RESOURCES for the FUTURE

Flexible Electricity Demand and Decarbonization:

Policy, Prices and Automation

Karen Palmer

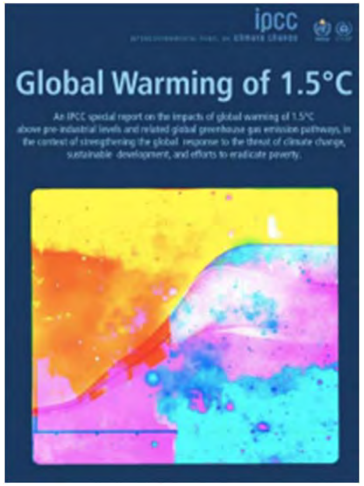
IIPF Annual Congress 2020

August 19, 2020

(Talk draws on joint work with Dallas Burtraw, Jhih-Shyang Shih, Kathryne Cleary, Casey Wichman, Josh Blonz and Derek Wietelman. Acknowledge funding from the Alfred P. Sloan Foundation.)

The Climate Change Imperative

- IPCC says to stay below 2 degrees C warming need to reduce CO_2 emissions to 25 percent below 2010 levels by 2030
  - for 1.5 degrees C, limit is 45 percent below 2010 levels.
- CO_2 emissions must be near zero by 2070 (for 2 degrees) and by 2050 (for 1.5 degrees)
- Energy use is a major culprit – need big changes
- Electricity
  - the initial target for decarb policy
  - will play a bigger role in future



Deep Decarbonization

- "All deep decarbonization pathways incorporate 'three pillars' of energy system transformation: energy **efficiency** and conservation, **decarbonizing electricity** and fuels, and **switching end uses** to low-carbon supplies…

  …Much of the direct combustion of fossil fuels …is **replaced by decarbonized electricity**, which more than doubles the share of electricity in final energy consumption in 2050." (options to reduce GHGs by 80% by 2050)

  -- *Pathways to Deep Decarbonization Synthesis Report,* 2015.

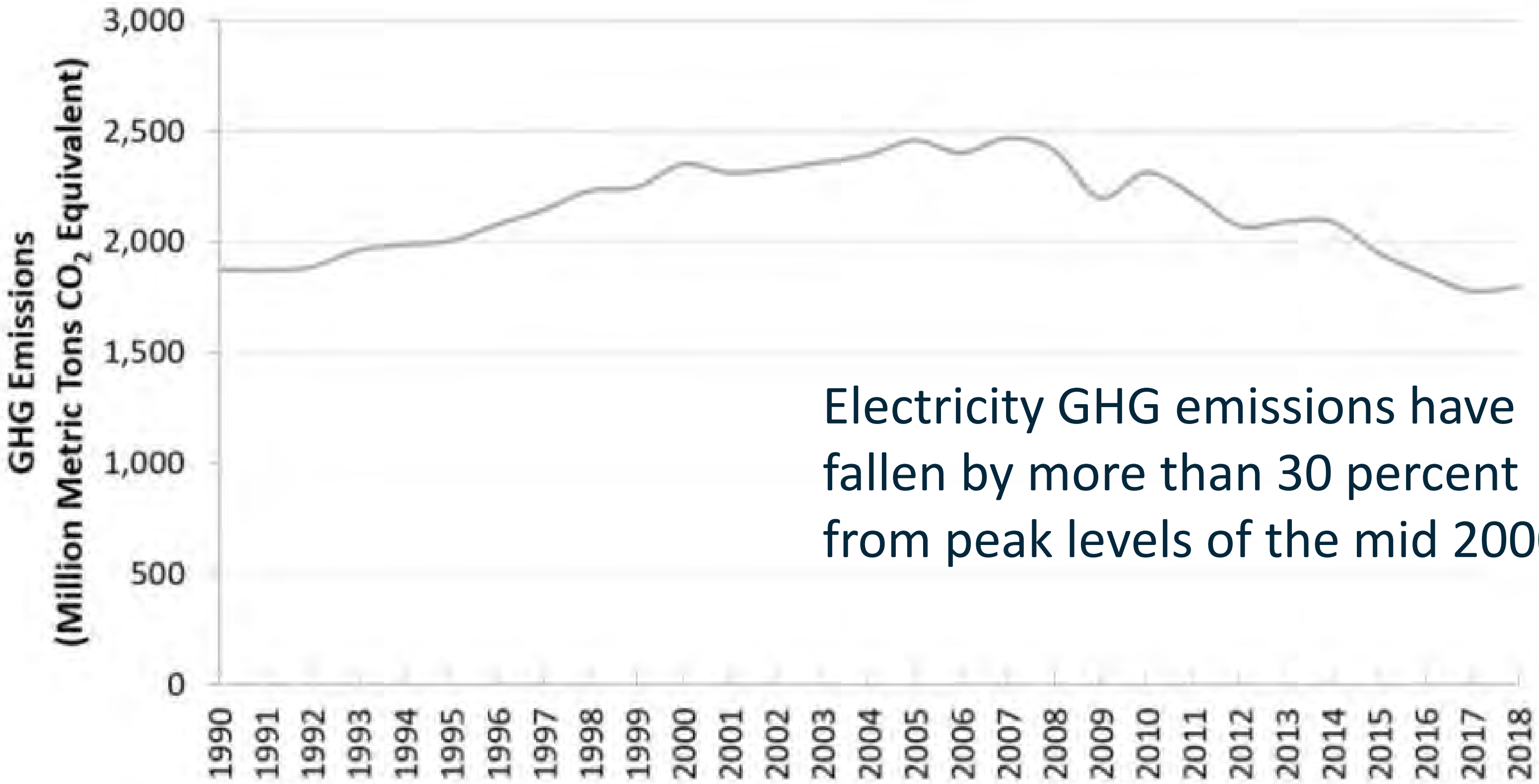
….**all with profound implications for how the electricity system and markets will work.**

What this talk is about:

- Managing electric supply to meet parametric demand would
  - impede decarbonization progress
  - raise consumer costs
- Need to cost-effectively bring demand to supply
- The keys to making that shift include
  - Efficient time varying electricity rates
  - Lower costs of consumer engagement
  - Consumer acceptance of automation
  - Enabling clean energy storage in newly electrified devices
- Discuss research on ways to engage demand in two contexts
  - Thoughts on potential new models for the electricity sector

Background on Electricity

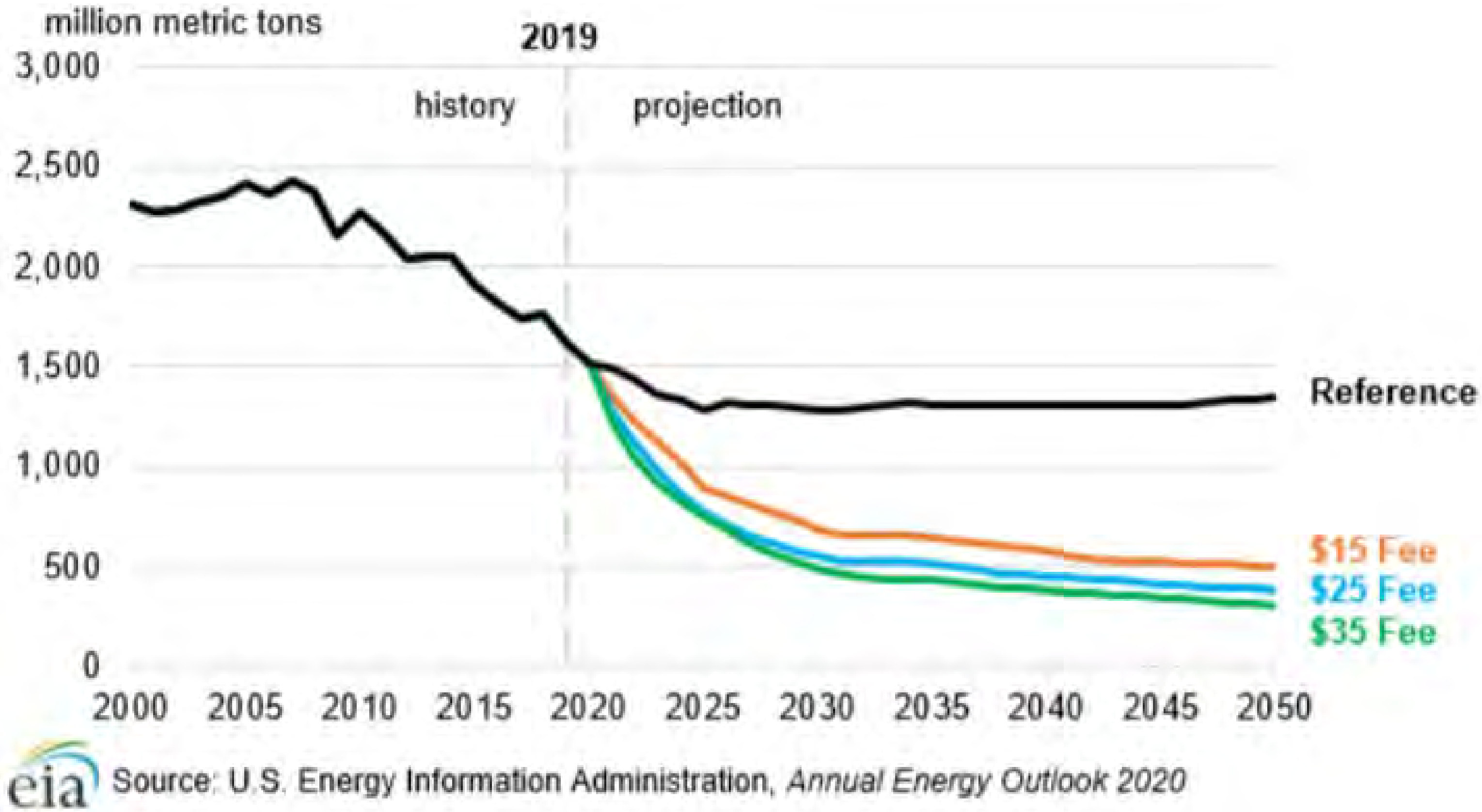
US Greenhouse Gas Emissions from Electricity



Electricity GHG emissions have fallen by more than 30 percent from peak levels of the mid 2000s.

All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018*.

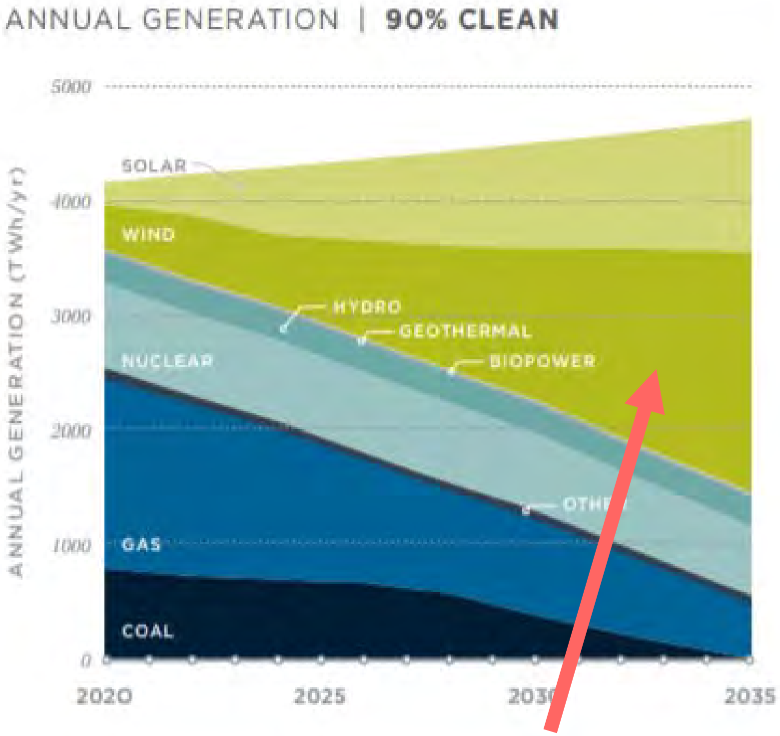
The Future Emissions Trajectory Depends on Policy

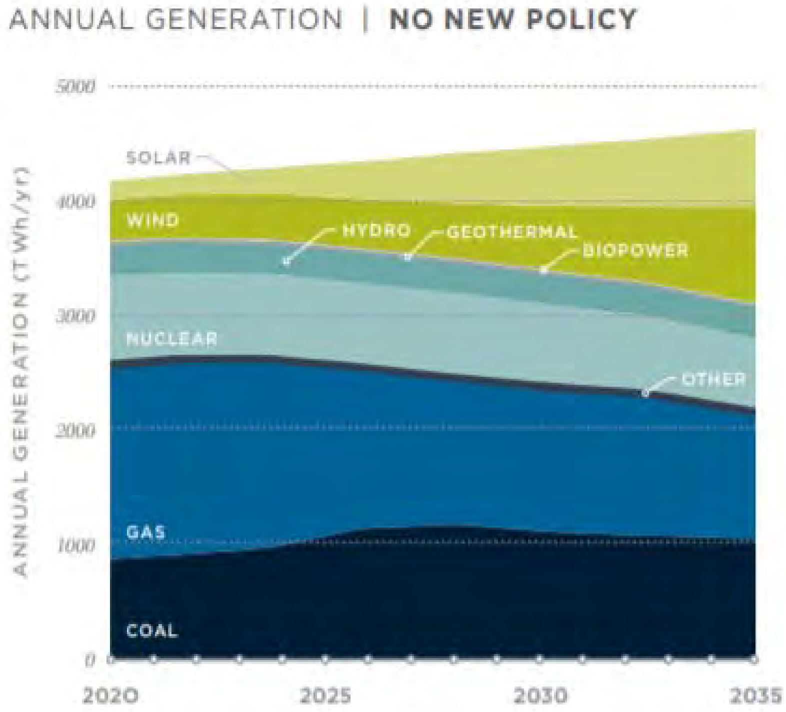


Policy is necessary for continued progress on decarbonization.

Carbon pricing is one approach that could yield big reductions, but which faces political hurdles.

Generation Mix with Deep Decarbonization





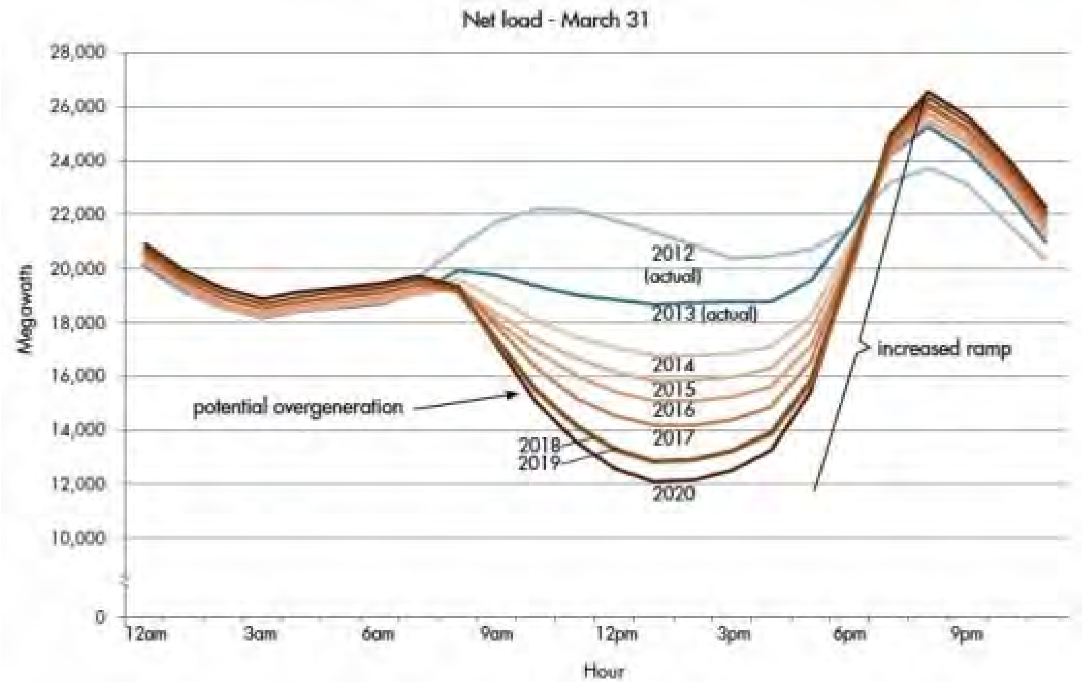
Clean energy standards (CES) are another policy; endorsed by the Biden campaign & favored in several states.

Left graph is for **90% CES by 2035** in the US.

Wind and solar generation play a big role in largely decarbonized sector.

Source: 2035, The Report (Goldman School of Public Policy, 2020)

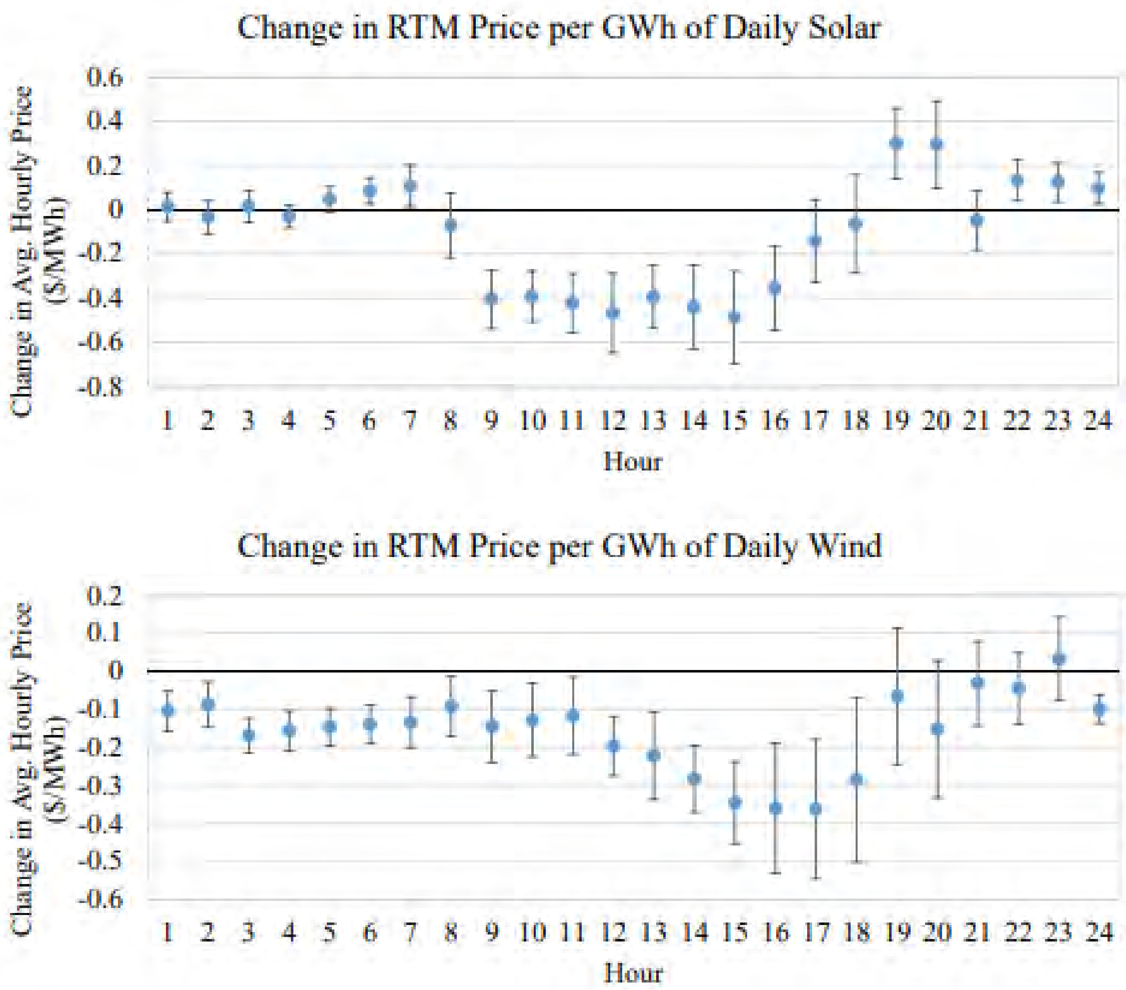
Renewables Integration Challenge



Intermittent RE generation challenges grid operation (the Duck Curve)

- Does not track electricity demand
- Big fluctuations in generation needs and premium on flexibility

Abundant RE depresses electricity prices; solar & wind value

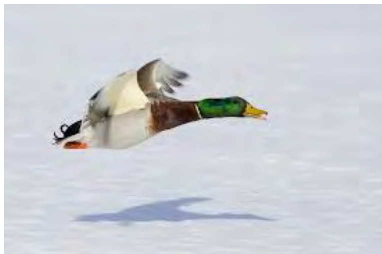


Excess renewables generation can lead to curtailment and fewer than expected clean MWh.

Source: Bushnell and Novan, 2018, Setting With The Sun: The Impacts Of Renewable Energy On Wholesale Power Markets

Restoring value to high penetration of RE generation

- Many strategies available:
  - grid scale storage (batteries, pumped hydro, etc.)
  - transmission to link different regions
  - both are costly
- Focus on demand and finding ways to bring demand to supply
- Reshape the Duck Curve
  - Absorb the belly by shifting demand to low cost hours
  - Flatten the ramp by shifting demand away from high cost hours
  - Standing duck becomes a flying duck



Use time varying pricing to engage consumers?

- Costs of supplying electricity fluctuate by hour and season
- Electricity prices paid by consumers rarely reflect actual costs
  - Typically prices are fixed (or maybe increasing block)
  - Time-of-use (TOU) prices capture cost variation imperfectly
  - Critical peak pricing applied to highest demand hours in some places
  - Efficient real-time pricing reflecting wholesale price variations is rare
- Economics literature on efficiency gains from real-time pricing
  - Holland and Mansur 2006; Borenstein 2005, 2012; Borenstein and Holland 2005; Blonz 2016 – savings from reduced need for peakers

Why so little dynamic/time-varying pricing?

- Meters that track electricity use by hour are not universal
- Political support is low
  - Regulators want to protect consumers from high prices
  - Peak energy prices could be order of magnitude higher
  - Compensating losers from shift could be expensive (Borenstein 2007)
- Limited consumer willingness to monitor price and adjust demand
  - Need advanced notice to inform purchase decisions
  - Competing demands for consumer attention

New technologies and electrification *to the rescue*

- Automation to help consumers respond to price fluctuations
  - Software and devices can alter demand in response to price signals
  - Consider smart thermostats that respond to time-varying prices

- Newly electrified loads and demand scheduling
  - Electric vehicles, building heating and cooling, and water heaters have built-in energy storage
    - Enables separation in time of electricity use and energy service consumption
  - Consider smart electric water heaters that optimize heating behavior

- Recent research helps inform the rescue plan

Smart Thermostats and Time Varying Prices

Pricing and Automation Working Together

Low prices of electricity in *renewable-abundant* hours can be good news for consumers

- Consumers have low price-responsiveness
- Cost of monitoring price fluctuations is high
- Automation could help with both
  - Will consumers buy-in?
  - At what cost?

Consumers are buying smart thermostats

- Opportunity to introduce automation at low-cost

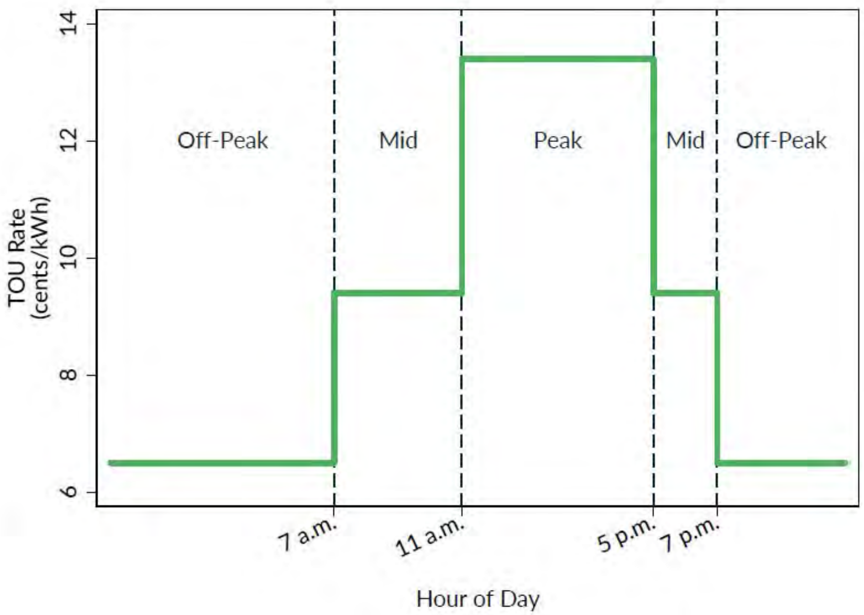
Setting for the Experiment: eco+ automated TOU feature

TOU automation optimizes thermostat schedule to Time of Use rates

- Pre-cooling during off-peak periods
- Letting indoor temperature float during peak price periods
- Customer sets parameters that govern the extent of "float"

We observe when feature is "activated"

Ontario Time of Use rates for the summer



Description of the Experiment

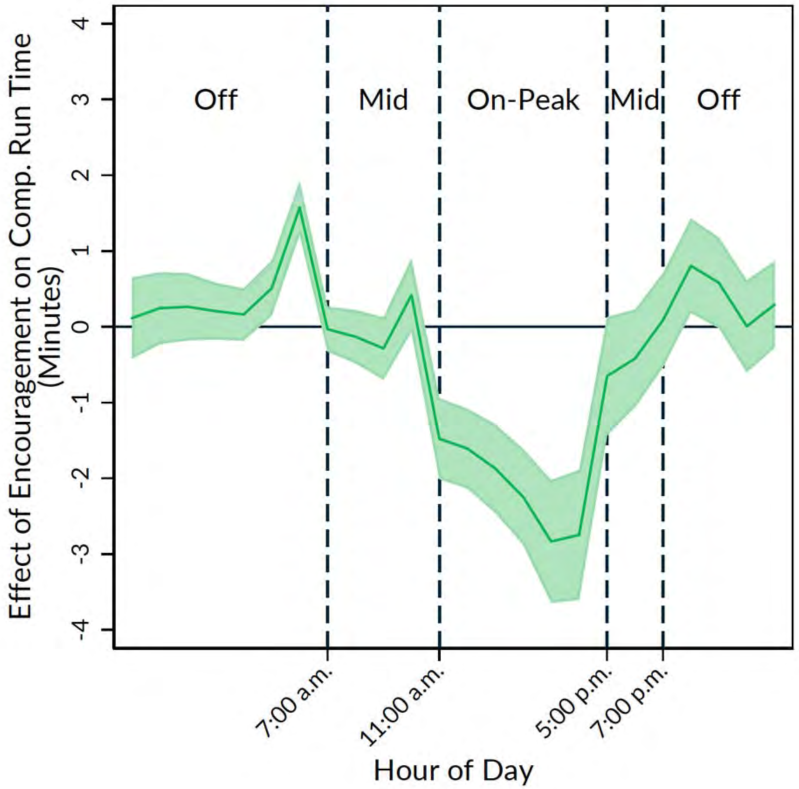
Our research questions:

- Does ecobee's eco+ TOU automation:
  - Shift energy consumption within the day?
  - Reduce overall energy use?
  - Change "comfort" levels in the home?
- How do households respond?

We used a randomized encouragement design

- Focused on Ontario where TOU pricing is the rule
- Experiment executed (by ecobee & RFF) in summer 2019

Empirical results: Compressor run-time



Compressor Run Time

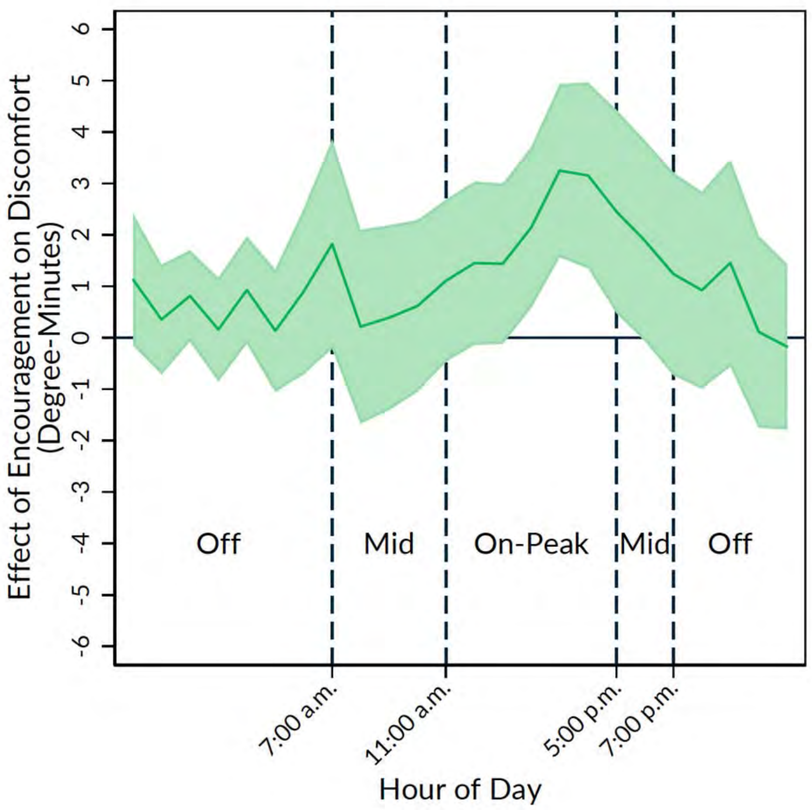
Notes: Coefficients are hourly ITT estimates for compressor run-time. 90% confidence intervals presented by the green shaded area. TOU rate periods are denoted by the dashed lines.

Pre-cooling effect from 6 – 7 a.m.

Large decreases during peak pricing periods

Small “catch-up” effect in the off-peak evenings

Empirical results: Discomfort



Temperature Discomfort

Notes: Coefficients are hourly ITT estimates for in-home temperature discomfort. 90% confidence intervals presented by the green shaded area. TOU rate periods are denoted by the dashed lines.

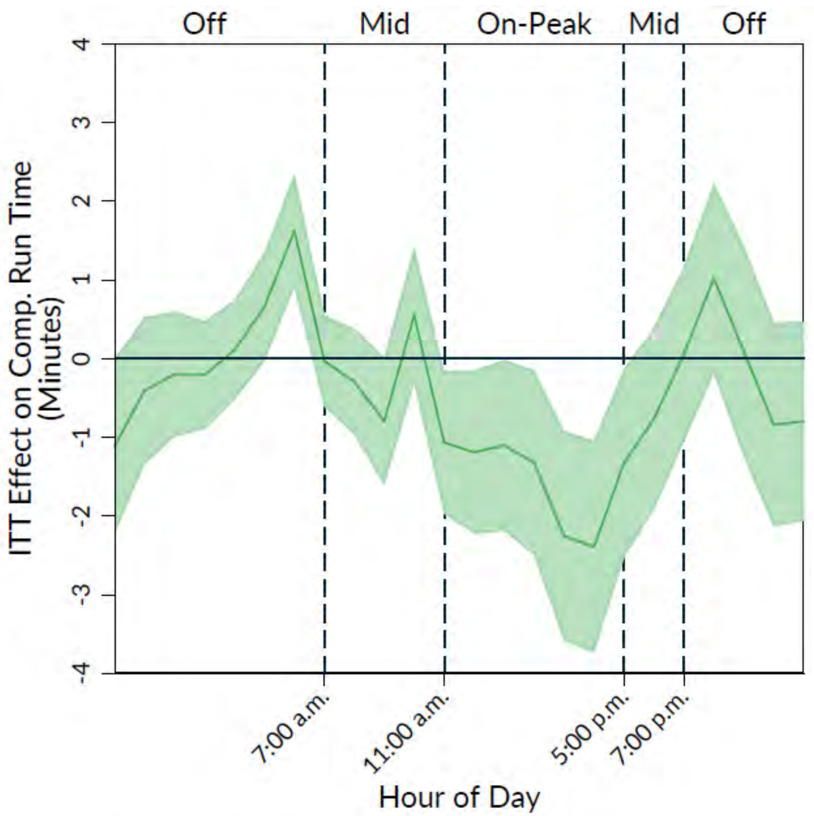
Discomfort measured as deviations from preferred temperatures times minutes experienced (discomfort degree minutes).

Majority of increases in discomfort is during on-peak times of the day.

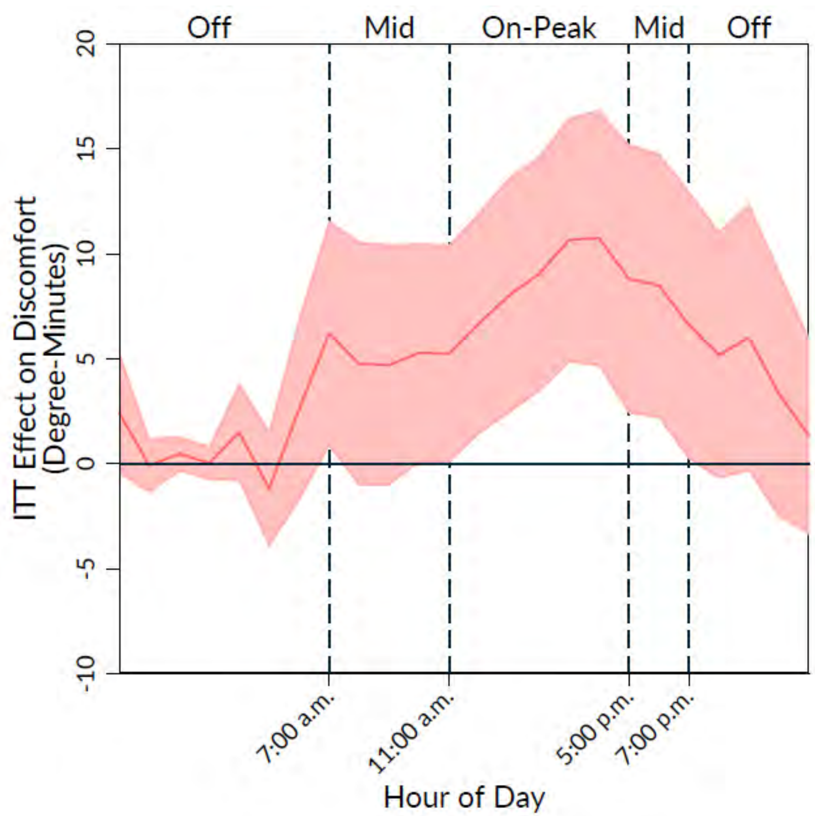
On average, automated-TOU feature increases discomfort by 8 – 26% relative to control group.

"Often Home" group saves energy & has more discomfort

Compressor Effects

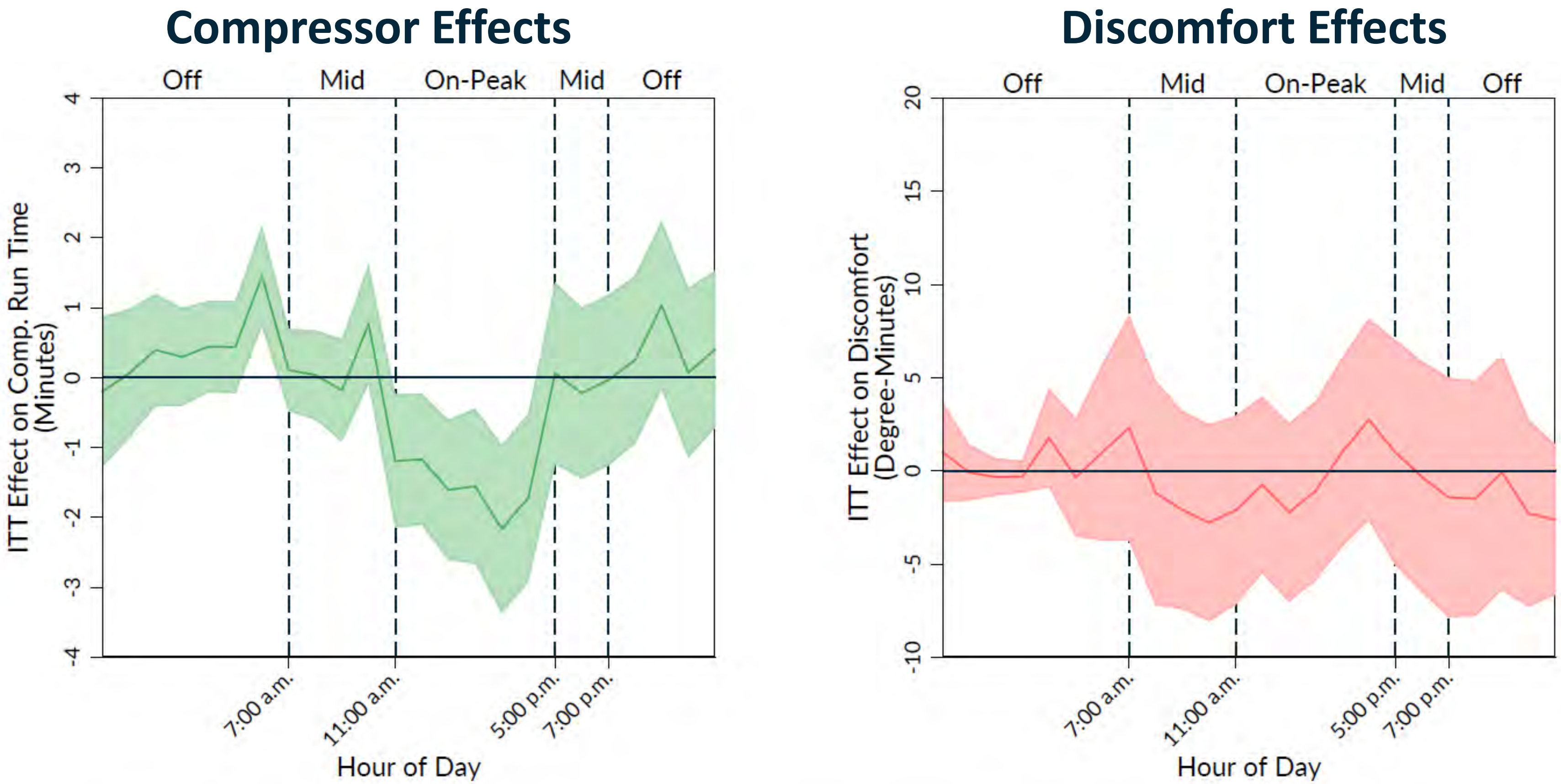


Discomfort Effects



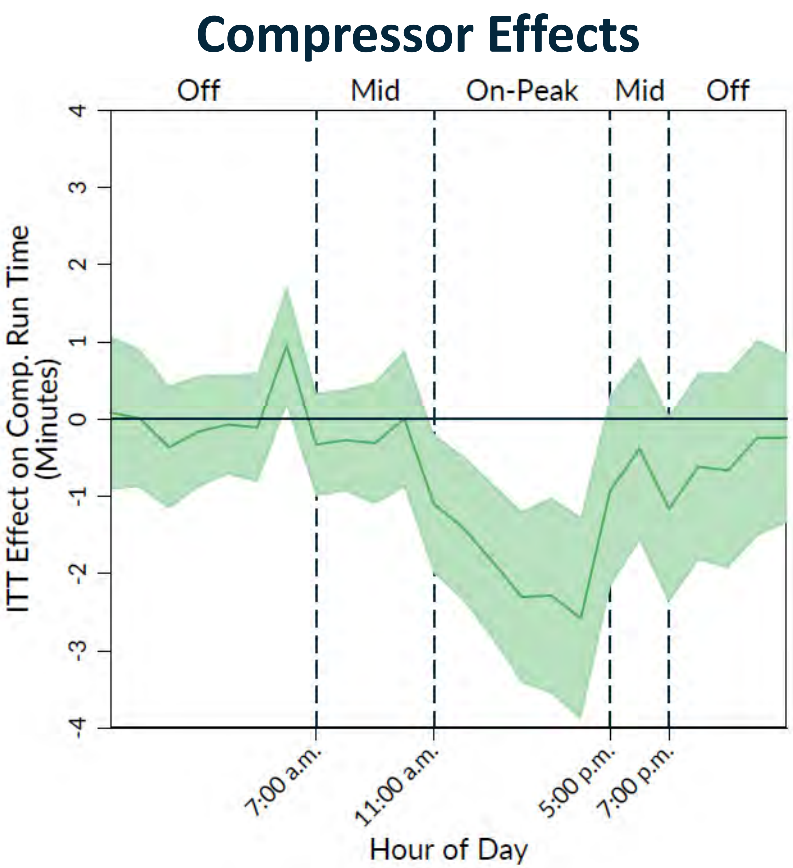
Notes: Coefficients are hourly ITT estimates for compressor run-time (left) and discomfort (right). 95% confidence intervals presented by the green shaded area. TOU rate periods are denoted by the dashed lines.

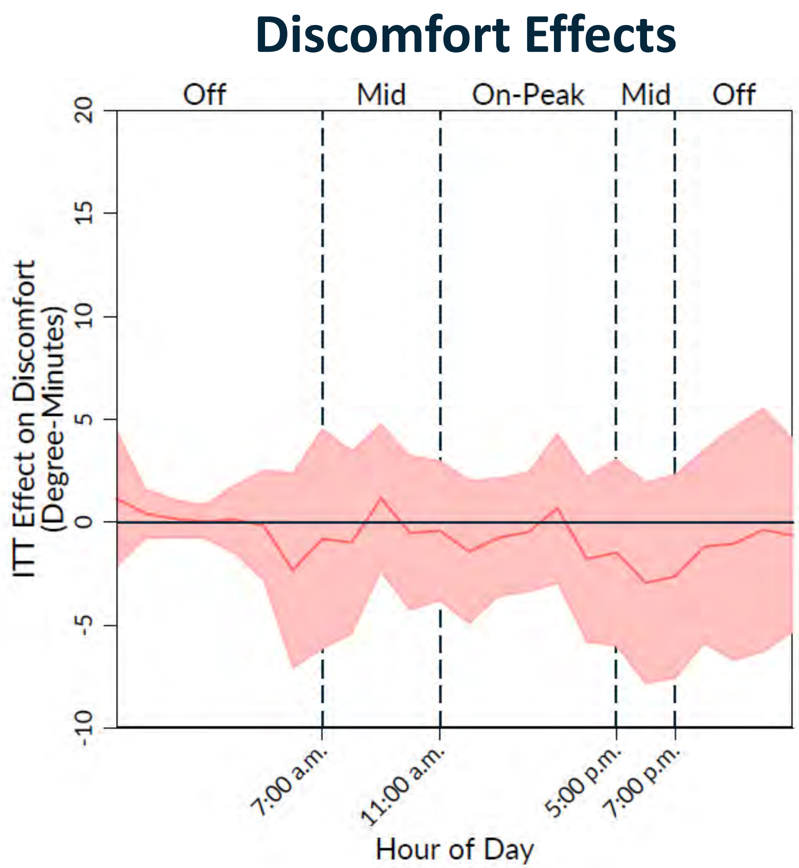
"Sometimes Home" group bears no discomfort cost



Notes: Coefficients are hourly ITT estimates for compressor run-time (left) and discomfort (right). 95% confidence intervals presented by the green shaded area. TOU rate periods are denoted by the dashed lines.

“Hardly Home” group bears no discomfort cost





Notes: Coefficients are hourly ITT estimates for compressor run-time (left) and discomfort (right). 95% confidence intervals presented by the green shaded area. TOU rate periods are denoted by the dashed lines.

Contextualizing our smart thermostat results

Overall, we estimate 17-20% reductions in peak period compressor run time and 8 – 26% increases in peak period discomfort

What does automated TOU-responsiveness mean for electricity use and bills?

- 7 % reduction in electricity use during peak hours
- 2 % reduction in electricity use
- 1 % reduction in electricity bills

Evidence that automation can improve responsiveness to time-varying prices:

- consumers are willing to sacrifice control
- sometimes and hardly home customers bear zero discomfort costs

- Suggests a role for automation in better matching demand to supply

Optimizing Electrified Water Heaters

Background on Water Heating

- In the US, 48 % of residential water heaters use natural gas and 46 % use electricity
- Natural gas water heaters contribute ~ 1 % of US CO_2 emissions
- Water heating is responsible for 9% of residential electricity use
- Conventional hot water heaters use energy in a predictable and inflexible manner with differences across fuel types.

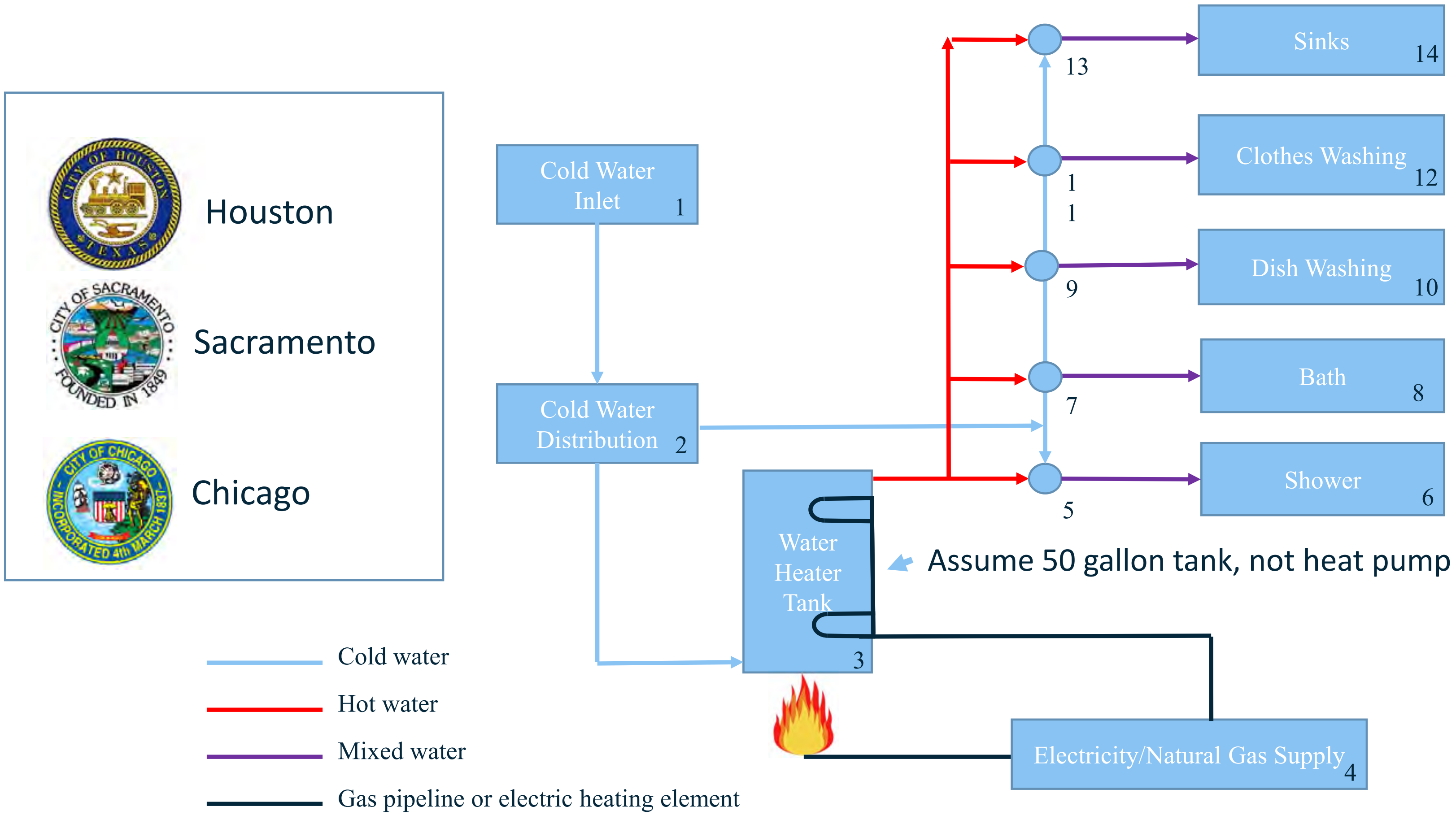
Potential benefits of widespread electrification

- If water heaters respond to variation in RE supply, they could store clean energy
- Taking the temporal demand of *hot water services* as given, thermal storage could
  - **Support the market for RE** through time shifting of *electricity use*
  - Reduce direct **GHG emissions** from water heating with natural gas
  - Reduce GHG emissions from conventional heating with electricity
- Parra et al (2016) find that water heaters are more cost-effective energy storage than lithium ion or lead batteries for integrating home solar

Water heater questions we seek to answer

- Could grid-connected electric water heaters save consumers money relative to:
  - Heating water with natural gas?
  - Conventional electric?
- What electricity pricing regimes would be necessary?
- What are the potential GHG benefits?
- What are the technical, regulatory or economic barriers to the introduction of grid-connected water heaters?

Water Heating (WH) System and Data

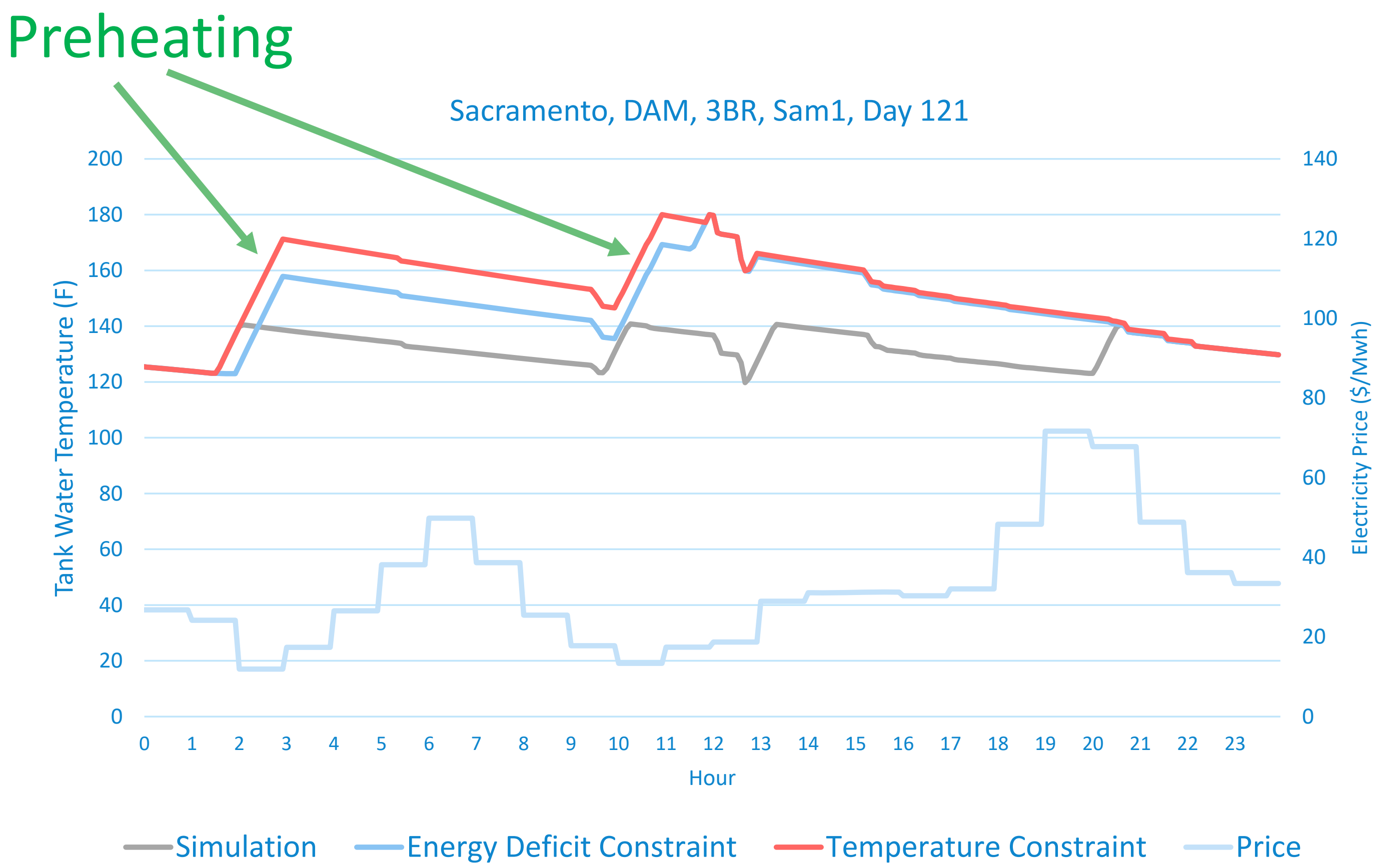


Focus on 5 hot water end uses for 5 different home sizes based on number of bedrooms.

Annual high frequency (second by second) hot water consumption profiles by end use for 3 cities from DOE domestic hot water event generator.

WH efficiency and other attributes based on new WH model for each fuel type.

Example: Anticipating the Day Ahead Market Price



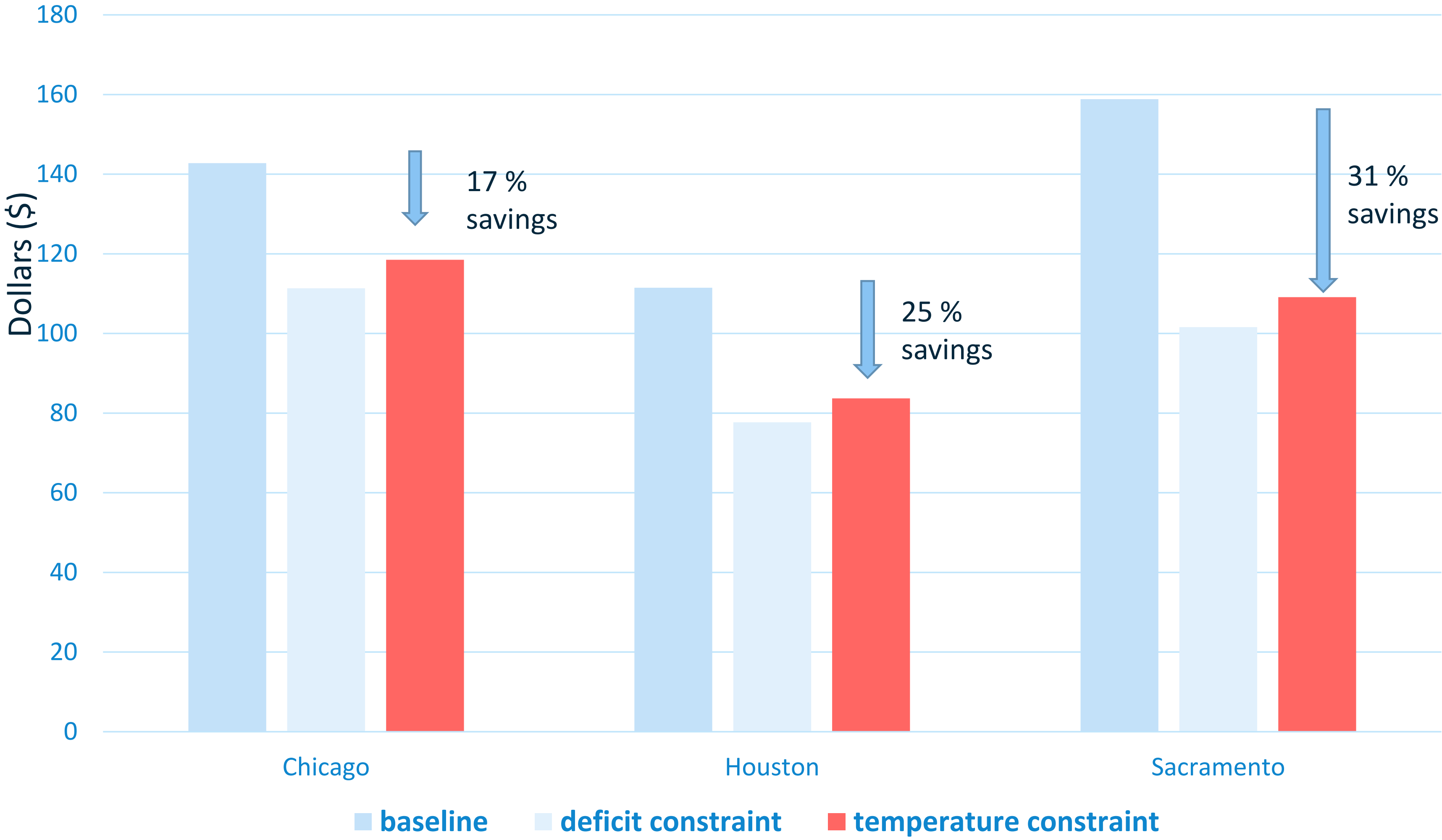
Temperature Constraint
energy cost = $0.179 /day

Energy Deficit Constraint
energy cost = $0.157 /day

Simulation (electricity)
energy cost = $0.323/day

In this work *comfort* is same or better under optimization as under regular operation.

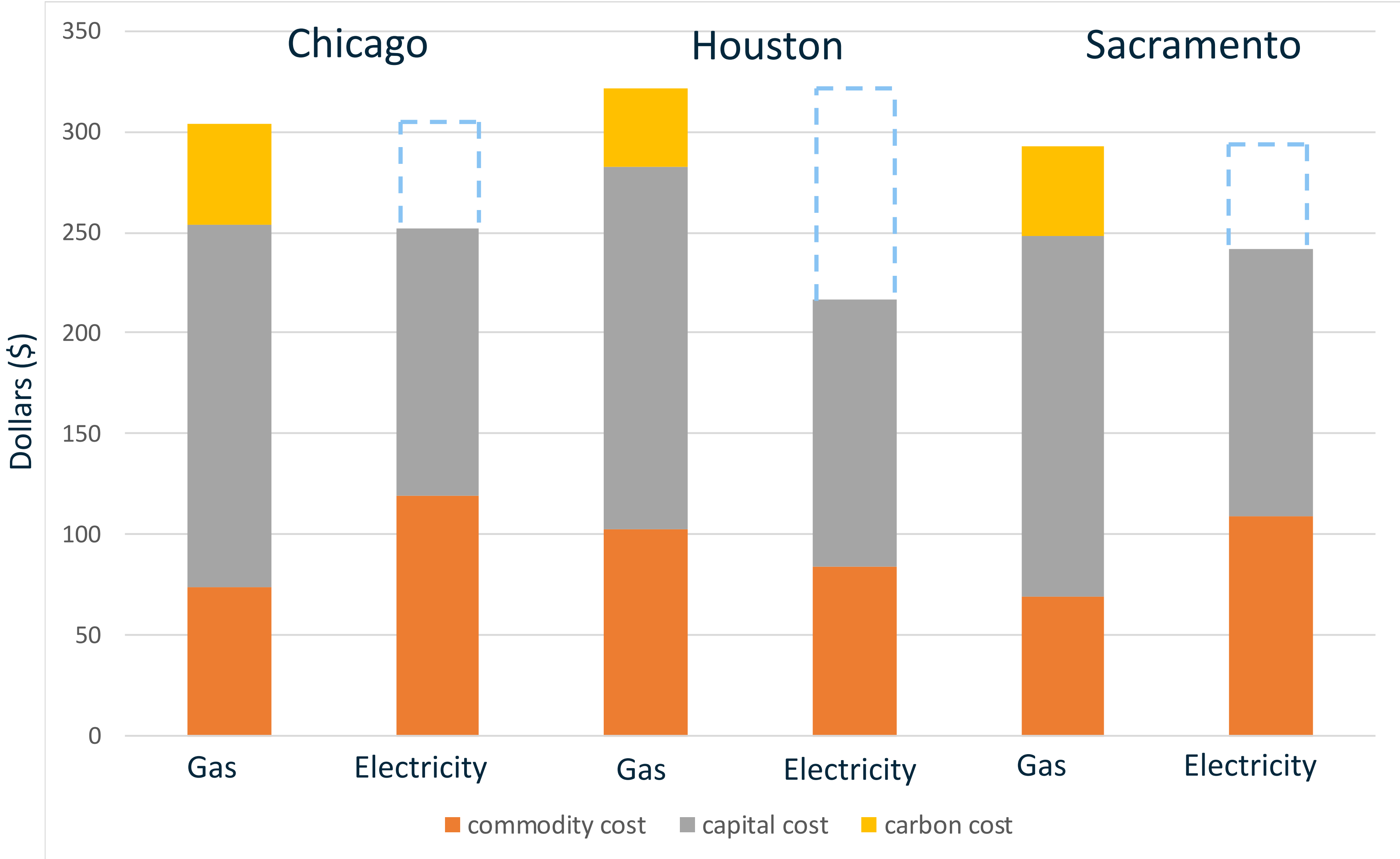
Average Annual Energy Cost for Water Heating at Day-Ahead Prices



The Value of Thermal Storage:

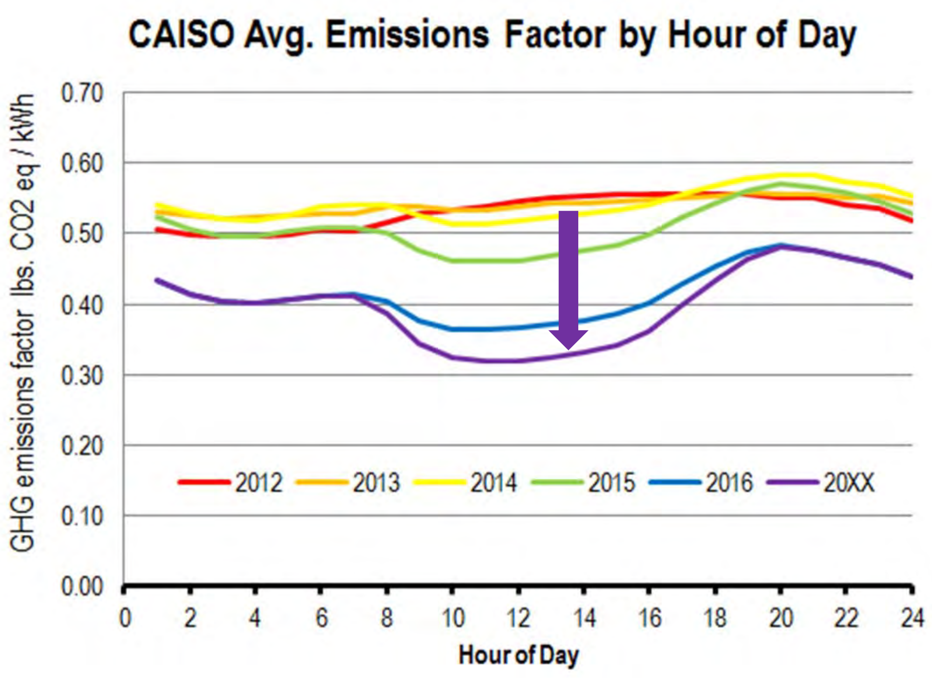
Optimization leads to biggest cost savings in Sacramento, where day-ahead electricity prices vary the most.

Annual Carbon Cost of Heating Water (3 bedroom)



Empty boxes indicate carbon cost “head room” that makes society indifferent between optimized electric and gas water heating.

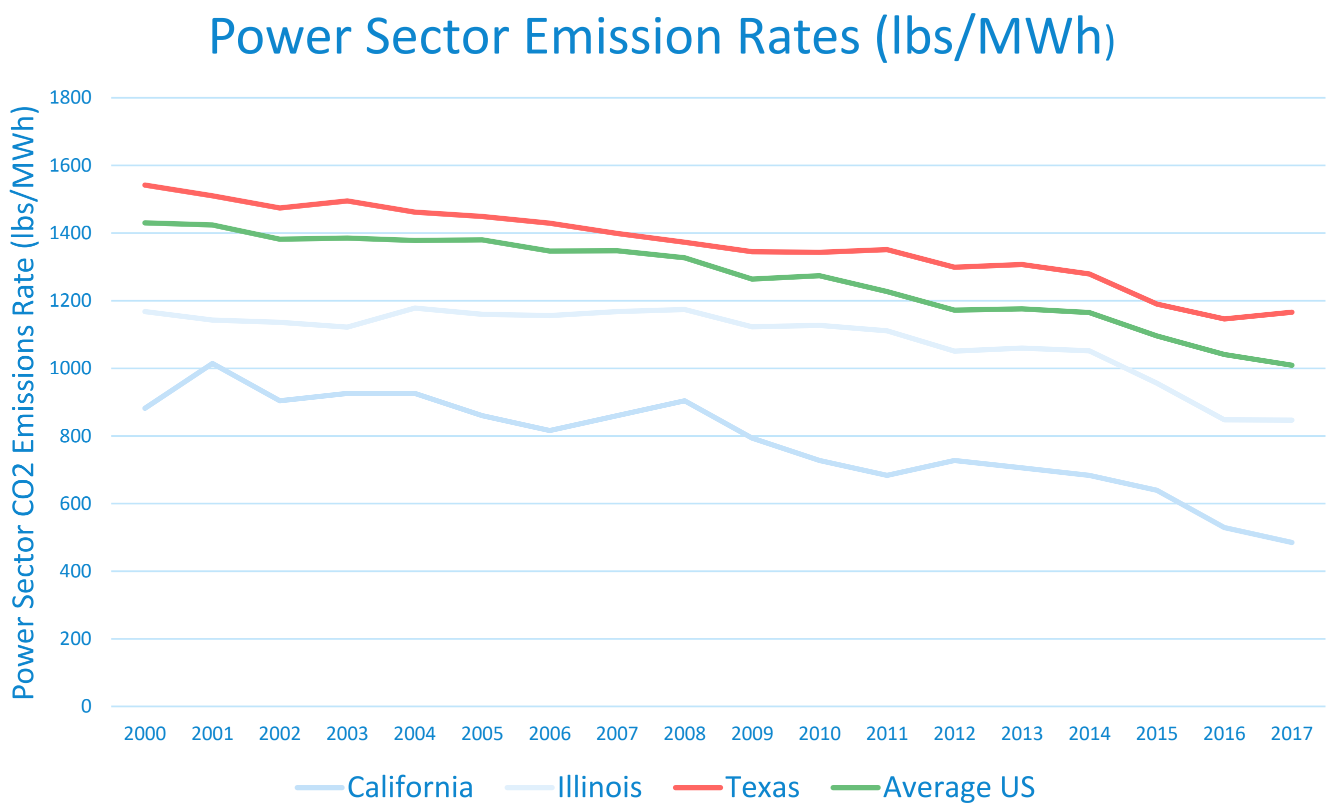
CO_2 Emissions Rates Vary within a Day



(Source: http://beyondefficiency.us/blog/whats-dirtiest-time-day-use-electricity)

- In CA low emissions rate hours are also low-cost hours when optimized water heaters will consume electricity.
- Intra-day and inter-month variation in emissions rates is present across the country.
- Estimates of CO_2 emissions rates based on current data may not predict the future well.

Power Sector Emissions Rates are Falling over Time



Sources: EIA State Electricity Profiles 2017, Table 7;
California Air Resources Board GHG Emission Current Inventory.

- Texas, US, and California emissions rates correspond to emissions intensity of electricity consumption
- Illinois displays the emissions intensity of electricity generation in the state

What about Fixed Costs of Electric Grid?

- The greatest opportunity to incentivize electrification in WH is evident with ***day-ahead wholesale prices***. But households pay ***retail prices*** including administration, and (sunk) fixed transmission and distribution.
- New sources of electricity demand introduce incremental grid costs through investment and congestion. Likely to be modest.
- Incremental grid costs are possibly negative if new loads enable renewable integration.

Win-Win Cross-Subsidies to Achieve Electrification?

- Efficiency (Ramsey) suggests placing recovery of shared fixed (grid) costs on inelastic demand. This might suggest charging incumbents for sunk costs.
- There is not fairness criterion to guide grid cost recovery beyond the Shapely value.
- If public policy aims at (a) *electrification* to achieve (b) *decarbonization*, then separately metered prices for beneficial electrification may be justified

Future Models for Engaging Demand

Could the future be Energy-as-a-Service (EaaS)?

- With electrification, is it time to redefine the market?
- Control devices and data will be important for realizing gains described above. Should management of both be outsourced?
- Electricity is an intermediate good that powers energy services (hot water, etc.)
- Consumers value the energy service that electricity provides
- EaaS provider charges for the energy service rather than the electricity

Energy-as-a-Service

- Enables demand shifting in response to prices without consumer involvement
- EaaS company charges consumers for hot water and manages grid-connected electric WH as a subscription (or EV charging)
  - EaaS provider profits from cost savings of shifting demand for electricity in time without compromising value for the customer
  - Enables participation of water heater in wholesale markets for ancillary grid services that bring additional value
- Service model subscription could even replace device ownership
- Stay tuned…

Summary

- Achieving long-term climate goals requires decarbonization of electricity production and electrification of additional energy uses.
- Integration of renewables poses challenges with matching demand and supply
- Automation and electrification can help facilitate efficient demand shifting with direct and indirect climate benefits.
- Innovations in rate design and other regulatory reforms will be important steps in realizing the renewable integration opportunities.

RESOURCES *for the* FUTURE

Thank you.

- Find out more about RFF online: **www.rff.org**
- Follow us on Twitter: **@rff**
- Subscribe to receive updates: **rff.org/subscribe**