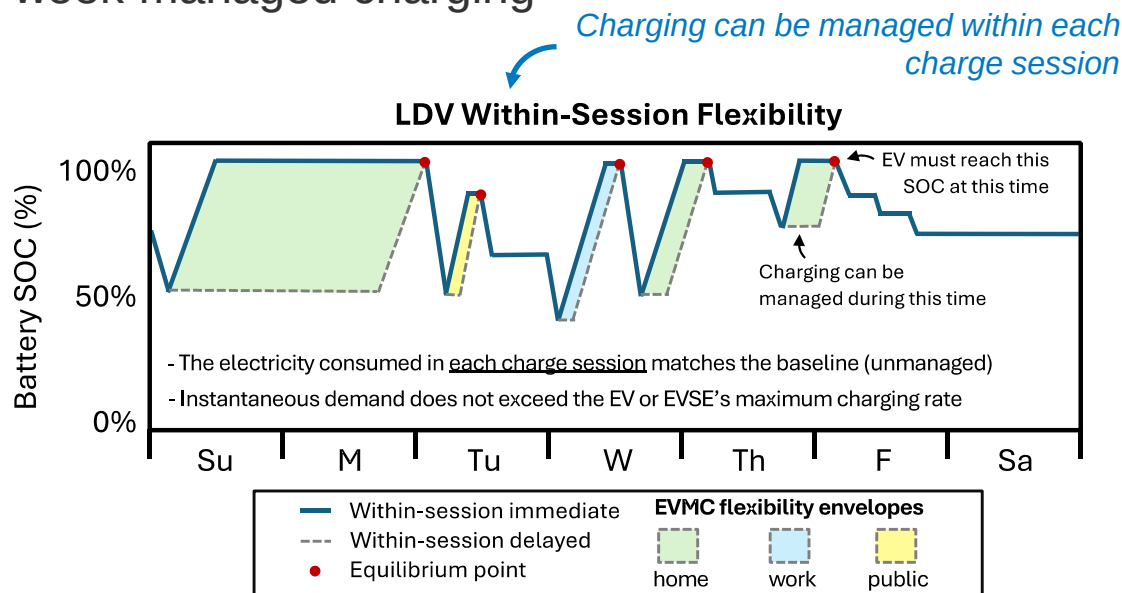
ReEDS projects generation, transmission, and storage investments and retirements (power system evolution) at a continental scale.

Agg. EVMC Resource –
re-shaped load or storage-like dispatchable resource

Technical Approach: EVs, EVSE, and Charging



- Bottom-up vehicle-level modeling framework **compatible with standard TEMPO national outputs**; adaptable to other adoption models.
- Baseline **EVSE access and charging behaviors simulated in EVI-Pro**; Ability to model alternative EVSE access and charging behavior scenarios to represent different EVSE network buildouts.
- Simulation of **immediate and delayed charging** behaviors defines flexibility bounds for within-session and within-week managed charging



Study leverages real-world operating data for **~200,000 unique vehicle weeks** covering **all on-road vehicle segments**.

Vehicle Class + Segment	Vehicle-Weeks	Source
LDVs	116,638	2017 NHTS
Local Class 2b-3 M/HDVs	23	Fleet DNA
Local Class 4-6 M/HDVs	349	Fleet DNA
Local Class 7-8 M/HDVs	2,200	OEM telematics
Regional M/HDVs	11,588	OEM telematics
Long-haul M/HDVs	37,075	OEM telematics
Transit buses	21,694	GTFS
School buses	254	Fleet DNA

Total 1-Week Vehicle Travel Profiles

189,821

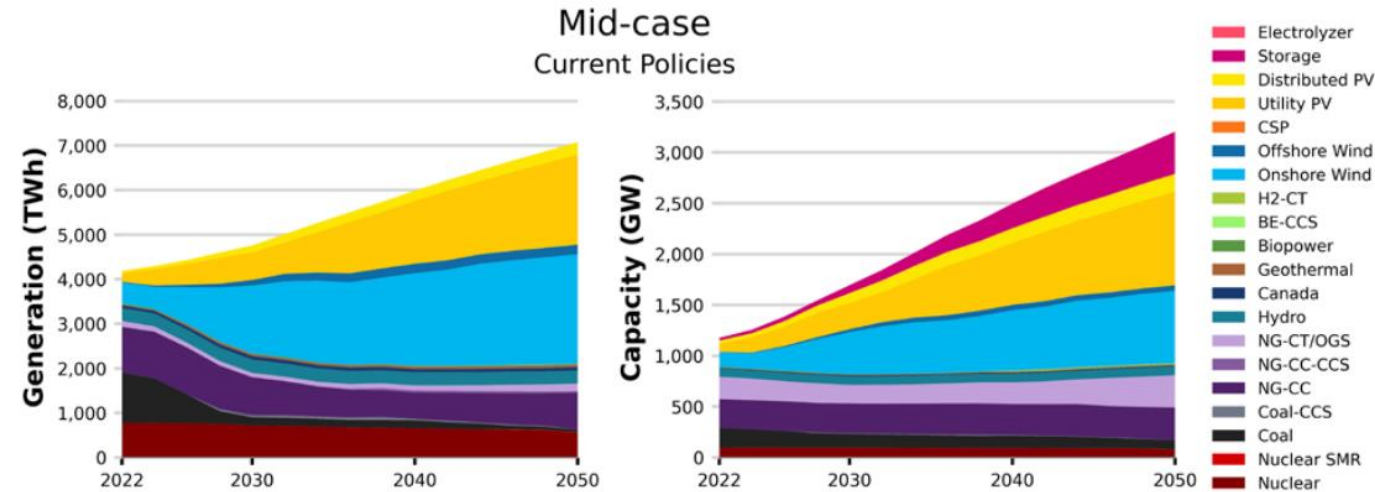
Relevant Milestones:

- ✓ **FY24 Q4** – County-level hourly baseline (unmanaged) and flexibility (immediate, delayed) load profiles
- ✓ **FY25 Q2** – Draft journal article describing EV charging and flexibility resource data

EV Managed Charging as a Selectable Grid Resource

- EV charging flexibility is first represented at the individual (sample) vehicle level, based on baseline, immediate, and delayed charging behavior simulations
- Starting with individual vehicles enables realistic modeling of aggregate flexibility for different dispatch mechanisms, including direct load control (DLC), time-of-use rates (TOU) and real-time pricing (RTP)
- DLC managed charging is represented in ReEDS as a grid-dispatchable storage-like resource; TOU and RTP managed charging are pre-computed shape resources
- Supply curves describe the relationship between money spent by utilities to enable managed charging and the percent of EVs actively participating
- Describing EV managed charging's physical capabilities (storage or shape resources) and costs (supply curves) lets ReEDS choose when and where to deploy EV managed charging (alongside other options) to help meet grid reliability needs

Example ReEDS Outputs: 2023 Standard Scenarios



(Gagnon et al. 2024)

*ReEDS determines the least-cost generation, storage, and transmission capacity build-out that meets grid reliability, policy, and other constraints. **Key inputs include load, technology cost, and fuel cost projections.***

Relevant Milestones:

- **FY25 Q4** – Draft journal article describing impact of different EVSE deployment and EV managed charging approaches on grid system build out, costs, and emissions

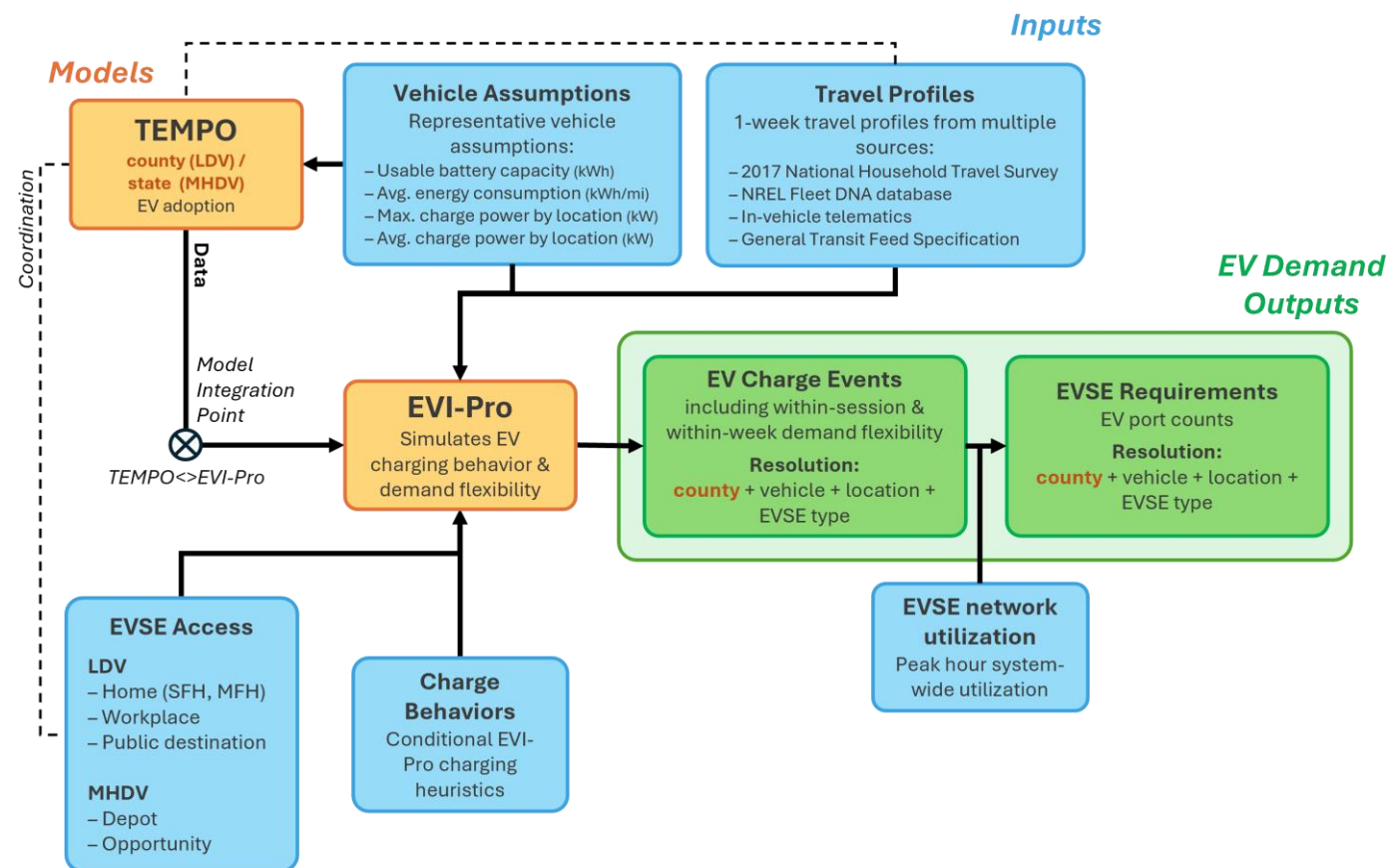
Accomplishment: EV Simulation Pipeline

Features

- Configurable & self-documenting
- Fast (national runs with county resolution in <2 hours)
- Integrates **TEMPO** and **EVI-Pro**
- Stores data in efficient formats (e.g., toml, parquet)

Results Resolution

- Year: through 2050
- County
- Vehicle type (13):
 - LDV: car
 - LDV: light truck
 - MDV: Class 2b-3 (local, regional, long-haul)
 - MDV: Class 4-6 (local, regional, long-haul)
 - HDV: Class 7-8 (local, regional, long-haul)
 - School Bus
 - Transit Bus
- EVSE location type (8):
 - LDV: home (SFH, MFH), work, community, corridor
 - MHDV: depot, community, corridor
- EVSE power level:
 - L1 (120V AC)
 - L2 (220/240V AC)
 - 50 kW-2+ MW (DC)



Key capability coordinates assumptions and modeling approaches across many VGI projects

Accomplishment: EV Adoption and Charging Data

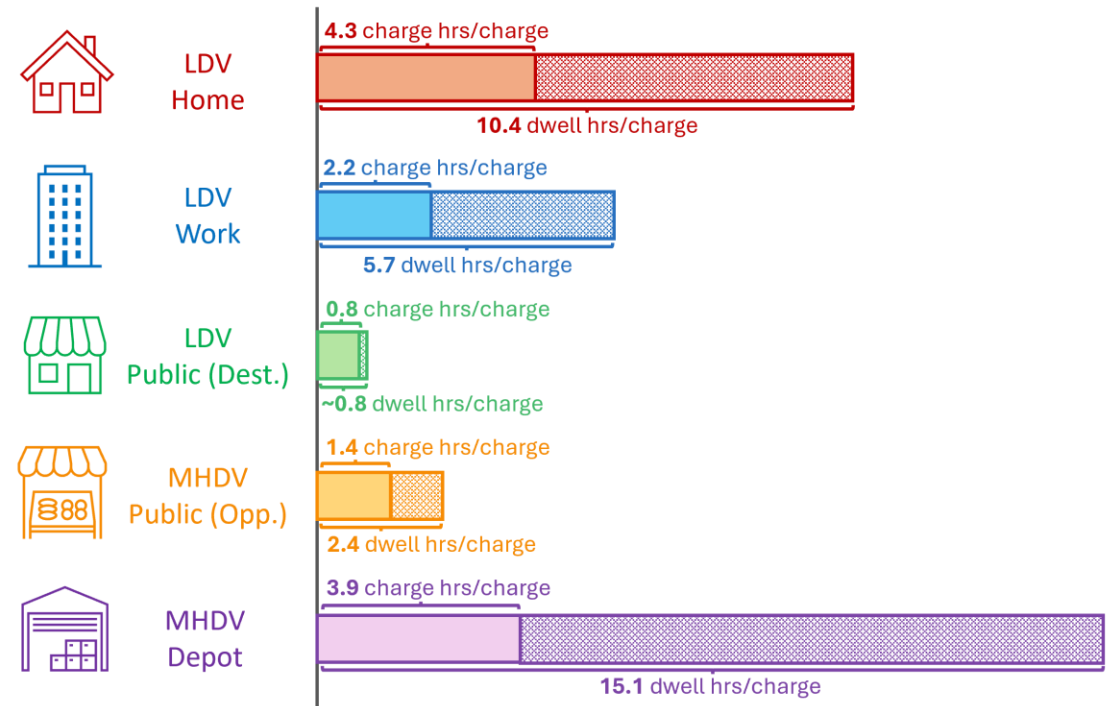
Status

- Charging scenarios are nearly finalized (April 2025), targeting final data in FY25 Q3.
- EV simulation pipeline utilized across multiple DOE projects (this project plus VAN052, VAN061, ELT295, EERE/SA Integrated Energy Futures [IEF]).

Key Features and Outputs

- Session-level EV demand and flexibility parameters
- Within-week flexibility datasets
- Annual hourly (8760) load profiles
- EVSE port counts
- Additional Metrics: EVSE utilization, EV/EVSE load factor, coincidence factor, EVSE access %, etc.

Modeled EV Charging and Dwell Durations
Lower charge-to-dwell hour ratios indicate higher demand flexibility potential



Modeled EV charging and dwell durations for LDV home charging (red), LDV workplace charging (blue), LDV public destination charging (green), MHDV public opportunity charging (orange), and MHDV depot charging (purple). Lower charge-to-dwell duration ratios are one indicator of higher demand flexibility potential. **Results are preliminary and subject to change prior to final publication.**

Accomplishment: Draft Article Describing Flexibility Resource

Results Outline

- **Dynamics of EV Demand Flexibility**
Amount of flexibility under Baseline VGI, different adoption levels, by vehicle class, location, and EVSE type over time.
- **Impacts of Alternative EV Infrastructure Deployment Strategies**
Impact of different EVSE deployment strategies on unmanaged charging profiles; impact of EVSE deployment and VGI strategies on magnitude and timing of flexibility.
- **Representing EV Demand Flexibility in Grid Models**
How flexibility data can be processed (e.g., dispatched, aggregated, scaled) to create accurate representations of EVMC resource in grid models.

VGI Strategies

VGI Strategy	Description
Baseline	EVSE access evolves based on current (2025) charging preferences and observed trends.
Daytime	Greater daytime and reduced nighttime EVSE access to align charging with solar generation (applies to High EV adoption only).
Flat	Increased daytime EVSE access and preference for low-power charging, resulting in a flatter load curve (High EV adoption only).
Flex	Expanded EVSE access at all locations with preference for high-power charging, providing maximum flexibility for active management strategies (High EV adoption only).
Stress	Increased overnight EVSE access and fast charging preference, exacerbating evening peaks if unmanaged (High EV adoption only).

Timeline

- ✓ FY25 Q2 – Draft article
- FY25 Q3 – Finalize data and graphics
- CY25 – Submit and publish

Accomplishment: EV Managed Charging Supply Curves

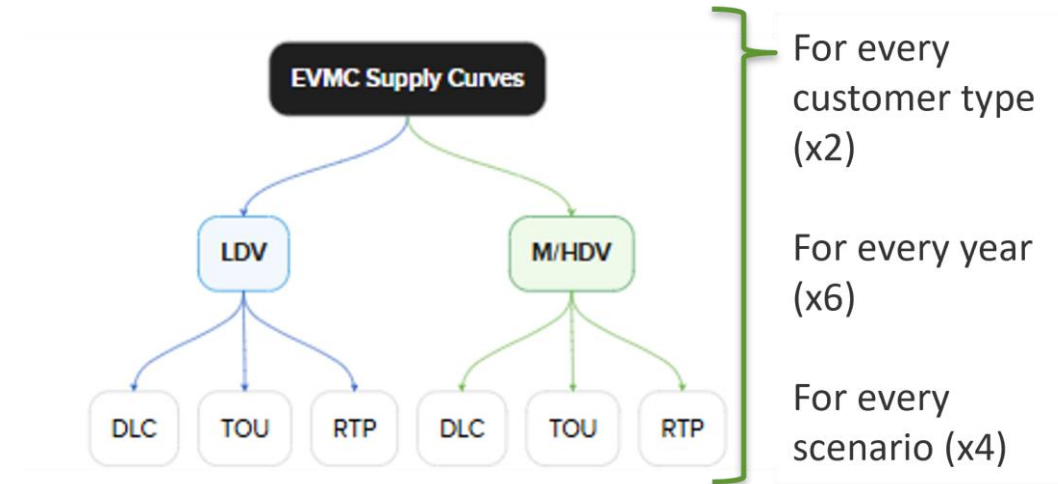
How much does EVMC Cost?

- Supply curves answer this question in a way that enables ReEDS to select cost-optimal quantities of EVMC

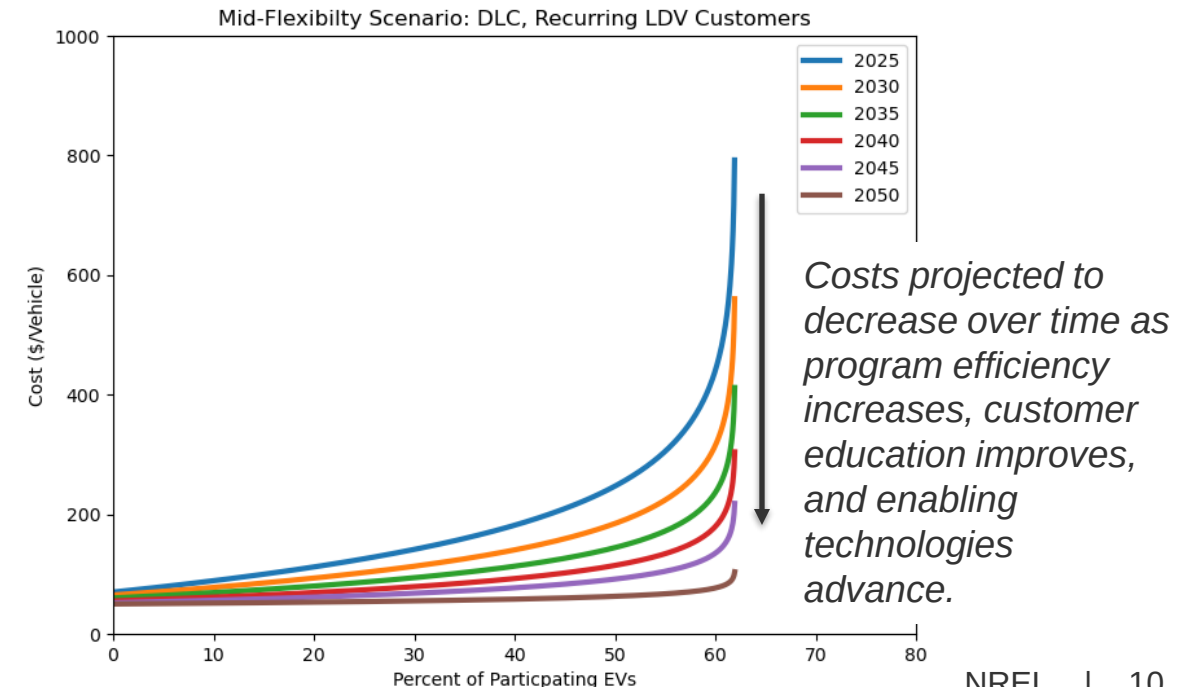
Accomplishments

- Sourced data on *administrative and operating costs, marketing, incentives, and hardware*; as well as *upper limits on enrollment* from a variety of reports and utility filings found in part via interviews with subject matter experts
- Shaped this data into cost by category assumptions that vary by vehicle type, new / recurring participants, dispatch mechanism, scenario, and year
- Drafted journal article and GitHub repository for data publication expected in 2025
- First of its kind dataset with multiple forward-looking cost scenarios for M/HDV, in addition to LDV, programs

A total of 288 supply curves describe possible costs from 2025 to 2050



Four flexibility scenarios provide different narratives to 2050



Accomplishment: EVMC in ReEDS

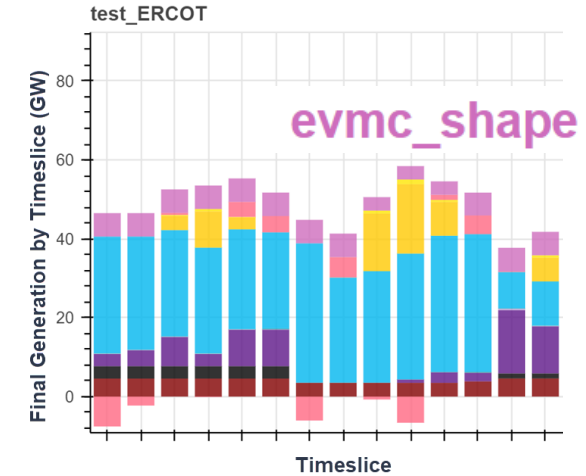
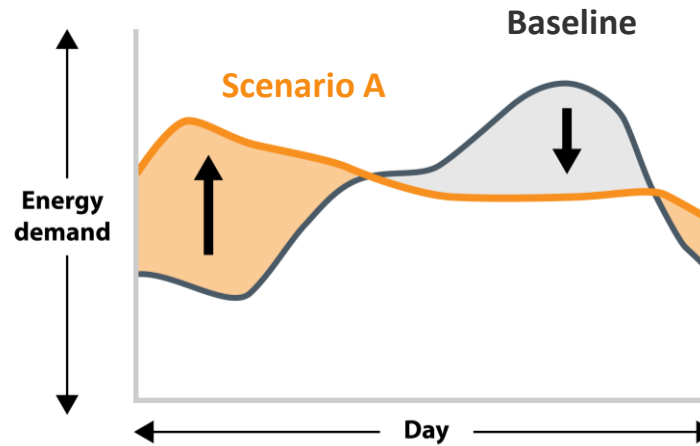
Timeline & Status

- FY24: Initial prototyping, outputs script, and parallelization of evmc_shape calculations
- FY25 Q1-Q2: Updates to work with the latest version of ReEDS, which iterates with the Probabilistic Resource Adequacy Suite (PRAS)
- FY25 Q3-Q4: Will focus on refining the data passed to ReEDS and iterating on analysis results

Example Outputs

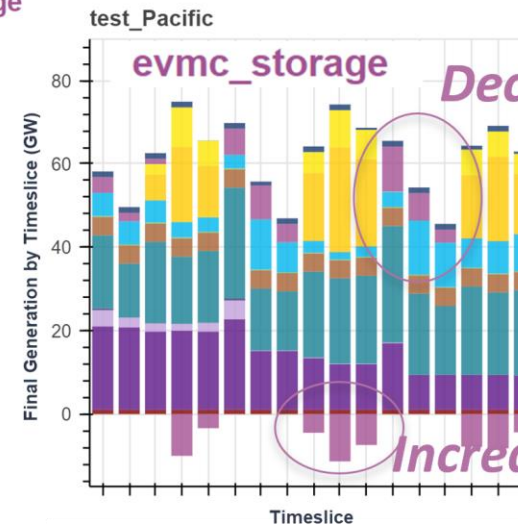
- **EVMC capacity adopted by ReEDS (MW)**, including new, continuing, and retiring capacity; segmented by region, year, EVMC type, and bin
- **Number of participating vehicles**, including new, continuing, and leaving; segmented by region, year, EVMC type, and bin; in total and as fraction of EVs
- **Total amount of energy shifting (MWh)**, energy shifting per participating vehicle (kWh/vehicle-year), fraction of baseline EV load shifted
- **Capacity value provided by EVMC (\$)**, **energy value provided by EVMC (\$)**, capacity value and energy value per vehicle (\$/vehicle-year)

Shape resource replaces baseline charging profile with TOU or other static managed charging profile (“Scenario A” in graphic)



Storage resource is directly dispatchable by ReEDS and is used to represent Direct Load Control (DLC)

Canada
pumped-hydro
evmc_storage
battery_4
distpv
upv
wind-ofs
wind-ons
lfill-gas
biopower
geothermal
hydro
o-g-s
gas-ct
gas-cc
nuclear



Decreased EV charging

Increased EV charging

Responses to Previous Year Reviewer Comments

This project was last reviewed in 2023. Overall, reviewers found the project relevant to DOE objectives, addressing technical barriers, having sufficient resources, and on track. Three significant comments were:

- No pricing mechanism or other linkage to balance EV adoption in TEMPO with electricity price from ReEDS
 - *This is a correct observation. The EV adoption scenarios in this project (low, mid, and high) are aligned with other projects and not necessarily with electricity price changes as modeled in ReEDS.*
 - *There is a separate TEMPO-ReEDS linkage project that is addressing this question.*
- No accounting for upgrades to the distribution system, including to-the-meter and behind-the-meter for MD/HD sites
 - *There are two types of costs relevant to the reviewer's comment: distribution and behind-the-meter upgrade costs required for EV adoption, and any changes to those costs affected by EV managed charging.*
 - *Ongoing work by the transportation modeling teams accounts for EV adoption behaviors in the presence of many real-world considerations, including fleet electrification costs. There are also projects such as ELT295 and EERE/SA IEF Task 2-1, Subtask 4 that are focused on distribution upgrade costs.*
 - *In this project with the ReEDS model, we are focused on estimating the impacts of EV adoption and EVMC on bulk power system build-out and costs. For future work we would like to extend this approach to incorporate aggregate distribution system cost impacts of different EV managed charging approaches (as determined by projects like ELT295 and IEF), to ensure that managed charging approaches are not inadvertently shifting costs between the bulk and distribution systems.*
- How is the team modeling the human behavioral aspect of managed charging? For example, MD/HD fleets often are not managed even though they have strong financial incentives, ability to shift charging, and requisite software.
 - *First, we primarily model "within-session" flexibility, which assumes that people do not change their plug-in behaviors.*
 - *Second, we have developed supply curves, which articulate how increased utility investment is required to achieve higher levels of participation and how costs are expected to decline over time (to 2050). The supply curves never reach 100% participation for any dispatch mechanism, year, or scenario, as we believe that even if EVMC is very easy, some segment of drivers will opt-out. There are also multiple flexibility scenarios: low-flex, mid-flex, flat, and high-flex, that describe different narratives for how costs and willingness to participate might evolve over time.*

Collaboration with Other Institutions

- **Technical advisory committee:** Diverse group of research and industry stakeholders established to help guide research through discussions and feedback on technical and strategic aspects of the project.
 - **Virtual meetings** to solicit feedback, review progress and findings, and advise on project approach and results dissemination.
 - Technical advisory committee members also serve as **external reviewers** for the project's **written and data products**.
- **Cross-institution coordination:**
 - Coordinating with VAN050, VAN052 and VAN061 on EV demand modeling.
 - Coordinating with ELT295 on distribution system impacts analysis, EVMC costs, and results extrapolation.
 - Coordinating with EERE Strategic Analysis (SA) team Integrated Energy Futures (IEF) and TEMPO-ReEDS linkage projects.

Technical Advisory Committee*

Industry	Organization
Auto OEM	Daimler Truck North America Ford
Community transport	Dallas-Ft. Worth Clean Cities NJ Clean Cities TN Clean Fuels
EV service provider	ChargePoint
ISO/RTO	California ISO PJM
Research/consulting	Atlas Public Policy Boston University Carnegie Mellon University Karlsruhe Institute of Technology North Carolina A&T State University Smart Electric Power Alliance
Software/aggregators	Camus Energy FlexCharging
Utilities	National Grid PG&E
Regulators	California PUC

OEM: Original Equipment Manufacturer
ISO: Independent System Operator
PUC: Public Utility Commission
RTO: Regional Transmission Operator

*as of 04/07/25

Remaining Challenges & Barriers

- **Challenge:** EV managed charging must be aggregated and binned to represent the physical resource and its costs at a resolution that is computationally manageable in ReEDS.
 - The EV simulation framework produces data for millions of sample vehicles, but ReEDS can only handle tens of EVMC resources per region and year. The team has developed and will continue refining methods for grouping vehicles and binning supply curve data to create the requisite mappings between the two resolutions.
- **Challenge:** There could be a need to iterate between ReEDS and estimates of TOU and RTP prices.
 - Especially with many vehicles participating, EVMC can shift the supply-demand balance enough to change bulk power system energy prices. After running ReEDS with initially-estimated TOU and RTP prices and seeing what EVMC resources are selected, we will analyze output price data to determine if iteration is required.
- **Challenge:** The project scenario framework must be implemented based on current transportation and grid modeling features, options, defaults, and other guidelines, which are in constant flux.
 - By aligning transportation analysis assumptions with other projects and leveraging ReEDS Standard Scenario assumptions, our analysis will be interpretable and actionable within a wider ecosystem of data and findings.
- **Challenge:** This project is generating a lot of data and analysis, which could be hard for potential users to access and navigate.
 - The EV load profiles and flexibility data are to be published using dsgrid. We are also in discussions with the VGI Toolkit about ways to improve access and make the data more actionable.

*In the closing months of this project, we are **confident of success**, managing remaining challenges, and **looking forward** to dissemination, use, and **impact**.*

Proposed Future Research

FY 2025

Q3	• Submit EVMC supply curve journal article • First full iteration (using near-final EV data at scale) of EVMC aggregation and binning • Finalize EV adoption scenarios and load profiles • Submit journal article describing EV managed charging resource
Q4	• Finalize grid scenario assumptions • Further grid modeling refinements • Initial analysis results • Final TAC meeting
Q4 Milestone	<i>Draft journal article describing impact of different EVSE deployment and EV managed charging approaches on grid system build out, costs, and emissions</i>
FY 2026	
Q1	• Finalize and publish national-scale analysis of EV integration into bulk power systems • Finalize and publish remaining project data, especially managed charging profiles
Potential Future Work	
TBD	• Incorporate aggregate data on how different EVMC approaches impact distribution system (upgrade) costs into ReEDS analysis • Extend flexibility modeling methods to vehicle-to-grid (V2G) dispatch mechanisms • Develop output datasets suitable for direct import into a variety of grid planning tools

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

Objective

Simulate the **evolution of the U.S. bulk power system** (through 2050) to analyze potential large-scale EV charging across all on-road vehicle segments. Assess the **opportunity and value of EVMC** for managing future EV loads on the bulk power system.

Accomplishments

- HPC-enabled EV modeling pipeline that integrates tools, is fully configurable, runs quickly, and produces data in a standardized format
- EV adoption and charging data that starts at the sample vehicle level and applies weights to describe national-scale EV fleets across different regions (to county-level), scenarios (configurable), and years (to 2050)
- Multiple charging profiles per sample vehicle bound within-session and within-week flexibility, enabling description of the flexibility resource and its representation within MW-scale bulk power system planning models (FY25 Q2 draft journal article, to be submitted FY25)
- Supply curves describe the relationship between utility investment and EV managed charging participation across vehicle types, dispatch mechanisms, scenarios, and years
- The ReEDS model has been extended to enable evmc_shape and evmc_storage resources, and to compute capacity, energy, cost, emissions, and per-vehicle outputs desired for analysis

Next Steps

- Finalize modeling assumptions; Publish transportation and supply curve data
- Complete and publish national-scale grid integration analysis

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

Thank You

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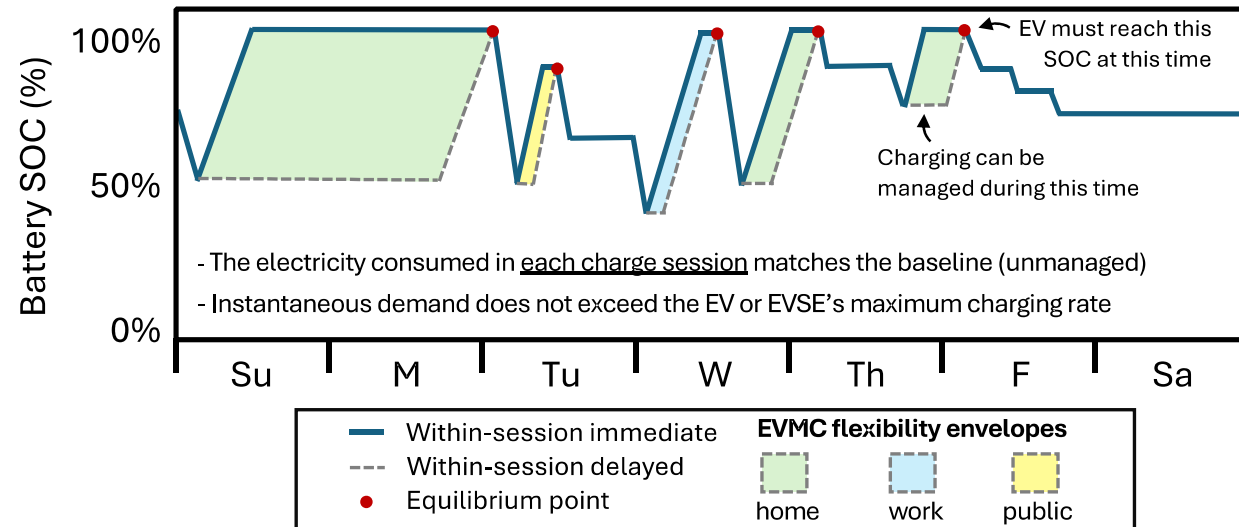
Technical Backup Slides

Two Types of Charging Flexibility

We develop **EV flexibility models** (“flexibility envelopes”) that define when, where, and to what extent vehicles can participate in managed charging, considering variable EVSE access, realistic EV and EVSE charging rate limits, and the need to preserve mobility.

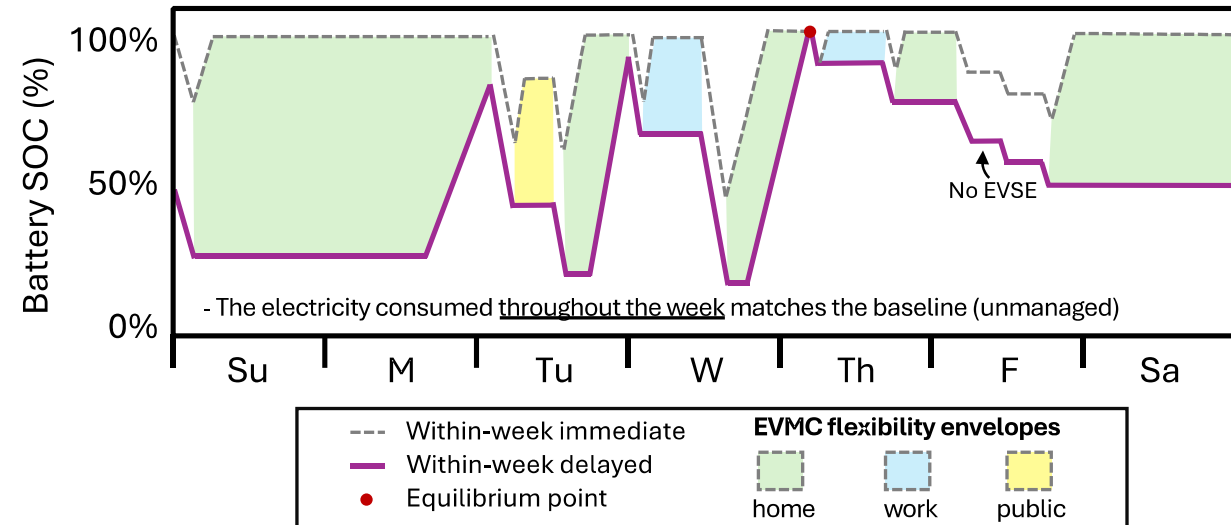
Charging can be managed within each charge session

LDV Within-Session Flexibility



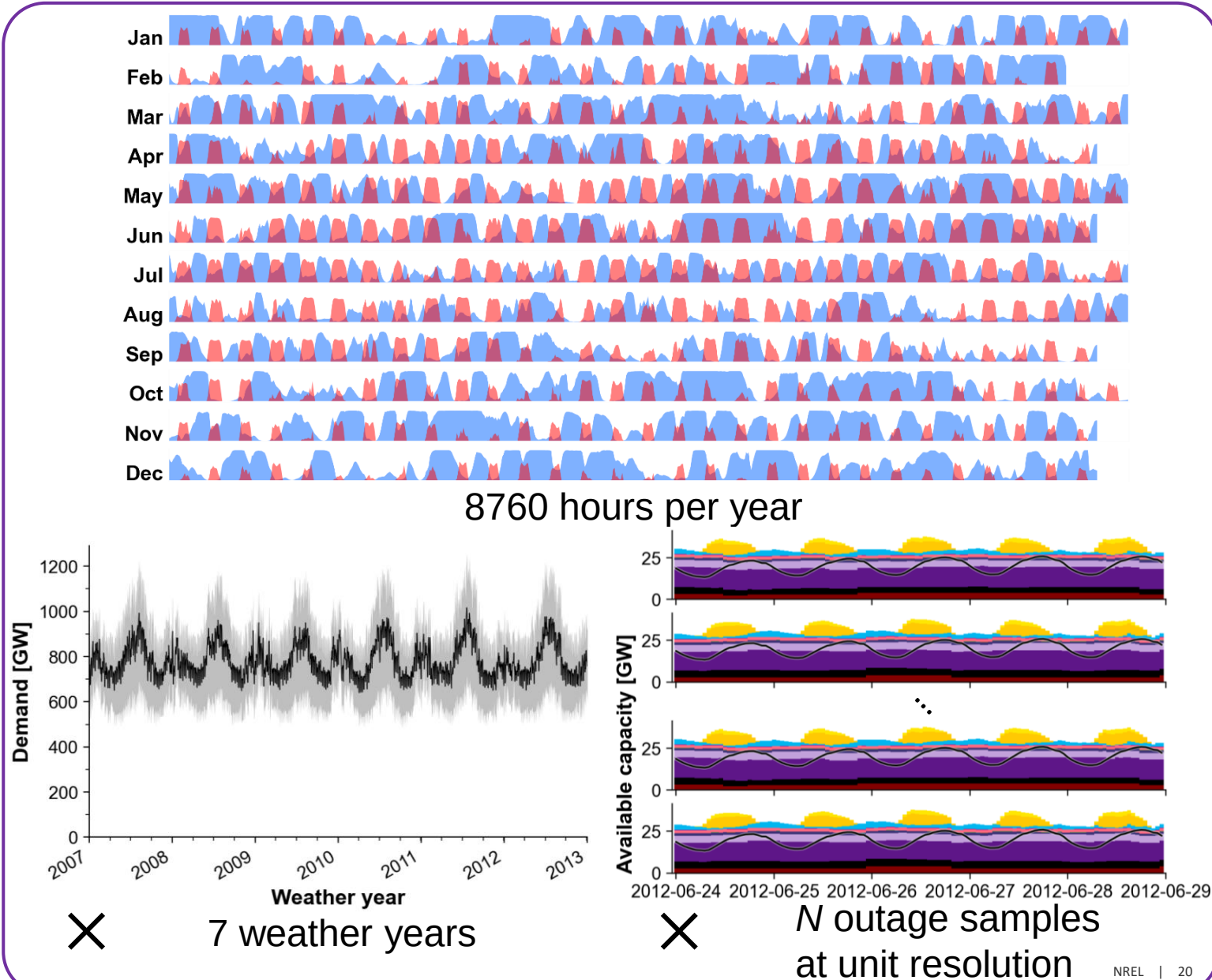
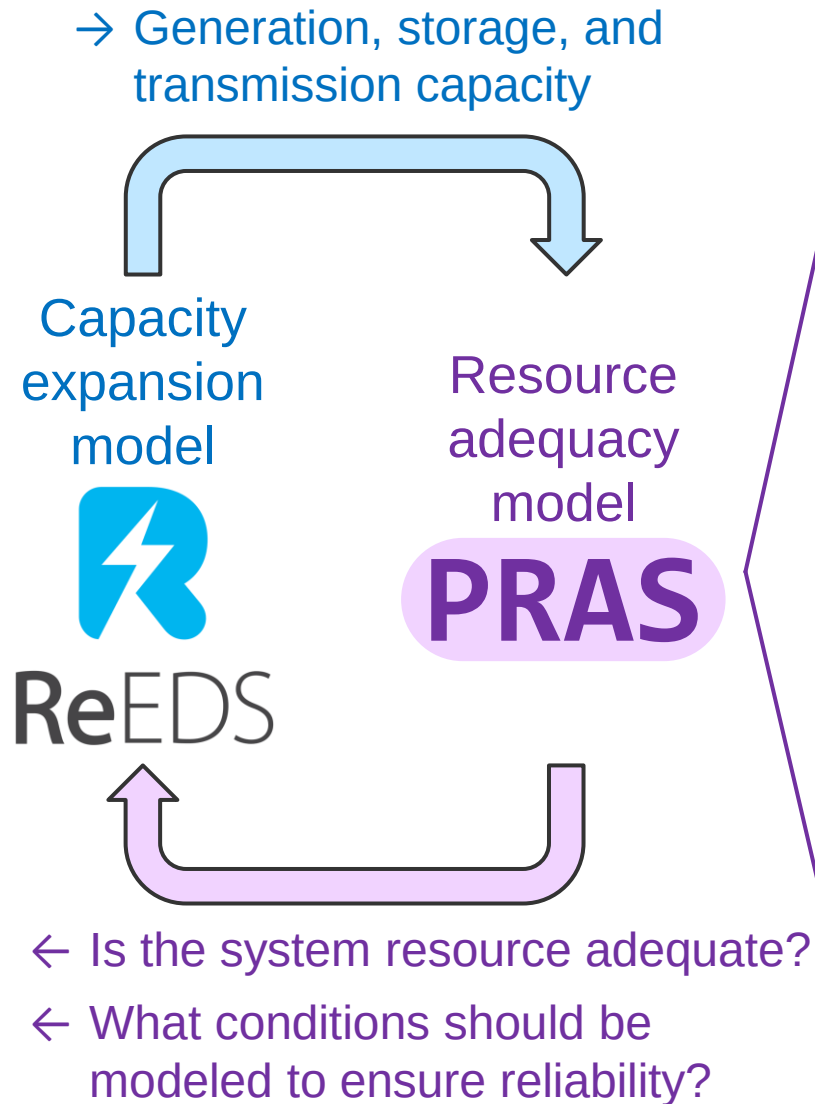
Charging can be managed across sessions/throughout the week

LDV Within-Week Flexibility



Shaded = opportunities for managed charging

ReEDS iterates with a probabilistic resource adequacy model, PRAS, to achieve similar reliability levels across scenarios



Enhanced EVMC Modeling Resolution

