Metrics to describe changes in the power system need for demand response resources

Sam Murthy, Andy Satchwell, Brian Gerke
Lawrence Berkeley National Laboratory

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Motivation: Demand Response is beneficial but how do we measure changes in the power system's need for DR?

The evolving supply side

- Increasing renewables are changing the **type, magnitude** and **timing** of demand response (DR) needed for grid operations
- Integrating renewables requires flexibility (load shift) as well as peak management (load shed)
- DR is likely to be utilized beyond system peak hours to balance renewables

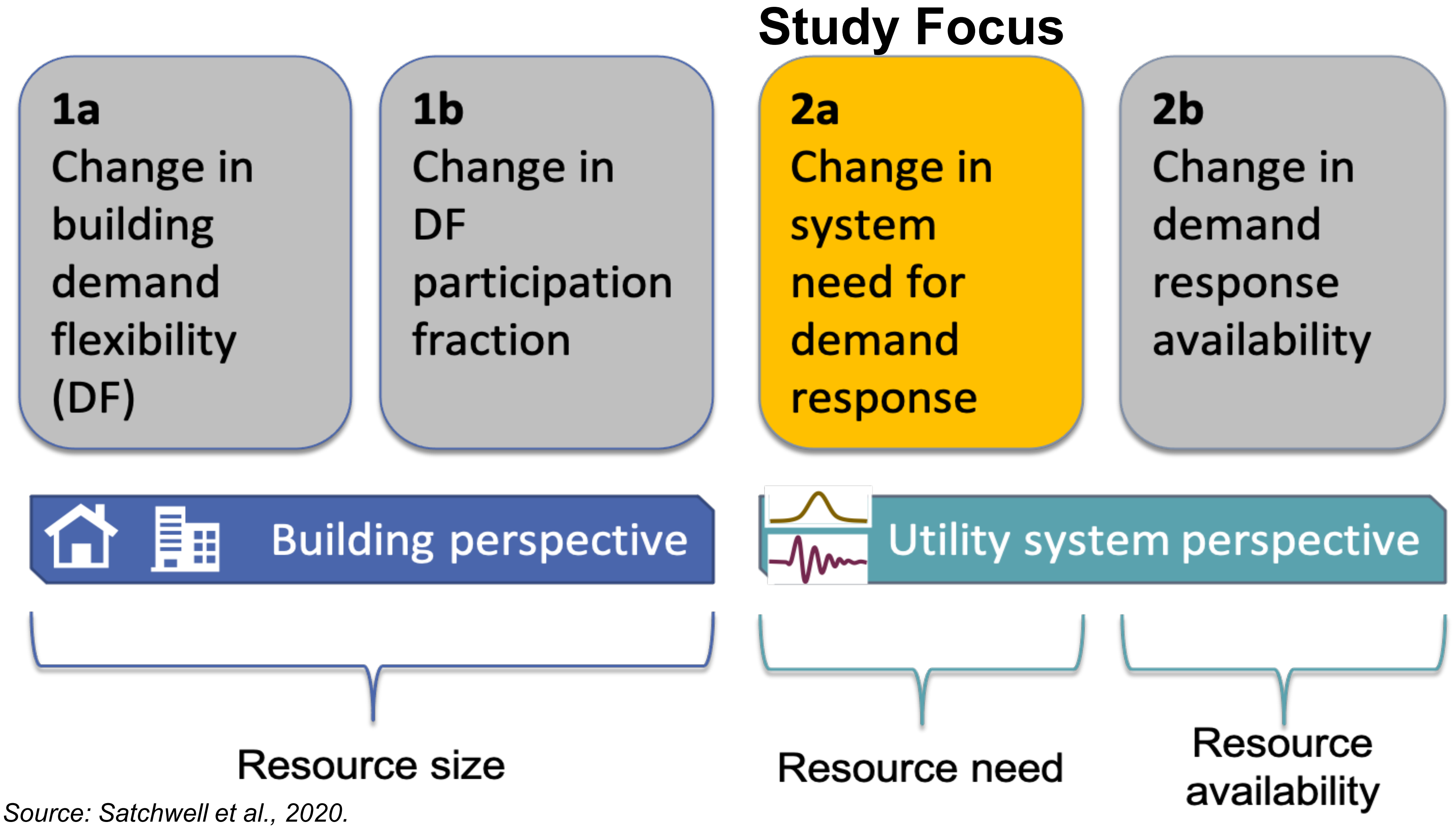
The evolving demand side

- Widespread adoption of energy efficiency (EE) for decarbonization will also change **how much** DR the system needs and **when** it's needed
- End-use electrification may drive even larger changes in DR needs

Metrics for assessing system DR needs

- "System need for DR" is a fairly ill-defined concept, making changes hard to quantify
- We develop **specific, quantitative metrics** for assessing changes in DR need and observe changes induced by EE and VRE

EE and DR interactions framework



Source: Satchwell et al., 2020.
Available at: https://emp.lbl.gov/publications/conceptual-framework-describe-energy

Scope and boundaries

DR Types considered

- We develop metrics for the types of DR that are most commonly implemented, namely **“shed”** and **“shift”** resources, dispatched over timescales of a few hours
- We do not consider more hypothetical resources like long-term load shifting or fast modulation DR for ancillary services

Drivers of DR Need

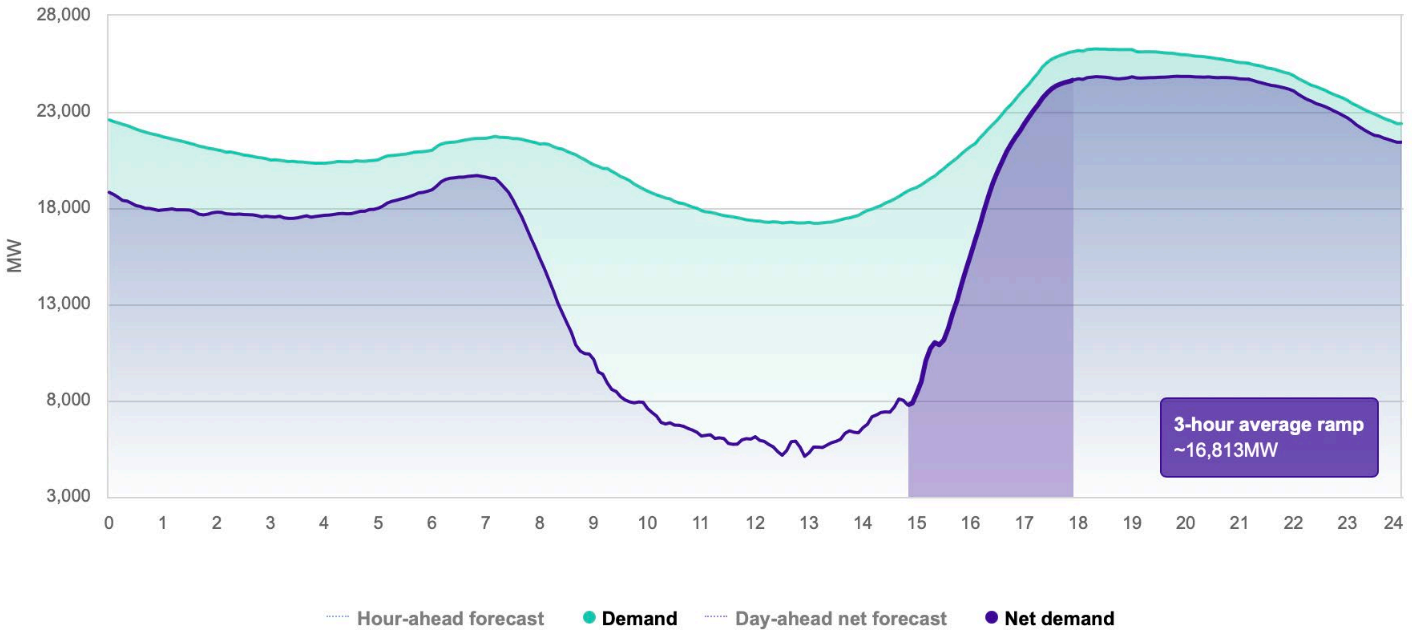
- We develop metrics that are based only on features of the *system level* ***net load.***
- The analysis is focused on metrics for assessing the *change* in need for DR **relative to a reference scenario** *within* a given system
- We do not account for incremental costs of EE or DR, that is typically required for utility resource planning
- We investigate changes driven by EE adoption scenarios. But our metrics can be applied to analyze the effects of other system-level load changes as well.

A focus on descriptive metrics

- We focus more on the effects of load shape changes on DR needs, rather than the causes: **the HOW**, not the WHY
- The study is intended to describe a viable methodology to **identify the type of DR** that is most valuable and **evaluate the change** in the need for DR on a system level

We used California system data since it has a high penetration of RE

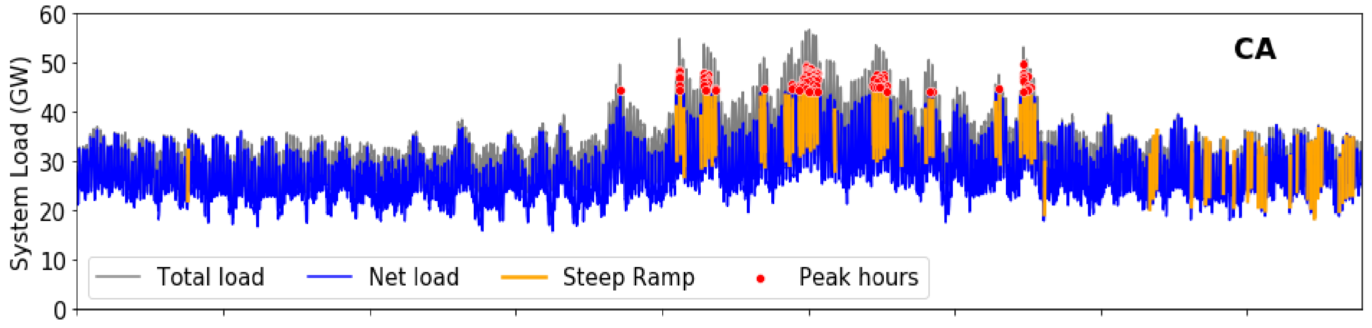
- Because of the high penetration of solar energy in California, we can observe a lot of fluctuations in the net load
  - Midday net load reduces causing steep evening ramps
- We were able to establish the need for shed DR and shift DR within the California system
  - The need for shift DR was not so pronounced in Texas or New England as of 2016 data

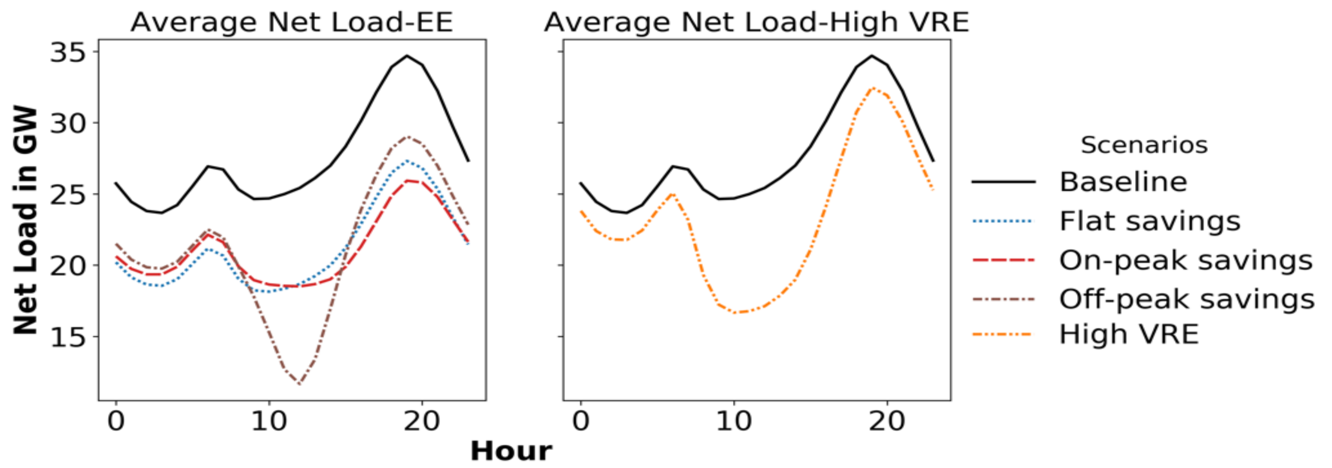


CAISO gross and net demand for Jan 1 2022
Source: CAISO

When and under what load conditions does the system need DR?

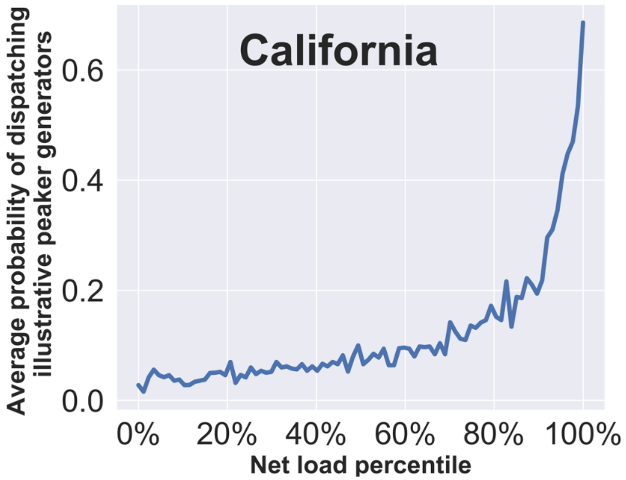
- Identify grid conditions that indicate the highest value of DR using actual power system data for 2016
  - Probability of peak generator dispatch
  - High wholesale electricity prices
  - High average hourly heat rate
- Using the correlation, identify reasonable threshold values for metrics definition
- Timing of the need for DR is also important for program design considerations
- Develop scenarios to apply the metrics and examine how the need for DR changes
  - Flat EE savings (e.g., LED lighting)
  - On-peak EE savings (e.g., smart thermostats)
  - Off-peak EE savings (e.g., commercial heating upgrades)
  - High VRE



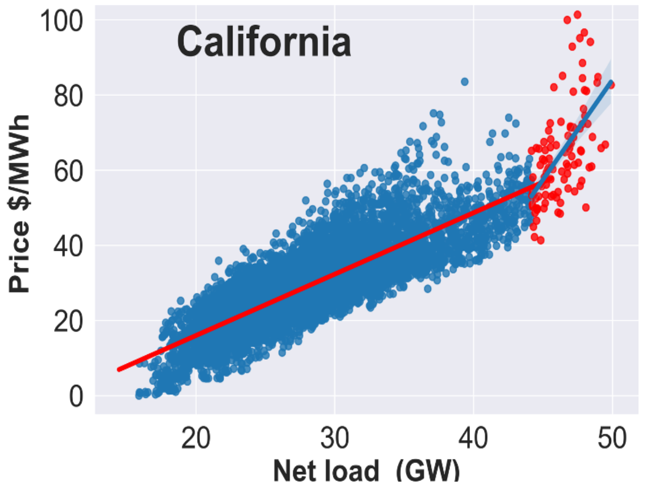


Shed DR Metrics

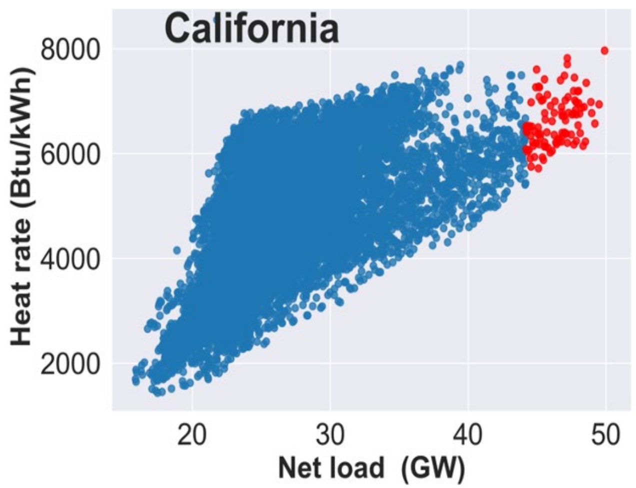
How does shed DR provide value to the system?



- Dispatch probability of peaker plants as a proxy of generation capacity
- Peak = Top 100 net load hours
- Average probability of peaker dispatch is significantly higher in the peak load hours.
- Shed DR can provide substantial value in these hours to eliminate the need for such generators



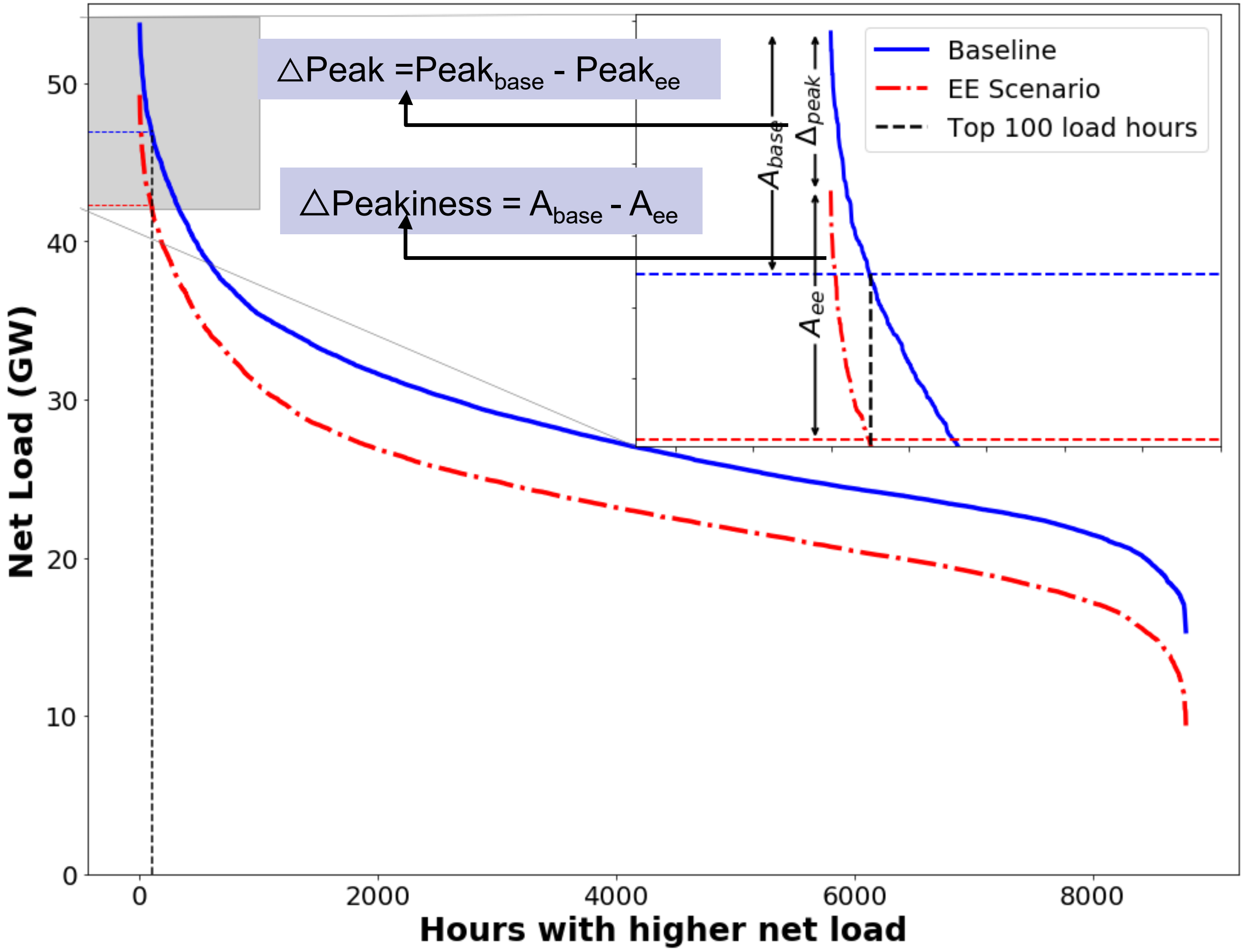
- Correlation of wholesale electricity price and net load
- Steeper trend in the top 100 net loads (red dots) imply peak loads drive peak prices
- Other exogenous factors (e.g., high natural gas price) could also drive prices high
- Shed DR can reduce peak loads and peak prices



- Average heat rate as a proxy for production costs
- Peaker plants with low utilization factor tend to come online during peak hours
- Elevated heat rate in the peak hours (red)
- Shed DR can further reduce the utilization of such generation and lower production costs plus emissions

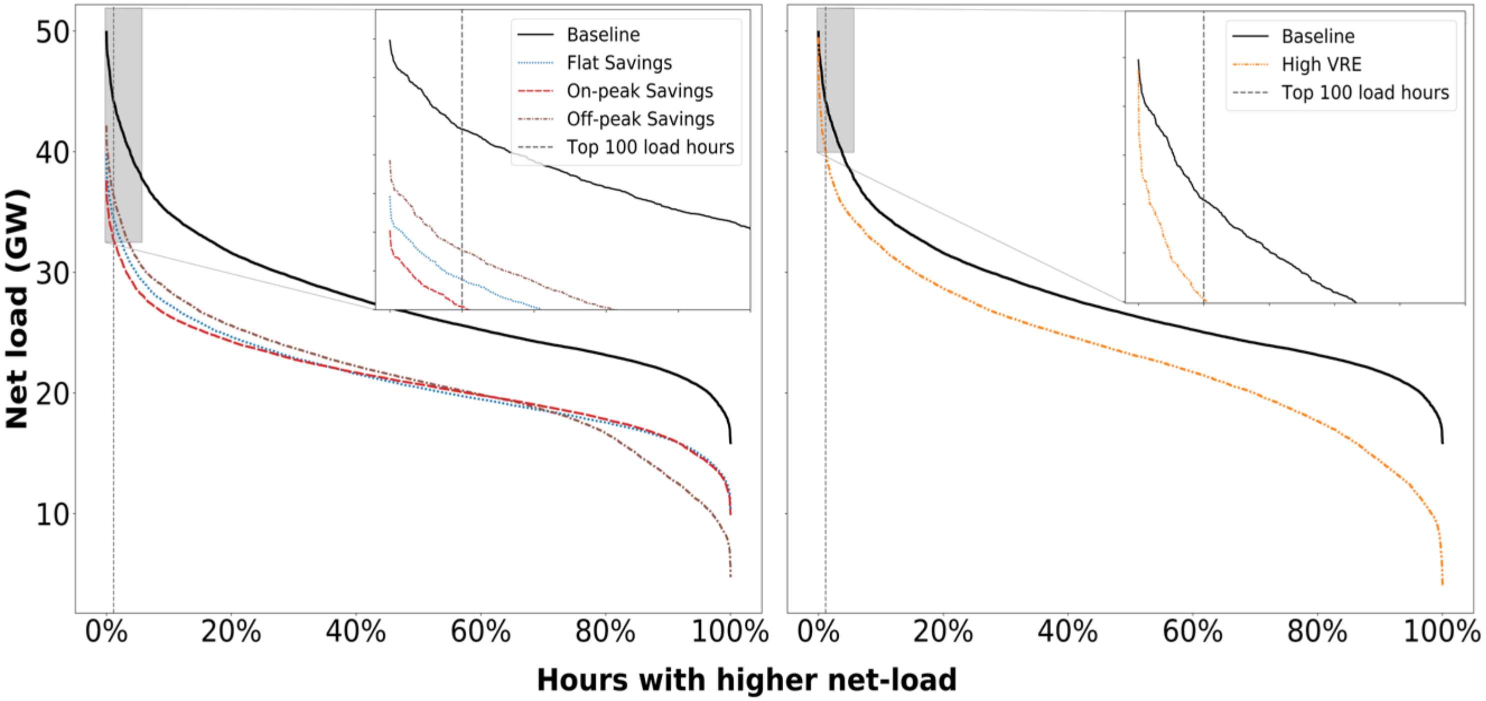
Two metrics to identify the system need for shed DR

- Change in the **absolute system peak demand**
  - Indicates the **short-run need for DR**, with a fixed generation stack
- Change in system "**peakiness**"
  - Peakiness is the additional load required only in the top-100 net-load hours
  - This indicates the change in the long-run need for DR
    - Generation stacks tend to evolve over time
    - Reduction of load in the top 100 hours (e.g., because of EE) can lead to lower need for peaking resources, including shed DR



How do shed metrics apply to the scenarios?

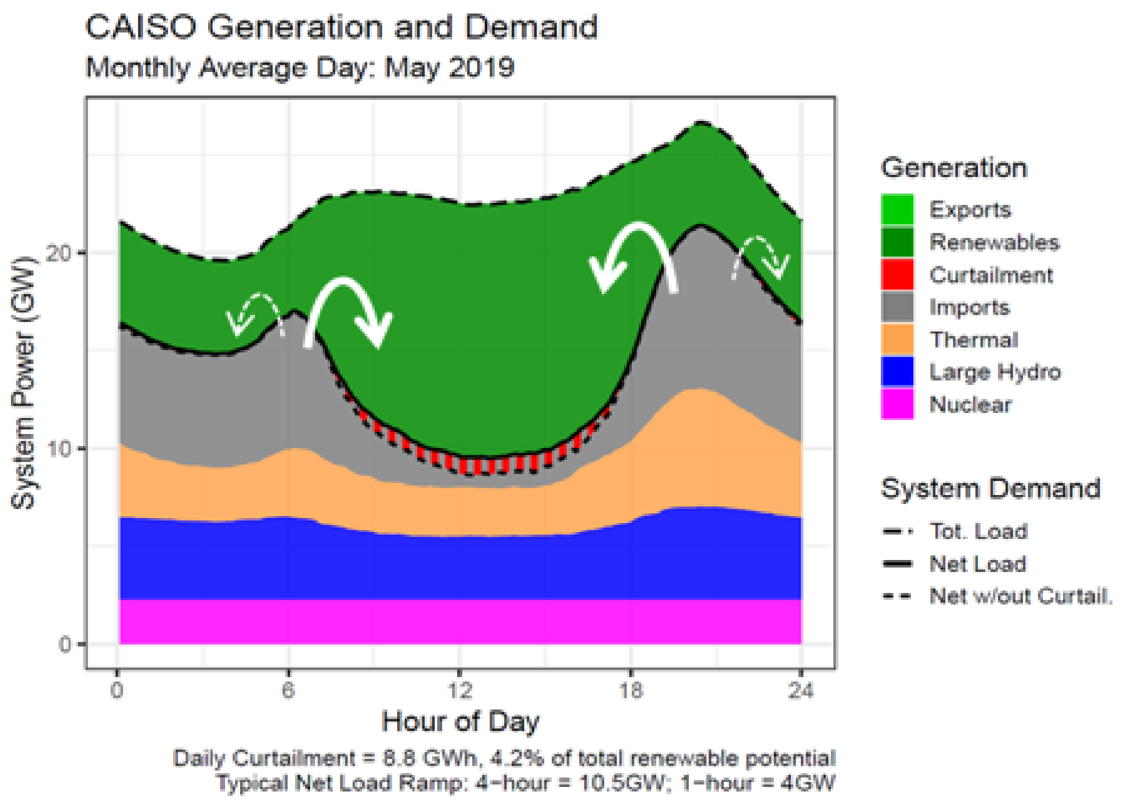
- Reduction in peak load (e.g., EE or VRE driven) are beneficial for the system
  - Amount of reduction depends on the degree of coincidence. Higher coincidence -> higher reduction
  - On-peak EE savings has the highest reduction in peak load. Implies the largest reduction in the need for Demand Response
- Coincident peak reductions (flat and on-peak EE savings) reduce the peakiness metric
  - High VRE creates the largest increase in the need for shed DR in the long term
    - Midday net load reductions lead steep increases in the evening net load



Shift DR Metrics

What is shift DR and how to identify the need for shift DR?

- Reduction in the load during the peak hours offset by increased consumption during adjacent off-peak hours
  - Analogous to a flexible or ramping generator
- Can be identified by the presence of a steep ramp
- We use absolute values of three hour net-load ramps to define the metrics
- Two kinds of shift DR considered in our study:
  - Large infrequent ramps that call for a dispatchable DR product
  - Frequently occurring, moderately high ramps that can be addressed using load modifying approaches (e.g., Time-of-Use rates)



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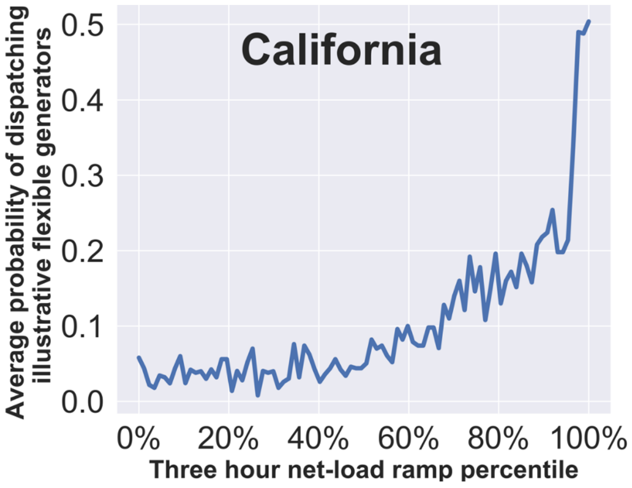
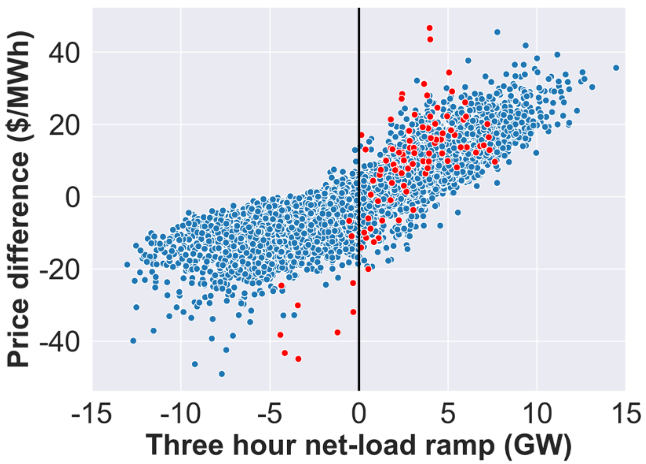
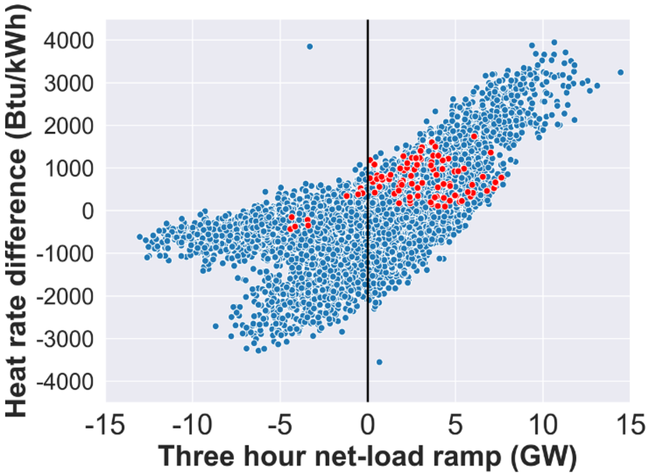






- Peaker plants provide flexibility as fast-start, fast-ramp resources
- Peaker plants are preferentially dispatched to serve steep ramps
- Dispatchable shift can reduce the extreme ramps (90^{th}-100 percentile)
- Load modifying shift DR (e.g., TOU rates) can reduce moderately high ramps

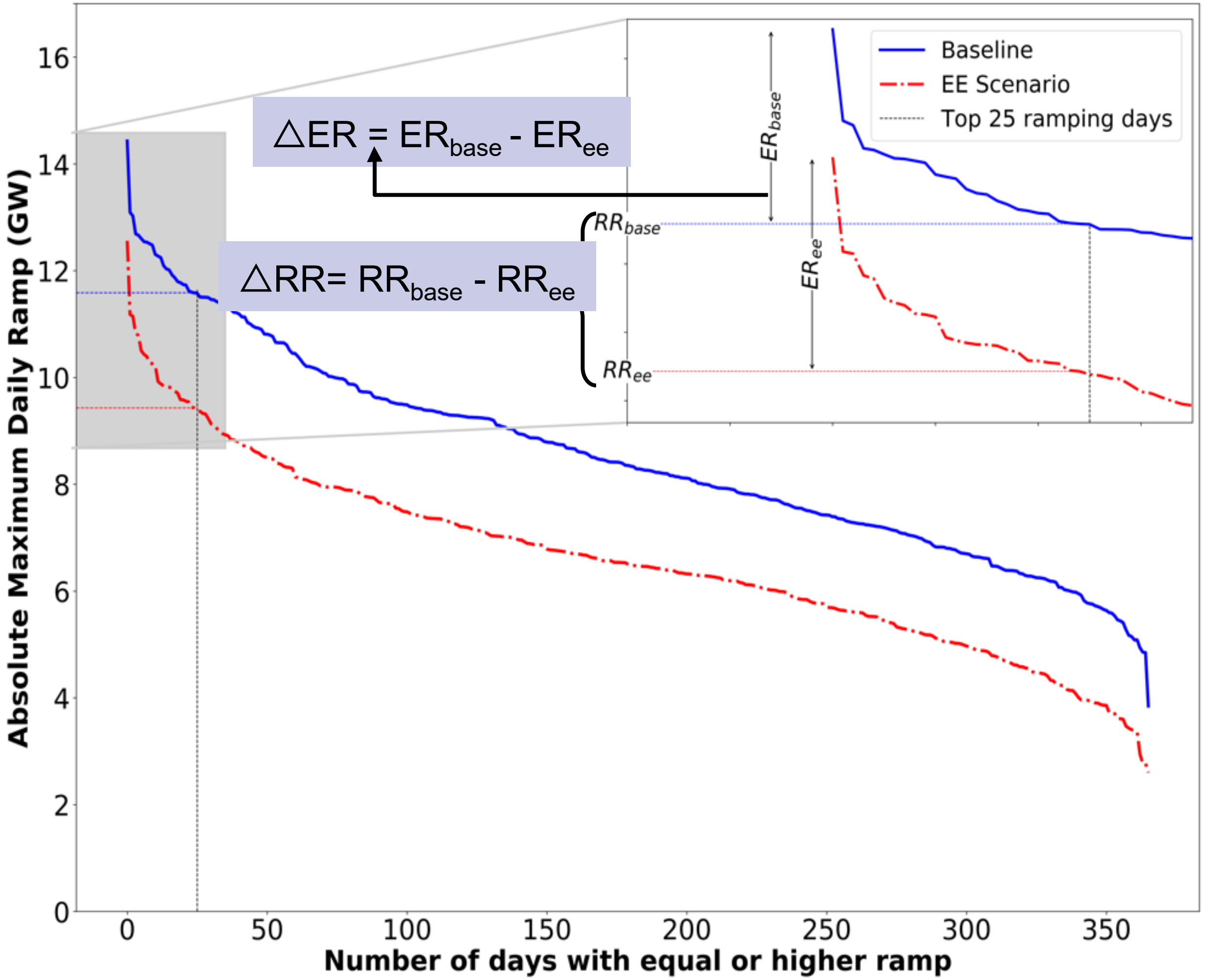
- Large three-hour ramps associated with similar swings in wholesale price
- Indicates the opportunity for arbitrage
- Large swings in prices in hours outside of the top 100 net load hours (red)

- Large three-hour ramps associated with similar swings in dispatched generators' average heat rate as well
- Large differences observed in heat rate with big three hour net-load ramps outside of the peak load hours

Shift DR has value to the system in addition to shed DR

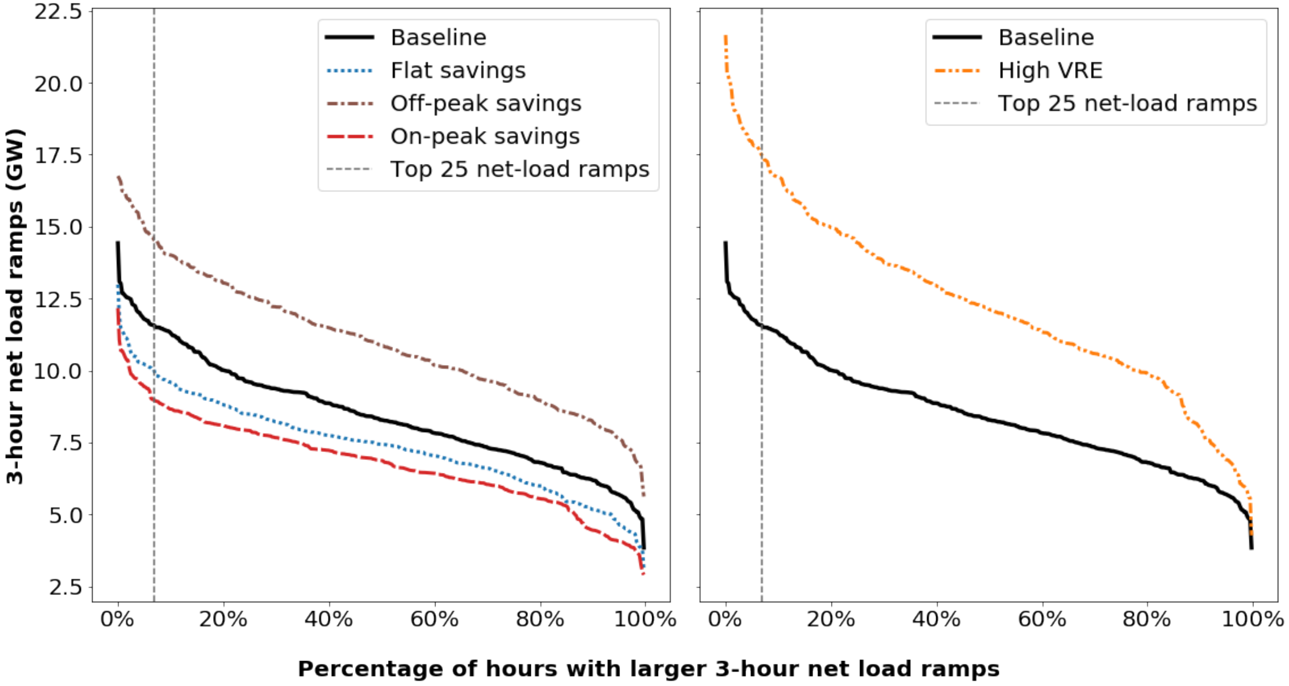
Two metrics to identify the system need for shift DR

- **Ramp frequency curve** is constructed using absolute value of daily maximum three hour difference of net loads and ordering them
  - We use **25-th highest ramp as the threshold**
- 2 metrics to determine how the need for shift DR changes
- Change in **routine ramping**
  - Routine ramping is the 25th highest ramp value
  - Represents the magnitude of more **commonly occurring ramps** in a system
- Change in **extreme ramping**
  - Extreme ramping is the need for additional ramping in the top 25 days
  - Represents the **need for dispatchable shift DR**



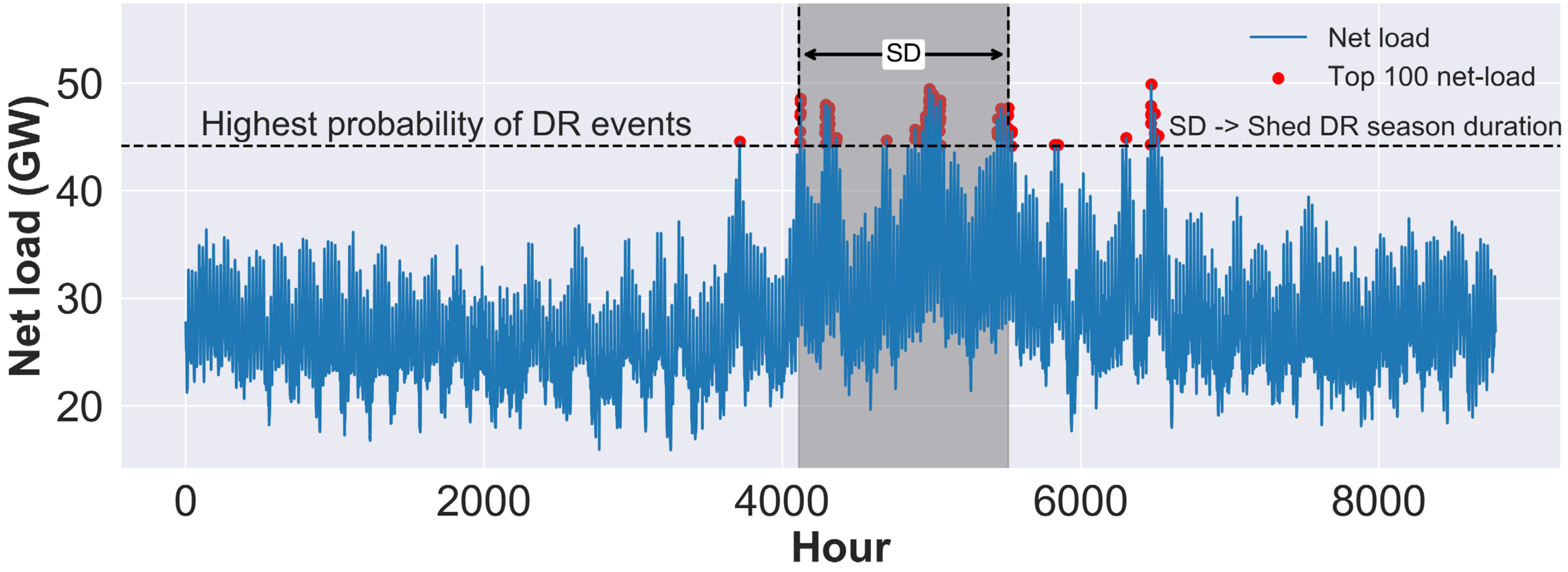
How do shift metrics apply to the scenarios?

- Routine ramping
  - Coincident EE-driven peak load reductions help alleviate ramping concerns by reducing routine ramps in the Flat and On-peak EE savings scenarios
  - Savings in the off-peak period (EE or VRE driven) exacerbate the evening routine ramps
- Extreme ramping
  - Demand-driven reductions push the high ramping days towards fall/winter seasons
  - Supply-side fluctuations on these days can drive up the need for extreme ramping in some cases (e.g., Flat and On-peak EE savings)
- High VRE increases the need for both by exacerbating the ramps overall
  - Largely driven by the type of VRE (e.g., wind versus solar) in a system
  - Solar generation tends to cause evening ramps consistently



Metrics to consider for DR program design

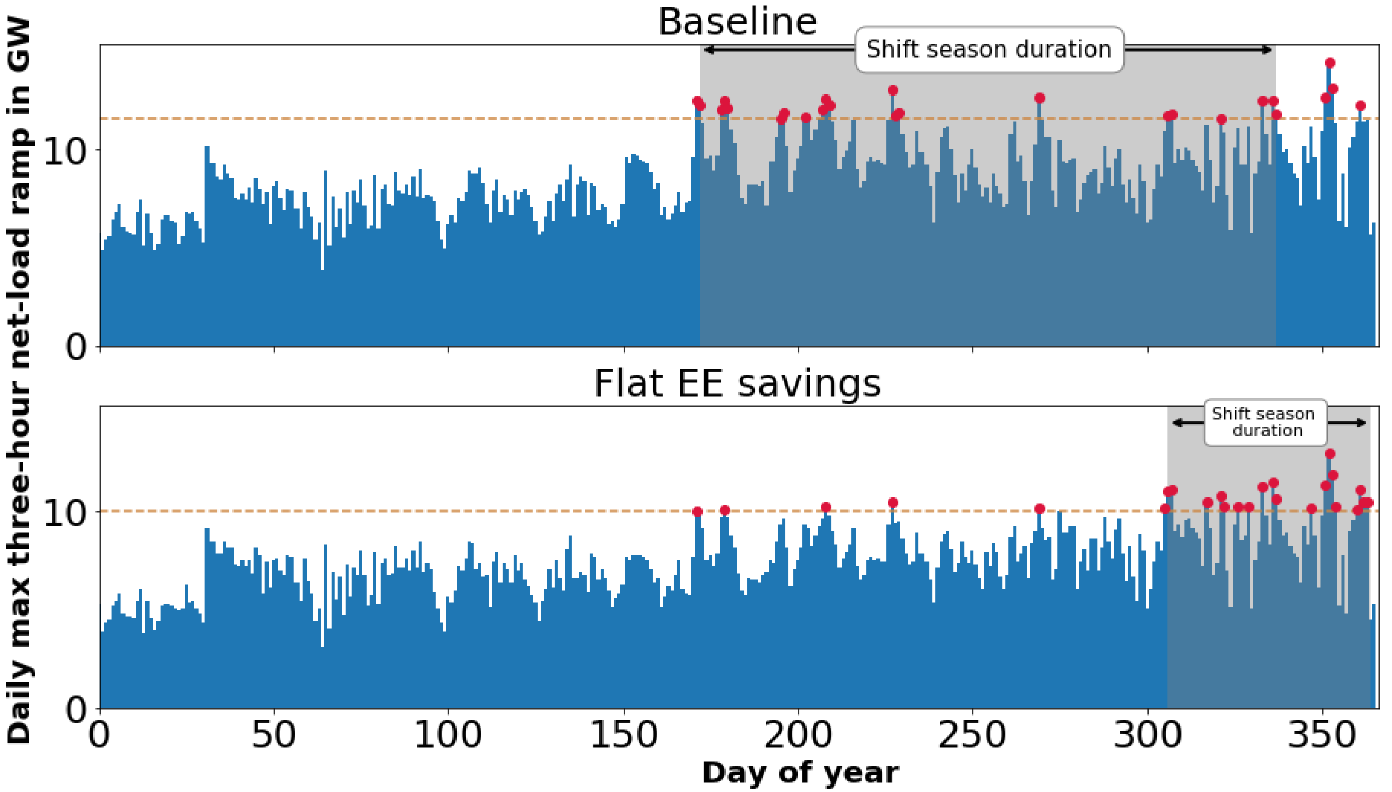
Seasonality and frequency of DR events are key to informing DR program designs



- Temporal distribution of DR events will determine the target customer groups and specific end-uses for an effective DR program
- 3 metrics for program design consideration
  - **Number of shed DR events** – Number of days represented by the top 100 net load hours
  - **Shed season duration** – Shortest duration (in days) containing *80% of the top 100 net load hours*
  - **Shift season duration** – Shortest duration (in days) containing *80% (or 20) of the top 25 highest ramping days*

Application of program design metrics to the scenarios

- Shed event days
  - Increased number of shed event days implies shorter duration of each individual event
- Shed season duration
  - Lower net load (EE or VRE driven) can push the shed season duration from summer to shoulder or winter seasons
- Shift season duration
  - EE and VRE driven load changes pushed the top 25 ramps completely out of summer for all scenarios and emphasized winter peaks
- These observations can really change the end-uses being targeted by DR program



Summary of metrics

Shed DR need	System need for ***peak generation capacity*** **to meet peak demand**	**Peak load**	Maximum hourly system net load
		System "peakiness"	Height of system peak net-load above the 100th-highest hourly net-load
Shift DR need	System need for ***flexible capacity*** **to handle upward or downward ramping**	**Extreme ramping need**	Maximum annual three-hour absolute (upward or downward) net-load ramp compared to the 25th-highest ramping day
		Routine ramping need	Maximum daily three-hour absolute (upward or downward) net-load ramp on the 25th-largest ramping day
Program design implications	**Seasonality and frequency of DR events**	**Shed event days**	Total number of unique days represented within the top 100 hours of annual net demand
		Shed season duration	Duration of the shortest period containing 80 of the top 100 hours of annual net demand
		Shift season duration	Duration of the shortest period containing 20 of the top 25 ramping days

Conclusion

- DR is a valuable resource in decarbonizing the power grid and need new ways to measure its value
- **7 Metrics** to quantify the change in the system need for DR by considering both **magnitude and timing** of the need for shed and shift DR
- Metrics can be applied to quantify how the need for DR evolves as a result of **changes on both supply-side** (e.g., High VRE integration) **as well as demand-side** (e.g., EE deployment, building and transport electrification)
- Key takeaways from application of DR metrics:
  - Coincident peak reductions are highly effective in reducing the need for shed DR
  - Shift DR metrics are largely driven by the type of VRE in a system (e.g., wind versus solar)
  - System level changes can shift the need for DR from summer to fall/winter season
- Metrics can be easily calculated using publicly available data
  - The threshold values can be modified to suit an individual system (e.g., top 10 ramping days instead of top 25)
- Metrics can be useful for various stakeholders in the electricity industry
  - Help **identify the type of DR** that can be most valuable for a system
  - Incorporating **seasonality and duration** can target customer groups and end-uses that align better with the system need

Contacts

Sam Murthy, smurthy2@lbl.gov

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