

Future Energy Systems Center

System Impacts of Decarbonization Pathways for Space Heating in Cold Climates

Project Update

April 2, 2024



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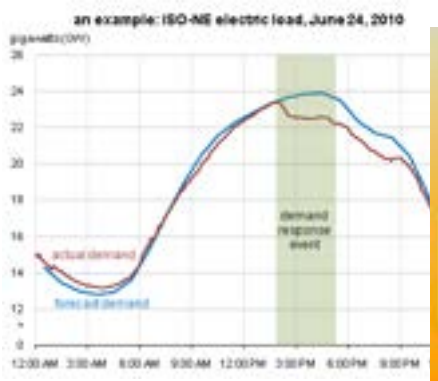
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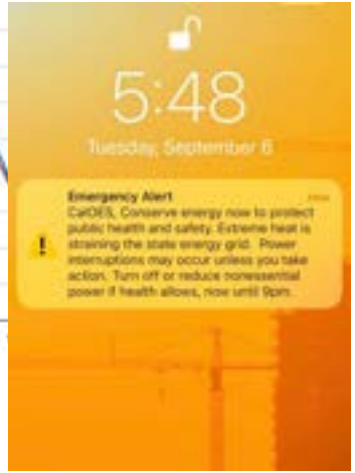
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Motivation: Electrification coupled with grid decarbonization will create opportunities for demand-side participation in system balancing

In a typical power system balancing model, supply follows demand and demand response is restricted to niche applications…



https://www.eia.gov/todayinenergy/detail.php?id=130



…but, through electrification and demand-side technologies, residential side loads have potential to contribute to system balancing (price responsiveness)





Source: Google images

Motivation: Impact of Flexibility

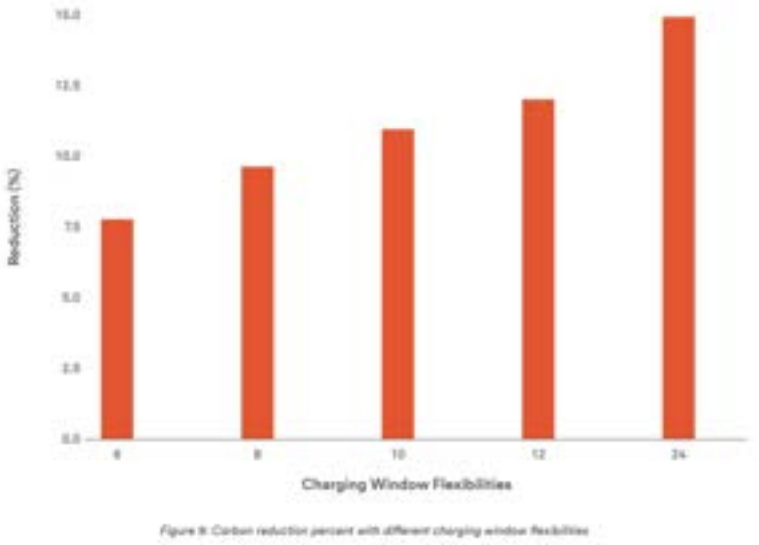
We are already seeing the impact of flexible demand on reducing carbon emissions and energy savings; this will only increase with adoption of EVs and heat pumps

New study highlights 8-14% carbon reduction potential on average and up to 43% through EV charge automation

Abstract

This study used over 100,000 sessions of in-field electric vehicle (EV) charging data and the analysis of location- and time-based fuel mix of the power grid to characterize the carbon intensity of common EV charging patterns. Combining these data sets, the study showed that optimizing EV charging for carbon intensity would yield 8-14% reductions in related carbon on average across 44 states, and an average reduction of 43% in California due to the higher proportion of renewable energy.

Reduction in CO2 emissions based on Charging Window (avg. across US States)



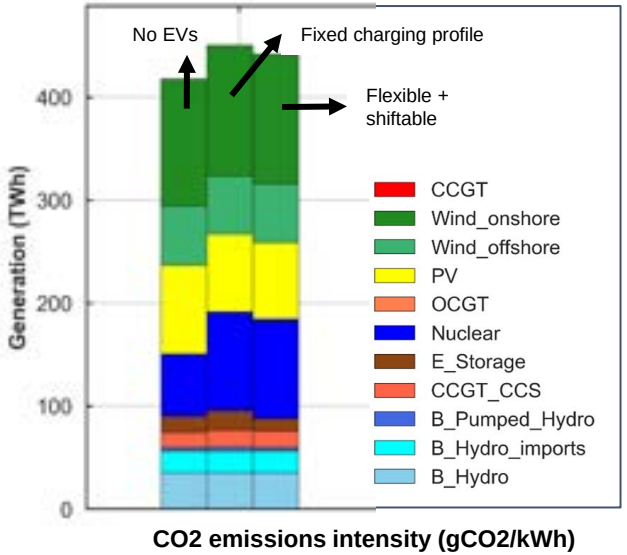
Source: https://sense.com/whitepapers/Sense-EV-Carbon-Research.pdf

Context: Flexibility can impact the Resource Mix of supply

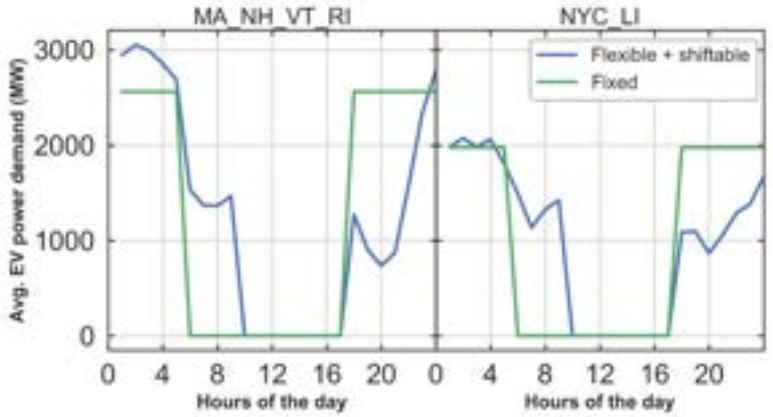
"Flexible + Shiftable" charging load reduces the need for storage discharge and increases adoption of less flexible technologies like nuclear (hourly demand shiftable up to 4 hours)

Impact of EV charging flexibility on generation mix (U.S. Northeast case study)

Reduced reliance on battery storage discharging with flexible+shiftable EV demand



Avg. daily charging profiles: fixed vs. flexible (EI = 2 gCO_2/kWh, U.S. Northeast case study)



Source: Unpublished results from MITEI Future of Energy Storage Study

Co-optimizing demand with bulk power system supply does not reflect reality

❌ **Flexibility (load shifting), not Elasticity (price responsive)**

- Load shifting and flexibility resources are modeled with perfect foresight
- Does not capture demand elasticity – only captures demand flexibility

❌ **Tariffs are not realistic**

- Load is exposed to real-time energy prices + no distribution network costs

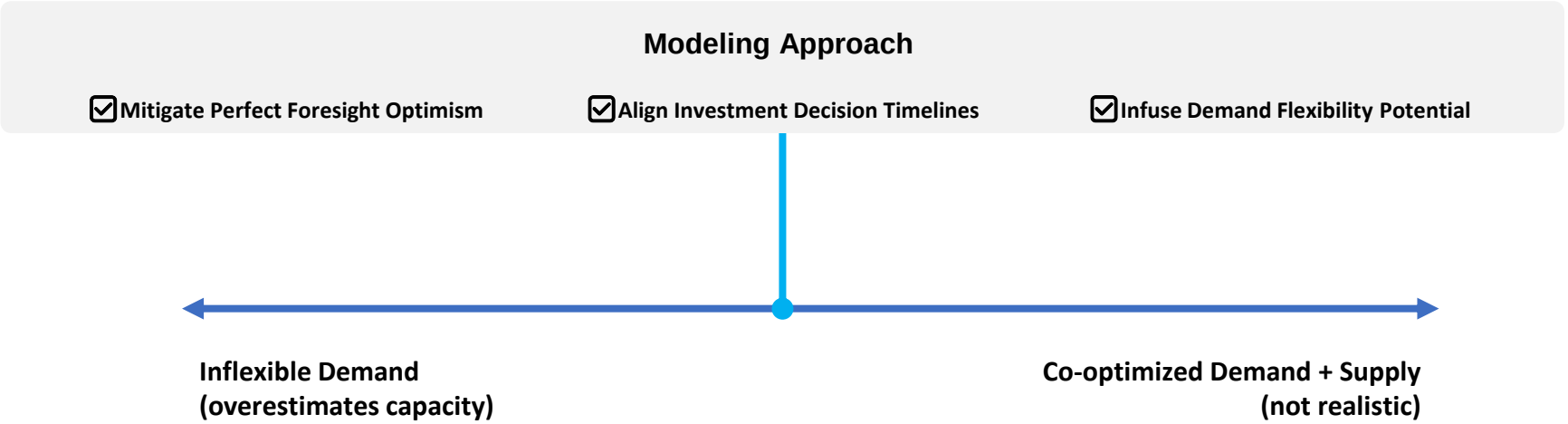
❌ **Lack of Consumer Behavior**

- Customers respond to retail tariffs that are not in sync with wholesale tariffs – some latency
- Unable to model consumer level price responsiveness to different rate structures (fixed, real-time, TOU)



Image: https://www.amone.com/blog/six-ways-lower-heating-bill/

Objective: Develop a co-simulation framework to impact of demand flexibility and elasticity on bulk power system investments and operation



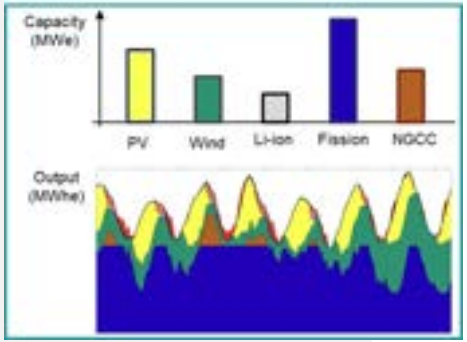
Approaches for modeling demand in bulk power system planning

Solution: Integrate a top-down capacity expansion model with bottom-up residential demand profiles

Top-down

GenX, bulk power system capacity expansion model

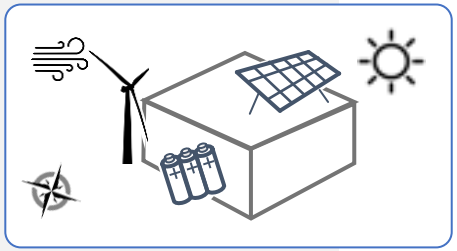
- Evaluates cost-optimal generation portfolio, energy storage, and transmission investments to meet demand + other constraints
- Can adhere to various technological and physical grid operation constraints, resource availability limits, and other imposed environmental, and policy constraints



Bottom-up

Distributed Energy Consumption in Actively Responsive Buildings (DECARB)

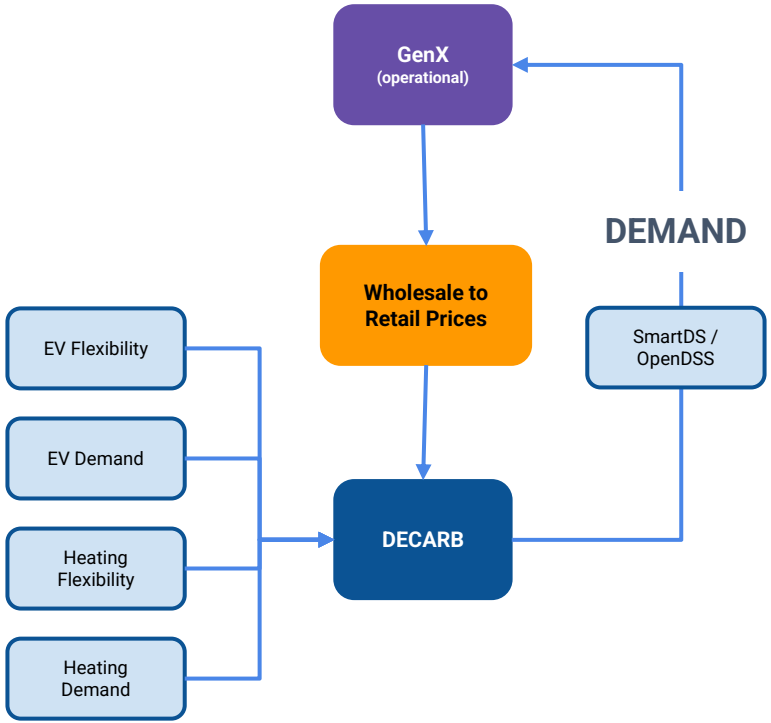
- Physics based thermal model that models the energy use of buildings and allows for price responsiveness through controllable loads
- Able to support flexibility behavior through price signals sent to the optimization model



Proposed co-simulation workflow (under development)

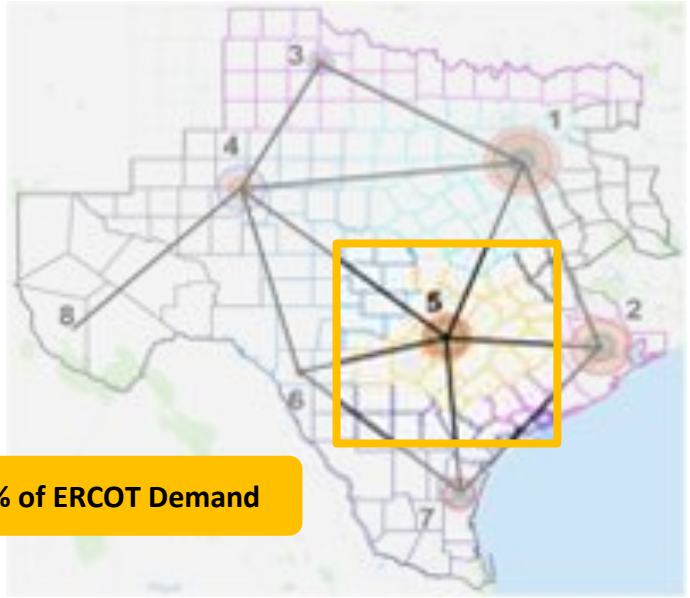
Link a bottom-up model (DECARB) to GenX to allow for time lags that can reflect the actual sequence of market events:

- GenX forecasts prices for a specific year.
- Pricing module sets retail energy tariffs based on these forecasts.
- DECARB simulates consumer responses to these tariffs.
- SmartDS / OpenDSS maps residential demand to feeders and subs-station profiles
- GenX adjusts to the predicted demand, considering the time lags and output new prices



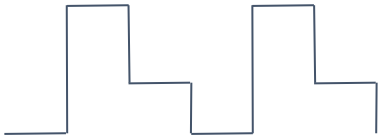
Case Study: Modeling South Central, TX with realistic retail tariffs for EV Demand flexibility

- **Region:** South Central, Texas
- **Year:** 2030
- **System:** 8-Bus ERCOT System
- **Mandate**: 50% Renewables Penetration
- **Demand Side Flexible Resource**: EV Demand
- **EV Demand:** Every home in Zone 5 has an EV
- **Retail tariff scenarios:**
  - Fixed Tariff
  - TOU Rate Block (optimized)
  - Real Time Pricing



~8% of ERCOT Demand

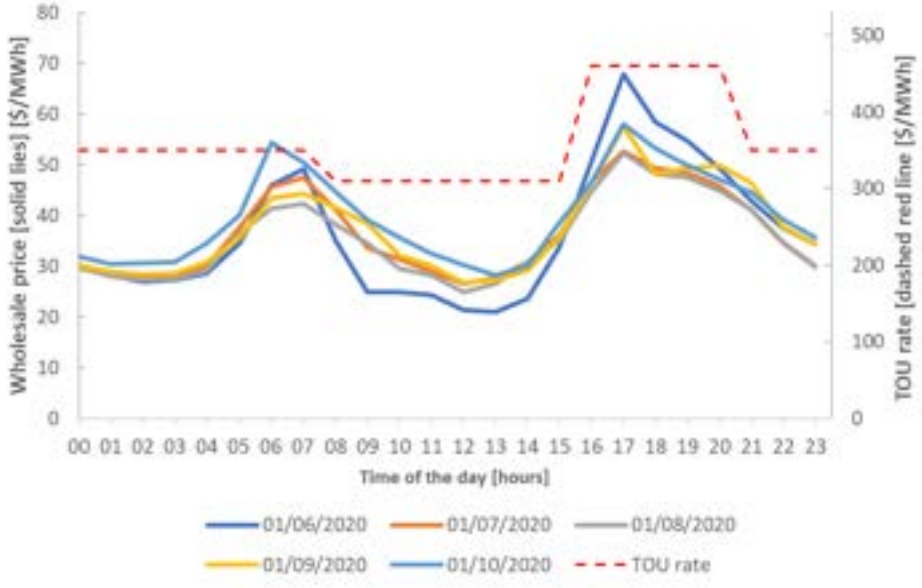
Tariff Scenarios in Detail

	Fixed	TOU	Real Time
Customer Charge	$4.79/month	$4.79/month	$4.79/month
T&D Charge	$0.048/kWh	$0.048/kWh	$0.048/kWh
Energy Charge	$0.023/kWh		

Charges from AEP's rate schedule: https://ftp.puc.texas.gov/public/puct-info/industry/electric/rates/Trans/AEP.pdf

Context: TOU rates can incentivize desirable load shifting

Standard, non-optimized block based time of use rates can shape right, but not the magnitude of the price. Optimizing the time of use rate block structure can create a better proxy for wholesale prices.





Optional TOU rate for residential consumers SCE (2022)

Computing TOU Rate Blocks

GenX LMP Prices

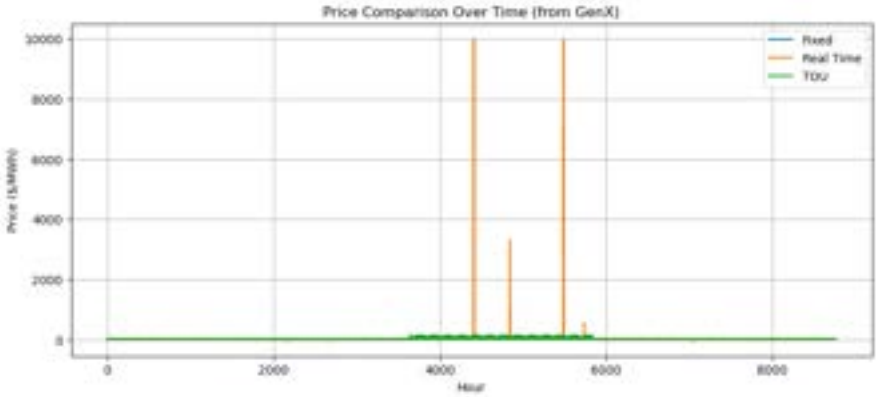
Step 1:
Sort prices by season, day-type and hour

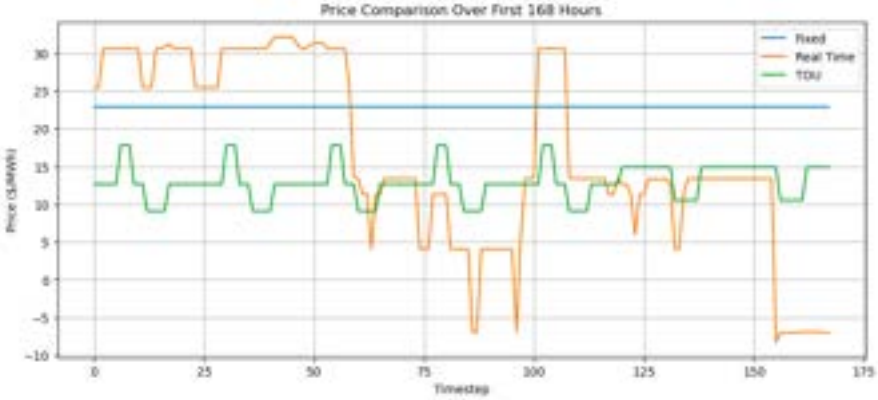
Step 2:
Partition the hours based on historical (Y) years data with desired (N) periods

Step 3:
Run regression to determine coefficients for prices

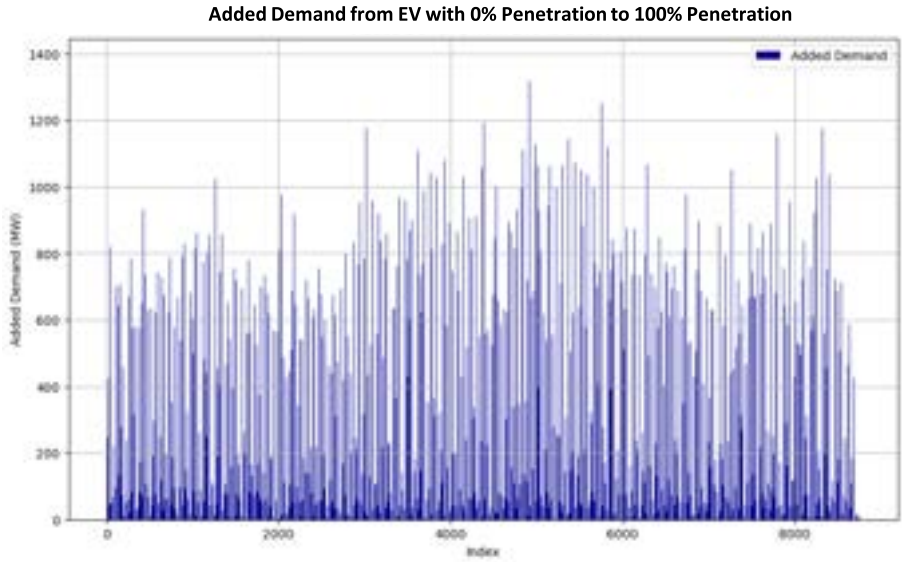
Step 4:
Scale TOU rates equal to the load-weighted average price in DA prices

Retail Rates





Results: Base Case - from 0% EV penetration to 100% adoption

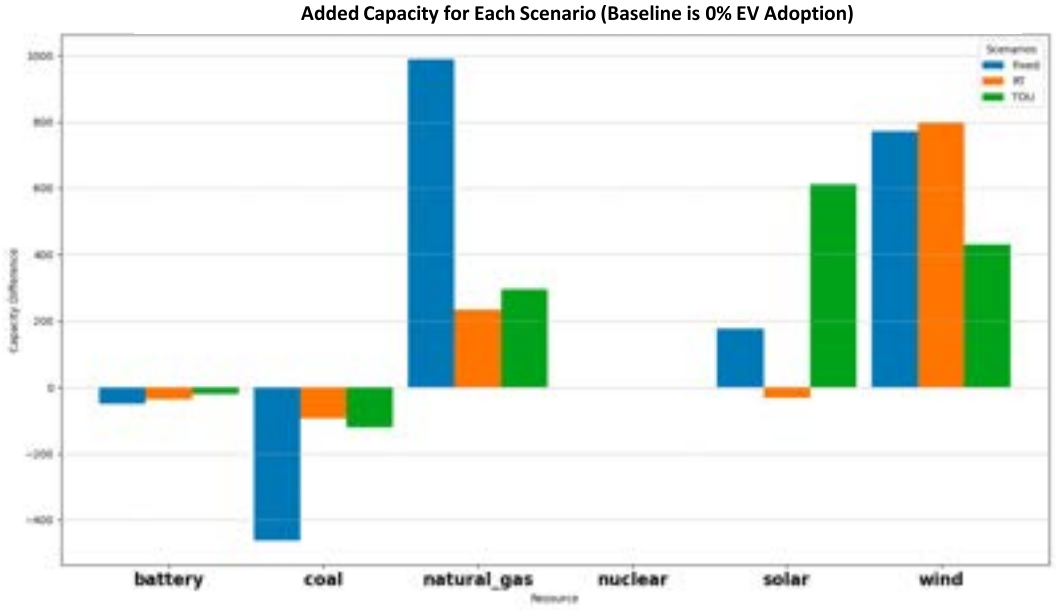


Incremental System Impacts of Adoption (from 0% to 100%)

Consumption Added	**3.1 GWh**
Incremental Peak Demand	**1377.0 MW**
Capacity to Serve Load	**1425 MW**
Costs per MW of Additional Consumption	**$52.32 / MWh**

FINDING #1

Rate adjustments can reduce the need for additional capacity



Capacity Impacts by Scenario

Note: Incremental Peak EV Demand from Fixed Case (1377 MW)

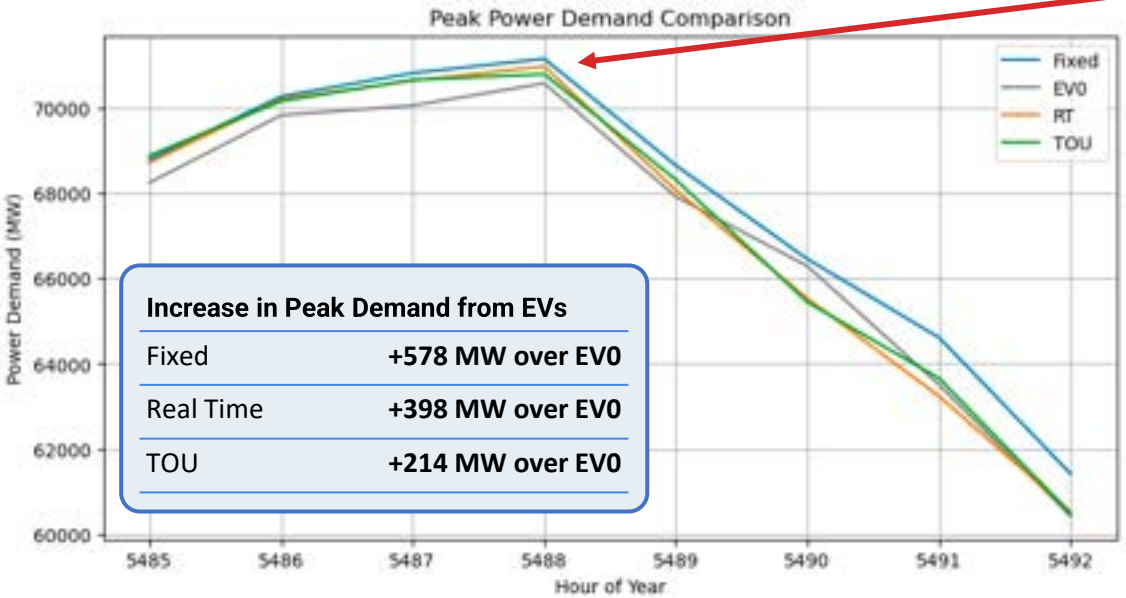
Fixed	**1425 MW (+3.4% of Fixed Peak)**
Real Time	**868 MW (-36.9% of Fixed Peak)**
TOU	**1196 MW (-13.1% of Fixed Peak)**

FINDING #2

TOU Rates protect consumers while reducing the peak demand from EVs

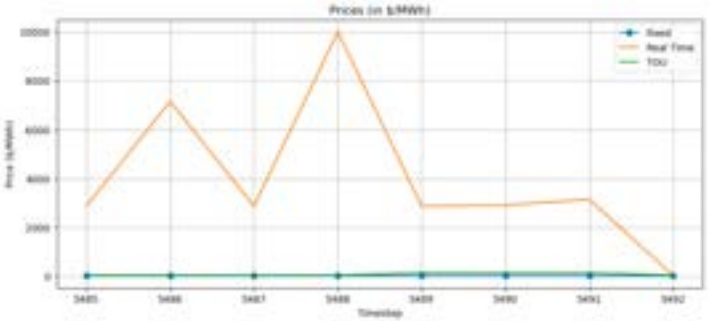
Hour 5488 = August 16th @ 4PM





Increase in Peak Demand from EVs	
Fixed	**+578 MW over EV0**
Real Time	**+398 MW over EV0**
TOU	**+214 MW over EV0**

Real Time Price = $9999 / MWh



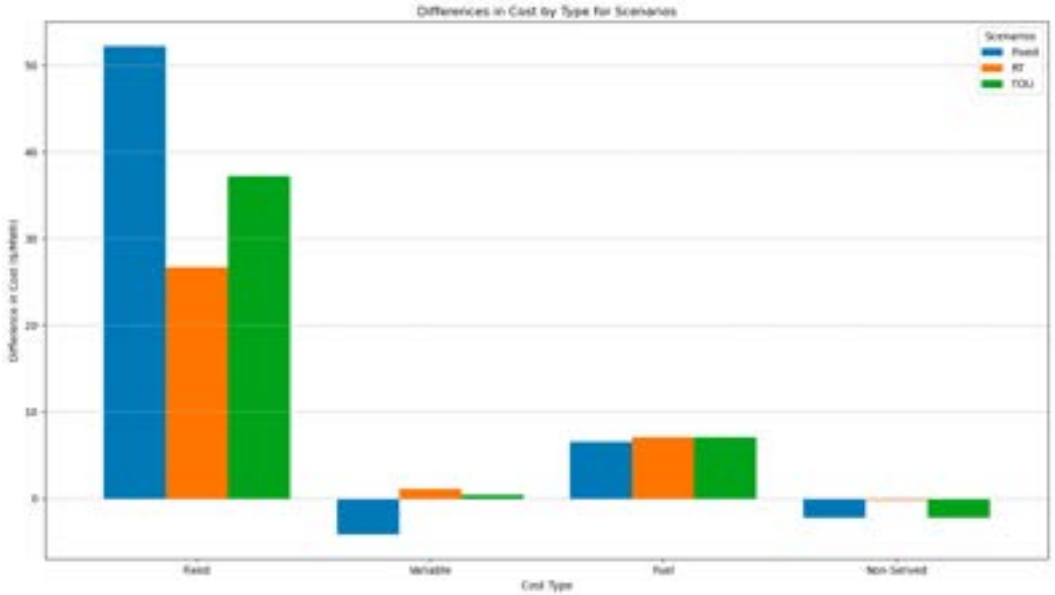
FINDING #4

Costs see a reduction compared to inelastic modeling

System Costs impact of adding EV Demand under different retail tariff schemes

Fixed	**+$52.32 / MWh**
Real Time	**+$34.58 / MWh**
TOU	**+$42.35 / MWh**

Net Costs
EV100 Scenarios = [Fixed, RT, or TOU]
(EV100 Scenario Costs - Baseline Costs (EV0)) / Δ (Annual Demand)



Levelized Cost of Charging

Real-time tariff allows for most flexibility to capture low/negative price hours but there is still consumer benefit from a TOU rate design

Levelized Cost
Total Cost of EV Charging / Total Consumption by EVs

	Fixed	TOU	Real Time
Levelized Charging Cost ($/kWh)	$0.070	$0.065	$0.051
Change compared to Fixed (%)	–	**-8%**	**-27%**

Note: cost includes distribution network charge of $0.048/kWh

Key Takeaways

- Within the constraints of clean electricity policies, **demand-side flexibility lessens the need for additional capacity and reduces system costs**, particularly when considering shiftable technologies like electric vehicle (EV) demand
- Utilizing **time-of-use tariffs captures many advantages of real-time retail pricing, while concurrently protecting consumers** and making the electrification of end-use applications more cost-effective
- The **co-simulation framework provides a more nuanced and realistic platform for evaluating various retail rate structures** and demand-side strategies, adding behavioral responses to traditional demand-supply co-optimization methods



Photo: depositphotos.com

Next Steps

1. **Adapt the co-simulation loop to account for rollout periods through multiple investment planning years**
    a. Model different investment decision planning frequencies (outer loop)
    b. Identify how the system behaves and if prices converge or continuously oscillate as consumers react based on new rates
2. **Add in heating demand profiles to housing stock**
3. **Scale to entire ERCOT system**

