

Background and Motivation

The Challenge

Transportation electrification presents unprecedented challenges for electric grid planning. Most existing EV integration studies suffer from critical limitations:

- Transportation models are oversimplified
- Grid models lack sufficient fidelity
- Studies use small test systems that do not capture real-world complexity

Scale of Prior Work

The largest known combined T&D study prior to this work used only a 240-bus transmission grid with an 8,500-node distribution feeder replicated 19 times.

Unified Modeling Approach

Transportation Simulation

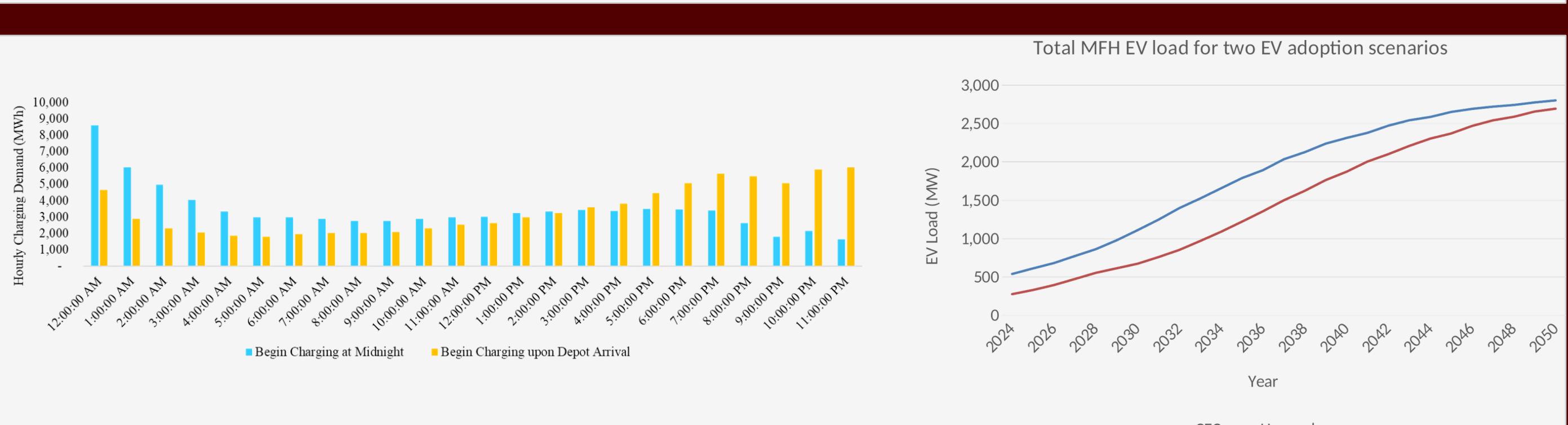
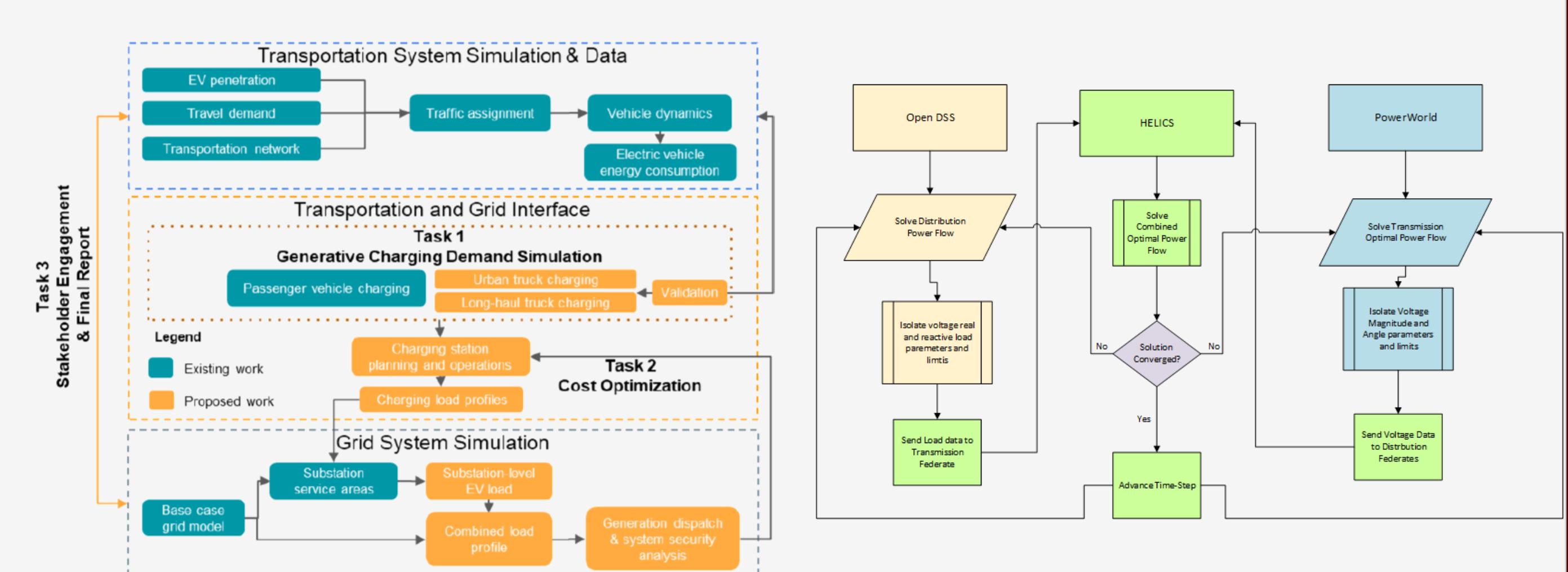
- Agent-based models generate synthetic trips using regional travel demand data, Bayesian networks, and commercial vehicle surveys
- Energy consumption computed using EPA MOVES model with seasonal adjustments
- Routing via OSRM-based network graphs

Grid Co-Simulation

- Transmission: Positive-sequence OPF using PowerWorld Simulator
- Distribution: Unbalanced 3-phase power flow using OpenDSS
- T&D interface shares voltage magnitudes, angles, and load values

Cost Optimization

- Operating costs from OPF-based generator dispatch
- Capital costs from MW-mile overload metrics
- Rate structure design using LMP thresholds to flatten demand curves



Case Study 1: Heavy-Duty Truck Electrification (Texas)

Study Scope

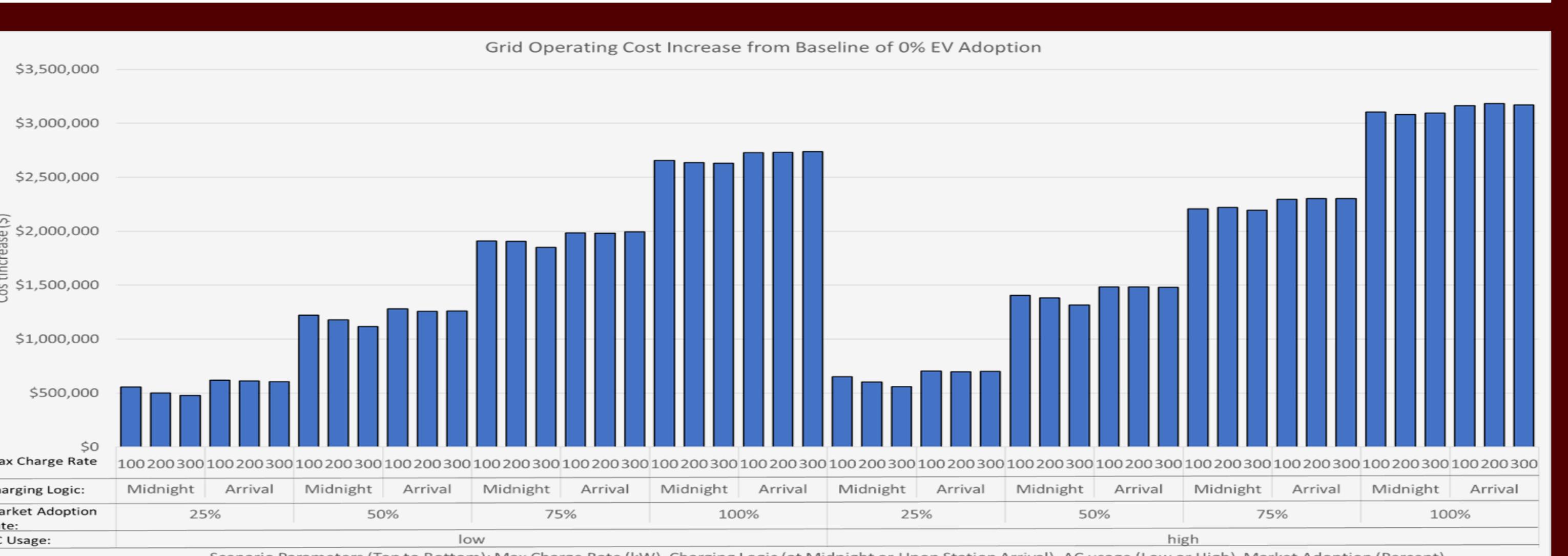
- Houston-Dallas-Fort Worth I-45 Corridor
- 96 scenarios varying charge rate, adoption, charging logic, depot location, and season

Grid Model Scale

- Transmission: 7,000 buses, 731 generators, 75 GW peak load (ERCOT synthetic)
- Distribution: 6,500+ feeders, 1,000,000+ nodes across Houston and Dallas

Key Results

- Midnight charging reduces operating costs by up to 21% (\$34.7M/year savings)
- Capital costs represent ~12% of total yearly EV adoption cost
- LMP-based rate structures achieve additional 0.1-9% cost reductions
- Higher charging rates (200-300 kW) reduce operating costs by \$9-12M/year



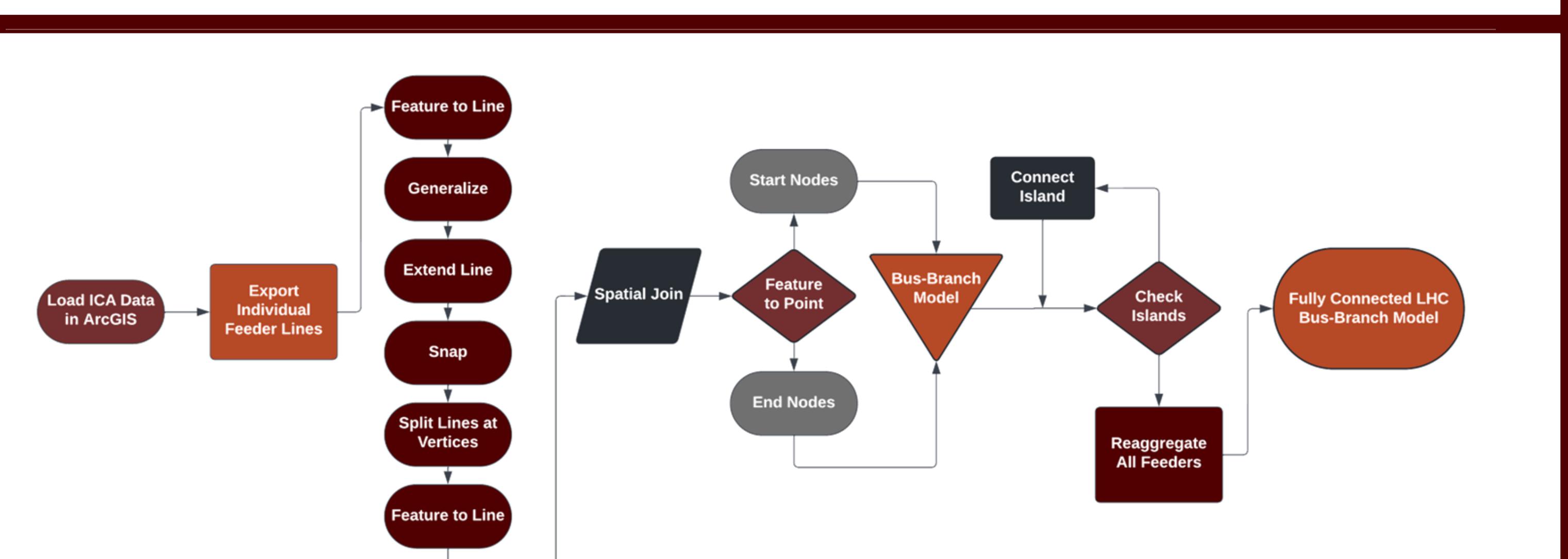
Case Study 2: Multi-Family Housing (California)

Study Scope

- Pacific Gas & Electric service territory (70,000 sq. miles)
- 25,261 multi-family housing properties analyzed
- 3,020 distribution feeders modeled from PG&E GRIP data

Charging Demand Estimation

- Agent-based Mobiliti simulation: 847,000 synthetic vehicle-days
- 2025 baseline: 1.47 GWh/day MFH charging demand (11% EV adoption)
- 2040 projection: 10.5 GWh/day (78% EV adoption)



Key Findings

Grid Readiness Assessment (MFH)

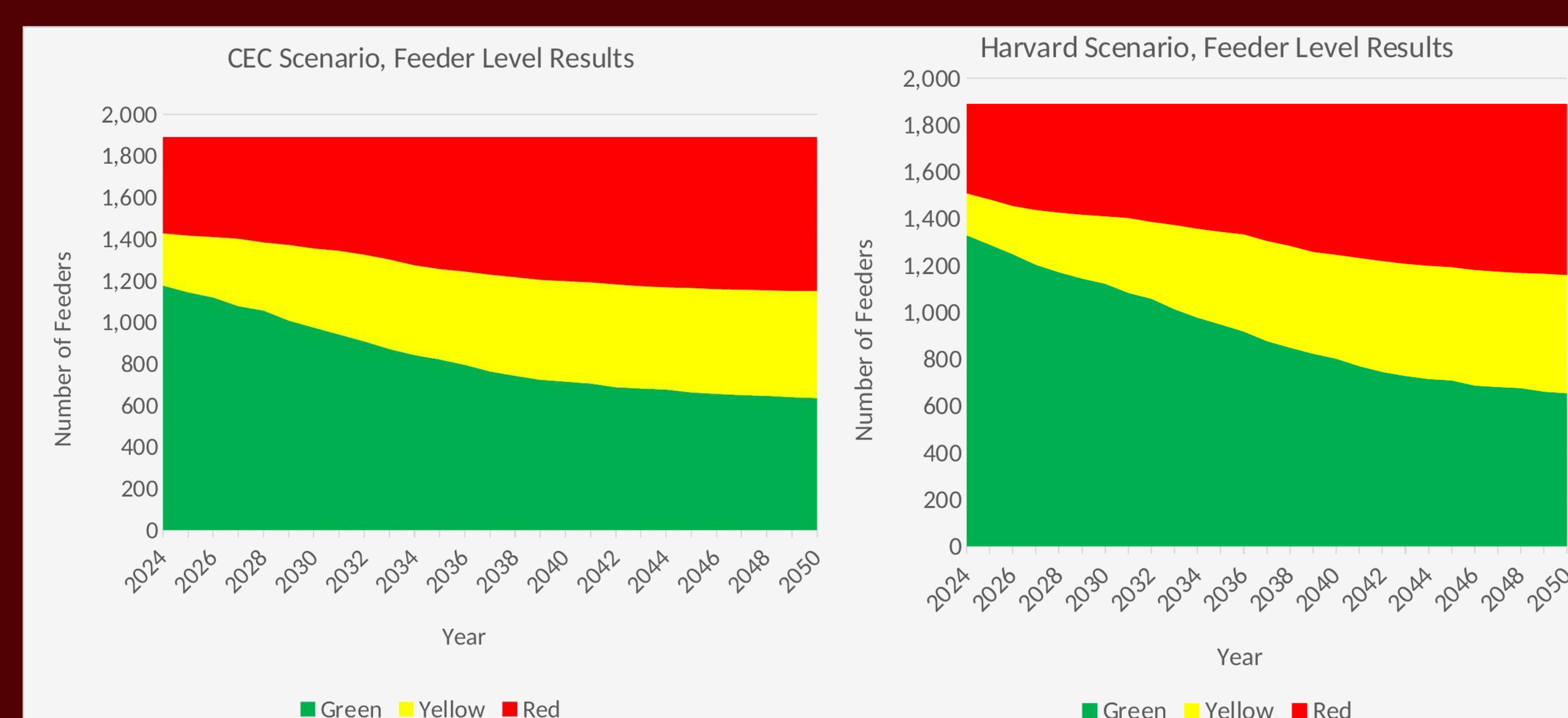
- 55% of properties have adequate grid capacity under 2025 conditions
- 42% remain grid-ready at 78% EV adoption (2040)

Cost Optimization (HD Trucks)

- Smart charging strategies reduce total costs by 20%+
- LMP-based rate design eliminates most transmission overloads

Computational Efficiency

- Python automation reduced 96-scenario simulation from 30 days to 13 hours
- Split-level spatial mapping enables utility-scale analysis



Implications

For Utility Planning

- Proactive infrastructure investment can maintain pace with EV adoption
- kW-mile overload metric enables prioritized, targeted upgrades

For Policy Development

- Demand-side interventions significantly reduce infrastructure costs
- Framework supports adaptive planning under regulatory uncertainty

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Selected References

- [1] Safdarian et al., "Technical Impacts of Light-Duty and Heavy-Duty Transportation Electrification on a Coordinated T&D System," *IEEE Trans. Transportation Electrification*, 2024.
- [2] Wert et al., "Spatiotemporal operational emissions associated with light-, medium-, and heavy-duty transportation electrification," *IEEE Trans. Transportation Electrification*, 2023.
- [3] Li & Jenn, "Distribution grid impacts of electric vehicle charging," *PNAS*, 2024.