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SCALED IMPLEMENTATION OF SMART CHARGE MANAGEMENT FOR ELECTRIC VEHICLES



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PROJECT OVERVIEW

Timeline	Barriers Addressed
• Project start date: 5/1/2025 • Project end date: 4/30/2026 • Percent complete: 100%*	• Lack of quantified net economic value of EV capacity management in deferring distribution grid upgrades • Lack of scalable analysis method in understanding the distribution benefits with feeder level information
Budget	Partners/Collaborators
• Total Project Funding: \$500K • ANL: \$250K • NLR: \$250K	• Argonne National Laboratory • National Laboratory of Rockies

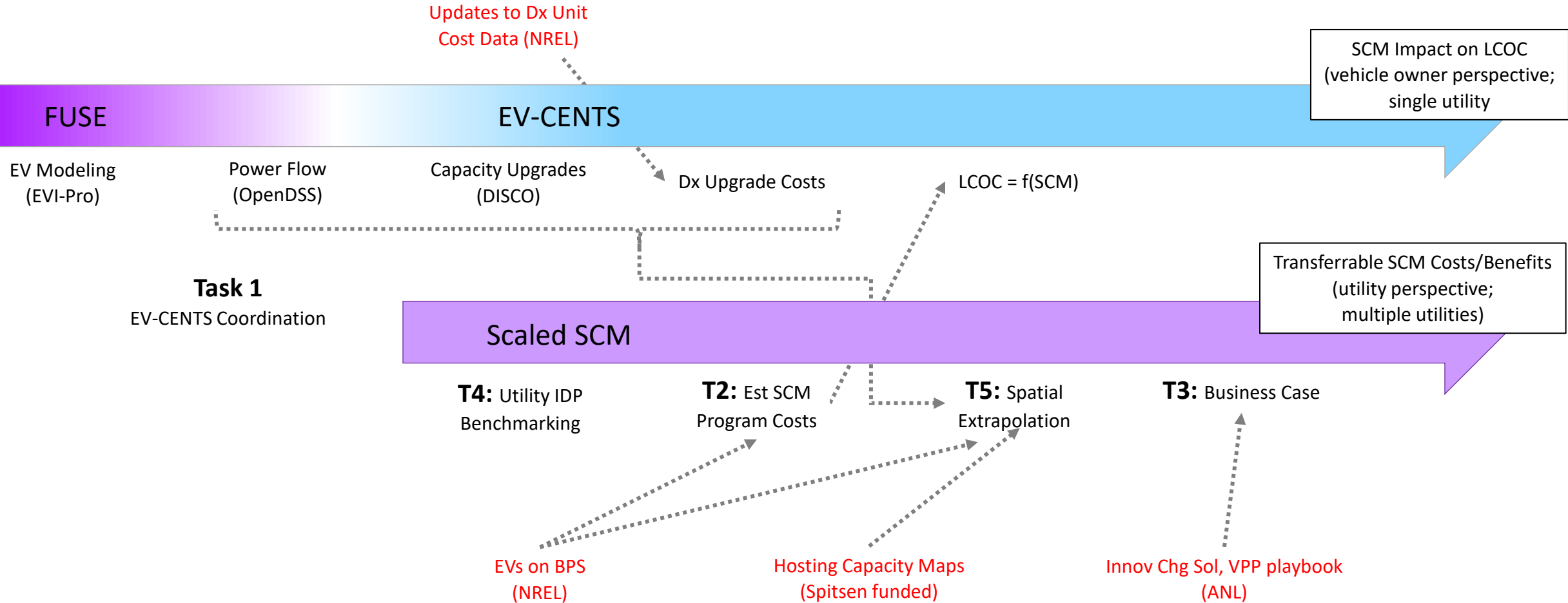
RELEVANCE AND OBJECTIVES

Evaluate the economics of scaled light-duty SCM programs throughout the United States

- EVs represent a new, relatively large, and extremely flexible load for electric utilities.
- SCM presents many potential benefits to EV owners and to ALL ratepayers (deferring distribution upgrades, right-sizing, etc.).
- Detailed modeling has demonstrated said benefits in select service territories, but utilities have been hesitant to view findings as broadly transferable.
- Scaled SCM will develop and apply a rigorous approach for translating detailed grid modeling of real-world circuits to other service territories across the country.

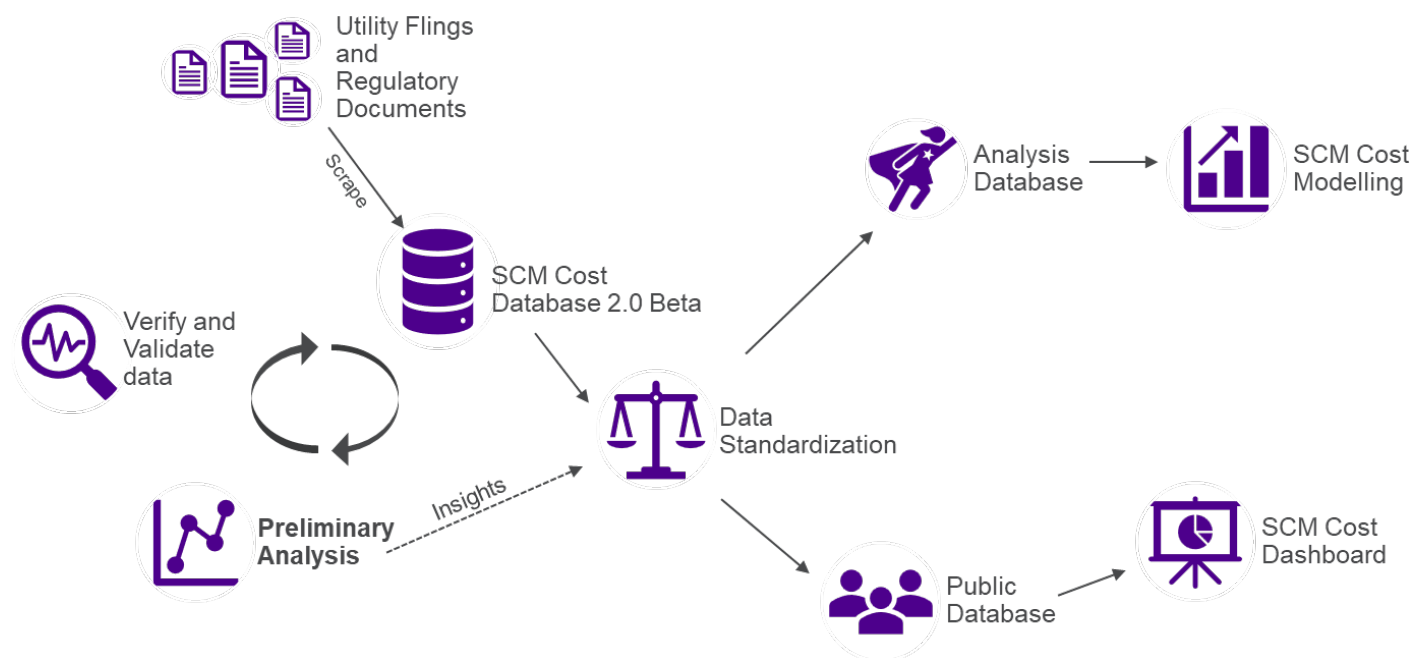


APPROACH: BUILDING UPON RELATED WORK



APPROACH: UTILITY PROGRAM COSTS

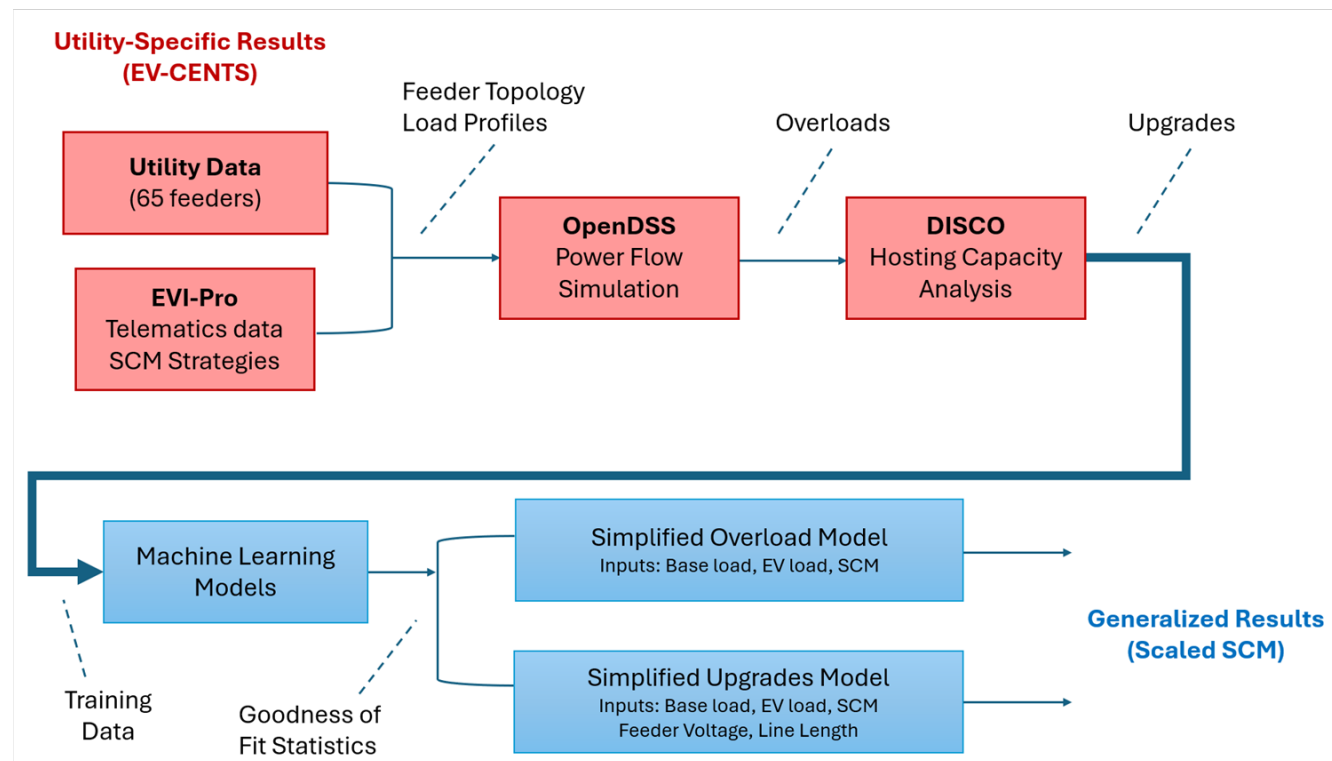
- Conduct a comprehensive review utility filings to determine the costs of various SCM pathways and existing programs.
- Analyze SCM implementation costs by considering different stakeholders, control methods, charging standards, and on-board technologies, leveraging insights from the Virtual Transformer study and expert interviews.
- Develop cost curves from the analysis and apply them to EV-CENTS charging scenarios to extrapolate generalized SCM implementation costs.



APPROACH: DISTRIBUTION SYSTEM BENEFITS

- Extract key features from detailed grid data and EV charging demand simulations for a selected "in-sample" utility region.
- Develop a model using AI techniques to determine the relationship between the "in-sample" features and the associated utility upgrade costs.
- Apply the trained model to "out-of-sample" regions to estimate grid upgrade costs and perform a comparative analysis of SCM costs and benefits.

Process diagram for calibration of SCM benefits model



APPROACH: NET PRESENT COST (NPC) COMPARISON

- **Scenarios:** EV penetration levels, Unmanaged baseline, SCM enrollment levels
- **Annual cost streams:** grid upgrades (transformers, conductors, protection)
- **SCM enablement:** DERMS/IT, telemetry & comms, program admin, incentives, O&M
- Avoided/deferred upgrades attributable to SCM flexibility
- Build year-over-year cost trajectories per scenario over a 10–15 year horizon

$$\text{NPC} = \sum_{t=0}^T \frac{C_t}{(1+r)^t}, \text{ where } r = \text{discount rate}$$

- **Deferral valuation:** Benefit = $C_{\text{now}} - \frac{C_{\text{later}}}{(1+r)^n}$
- **KPIs:** Benefit-Cost Ratio (BCR), Levelized Cost of Capacity Relief (\$/kW-yr), Payback year
- **Heatmap:** ΔNPC (SCM vs unmanaged) across EV penetration, SCM enrollment

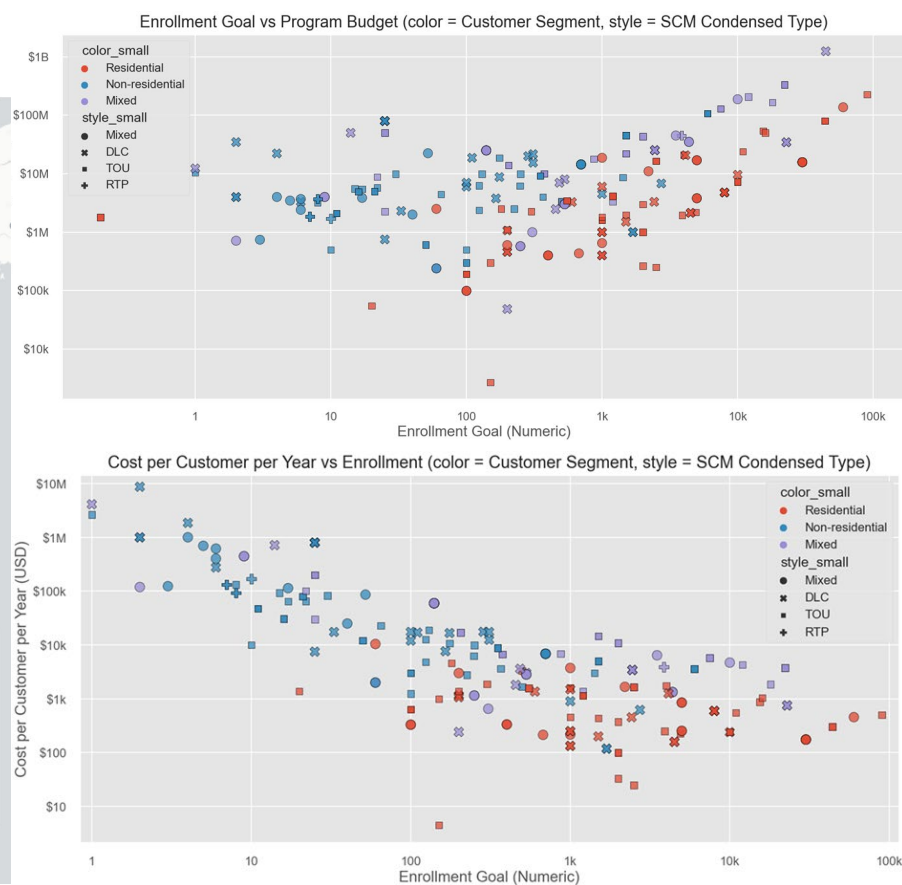
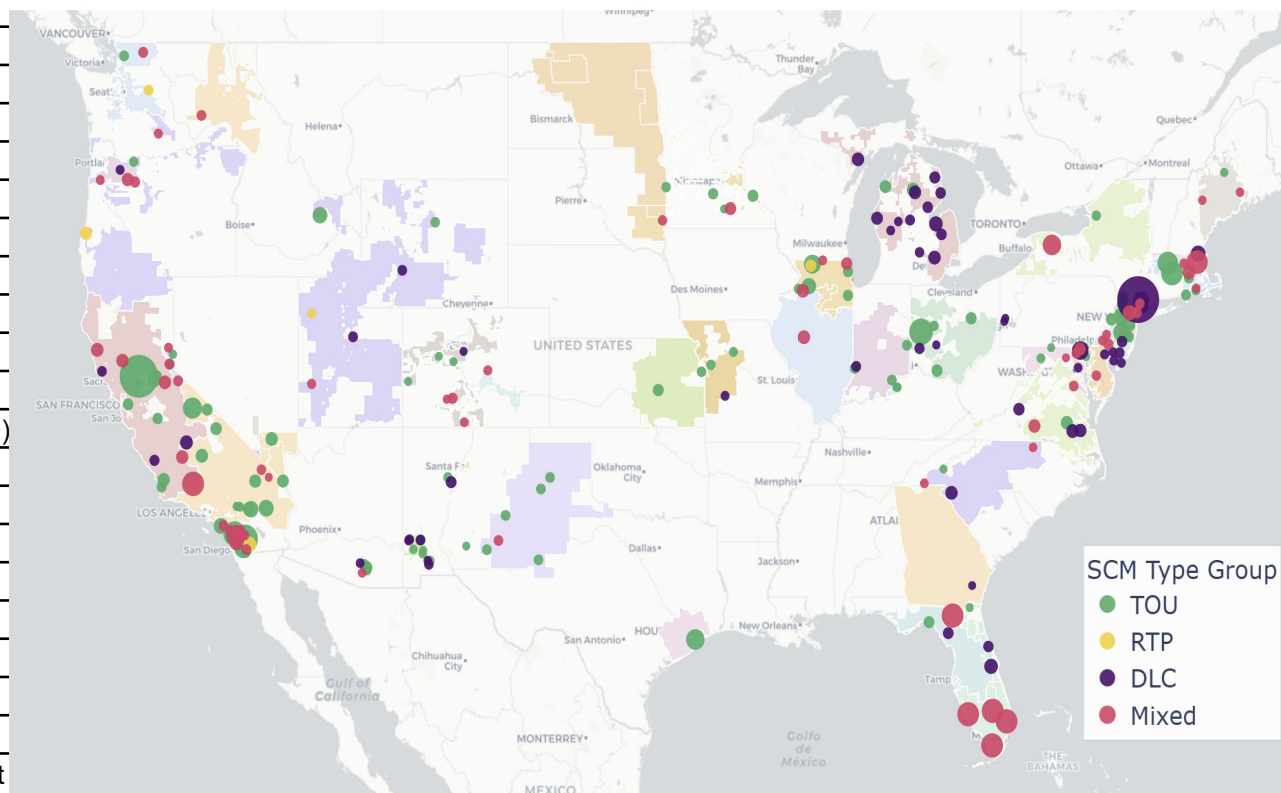


STANDARDIZED UTILITY PROGRAM COSTS DATABASE

32 States, 66 Utilities, 236 SCM Programs

- Utility filings describe budget components using inconsistent terminology.
- Customer type labels mix rate class, charging behavior, and infrastructure context
- Standardization enables cross-program comparison and analysis.

Program Name
Utility
State
Utility Filing Number
Report Month
Report Year
Start Year
End Year
Duration (Years)
Criteria to opt in
Low Income Eligibility
Charger Type
Program Budget (USD)
Funding Source
Source File
Customer Type
SCM Type
Enrollment Goal
Enrollment Unit
Budget Category
Budget (USD)
Budget Functional Unit



AS PROGRAM ENROLLMENT INCREASES, THE PER-PARTICIPANT COST GENERALLY DECREASES.

Cost function – Four parameters model

$$C(x) = \frac{a}{x} + b + c \cdot (1 - e^{-\beta x})$$

a / x — Fixed-Cost Dilution

- Platform dev, regulatory filings
- one-time marketing, incurred regardless of enrollment
- Declines rapidly as x grows

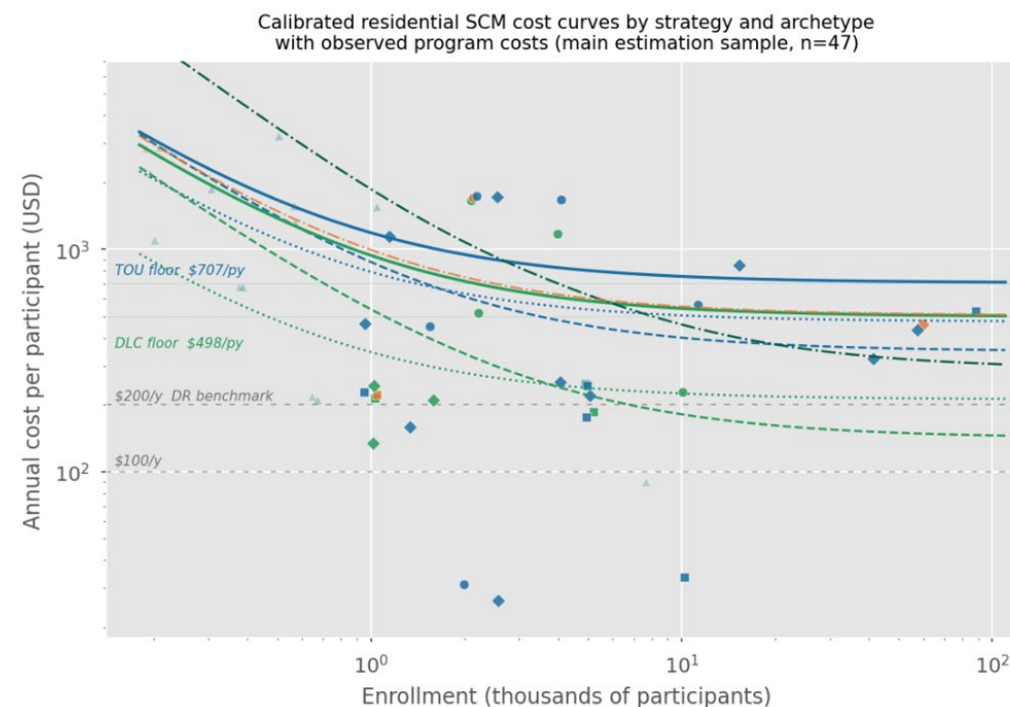
b — Persistent Cost Floor

- Steady-state operating cost:
- platform licensing, customer support, reporting obligations
- Long-run minimum per-EV cost

$c \cdot (...)$ — Enrollment Saturation

- Per-unit hardware & telematics
- costs that accumulate then plateau
- β controls saturation speed

- Developed and calibrated a supply curve model to represent the program costs of utility SCM programs.
 - Per-participant costs decline 5.4× between <1k and >5k enrollment; fixed-cost dilution dominates early phases.
 - TOU floor ~\$707/py, DLC floor \$288–498/py — scale alone cannot reach DR-comparable costs without structural changes



DEVELOPED A MODEL TO PREDICT BOTH VOLTAGE OVERLOADS AND ESTIMATED UPGRADE COSTS.

Distribution System Benefits

- Calibrated a machine learning model to quantify the distribution grid benefits of EV Smart Charging Management (SCM) under various control strategies
 - Achieved a mean absolute error of approximately 5%.

INPUTS (constrained values)

Feeder voltage, length
Base load (mean, peak)
EV load (mean, peak)
Base + EV load (peak)
SCM strategy
TOU immediate
TOU random
Centralized
Day ahead
Depot/transformer

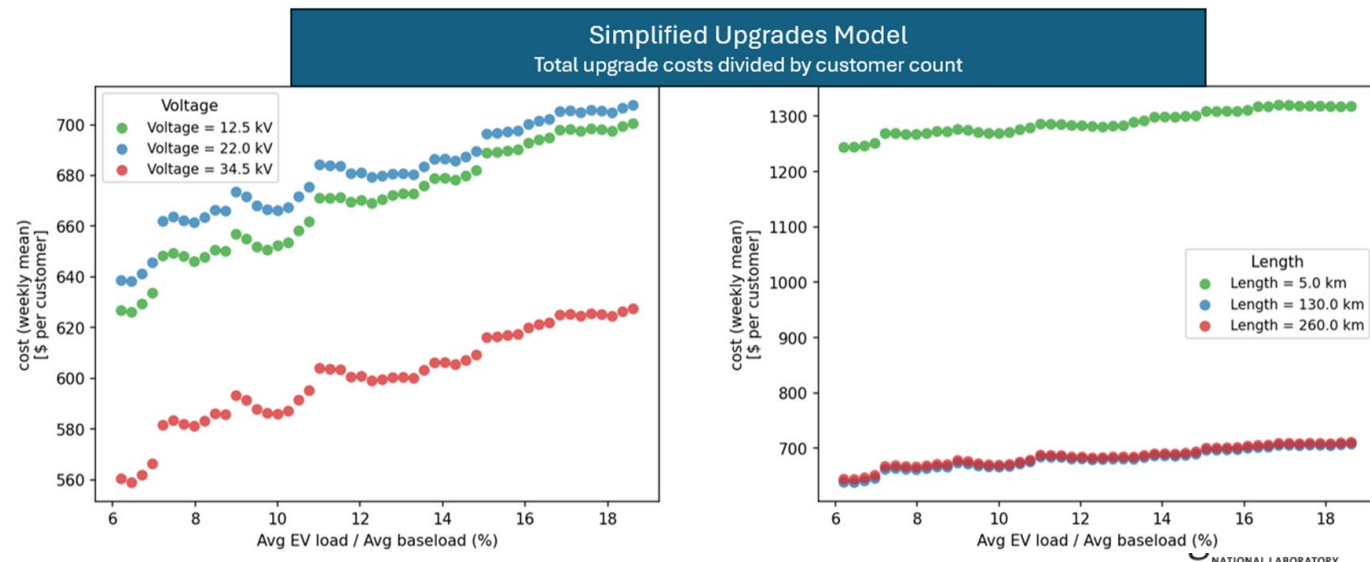
Feeder-level ML Model(s)

Trained on:
Utility-provided feeder data
Modeled EV loads (EVI-Pro)
Power flow simulation (OpenDSS)
Hosting capacity simulation (DISCO)

OUTPUTS

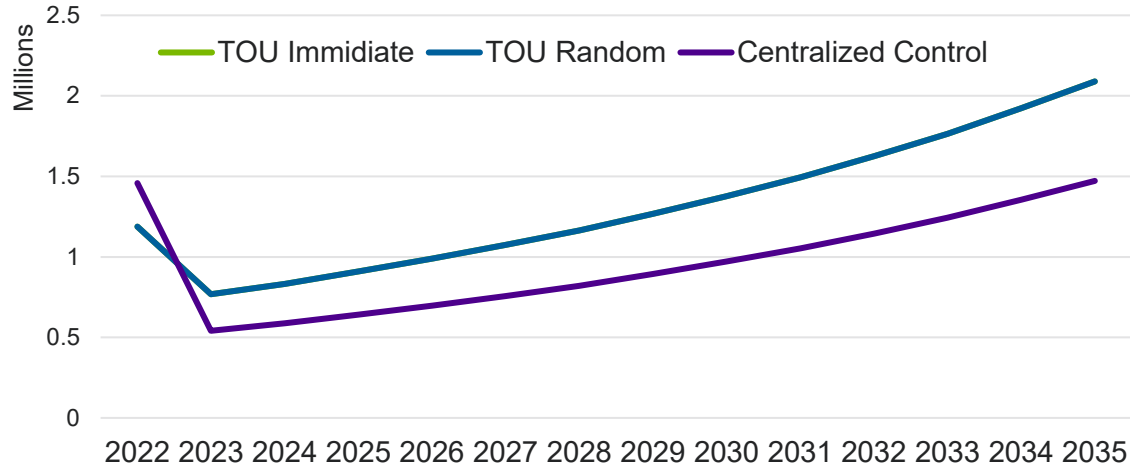
Primary/secondary transformers
Overload frequency, severity
Equipment upgrades
Upgrade costs

- The model is sensitive to key grid characteristics—including baseload conditions, EV load, feeder line length, and feeder head voltage



COST OF SCM IMPLEMENTATION

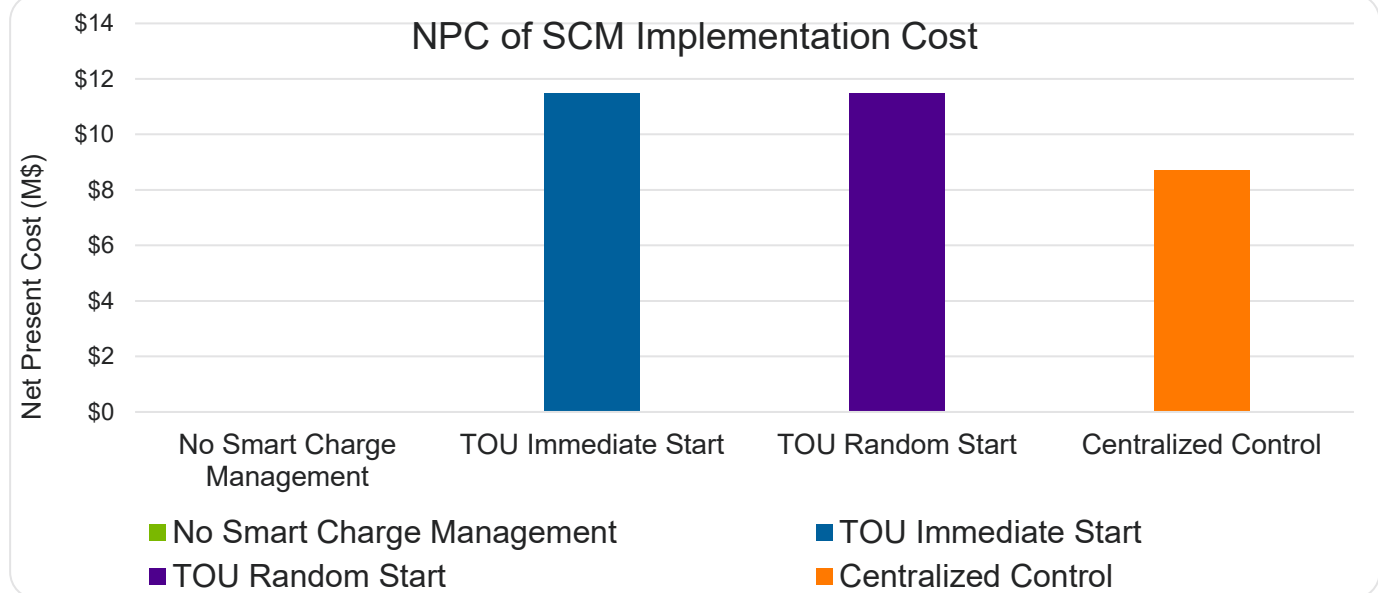
Nominal SCM Implementation Cost



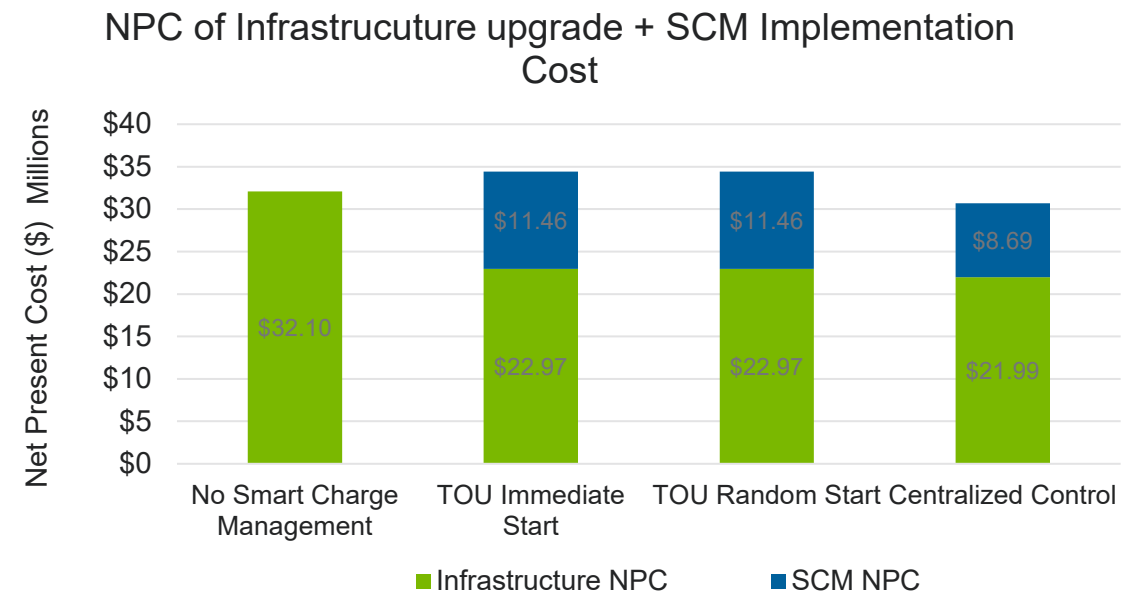
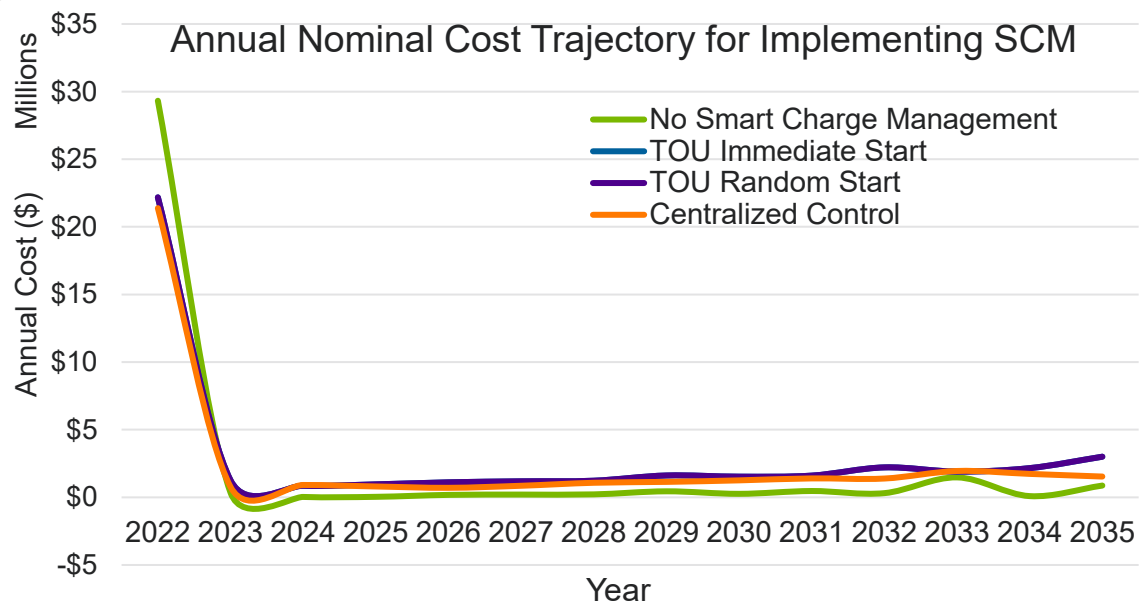
Global Assumptions	
Analysis Start Year	2022
Analysis Horizon (Years)	14
Inflation Rate	3.5%
Discount / Interest Rate	7.0%
Real Discount Rate	3.4%
Number of Feeders	10
Customer Growth Rate	5.0%

$$C(y) = a + bx$$

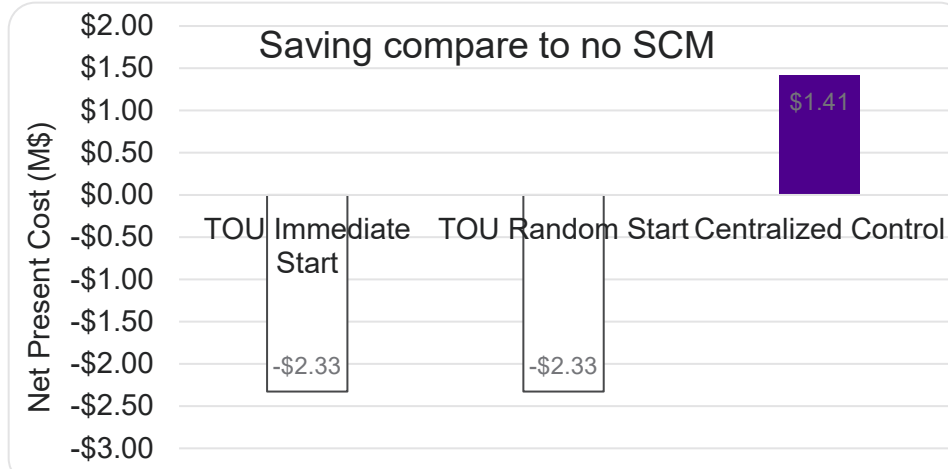
Scenario Parameters (Managed Cases)		
Scenario	a	b
TOU Immediate Start	\$48,000.00	\$706.86
TOU Random Start	\$48,000.00	\$706.86
Centralized Control	\$96,000.00	\$497.92



TOTAL COST



Scenario	Infrastructure NPC	SCM NPC	Total NPC	Savings vs No SCM
No SCM	\$32,098,748.38	\$0.00	\$32,098,748.38	\$0.00
TOU Immediate Start	\$22,965,902.47	\$11,460,300.21	\$34,426,202.69	-\$2,327,454.31
TOU Random Start	\$22,965,902.47	\$11,460,300.21	\$34,426,202.69	-\$2,327,454.31
Centralized Control	\$21,992,894.03	\$8,694,670.97	\$30,687,565.00	\$1,411,183.38



FY2025-26 MILESTONES

Work has been completed in Q3

Milestone	Milestone Name / Description	Milestone Type	Status
FY25Q3	Catalog each utility identified, provide a brief summary of their IDP, and include relevant metadata. Identify and analyze trends emerging from the reviewed IDPs.	Quarterly	Completed
FY25Q4	Draft SCM cost curves (cost vs. participation rate, control method, technology standards, etc.).	Quarterly	Completed
FY26Q1	Out-of-sample hosting capacity maps are used to produce estimates for regions with comparable attributes to the in-sample training datasets. Identify macroscale differences in SCM costs/benefits across different geographies and utility structures.	Quarterly	Completed
FY26Q2	Develop methods to price or monetize distribution-level SCM benefits	Annual	Completed

RESPONSES TO REVIEWER FEEDBACK

This project was not reviewed in 2025

COLLABORATION AND PROPOSED RESEARCH

Collaboration

- ANL and NLR worked together to collect data, conduct analysis and finalize the report

Proposed Research

(Note: Any proposed future work is subject to funding levels)

- Continue the effort collecting available SCM cost data, validating the cost function and building a public accessible database with visualization
- Refine SCM benefits ML models to account for additional features and apply to new out-of-sample utility service territories

SUMMARY

❑ **Objective:** Evaluate the economics of scaled light-duty SCM programs throughout the US

❑ **Outcomes:**

- Costs and benefits of utility SCM programs are modeled based on level of customer participation.
- Costs are based on a detailed review of existing utility programs with forward looking estimates calibrated to simplified equations
- Benefits are estimated by calibrating machine learning models to training data derived from real-world utility feeders with varying levels of simulated EV load (emphasis on distribution benefits of SCM programs)
- Simplified cost and benefit models for SCM programs currently being integrated into a case study for out-of-sample utility territories and exemplar feeders

❑ **Deliverables**

- Utility program costs database and cost functions to understand scaled up cost per participant
- Validated machine learning models to estimate the distribution benefits of SCM

❑ **Milestones:** Successful monthly, quarterly, and annual milestones delivered on time and within budget



Argonne

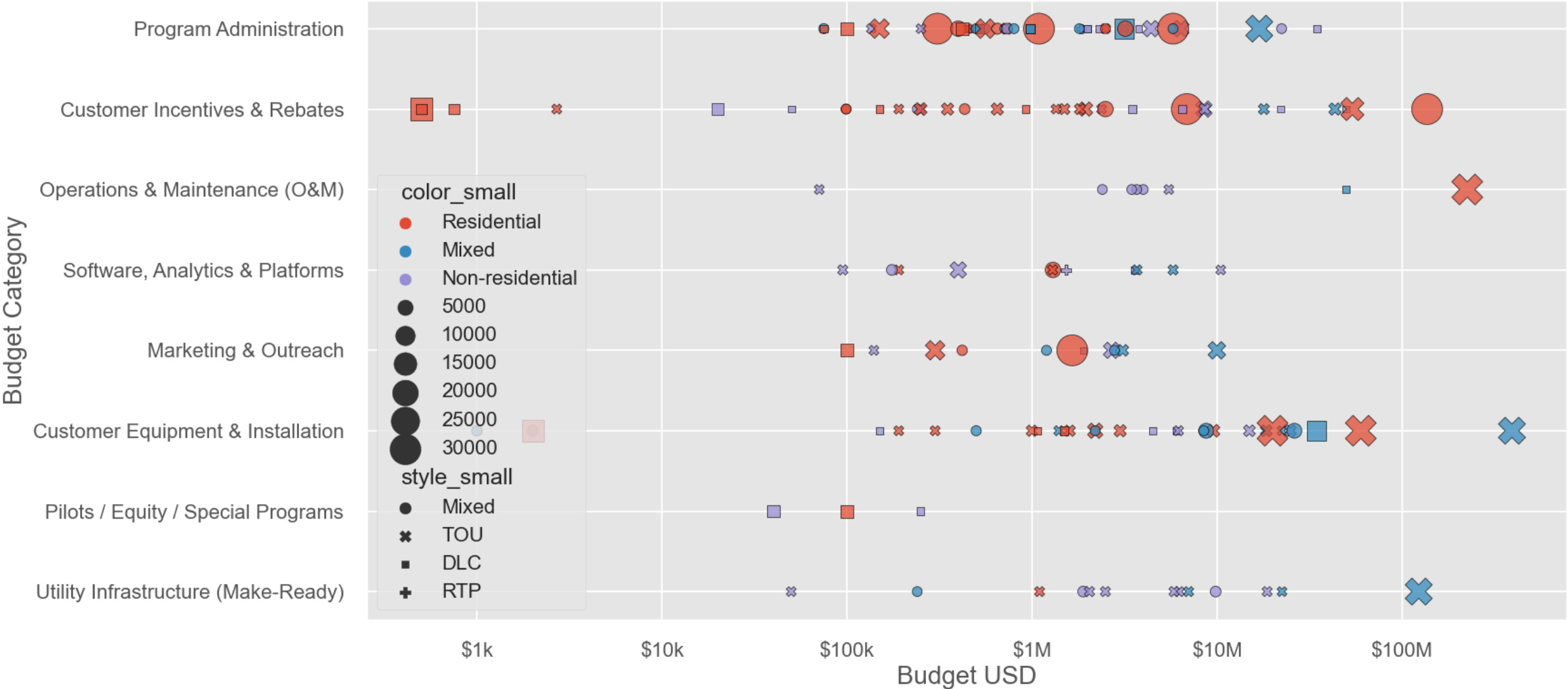
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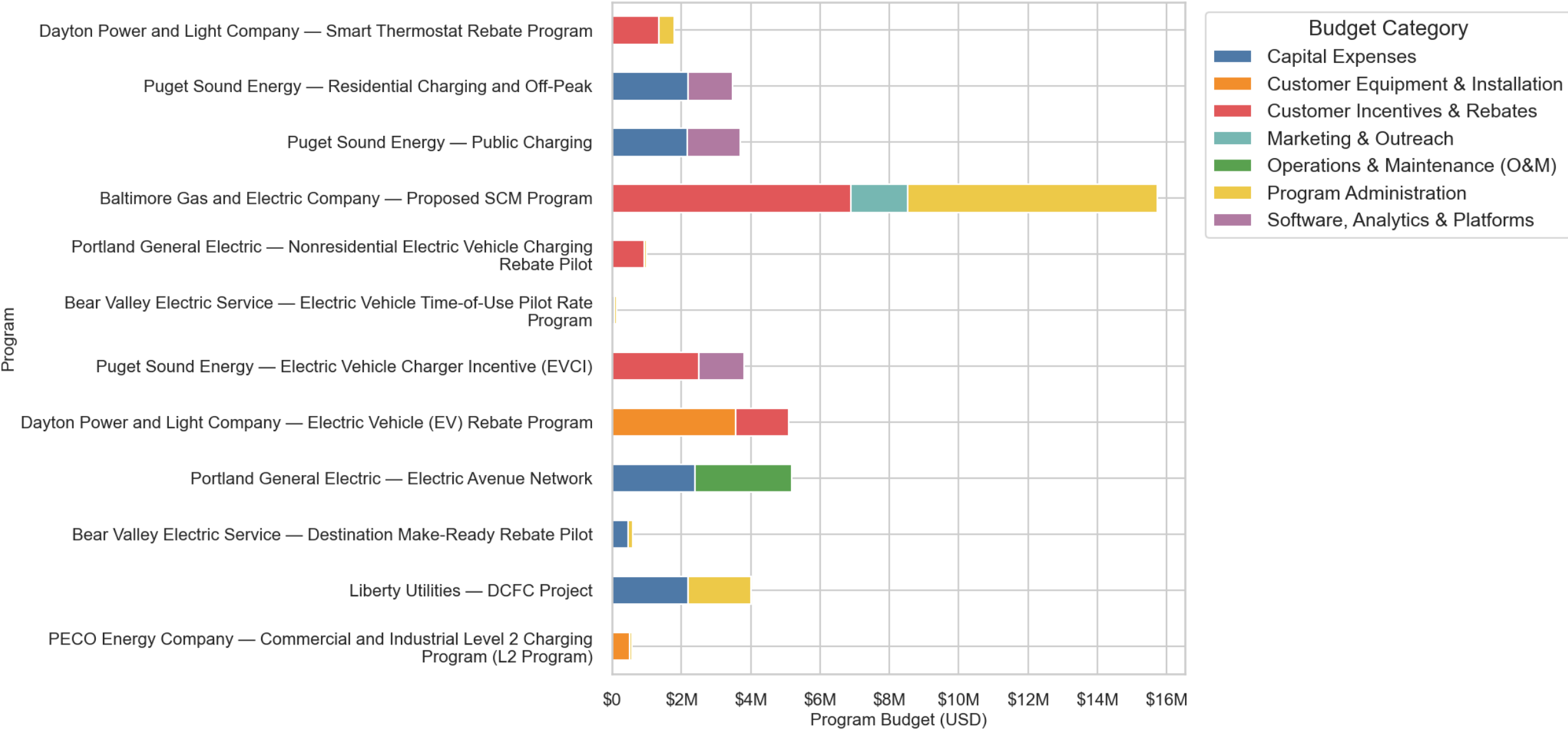
TECHNICAL BACKUP SLIDES

Utility programs budget component values reported

Component values by Customer Segment (style = SCM Condensed Type)



Utility programs budget breakdown by program



THANK YOU

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