Private vs. public value of U.S. residential battery storage operated for solar self-consumption

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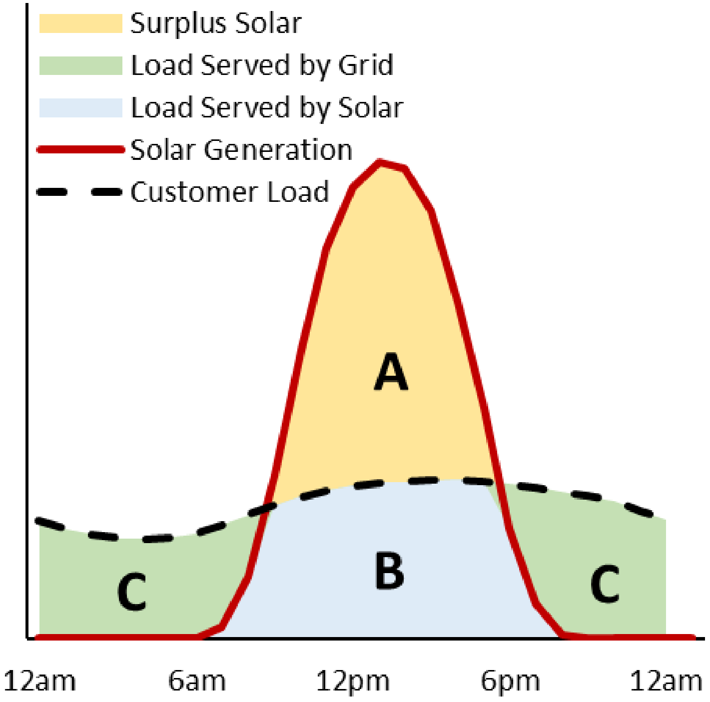
Public Webinar

August 4, 2022

This work was funded by the U.S. Department of Energy Solar Energy Technologies Office, under Contract No. DE-AC02-05CH11231.

Context and Motivation

- Net billing has emerged as the *de facto* successor to net metering in many jurisdictions
- Its defining feature is an **asymmetric pricing structure**: solar generation can offset contemporaneous load at the full retail rate (Area B), but any surplus solar exported to the grid (Area A) is compensated at a specified grid export rate, typically less than the retail rate
- Creates an incentive to use battery storage to **arbitrage** between retail and grid-export prices, by shifting surplus solar generation to meet residual load (Area C)



Questions:

- *What benefit does this arbitrage behavior provide to the electric system?*
- *And how does that compare to the private benefit received by the solar+storage customer?*

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Key Findings

1. The bill savings from arbitrage between retail and wholesale prices typically is not enough, on its own, to justify storage investments at current costs

2. When net billing is coupled with flat retail and grid export rates, the resulting storage dispatch profile yields virtually no value to the system

3. Introducing *highly* time differentiated rates can *partially* mitigate this deficiency, particularly if customers are allowed and incentivized to discharge to the grid during the highest-value peak hours

4. Net billing continues to lead to inefficient outcomes even in high-solar penetration markets where wholesale prices resemble the “duck curve”, and the suboptimality can become even more severe in some cases

Organization

- Data and Methods
- Core Results
- High Solar Futures
- Decomposing the Value Gap
- Conclusions

Data and Methods

Data and Methods (Core Analysis)*

Load Data: Metered hourly loads from ~1800 residential customers *without* PV or storage, across 6 utility service territories, from 2012-2013

Solar Profiles: Simulated using NREL's System Advisor Model for the same locations and time period as the load data

Market Data: Day-ahead energy market prices and balancing authority system loads for the same locations and time period as the customer load data

Key Assumptions: (a) PV & storage sizing, (b) tariff design, (c) grid charging/ discharging rules

Storage Dispatch Model: Dispatch storage to maximize private value to the customer

Outputs: Energy + peak value of storage and customer bill savings, in units of ***$ per kWh of storage capacity per year***; also grid export levels

**Several supplemental analyses were performed with other datasets, as described elsewhere*

Side Bar: A word on PV and storage sizing in this analysis

- Throughout the analysis, we refer to PV and storage sizes in normalized units

- PV sizing
  - Normalized to the fraction of annual customer consumption
  - We explore multiple PV sizes, but most of the analysis focuses on size **1.0** where the PV system generates 100% of annual customer load (~ 4-8 kW)

- Storage sizing
  - Denominated as a fraction of average daily PV generation
  - We explore results across storage sizes (varying kWh capacity, and assuming 2-hour duration)
  - We explore multiple battery sizes, but most of the analysis focuses on size **0.5**, where storage energy capacity is equal to 50% of average daily PV generation (~10-15 kWh with PV size 1.0)

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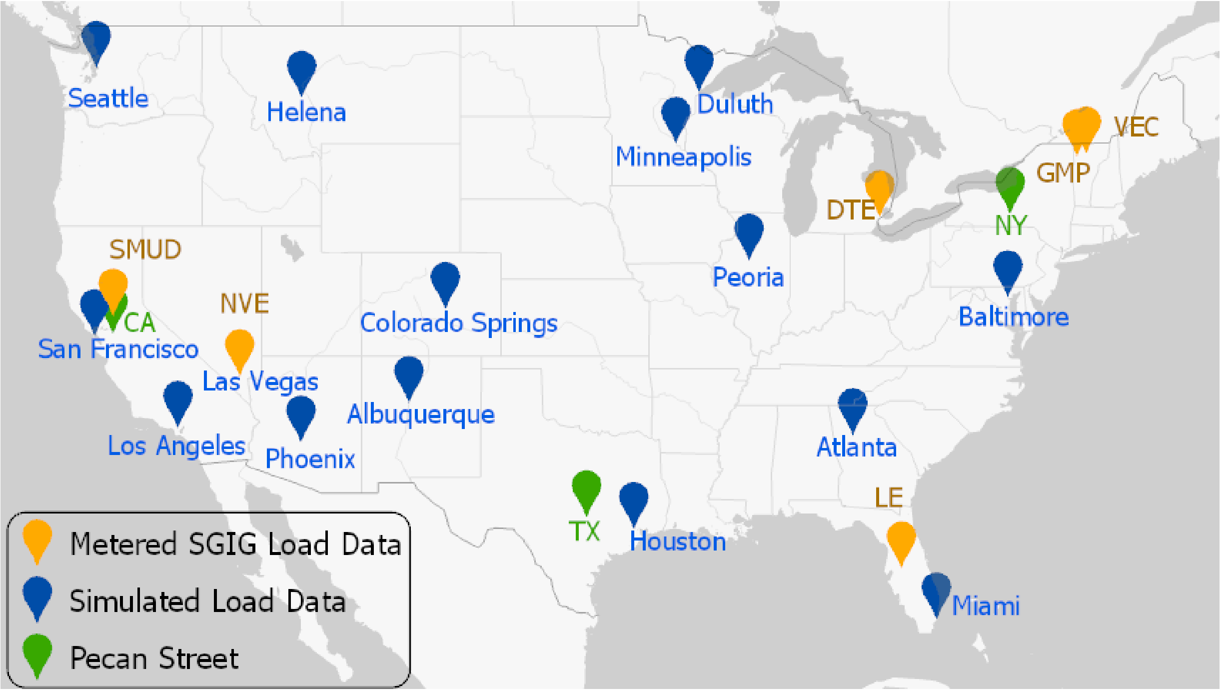
Load Data: Additional Details

- Primary analysis relies on metered load data from six utilities, collected through the Smart Grid Investment Grant (SGIG) Program
  - Detroit Edison (DTE)
  - Green Mountain Power (GMP)
  - Lakeland Electric (LE)
  - Nevada Energy (NVE)
  - Sacramento Municipal Utilities District (SMUD)
  - Vermont Electric Cooperative (VEC)

- Secondary/supplemental parts of the analysis rely on Simulated Load and Pecan Street data.



Core Results

Some Initial Assumptions (to be relaxed later)

1. Net billing asymmetry

2. Flat retail prices for both consumption and exports

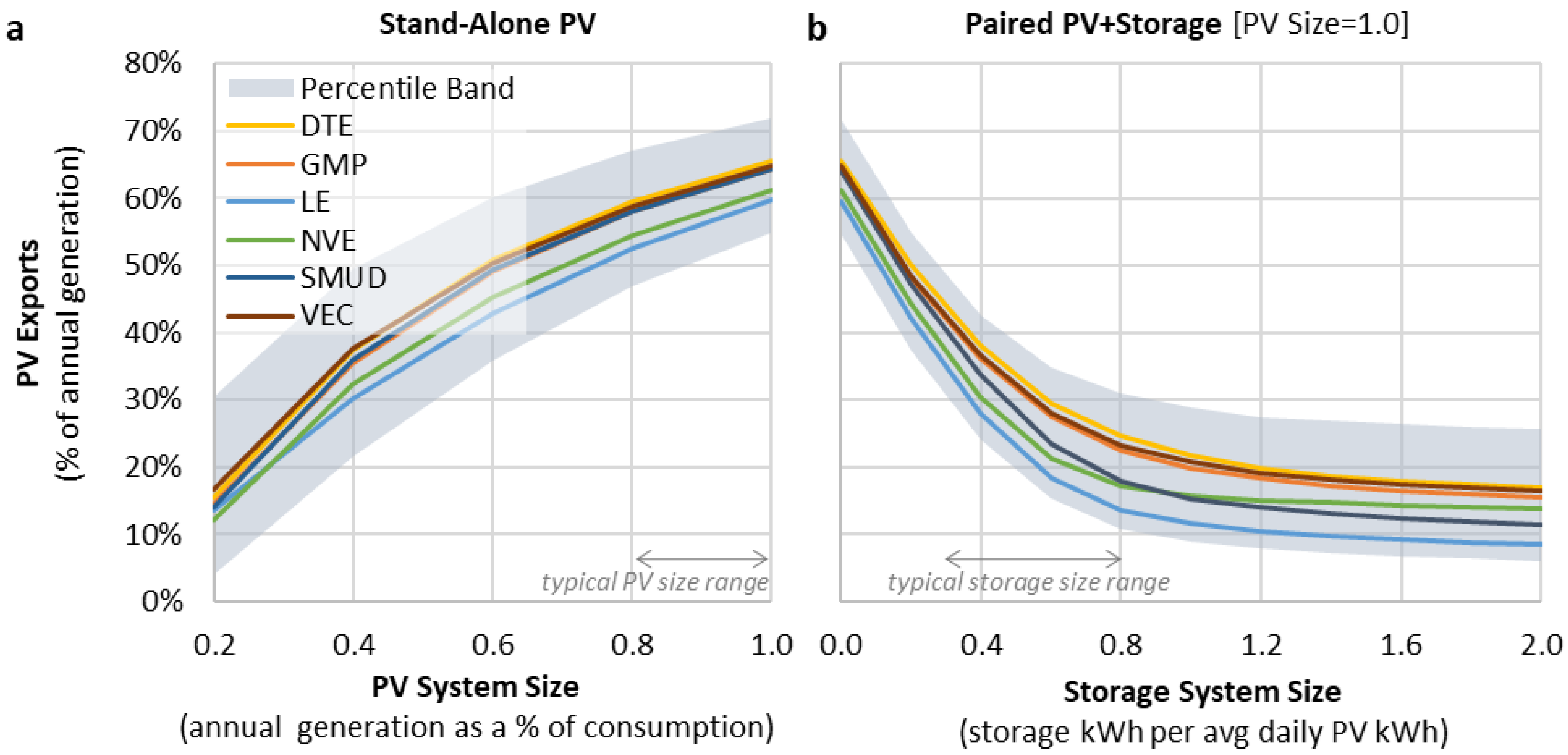
3. Storage only charges from solar, and only discharges to load
   - Incentivized by net billing asymmetry
   - Other grid charging/discharging constraints: ITC, interconnection rules, tariff provisions, etc.

These assumptions are inter-related

- Time-varying rates impact results most when storage can freely charge from / discharge to the grid
- Charging/discharging constraints matter only if there are time-varying price signals

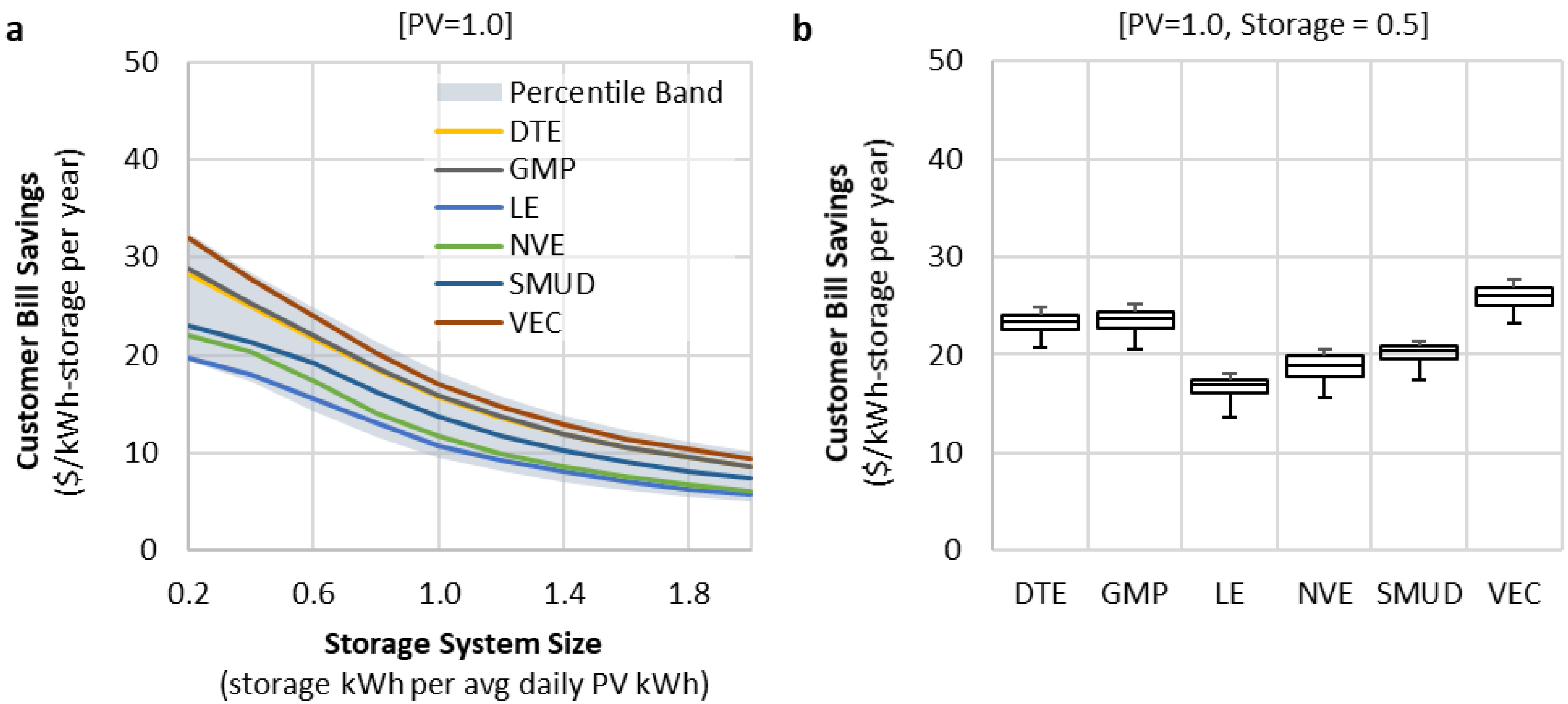
Solar PV Grid Exports with and without Battery Storage

- Grid exports increase with PV system size
- Typically-sized stand-alone PV exports **47-72%** of annual PV generation across customers
  - Typically-sized storage could reduce grid exports to **11-31%**
  - Larger batteries reduce exports with diminishing returns (less net load to offset)



Bill Savings During Self-Consumption

- Bill savings from solar arbitrage diminish with larger storage
- Bill savings do not cover upfront cost of battery
  - For a typical system configuration (Panel b), annual bill savings range $17-26/kWh-storage across utility medians
  - Compare to current residential storage cost of $700-1300/kWh-storage (payback period of >20 years)



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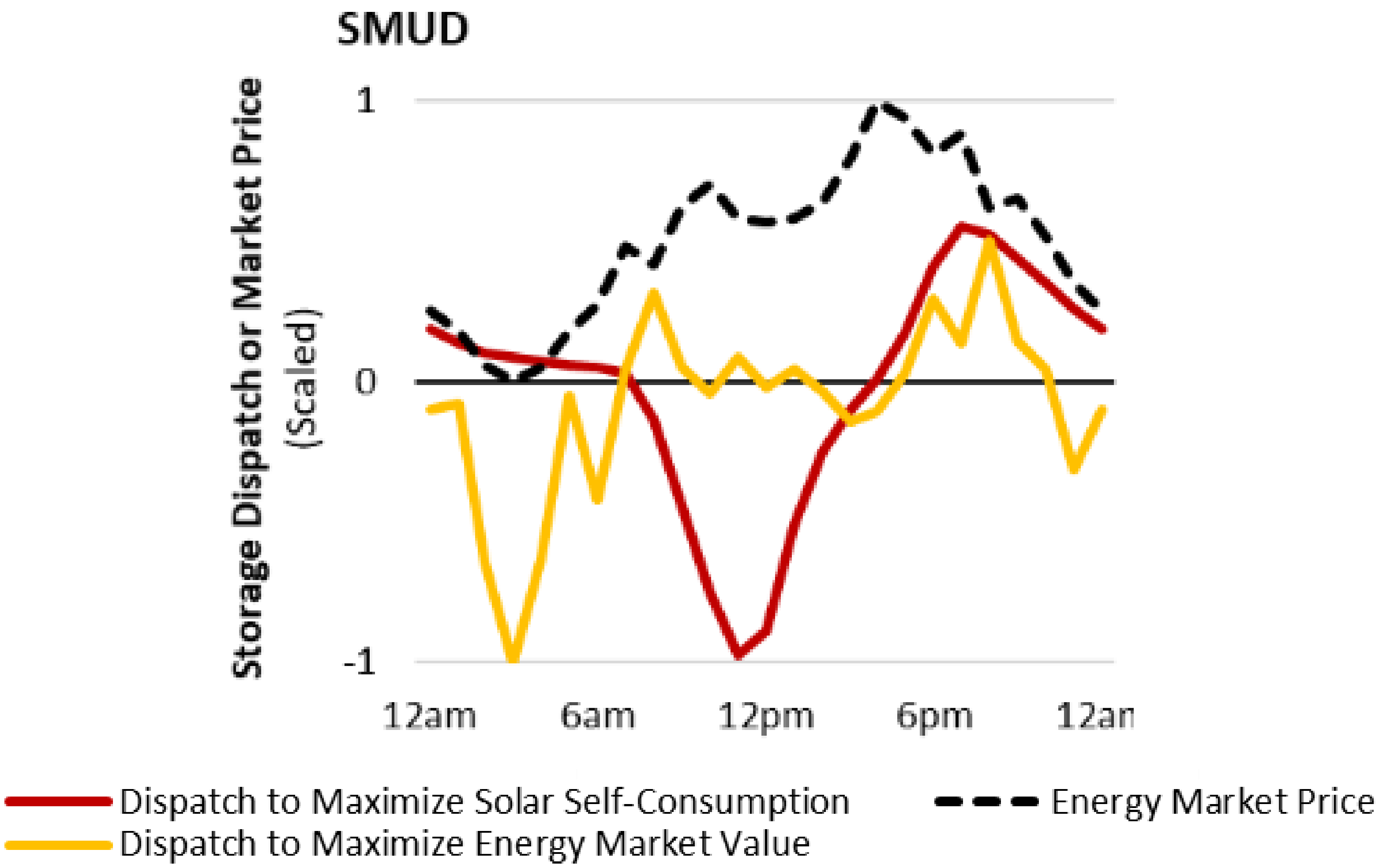
Alignment of Storage Dispatch and Energy Market Prices

- Both charging and discharging are misaligned with energy market prices
  - Charging during daytime hours, when prices are relatively high
  - Discharging begins in the evening to align with prices, but continues through the night, when prices are low

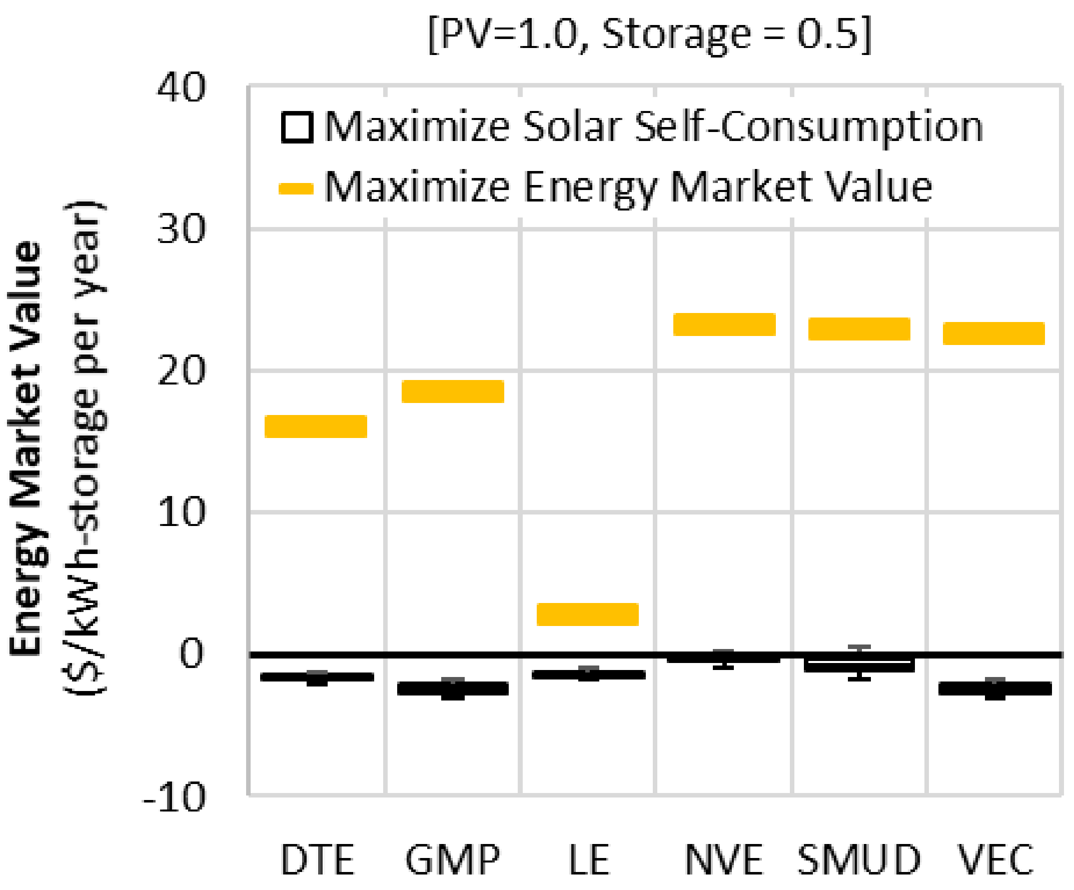
Annual average dispatch profiles and market prices



Energy Market Value of Storage for Self-Consumption

- Energy market value of storage under base case is effectively zero due to temporal misalignment

- In comparison, storage to maximize energy market value would yield a value of $16-23/kWh-storage annually across all utilities except LE (not in/near organized market)

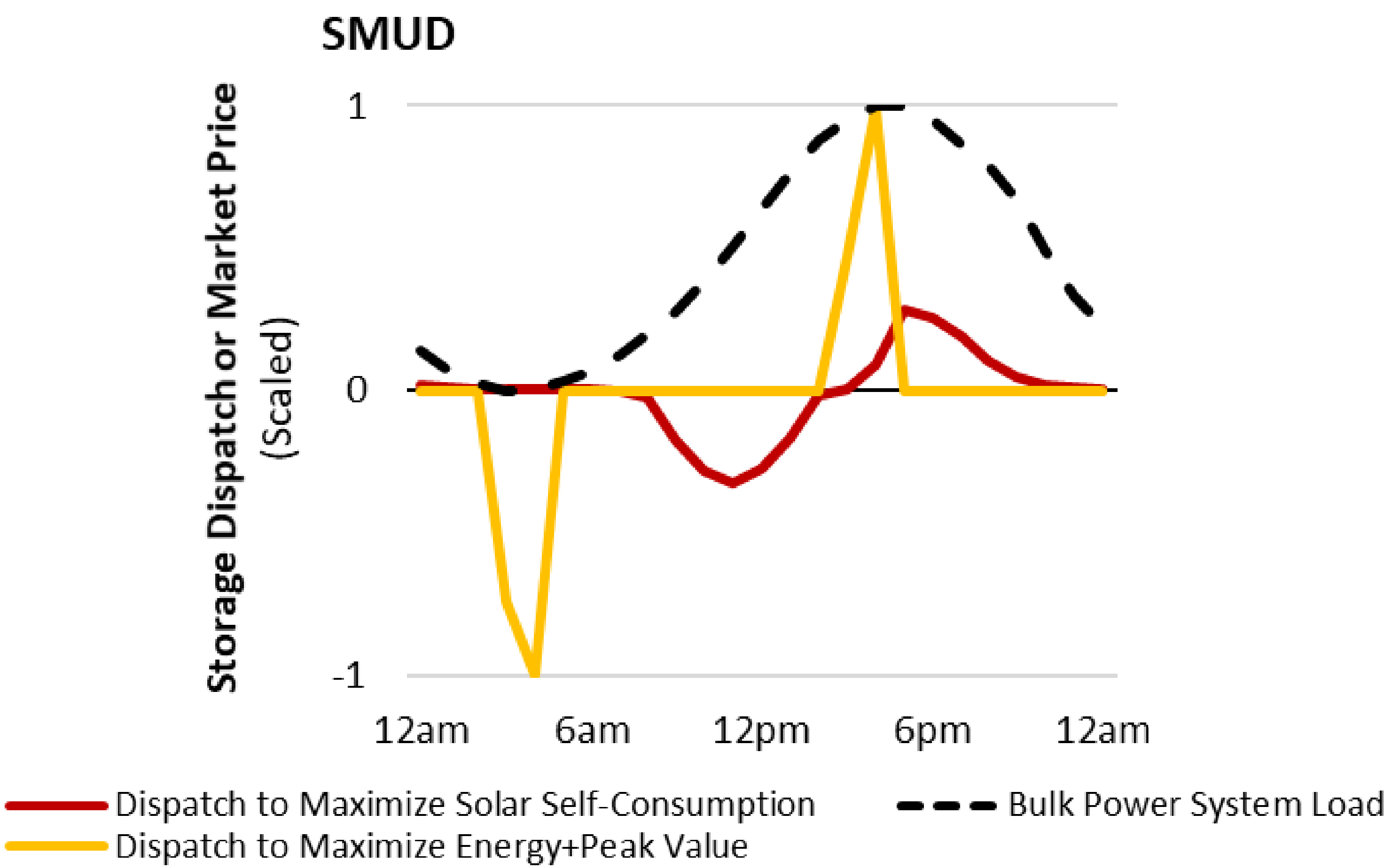


Alignment of Storage Dispatch and System Peak Demand

- Storage operated ***solely*** for self-consumption sits largely idle on peak days
  - Increased customer load results in less solar available to charge storage for dispatch during peak

- The (little) storage dispatch that occurs is not well-aligned with peak hours…

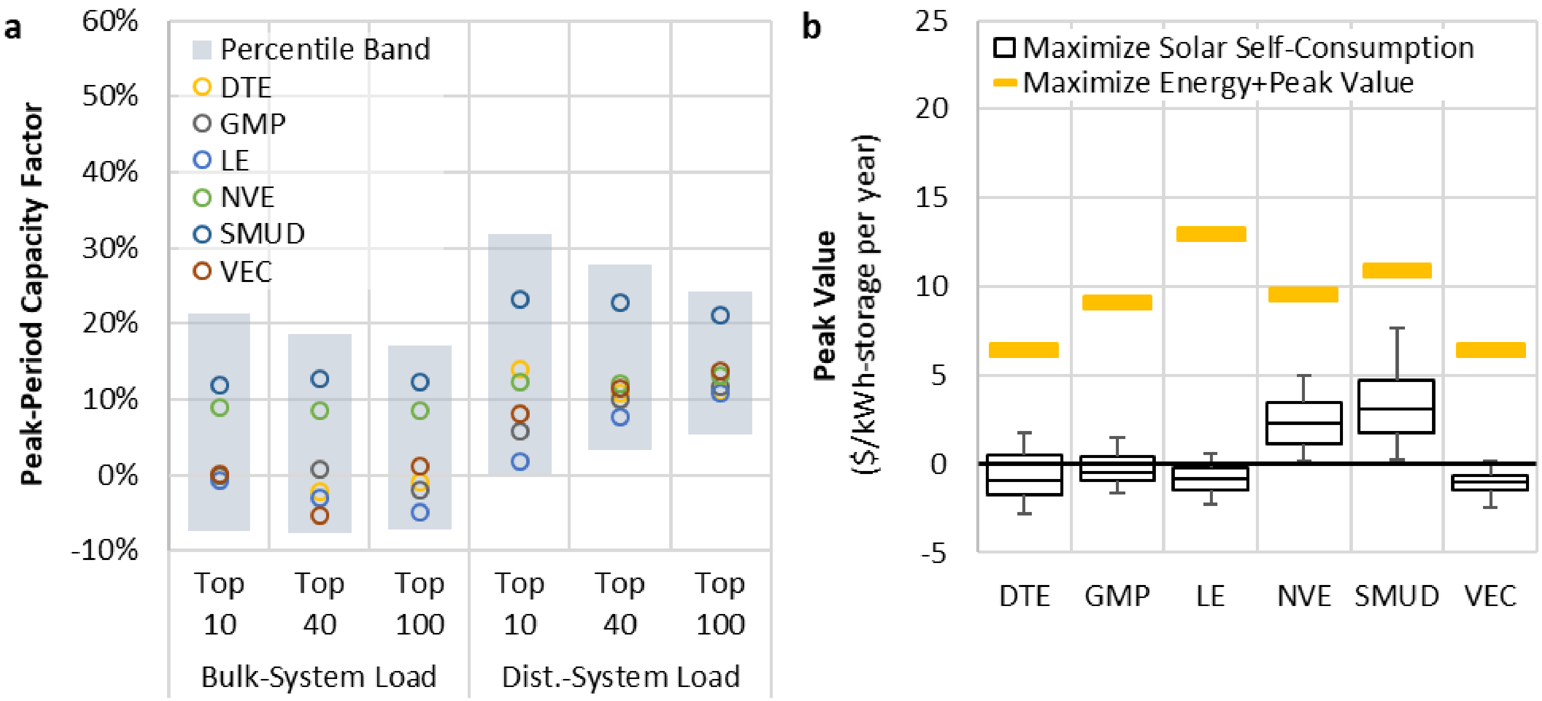
Storage dispatch profiles on system peak-day



Peak Value of Storage to Maximize Solar Self-Consumption

- …This is true across other definitions of "peak value", e.g., generation and T&D capacity
  - Storage operated for solar self-consumption has low peak coincidence (panel a), though somewhat higher relative to distribution peak

- At a marginal peak value of $50/kW-year over 40 peak hours:
  - Best case (yellow lines in panel b): $6-13/kWh-storage



Assessing the Persistence of the Value Gap

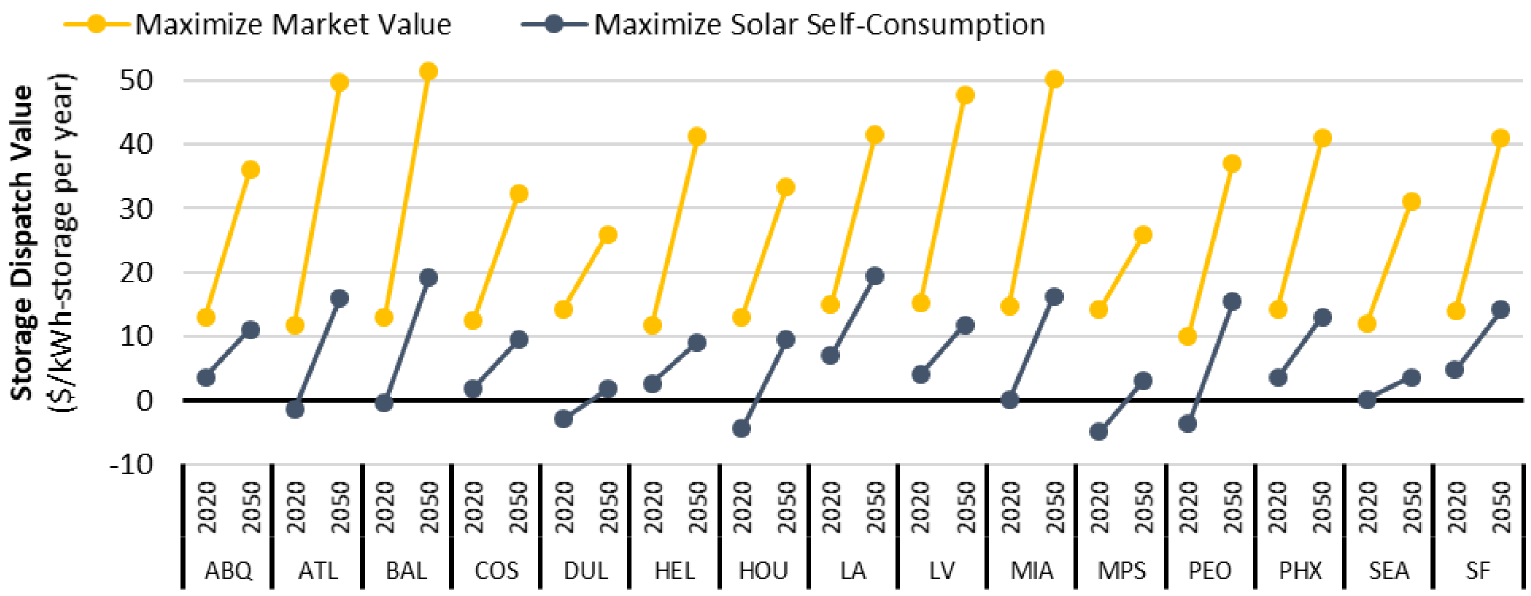
How does this analysis hold up in high-RE futures?

- Increasing renewable energy (RE) generation → “duck curve” wholesale energy market prices (low in the middle of the day and highest in early evening hours)
  - *Should* align better with the dispatch profile of storage base usage (solar self-consumption)

- ***Is this the case?***
- We re-ran our analysis scenarios using projected, high RE scenario thru 2050
  - 2020 Standard Scenarios, Low RE Cost Scenario (combined solar+wind generation reaches 60% of total U.S. electricity generation) for 15 locations across US

Storage Dispatch Value in a High-RE Future

- Value of storage for solar self-consumption rises by avg. of $10/kWh-storage, over 15 locations
- Yet, the market-based dispatch value rises by avg. of $26/kWh, *widening* the value gap
  - Prices become more volatile over time as RE increases; increased capacity value
- Storage for solar self-consumption remains unable to capture value during spike in prices



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Decomposing the Value Gap

Scenario Design to Decompose Contributing Factors

- The "value gap" between net billing with flat rates and full market-optimized dispatch is due to a combination of factors: asymmetric pricing, flat rates, and restrictions on grid charging/discharging
- To disentangle the relative effects of each, we compute storage dispatch value over a structured sequence of scenarios that move incrementally from our two bookend cases:

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Net billing with flat rates	***Replace flat prices with hourly prices***	***+Allow grid charging***	***+Allow limited grid discharging***	***+Allow unlimited grid discharging***	***+Symmetric price for exports and consumption***
	Retain fixed pricing differential for exports vs. consumption		Hourly grid discharge from PV+storage capped at PV nameplate kW (DC-coupled)	Hourly grid discharge from storage limited only to storage kW capacity (AC-coupled)	Full market-based dispatch (as if it were front-of-meter, standalone storage)
	No grid charging or discharging allowed				

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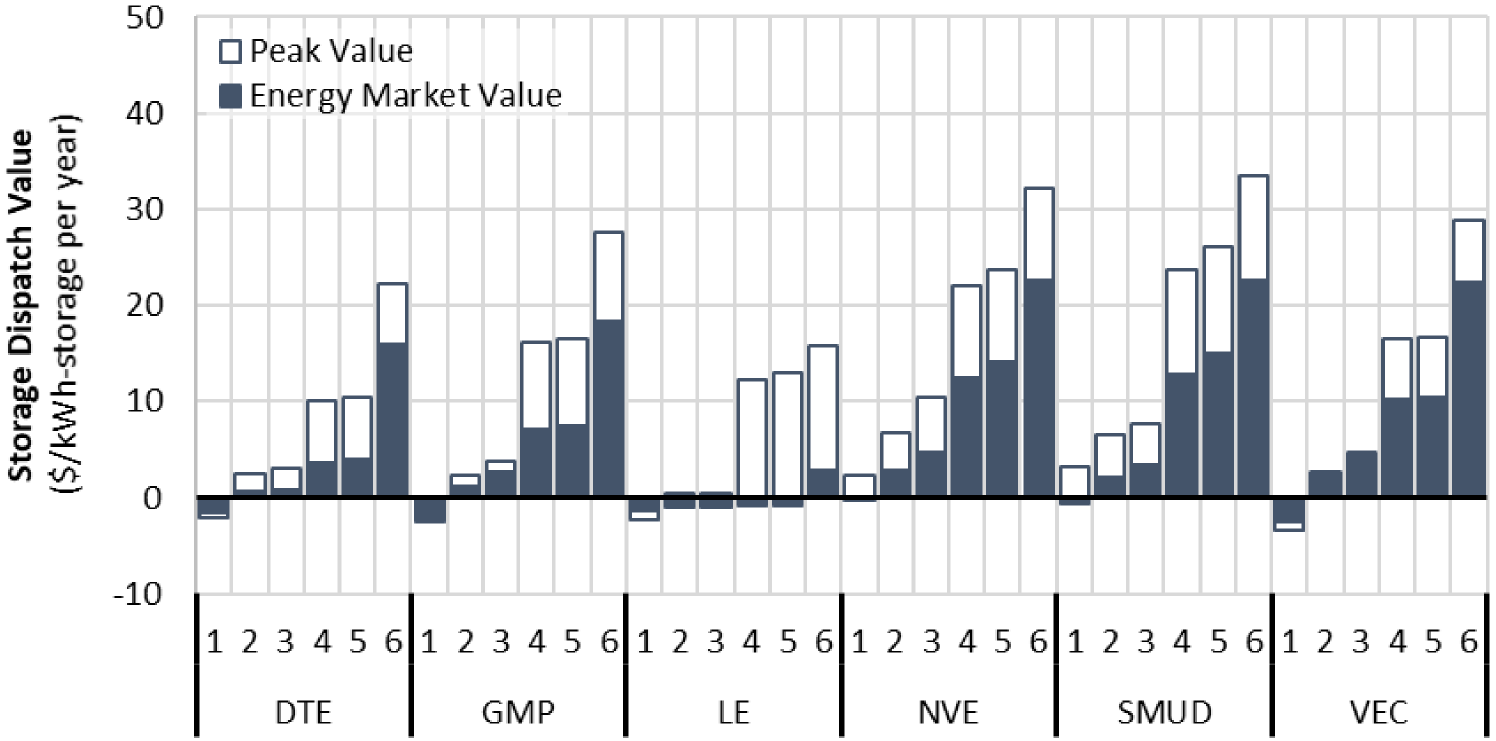
Storage Value across Tariff Scenarios

Stepwise…

- …Time-invariant pricing impact in isolation is quite small
- …Constraints on grid *charging* have little additional effect
- …Constraints on grid *discharging* have larger additional effects
  - Allows peak value capture
- …Asymmetric pricing is responsible for 30-50% of overall value gap
  - Mostly energy value impact

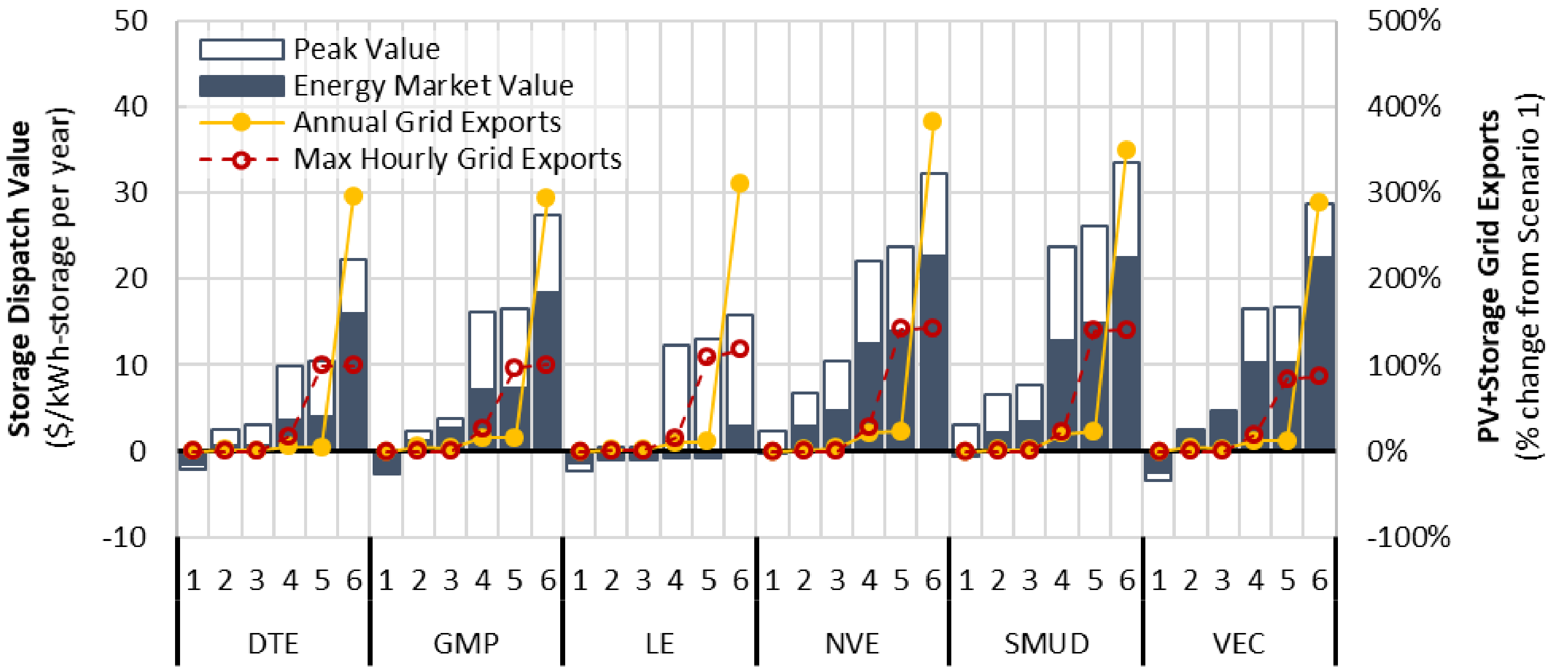


Notes: Plotted values are medians across all customers of each utility.

Scenario 1: Net billing with flat prices
Scenario 2: Net billing with hourly prices, no grid charging or discharging
Scenario 3: Net billing with hourly prices, grid charging allowed, no grid discharging
Scenario 4: Net billing with hourly prices, grid charging allowed, partial grid discharging allowed
Scenario 5: Net billing with hourly prices, grid charging allowed, full grid discharging allowed
Scenario 6: Market-based dispatch with hourly prices, grid charging and discharging allowed

Grid Exports across Tariff Scenarios

- Grid export metrics considered:
  - Annual (solar self-consumption)
  - Hourly max. (local grid stress)
- *Limited* grid discharge (Scen. 4) avoids notable increases in max. grid exports while still capturing 50% - 70% of potential value and without degrading self consumption levels
- Unlimited grid discharge (Scen. 5) doubles max. grid exports vs. no grid discharge
- Eliminating asymmetry (Scen. 6) results in 4-5 times more annual grid exports (greater than standalone PV)



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Scenario 6: Market-based dispatch with hourly prices, grid charging and discharging allowed

Conclusions

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- Net billing results in suboptimal storage dispatch, which may…
  - Create deadweight loss: large customer outlays for storage equipment that provides little societal benefit
  - Undermine the intent of NEM reforms: Using storage to move solar grid exports back behind the meter maintains the same sales/revenue erosion issues as with NEM
  - Perpetuate inequities: insofar as those customers who receive the greatest benefit under net billing are those that can afford to co-install storage with solar
- These issues can be partially mitigated through tariff designs or programs that incentivize customers to discharge to the grid during the highest value hours
  - For example, TOU and CPP rates, and demand response programs
  - Requires consideration of, and potential tradeoffs with, local distribution network impacts

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Acknowledgements

This work was funded by the U.S. Department of Energy Solar Energy Technologies Office, under Contract No. DE-AC02-05CH11231.