Berkeley Lab's PRESTO and a Case Study Application

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Agenda for today

- Berkeley Lab research on PV+storage in backup power applications
- Overview of PRESTO Model and demonstration
- PRESTO Case Study: *Backup Power Performance of Solar-plus-Storage Systems during Routine Power Interruptions*
- Q&A

Berkeley Lab Research on PV+Storage for Backup Power

Overview: 3-year research program to analyze the capabilities of behind-the-meter solar photovoltaics + storage systems (PVESS) in backup power applications

Research: A series of studies evaluating…

- PVESS backup power performance across a broad range of geographies, building types, and interruption conditions (both short- and long-duration interruptions)
- Impacts on PVESS backup capabilities as buildings become more efficient, flexible, and electrified
- Tradeoffs between use of PVESS for backup power and other competing uses

Public Data and Tools:

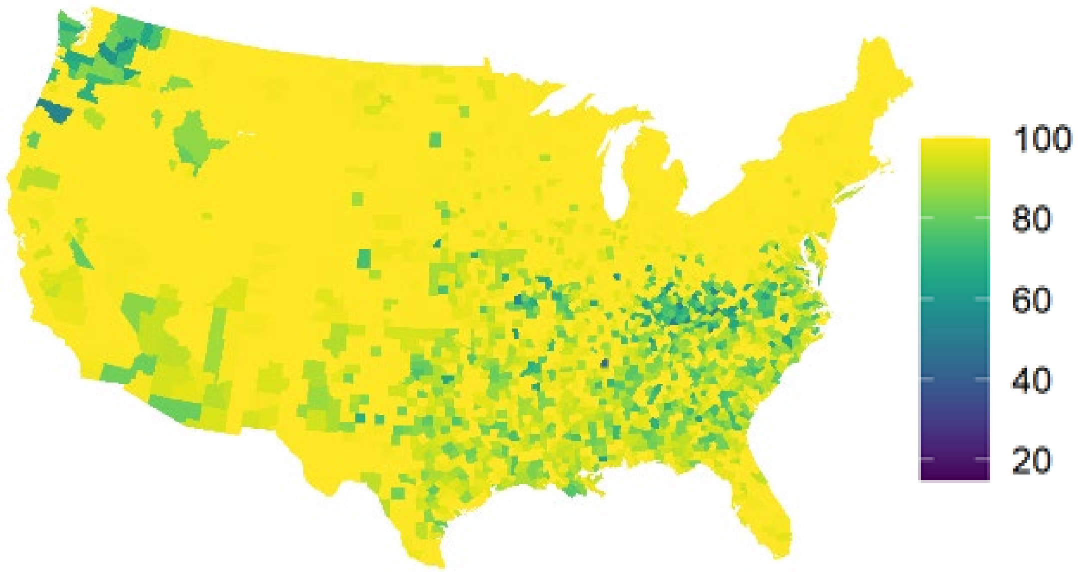
- Power Reliability Event Simulator TOol (PRESTO)

Illustrative Results: How would a PVESS perform in providing backup during long-duration power interruptions?

- Results shown here are for the median single-family home with PV plus 30 kWh storage
- Backup power provided to heating and cooling loads as well as other basic critical loads
- Throughout much of the U.S., the PVESS could provide complete backup over 3-day power interruptions in any month of the year
- Lower performance in some regions:
  - Southeast / Northwest where electric-resistance based heating is common (affecting performance in winter months)
  - Southwest / Southeast with large cooling loads (affecting performance in summer months)

% Critical Load Served

Average over 12 monthly interruption events



Source: https://emp.lbl.gov/publications/evaluating-capabilities-behind-meter

Power Reliability Event Simulation TOol

Development, implementation, validation and usage

PRESTO

POWER RELIABILITY EVENT SIMULATION TOOL

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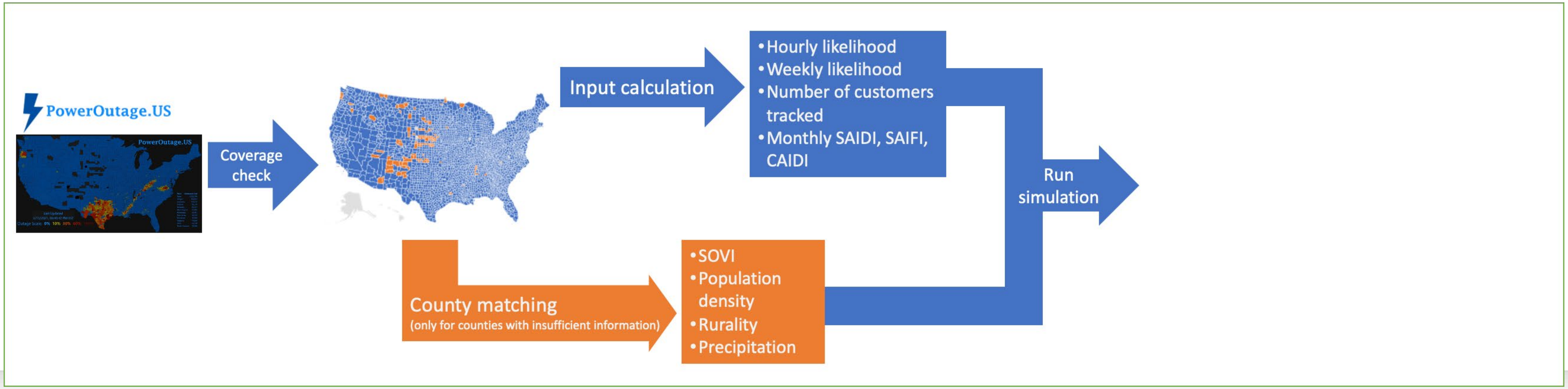
Motivation to develop PRESTO

- PRESTO was developed to **enable the analysis of PVESS backup power applications**, but could be applied more broadly to evaluate the impacts of short-duration power interruptions and potential mitigation measure
- PRESTO fills in a **gap of customer-level power interruption data** that is suitable to test mitigation strategies against these stochastic types of events
  - Utility data is typically clustered at the circuit or feeder level and is not publicly available
  - Smart meter data is typically unavailable or requires onerous confidentiality agreements
  - Simulating interruptions through asset-level outages requires complete knowledge of distribution system topology and infrastructure, neither of which are available
- Even in the cases in which empirical data might be available, it will likely not have **the time horizon and spatial resolution to capture a wide range of situations** that customers – and their mitigation strategies, may be subject to.

Power Reliability Event Simulation TOol (PRESTO)

PRESTO
POWER RELIABILITY EVENT SIMULATION TOOL

- Simulate PVESS effectiveness for customer-side short power interruptions by generating realistic profiles that encompass timing, duration, and frequency.
- PRESTO training data is derived from PowerOutage.US (POUS) dataset, which compiles hourly outage data from various utilities from mid-2017 to late 2021.
- Statistical analysis of historical data is used to design and calibrate PRESTO



DEMO: https://presto.lbl.gov/home

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PRESTO

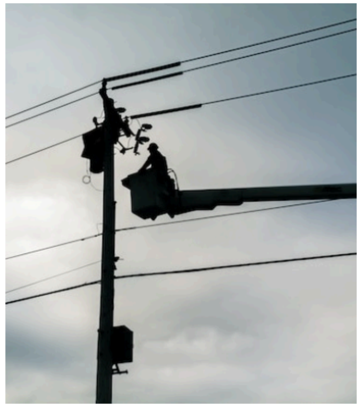
POWER RELIABILITY EVENT SIMULATION TOOL

The Power Reliability Event Simulation Tool (PRESTO) is a tool created by Lawrence Berkeley National Laboratory (LBNL) that realistically simulates the timing and duration of individual customer-level power interruptions for any county in the continental U.S.

What does it do?

How does it do it?

What are the outputs?



There are two ways to access and use the PRESTO model:

- **The graphical user interface (UI)** mode allows users to conveniently select a county in the continental U.S. for straightforward simulation. The user can visualize the default duration and frequency of interruptions, override them if desired, visualize the results of the simulation, and download a text file with the results. The UI mode is intended for quick analysis of a specific location in the country.

Start Using the PRESTO UI

- **The application programming interface (API)** allows users to create formulaic queries to run the PRESTO model in batch mode. Following the API query design instructions, users can retrieve simulations for many counties, either manually or through third party scripts. The API mode allows the users to integrate PRESTO into a broader simulation workflow, as well as automatize simulations for tens or hundreds of counties at a given time.

Learn More About the PRESTO API...

The PRESTO model team gratefully acknowledges funding from the Solar Energy Technology Office (SETO) of the Energy Efficiency and Renewable Energy office of the U.S. Department of Energy under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231

POUS Dataset

- The POUS data reports counts of customers interrupted by utility-county combinations for the years 2017 (partial) through 2021 (partial).
- The data is obtained by web scraping utilities' outage reporting web pages
- Data comes in an 8760 format
  - Hourly counts of customers interrupted by utility-county combination
  - Hourly recording of the maximum number of customers tracked
- We identified the duration and number of customers affected by non-continuous events in each county-month combination, and calculated SAIDI and SAIFI for each combination.

data_year	data_mor	data_day	data_hou	countyfips	cust_tr	cust_out
2018	1	1	18	18001	12337	13
2018	1	5	23	18001	12337	4
2018	1	7	15	18001	12337	4
2018	1	10	15	18001	12378	38
2018	1	10	16	18001	12378	38
2018	1	10	17	18001	12378	38
2018	1	10	18	18001	12378	28
2018	1	10	19	18001	12378	28
2018	1	11	15	18001	12378	7
2018	1	11	16	18001	12378	4
2018	1	12	1	18001	12378	4

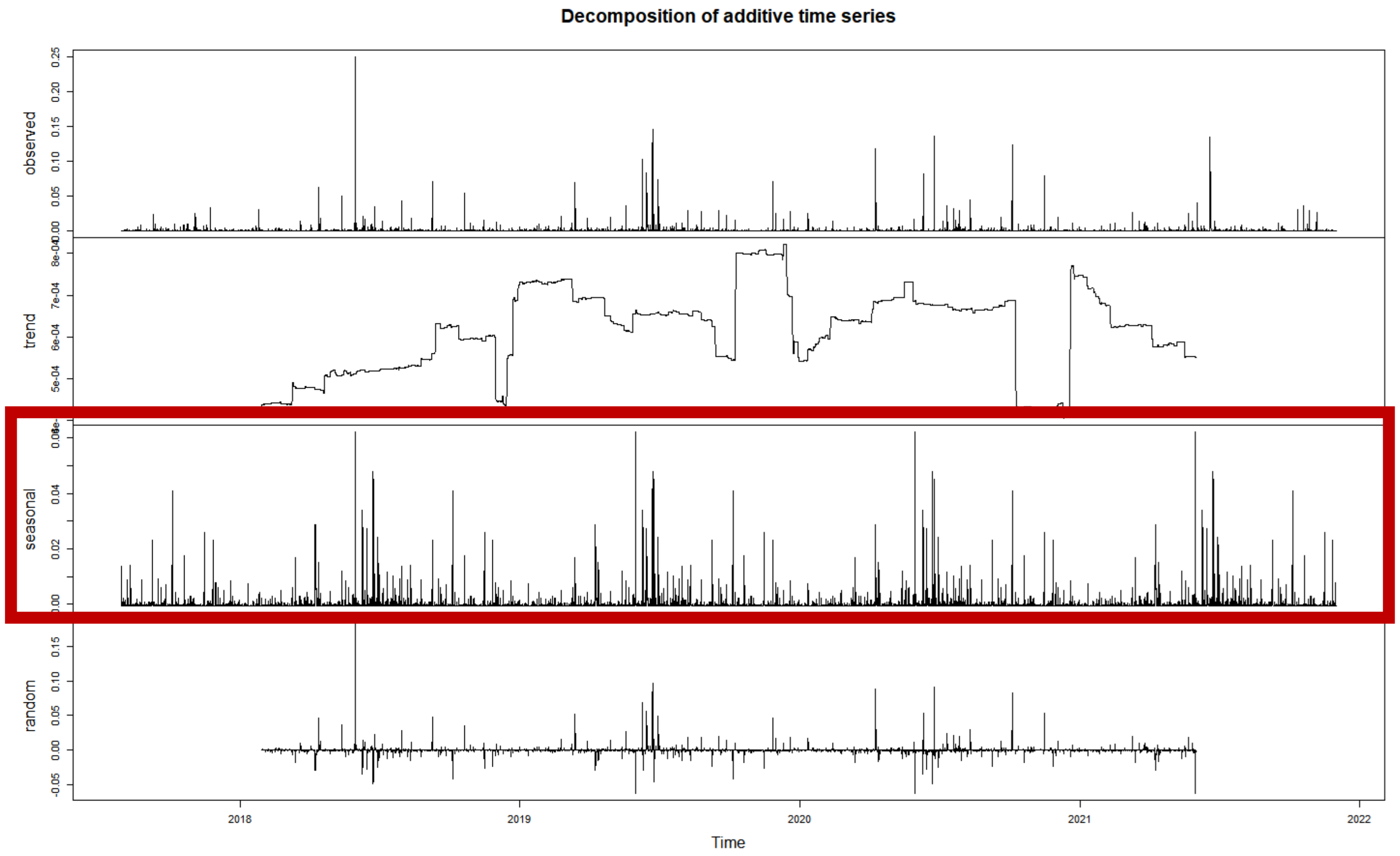
Continuous event

Continuous event

Event id	Total duration of customers interrupted	Maximum customers interrupted
1	13	13
2	4	4
3	4	4
4	170	38
5	11	7
6	4	4

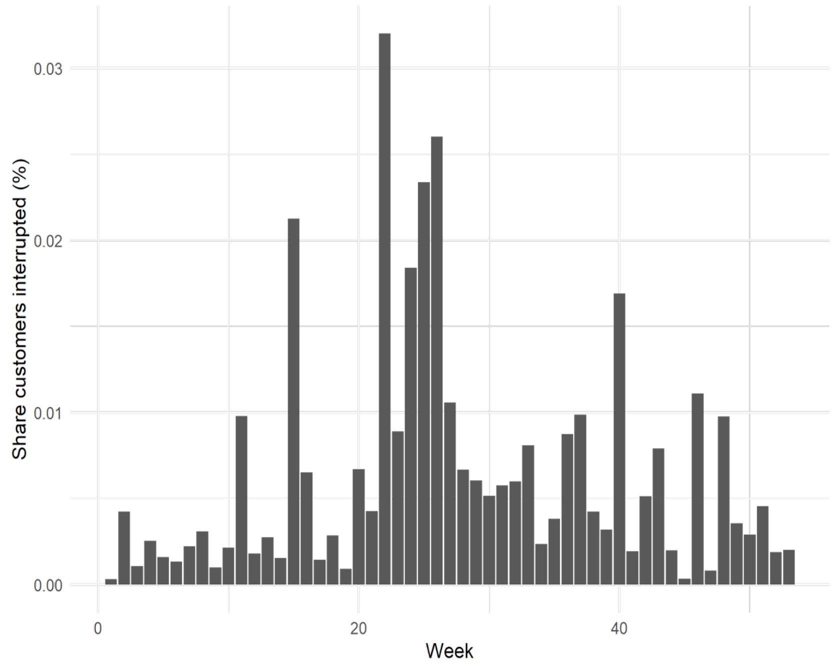
PRESTO input calculations (1)

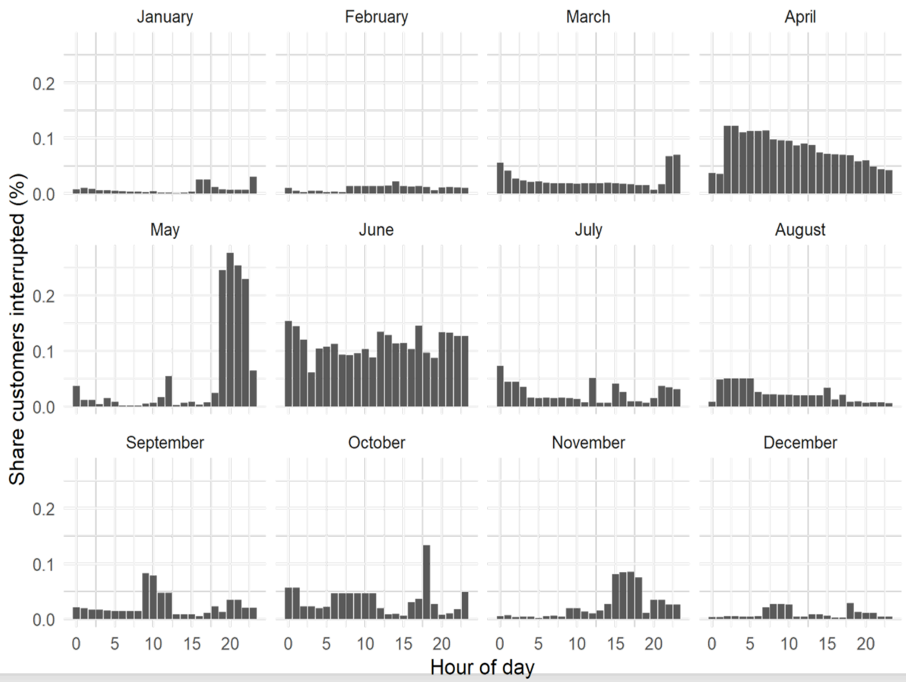
- We used standard time-series decomposition techniques for each county to produce a **seasonal**, **trend**, and a **random component**
- The seasonal component captures several year's worth of information, such that it reflects the long-term behavior of the county interruption
- From the seasonal component for each county, we calculated:
  - The likelihood of an interruption occurring each week of the year
  - The likelihood of an interruption occurring on a given hour of the day for each month



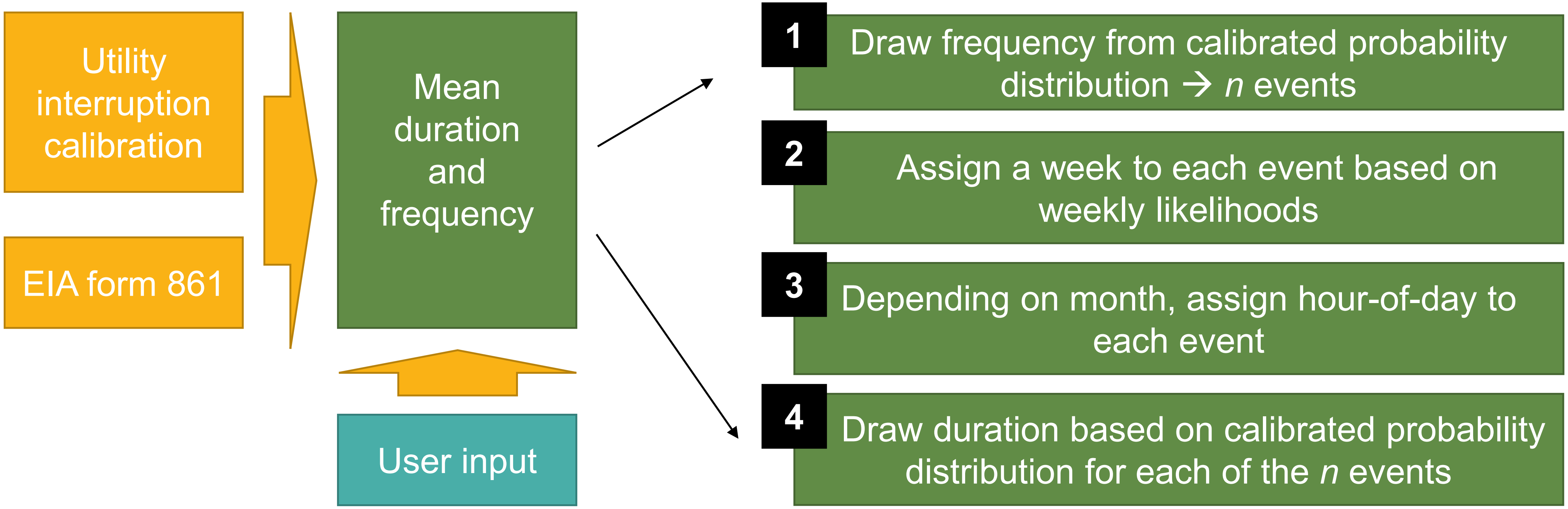
PRESTO input calculations (2)

- The timing is split into two components: weekly and hour-of-day
  - Weekly interruptions are determined by the average percentage of customers interrupted during a specific week of the year
  - Hour-of-day interruptions are based on the average percentage of customers interrupted during a specific hour of the day, for each month.





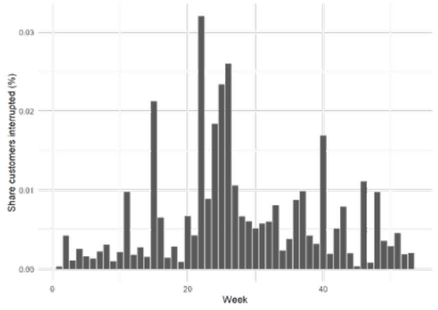
PRESTO logic



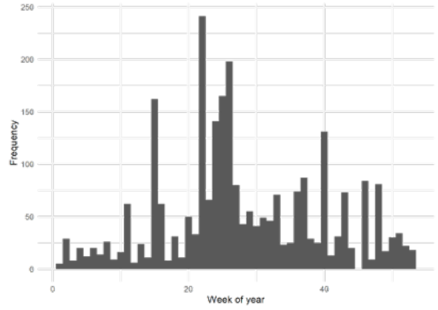
Validation of POUS output

- As there is no publicly available customer-level interruption datasets exist for direct PRESTO output comparison, we developed three alternative and complementary validation approaches:
  - Validate the training data against empirical aggregates reported by utilities (via EIA-861)
  - Compare PRESTO outputs against training data (POUS outage logs)
  - Compare PRESTO outputs against non-training data

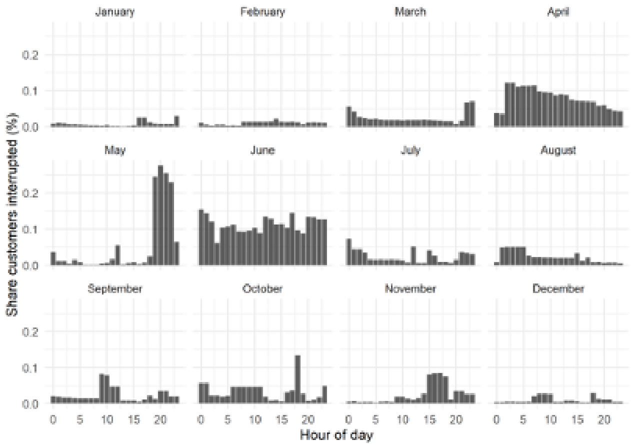
Empirical seasonal (weekly) likelihood



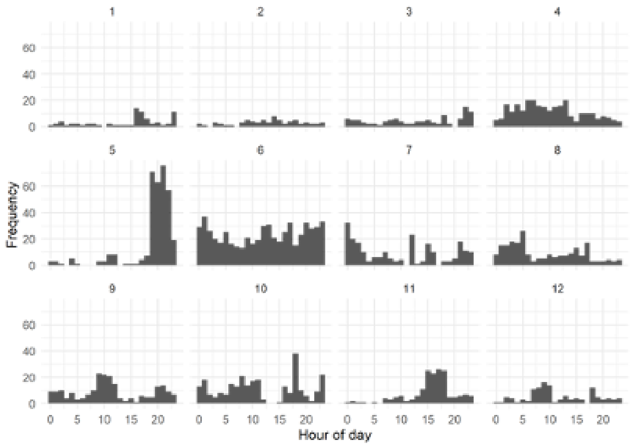
Modeled distribution of interruptions by week



Empirical hour-of-day likelihood



Modeled distribution of interruption by hour of day



Backup Power Performance of Solar-plus-Storage Systems during Short-Duration Power Interruptions

A Case Study Application of Berkeley Lab’s PRESTO

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Motivation for this analysis

- Prior research on PVESS backup power has focused on long-duration power interruptions; lends itself to scenario-based analysis, analyzing backup performance during individual events
- However, most power interruptions are relatively short duration, typically lasting minutes to hours, and are unpredictable
- The battery state of charge (SOC) may be low when the event occurs, depending on how the customer uses the battery on a day-to-day basis (e.g., for TOU arbitrage or solar self-consumption)
- Case study demonstrates how PRESTO can be used in analyses to estimate the expected performance of a PVESS for providing backup power during short-duration power interruption events

Overview of the dataset and modeling structure

Time-Series Data

PRESTO | POWER RELIABILITY EVENT SIMULATION TOOL

Power Interruptions*

- Short-duration power interruptions simulated by Power Reliability Event Simulation TOol (PRESTO)

REopt

State of Charge (SoC) calculator*

- The initial percentage of battery storage charged for a typical home during the onset of a power outage as determined by NREL's ReOPT

ResStock

End-Use Load Profiles*

- Simulated hourly profiles from NREL's ResStock energy modeler
- Building characteristics statistically informed by Census and RECS data
- Data validation using actual electricity consumption
- TMY3 and AMY weather data

NREL/SAM

System Advisor Model (SAM)

Solar Profiles*

- Simulated using NREL's System Advisor Model (SAM)
- TMY3 and AMY weather data

All time-series input data temporally and geospatially aligned

PVESS Evaluation

Assumptions / Scenarios

- PV & storage sizing
- Load scenarios

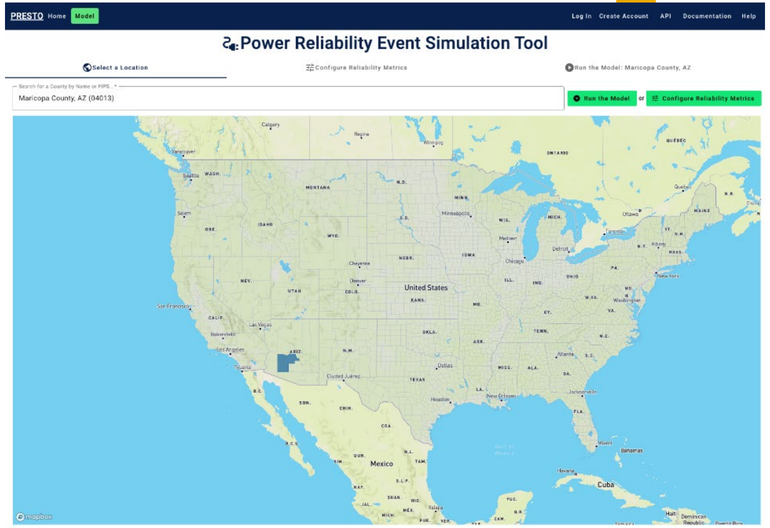
Storage Dispatch Model:
Dispatch storage to meet specified load during power interruption

Output Metric:
Percent of load served (with energy constraint and capacity constraint) during interruption

Model specifications

- Representative single-family detached home selected from ResStock for three counties:
  - Maricopa County, AZ; Middlesex County, MA; Los Angeles County, CA
- PV systems sized to generate 100% of annual energy consumption
- Initially assume 10 kWh battery with a minimum of 5% SoC (which is low; we want to "stress test") and no grid charging (i.e., customer prefers to charge from solar)
- Assume daily storage cycling to manage time-of-use (TOU) charges
- Three different backup configurations considered
  - *Limited Critical Loads*: Refrigeration, lighting during evening hours, well pump, basic plug loads
  - *Critical Loads*: All of the above plus heating and cooling (analysis focuses mostly on this scenario)
  - *Whole-Home*: All loads

Simulating short-duration power interruptions using PRESTO



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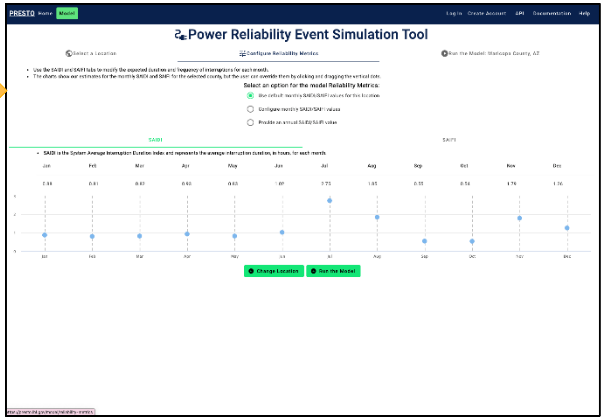
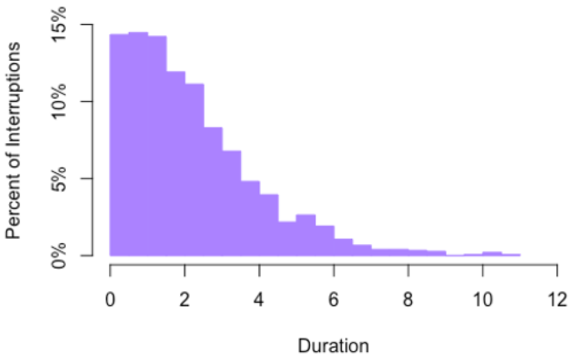
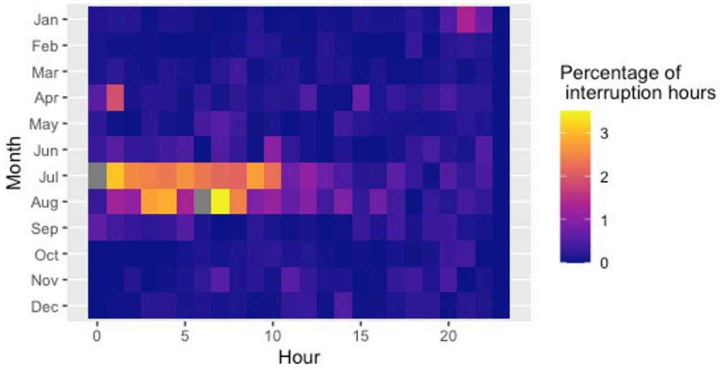


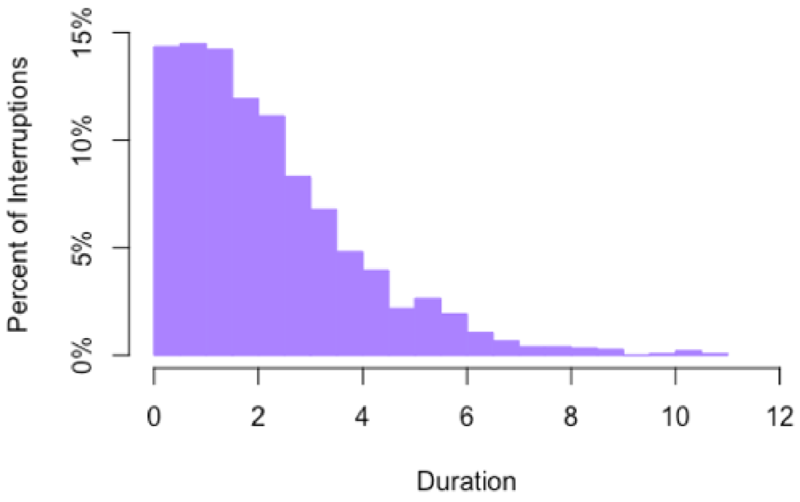
sim	id	data_week	data_day	hour_of_day	dur	data_month
1	1	10	9	1	10.4	3
1	2	11	11	11	26.5	3
1	3	34	22	23	1.2	8
2	1	49	4	9	4.8	12
3	1	2	12	5	1.6	1
4	1	42	14	23	17.6	10
4	2	10	8	22	26.8	3
4	3	48	1	15	3.5	11
4	4	9	29	0	5.3	2
4	5	3	15	12	2.3	1

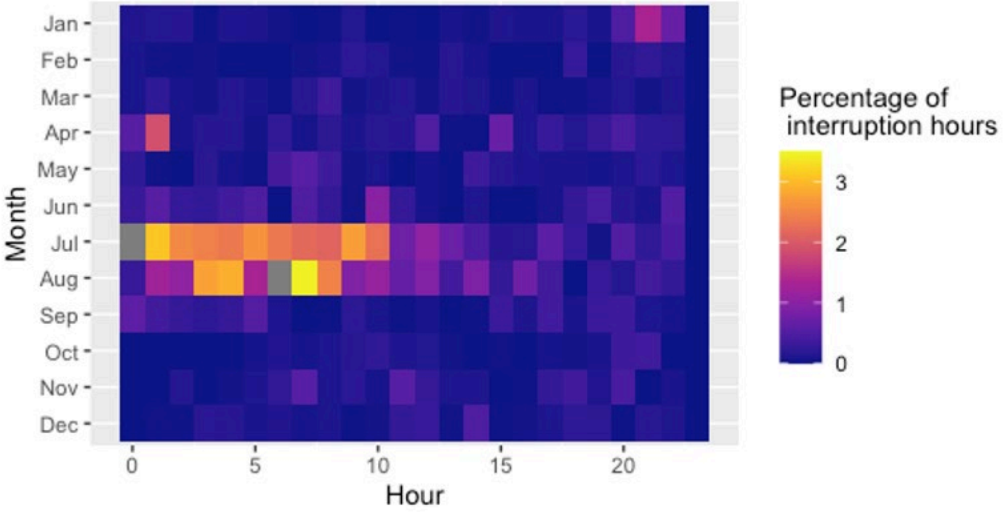




PRESTO Outputs for Maricopa County, AZ

- Ran PRESTO over 1,000 simulation years
- Generated 1,520 interruption events (1.52 events per year)
- Most of those events were relatively short (median=1.8 hours, mean=2.2 hours)
- Most of those interruptions occurred in July and August, during early morning hours



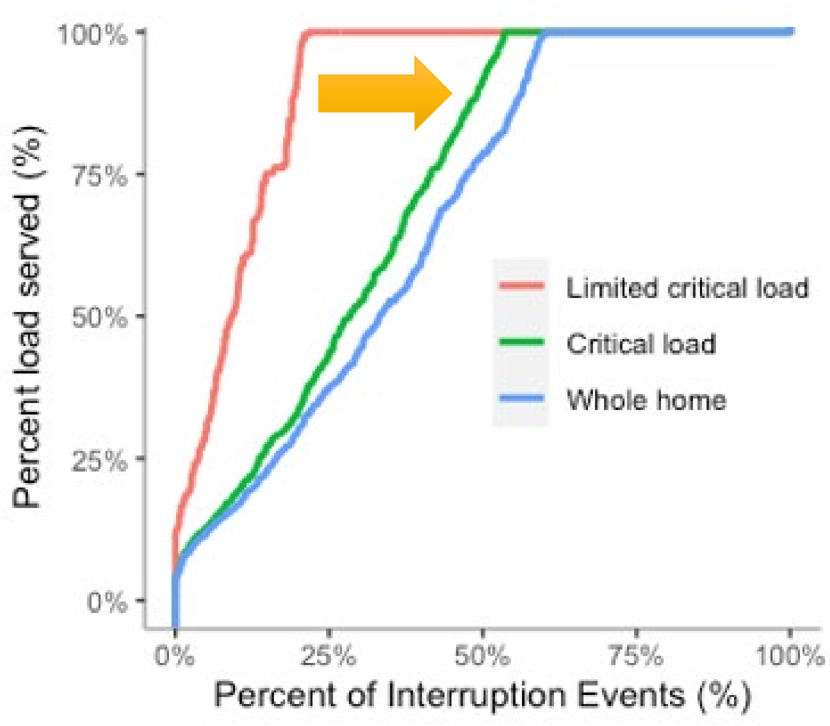


How well does the PVESS perform across the three backup load configurations?

- PVESS performance measured in terms of % of backup load served; figure shows the distribution across all interruption events
- For "Limited Critical Load" backup, the system fails to meet all backup load in 16% of interruptions (i.e., fully meets backup load in 84% of events)
- For the other two backup configurations, shortfalls occur in about 50% of interruptions
- These results reflect conservative assumptions (small system, no grid charging, backup reserve set to only 5%)

PVESS Backup Power Performance

Three backup load configurations

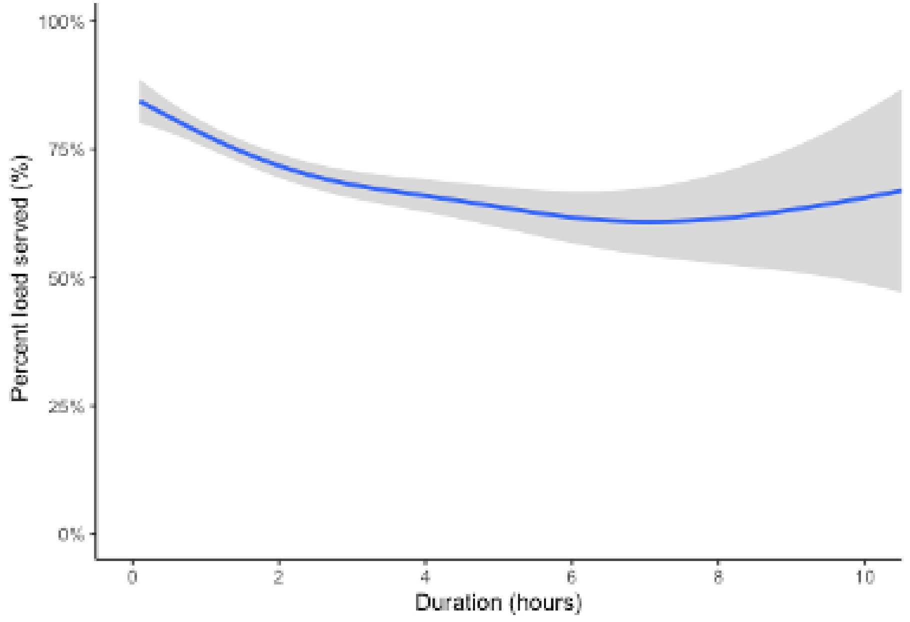


For median single-family home in Maricopa County, AZ

How is PVESS performance impacted by event duration?

- For the shortest events, backup performance averages roughly 75% of load served
- Backup performance generally declines with longer events
- Trendline reverses directions after ~8-hours as those interruptions tend to include more day-light hours where PV contributes to mitigation
- Recall, the simulated Maricopa County interruptions tend to begin in early morning hours

PVESS Backup Power Performance:
Critical Load backup case



For median single-family home in Maricopa County, AZ

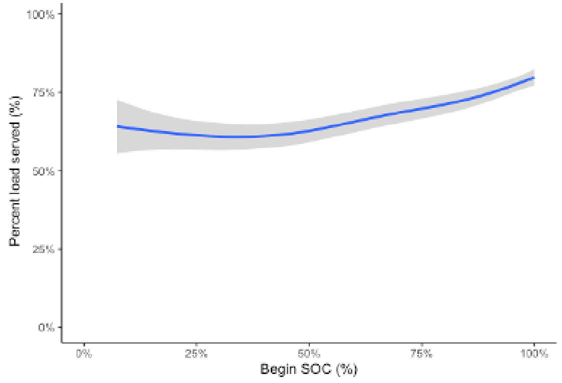
For median single-family home in Maricopa County, AZ

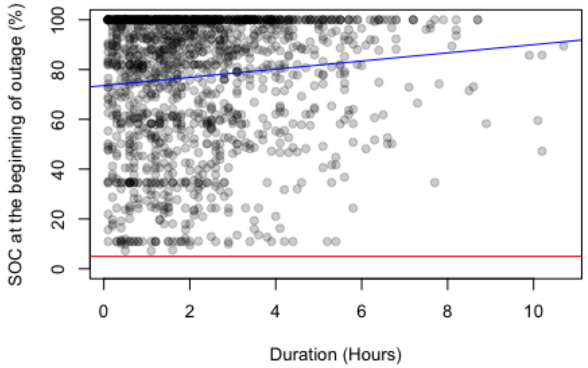
How is PVESS performance impacted by the initial battery SoC?

- All else being equal, intuition suggests backup performance will be higher the greater the initial battery SoC at the beginning of the interruption event
- Contrary to that expectation, the performance trend for our representative Maricopa Co. home is actually flat for beginning SoC up to ~50%
  - Due to the confounding relationship between event duration and initial SoC (scatter plot)
  - Beyond 50% initial SoC, backup performance rises with the initial SoC, as expected
- Even for events where the initial SoC is 100%, the system still generally does not meet all critical load, reflecting the mismatch between battery sizing and the amount of load
- Further investigation is needed to determine the impact of other variables on % load served, such as the timing of power interruptions and the loads that need to be served during power interruptions

PVESS Backup Power Performance:

Critical Load backup case



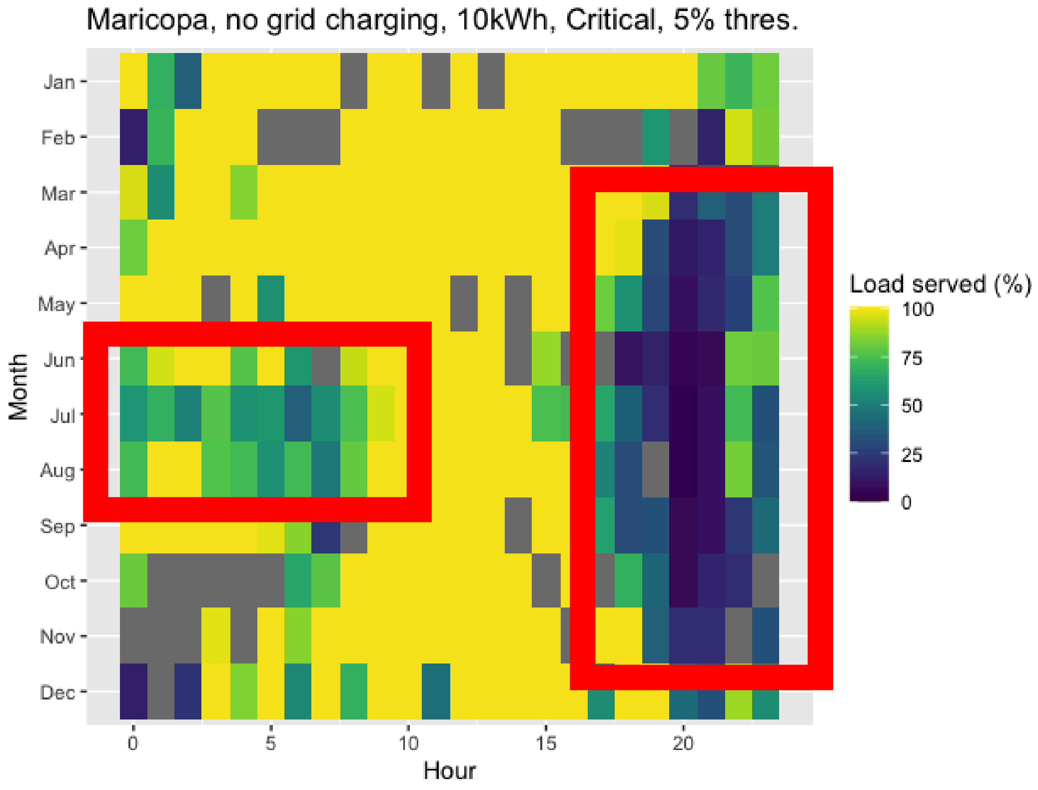


For median single-family home in Maricopa County, AZ

How is PVESS performance impacted by event timing?

- Performance is lowest for interruptions during evening hours in warm-weather months
  - Significant air-conditioning load
  - Utility's TOU schedule incentivizes battery discharge from 3-8 pm
  - No PV generation to recharge the battery
- During early morning hours, when most interruptions occur, backup performance hovers around 75% of load served:
  - Low SoC when events strike, as the battery hasn't yet had a chance to recharge from solar

Percent of Critical Load Served

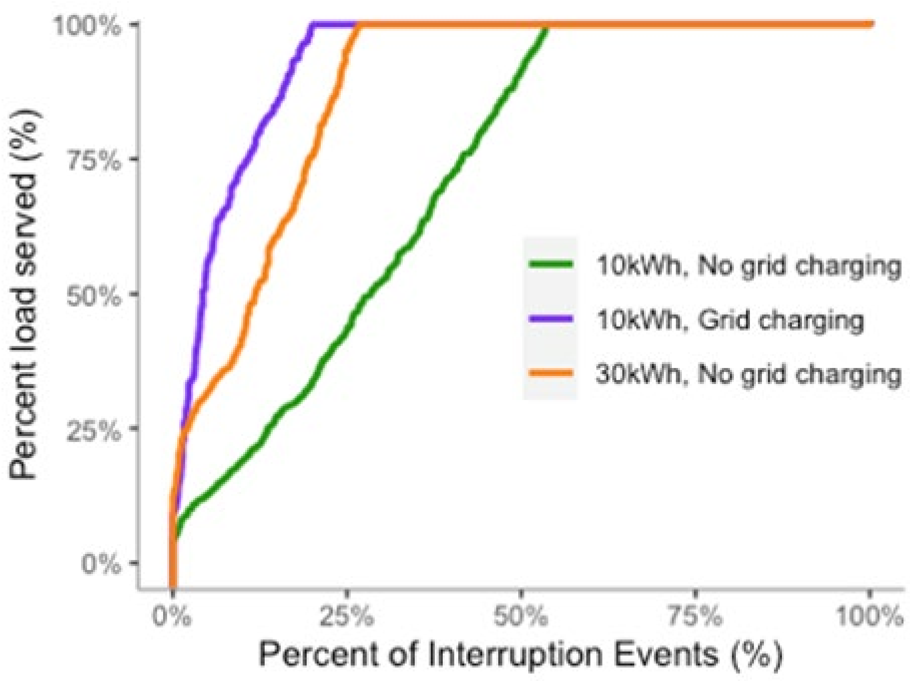


Options for improving backup performance

- Various strategies could be employed to improve backup performance; here we consider two:
  - Grid charging (rather than only from solar)
  - Increasing the battery size to 30 kWh
- Both measures significantly improve performance, though neither is sufficient to ensure full backup over all events
  - Notably, grid charging a small battery outperforms not grid charging a larger battery
- Other strategies (not modeled here):
  - Higher backup reserves
  - Temperature set-point adjustments

PVESS Backup Power Performance

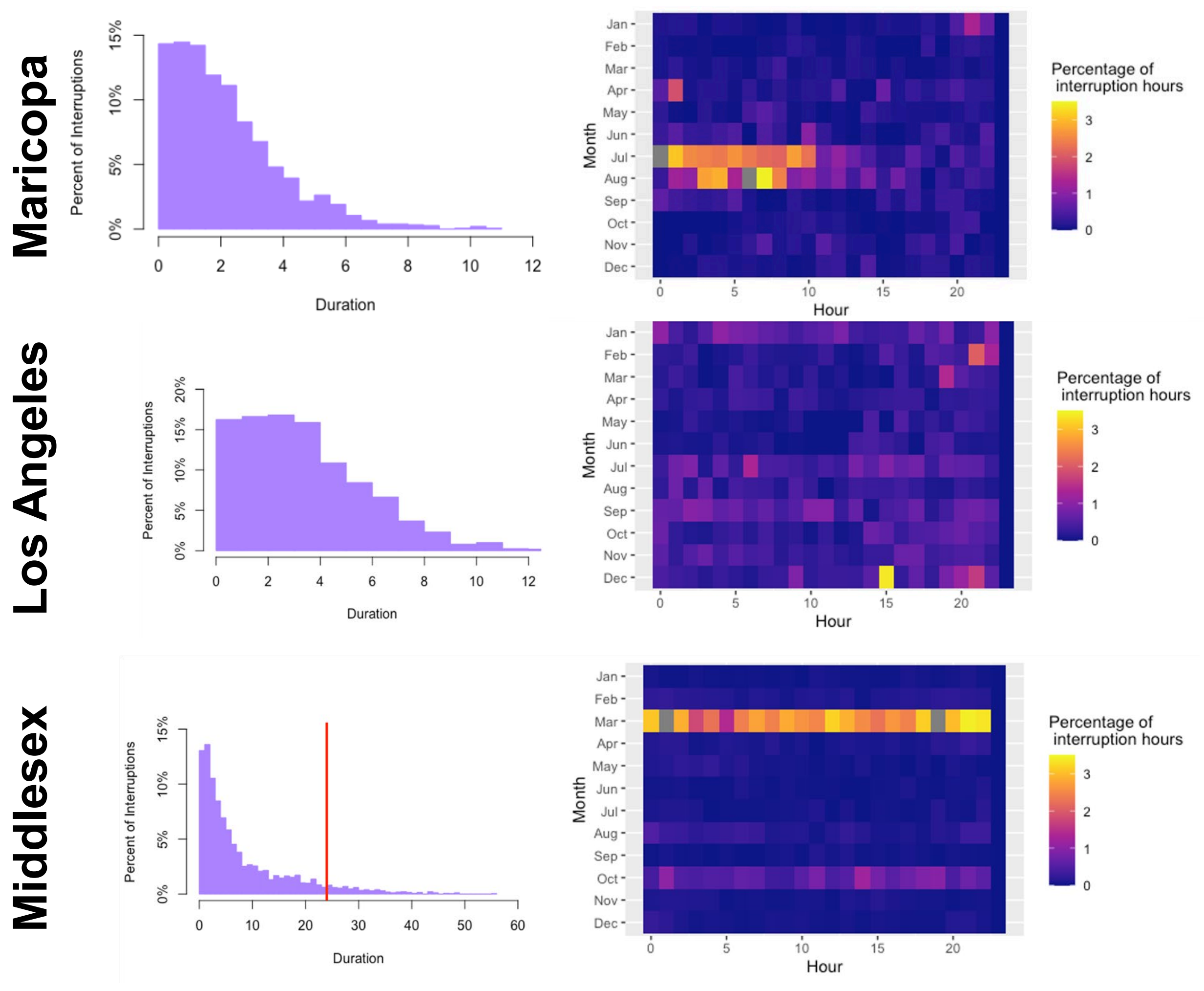
Critical Load backup case



For median single-family home in Maricopa County, AZ

PRESTO outputs for three counties

- PVESS backup performance in other locations can reflect local power interruption patters
- For example, while interruptions in Maricopa are concentrated in early morning hours, interruptions in Los Angeles and Middlesex counties occur with relatively equal probability across hours of the day
- In Middlesex, interruptions are concentrated in March, reflecting the specific historical period (2017-2021) used to train PRESTO

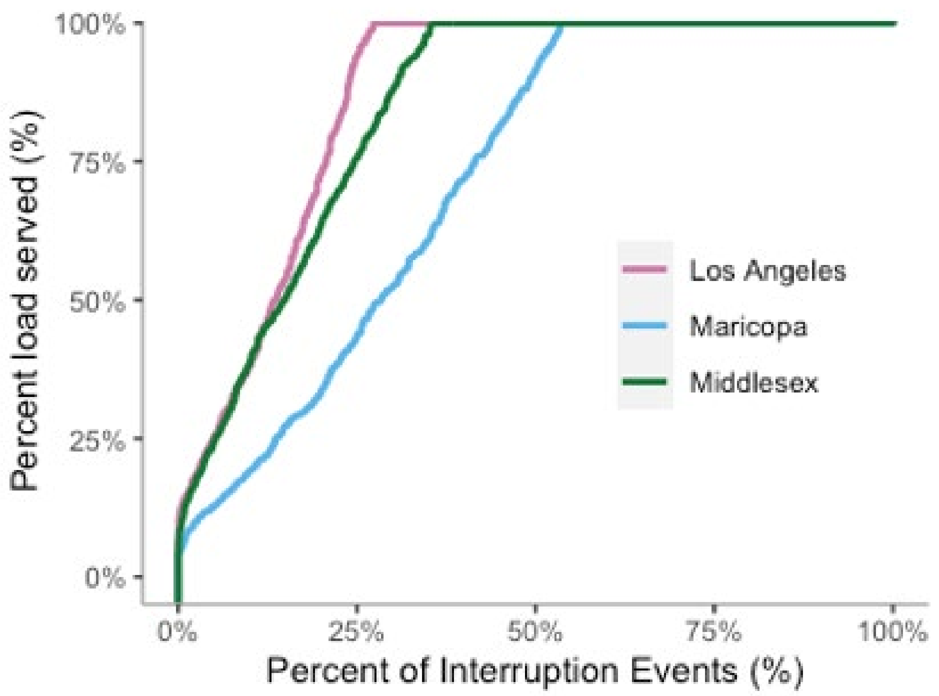


Regional differences in PVESS backup performance

- Backup performance is higher in both Los Angeles and Middlesex, compared to Maricopa, reflecting differences in:
  - **Loads:** Much lower cooling loads in Middlesex and Los Angeles
  - **Interruption patterns:** More likely to occur when battery state of charge is relatively high
  - **Rate structures:** TOU rate in Middlesex county has a broad peak period from 8 am to 9 pm

PVESS Backup Power Performance

Critical Load backup case



Q&A

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