Impacts of DERs on net loads and approaches for actively managing load shapes

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for Midwest/MISO Region
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Impacts of DERs on net loads and approaches for actively managing load shapes

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Lawrence Berkeley National Laboratory

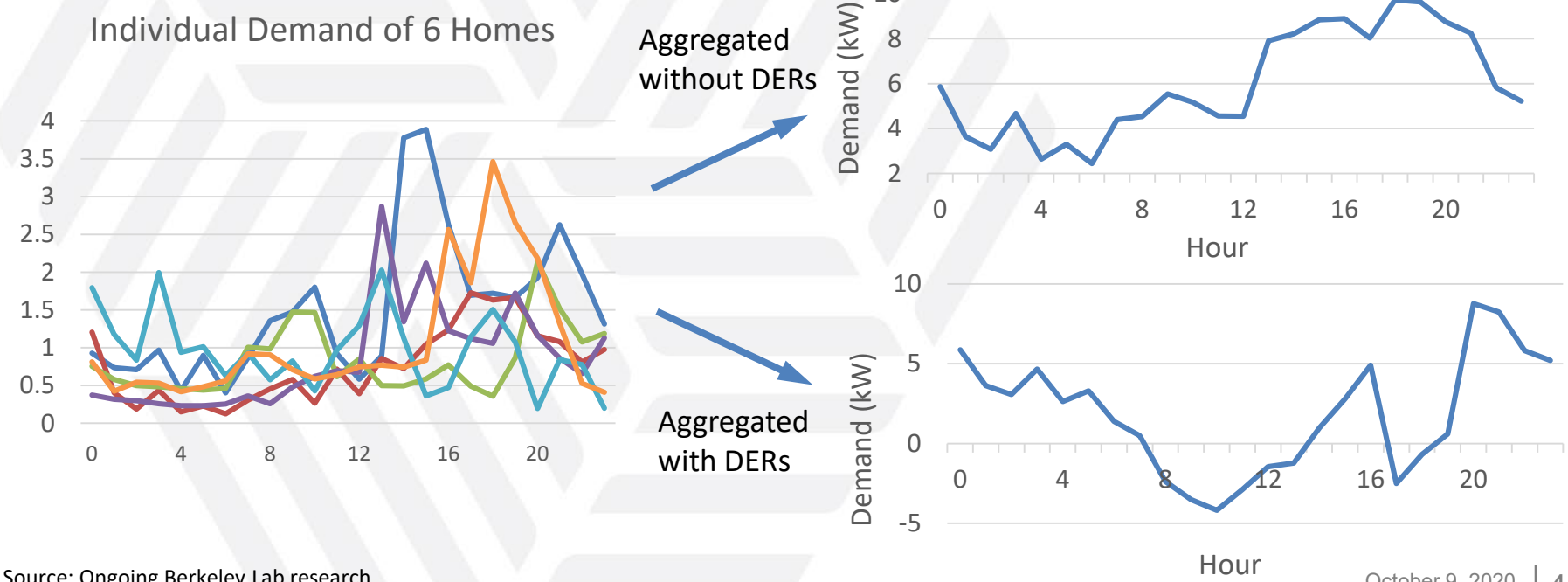
Agenda

- Overview
  - Definition of net load
  - Importance of net load shape management
  - Current trends in net load shapes
- Impact of individual distributed energy resources (DERs) on net load
  - Solar
  - Energy storage
  - Energy efficiency
  - Demand response
    - Time-of-use
    - Critical peak pricing
    - Direct load control
- Combined impact of multiple DER strategies
- Utility strategies for managing net load shapes
- Questions states can ask
- Resources for more information

What are net load shapes?

- The profile of a customer's grid electricity demand over time as affected by behind-the-meter generation and other DER technologies

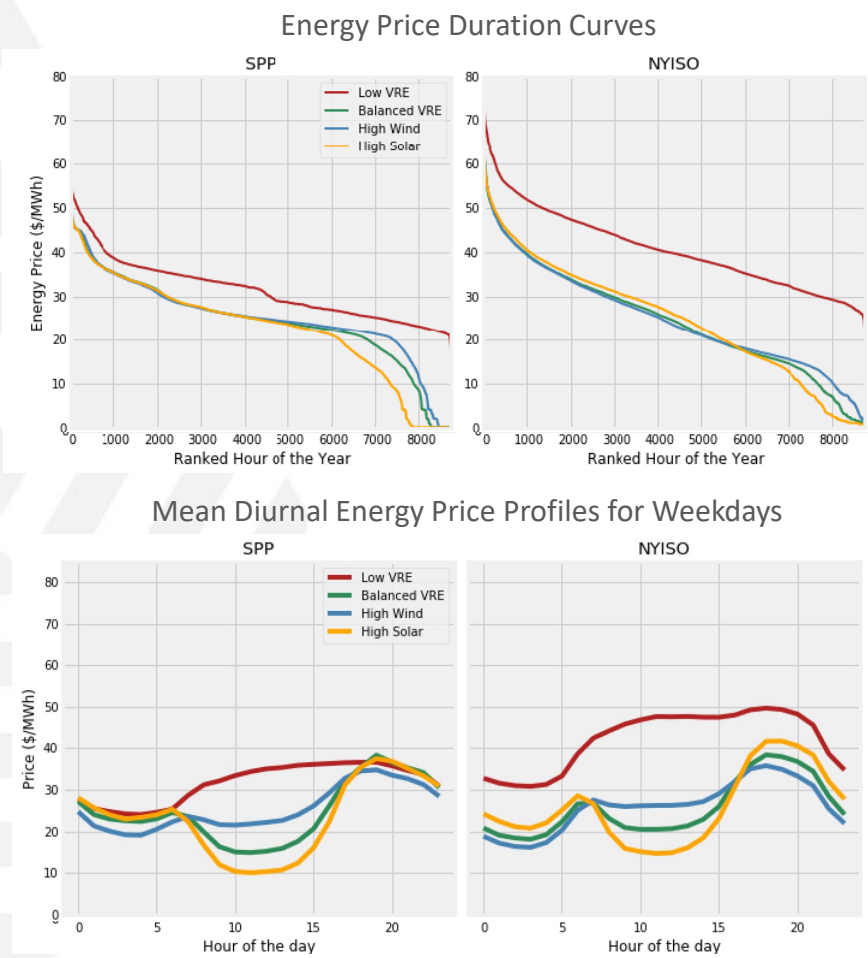
- Net load lessens the impact of idiosyncrasies in individual load shapes but accentuates shared patterns of behavior.



Source: Ongoing Berkeley Lab research

DERs are a growing opportunity for net load shape management.

- More flexible electricity systems are more reliable and resilient.[1]
  - DERs offer the opportunity for utilities and customers to control electricity loads during periods of high system demand and costs.
  - Top figure shows energy price curves that demonstrate how a small portion of hours during the year have much higher prices.
- Variable renewable energy (VRE) increases the need for more flexible loads and more opportunities to shift load to periods with lower energy prices.
  - Bottom figure shows simulated diurnal energy prices and energy price duration curves with increased VRE penetration.[2]
  - Potential for better alignment of solar and demand during summers, when energy prices typically are higher
  - VRE-generated electricity can be stored and dispatched when there is more need.
- State climate goals also will require flexible resources to balance generation and load.



Source: Seel, J., A. D. Mills, and R. Wiser. *Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making*. 2018.

Net load shapes are changing — for example, with increasing penetration of distributed solar.

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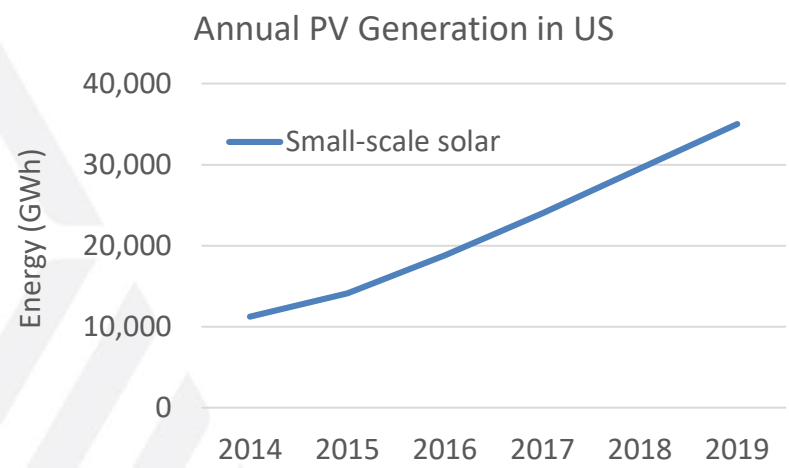
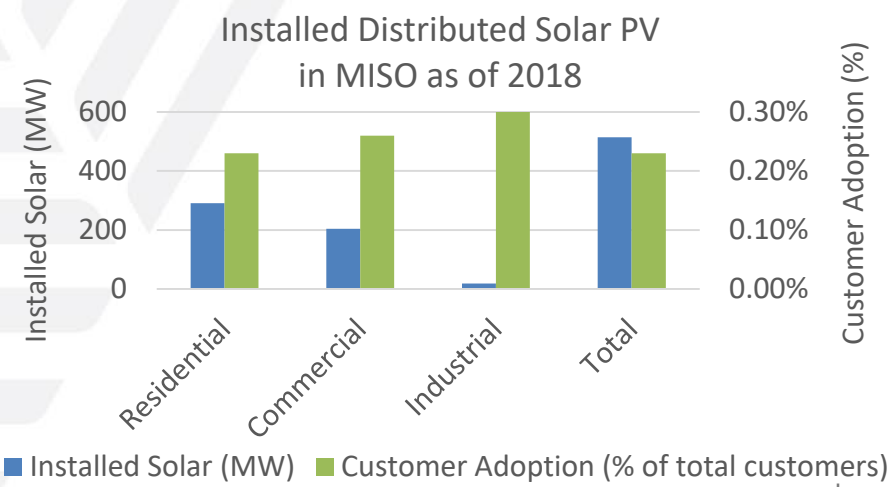
- The upper-right figure shows how annual generation of small-scale solar (i.e., residential and commercial) is increasing each year, as estimated by EIA.[1]
- As solar capital costs decrease, customers will continue to install more distributed solar.
- Distributed solar adoption levels in MISO are not high, as shown in the lower-right figure, but emerging regulatory goals indicate that may change.
  - 4 states working towards plans for 100% clean energy goals by 2050 (MN, WI, IL, MI),[2] with many cities also establishing decarbonization goals
- Many large utilities in MISO's footprint have set clean energy and decarbonization targets:
  - Xcel Energy, Ameren, Duke, and Alliant have net-zero carbon by 2050 goals.
  - Other utilities in the region also are working towards carbon reduction targets.



Source: EIA Electric Power Monthly

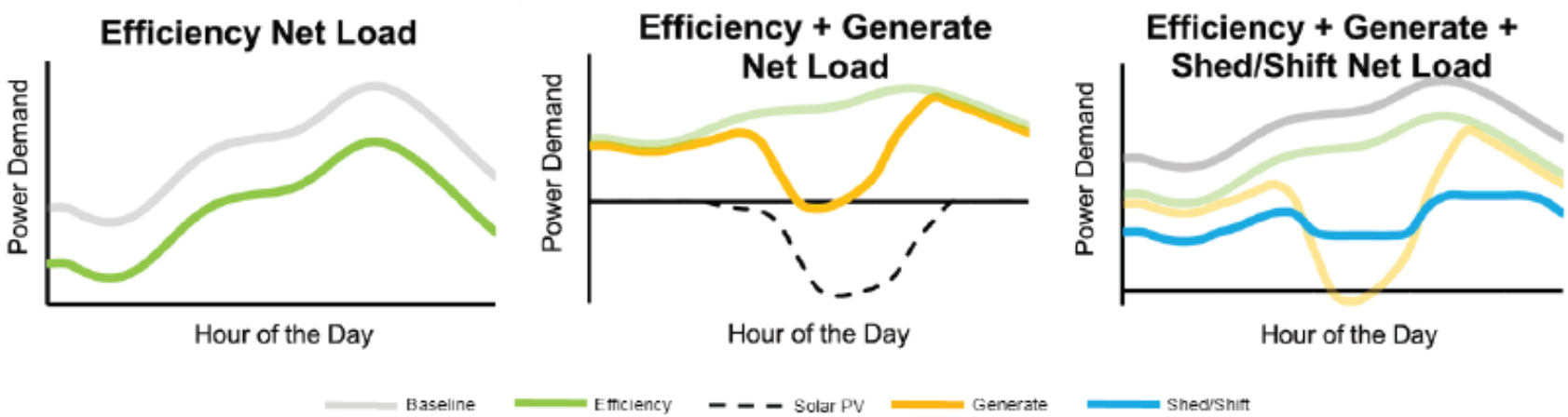


Source: 2018 EIA-861 data

Impact of individual DERs on net load

- DERs can impact net load in the following ways:
  - Generation: Provide electricity onsite, behind-the-meter, from sources such as solar or storage discharge. Reduce grid demand and potentially export electricity back to the grid.
  - Energy efficiency: Long-term reduction in energy usage with changes in customer end-uses.
  - Load shifting: Change the timing of electricity usage using DERs such as storage or behavioral demand response
  - Load shedding: Reduce intended electricity usage, usually for a scheduled period, using DERs such as demand response

Impact of DERs on Net Load Shape[1]



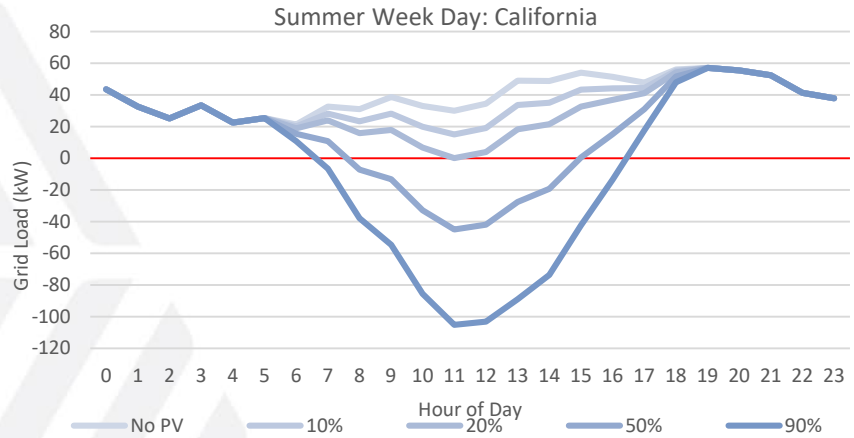
Source: Neukomm, et al. *Grid-Interactive Efficiency Buildings*. 2019.

How DERs affect net load shapes: Illustrative examples

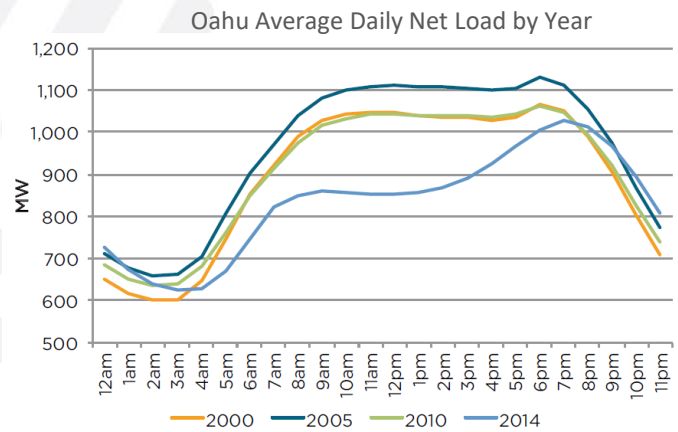
- Distributed solar
- Energy storage
- Energy efficiency
- Demand response
  - Time-of-use
  - Critical peak pricing
  - Direct load control

Distributed solar PV lowers midday net load through self-consumption and export.

- Customers use onsite solar PV for self-consumption, reducing electricity purchased from the grid.
  - Solar PV lowers net load while generating during midday.
  - Excess solar PV is exported to the grid through net metering and other programs.
  - The top figure shows the modeled impact of increasing solar penetration on an aggregate load of 60 homes in California.
  - The bottom figure shows historical average daily load for Hawaiian Electric Company.
- Utilities can use several strategies to manage net load impacts from solar PV.
  - Set late-in-day peak periods (for time-of-use) that promote west-facing solar installations
  - Change compensation for solar exports
  - Establish time-based rates to shift demand to midday
  - Promote technologies that smooth midday curve (e.g., energy storage)



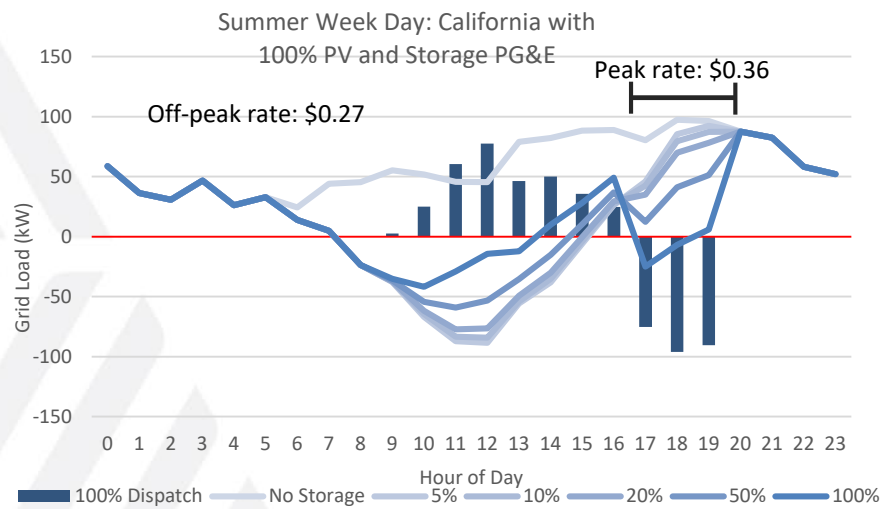
Source: Ongoing Berkeley Lab research

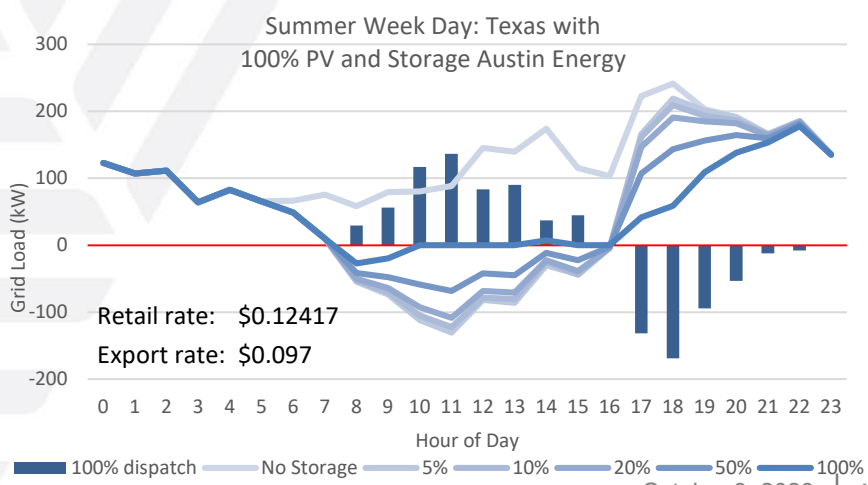


Source: The Economic Research Organization at the University of Hawai'i. *Estimating the Opportunity for Load-Shifting in Hawaii: An Analysis of Proposed Residential Time-of-Use Rates*. 2016.

Customers can use storage with solar PV to increase system value, smoothing peaks.

- Energy storage can charge from solar PV generation and discharge during other periods, reducing the impact of solar PV on midday net load.
- Storage has incentive to dispatch:
  - When exporting solar is less valuable than offsetting net load at other periods (top figure)
  - When it can offset positive net load during peak period (top figure) with TOU pricing
- With value-of-solar tariff, storage dispatch is always more economic than solar PV export.
  - Bottom figure shows modeled impact of solar and storage on net load for 60 homes with flat-rate pricing and a value-of-solar tariff.
  - Storage absorbs more generation, with larger impacts on midday and evening loads.
- With TOU rates and net metering, storage only discharges during peak period.
  - New peak from storage discharge as peak period begins; excess solar exported (bottom figure)

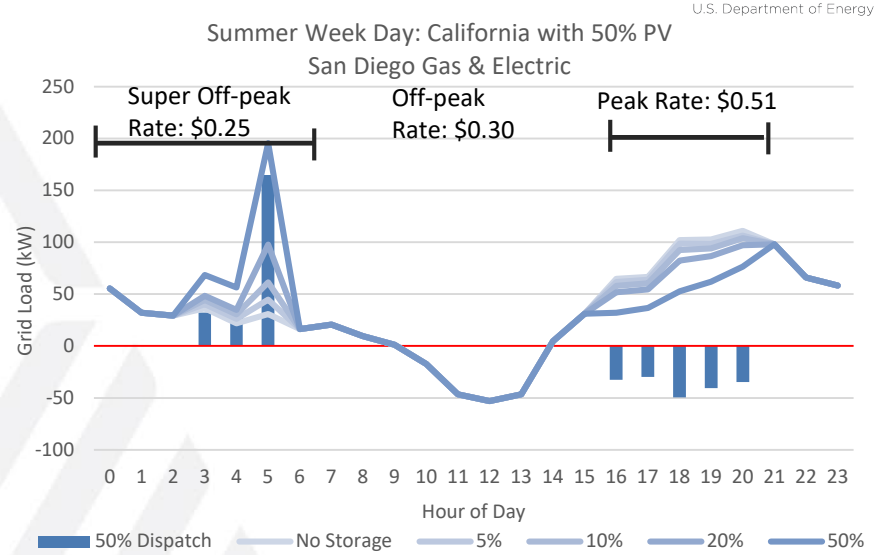


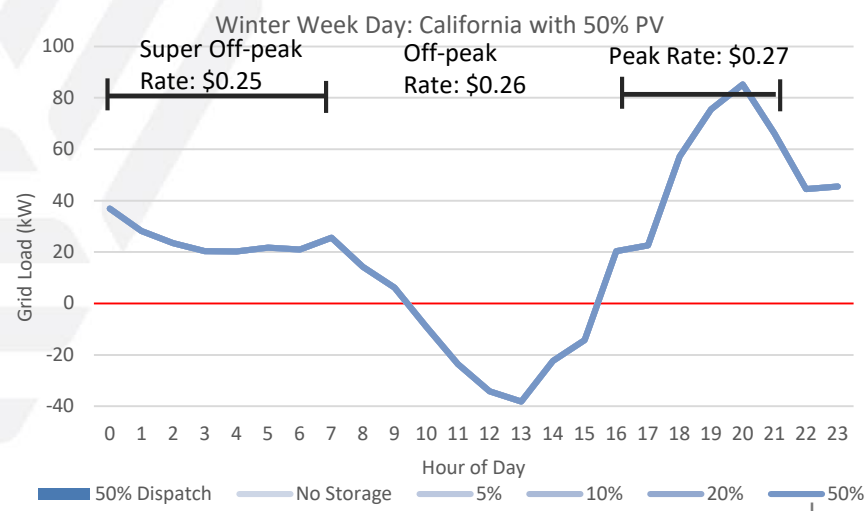


Source: Ongoing Berkeley Lab research

Storage behavior is sensitive to electricity prices, rate schedule, and efficiency losses.

- With net energy metering 2.0, solar export rates are slightly lower than retail rates due to non-bypassable charge (~$0.02/kWh).
  - Figures show impact of seasonal electricity price variation on modeled net load for 60 homes with TOU pricing and net energy metering 2.0.
- Storage can create value for customer by charging from grid during off-peak, leading to new net load peaks if not managed.
  - Top figure shows storage charging during morning super off-peak period in summer despite solar availability because of greater value to customer
- Smaller difference in winter TOU prices eliminates an incentive to dispatch through grid or solar charging (bottom figure)
  - Storage will not discharge if price differential of charging and discharging periods is too small.
  - Although price differential is positive, storage must overcome roundtrip efficiency losses in order to provide value through dispatch.

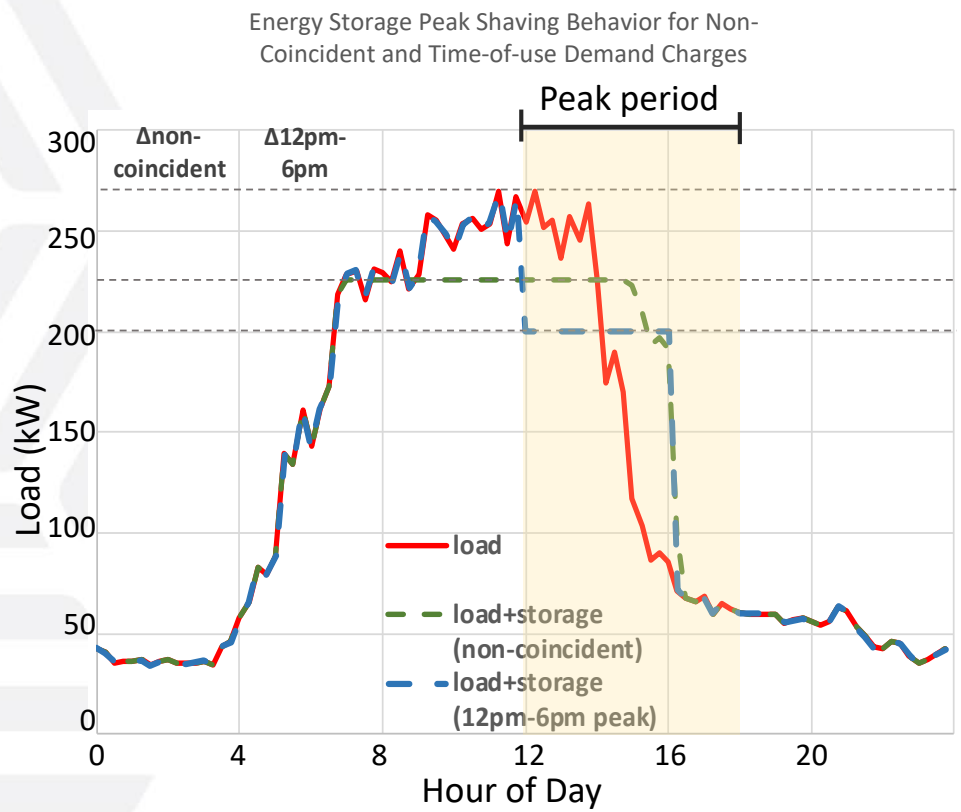




Source: Ongoing Berkeley Lab research

For large commercial customers, storage behavior is driven by demand charges.

- Large commercial customers with demand charges ($/kW) are adopting standalone storage to target daily peak shaving.
  - Non-coincident demand charges apply to the customer's highest demand any time during billing period. Coincident demand charges apply only to defined periods.
- Storage charges when customer demand is low and discharges when demand exceeds target.
  - Behavior is dependent on storage dispatch algorithm's ability to predict time, duration, and amplitude of peak.
- Storage shaves peak throughout day for non-coincident demand charges, but only dispatches during peak with TOU demand charges (see figure).
  - For TOU demand charges, demand reduction is more significant as the same amount of energy is discharged from storage in a shorter period.
  - Peak shaving with non-coincident demand charge creates a flat net load throughout the day. With TOU demand charges, it creates a large ramp between the peak period and other hours.



Source: Darghouth, N., G. Barbose, and A. Mills. *Implications of Rate Design for the Customer-Economics of Behind-the-Meter Storage*. 2019.

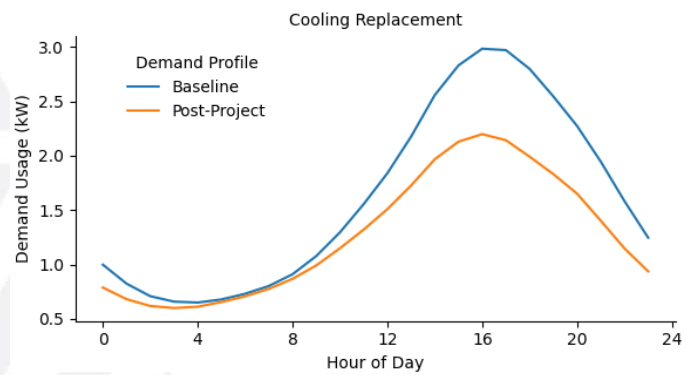
What can utilities do to manage net load impacts from storage?

- Paired solar and storage provides load reduction and load opportunities only when price signals incentivize storage dispatch.
  - For example, winter TOU prices with smaller price differentials may lead to inactive storage.
  - Standalone storage can provide load shifting through grid charging, but may also create new net load peaks.
- Utilities can design rate structures that incentivize when storage charges and discharges based on desired impact.
  - For example, non-coincident demand charges target daily reduction of consumption, while TOU demand charges cause higher reduction only during peak demand.
- Utilities can design value of solar tariffs to incentivize maximizing self-consumption of solar generation or solar export.

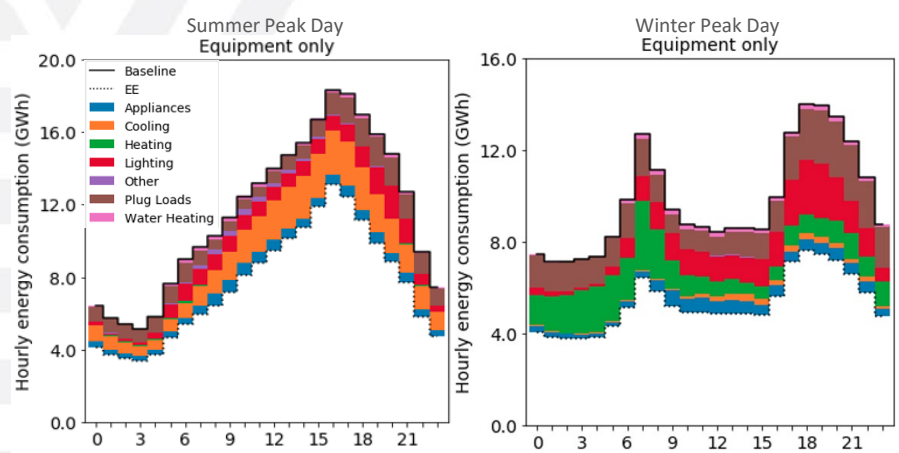
Energy efficiency measures affect net loads without active management.

- Energy efficiency impacts vary based on applied measure, generally decreasing net load shape in line with customer's usage.
- Efficiency programs to upgrade buildings target common equipment like lighting, cooling, heating, water heating, envelope, and large appliances.
- Improved building performance can reduce system peak demand — e.g., during peak hours for space heating or cooling.
  - Top figure: avr. measured impact of cooling equipment replacements in CA homes
- Efficiency upgrades affect different time and seasonal periods of net load.
  - Bottom figure: simulated impact of other equipment upgrades for CA homes
- Diversity of efficiency measures provides opportunities for specific demand reduction
  - Utilities can strategically design programs to target reduction by period, season, and customer sector.

Measured Impact of Residential Energy Efficiency Upgrades for Summer Day



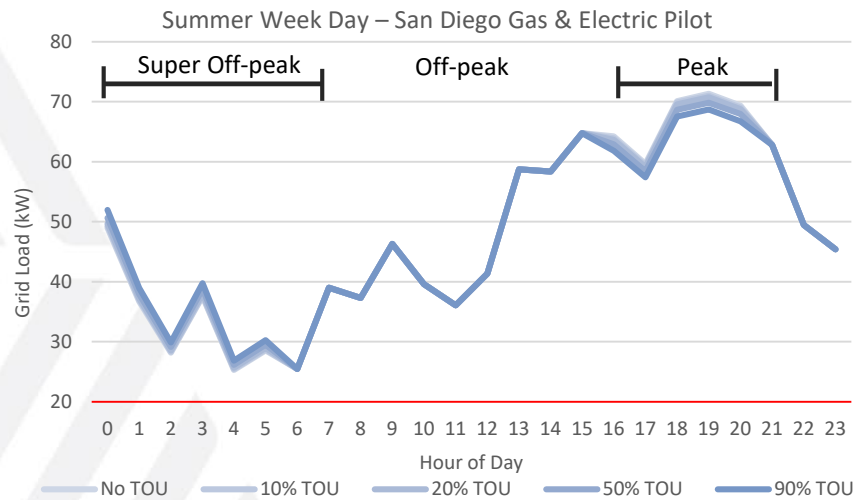
Simulated Impact of Residential Energy Efficiency Upgrades

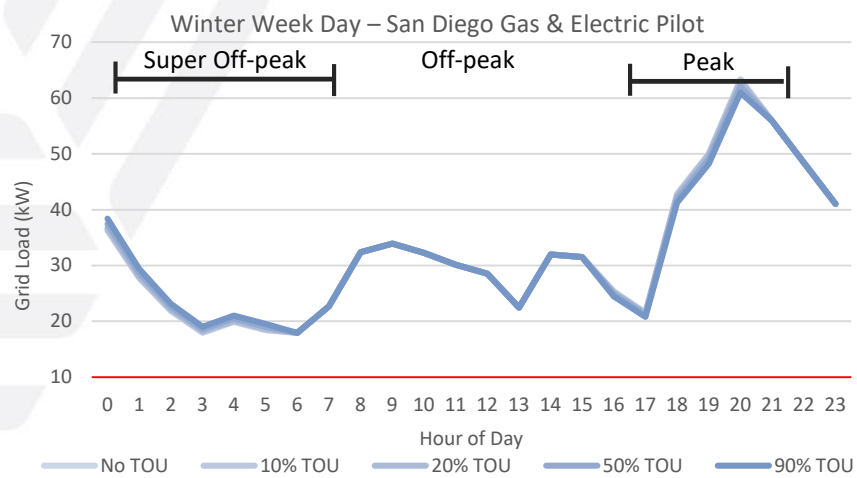


Source: Figures from ongoing LBNL research

TOU rates provide demand response through price responsiveness.

- TOU pricing growing due to increase in:[1]
  - Advanced metering infrastructure
  - Increased DER penetration
  - Surplus DER generation during midday
- TOU rate design can impact net load by influencing changes in customer behavior, even absent enabling technologies.
  - Despite behavior diversity, customers consistently reduced or shifted peak period consumption in utility pilots[2]
- Example: modeled customer response to TOU pricing based on measured response (see figures showing 60 homes)
  - For 3-period pricing, customers decreased usage during peak period and slightly increased usage during super off-peak.
  - Increase in off-peak usage near zero for 2-period rates (not shown), despite decrease in on-peak usage
- Studies show high retention rate for opt-in and opt-out groups, with opt-in recruitment 15% on average[2]

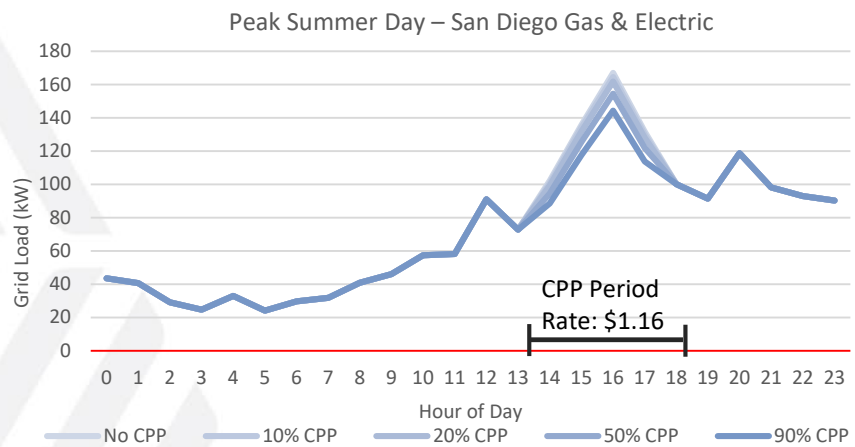




Source: Ongoing Berkeley Lab research

Critical peak pricing provides more control through customer response on peak days.

- Under critical peak pricing (CPP), customers pay a higher price for energy during a pre-defined period during critical event days (i.e., days with high demand).
- CPP provides a day-ahead net load management for targeted peak reduction.
- Critical peak period prices are generally much higher than TOU peak prices and only occur when called (typically 5-22 days per year[1])
  - Median on-peak to off-peak price ratio is 2.7 to 1 for TOU[2] compared to lowest critical peak price ratios around 4 to 1[1]
  - Customers incentivized to enroll through slight price reduction for non-peak periods
- Figure shows net load with modeled customer response to a critical peak period on a peak summer day
- Combination of higher price signal and advance notification to customers leads to higher reduction during critical peak period



Source: Ongoing Berkeley Lab research

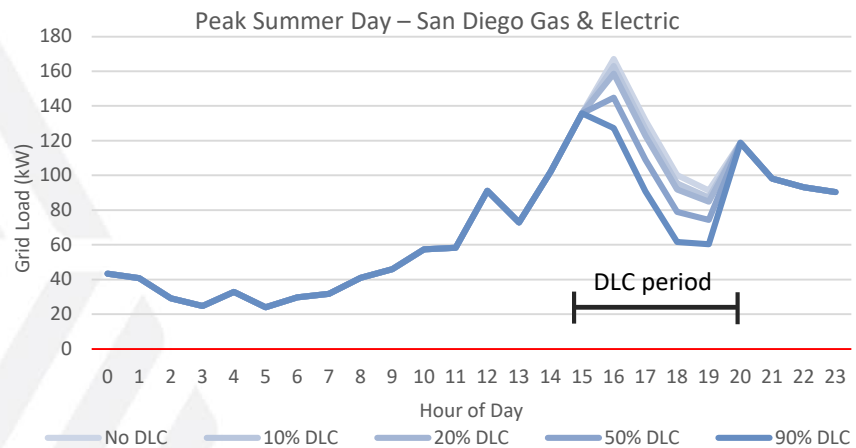
Time-Based Pricing Programs[3]

Program	Definition
Time-of-use	Fixed, pre-set retail rates vary by time of day, season, and day type. Generally, period are defined as peak, off-peak, and potentially others.
Critical Peak Pricing	Event is called day-ahead, and infrequently, where customers pay a pre-defined electricity price premium during event period.
Critical Peak Rebate	Like critical peak, event is called day-ahead and infrequently. Unlike critical peak pricing, customer received a rebate for reducing during event.
Variable Peak Pricing	Peak hours are defined, like TOU, but peak price is adjusted daily based on wholesale market prices.
Real-time Pricing	Customers are charged prices that vary over short time intervals, typically hourly, that are set one day in advance.

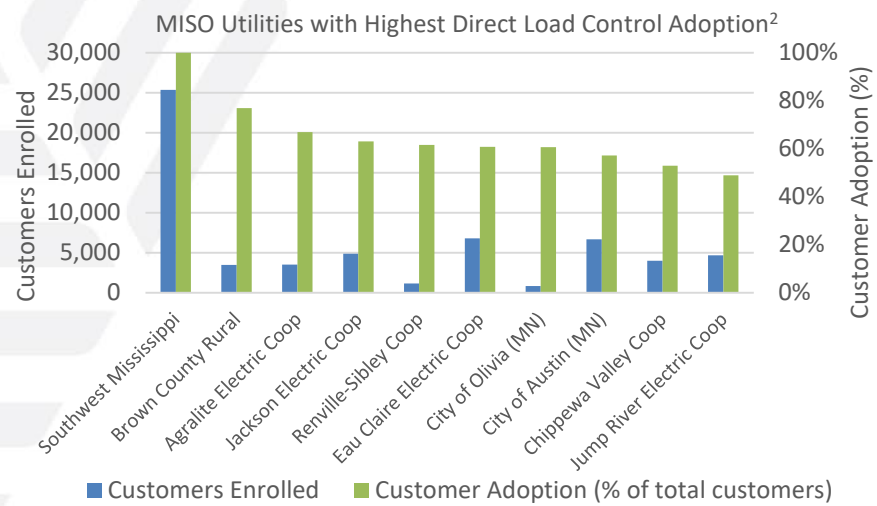
Source: Cappers, R. and R. Scheer. 2016.

Direct load control provides predictable impact on peak days.

- Direct load control (DLC) allows utilities to remotely cycle air conditioners and water heaters, or adjust thermostat settings, during events for pre-established periods.
  - Equipment cycled between 50%-100% during event depending on program
- Like CPP rates, there's a cap on the number of events per year.
  - Customer can opt out for single events.
- Customer receives an annual credit or enrollment incentive.
- Top figure shows modeled net load impact of air conditioning DLC during a peak summer day for varying levels of DLC enrollment
- Programs largely target residential (4M enrolled in U.S. as of 2018); small C&I customers enroll to a smaller extent (84,000 as of 2018)[1]
  - Bottom figure shows top 10 utilities in MISO by customer enrollment in DLC



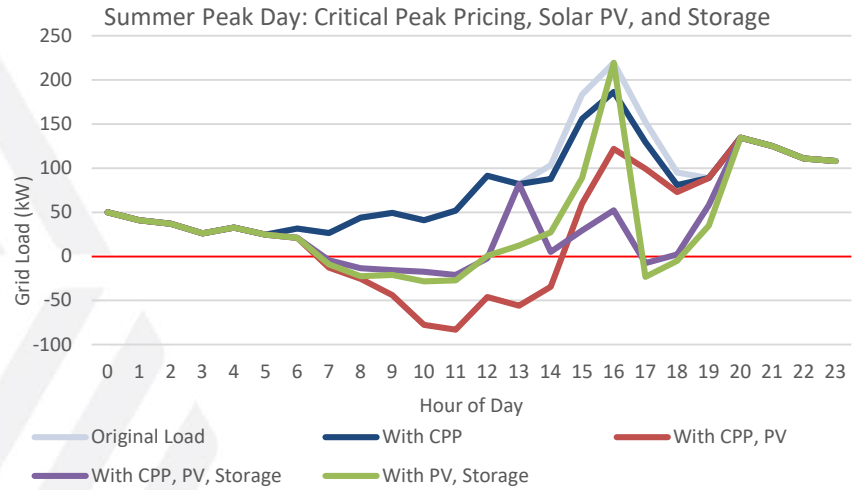
Source: Ongoing Berkeley Lab research

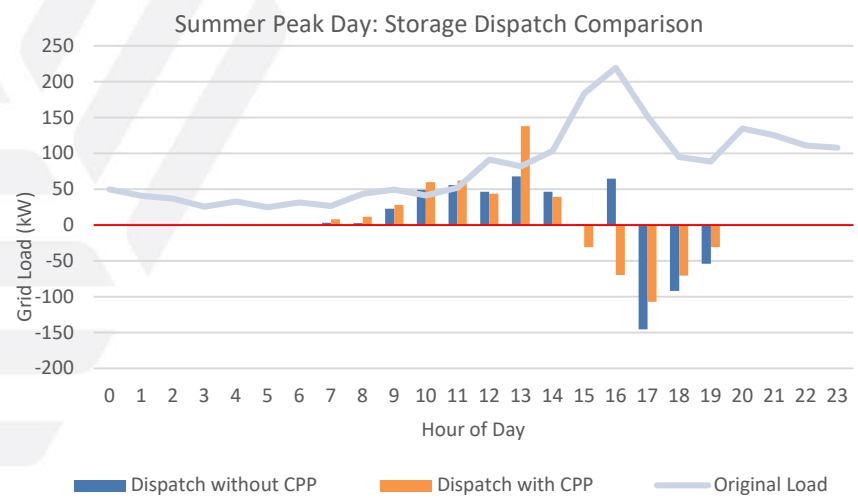


Source: 2018 EIA-861 data

Combined DERs provide strategies for managing different net load needs.

- Combining DERs provides utilities with a menu of options that allow them to generate, shift, and shed.
- On peak days, solar and storage provide additional benefit by responding to changes in net load profile from DLC and peak period rate for CPP.
- Top figure shows changes in net load as DERs are sequentially applied for a peak day (for Pacific Gas and Electric).
  - CPP alone: est. 15% reduction in customer usage during event period (2 pm to 7 pm)
  - With solar PV: Reduces midday net load; generation overlaps with CPP in afternoon
  - With storage: Charges from solar, absorbing all generation at 1 pm and fully discharges during CPP period
- Without critical peak period, storage would have dispatched only during peak period from 5 pm to 8 pm (bottom figure).





Source: Ongoing Berkeley Lab research

Figures demonstrate interaction of DERs with 100% customer adoption.

Looking forward: Utilities are designing platforms to tap into DER flexibility.

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- Utilities are exploring how to have more visibility and control for better DER management.
- In California, Rule 21 requires all distributed solar to use inverters with remote communication and grid service capabilities.
  - While platforms are still developing, distributed solar PV installations will be capable of utility control without requiring additional technological upgrades.
  - CA passed a bill in 2019 that will foster higher adoption of demand response-ready appliances.[2]
  - Such regulations enable technologies that provide utilities with more visibility and control.
- Some utilities are creating centralized platforms for aggregating dispatchable DERs to control net load, such as “virtual power plants” (VPPs), that can potentially operate DERs synchronously, provide grid services, and participate in wholesale markets.
  - Like direct load control, utilities can schedule and dispatch other DERs, such as energy storage systems.
  - By aggregating smaller resources, VPPs facilitate a unified approach to providing demand response and other grid functions for greater impact.
- Some utilities testing VPPs through pilots:
  - Portland General Electric, Southern California Edison, Austin Energy, California Community Choice Aggregators

Questions states can ask

- How are your utilities planning for increasing solar PV penetration?
- What risks are utility systems currently facing from distributed solar PV impacts on net load?
- What DERs and DER programs are currently available for active management of net loads?
- How have programs historically used DERs during peak demand? What best practices have been learned?
- How is design of energy efficiency programs addressing peak demand reductions and changes in peak demand periods?
- How are utilities recruiting and incentivizing customers to enroll in active demand management programs?
- Do utilities have a platform in place for controlling DERs? Which DERs and customers are eligible?
- How are utilities using pilots and research to better understand net load shapes with higher DER adoption?

Resources for more information

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- Schwartz, L., M. Wei, W. Morrow, J. Deason, S. Schiller, G. Leventis, S. J. Smith, W. L. Leow, T. Levin, S. Plotkin, Y. Zhou, and J. Teng. *Electricity End Uses, Energy Efficiency, and Distributed Energy Resources Baseline*. 2017.
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- Satchwell, A., P. Cappers, J. Deason, S. Forrester, N. M. Frick, B. F. Gerke, and M. A. Piette. *A Conceptual Framework to Describe Energy Efficiency and Demand Response Interactions*. 2020.
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- Gerke, B., G. Gallo, S. J. Smith, J. Liu, S. V. Raghavan, P. Schwartz, M. A. Piette, R. Yin, and S. Stensson. *The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030*. 2020.
- Potter, J., E. Stuart, and P. Cappers. *Barriers and Opportunities to Broader Adoption of Integrated Demand Side Management at Electric Utilities: A Scoping Study*. 2018.

Integrating Load Shape Analysis into Grid Modeling

Matt Leach

National Renewable Energy Laboratory (NREL)

Objectives

Understanding building energy consumption at scale

Capturing building demand flexibility

Utilizing grid model to evaluate flexibility dispatch

Key Takeaways

Demand flexibility should be treated on par with supply-side options so all grid impacts, costs, and benefits to the utility system can be quantified and monetized

DOE and the national labs are developing new tools and analytics to account for:

1. All electric utility system economic impacts resulting from demand flexibility
2. Variability in value based on when and where demand flexibility occurs
3. Impact of distribution system savings on transmission and generation system value
4. Variability in value due to interactions between DERs (and between DERs and other system resources) providing demand flexibility
5. Benefits across the full expected lives of the resources

Key Benefits of GEBs

Understanding the potential of building end uses to provide demand flexibility to the grid and devising programs to facilitate and incentivize the dispatch of those resources will:

1. Reduce grid congestion (at both the bulk power and distribution scales), especially during peak demand periods

2. Lower energy bills by reducing the need for future investment in supply-side generation

3. Align building energy demand with peak solar and wind output to reduce the need for curtailment of renewable generation

4. Reduce overall grid operating costs and net electricity costs for participating buildings

Understanding Building Energy Consumption

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Where is energy used in the US building stock?

- Where geographically?
- What building types?
- What end uses?
- At what times?

How can buildings provide service to the grid?

- What is the role of efficiency?
- What is the capacity for load shaping?
- What are the time/location/configuration dependencies?

ResStock and ComStock

Bottom-Up Engineering Models of the U.S. Building Stock

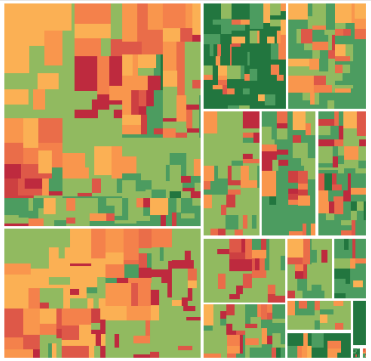
- ResStock – Residential Stock
- ComStock – Commercial Stock

Simple, fast	Simple & fast enough	Complex, slow

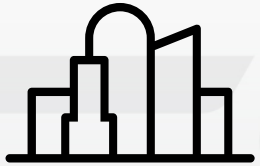
Finding the Balance between Speed and Complexity

- Highly granular building stock to capture diversity
- Sub-hourly detail – calibrated to real data
- Can model controls, demand response, etc.
- Includes measure interaction
- Visualizations for slicing data

High-granularity



ResStock / ComStock Overview



Building stock characteristics database

+

Physics-based computer modeling

+

High-performance computing

ResStock / ComStock Overview

Building stock characteristics database

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Physics-based computer modeling

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High-performance computing

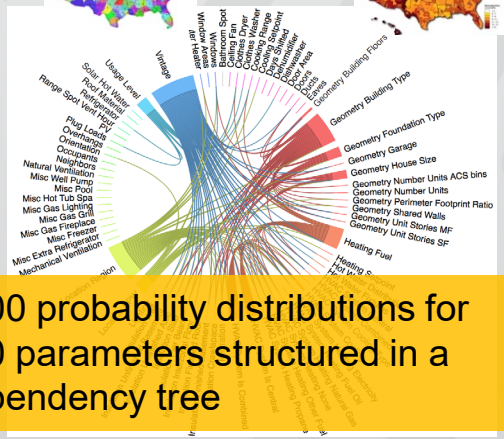
Large public and private datasets

Census Data

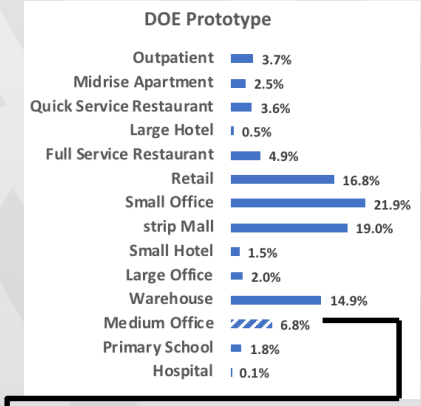
Building Characteristics

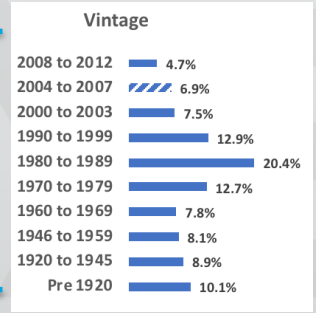
Climate Locations

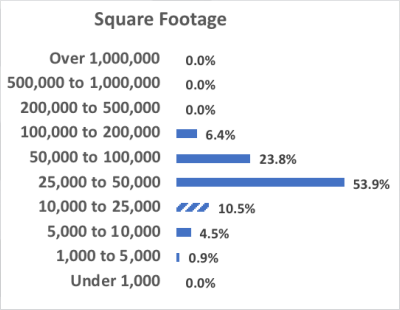
Costs

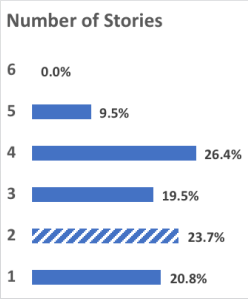


6000 probability distributions for 100 parameters structured in a dependency tree









ResStock / ComStock Overview

Building stock characteristics database

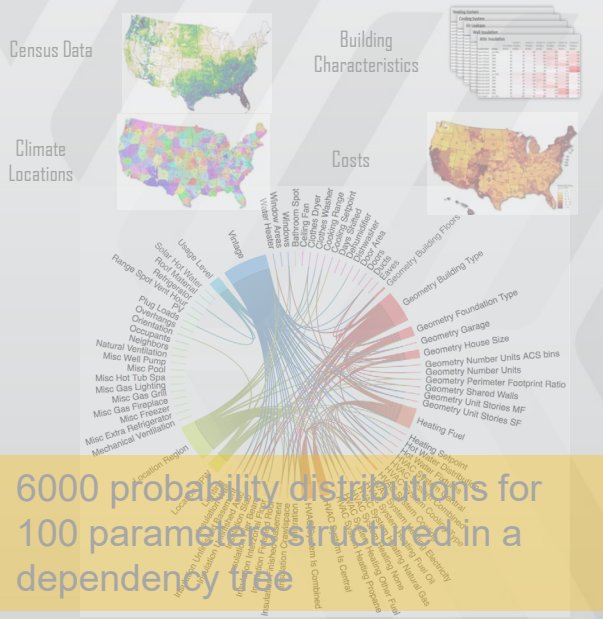
+

Physics-based computer modeling

+

High-performance computing

Large public and private datasets



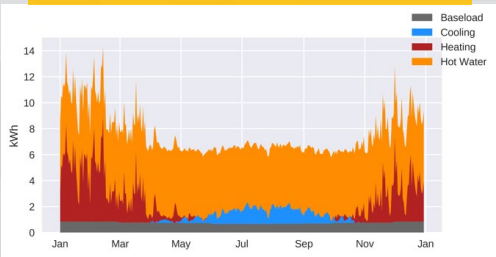
6000 probability distributions for 100 parameters structured in a dependency tree

DOE energy models

OpenStudio

EnergyPlus

Detailed sub-hourly energy simulations



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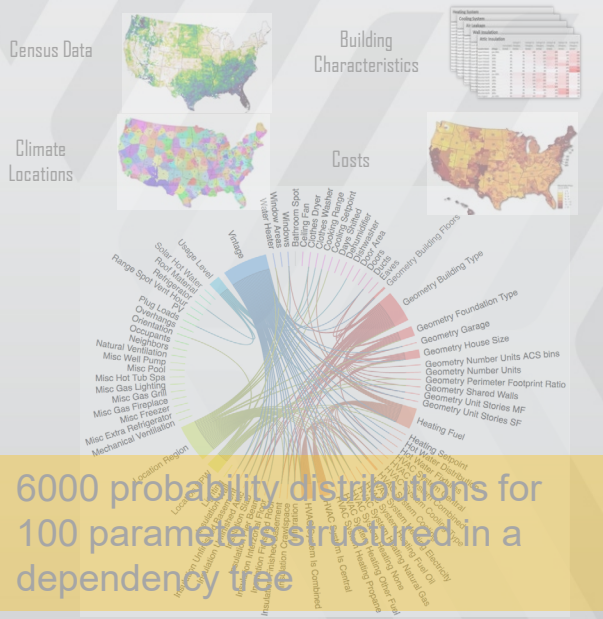

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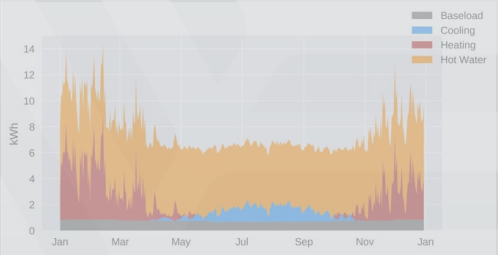


~800,000 simulations

NREL's supercomputer

Cloud computing

amazon web services

Big data technology stack

docker

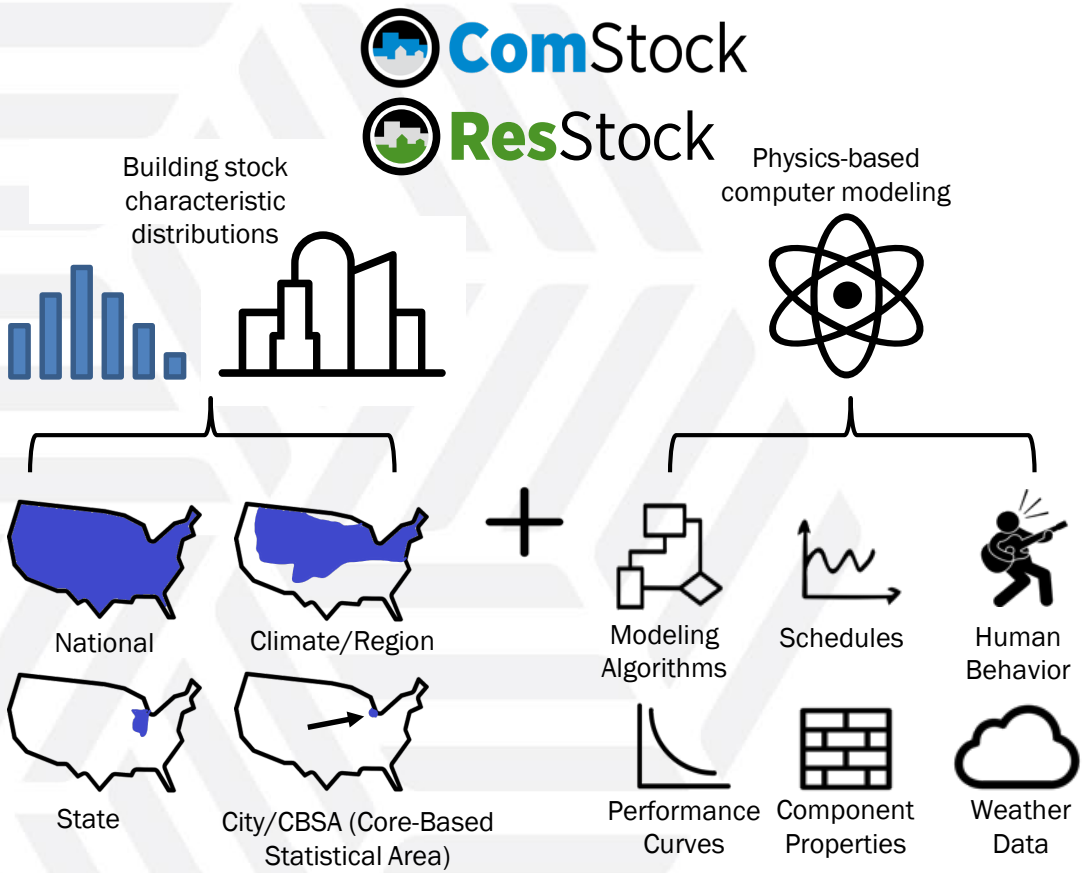
DASK

Parquet

presto

Amazon Athena

Calibration via End Use Load Profiles (EULP) Project



https://www.nrel.gov/buildings/end-use-load-profiles.html

Overall EULP Calibration Approach

1. **Compare to widely available data,** including EIA annual electricity sales by utility and customer class load profiles

2. **Study regional transferability of non-weather-dependent end uses** and apply schedules nationally (or regionally if supported by data)

3. **Perform enhanced calibration for five regions** for which we have utility Advanced Metering Infrastructure (AMI) data and customer metadata

Guiding principal: Change model inputs only when supported by data

EULP Model Calibration Data

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

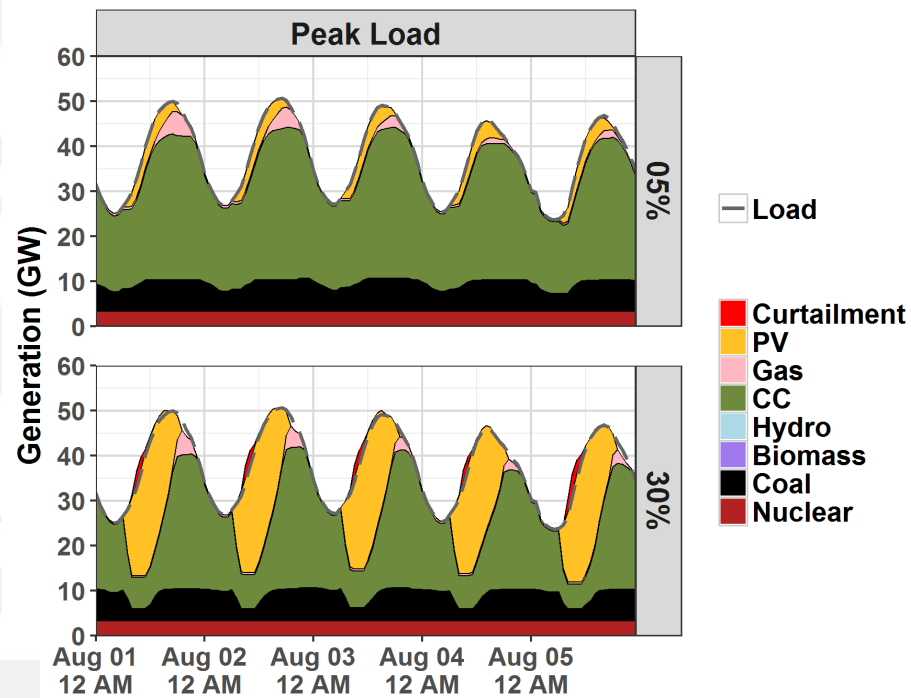
Summary of Calibration Data Classes

Type of Calibration Data	Summary of Availability
Utility Sales: Annual sales/consumption data by sector by utility	Universally available from U.S. Energy Information Administration (EIA)
Load research data: Utility customer class aggregate load shapes	Acquired for ~20 utility companies and the Electric Reliability Council of Texas
Advanced metering infrastructure (AMI) + metadata: Whole-building AMI data joined with building characteristic metadata	Acquiring ~5 data sets across multiple census divisions, via NDAs with utility companies
Submetered: End-use metering data, including smart thermostat data	~4 data sets publicly available for residential; procured ~10 data sets under NDA for commercial

Potential Value of Demand Response in Bulk Power Systems

Assumptions

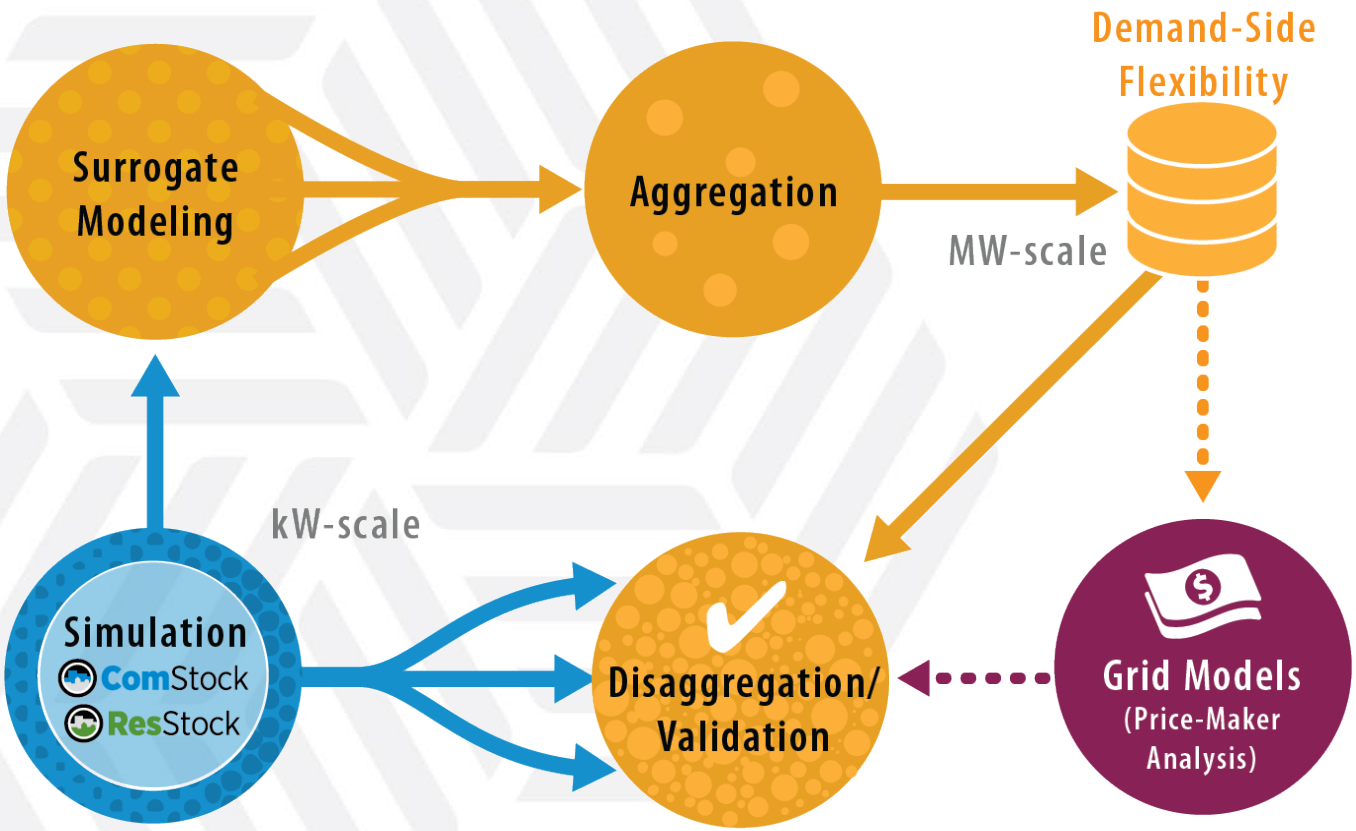
- Demand response resource is given
- Zero marginal cost
- Centrally dispatched along with everything else to minimize system cost



Hale, Elaine T., Brady L. Stoll, and Joshua E. Novacheck. 2018. "Integrating Solar into Florida's Power System: Potential Roles for Flexibility." Solar Energy 170: 741–51. https://doi.org/10.1016/j.solener.2018.05.045

This way we can measure the maximum value of the resource without predicting future market structures (utility tariffs, aggregation programs).

Building Modeling / Grid Modeling Iteration and Validation Cycle



Demand Response Resource Categories

1. **Schedulable -** discrete decisions per end-use, little environmental coupling (ex. pumping)

2. **High Thermal Capacity Storage -** set-point-driven, moderate environmental coupling (ex. refrigeration)

3. **Storage -** often set-point-driven, potential for high environmental coupling (ex. heating and cooling)

4. **Sheddable -** little tolerance for change in service levels; capacity-only resources (ex. lighting, ventilation)

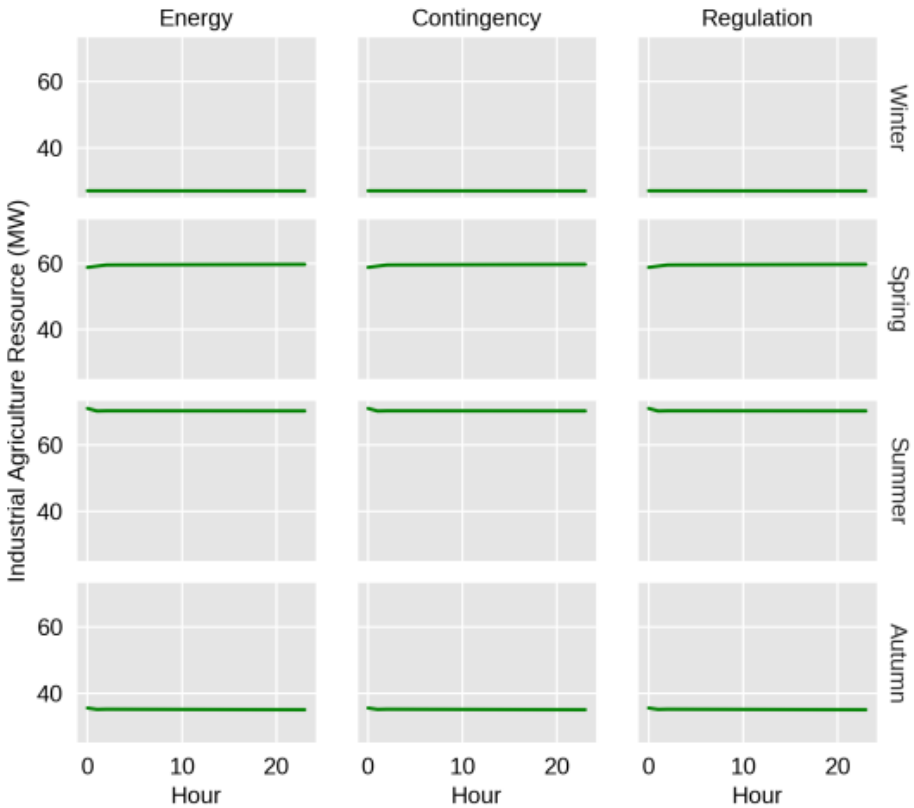
Guiding principal: Change model inputs only when supported by data

Schedulable Resource: Agricultural Pumping

Modeled as Generator with Storage Reservoirs

- Generation capacity is maximum over all services
- Pumping Capacity(i) = min(2*Energy(i), max(Energy)) - Energy(i)
- Storage must hit a weekly target (daily for other schedulable end-uses)

Average Daily Profiles by Service/Season



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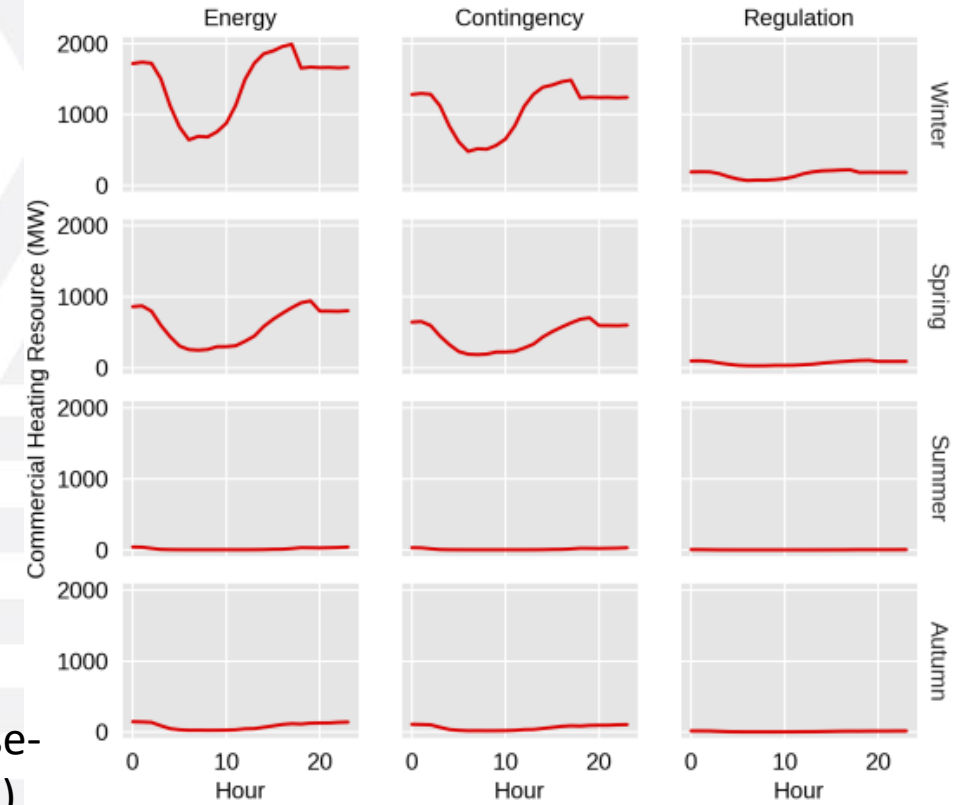
Storage Resource: Commercial Heating

Modeled as Generator with Storage Reservoirs

- Generation capacity is maximum over all services
- Pumping Capacity(i) = min(max(Energy) - Energy(i), max(Energy(day))
- Storage must hit a daily target
- Pumping is restricted to 3am – 7pm (make up during occupied hours)
- Energy shifting is limited to a total of 2 use-hours (sum(Generation(i) / Energy(i)) $\leq$ 2)

Average Daily Profiles by Service/Season



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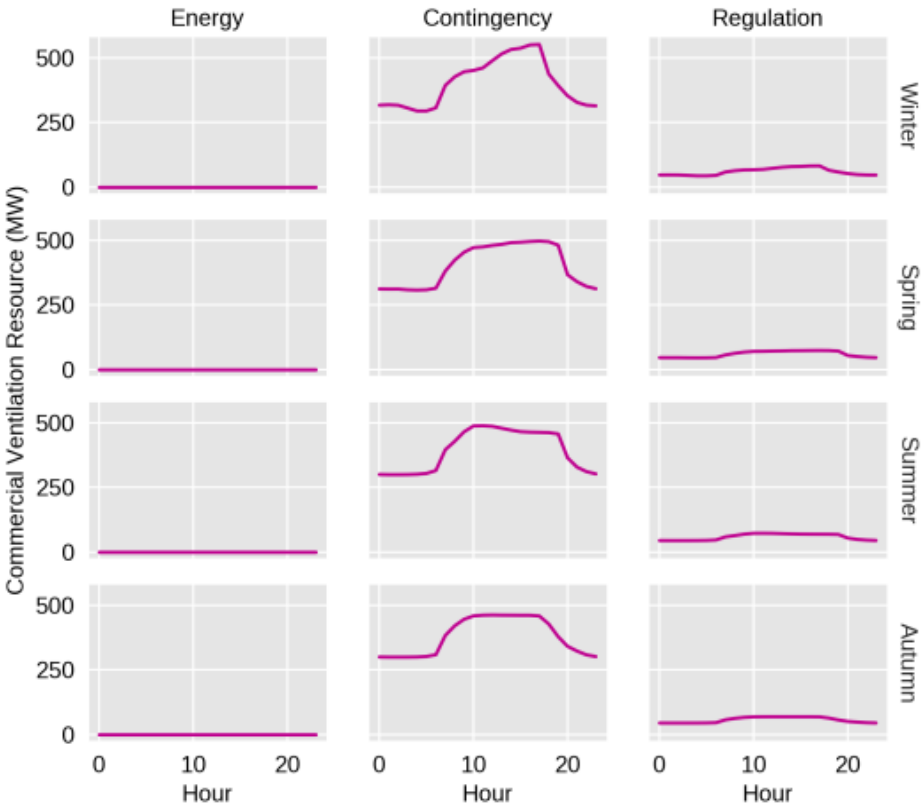
Sheddable Resource: Commercial Ventilation

Modeled as Plain Generator

- Generation is restricted to zero
- Reserves provision restricted to the appropriate profile

Average Daily Profiles by Service/Season



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Thank you!

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