

Future Energy Systems Center

System Impacts of Decarbonization Pathways for Space Heating in Cold Climates

Project Update

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Presentation Outline

- Motivation
- Methodology
- Results
- Conclusions & next steps

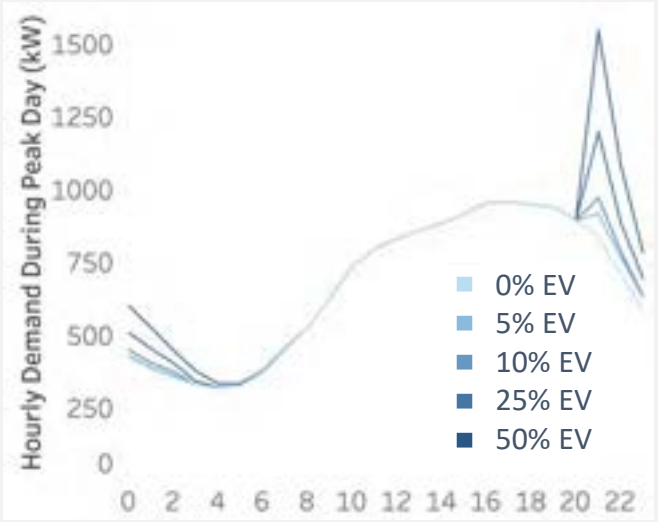
Project motivation and objectives

Motivation

- Electrification of heating and transportation will lead to significant grid investment driven by peak demand growth
- Time-differentiated tariffs are effective at shifting demand and reducing operating costs for electric vehicles and heat pumps
- Yet the leading states are adopting simple time-of-use tariffs that will create new peaks due to bunched flexible demand, especially from EV charging



Source: US DOE



Objectives

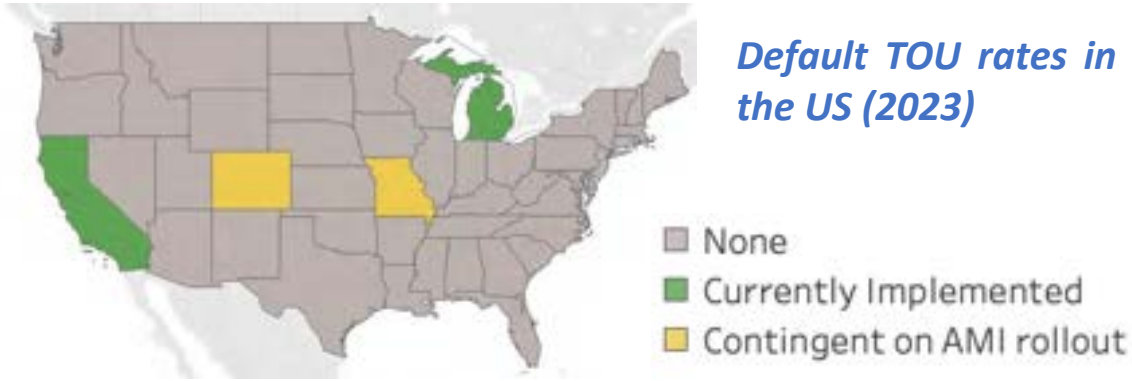
1. Model household responses to alternative tariff designs
2. Compute network investments required to support electrification
3. Provide menu of rate design alternatives for state PUCs aiming to achieve strategic electrification

Context: what do residential electricity consumers pay in the US?

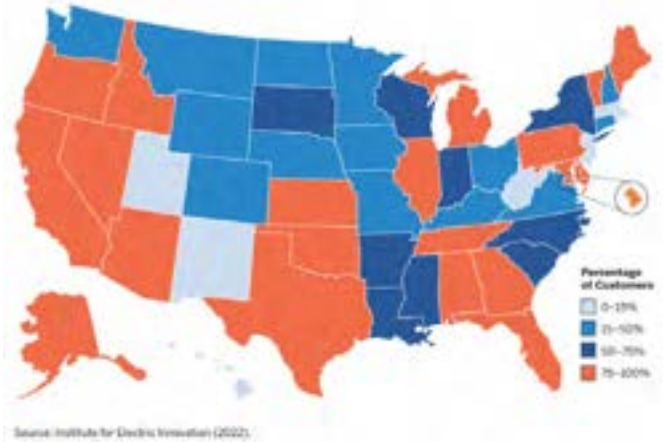
- For most of the consumers electricity is priced as:
  - a flat volumetric rate, i.e., a constant $/kWh price, determining most of the bill
  - a small fixed charge ($/connection)

- The volumetric rate ≈ dividing the total costs a utility must cover in some period by the expected kWh demand in that period

- Only 7.3% of U.S. consumers are enrolled in time-varying rate plans (EIA, 2022)



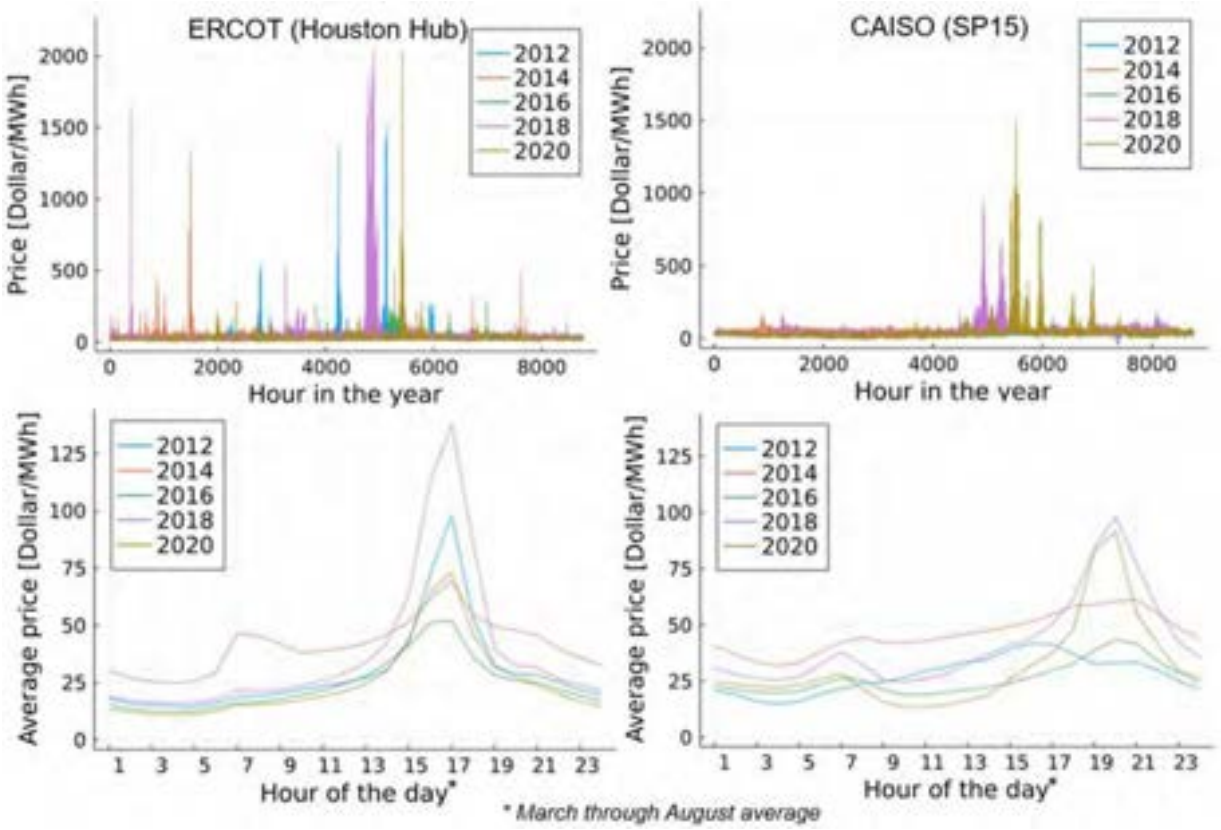
Default TOU rates in the US (2023)



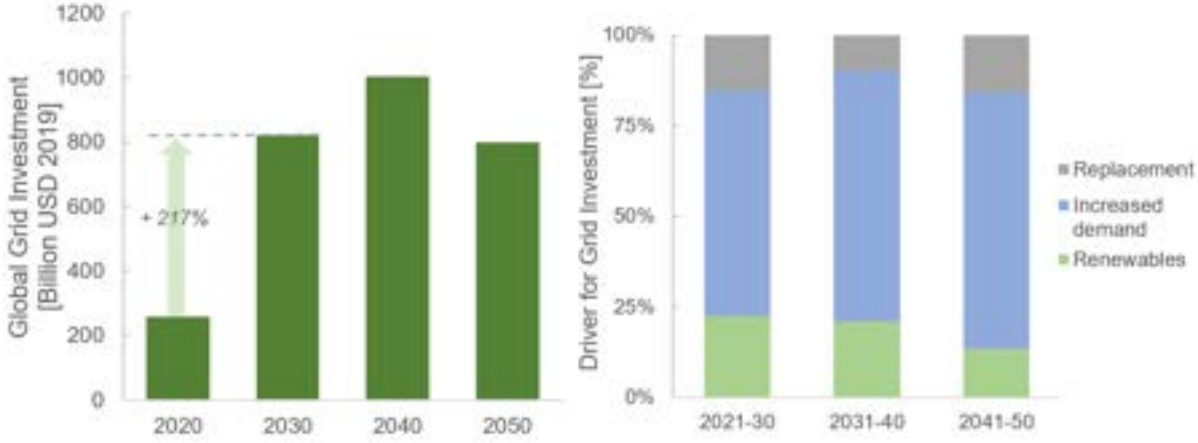
EIA (2022): 111 million advanced meters installed in residential (97 mil.) and commercial (13 mil.) locations in the U.S.

Two big pieces of the retail rate puzzle

1. Retail customers do not see the often-substantial hour-to-hour variation in the marginal cost of electricity supply, reflected in spot wholesale prices

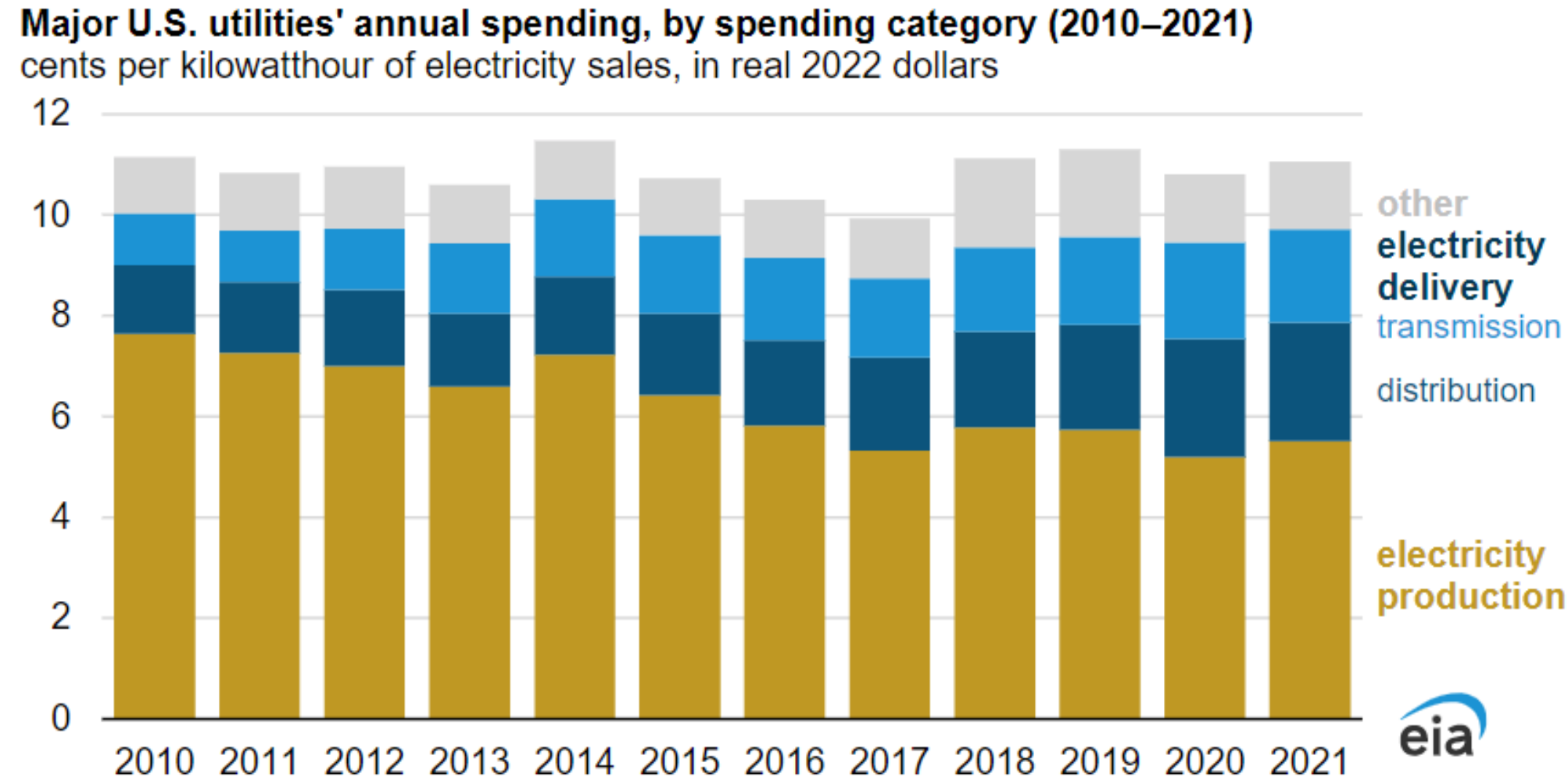


2. Investment-related costs are embedded into volumetric rates while in the short-run these costs are fixed and do not vary with instantaneous consumption



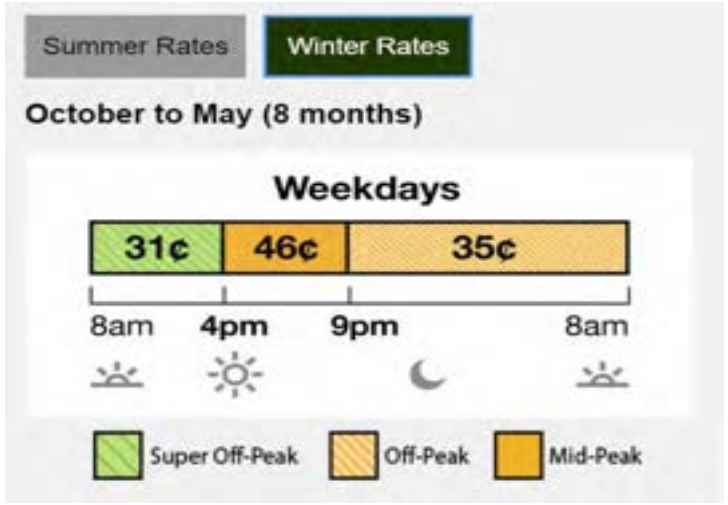
IEA 2050 Net Zero Emissions scenario (IEA, 2022)

Context: current composition of US utility costs



Data source: Federal Energy Regulatory Commission (FERC) Financial Report Form No. 1, as accessed by Ventyx Velocity Suite

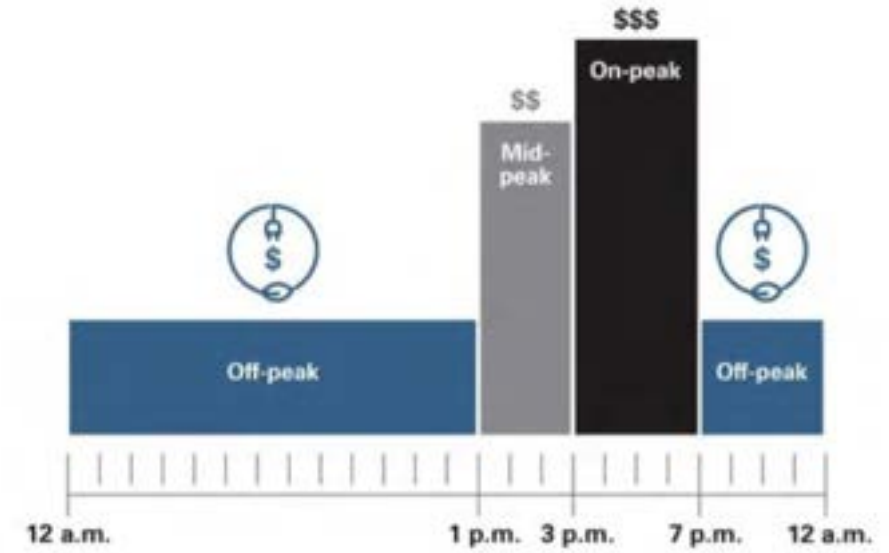
What are the leading states doing?



Source: Southern California Edison

	Oahu
Off-Peak (10 p.m. to 9 a.m.)	37.8
Mid-Day (9 a.m. to 5 p.m.)	28.0
On-Peak (5 p.m. to 10 p.m.)	45.1

Source: Hawaiian Electric

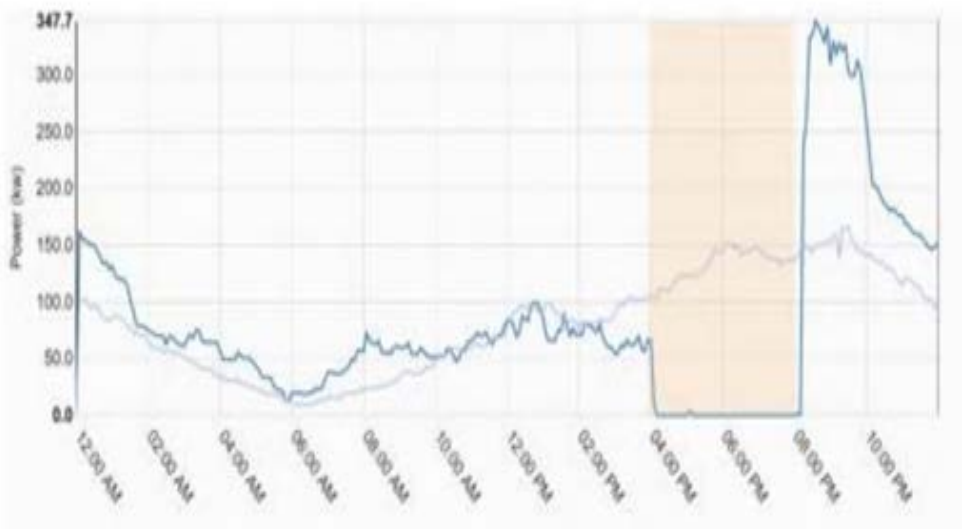


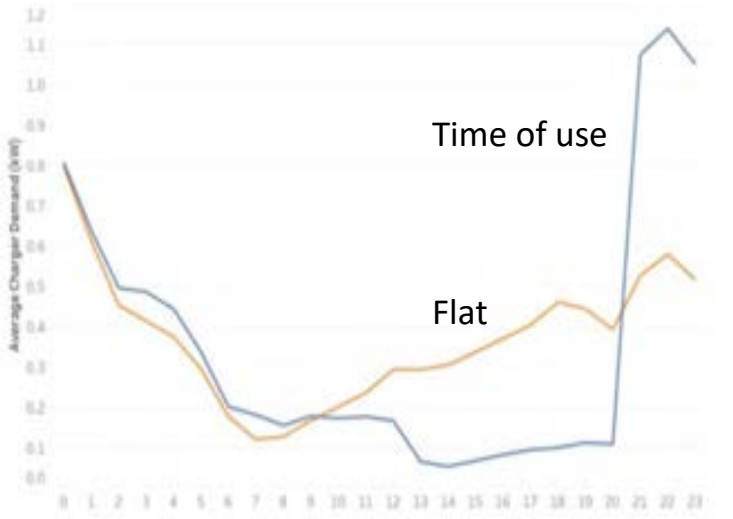
Source: Xcel Energy

Emerging preference for simple volumetric TOU, often with network and energy bundled into one charge

What programs exist specifically for EV charging?

Utility	State	Details
Xcel Energy	Minnesota	Unlimited charging between 9pm and 9am for $42.50/month
MMWEC	Massachusetts	$6/month credit to limit charging to 1.25 kW between 5-9pm on weekdays
PSEG	New Jersey	$0.105/kWh credit for off-peak charging (between 9pm – 7am M-F)
Sonoma Clean Power	California	$250 rebate + $5/month to allow curtailment up to 120 hours/year

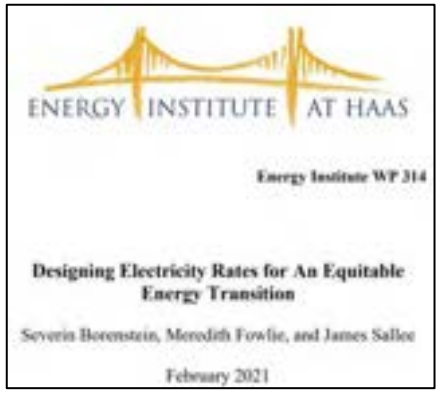




Programs lead to ”rebound” demand from devices responding to price

Source: Green Mountain Power 2021 Integrated Research Plan

What alternative network tariffs have been proposed?

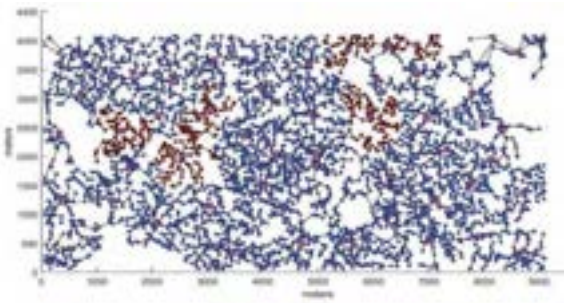


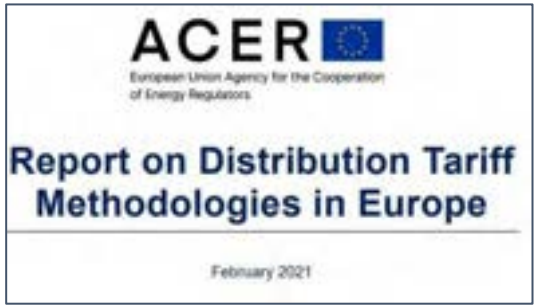












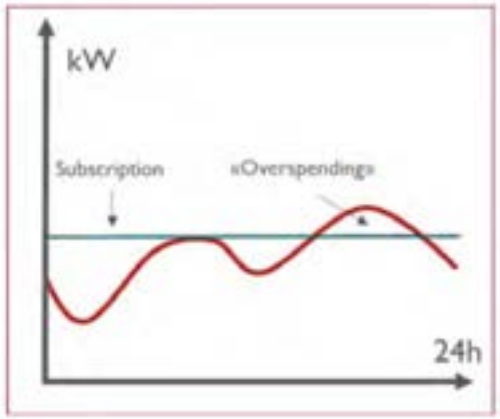
Fixed charges range from $24/month to $128/month

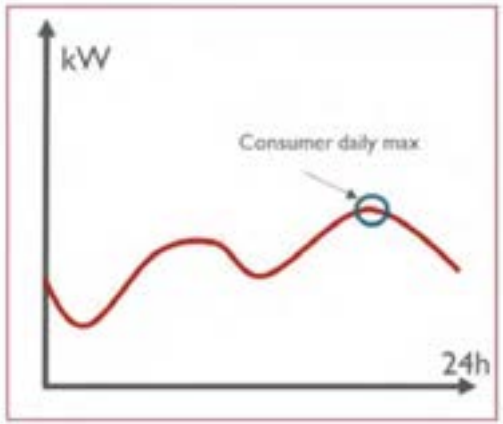
Charges reflect marginal network investment cost

What can we learn from our friends across the pond?

			
Capacity charge type	Subscribed	Subscribed	Measured
Time differentiation	No	Two periods with different prices	No
Level	About 20 euro/kW per year	About 25 euro/kW per year (total)	About 40 euro/kW per year

Source: NVE (2020)





Core research questions

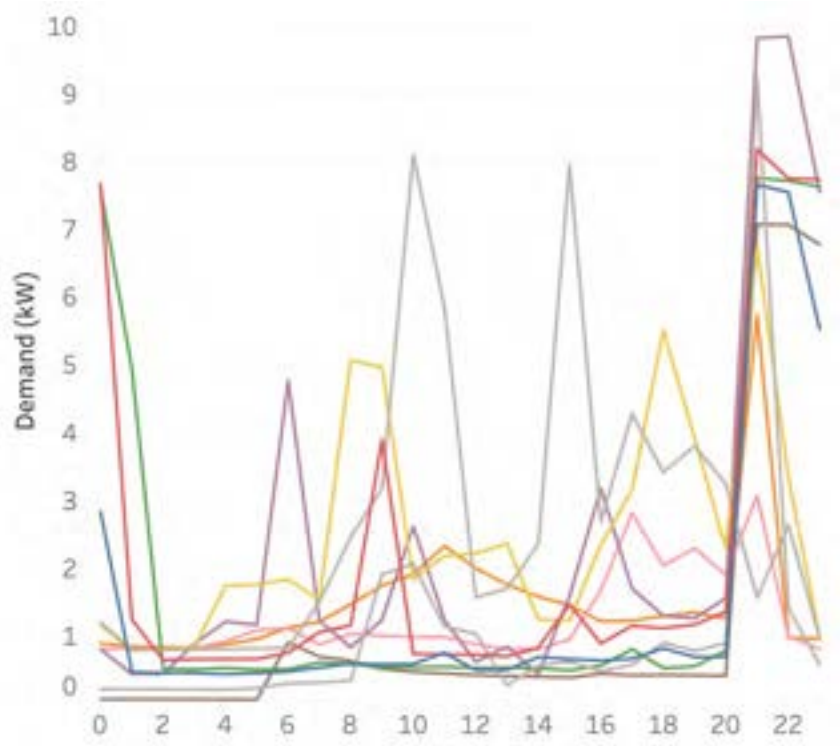
1. What are the cost impacts at the distribution level of electrification under simple TOU rates at high penetration?

2. Can we do better with alternative tariff designs?

Methodology: How do we assess tariff performance?

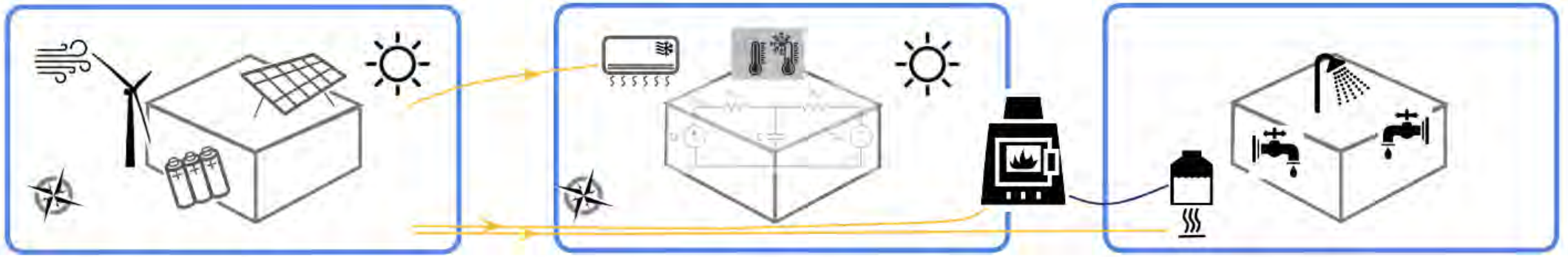
Simulate electrified homes independently reacting to prices at increasing levels of adoption





Methodology: How do we model the homes?

Distributed Energy Consumption in Actively Responsive Buildings (DECARB)



Electricity model

- Non-controllable load
- Demand response
- PV panels
- Batteries: Li-Ion
- Wind turbines
- CHP: by-product
- EV charging

Thermal model

- 2RC building model
- Location and orientation
- Occupancy
- HVAC: electricity - heat/cold
- CHP/Boiler: fuel - heat/cold (w/ chiller)

DHW model

- DHW demand
- Water heater
- CHP: by-product

Investment and O&M optimization

CO_2 emissions accounting

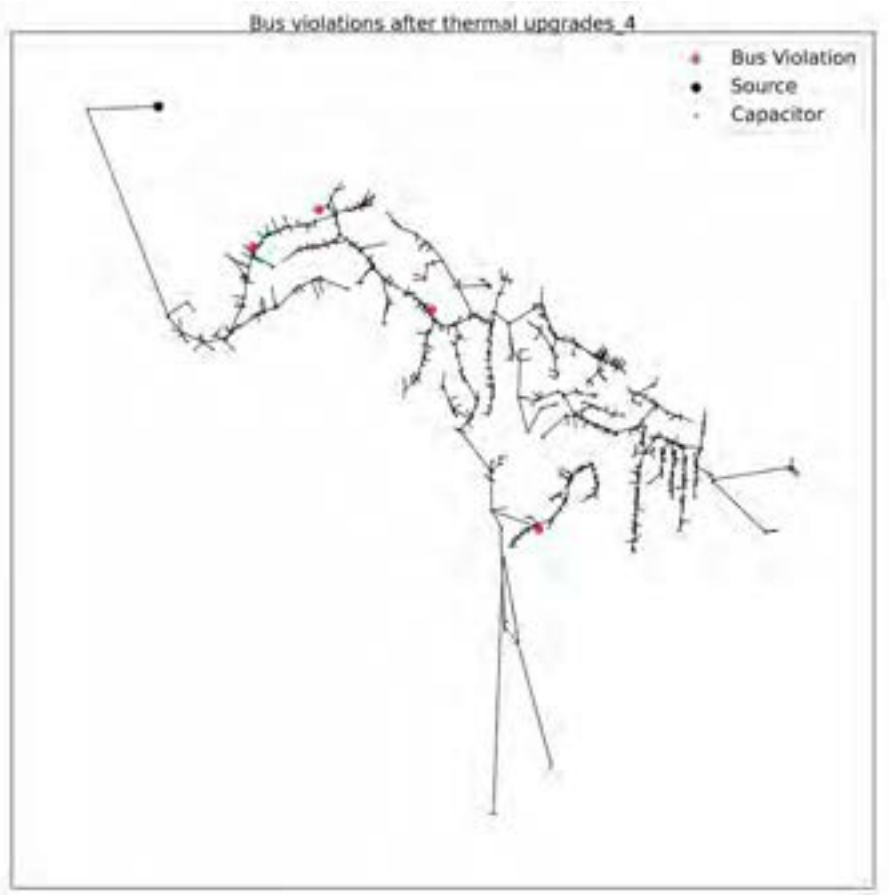
Methodology: How do we model the grid?

Synthetic distribution feeders calibrated against real networks

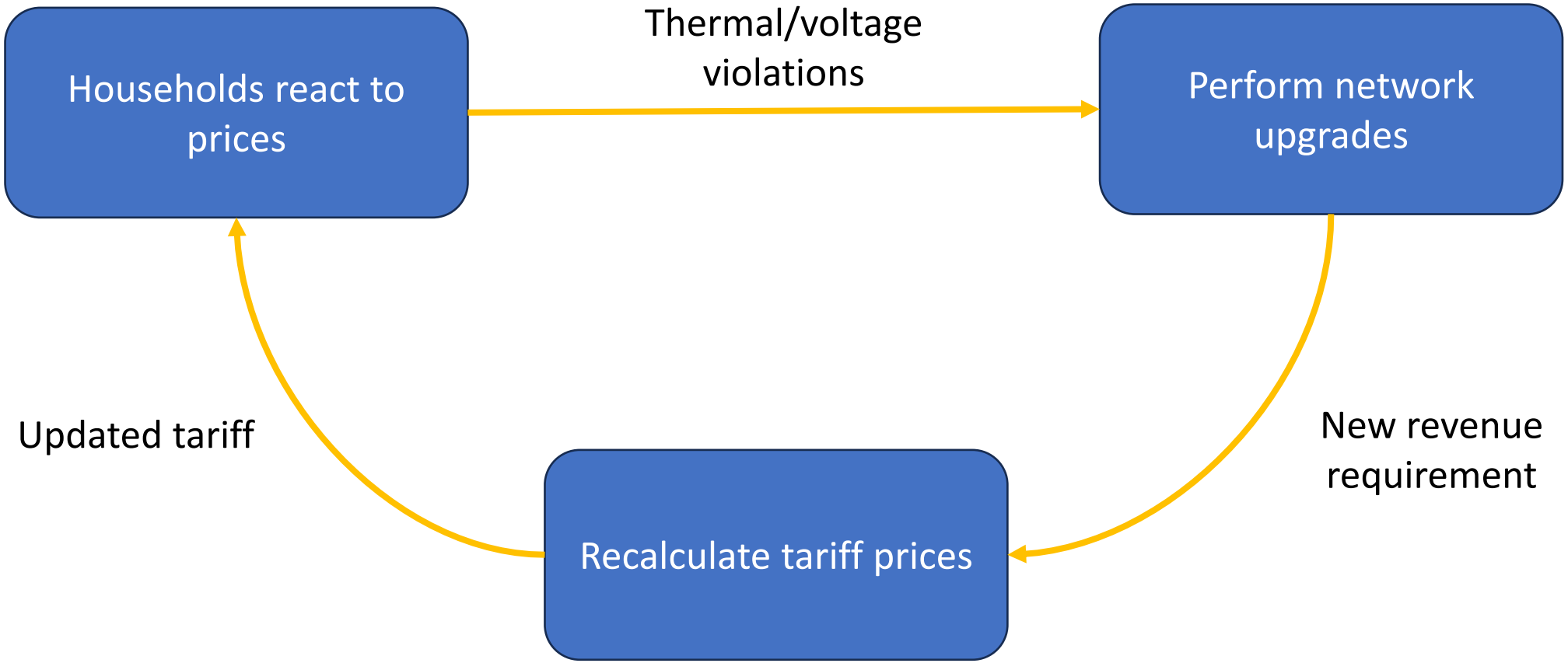
Smart-DS



Source: NREL/MIT/Comillas



Methodology: How is network investment connected to tariff prices?



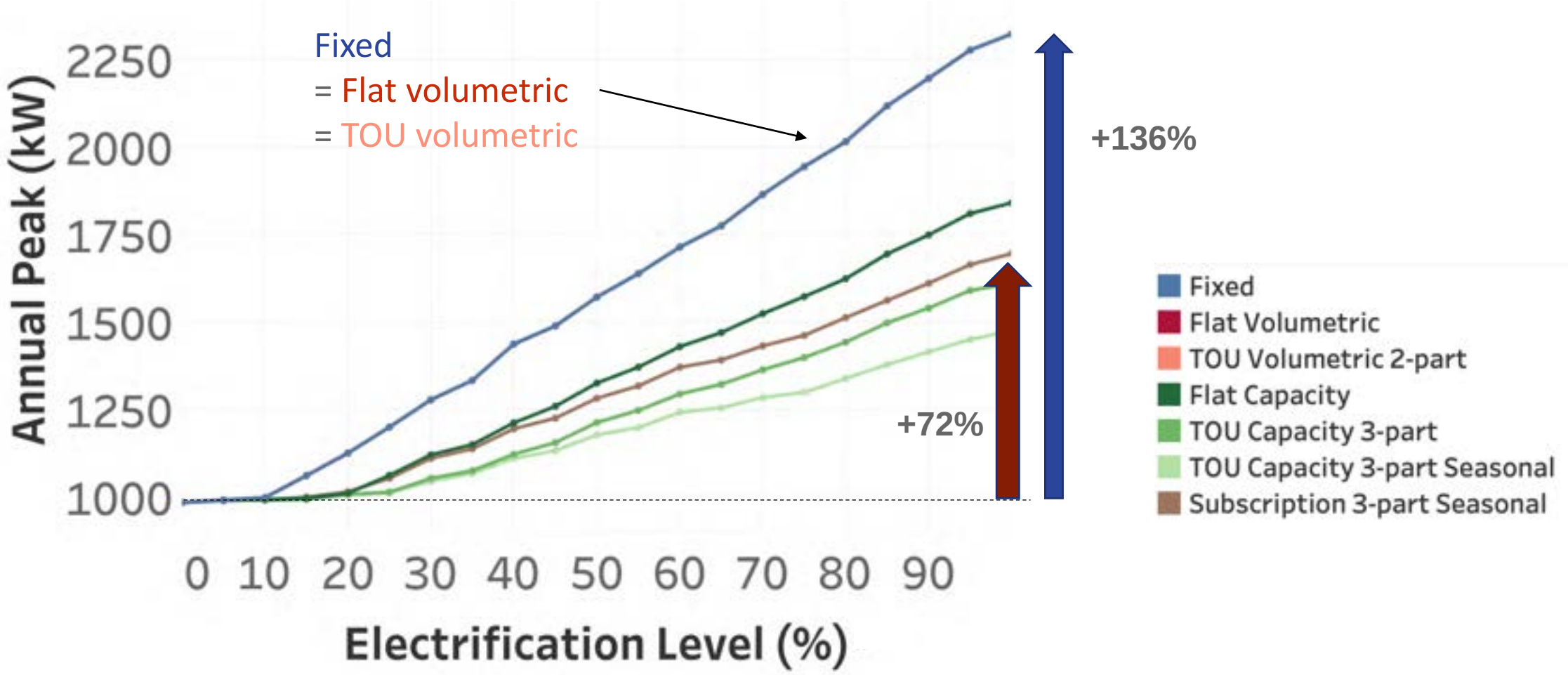
Methodology: What key metrics do we use to measure tariff performance?

kW	*$/kWh*	*+/- %*
Annual Peak	Levelized Charging Cost	Distributional Impact
the maximum hourly demand for the aggregated load over all consumers, measured in kW	*the average cost paid by EV households for EV charging*	*the average change in network cost paid by non-electrified households compared to status quo*

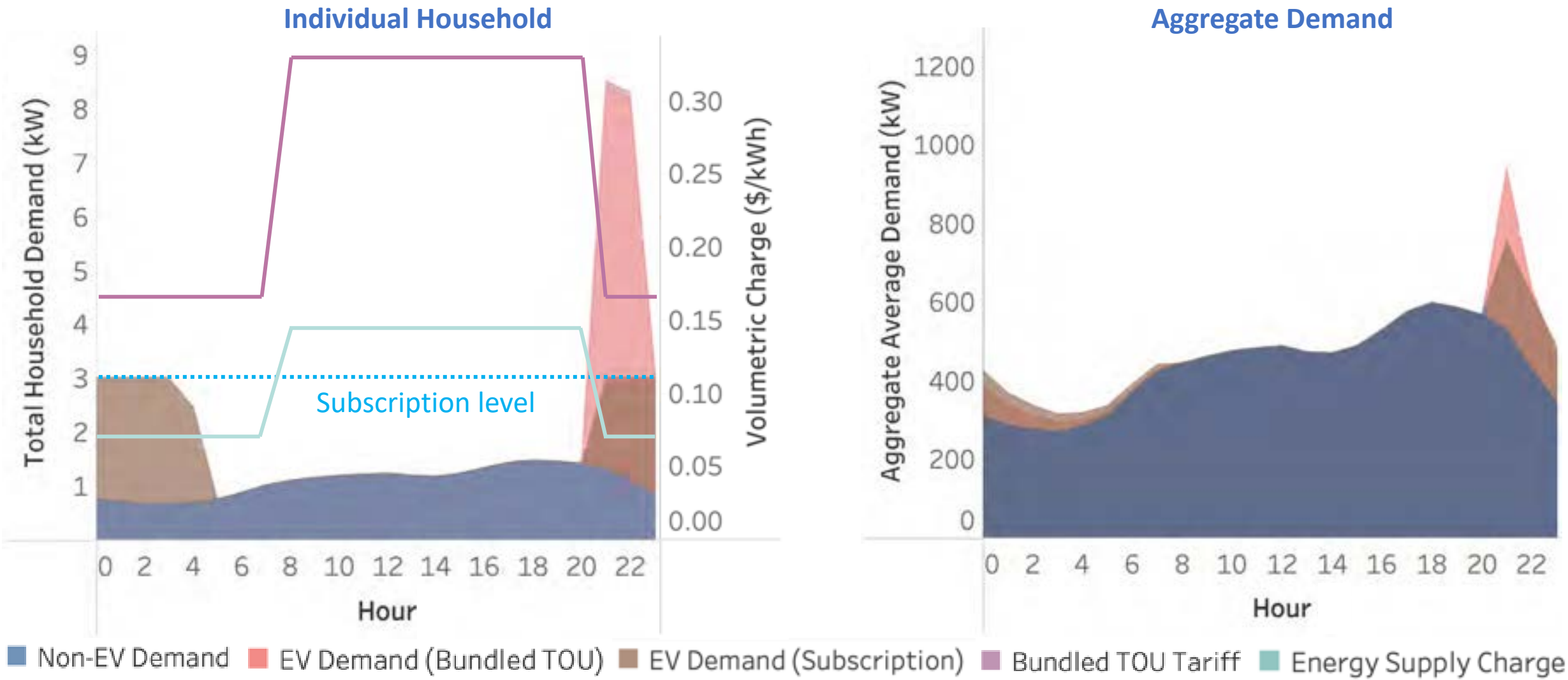
Methodology: Which tariffs do we test?

Tariff Type	Variant	Periods	Cost (at 0% electrification)
Fixed charge	-	1	$1000 per year
Per-kWh	Non time-differentiated (flat)	1	$0.11/kWh all hours
	Time-differentiated (TOU)	2	$0.07/kWh off-peak $0.18/kWh peak
Capacity	Demand Charge	1	$158/kW-year
	Demand Charge	3	$30/kW-year off-peak $70 /kW-year mid-peak $87/kW-year on-peak
	Subscription Charge	3	$14/kW-year on-peak $34/kW-year mid-peak $43 kW-year on-peak

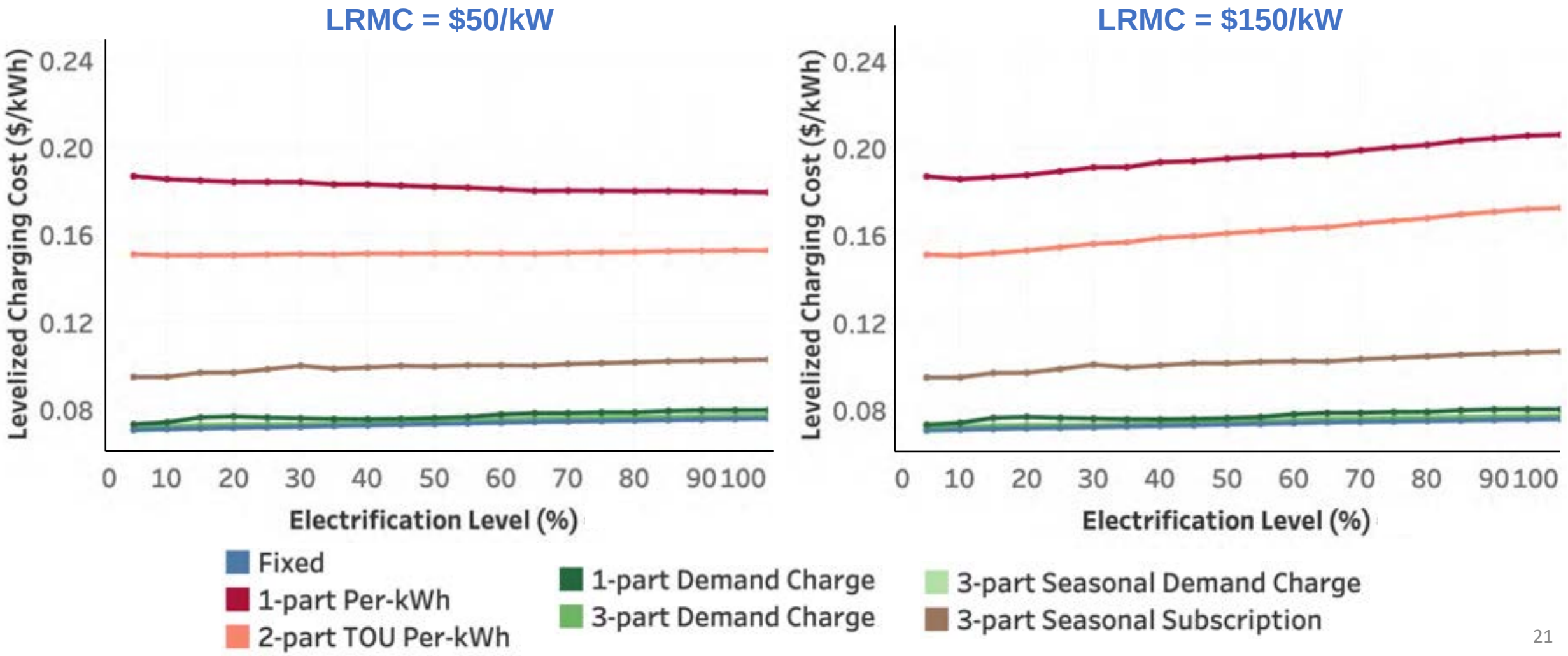
Results: What is the annual peak demand under each tariff at different electrification levels?



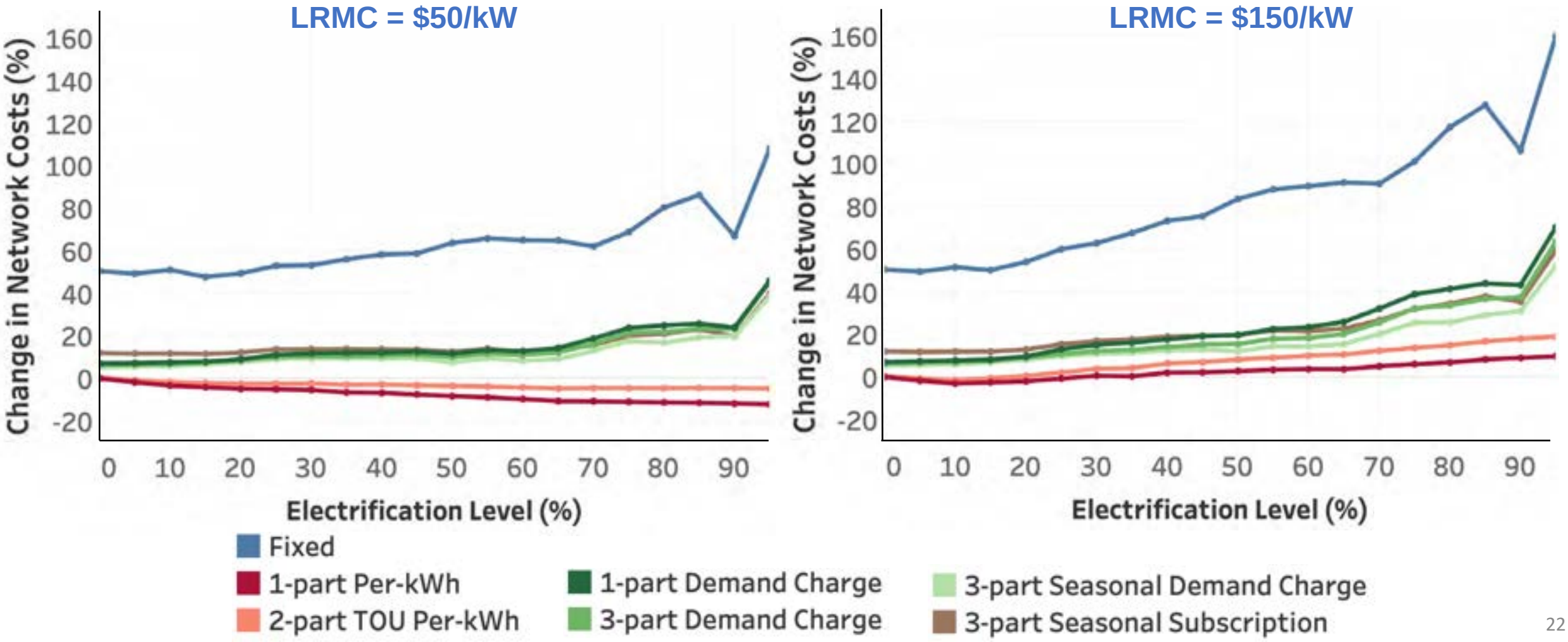
Results: What does demand on an average day look like?



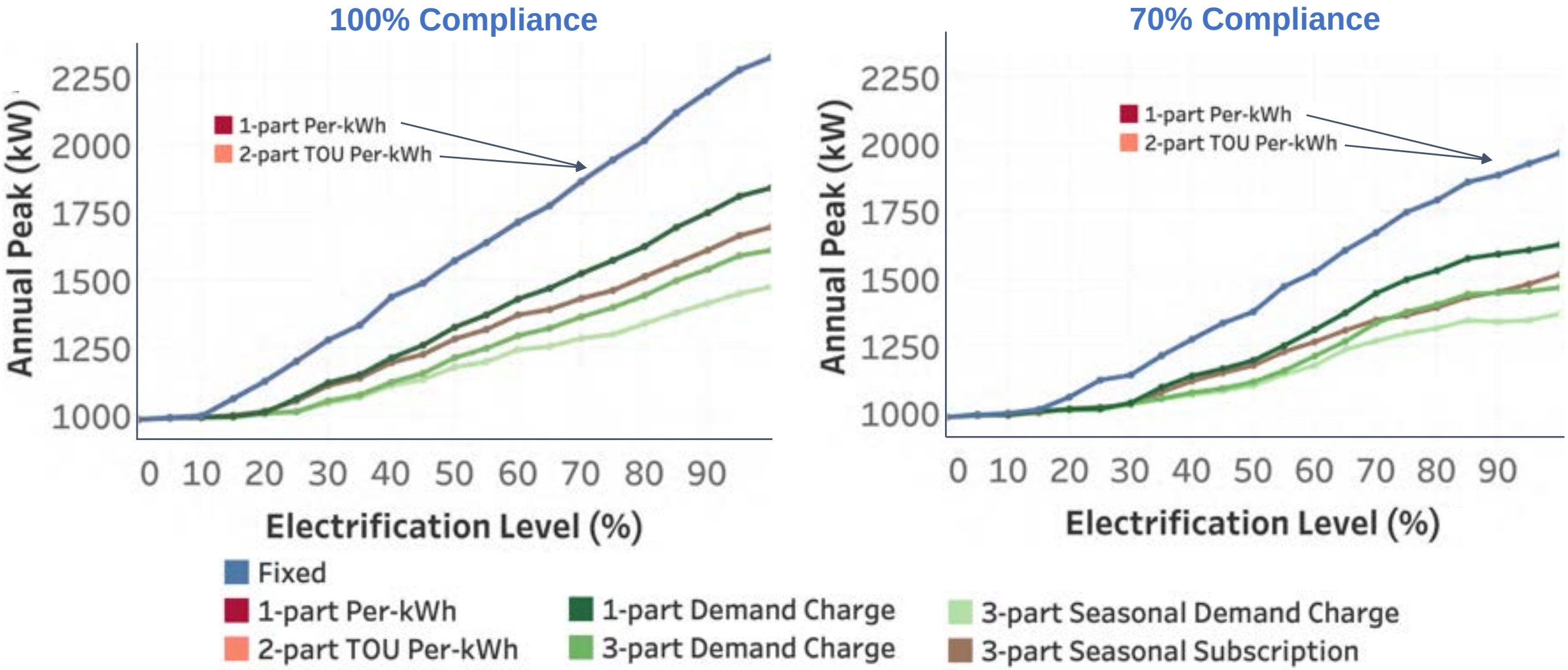
Results: What is the levelized charging cost under each tariff?



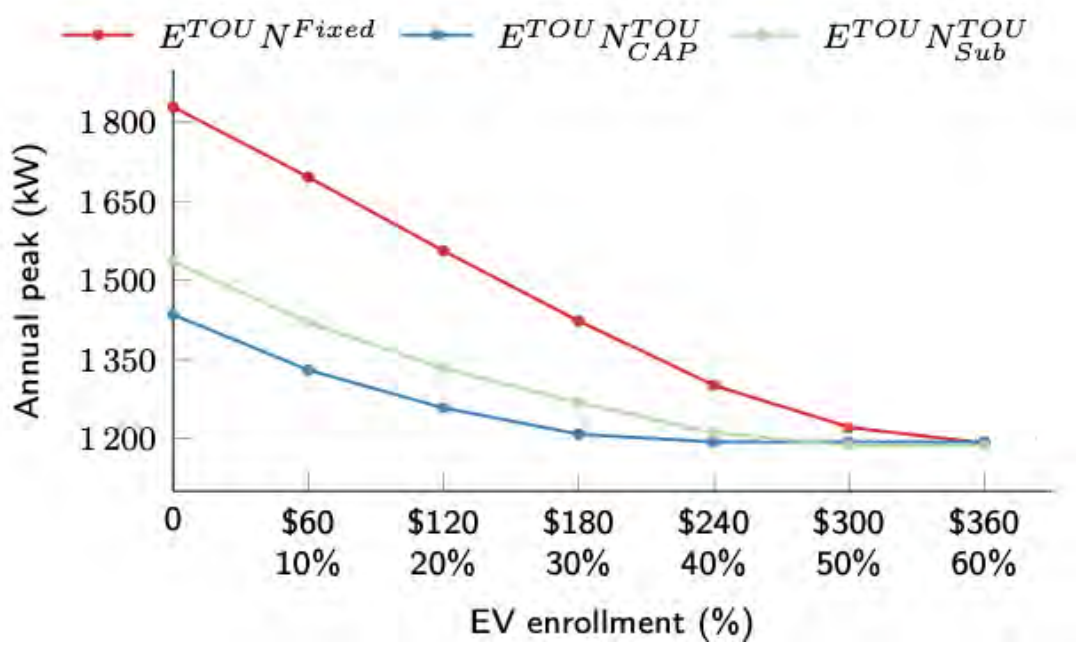
Results: What is the change in network for non-electrified homes cost under each tariff?

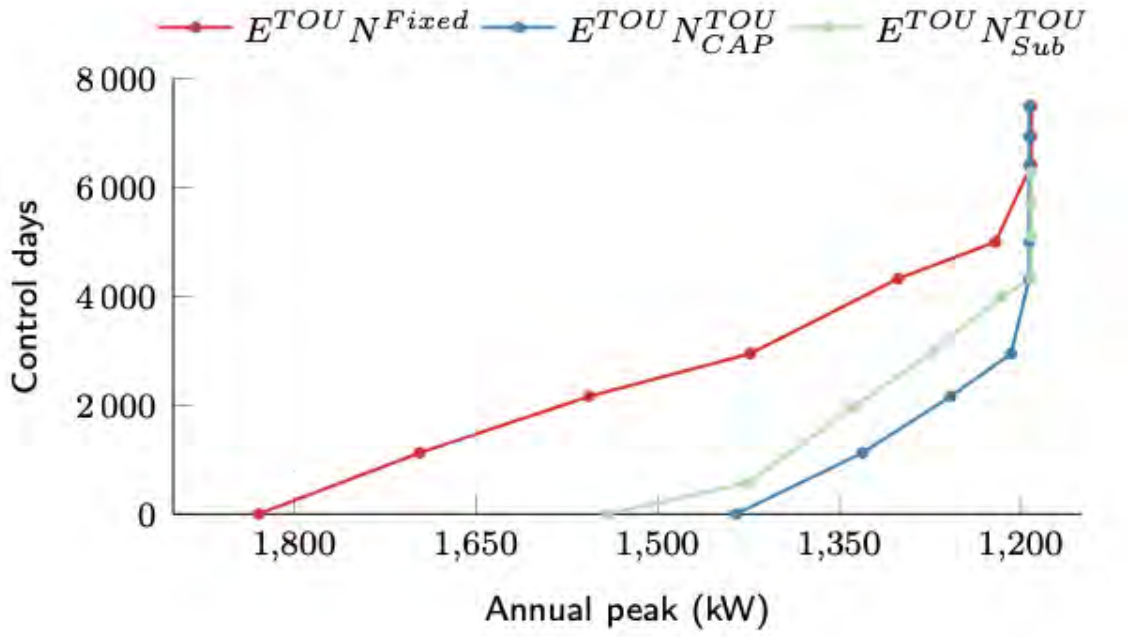


Results: What is the impact of non-compliance?



Results: What is the benefit of supplementary load control?





Key takeaway: fewer participants and control days needed with smarter underlying tariffs

Summary of Results

- Correlated EV charging very quickly becomes an issue under TOU rates (newly created peaks at **15% adoption levels**, and adoption will be concentrated!)
- Purely volumetric tariffs are not a good idea (no signal to limit aggregated peaks and makes electrification expensive)
- Demand charges perform well but are not easy to implement
- Subscription charges are a pragmatic solution and have several implementation advantages:
  - Bill stability and protection
  - Similar to internet plans that cap bandwidth
  - Close alignment with utility planning decisions
- Results improve if some customers ignore the price signal!
- Targeted load control can reduce peak demand dramatically, but is not a substitute for sound tariff design

Conclusion

	Yesterday	Tomorrow	>2030
Energy costs	Mostly flat volumetric	Opt-out TOU + possible load control	Real-time pricing + insurance/hedge
Network costs	Mostly flat volumetric	Capacity charges (time-element) + small fixed charges	Dynamic capacity charges + differentiated fixed charges
Taxes and levies	Mostly flat volumetric	Reduced, mostly fixed charge	Out of the bill

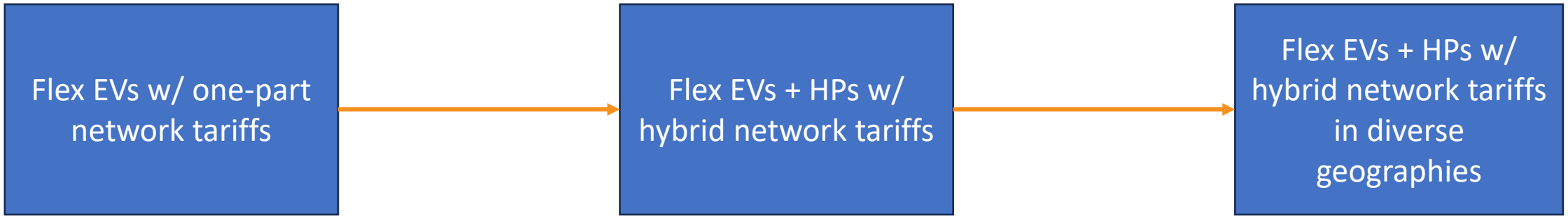


Adoption of smart technologies to make response "frictionless"

- Tariff design can make electrification cheaper while reducing the need for network upgrades
- But bad tariff design increases peak demand and shifts costs onto customers with the least ability to pay
- Regulators should think beyond TOU (e.g., subscription charges) to balance stakeholder interests and accelerate decarbonization

Remaining project activities and next steps

- Refine heat pump model to reflect accurate system sizing and backup heat options
- Introduce differentiated fixed charges to mitigate distributional impacts and recover part of distribution costs
- Expand to more regions (to understand geographic variation)



Q&A and Project Discussions