Bill Savings vs. Backup Power:

Evaluating operational tradeoffs for home solar+storage systems

Will Gorman, **Galen Barbose, Sunhee Baik, Cesca Miller**, Juan Pablo Carvallo

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Webinar Overview

- Introduction
- Data and Methods
- Results
- Conclusions
- Q&A

Context and Motivation

- Adoption of residential solar photovoltaic+energy storage systems (PVESS) is driven by both bill savings opportunities and customer demand for backup power
- Prior work by this team has explored PVESS backup power during long duration interruptions, which often come with some advance warning
- But many power interruptions are unpredictable (and often relatively short)
- To maintain readiness for these types of events, customers can set their battery to maintain some minimum capacity in reserve in case of an interruption
- The higher the reserve setting, the greater the reliability value to the customer, but less capacity is available for day-to-day bill management (an opportunity cost)
- This study evaluates this tradeoff associated with the backup reserve setting

Study Overview

Approach: Simulation-based analysis using modeled solar and end-use level load profiles, and stochastic simulation of power interruption events

Key Elements of Study Scope:

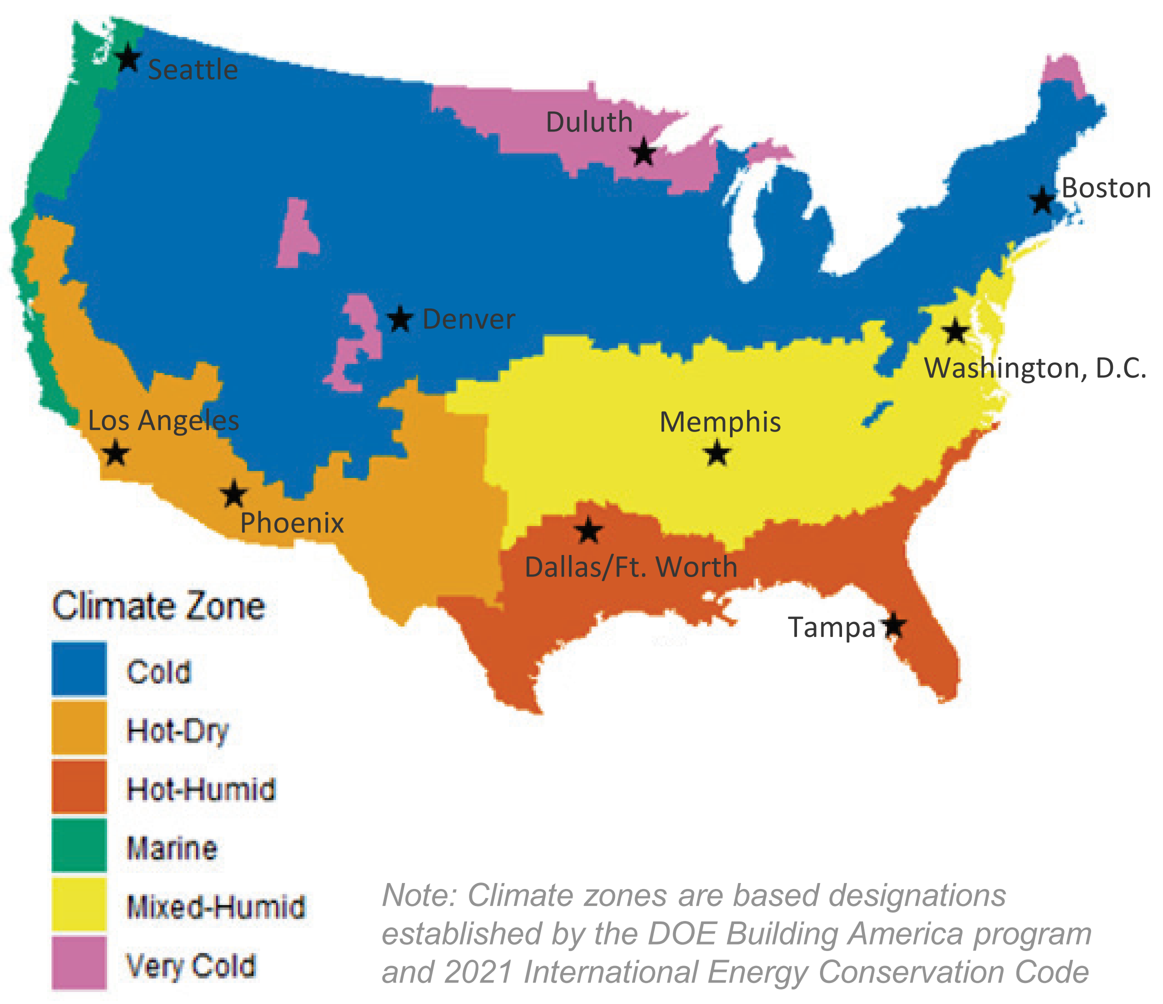
- Single-family residential buildings across a diverse set of climates and geographies
- Empirically based mix of short- and long-duration events
- Standardized set of tariff structures and PVESS configurations across all locations
- Scenario analysis: base-case with sensitivities around key assumptions

Key Caveats:

- Analysis predicated on interruptions that occur without forewarning
- Not a cost-effectiveness evaluation; does not consider storage costs

Data and Methods

Ten Locations Studied

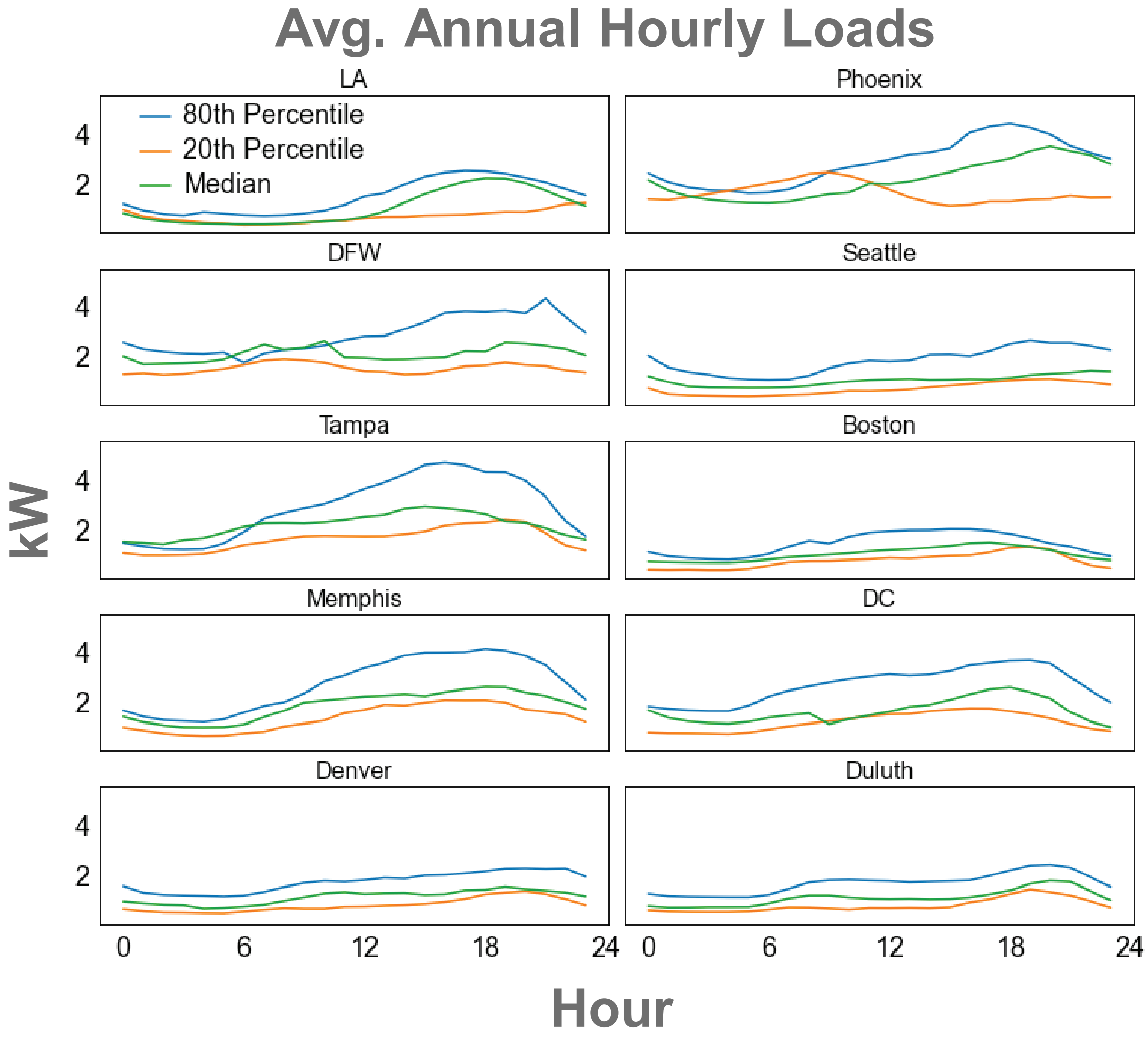


Note: Climate zones are based designations established by the DOE Building America program and 2021 International Energy Conservation Code

- Selected ten counties, each encompassing a metropolitan area and spanning a diverse range of climates
- Analysis captures locational differences in:
  - Loads (climate and building stock)
  - Solar generation
  - Interruption patterns
- Analysis does _not_ consider specific rate structures in each location

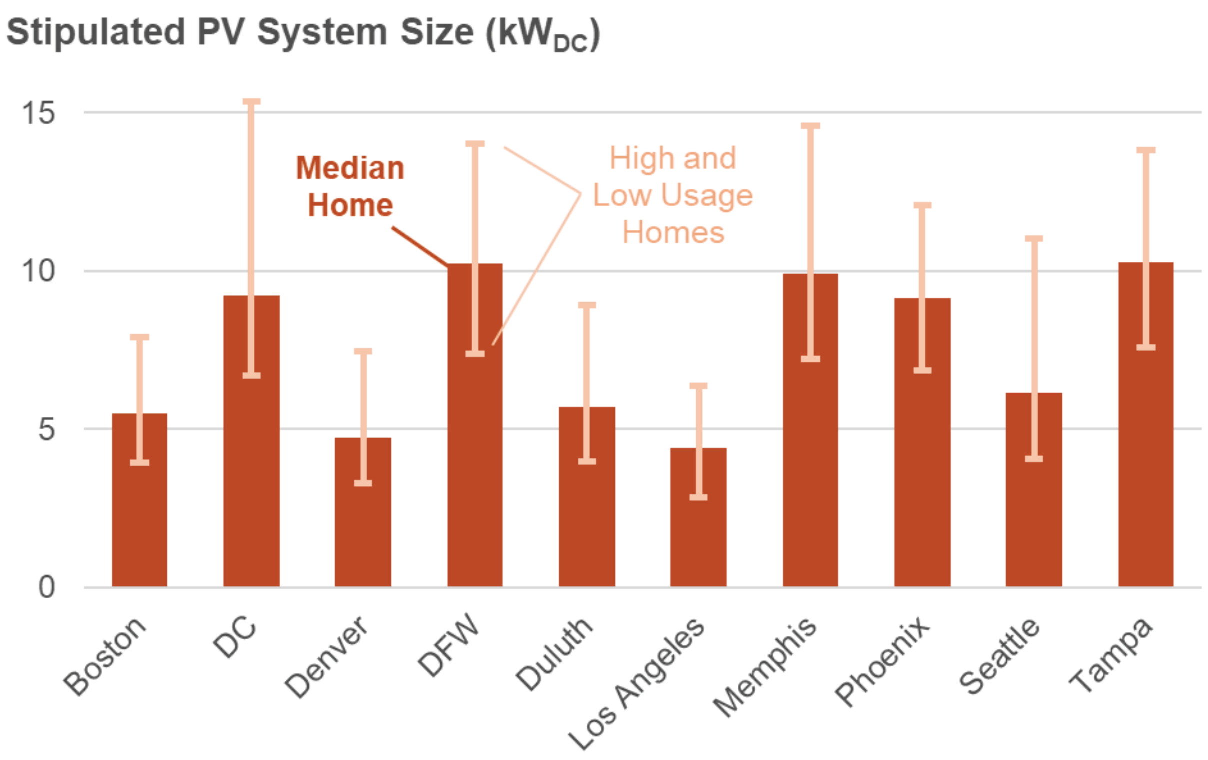
Building Load Simulations

- Used publicly available profiles developed with NREL's ResStock building simulation platform
- Base-case analysis relies on load profiles for representative "median" customer in each location
- Sensitivity analyses based on load profiles for the 20th and 80th percentile customers, based on annual electricity consumption levels



PV System Sizing and Generation

- PV system sizes stipulated based on annual energy consumption, subject to available roof area
- Hourly PV generation simulated with NREL's System Advisor Model (SAM)
- Synched up to the same weather data as used for the loads



Power Interruption Events

- Simulate stochastic power interruption events for each location using Berkeley Lab's PRESTO model (1,500 years per location)
- PRESTO trained on historical hourly interruption data for each U.S. county for the years 2017-2021 (from PowerOutage.US)
- Reflects interruption patterns over that specific historical period; some locations (DFW, LA) had long-duration interruptions in that period
- Does NOT reflect longer term historical patterns or projected future patterns

Consider the results as reflecting a diversity of interruption patterns, without ascribing too much significance to the specific locations

Summary of Simulated Power Interruption Events for Study Locations

Location	Percent of years with at least one interruption	Average interruptions per year	Average duration per interruption event (hours)
Boston	48%	0.98	19.61
DC	67%	0.76	9.29
Denver	73%	0.84	3.97
DFW	48%	0.49	**34.69**
Duluth	68%	0.79	5.81
LA	29%	0.29	**39.51**
Memphis	79%	1.04	5.75
Phoenix	99%	**2.22**	6.77
Seattle	71%	0.87	12.97
Tampa	71%	0.84	9.63

Tariff Structures and Grid Charging/Discharging Rules

We consider two common tariff structures where storage provides bill savings:
1) Net billing with flat rates
2) Net metering with TOU rates

Under both structures, storage generates bill savings by arbitraging between high and low prices

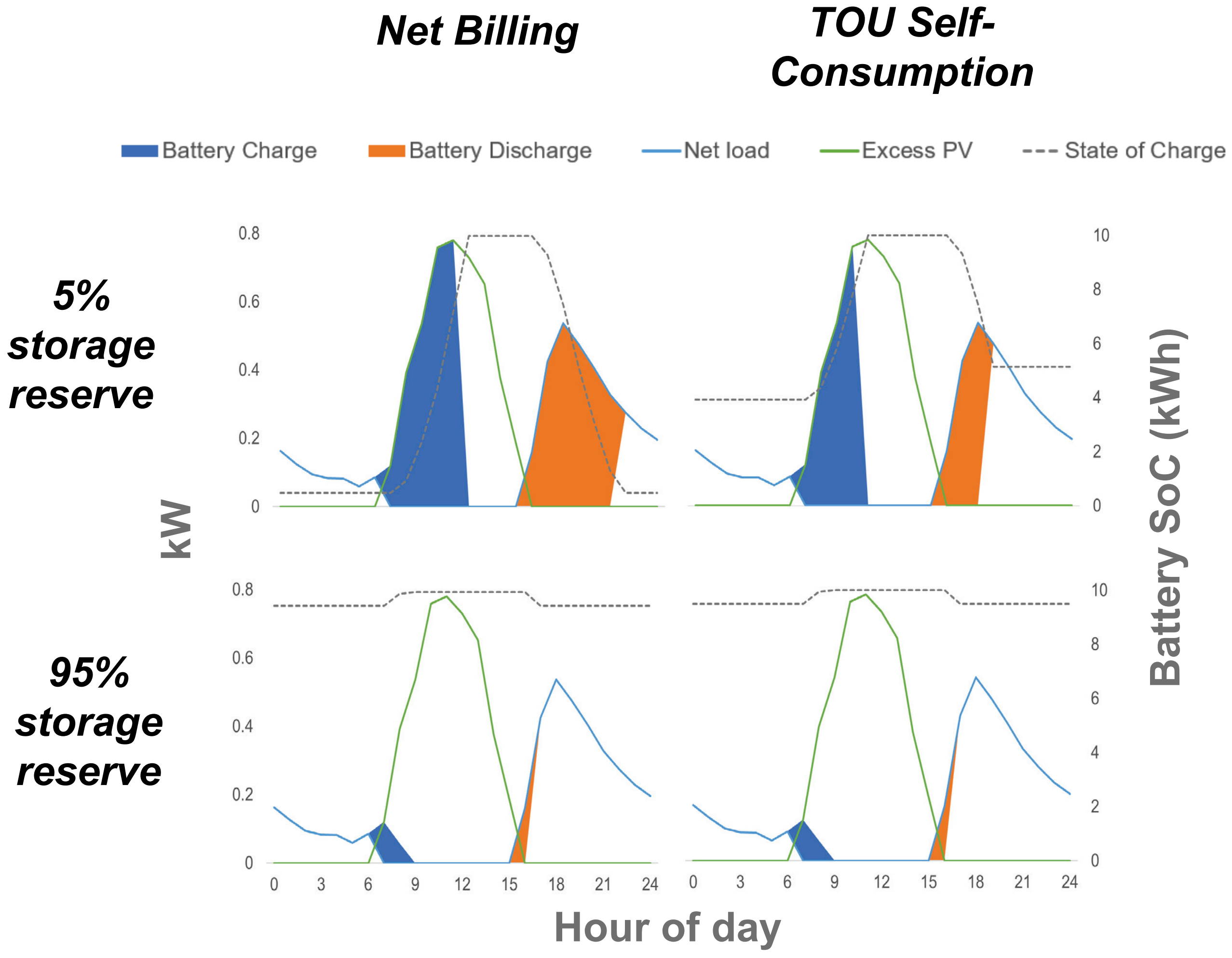
Storage dispatch is also impacted by grid charging and discharging constraints:

- Default is that storage charges only from surplus solar and discharges only to meet net-load
- Net metering TOU variants allow grid charging and/or grid discharging (see table)

Tariff Structure Variant	Grid charging	Grid discharging
Net billing	No	No
TOU self-consumption	No	No
TOU grid charging	Yes	No
TOU grid discharging	No	Yes
TOU front-of-the-meter	Yes	Yes

Illustrative Dispatch Profiles for Two Tariff Structures and Two Storage Reserve Levels

- Storage charges from excess solar during morning hours and discharges in the late afternoon and evening after solar drops off
- Under net billing, storge discharges down to the reserve level
- In contrast, under TOU self-consumption (no grid discharge), storage discharges only partially
- Increasing battery reserve levels reduces the depth of discharge



Note: For ease of interpretation, battery charge and discharge are both shown as positive values, differentiated by their shading.

Results

Results Organization

- **Building Intuition: Stepping through the Memphis Base-Case**
  - Bill savings from storage across reserve levels
  - Reliability value across reserve levels
  - Total customer value of storage across reserve levels
- **Base-Case Results for All Locations**
- **Sensitivity Cases**

Base-Case Assumptions and Sensitivities

Parameter	Base-Case	Sensitivities
Price arbitrage differential[a]	$0.05/kWh[a]	$0.10, $0.15, and $0.20/kWh
Base price[b]	$0.10/kWh[b]	$0.20/kWh
Value of Lost Load (VoLL)	$5/kWh[c]	$10 and $50/kWh
Interruption frequency	Historical county-average[d]	2x and 10x the base-case values
Battery size	10 kWh[e]	30 kWh
Customer load profile	County median from ResStock[f]	20th and 80th percentile customers

(a) "Price arbitrage differential" refers to the price differential between peak and off-peak or between import and export prices. The base-case assumption is intentionally small, to focus initially on cases where the results are driven more strongly by reliability value.

(b) "Base price" refers to either the off-peak period price (for TOU rates) or the export price (for flat net billing). A higher base price increases the cost of round-trip efficiency losses.

(c) The base-case VoLL assumption is roughly equal to the average residential VoLL within the literature (see slide 53).

(d) The base-case interruption frequency for each county is based on historical interruption data obtained from PowerOutage.US for 2017-2021.

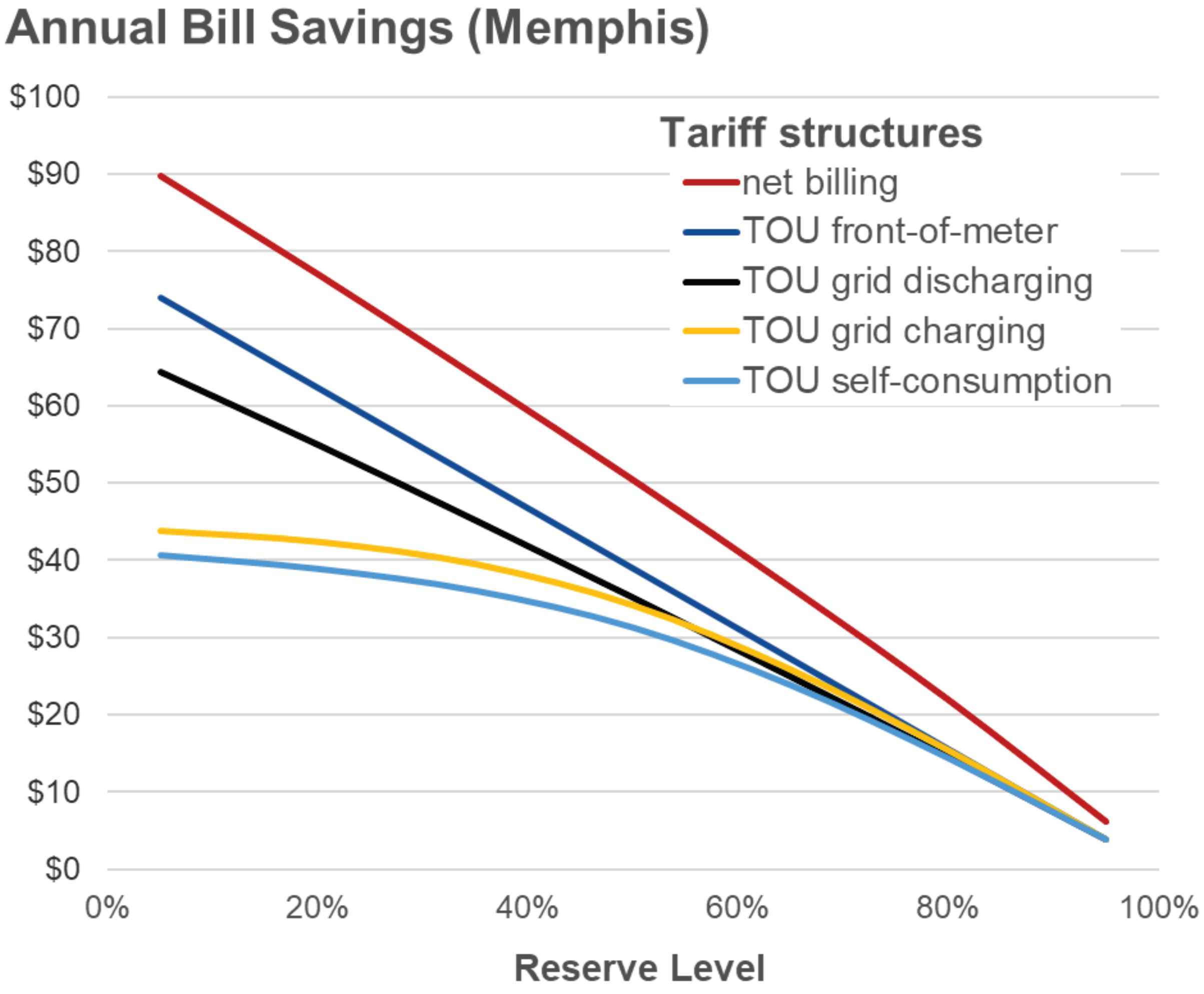
(e) The base-case battery size roughly corresponds to the most-typical battery size observed within the market today, whereas the larger battery size in the sensitivity case may be more reflective of how a customer would size its battery for whole-home backup.

(f) The base-case customer load profile is based on the ResStock building model with the median annual electricity consumption for the county, while the sensitivities are based on the building models with the 20th and 80th percentile annual electricity consumption levels.

Bill savings from storage decline with reserve levels

At different rates depending on tariff structure

- Steepest decline is for net billing and TOU rates that allow grid discharging, where bill savings fall more-or-less linearly with reserve level
- For TOU cases *without* grid discharge (bottom two lines), changes in bill savings are gradual up to ~40% reserve level
- In those cases, a substantial portion of battery capacity tends to sit idle anyway (not enough peak-period net load to fully discharge the battery)

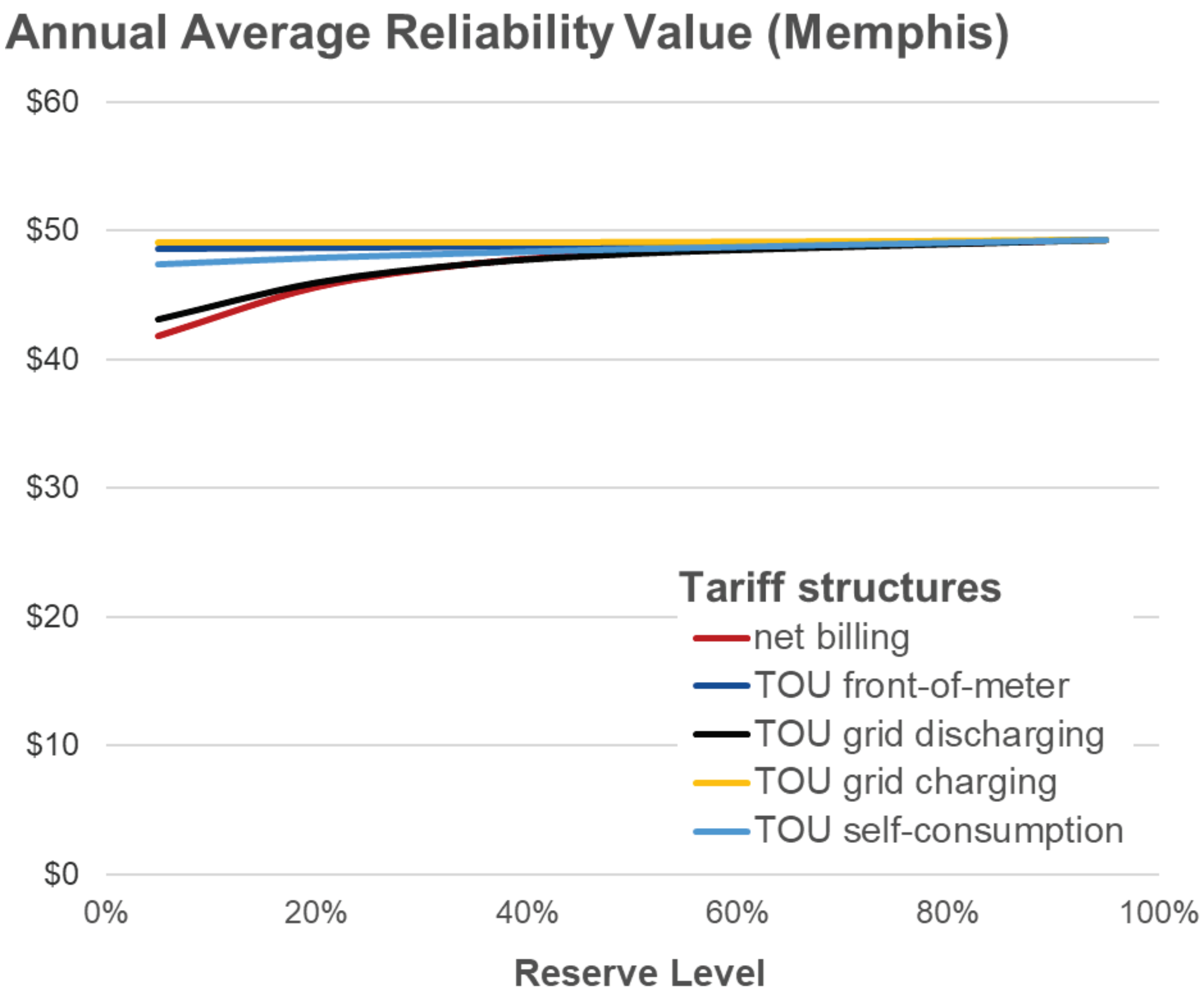


Reliability value is fairly insensitive to reserve level

At least for these base-case annual average values

Surprising result reflects several factors:

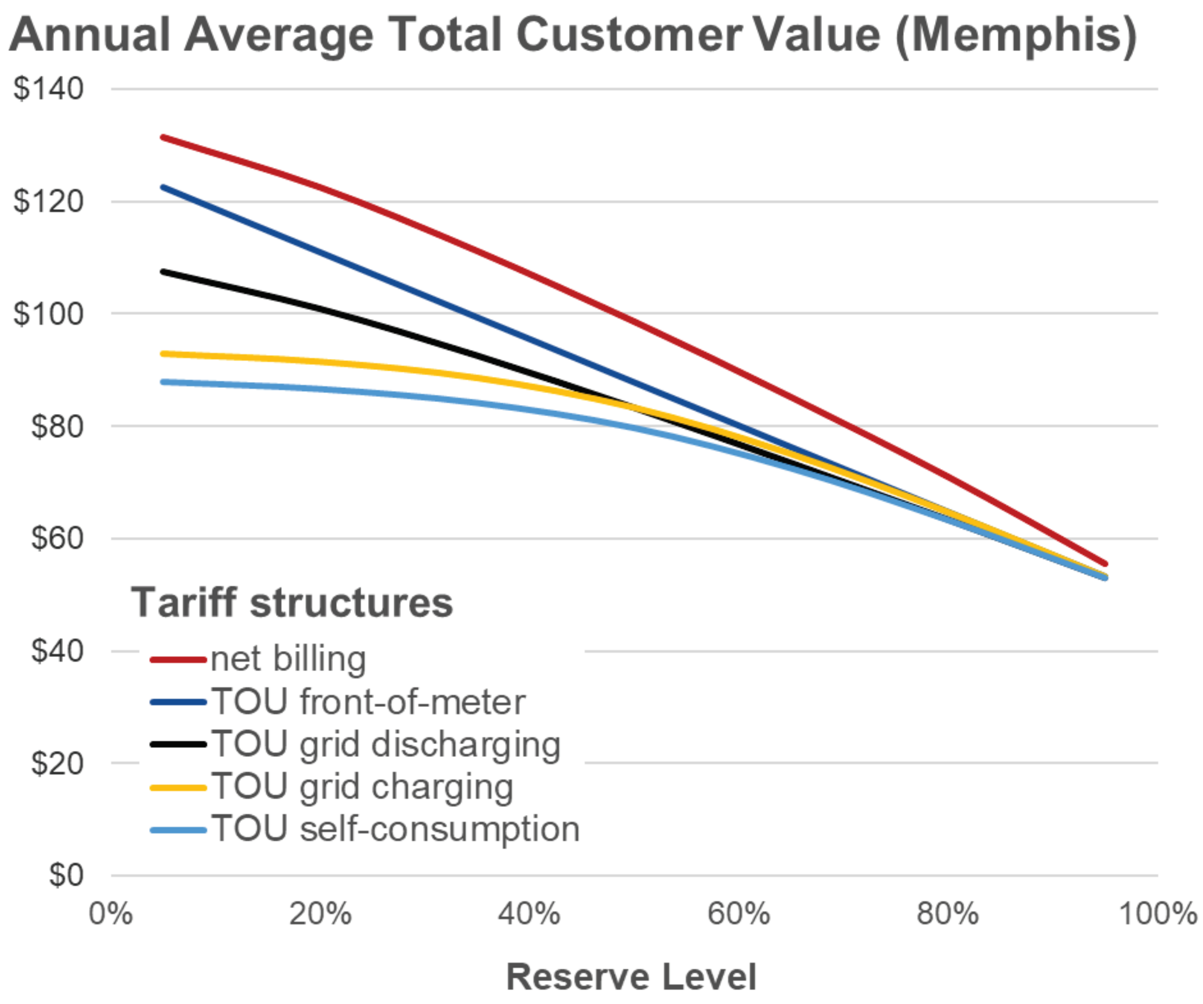
1. The simulated power interruptions are relatively infrequent and short, based on the specific historical period used
2. PV generation meets most of the energy needs during the interruption; the net load served by the initial SoC on the battery is often quite small
3. The initial SoC at the start of interruption events is often quite high, even at low reserve levels, depending on the tariff structure



Total customer value is maximized with low reserves

Under the specific set of base-case conditions assumed here

- Total customer value declines monotonically with increasing reserves, largely mirroring the corresponding drop in bill savings
- As such, total customer value is greatest when reserves are kept as low as allowed by the battery manufacturer
- Under TOU rates without grid discharging (the bottom two lines), total customer value is fairly flat up to ~40-50% reserves

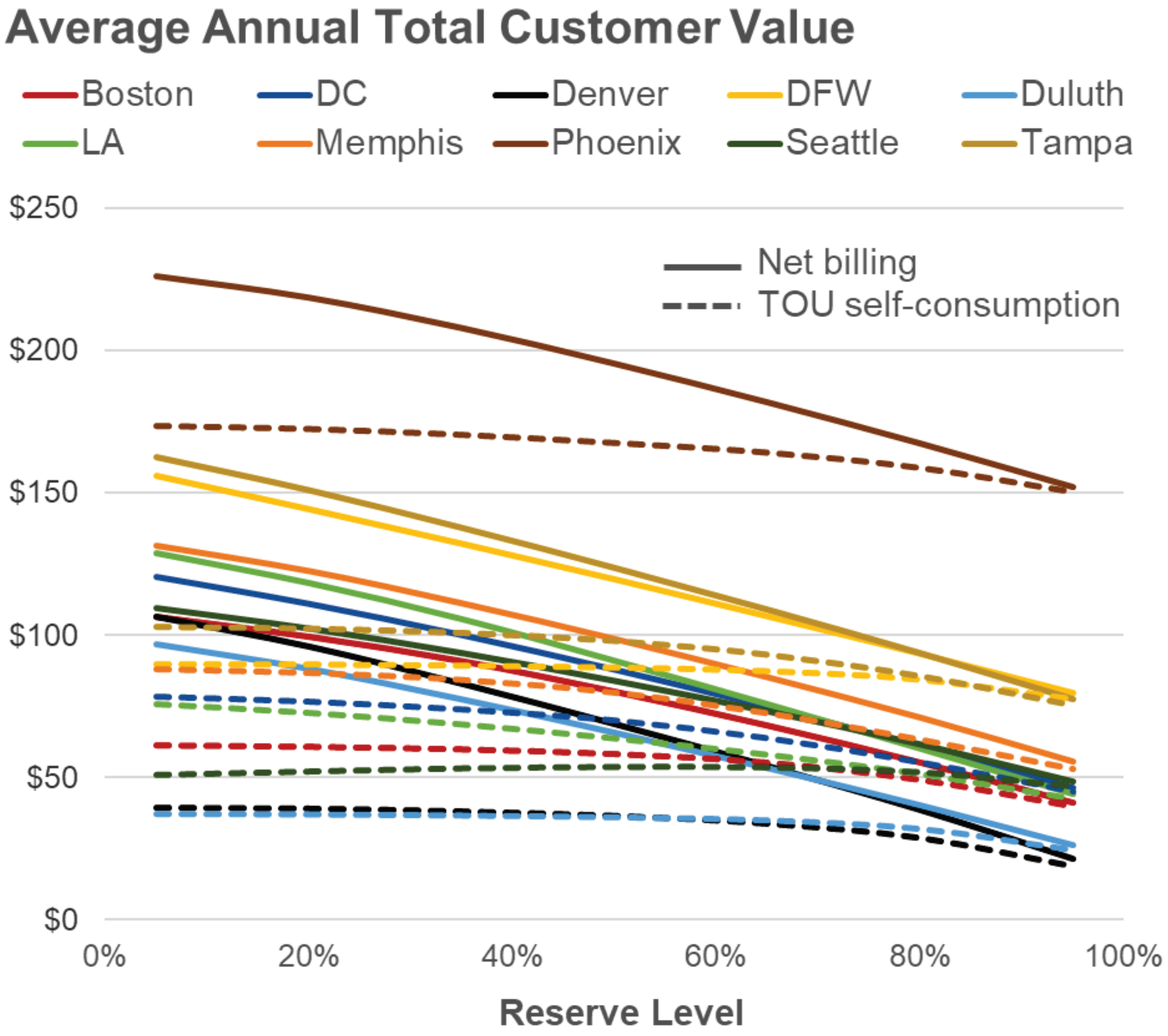


Results Organization

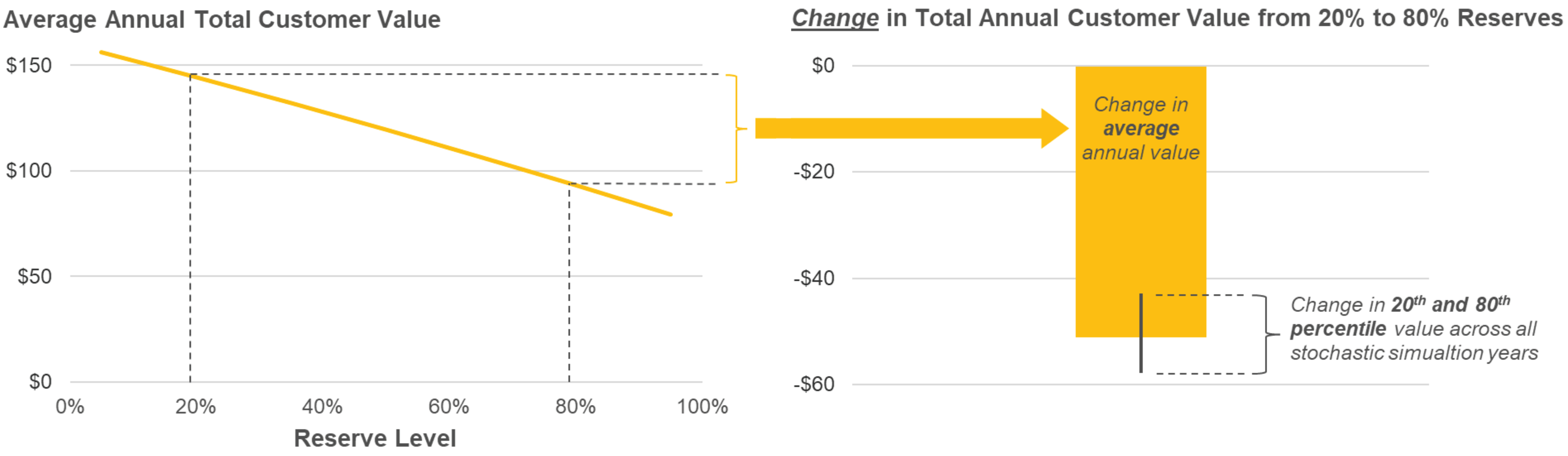
- Building Intuition: Stepping through the Memphis Base-Case
- **Base-Case Results for All Locations**
  - Focus on the “bookend” tariff structures: net billing and TOU self-consumption
- Sensitivity Cases

Total customer value is maximized at low reserves across all locations, even if only marginally so

- All locations show same trend as Memphis: total customer value declines with reserve level
- Opportunity cost of foregone bill savings more than offsets any gain in reliability value
- The decline under the TOU self-consumption tariff is quite modest compared to net billing
- These results are based on “average” value across all simulation years



Alternative Figure Format for Remaining Results



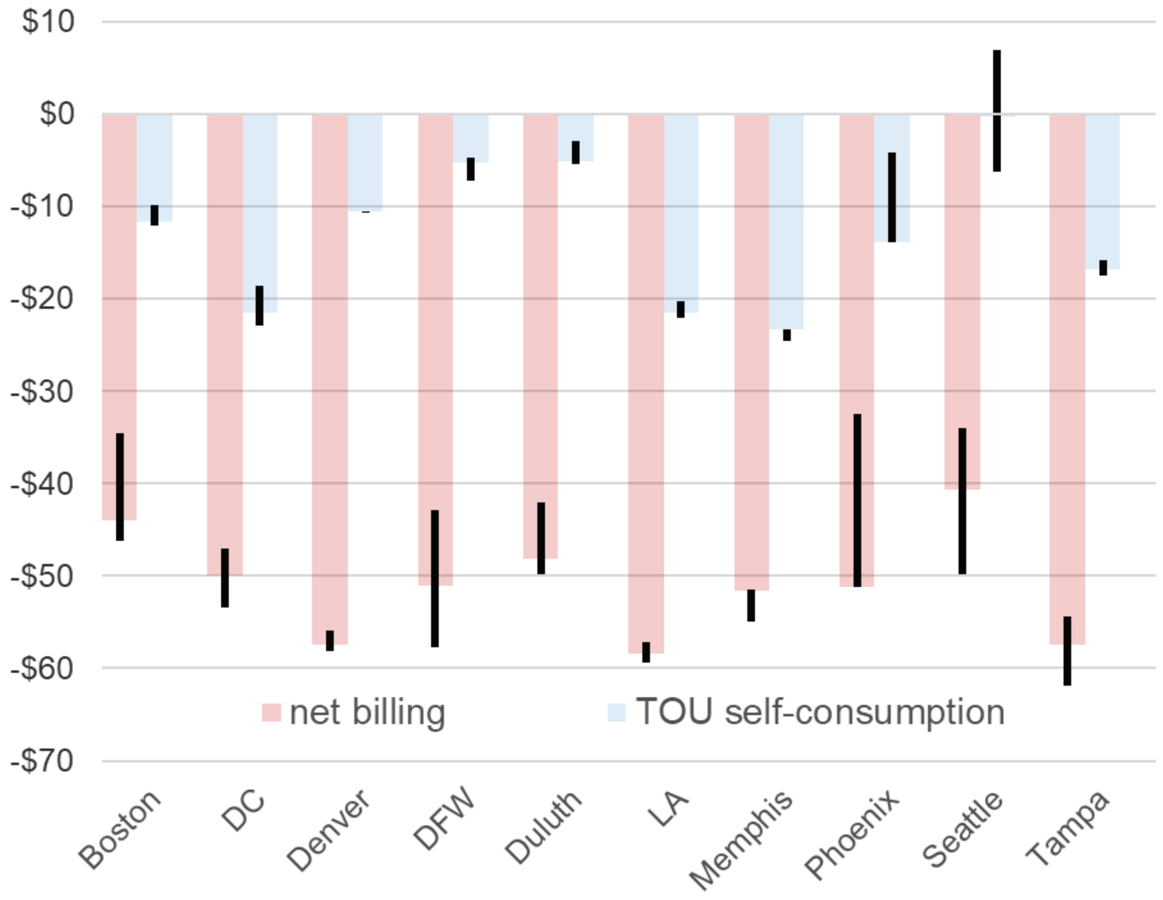
Alternative format is more compact, and allows us to add in error bands to show the range across stochastic simulation years

The same basic trends hold even under worse-than-average interruption years (with one modest exception)

- Under worse-than-average interruption years, reliability value will tend to be higher, and potentially also more sensitive to reserve level
- Yet even in those years, total customer value still tends to decline with increasing reserves (under our base-case assumptions)

Change in Total Annual Customer Value when Increasing Reserves from 20% to 80%

Bars show averages and error bands show range across simulation years



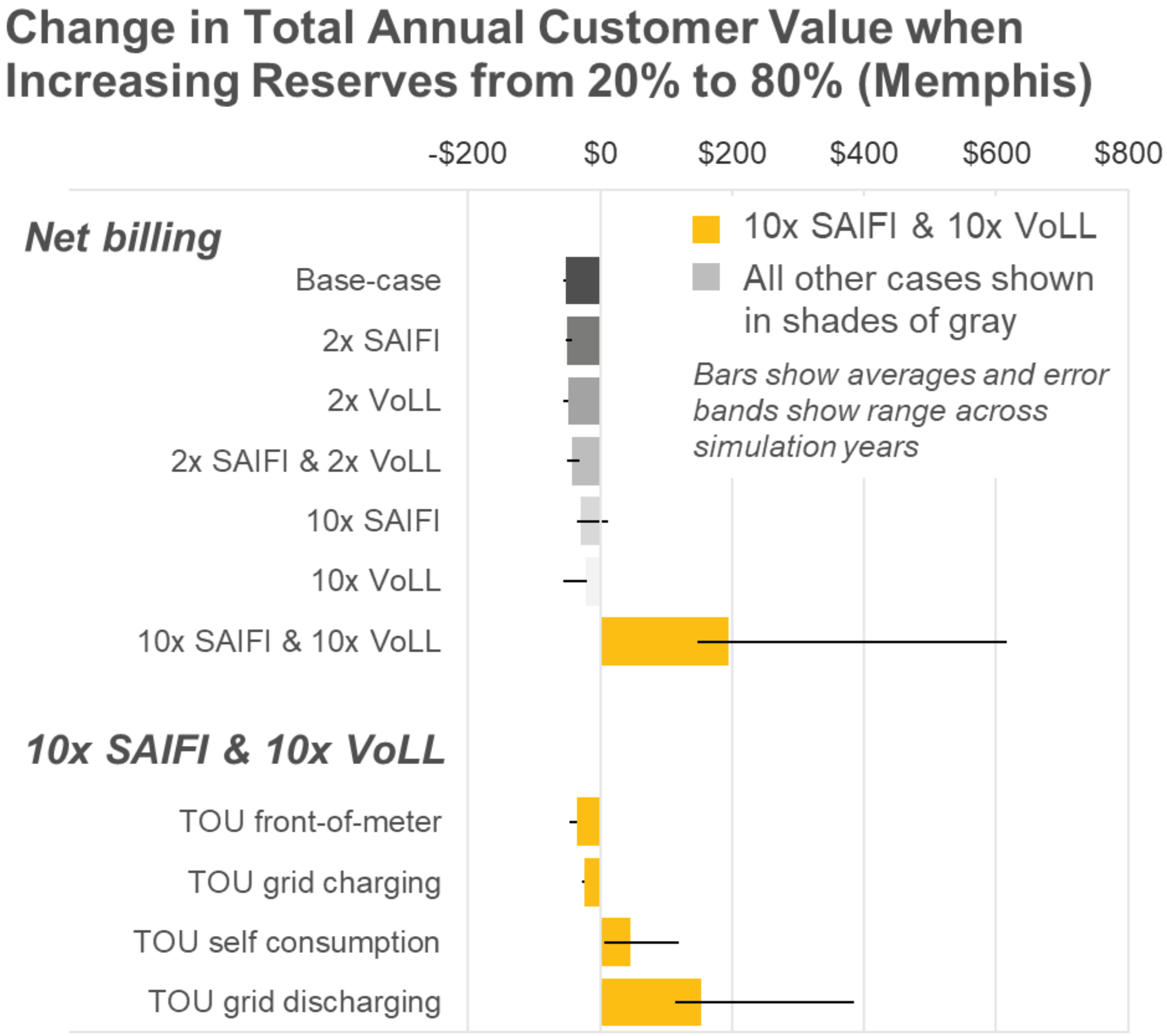
Results Organization

- Building Intuition: Stepping through the Memphis Base-Case
- Base-Case Results for All Locations
- **Sensitivity Cases**
  - Increasing interruption frequency (SAIFI) and VoLL
  - Increasing pricing differential
  - See full report for other sensitivities (battery size, building load, base-price)

Total customer value increases with reserve level, if VoLL and interruption frequency are sufficiently high

We apply progressively higher SAIFI and VoLL to the Memphis base case, starting with the net billing tariff structure

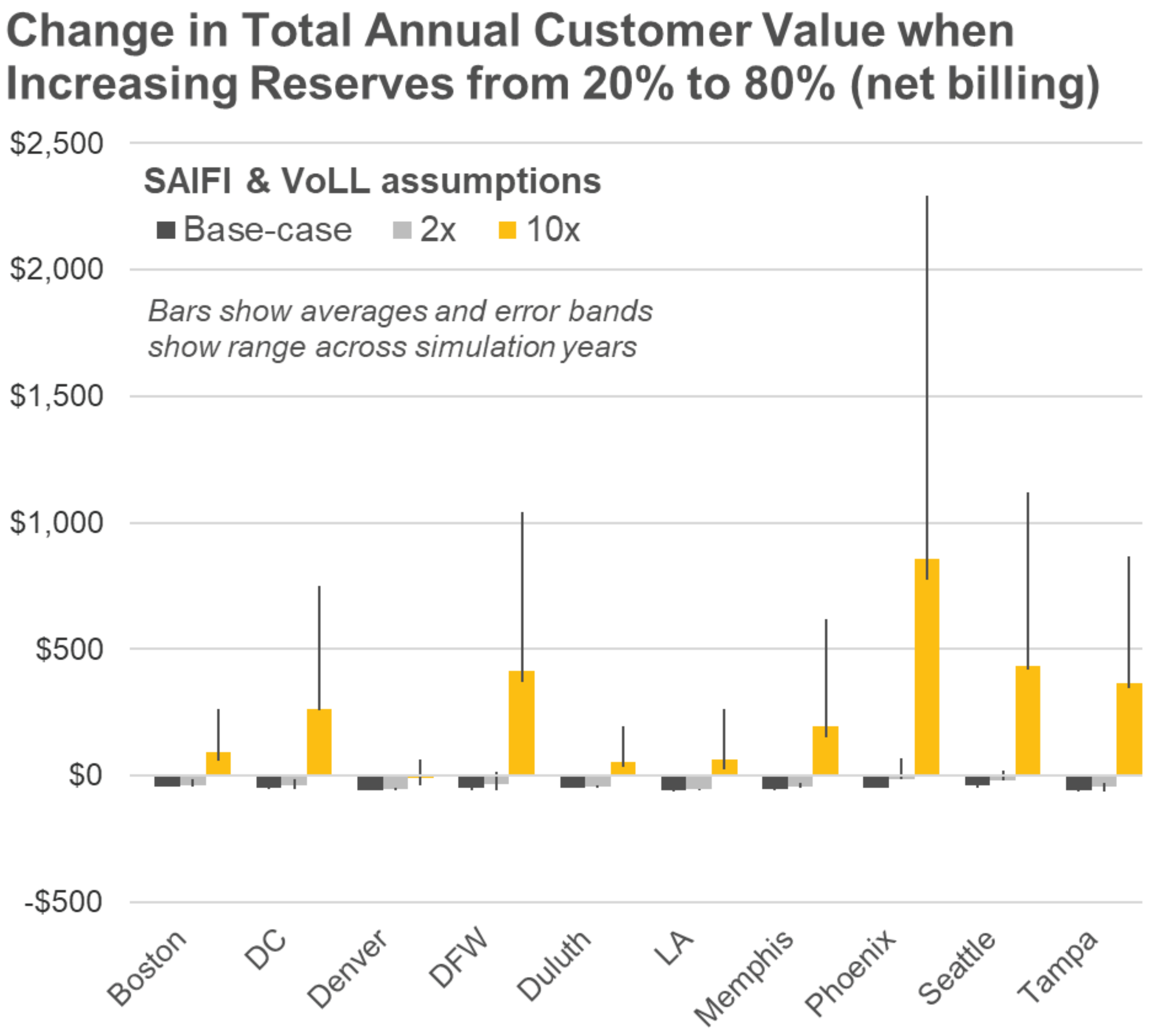
- Doubling SAIFI and VoLL does not materially change the results from the base case
- Only with the highest (10x) SAIFI and VoLL assumptions do the results flip
- The effect is less pronounced for the other tariff structures



Results for other locations are similar, though in some cases considerably more pronounced

Focusing here on net billing:

- Doubling the SAIFI and VoLL does not materially change the results from the base-case in any of the study locations
- At 10x SAIFI and VoLL levels, total customer value increases with reserve level in almost all locations
- In some locations, the swing is quite substantial, partly reflecting base-case interruption profiles

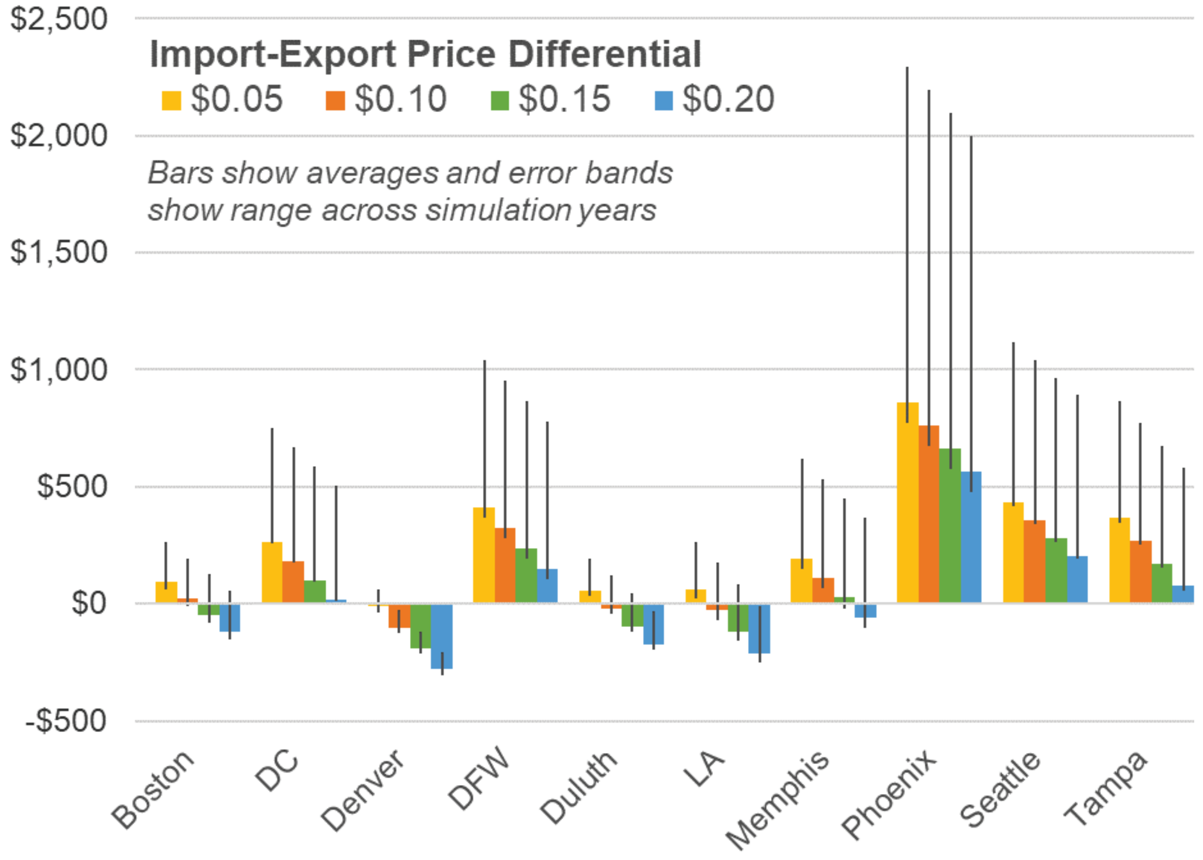


Larger price differentials can shift the economics back towards lower reserve levels, though not everywhere

- Previous trends assume a modest differential ($0.05/kWh) between import and export prices
- Raising the price differential increases the opportunity cost of holding battery capacity in reserve
- In half of the study locations, a $0.20/kWh price differential flips the results back into negative territory (i.e., customer is better off maintaining low reserves)
- In other locations (i.e., with more severe interruptions and/or higher customer loads), total customer value is still greatest with high reserves

Change in Total Annual Customer Value when Increasing Reserves from 20% to 80%

Net billing with 10x SAIFI & 10x VoLL



Conclusions

Key Take-Aways

- Across all locations, reliability value is (surprisingly) insensitive to reserve level
- As a result, the opportunity cost of maintaining higher reserves tends to outweigh any gains in reliability value from mitigated power interruptions
- This finding is robust across tariff structures and most of the sensitivities considered
- There are a limited set of circumstances within the set of conditions we analyzed where raising the reserve setting increases total customer value (bill savings + reliability value):
  - Customer resides in a location with exceptionally poor reliability
  - *And* customer has exceptionally high VoLL
  - *And* customer is on a net billing rate or on a TOU rate that allows grid discharging but *not* grid charging
  - *And*, depending on the location, the price differential on that rate is relatively modest

Conclusions

- Bill savings and reliability value are both important parts of the overall value equation for a customer investing in PVESS
- Bill savings tend to be more sensitive to the reserve level setting, and therefore in most circumstances justify maintaining as low a reserve setting as allowed
- The specific circumstances of any individual customer matter, and should be considered when making decisions about reserve level settings
- Tariff/interconnection rules impact how customers make this tradeoff
- Technological advancements may also impact how customers make this tradeoff

Q&A

Download the report and webinar recording

Contacts

Will Gorman: wgorman@lbl.gov

Galen Barbose: glbarbose@lbl.gov

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