

ReNORM Software Results

for the CIDER Partner Electric Cooperatives

National Rural Electric Cooperative Association (NRECA) Research

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Overview

Problem Statement:

- Reliability of the bulk power system is getting worse
- Extreme outage events are increasing in frequency
- More DER than central generation in the USA now, double digit year-over-year growth
- But very few utilities (<5%) have visibility and control over DER, likely due to large costs of DERMS platforms
- In summary: reliability is decreasing, but DER can't currently be used to fight this trend

Proposed Solution:

- Through the NRECA's CIDER project, DER and equity considerations are being integrated into resiliency and restoration support software to unlock the potential of DER as resilience assets.

Overview

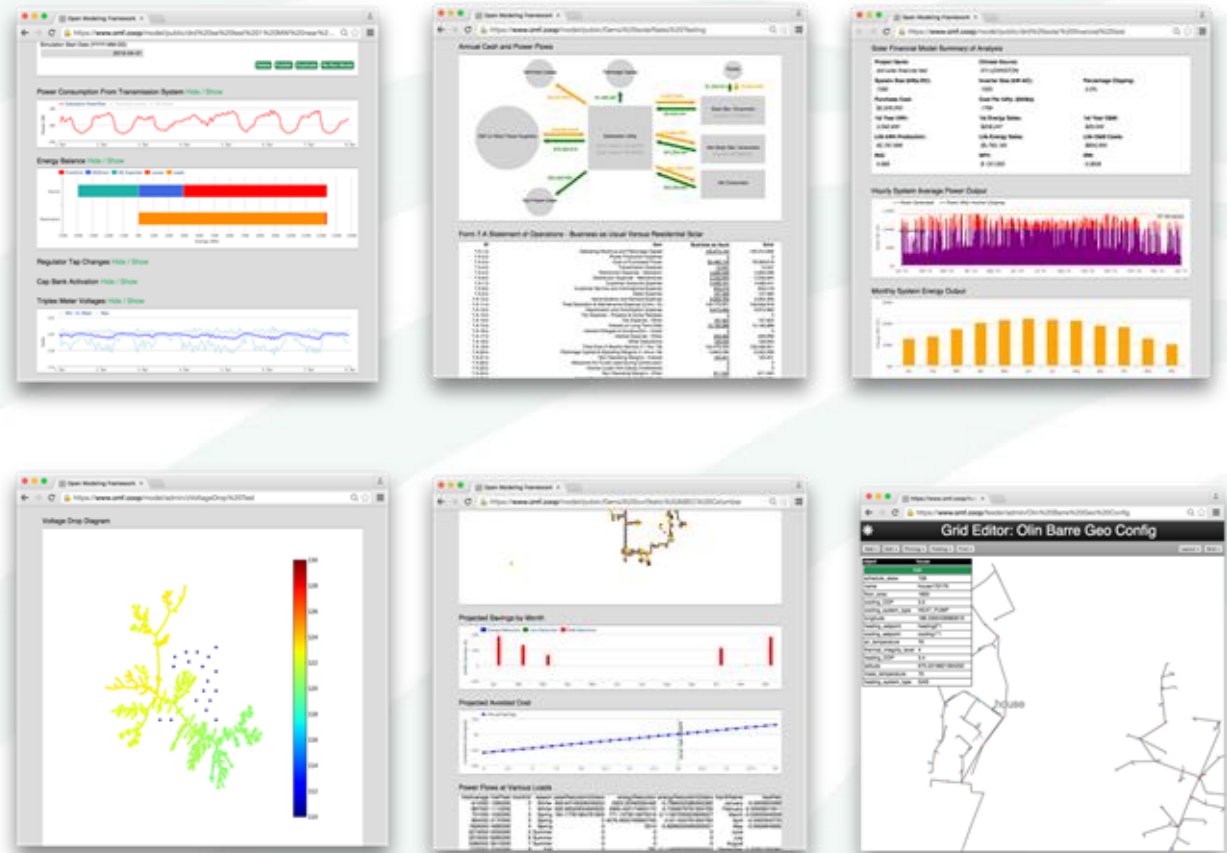
ReNORM is a set of 4 tools used together to support the deployment and operation of a DER management system (DERMS) at an electric cooperative distribution utility.

ReNORM - Resilience and Neighborhood Outage Restoration Modelset

- **omf.models.restoration** - identify switching orders and DER controls to restore an outage
- **omf.models.resilientCommunity** - calculate outage effects on individual consumers
- **omf.models.derUtilityCost** - calculates net utility benefits from a group of DER
- **omf.models.derConsumer** - calculate benefits to consumers from DER

ReNORM Software Hosted on OMF.coop

- Free and open-source electric utility modeling software
- Built over the last 10 years by the co-ops and the US Department of Energy
- Python backend and support libraries, light web-based frontend
- Main focus: applications that perform financial and engineering analysis for utilities on emerging technologies (solar, energy storage, networked controls)
- Secondary focus: environment for researchers to develop new models
- Users from 217 organizations (utilities, vendors, universities) as of July 2019



Detailed Results for models.restoration

Overview of Restoration Model

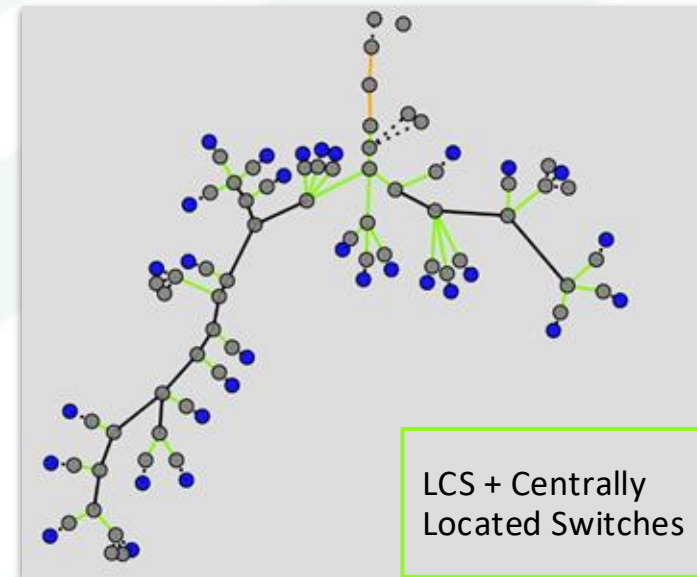
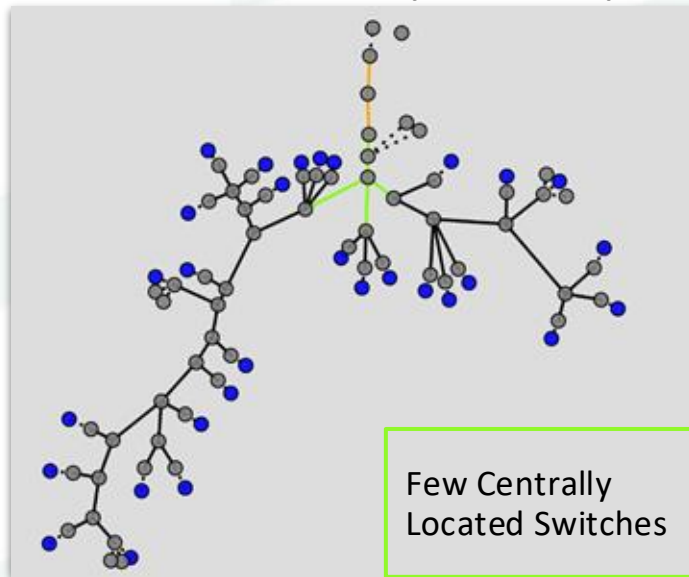
The Restoration Model informs control decisions to support loads during outages and events when generation cannot meet demand.

- Restoration uses the PowerModelsONM optimization library from Los Alamos National Laboratory.
- PowerModelsONM finds optimal series of control actions to support loads given available centralized and distributed energy resources.
- Restoration can be informed by user-selected load priorities.
- Users can choose to include metrics for social vulnerability in the restoration approach alongside technical and financial factors.

Using Restoration to Evaluate Switch Locations

One of the many ways to use Restoration is to evaluate new potential switch locations.

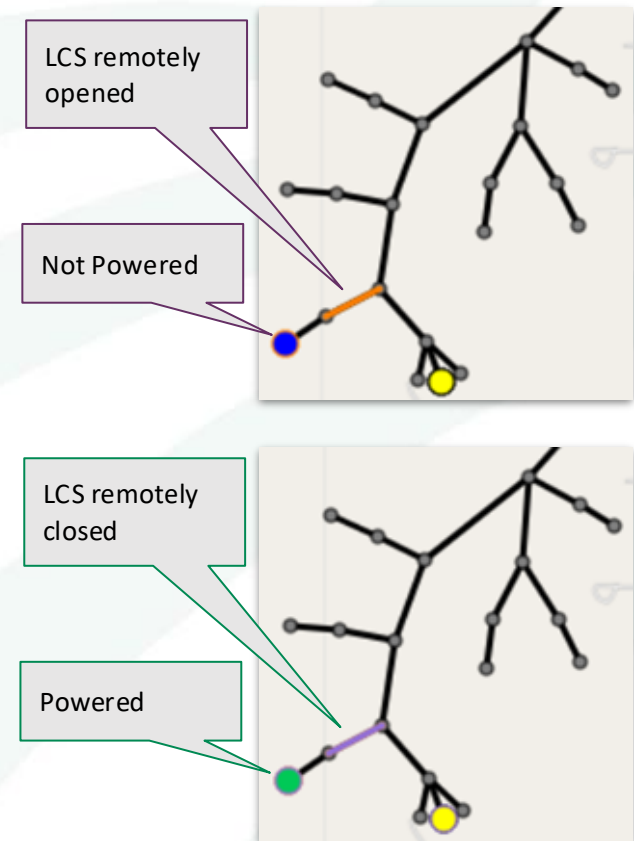
- We will use Restoration to demonstrate the benefits of implementing load-controlling switches (LCSs) at the point of load.
- LCSs allow for more fine-tuned control of load shed and behind the meter (BTM) DERs which can:
 - Improve uptime for customers
 - Help save time and money for co-ops



Benefits of LCSs: Business-as-Usual

Under normal operating conditions, demand on the feeder is met by generation resources. Under these conditions, LCSs can save time and money by enabling remote disconnection/reconnection for billing purposes.

- A technician wouldn't need to go out and manually disconnect a meter for failure to pay.
- An inspection may not be needed before remotely restoring power.
- Cost Savings:
 - Cost of sending out a technician
 - Cost of inspection
- Time Savings:
 - Time to schedule a technician
 - Time for a technician's transportation and work performed
- Customer Satisfaction Benefits:
 - Power can be restored faster after a delinquent payment is made



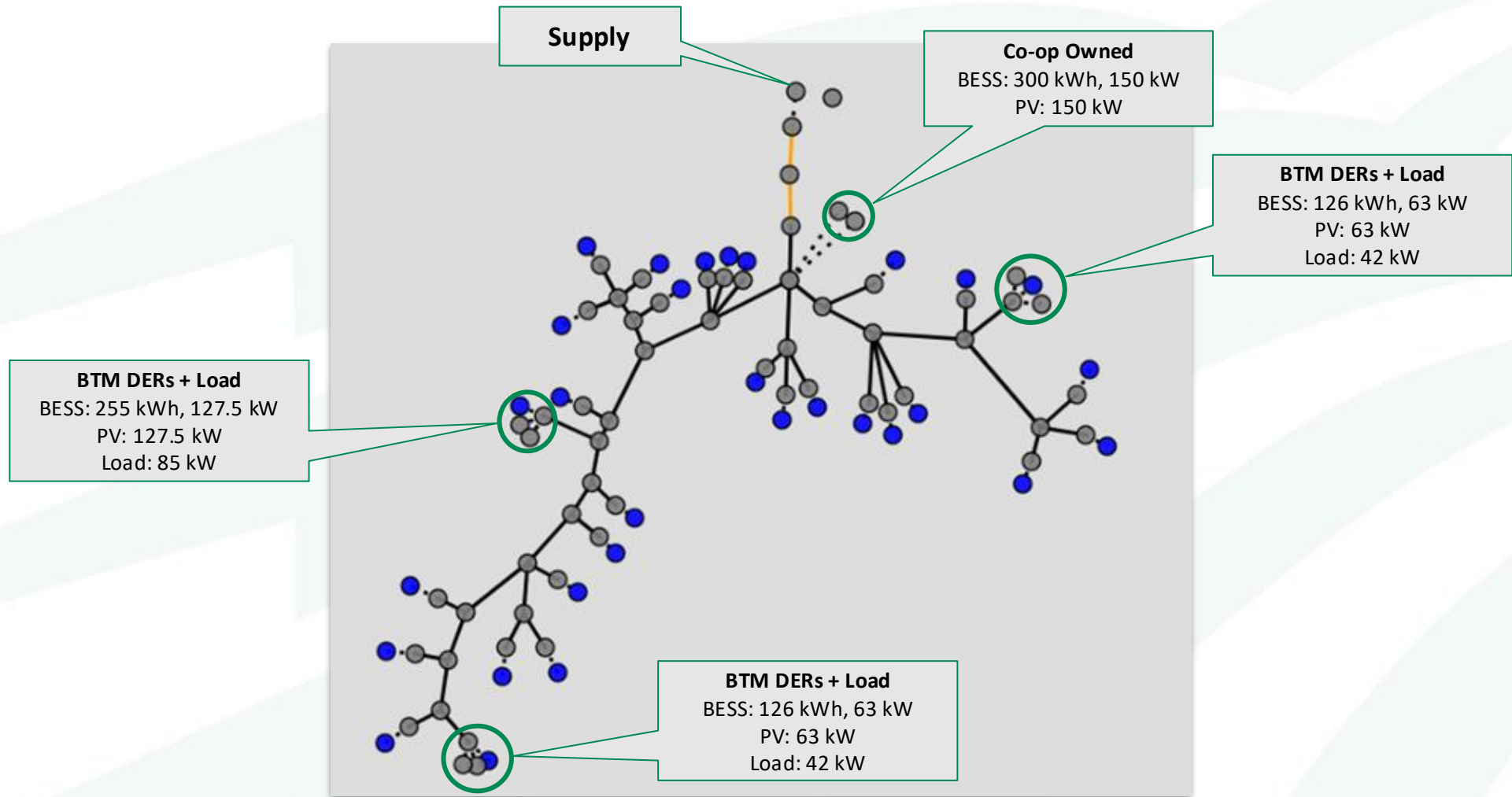
Benefits of LCSs: Full Outage Mitigated by DERs

During full outage scenarios, LCSs can allow for more precise control over DERs to support critical loads throughout the feeder, rather than needing to be able to support entire sections containing them.

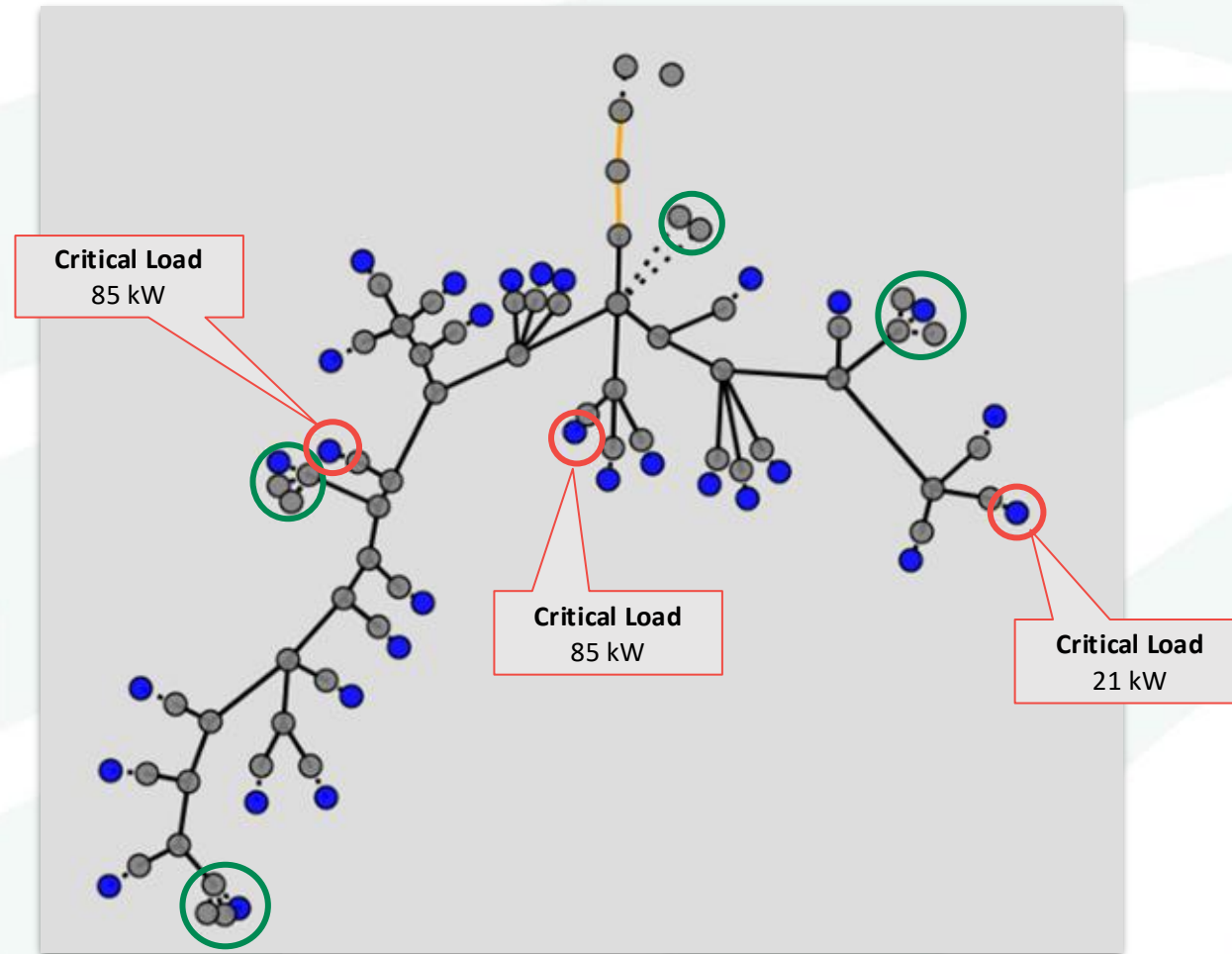
Scenario

- There is an intense heat-wave in mid June.
- The co-op sends out a message beforehand warning their members to make preparations for possible outages due to intense strain on the grid.
- Once the heat wave actually hits, it causes a 6 hour outage of supply power and outages are mitigated by both co-op owned PV and BESS and BTM DERs.

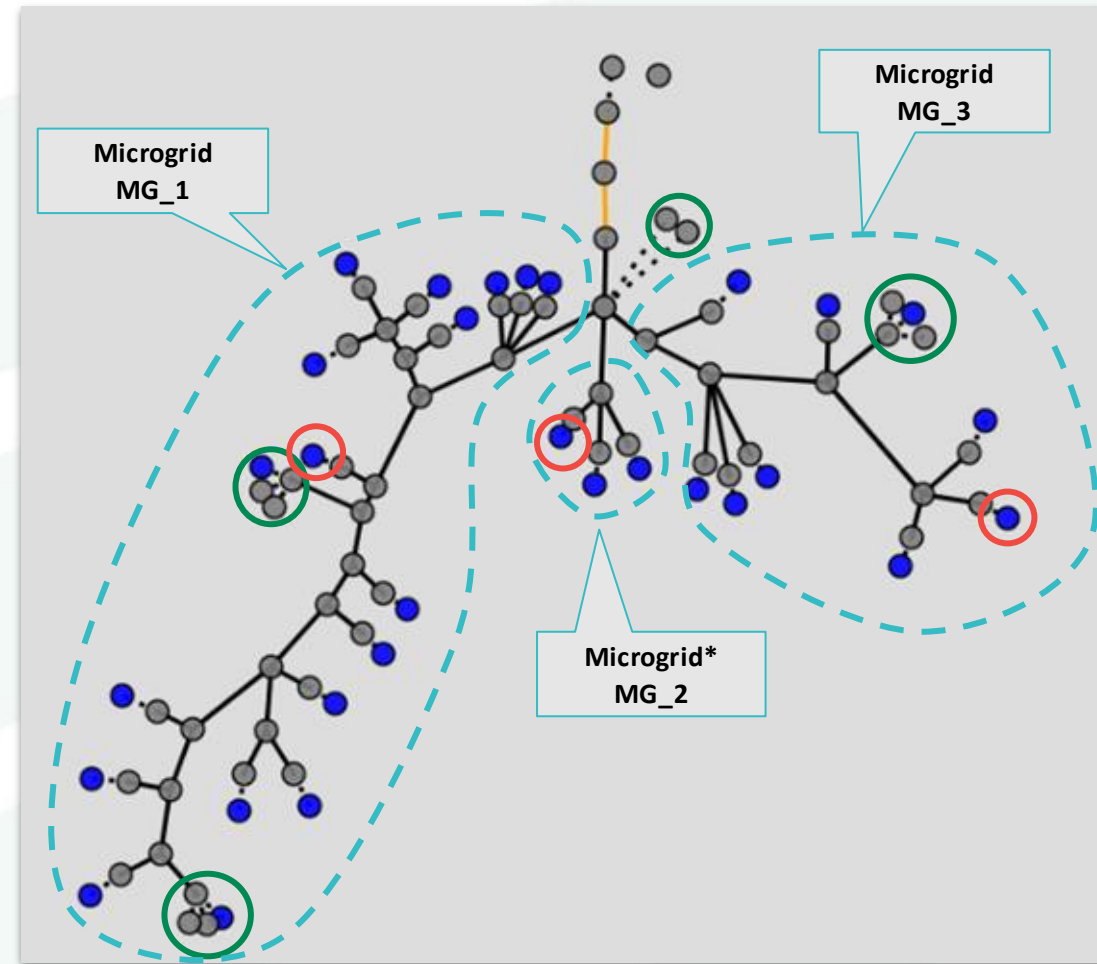
Benefits of LCSs: Full Outage Mitigated by DERs, Feeder Overview



Benefits of LCSs: Full Outage Mitigated by DERs, Feeder Overview



Benefits of LCSs: Full Outage Mitigated by DERs, Feeder Overview



Benefits of LCSs: Full Outage Mitigated by DERs, Maximum Loads Supported

Maximum Loads Supported

No LCSs:

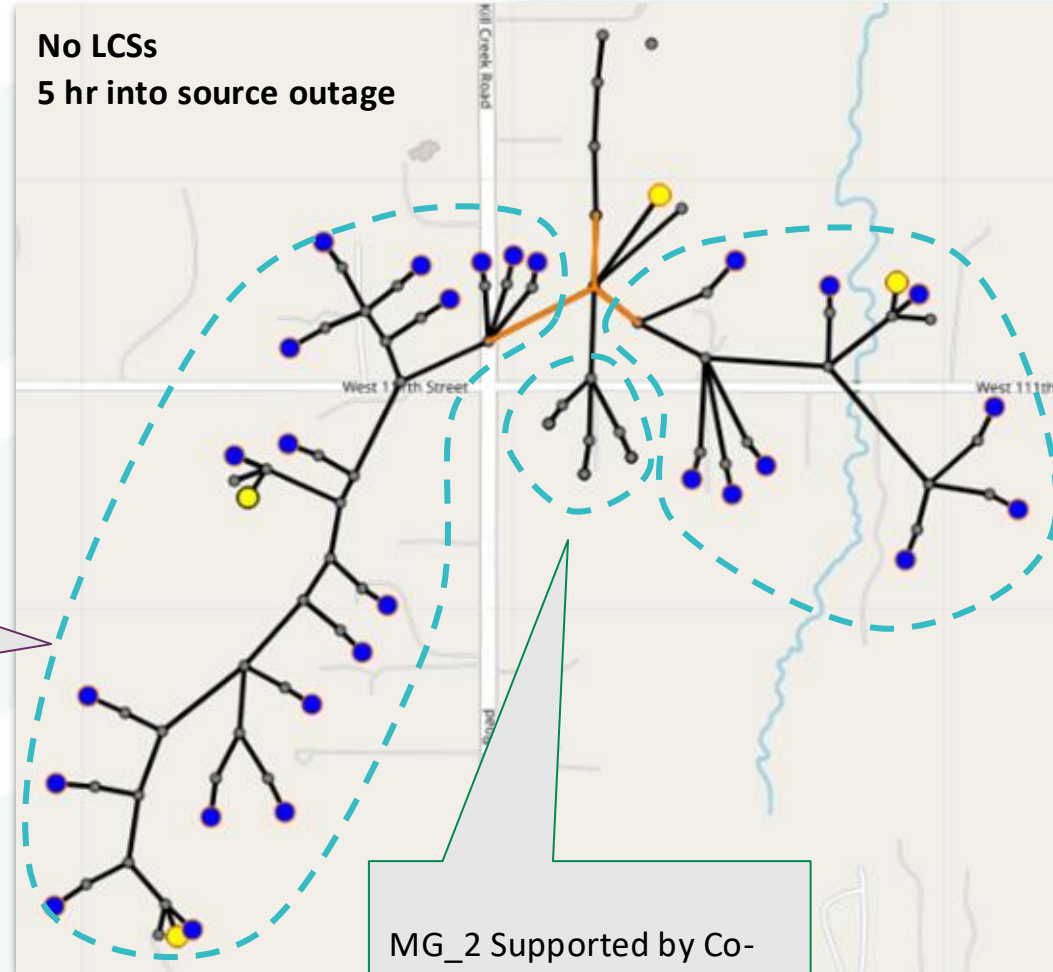
- For a load to be supported, there needs to be enough power from DERs to support the entire microgrid containing it.

LCSs:

- As many loads as possible can be supported by power from DERs by keeping some LCSs closed while opening as many as necessary to match demand to the DERs' output.

Benefits of LCSs: Full Outage Mitigated by DERs, Maximum Loads Supported

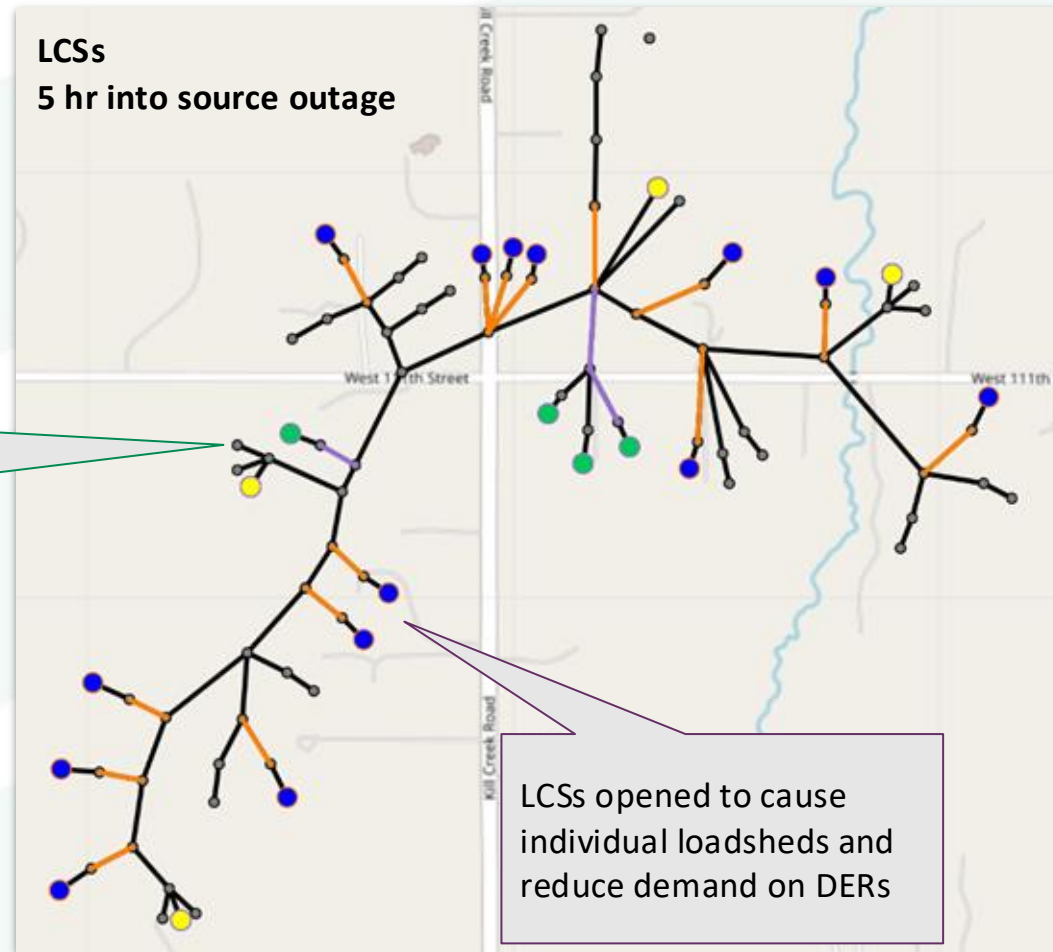
	Switch That Hasn't Opened (or Line)
	Open Switch
	Closed Switch
	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
	Loadshed
	Loadpickup
	Battery Control



Benefits of LCSs: Full Outage Mitigated by DERs, Maximum Loads Supported

	Switch That Hasn't Opened (or Line)
	Open Switch
	Closed Switch
	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
	Loadshed
	Loadpickup
	Battery Control

Loads throughout the feeder being supported by DERs



Benefits of LCSs: Full Outage Mitigated by DERs, Maximum Loads Supported

Metric (Simulation- Constrained)	Description	No LCSs	LCSs	Difference w/ LCSs
SAIFI	Number of interruptions for an average member.	1.0	0.63	0.37
SAIDI	Total minutes of interruption for an average member.	348	268	80
CAIFI	Number of interruptions for an average member who experienced at least one interruption.	1.0	1.06	-0.06
CAIDI	Minutes of duration for an average interruption.	348	423	-75
Mean Outage Incidence	Percent of loads experiencing an outage during the average simulation timestep.	48.33%	37.22%	11.11%

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
Whole System	348.0	1.0	348.0	1.0

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
Whole System	268.0	0.63	423.16	1.06

Benefits of LCSs: Full Outage Mitigated by DERs, Maximum Loads Supported

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Mean Outage Incidence	Percent of loads experiencing an outage during the average simulation timestep.	48.33%	37.22%	11.11%

Individual interruptions lasted longer and were slightly more frequent for those who experienced them

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
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In exchange for significantly lower interruption frequency and durations across the entire feeder

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
Whole System	348.0	1.0	348.0	1.0

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
Whole System	268.0	0.63	423.16	1.06

Benefits of LCSs: Full Outage Mitigated by DERs, Distribution of Loads Supported

Distribution of Loads Supported

No LCSs:

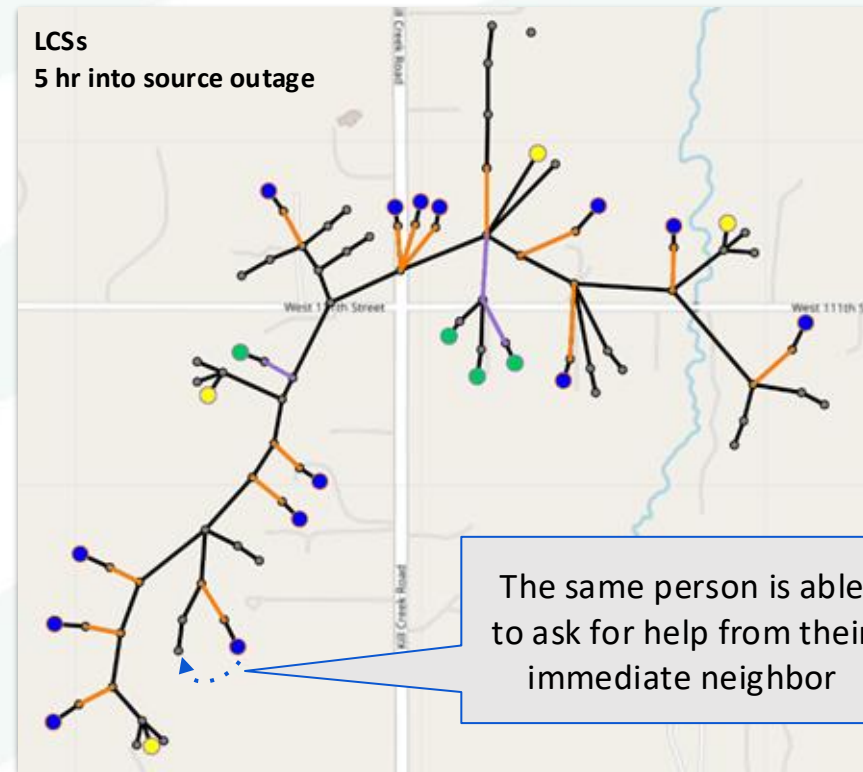
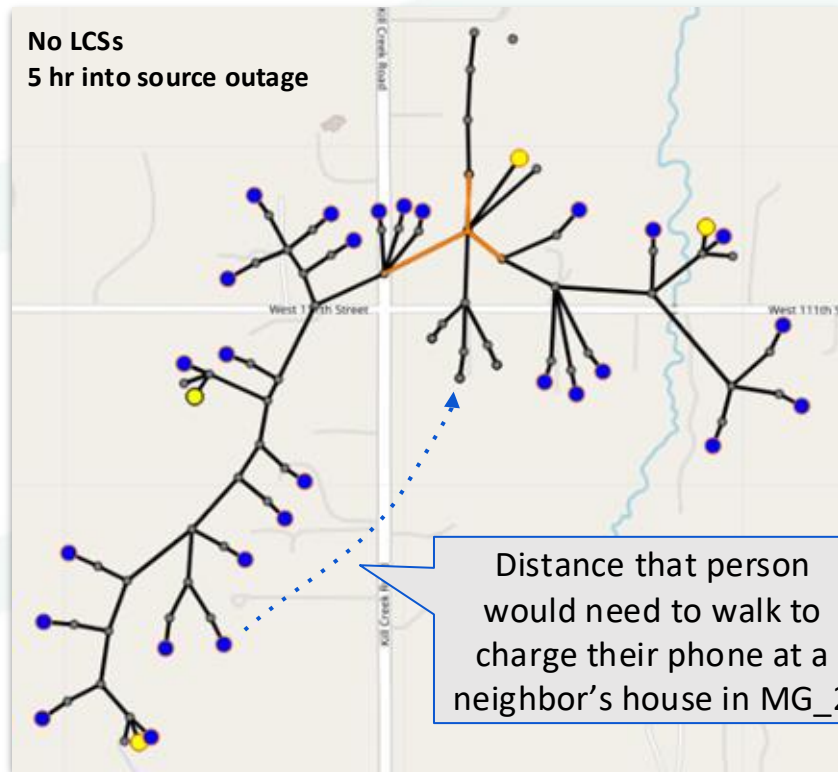
- Loads supported are geographically clustered based on microgrids.

LCSs:

- Loads supported are distributed throughout the feeder, lessening the impact on a single geographical area.

Benefits of LCSs: Full Outage Mitigated by DERs, Distribution of Loads Supported

Example: A person near the bottom of MG_1 has lost power and needs to charge their phone to call a sick family member they're worried about.



—	Switch That Hasn't Opened (or Line)
—	Open Switch
—	Closed Switch
•	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
•	Loadshed
•	Loadpickup
•	Battery Control

Benefits of LCSs: Full Outage Mitigated by DERs, Distribution of Loads Supported

Opportunity for new customer-facing programs using LCSs:

- Restoration is prioritized to a few community hubs spread geographically throughout the feeder.
- Notifications are sent and pamphlets are distributed informing where customers can go to charge their phones and escape the heat.
- More customers could be taken care of at those hubs than would be possible if they stayed home since it's more efficient to cool one building and have everyone go there than to cool many individual homes.

Benefits of LCSs: Full Outage Mitigated by DERs, Prioritizing Critical Loads

Prioritizing Critical Loads

No LCSs:

- The ability to support critical loads hinges on whether the microgrids containing them can be supported and how critical each microgrid as a whole is considered when weighed against others.

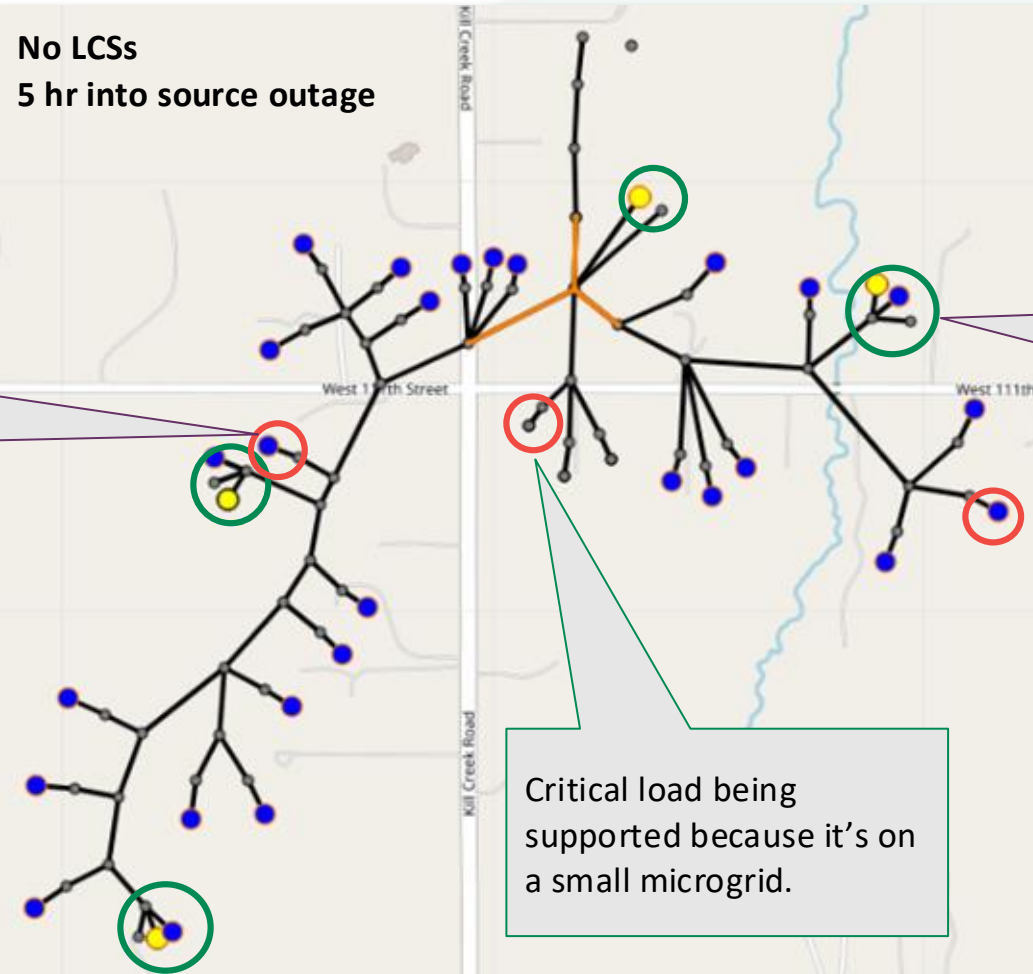
LCSs:

- Critical loads can be supported much more easily because the ability to support them does not hinge on the size of the microgrid they are in, only what DERs are available.

Benefits of LCSs: Full Outage Mitigated by DERs, Prioritizing Critical Loads

	Switch That Hasn't Opened (or Line)
	Open Switch
	Closed Switch
	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
	Loadshed
	Loadpickup
	Battery Control

Critical load not supported because there's not enough power to support its entire microgrid



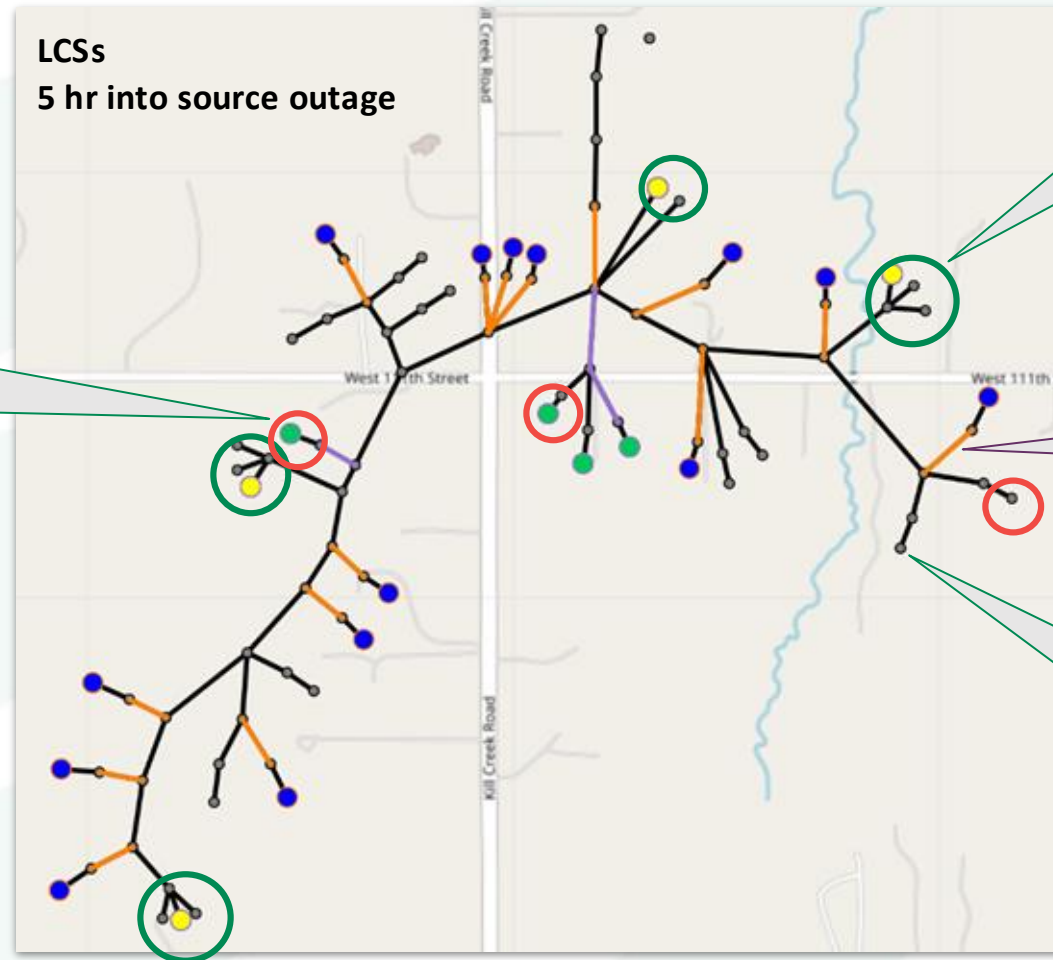
Load with BTM DERs not supported because it can't island without an LCS and there isn't enough power to support the entire microgrid.

Critical load being supported because it's on a small microgrid.

Benefits of LCSs: Full Outage Mitigated by DERs, Prioritizing Critical Loads

—	Switch That Hasn't Opened (or Line)
—	Open Switch
—	Closed Switch
•	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
•	Loadshed
•	Loadpickup
•	Battery Control

LCSs
5 hr into source outage



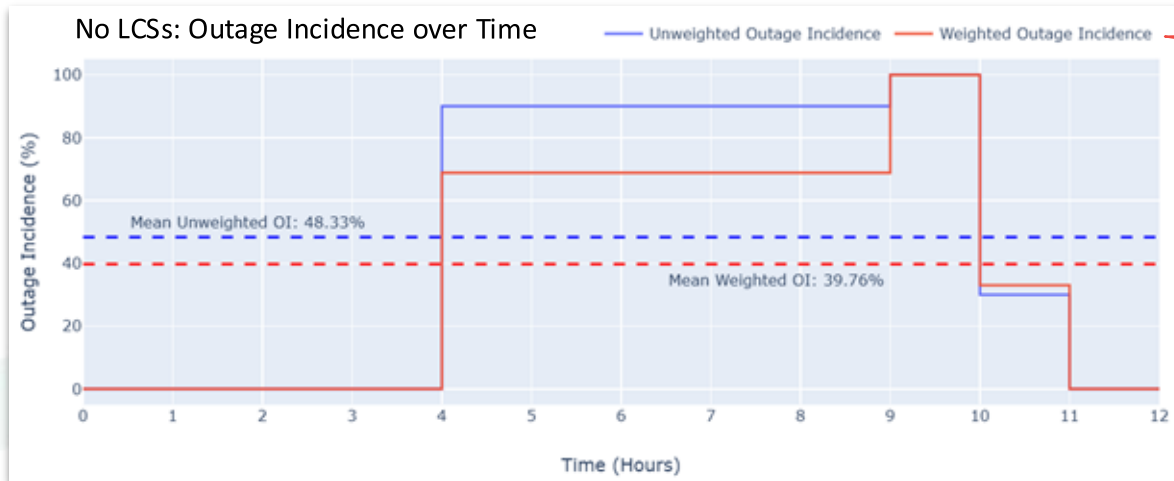
Critical loads being supported by available power from DERs

All loads with BTM DERs supported due to reduced demand from LCSs opening elsewhere

LCSs opened to cause loadshed of non-critical loads to reduce the demand on the DERs

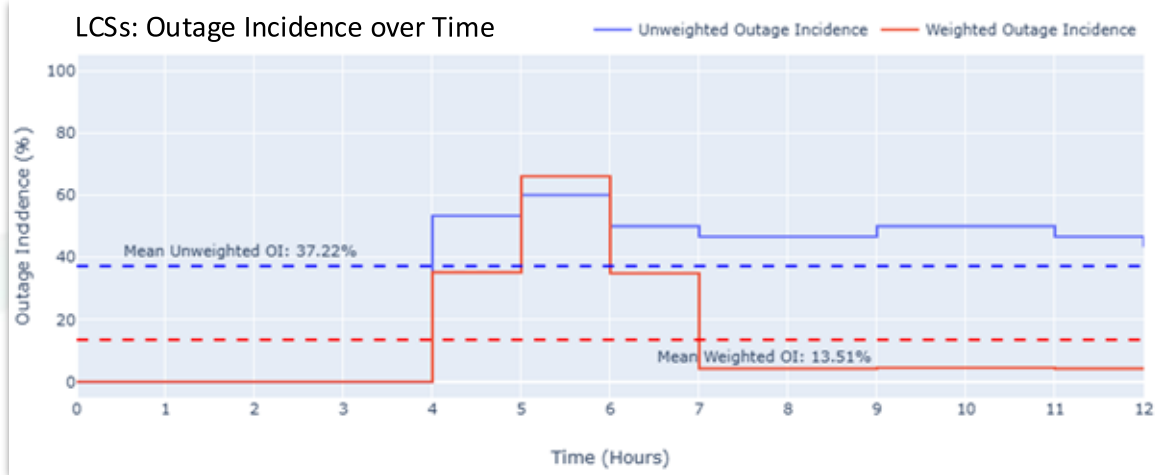
Low-demand non-critical load being supported by available power from DERs

Benefits of LCSs: Full Outage Mitigated by DERs, Prioritizing Critical Loads



Weighted by load
criticality.
 $w_{crit} = 100$
 $w_{noncrit} = 1$

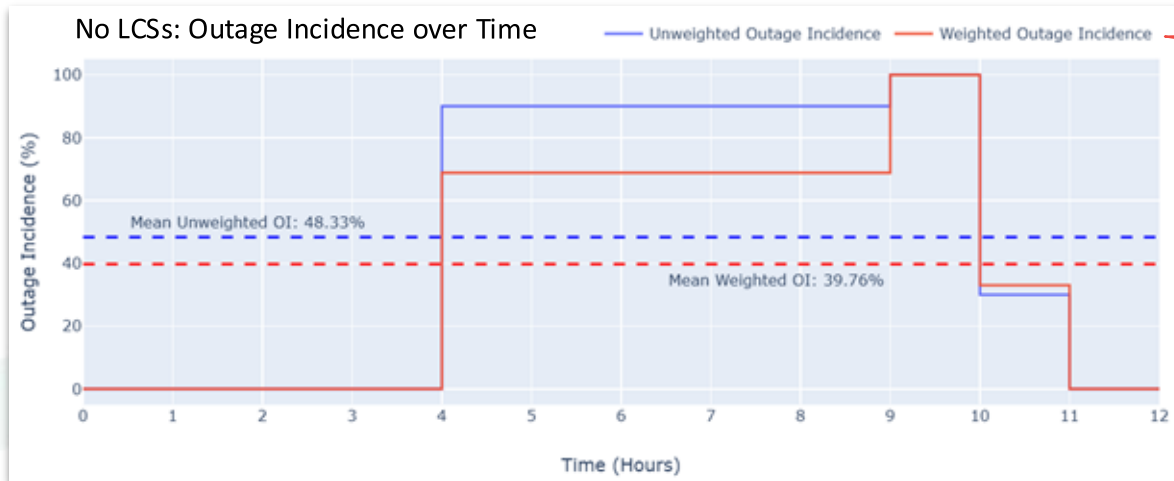
8.57%



The larger difference between mean weighted and unweighted Outage Incidence indicates greater prioritization of critical loads when LCSs are used

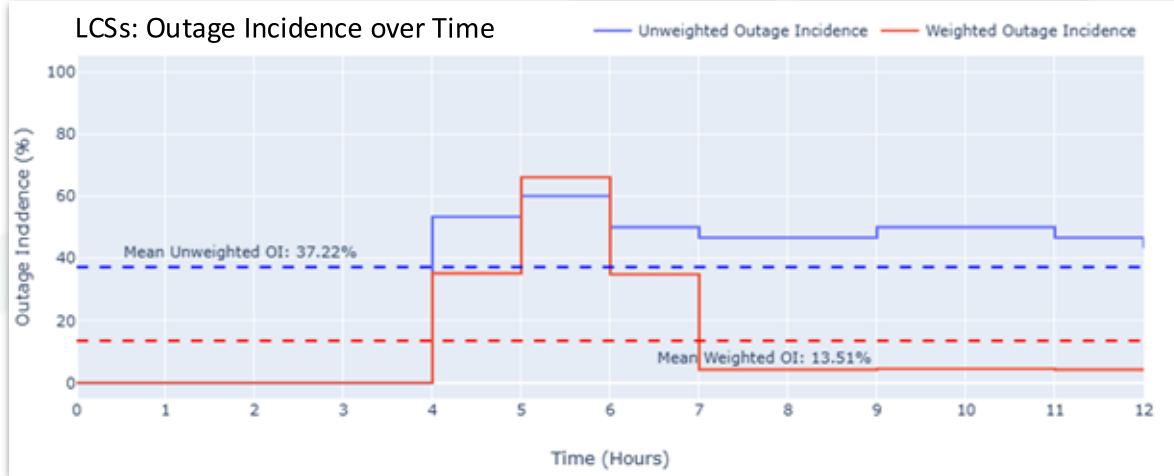
23.71%

Benefits of LCSs: Full Outage Mitigated by DERs, Prioritizing Critical Loads



Weighted by load
criticality.
 $w_{crit} = 100$
 $w_{noncrit} = 1$

8.57%



Difference of Weighted OI with
LCSs vs No LCSs:
26.25%!

23.71%

Benefits of LCSs: Full Outage Mitigated by DERs

During this full outage scenario, LCSs enabled:

- The optimal number of loads to be supported by DERs
- Restoration spread out across the feeder, rather than clustered geographically
- The ability to prioritize restoration to critical loads

Demonstrated through Restoration by:

- Improved SAIFI, SAIDI, and Outage Incidence in exchange for slightly worsened CAIFI and CAIDI
- Outage map visualizations
- An increase in the difference between mean weighted and unweighted Outage Incidence
- A much lower weighted outage incidence overall

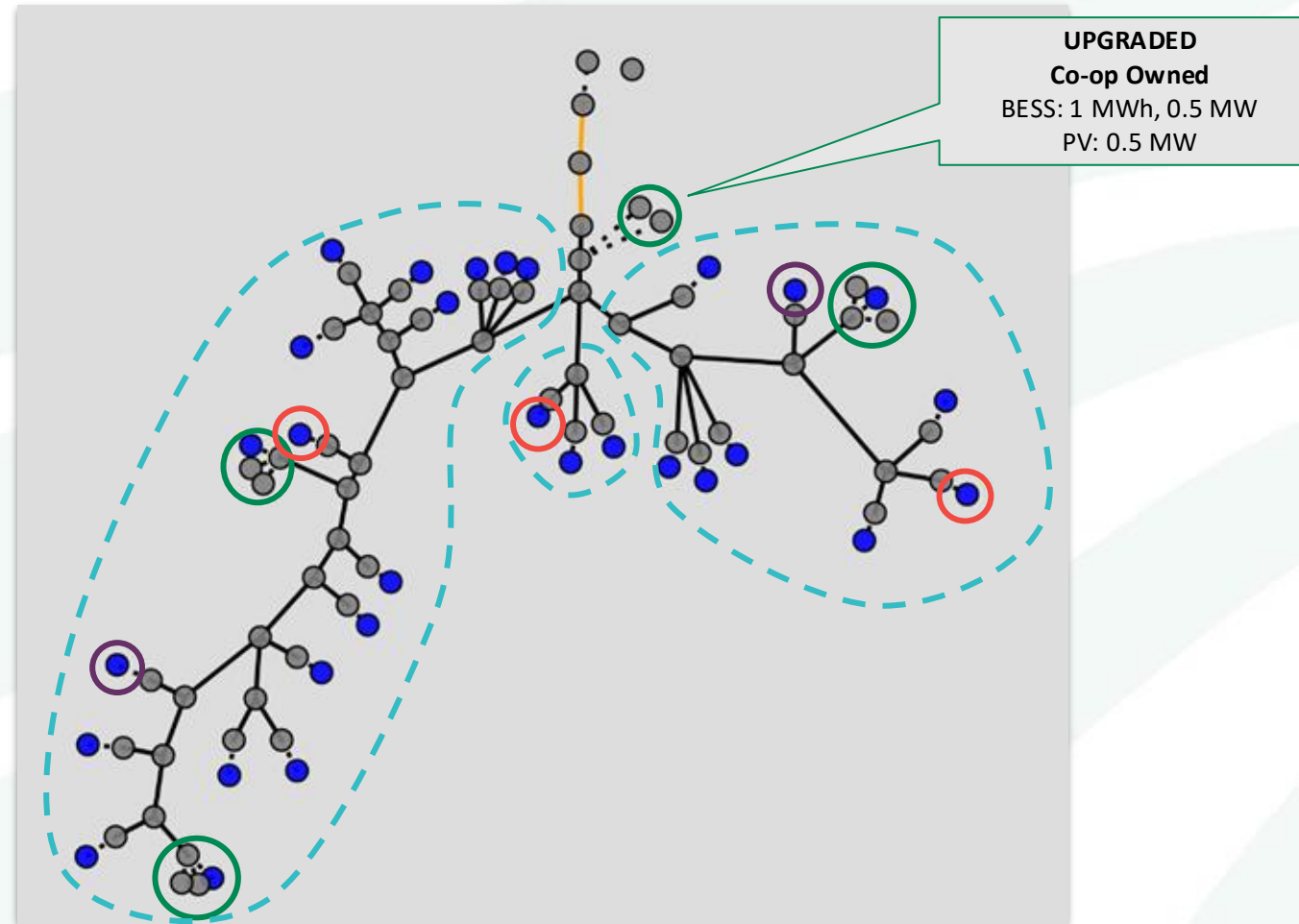
Benefits of LCSs: Demand Outpacing Generation

During scenarios where demand on the feeder exceeds generation, LCSs can allow for more precisely controlled load shed, shedding individual loads rather than entire sections.

Scenario

- There is another intense heat-wave in late August
- Since the last heat wave, the co-op has upgraded their PV and BESS, which can now support significant portions of the feeder for longer.
- The co-op sends out a message beforehand warning their members to make preparations for possible outages due to intense strain on the grid.
- Once the heat wave actually hits, it causes a 9 hour outage of supply power, requiring the feeder to be primarily supported by co-op owned PV and BESS.
- This time, the co-op owned PV and BESS support large portions of the feeder, avoiding a feeder-wide outage, but still cannot match the high demand on the system, requiring customers to be alerted and controlled loadshed to take place.

Benefits of LCSs: Demand Outpacing Generation



Benefits of LCSs: Demand Outpacing Generation, Maximum Distributed Loads Supported

Maximum Distributed Loads Supported

Much like the Full Outage Scenario, LCSs enable the maximum number of loads to be supported with a greater geographical distribution.

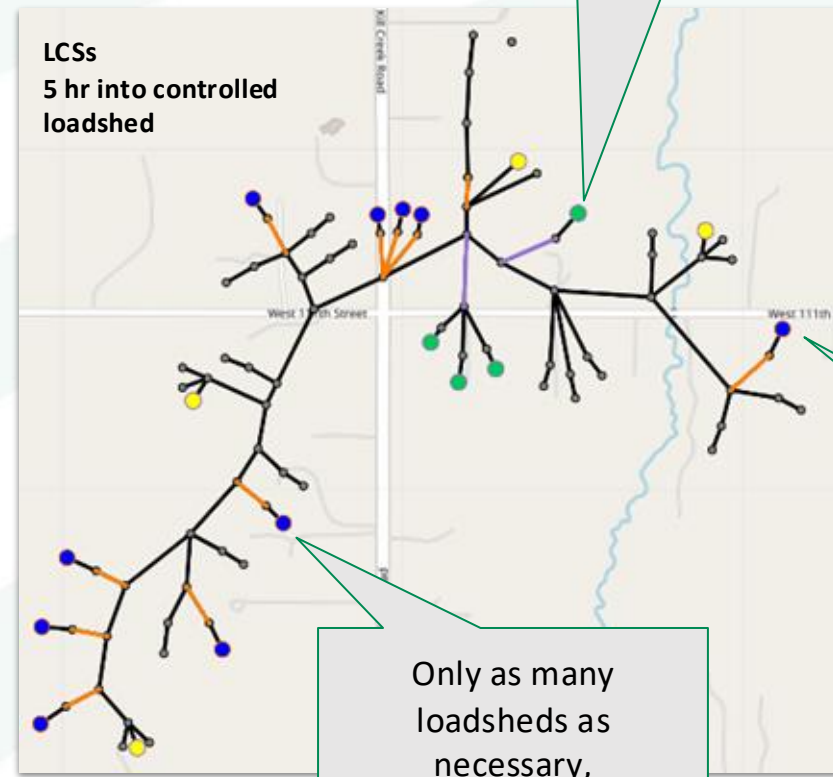
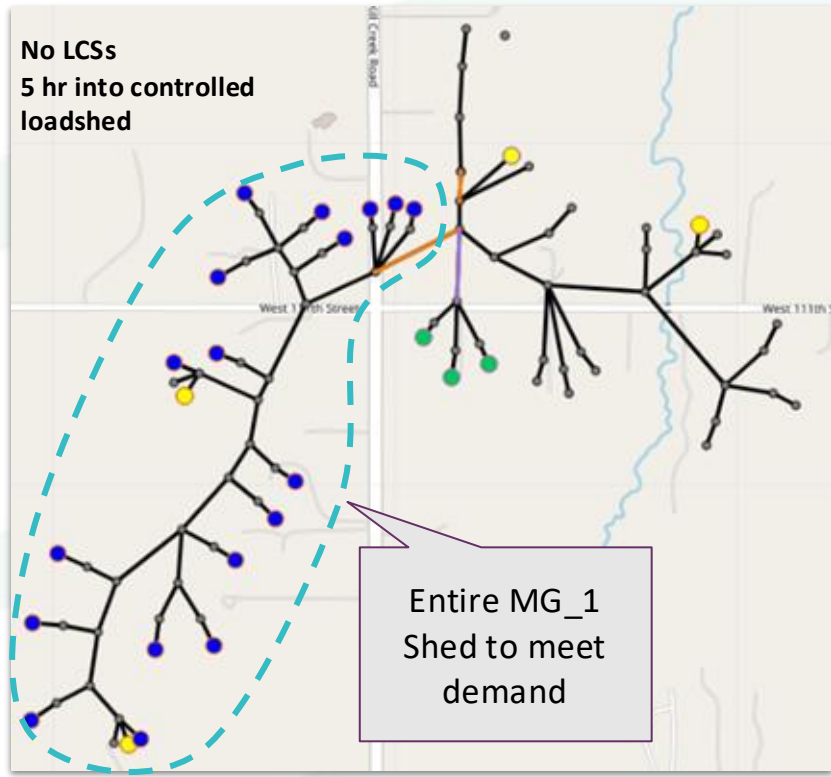
No LCSs:

- To meet demand, entire microgrids have to be shed at once, potentially causing more interruptions than necessary, centralized in a particular area.

LCSs:

- Co-ops can shed only the minimum number of loads necessary to meet demand.
- This loadshed can be done across the feeder to distribute its impact.

Benefits of LCSs: Demand Outpacing Generation, Maximum Distributed Loads Supported



—	Switch That Hasn't Opened (or Line)
—	Open Switch
—	Closed Switch
•	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
•	Loadshed
•	Loadpickup
•	Battery Control

Loadshed distributed across feeder

Benefits of LCSs: Demand Outpacing Generation, Maximum Distributed Loads Supported

Metric (Simulation- Constrained)	Description	No LCSs	LCSs	Difference w/ LCSs
SAIFI	Number of interruptions for an average member.	0.7	0.47	0.23
SAIDI	Total minutes of interruption for an average member.	366	190	178
CAIFI	Number of interruptions for an average member who experienced at least one interruption.	1.0	1.0	0
CAIDI	Minutes of duration for an average interruption.	522.86	407.14	115.72
Mean Outage Incidence	Percent of loads experiencing an outage during the average simulation timestep.	50.83%	26.39%	24.44%

LCSs produce an improvement in all metrics inspected!

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
Whole System	366.0	0.7	522.86	1.0

Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
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Cut down by almost ½!

Simulation-Constrained Metrics by Microgrid

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Simulation-Constrained Metrics by Microgrid

Microgrid ▲ ▼	SC-SAIDI ▲ ▼	SC-SAIFI ▲ ▼	SC-CAIDI ▲ ▼	SC-CAIFI ▲ ▼
Whole System	190.0	0.47	407.14	1.0

Benefits of LCSs: Demand Outpacing Generation, Prioritizing Critical Loads

Prioritizing Critical Loads

Much like the Full Outage Scenario, LCSs enable much greater prioritization of critical loads.

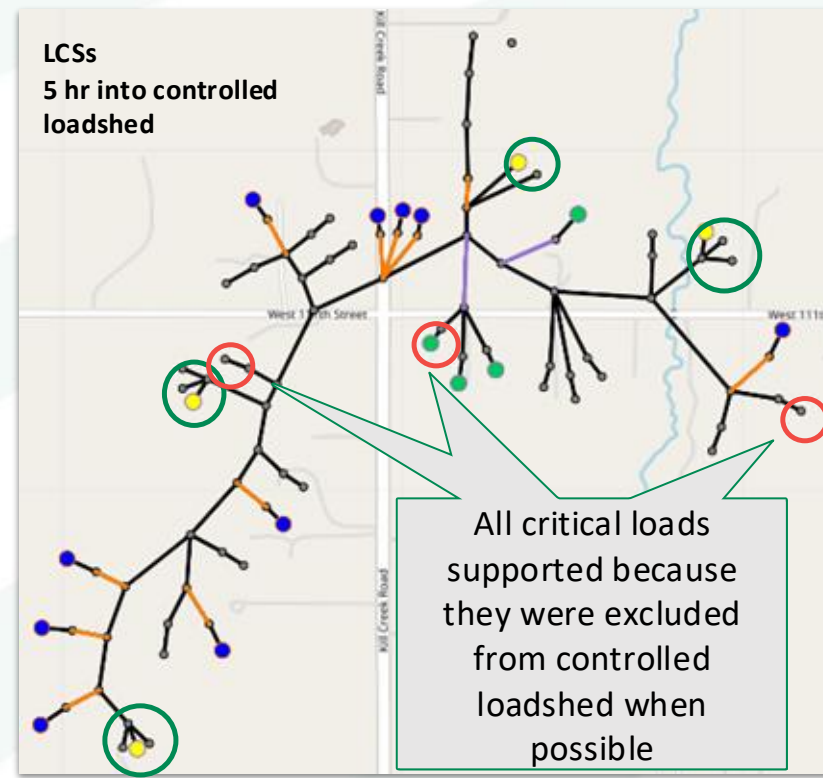
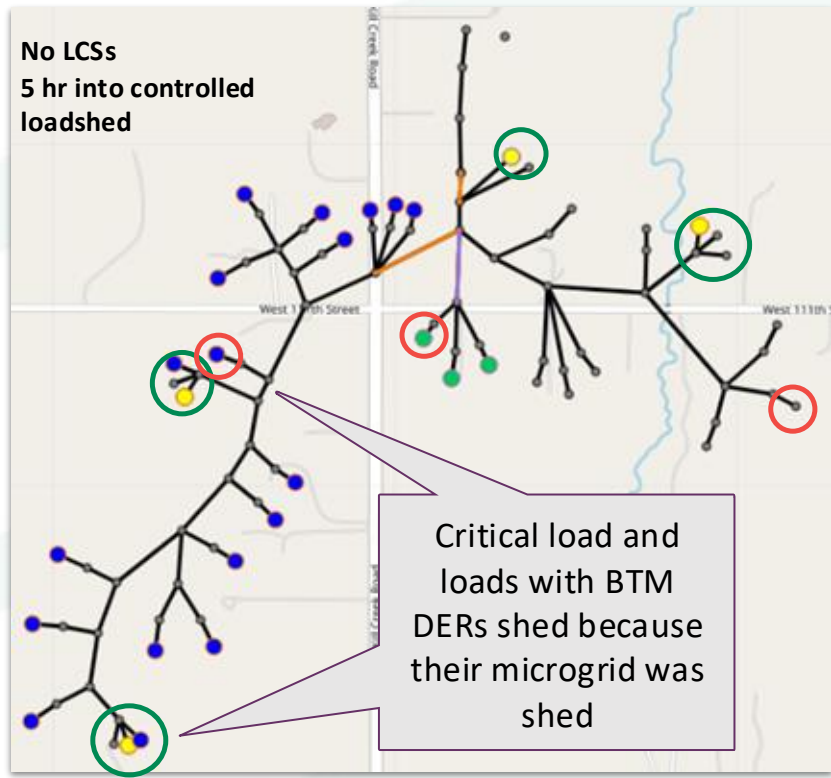
No LCSs:

- To avoid shedding critical loads, controlled loadshed would have to entirely avoid microgrids containing them.

LCSs:

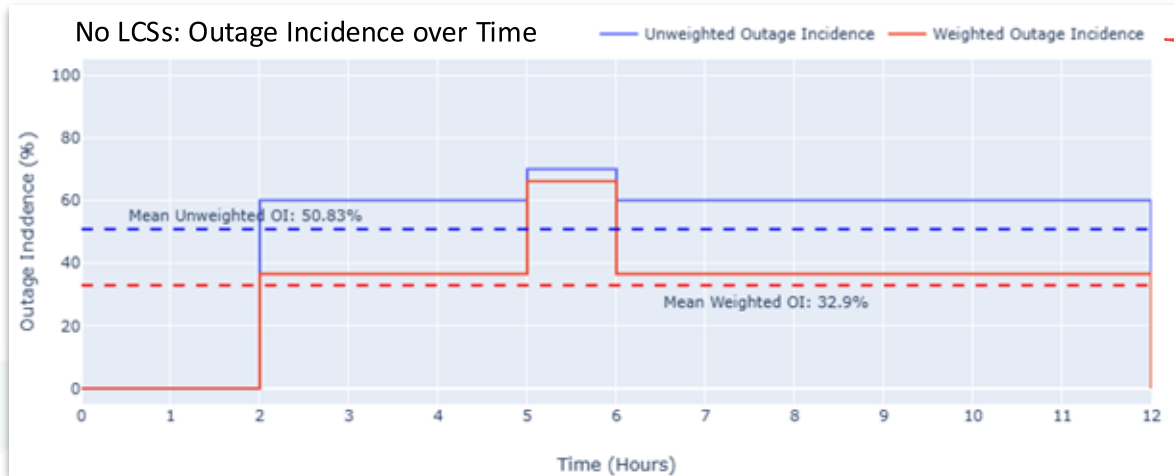
- Critical loads can be individually excluded from controlled loadshed.

Benefits of LCSs: Demand Outpacing Generation, Prioritizing Critical Loads



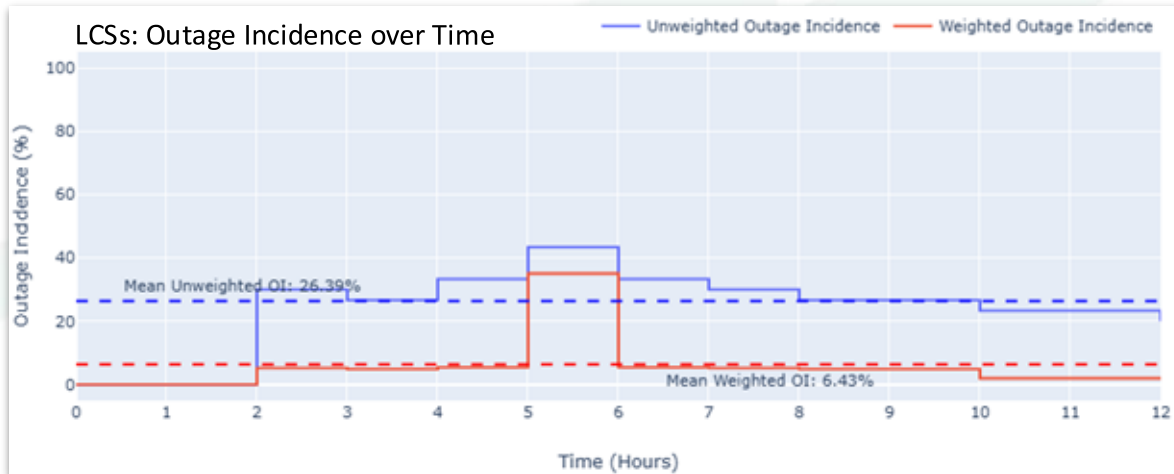
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•	Battery Control

Benefits of LCSs: Demand Outpacing Generation, Prioritizing Critical Loads



Weighted by load criticality.
 $w_{crit} = 100$
 $w_{noncrit} = 1$

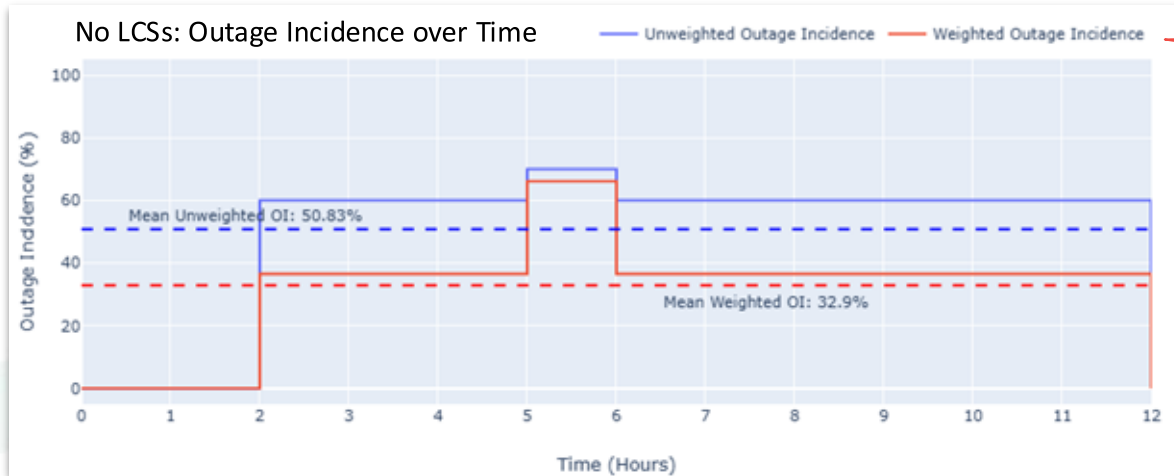
17.93%



The larger difference between mean weighted and unweighted Outage Incidence indicates greater prioritization of critical loads when LCSs are used

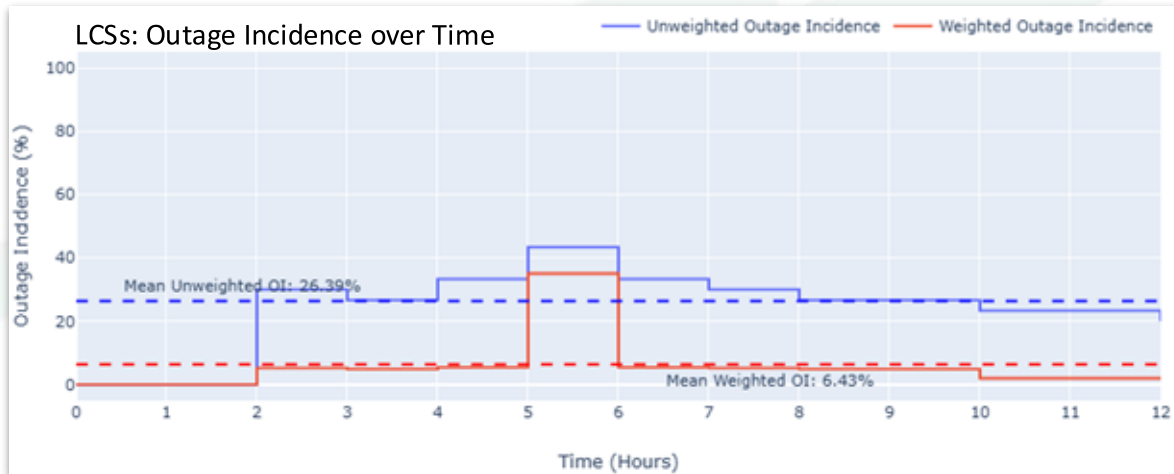
19.96%

Benefits of LCSs: Demand Outpacing Generation, Prioritizing Critical Loads



Weighted by load
criticality.
 $w_{crit} = 100$
 $w_{noncrit} = 1$

17.93%



19.96%

Difference of Weighted OI with
LCSs vs No LCSs:
26.47%!

Benefits of LCSs: Demand Outpacing Generation

During this controlled loadshed scenario, LCSs enabled:

- The optimal number of loads to be supported by DERs
- Restoration spread out across the feeder, rather than clustered geographically
- The ability to prioritize restoration to critical loads

Demonstrated through Restoration by:

- An improvement in all metrics inspected!
- Outage map visualizations
- An increase in the difference between mean weighted and unweighted Outage Incidence
- A much lower weighted outage incidence overall

Benefits of LCSs

By using Restoration to evaluate the placement of switches at POL, we were able to determine for our scenarios that:

- LCSs provide greater support for critical loads and distribute loadshed across the feeder, which can help reduce consequences of interruptions on customers.
- In a full outage scenario, LCSs enable better outcomes system-wide, at the cost of individual loads that experience interruptions experiencing them for longer and slightly more frequently.
 - This can provide information for co-ops to make informed decisions about how to approach restoration based on their priorities in such a scenario.
- In a controlled loadshed scenario, LCSs enable better outcomes across the board.

Load Criticality in Restoration

To determine critical loads like those used in the previous example, users can use two mechanisms built into the Restoration Model:

1. Criticality can be manually chosen with a Load Priorities File.
2. Criticality can be optionally set based on the Community Criticality Index (CCI) of each load.

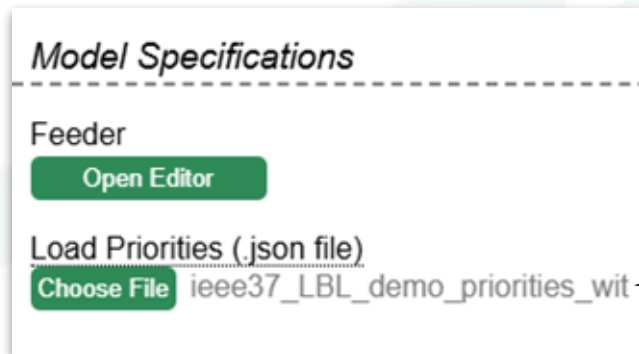
Model Specifications

Feeder Open Editor	Event Information (.json file) Choose File ieee37_LBL_demo_events.json	Solution Fidelity Low
Load Priorities (.json file) Choose File ieee37_LBL_demo_priorities_wit	Microgrid Tagging (.csv file) Choose File ieee37_LBL_demo_mgTagging.j	Impact of CCI High

Load Criticality: Load Priorities File

Using a Load Priorities file, users can choose how loads are considered by assigning them one of 3 values corresponding to different levels of criticality:

- 1 = Non-Critical Load (Default)
- 10 = Sub-Critical Load
- 100 = Critical Load



Model Specifications

Feeder

[Open Editor](#)

Load Priorities (.json file)

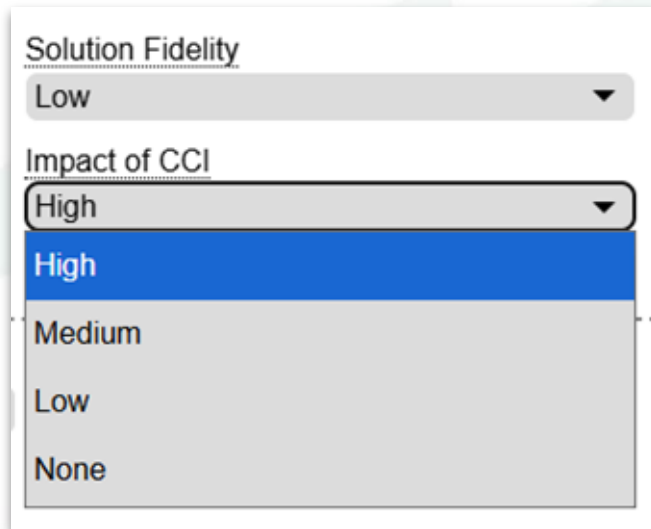
[Choose File](#) ieee37_LBL_demo_priorities_wit

```
{  
  "s722c": 100,  
  "s712c": 100,  
  "s730c": 100,  
  "s737a": 10,  
  "s720c": 10  
}
```

Load Criticality: Community Criticality Index

Users can also choose for load criticality to be determined based on the CCI of each load.

- CCI reflects individuals' relative vulnerability to outages at a load*.
- Based on a combination of technical factors and social vulnerability.



The screenshot shows a web form with two dropdown menus. The first menu, labeled 'Solution Fidelity', has 'Low' selected. The second menu, labeled 'Impact of CCI', has 'High' selected and is open, showing a list of options: 'High' (highlighted in blue), 'Medium', 'Low', and 'None'.

Impact of CCI relative to Load Priorities

Load Priorities : CCI	
High	1 : 1
Medium	2.5 : 1
Low	10 : 1
None	1 : 0

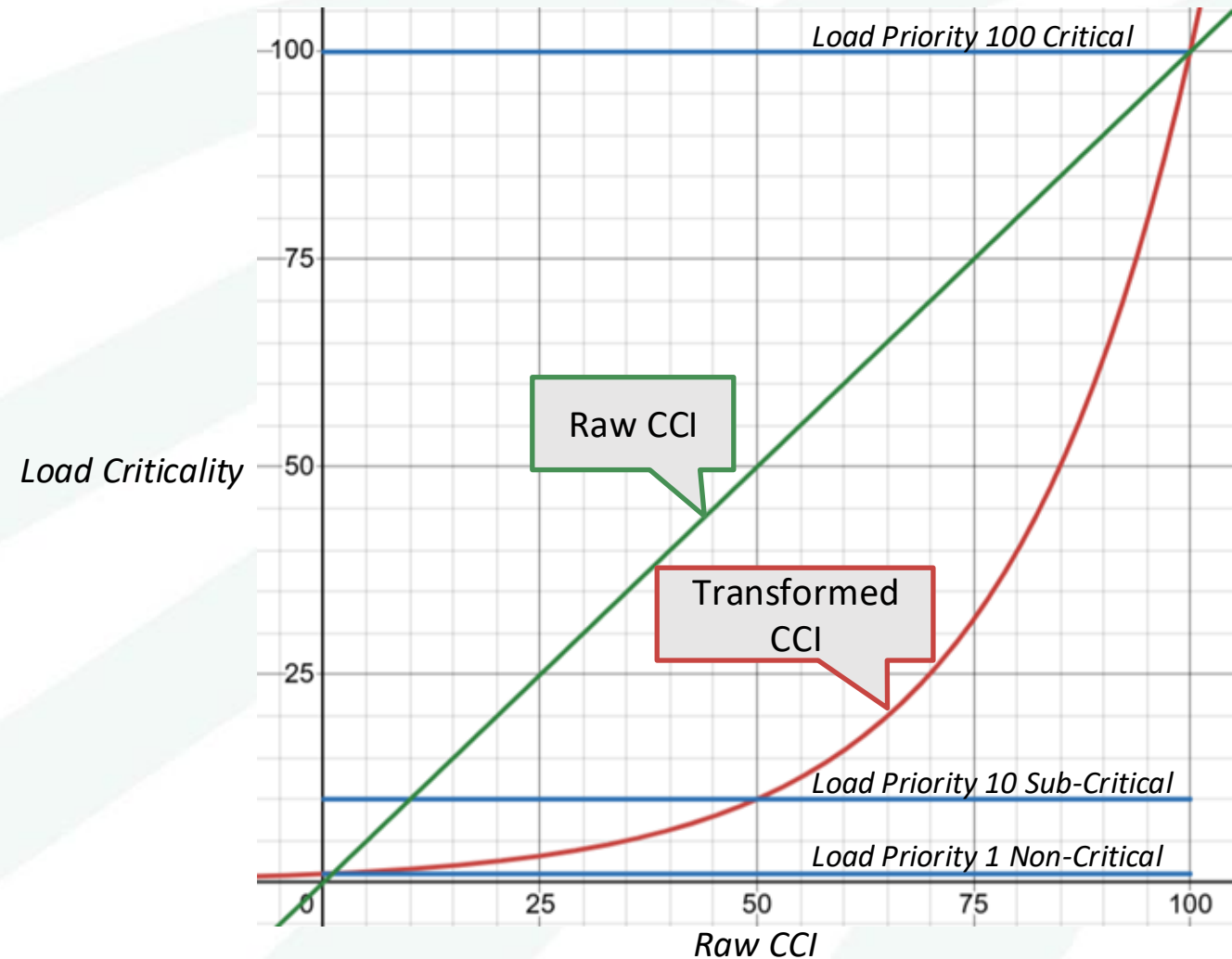
Load Criticality: Transforming CCI

CCI reflects the vulnerability of loads in a linear ranking from 0-100, but load criticality values are expected to follow the pattern that Load Priorities already use.

- If we use CCI as a criticality value as is, the top 90% of loads would be considered between semi-critical and critical.

To account for this, we transform Raw CCI values from a linear scale to an exponential one so that they follow the expected pattern more closely.

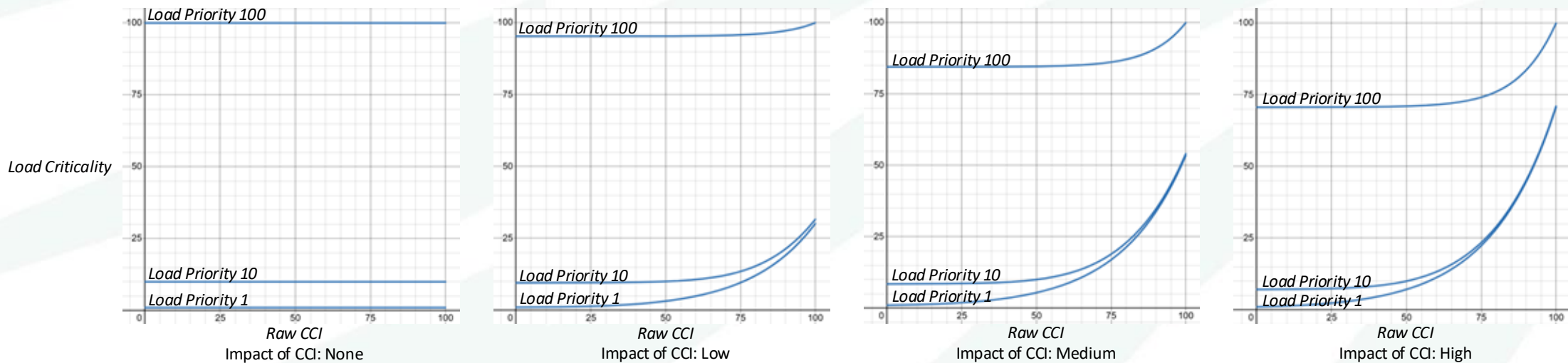
- If we use CCI as a criticality value after the transformation, the top 50% of loads will be considered between semi-critical and critical.



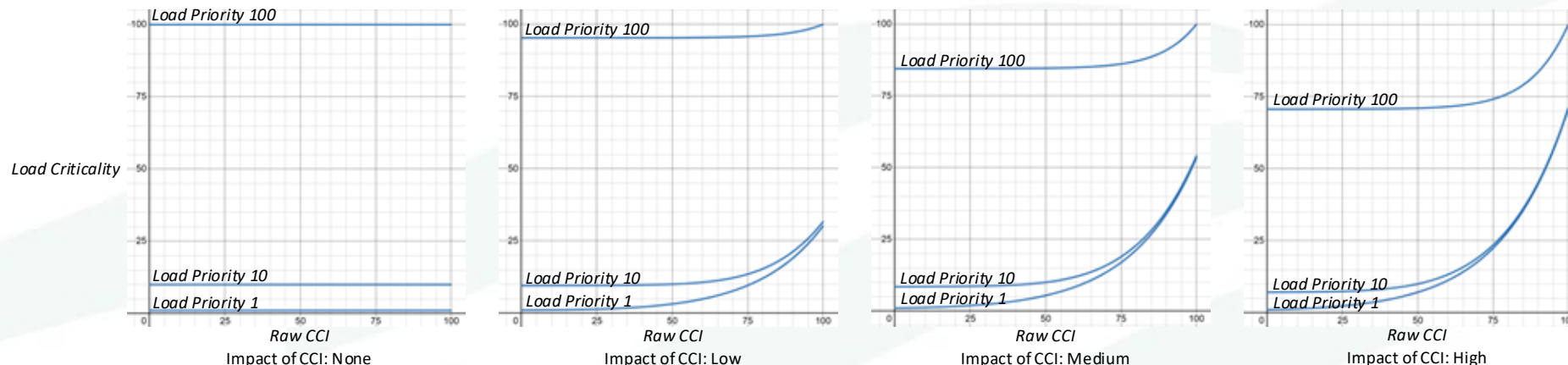
Load Criticality: Load Priorities & CCI

To determine load criticality using both Load Priorities and transformed CCI, we use a weighted Root-Mean-Squared function where weight is based on the user-selected Impact of CCI.

$$\text{Load Criticality} = \sqrt{\frac{\text{Impact} \cdot (\text{Xfrmd CCI})^2 + (\text{Load Priorities})^2}{\text{Impact} + 1}}$$



Load Criticality: Benefits



This implementation provides the following benefits:

- High user-chosen load priorities aren't brought down significantly by low CCI.
 - We don't want to negate something marked intentionally as important.
- Low user-chosen load priorities can be brought up significantly by high CCI, especially with very high CCI.
 - This is the desired effect of catching things that may be important to support but are easier to miss when prioritizing things manually.
- With Impact of CCI: High, the highest CCI loads with non-critical and sub-critical Load Priority are elevated to a similar level of criticality as the lowest CCI loads with Critical Load Priority, but never higher than that.
 - High CCI low Load Priority loads are effectively elevated to the lower end of Critical.

Detailed Results for models.resilientCommunity

Overview of Resilient Community Model

Description

Evaluates social data to determine the relative impact of outages to individual consumers, and uses this to identify the pieces of distribution system equipment that are most critical to the community it serves. This supports the inclusion of community impacts in resilience considerations.

User Stories

1. A cooperative distribution engineer or analyst wants to understand how outages impact their members to prioritize those who experience the most negative effects. The tool shows the criticality of each piece of equipment to the community's outage survivability, allowing them to be prioritized in resilience planning and recovery operations.
2. A researcher is investigating the connections between social metrics and the resilience planning and operation process.

Social Data for Resilient Community

The Federal Emergency Management Agency (FEMA) hosts a set of metrics called the [National Risk Index \(NRI\)](#) dataset. The NRI contains information for each census tract regarding relative risk indices, percentiles, and ratings that summarize:

- Social vulnerability
- Community resilience
- Risk of severe weather (e.g. wildfire, ice storm, hurricane, lightning, heat/cold wave, etc.)
- Expected financial loss due to natural hazards.

Of special relevance to the topic of individual vulnerability power outages (and conjoining weather events) is the component of the NRI dataset that captures a community's vulnerability to disaster – the Social Vulnerability Index (SVI)

Social Vulnerability Index (SVI)

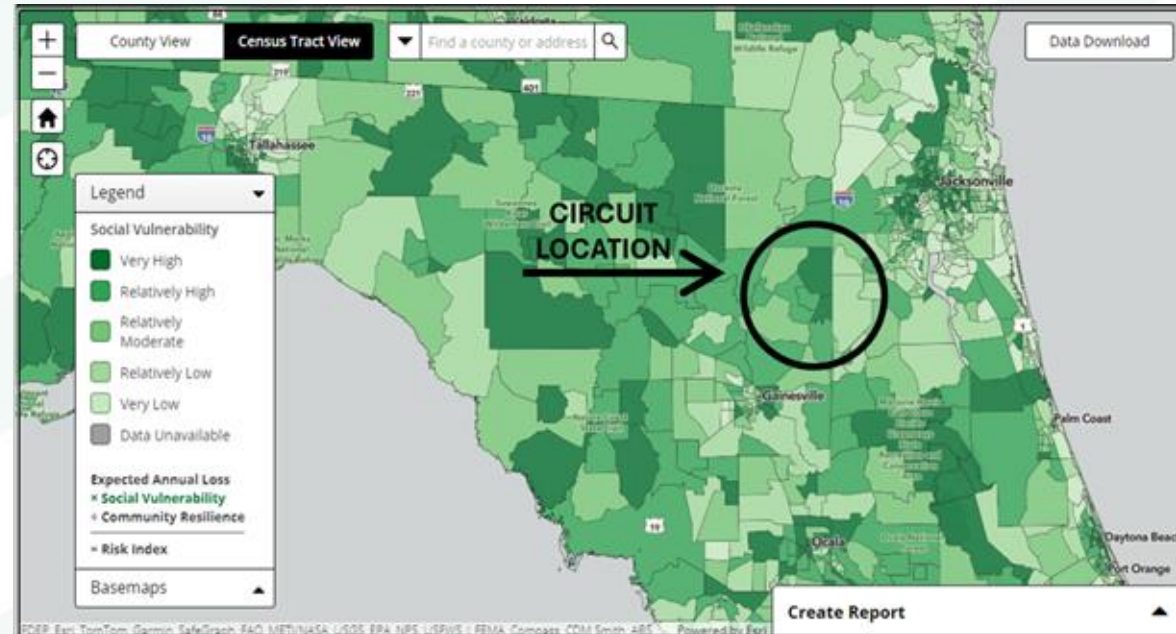
- The NRI defines social vulnerability as “the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood.”
- In the NRI, a SVI “score” and “rating” represent the relative level of a community's social vulnerability.

The SVI can provide insights into the scale of outage impacts on a community and was used as the base indicator of vulnerability for this model.

Test Circuit - Region in Florida

A test case was applied to test the functionality of the latest version of the resilient community software tool using a representative analysis on a circuit located in Florida.

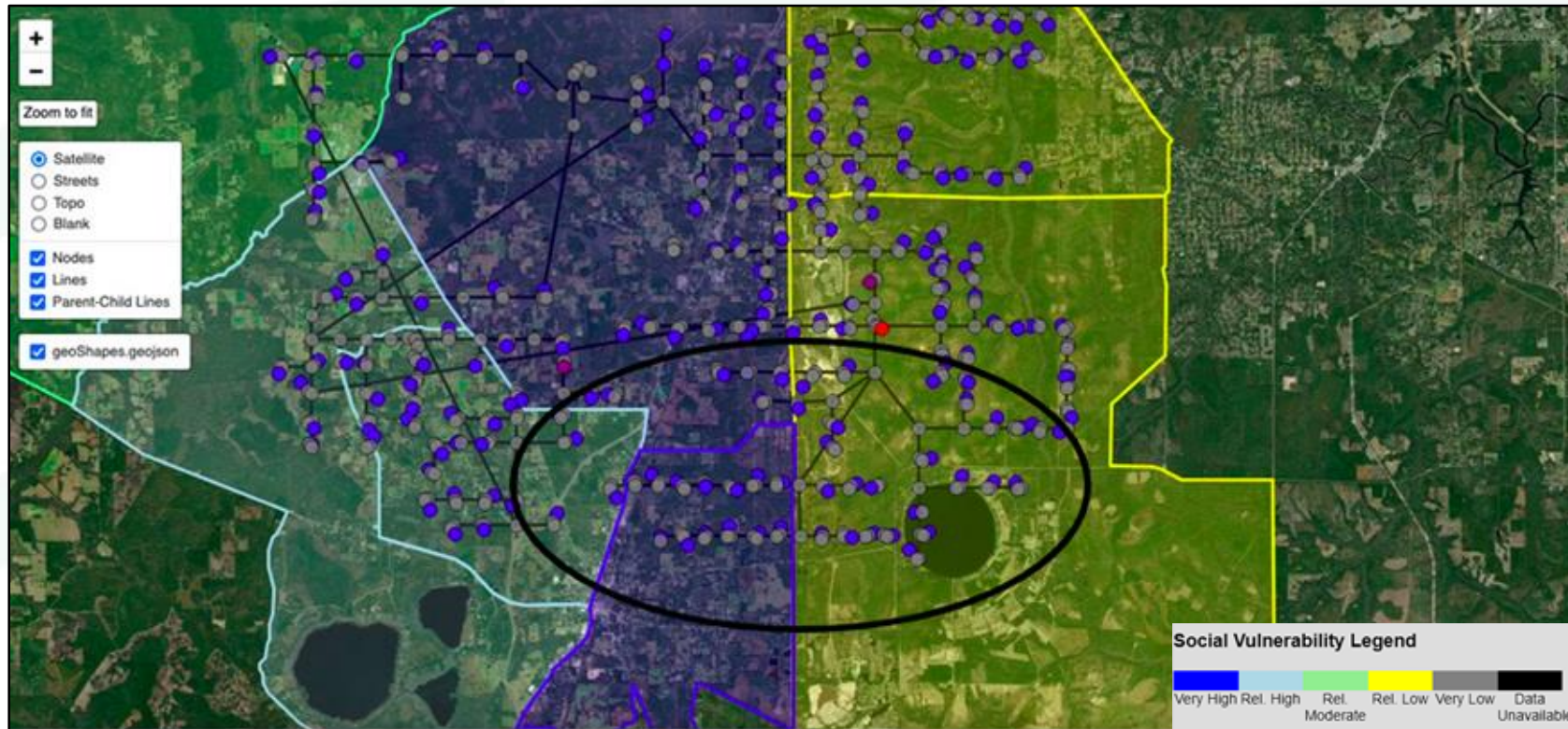
- Florida has a mixture of vulnerability levels across the state, which provides for an informative analysis.
- Florida is known for experiencing hurricanes, as it is a coastal state within proximity of warming currents from the equator.
- This area in Florida contains a good amount of census tracts for the size of the feeder being used



Map of the region in Florida displaying the circuit location in context with the social vulnerability index for census tracts in the area.

Equipment Criticality Analysis

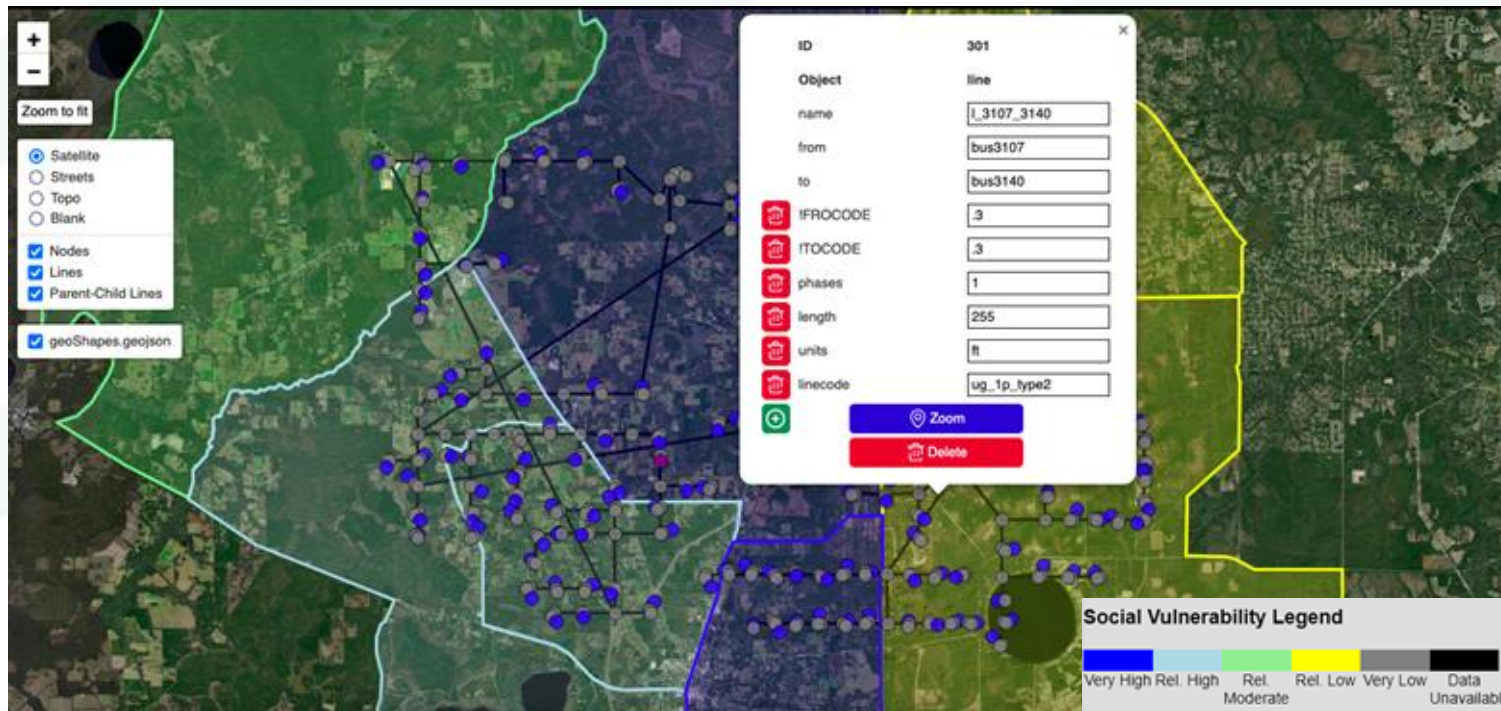
The Florida test case shows the relevance of location to the criticality analysis. In some situations, a piece of equipment may serve loads that span varying social vulnerability level areas.



Circuit map with social vulnerability index. A black circle highlighting the lines that travel through relatively low, relatively high, and very high vulnerability areas.

Equipment Criticality Analysis

Despite being located in a Relatively Low Vulnerability area, it is seen that line I_3107_3140 serves loads and other equipment in a Very High Vulnerability area as well as a Relatively High Vulnerability area.



Information regarding the observed line I_3107_3140

Equipment Criticality Analysis

Load Name	BSC	CCS	BCI	CCI	SVI Score	SVI Rating
load.load_3143	6.5	179.9	80.63	52.88	27.68	Relatively Low
load.load_3142	3.3	91.7	43.98	21.99	27.68	Relatively Low
load.load_3141	4.0	111.1	55.5	29.32	27.68	Relatively Low
load.load_3155	1.2	98.0	6.28	24.61	78.81	Relatively High
load.load_3154	3.9	355.8	54.97	79.06	91.04	Very High
load.load_3153	5.3	483.6	68.06	85.34	91.04	Very High
load.load_3152	1.7	156.5	13.09	43.46	91.04	Very High
load.load_3151	1.4	129.3	8.9	32.98	91.04	Very High
load.load_3150	2.1	195.4	21.99	55.5	91.04	Very High
load.load_3149	1.8	160.6	13.61	45.03	91.04	Very High
load.load_3148	8.8	799.3	91.62	95.29	91.04	Very High
load.load_3147	7.4	204.8	83.77	57.59	27.68	Relatively Low
load.load_3146	1.4	39.3	9.42	4.71	27.68	Relatively Low
load.load_3145	1.6	43.8	10.99	5.24	27.68	Relatively Low
load.load_3144	0.4	11.7	1.57	1.05	27.68	Relatively Low
load.load_3162	3.1	278.7	38.74	69.11	91.04	Very High
load.load_3161	2.2	201.9	23.56	56.02	91.04	Very High
load.load_3160	3.6	326	50.26	74.35	91.04	Very High
load.load_3159	8.6	782.4	90.58	94.24	91.04	Very High

Table containing downline load BCS, BCI, CCS, CCI, SVI, and Social Vulnerability rating for 'line I_3107_3140'

- Despite originating in a Relatively Low vulnerability area, line I_3107_3140 serves loads in multiple areas of varying vulnerability.
- The resilientCommunity model accounts for this situation by capturing downline loads during the evaluation of **BCS**, **BCI**, **CCS**, and **CCI** for pieces of equipment on the circuit.
- Incorporating all downline loads in the calculation connects the system information to sociodemographic and other locational information to capture variations in vulnerability.

Equipment Criticality Analysis

Load Name	BSC	CCS	BCI	CCI	SVI Score	SVI Rating
load.load_3143	6.5	172.5	55.63	52.88	27.68	Relatively Low
load.load_3142	3.3	91.7	45.7			Relatively Low
load.load_3141	4.0	111.1	55.5	29.7		
load.load_3155	1.2	98.0	6.28	24.61	72.0	
load.load_3154	3.9	355.8	54.97	79.06	91.04	
load.load_3153	5.3	483.6	68.06	85.34	91.04	Very High
load.load_3152	1.7	156.5	13.09	43.46	91.04	Very High
load.load_3151	1.4	129.3	8.9	32.98	91.04	Very High
load.load_3150	2.1	195.4	21.99	55.5	91.04	Very High
load.load_3149	1.8	160.6	13.61	45.03	91.04	Very High
load.load_3148	8.8	799.3	91.62	95.29	91.04	Very High
load.load_3147	7.4	204.8	83.77	57.59	27.68	Relatively Low
load.load_3146	1.4	39.3	9.42	4.71	27.68	Relatively Low
load.load_3145	1.6	43.8	10.99	5.24	27.68	Relatively Low
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load.load_3159	8.6	782.4	90.58	94.24	91.04	Very High

Base Criticality Score - Total Number of persons served at a load or by a piece of equipment

Base Criticality Score for a single load:

$$BCS_{Load} = \frac{\sqrt{kw^2 + kvar^2}}{pd} * N$$

- kw , opendss property used to compute active (real) power, portion of power that is absorbed and used by the load.
- $kvar$, opendss property represents the reactive (imaginary) power, power that is not used that flows throughout a grid.
- pd , peak demand (in kva) for the average load served by the system
- N , average number of occupants per home.

Base Criticality Score for a piece of equipment:

$$BCS_{Equipment} = \sum_{i=0}^n BCS_{Load_i}$$

Table containing downline load BCS, BCI, CCS, CCI, SVI, and Social Vulnerability rating for 'line l_3107_3140'

Equipment Criticality Analysis

Load Name	BSC	CCS	BCI	CCI	SVI Score	SVI Rating
load.load_3143	6.5	179.9	80.63	52.88		
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load.load_3150	2.1	195.4	21.99	55.5	91.04	Very High
load.load_3149	1.8	160.6	13.61	45.03	91.04	Very High
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Base Criticality Index - Percentile of number of individuals served at a load or by a piece of equipment.

- Allows for a ranking-based system among all loads or respective equipment on the feeder.
- Provides another way to visualize various components of an electrical circuit in relation with its importance to circuit criticality.

Table containing downline load BCS, BCI, CCS, CCI, SVI, and Social Vulnerability rating for 'line I_3107_3140'

Equipment Criticality Analysis

Load Name	BSC	CCS	BCI	CCI	SVI Score	SVI Rating
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Community Criticality Score - An individual's relative vulnerability to outages at a load or due to a piece of equipment.

Community Criticality Score for a load:

$$CCS_{Load} = BCS_{Load} * SVI_{Score}$$

Community Criticality Score for a piece of equipment:

$$CCS_{Equipment} = \frac{1}{\sum_{j=0}^k SVI_{Score_j}} * \left(\sum_{x=0}^z CCS_{Load_x} \right)$$

Table containing downline load BCS, BCI, CCS, CCI, SVI, and Social Vulnerability rating for 'line I_3107_3140'

Equipment Criticality Analysis

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Community Criticality Index - Percentile of an individual's' relative vulnerability to outages at a load or due to a piece of equipment.

- Allows for a ranking-based system among all loads or respective equipment on the feeder that incorporate social vulnerability levels.
- Helps identify components of the system for which uptime may be more important to the community.

Table containing downline load BCS, BCI, CCS, CCI, SVI, and Social Vulnerability rating for 'line l_3107_3140'

Equipment Criticality Analysis

Considering # people served by line object I_3107_3140	BCS: 82.2	BCI: 92.28
Line I_3107_3140 provides for around 82 people and is in the 92nd percentile of # of persons served among all objects on the circuit.		

Considering # people + social vulnerability information	CCS: 339.0	CCI: 80.98
The residents served by line I_3107_3140 are impacted by outages more heavily than around 81% of other residences on the circuit.		

Comparing the BCI to the CCI, line I_3107_3140 serves many more people than average for equipment across the circuit, and overall the individuals served are also more vulnerable than those served by other pieces of equipment on the circuit.

Despite the fact that this line reaches loads in areas of varying vulnerability, it is still in the upper percentile of equipment vulnerabilities in the circuit.

- This might indicate that there is a trend across the service area of more population-dense areas being more socially vulnerable to outages.

Community-Aware Restoration

Resilient Community can also be used to inform other models with community-aware data.

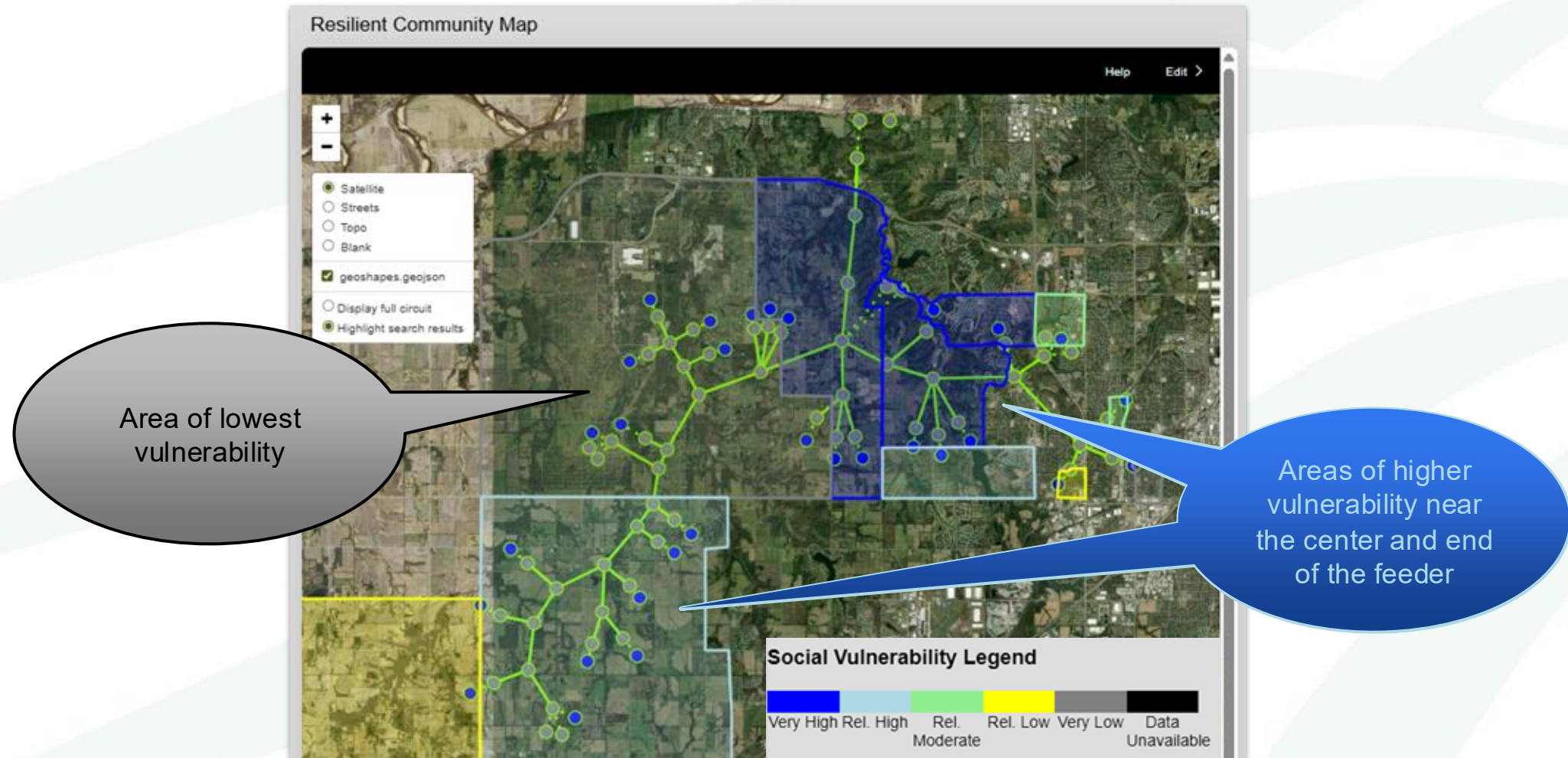
- In the Restoration model, CCI information provided by Resilient Community can allow for community-aware analysis and simulation of outage responses.

Scenario:

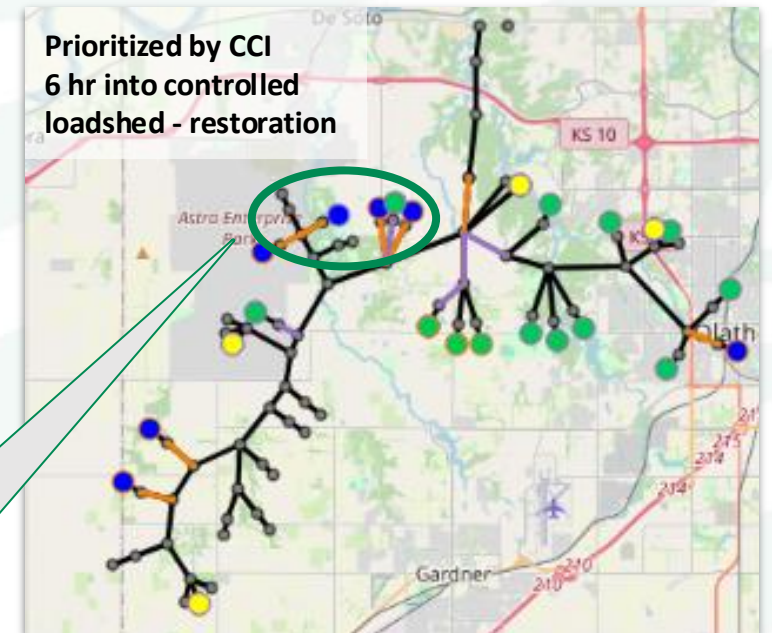
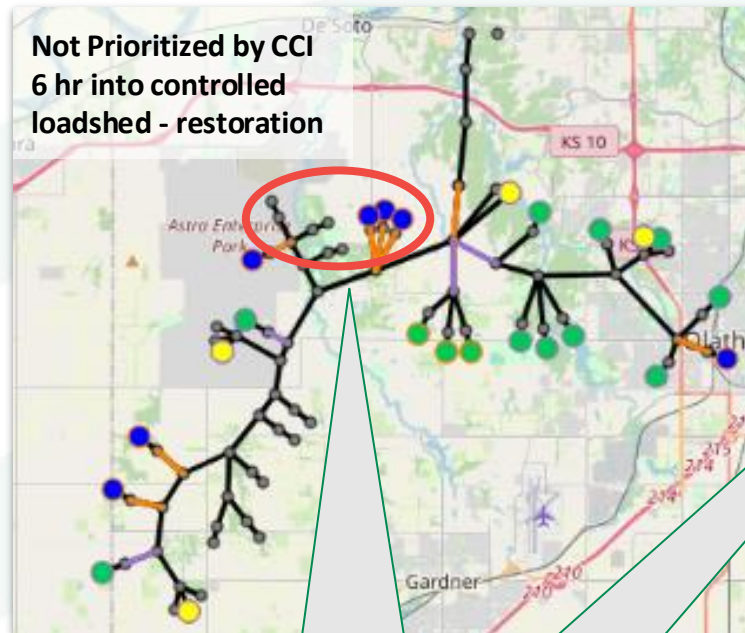
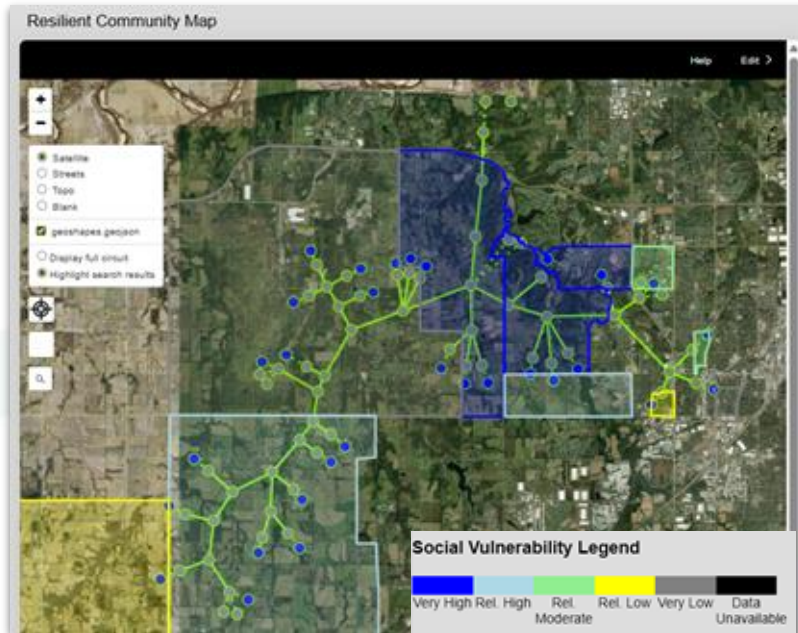
A cooperative distribution engineer or analyst wants to understand how prioritizing members who experience the most negative effects from outages could impact restoration approaches and outcomes.

1. They analyze their feeder with Resilient Community to get a sense of the vulnerability of different loads on the feeder.
2. They set up their feeder in the Restoration model with a controlled loadshed scenario identical to the one in the restoration section and run it twice:
 - Once without any load priorities
 - Once using CCI information given by Resilient Community to inform the simulation
3. Once their simulations are done running in Restoration, they compare the outputs of both, considering performance weighed by CCI.

Community-Aware Restoration



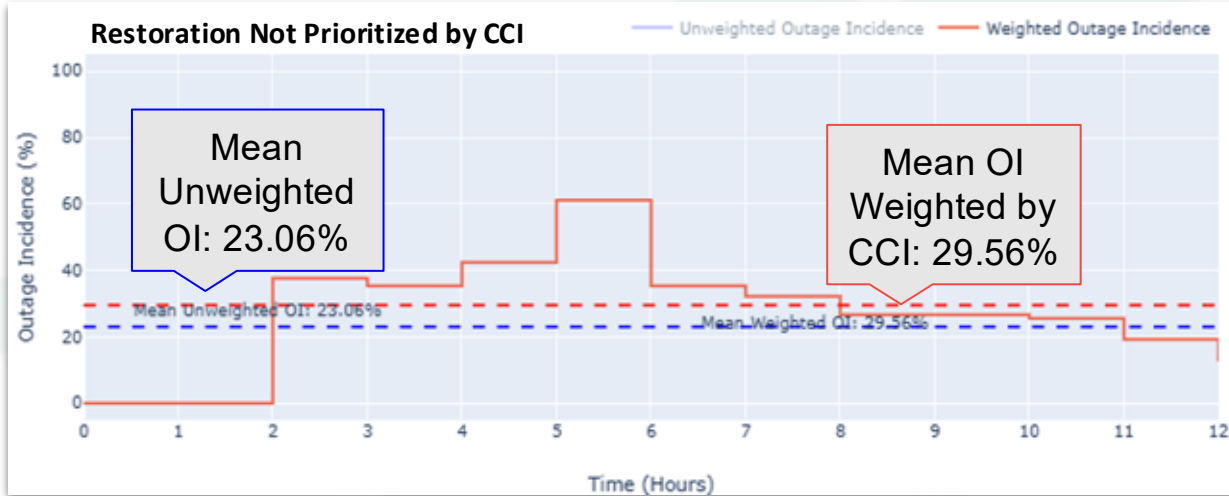
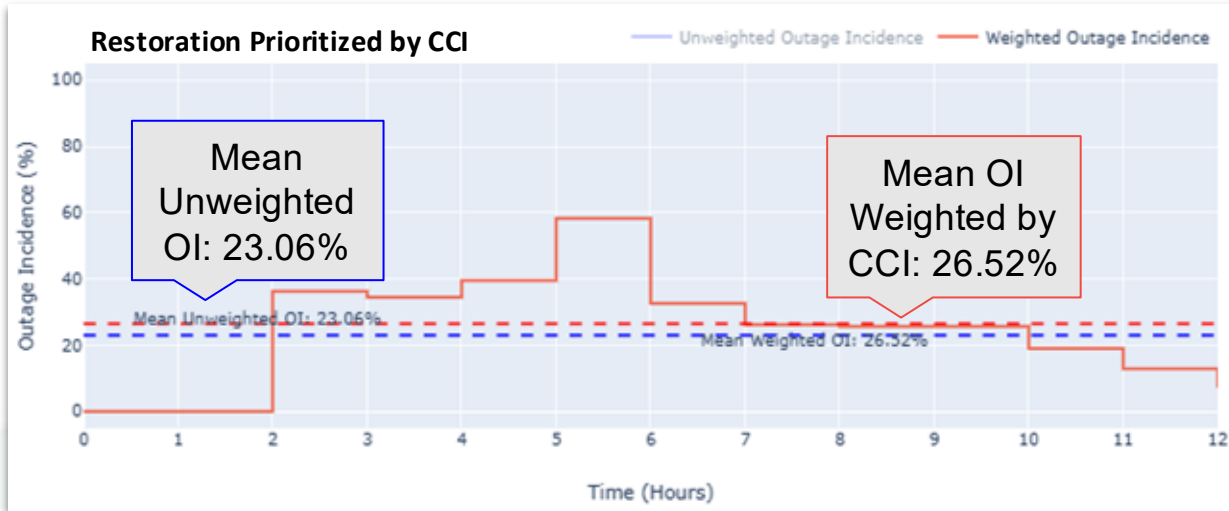
Community-Aware Restoration



When prioritizing by CCI:
Relatively Low CCI load shed in favor of Very High CCI load supported

—	Switch That Hasn't Opened (or Line)
—	Open Switch
—	Closed Switch
•	Load That Hasn't Been Shed (or Bus, PV, or Source, Per Feeder Overview)
•	Loadshed
•	Loadpickup
•	Battery Control

Community-Aware Restoration



Outage Incidence (OI):

% of loads experiencing an outage at a given timestep

Identical Unweighted OI

In this case, prioritizing CCI in the restoration approach does not change average performance across the system during the entire period of controlled loadshed

Lower CCI Weighted OI

In this case, prioritizing restoration by CCI results in lower average outage incidence specifically for higher vulnerability loads

Community-Aware Restoration

Restoration Prioritized by CCI

Simulation-Constrained Metrics by CCI Quartiles

CCI Quartile	SC-SAIDI	SC-SAIFI	SC-CAIDI	SC-CAIFI	Loads Served	Est. People Served	CCI of Average Customer
Low CCI	↑142.5	↑0.75	↑190.0	1.0	8	349.8	16.67
Low-Medium CCI	↓145.71	0.86	↓170.0	↑1.2	7	574.67	40.0
High-Medium CCI	94.29	0.14	660.0	1.0	7	500.96	66.67
High CCI	↓270.0	1.0	↓270.0	1.0	8	1148.78	93.33

Restoration Not Prioritized by CCI

Simulation-Constrained Metrics by CCI Quartiles

CCI Quartile	SC-SAIDI	SC-SAIFI	SC-CAIDI	SC-CAIFI	Loads Served	Est. People Served	CCI of Average Customer
Low CCI	↓90.0	↓0.62	↓144.0	1.0	8	349.8	16.67
Low-Medium CCI	↑71.43	0.86	↑200.0	↓1.0	7	574.67	40.0
High-Medium CCI	94.29	0.14	660.0	1.0	7	500.96	66.67
High CCI	↑300.0	1.0	↑300.0	1.0	8	1148.78	93.33

Prioritizing restoration by CCI results in comparatively higher outage severity metrics for loads in the lowest CCI quartile and comparatively lower metrics for loads in the highest CCI quartile.



Better outcomes for more vulnerable loads

Resilient Community Model

By using Resilient Community, co-ops can:

- Identify areas of higher vulnerability on their feeders to direct resources where they have the most impact.
- Identify critical equipment to aid in decision making about what to update and where to install redundancies.
- Integrate results with other models - e.g. with Restoration to enable the consideration of outage impact in restoration approaches.

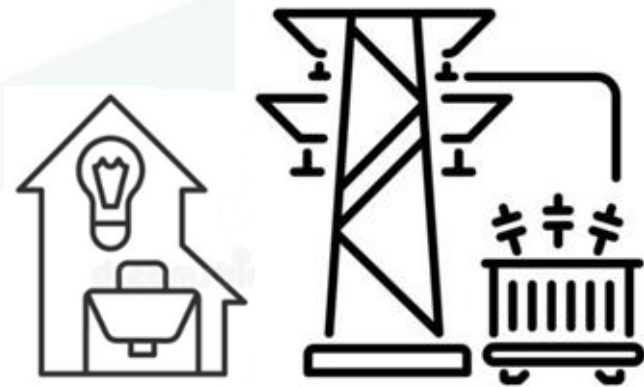
DERMS Program Design using derConsumer and derUtilityCost

Overview of Program Design Models

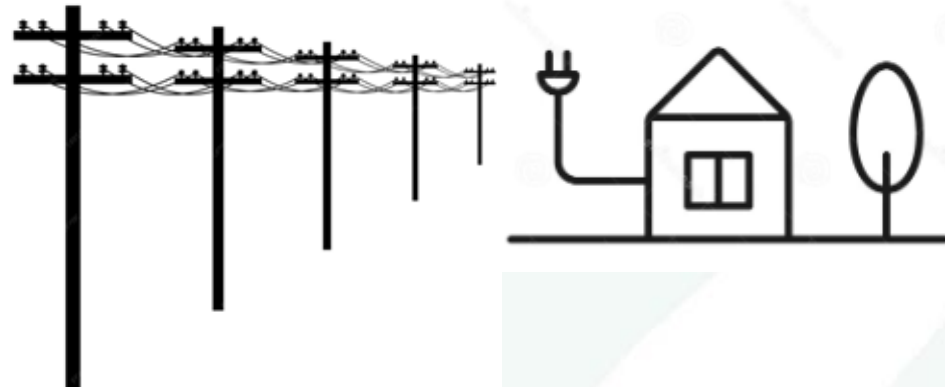
Description

These two models evaluate the financial and electrical outcomes of enrolling various consumer-owned energy resources in a co-op program from two perspectives: The Utility and The Consumer.

omf.models.derUtilityCost



omf.models.derConsumer



Consumer Compensation Options

Up-front Subsidies

\$/enrollment. Encourages new installations by offsetting costs.

Ongoing Subsidies

\$/month. Encourages increased program participation.

derUtilityCost – Required Inputs

Key inputs required from the utility:

- **Demand Curve:** Net hourly demand for the entire year (minus any existing utility-owned generation)
- **Temperature Curve:** Hourly air temperature data for utility's service area
- **Latitude & Longitude:** Approx. central location of utility service area
- **Year:** corresponds to the Demand & Temperature Curves
- **Random seed inputs:** These inputs allow the utility to reproduce a previous model run
- **Wholesale Energy Rate Structure:** The wholesale energy rate (\$/kWh) for the entire year
- **Wholesale Demand Rate Structure:** The wholesale demand charge (\$/kW/month or \$/kW/hr) for the entire year
- **Program Startup Costs (\$):** Total cost to establish the DER sharing program.
- **One-time and Ongoing Operational Costs (\$):** Total cost to maintain the program.
- **Portion of BESS Charge Used by Utility (%):** The fractional percent of a residential BESS's power and energy capacity used by the utility.
- **Upfront Subsidy (\$):** Subsidy that the utility pays to the member-consumer for device enrollment.
- **Ongoing Subsidy (\$/month):** Recurring payments the utility makes to the member-consumer for continued participation in the program.
- **Number of Devices:** Amount of individual DER devices in the program.

Either combined in a JSON input file, or given as two separate CSV files

Per DER technology (i.e. BESS, TESS)

BESS = (chemical) **B**attery **E**nergy **S**torage **S**ystem

TESS = **T**hermal **E**nergy **S**torage **S**ystem (e.g. Water Heaters + Air Conditioners + Heat Pumps)

derUtilityCost – Sample Inputs

Here, model inputs are shown; key values for tailoring the model are highlighted in yellow.

General Model Inputs		
Demand Curve (.csv file) Choose File example_load_utility_kW_2018	Temperature Curve in °F (.csv file) Choose File example_temperatures_open-r	Latitude 39.969753
Longitude -104.812599	Year 2018	Use the user-provided random numbers? No
Random Seed - BESS & GEN 2147483647	Random Seed - AC 2147483647	Random Seed - HP 2147483647
Random Seed - WH 2147483647	Random Numbers for Water Heater (.csv file) Choose File example_water_heater_random	
Financial Inputs		
Use Wholesale Energy & Demand Rate Structure (.json) file? ☐	Wholesale Energy & Demand Rate Structure (.json file) Choose File example_TODRate66a13566e9f	(Optional) Wholesale Energy Rate Curve (.csv file) Choose File example_TODRate66a13566e9f
(Optional) Monthly Demand Charges (.csv file) Choose File example_utility_monthly_dema	Financial Projection Length (years) 25	Discount Rate (%) 1
Program Startup Costs (\$) 200000	Ongoing Operational Costs (\$/month) 1000	One-time Operational Costs (\$) 20000
Home BESS - Upfront Subsidy Amount (\$) 50.0	Home BESS - Monthly Recurring Subsidy Amount (\$) 10.0	Home Heat Pump - Upfront Subsidy Amount (\$) 0.0
Home Heat Pumps - Monthly Recurring Subsidy Amount (\$) 1.0	Home Air Conditioners - Upfront Subsidy Amount (\$) 0.0	Home Air Conditioners - Monthly Recurring Subsidy Amount (\$) 1.0
Home Water Heaters - Upfront Subsidy Amount (\$) 0.0	Home Water Heaters - Monthly Recurring Subsidy Amount (\$) 3.0	Home Generators - Upfront Subsidy Amount (\$) 0.0
Home Generators - Monthly Recurring Subsidy Amount (\$) 0.0		
Home Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Number of Devices 5
Rated Power Capacity (kW) 20	Available Fuel 95	Fuel Cost 3.49

Wholesale rate is either combined in a JSON input file, or given as two separate CSV files

Home Chemical Battery Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Number of Home Chemical Batteries 20000	Portion of Charge Used by Utility (%) 20.0
Home Battery Power Capacity (kW) 5.0	Home Battery Energy Capacity (kWh) 13.5	
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Number of Devices 33000	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2.0	Thermal Resistance (°C/kW) 2.0	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72.5	Temperature Deadband (°F) 2.0	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Number of Devices 16500	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2.0	Thermal Resistance (°C/kW) 2.0	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67.0	Temperature Deadband (°F) 2.0	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Number of Devices 33000	Rated Power (kW) 4.5
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120.0	Coefficient of Performance 1.0
Temperature Setpoint (°F) 125.0	Temperature Deadband (°F) 5.4	

Delete Run Model Share Duplicate

Portion (%) of BESS available to the utility

Specify in-window or central AC power

derUtilityCost – Default Inputs

Default inputs used in this analysis:

- Discount Rate = 1%
- Projection Length = 25 years
- BESS variables
 - Portion of BESS Charge Used by Utility=20%
 - Tesla Powerwall specs: 5.0 kW, 13.5 kWh
- Thermal variables:

Only the first year is modeled, since the demand curve is for a single year. Model results from Year 1 are then projected onto all subsequent years.

	Setpoint (°F)	Deadband (°F)	Coefficient of Performance	Thermal Capacitance (kWh/°C)	Thermal Resistance (°C/kW)
Air Conditioner	72.5	2	2.5	2	2
Heat Pump	67	2	3.5	2	2
Water Heater	125	5.4	1	0.4	120

derConsumer – Required Inputs

Key inputs required from the consumer/member services representative:

- **Demand Curve:** Net hourly demand for a residence for the entire year (minus any existing member-owned generation)
- **Temperature Curve:** Hourly air temperature data for the utility's service area
- **Random seeds:** These inputs allow the user to reproduce a previous model run
- **Residential Rate Structure:** Hourly rate structure the member pays per kWh and/or kW
- **Year:** Corresponds to the Demand & Temperature Curves
- **Latitude & Longitude:** Approx. location of utility service area
- **Replacement Costs (\$):** When and how often to replace the BESS, generator, and inverter devices.
- **Retrofit Costs (\$):** Costs to retrofit devices for the DER program (e.g. \$175 for a water heater)
- **Portion of BESS shared with utility (%):** The percentage of the BESS that is controlled and used by the utility.
- **Subsidies (\$):** Any one-time and/or monthly subsidies the member-consumer receives from the utility.

Specified either
by a URDB
Label or JSON
input file

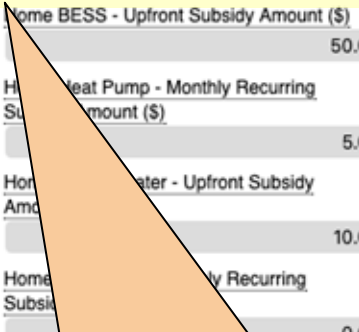
Per DER technology
(i.e. BESS, TESS)

BESS = (chemical) **B**attery **E**nergy **S**torage **S**ystem

TESS = **T**hermal **E**nergy **S**torage **S**ystem (e.g. Water Heaters + Air Conditioners + Heat Pumps)

derConsumer – Sample Inputs

Here, model inputs are shown; key values for tailoring the model are highlighted in yellow.

General Model Inputs		
Demand Curve (.csv file) Choose File example_load_consumer_10kW	Temperature Curve in °F (.csv file) Choose File example_temperatures_open-r	Latitude 48.197777
Longitude -114.316109	Year 2018	Use the user-provided random numbers? No
Random Seed - BESS & GEN 2147483647	Random Seed - AC 2147483647	Random Seed - HP 2147483647
Random Seed - WH 2147483647	Random Numbers for Water Heater (.csv file) Choose File example_water_heater_random	
Financial Inputs		
Use URDB Label? ☐	URDB Label 66a13566e90ecdb7d40581d2	(Optional) Residential Rate Structure (.json file) Choose File example_residential_tariff.json
Discount Rate (%) 1	Financial Projection Length (years) 25	Home BESS - Upfront Subsidy Amount (\$)  50.0
Home BESS - Monthly Recurring Subsidy Amount (\$) 10.0	Home Heat Pump - Upfront Subsidy Amount (\$) 10.0	Home Heat Pump - Monthly Recurring Subsidy Amount (\$) 5.0
Home Air Conditioner - Upfront Subsidy Amount (\$) 10.0	Home Air Conditioner - Monthly Recurring Subsidy Amount (\$) 5.0	Home Water Heater - Upfront Subsidy Amount (\$) 10.0
Home Water Heater - Monthly Recurring Subsidy Amount (\$) 5.0	Home Generator - Upfront Subsidy Amount (\$) 0.0	Home Generator - Monthly Recurring Subsidy Amount (\$) 0.0
Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Diesel	5
Efficiency (%) 35	Retrofit Cost (\$) 0.0	Available Fuel 1000
Fuel Cost 3.80	Generator Replacement Cost (\$/kW) 0.0	Generator Lifetime (years) 15
Chemical Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Battery Power Capacity (kW) 5.0	Battery Energy Capacity (kWh) 13.5
Retrofit Cost (\$) 0.0	Portion of Charge Shared with Utility (%) 20	Battery Replacement Power Cost (\$/kW) 0.0
Battery Replacement Energy Cost (\$/kWh) 0.0	Battery Lifetime (years) 10	Inverter Replacement Cost (\$) 0.0
Inverter Lifetime (years) 10		
If 20% of the BESS is shared with the utility, the other 80% is modeled in derConsumer		
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 13
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 150
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Rated Power (kW) 4.5	Retrofit Cost (\$) 175
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	

 Only one device is modeled per DER technology type

[Delete](#) [Run Model](#) [Share](#) [Duplicate](#)

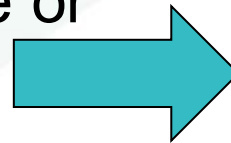
Tariff Inputs – Wholesale

The Wholesale Tariff input provides information about the utility's wholesale energy and wholesale demand rate structures. This can be given to the derUtilityCost model in two ways:

1. A Wholesale Energy Tariff (.csv) file and a Wholesale Demand Tariff (.csv) file,

OR

1. A Wholesale Tariff (.json) response file (created using REopt's [Custom Tariff Builder](#) (Requires a Google or Facebook account))



Period	Tier in Period	Max. Energy Purchases (kWh/month)	Energy Charge (\$/kWh)
1	1	100.0	0.02
2	2	unlimited	0.05
3	1	unlimited	0.1

	12 am	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm
Jan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Feb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Mar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Apr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
May	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Jul	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Sep	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Oct	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Nov	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1
Dec	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1

Tariff Inputs – Retail

The Residential Tariff input provides information about the utility's residential energy and residential demand rate structures. This can be given to the derConsumer model in two ways:

1. A Residential Rate Structure (.json) response file (created with REopt's [Custom Tariff Builder](#)),

OR

1. A URDB Label
(e.g. 67a65130767b93f0b5044b9a)



The URDB Label points to the utility's rate information stored in the [Utility Rate Database | Open Energy Information](#). In cases where the desired rate structure is not found there, the user may provide their own (.json) response file with the energy and demand rate structure information.

The Approach – Overview

derUtilityCost Scenario 1: “Base Case”

Run an initial Base Case (no subsidies or upfront costs) to determine the value that can be extracted from each technology, annually. **For the BESS tech, this can be viewed as either a fleet of residential batteries under a DER sharing agreement, or a single utility-owned BESS.**

Outputs:

Annual Savings for Technology

Determine Initial “Break-even” Monthly Subsidies

$$\text{Monthly Subsidy for Technology} = \frac{\text{Annual Savings for Technology}}{\text{Total \# of devices} \div 12 \text{ Months}}$$

derUtilityCost Scenario 2: “Adjusted Subsidies”

Run an Adjusted Subsidies case, consisting of the Base Case including the Initial “Break Even” monthly technology subsidies. This provides a “break-even case” where the DER subsidy costs = DER savings.

derConsumer

Run derConsumer with the monthly subsidies calculated from derUtilityCost Scenario 1. This shows how the subsidies provided by the utility affect the member-consumer’s savings.

Subsidy Modification

There are two subsidy inputs in the models: an upfront (one-time only) subsidy, and an ongoing monthly subsidy. The user may want to apply a combination of these subsidies for their program. Here is how the results from derUtilityCost can be used to identify an upfront subsidy and determine the remaining monthly subsidy amount for a break-even situation.

1. Run derUtilityCost to determine the total annual savings for each device.
2. Use the equation below to split the annual savings into the two subsidy amounts. This is your break-even case where the subsidy costs = savings from the DER.

Monthly Subsidy = (Annual Savings ÷ Total Number of Devices - **Upfront Subsidy**) / 12 Months

Example

- Assume that the derUtilityCost output indicates that the BESS annual savings = \$1,000
- A co-op is confident that they will be able to enroll at least 10 BESS devices in their program, and wants to pay no more than \$10 upfront to get those batteries enrolled.

For the subsidies to break-even with those savings, the monthly subsidy would have to be less than or equal to:

BESS Monthly Subsidy = (\$1,000 annual savings ÷ 10 total devices - \$10 upfront subsidy) / 12 Months = **\$7.50 monthly subsidy**

Deciphering BESS Deployment Levels

In 2021, U.S. utilities in 42 states reported 1,094 MW of small-scale battery capacity (i.e. battery systems under 1 MW) associated with customer-sited PV (net-metered and non-net metered) systems; about 740 MW of this was residential BESS ([EIA.gov](https://www.eia.gov)).

$$\frac{740 \text{ MW}}{42 \text{ States}} \approx \frac{881 \text{ MW}}{50 \text{ States}}$$

So across 50 states in 2021, there was roughly 881 MW residential PV co-located BESS. Applying growth between 2021 and 2024 updates this to 6,323 MW.



Growth since 2021 ^[1] (3,680 MW)	
2022	4,820 MW (+31.00%)
2023	9,276 MW (+283.07%)
2024	12,314 MW (+617.69%)

[1] For all market segments. See [CleanPower REPORT: Energy Storage's Meteoric Rise Breaks Another Record](#)

Assuming one Tesla Powerwall 2 per household at 5 kW each, our estimate of 6,323 MW nationally yields about 1,264,600 households having BESS installed in 2024.

Assuming a U.S. population of about 132,200,000 ([Total Households \(TTLHH\) | FRED | St. Louis Fed](#)), that's 1,264,600 / 132,200,000 = **0.9% of households with BESS installed.**

Connection/Communication Technologies

There are several devices on the market that could assist in controlling DER such as retrofittable controllers for water heaters, smart thermostats, and smart plugs for wall-plug AC units.



Water Heater controllers
(Aquanta)*



Smart Thermostats
(Ecobee, Honeywell)*



Smart Plugs
(Kasa, BK-LINK,
EIGHTREE)*

Output Calculations

Net Present Value (NPV) – Value of all future cash flows over an investment's lifetime, discounted to the present.

$$\sum_{t=0}^{M-1} \frac{values_t}{(1 + rate)^t}$$

Reference: <https://numpy.org/numpy-financial/latest/npv.html>

Where **rate** is the discount rate, and **values** are the projected cash flows = (Utility Savings – Utility Costs)_{*t*} for each year, ***t***, up to a total projection length of ***M*** years

Utility Savings = all DER Demand (kW) Savings + all DER Consumption (kWh) Savings

Utility Costs = startup costs + all operational costs + all subsidies

Simple Payback Period (SPP) – # of years to recover all initial costs based on the first year's cash flows.

Initial Investment

Utility Savings – Utility Costs

Initial Investment = startup costs + one-time operational costs + one-time subsidies

Utility Savings (Year 1) = all DER Demand (kW) Savings + all DER Consumption (kWh) Savings in Year 1

Utility Costs (Year 1) = ongoing operational costs + all DER ongoing subsidies

How to Consider Upfront + Ongoing Costs

“The Approach” in this analysis considers \$0 upfront startup costs and \$0 ongoing operational costs to obtain the net benefit from all DER. A utility ultimately wants to know if the program will pay itself off in a reasonable amount of time.

The following method can be used to adjust the break-even subsidies per technology to consider the payback of any startup and ongoing costs:

1. **Run the base case approach** and obtain break-even subsidies per technology (see slide “The Approach - Overview”)
2. **Reduce the break-even subsidies** by some fractional amount depending on the total costs and the individual technology subsidy amount according to:

Adjusted Monthly Subsidy, per tech = Break-Even Monthly Subsidy, per tech - X(Ongoing Monthly Costs)

where X = (Break-Even Monthly Subsidy, per tech / Sum of all Break-Even subsidies across all tech)

The annual ongoing cost is the sum of all monthly costs in the first year of analysis.

1. Consider the upfront and ongoing costs

~~Upfront Costs~~ = SPP(annual savings - annual subsidies - annual ongoing costs)

The utility determines an acceptable SPP (e.g. 5 years)

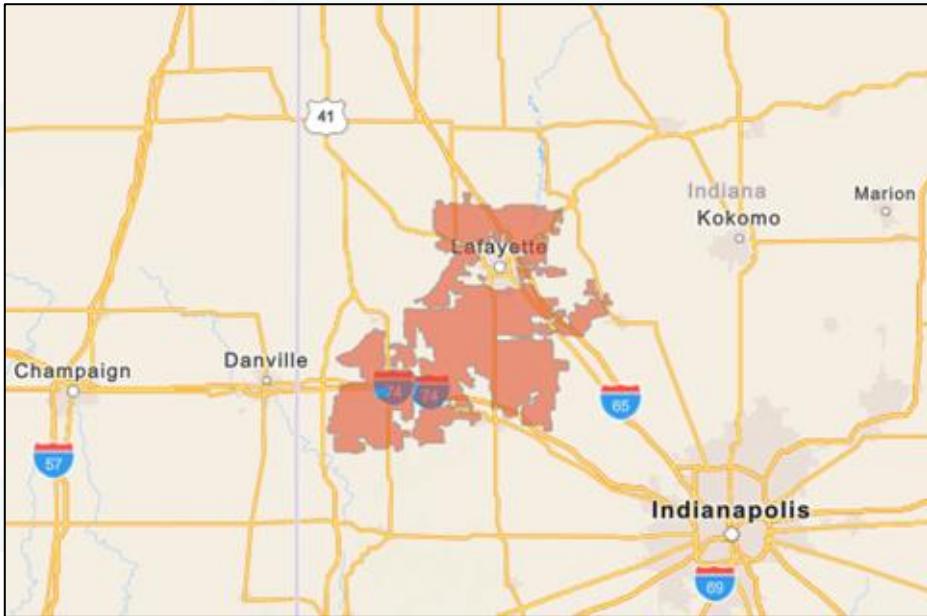
OR

Upfront Costs = SPP(annual savings - annual subsidies)

If the utility has already factored in the ongoing costs when calculating its annual subsidies, they do not need to include it again here. Instead, they would use this equation instead of the one above it, without the extra annual ongoing costs term.

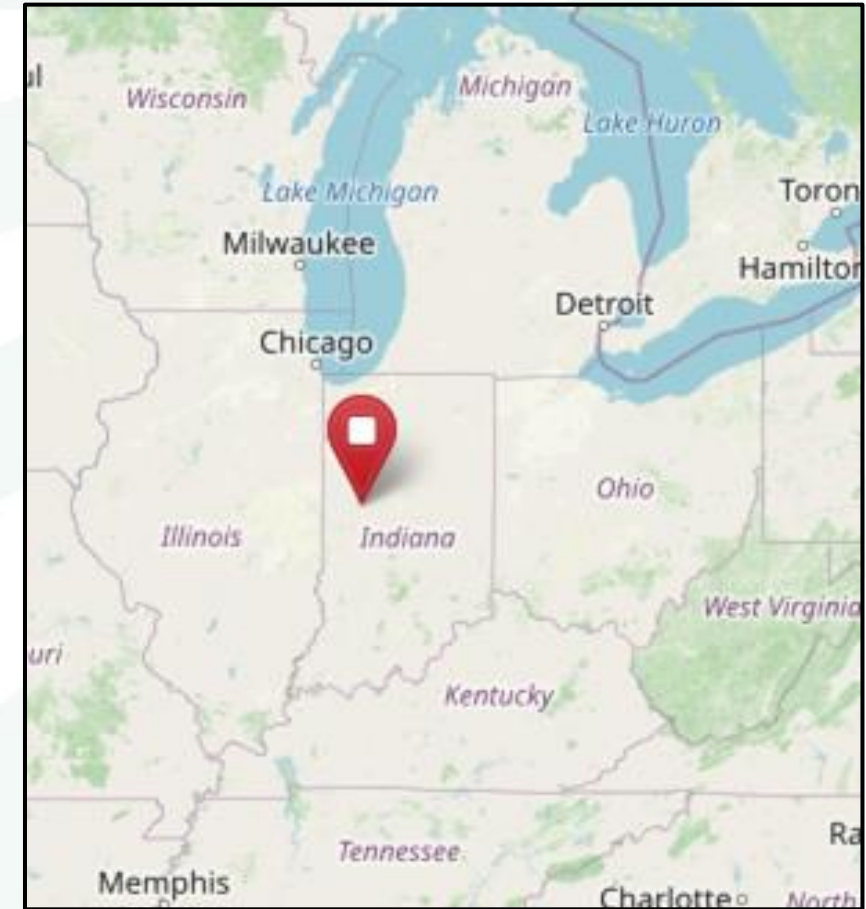
Detailed Results: Tipmont Electric Cooperative

Detailed Results: Tipmont



Tipmont's service area serving Tippecanoe, Montgomery, Fountain, Clinton, Carroll, White, Benton, and Boone counties in IN.

- Meters Served:** 36,060
Number of Circuits: 61
Annual sales: 555 MWh
Peak Demand
- Winter: 119.2 MW
 - Summer: 134.4 MW



Tipmont service area approximate centroid at (40.18809, -86.9039).

Detailed Results: Tipmont

Tipmont serves rural Indiana areas that experience the following grid-stressing weather events:

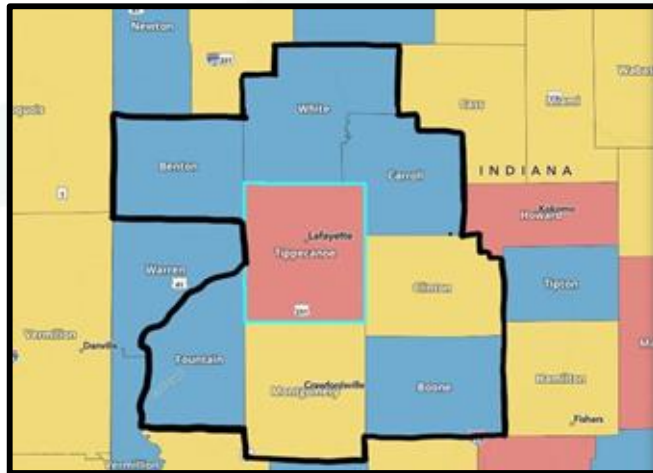
- Cold Waves
- Strong Winds
- Winter Weather

Reliability Metrics w/ Major Event Days:

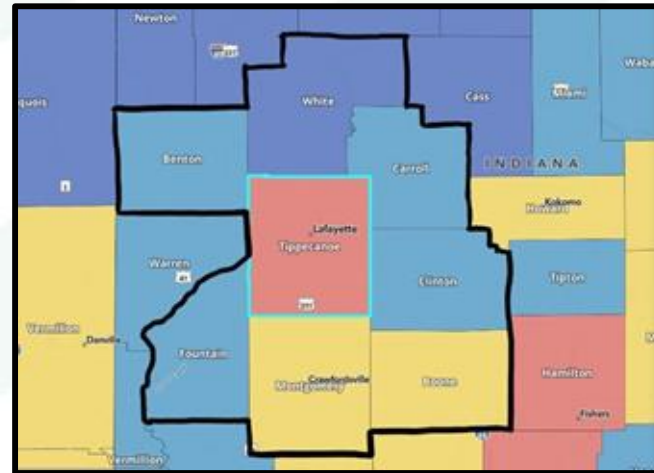
- SAIDI: 102.060
- SAIFI: 0.954
- CAIDI: 106.981

Reliability Metrics w/out Major Event Days:

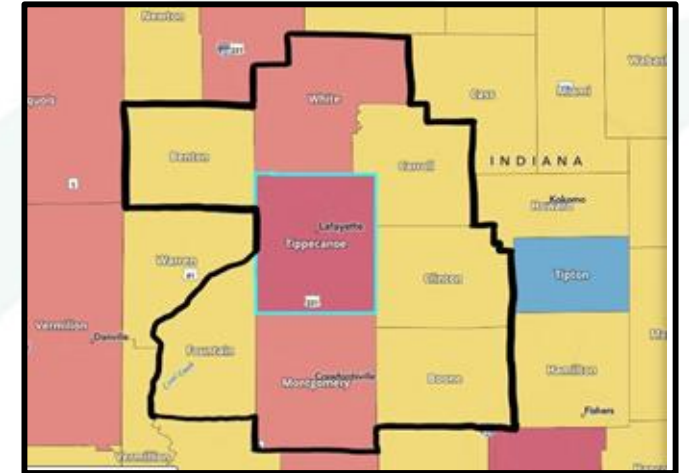
- SAIDI: 79.850
- SAIFI: 0.800
- CAIDI: 99.813



Strong Wind

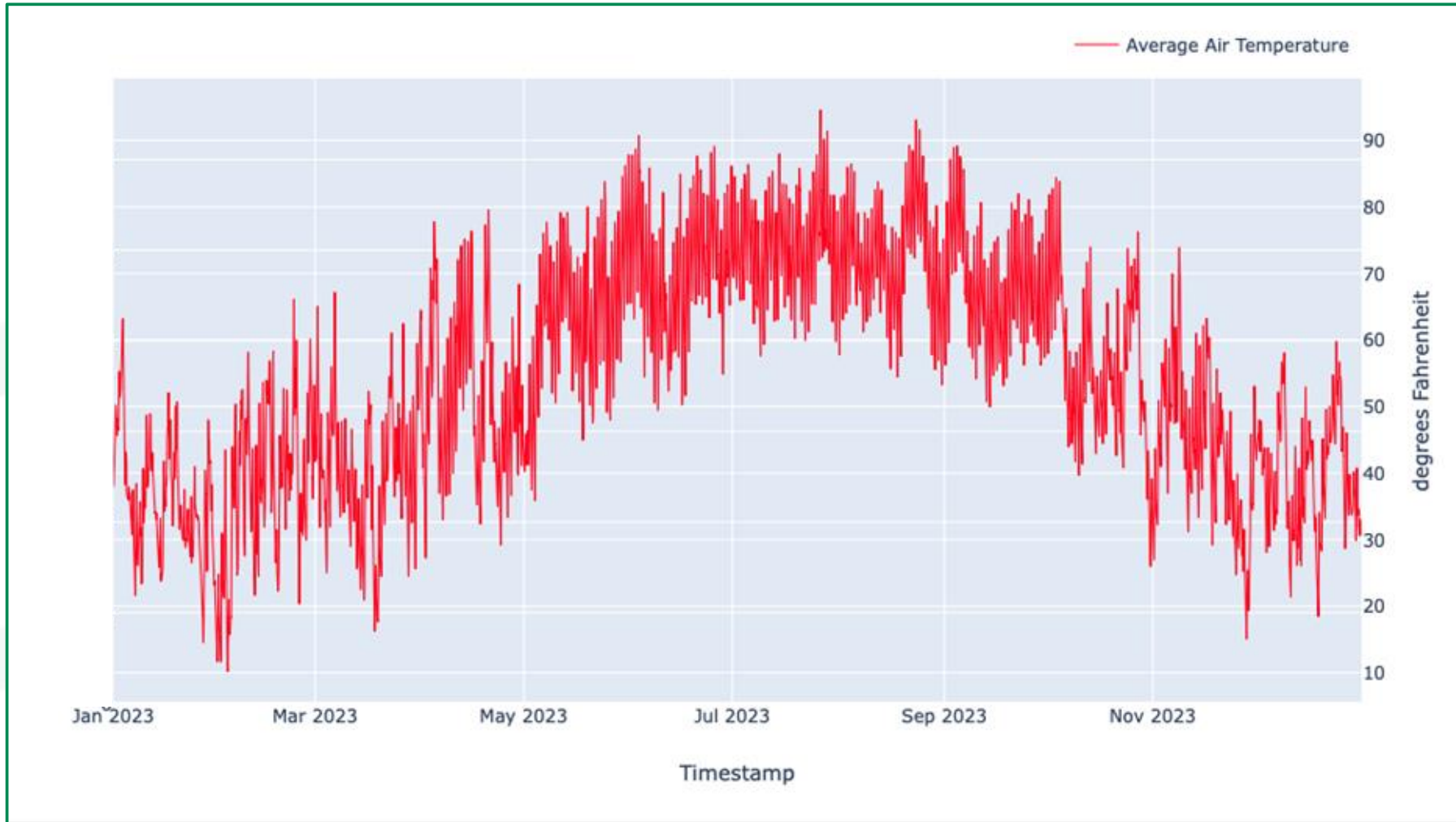


Winter Weather



Cold Wave

Tipmont – Annual Temperature Profile

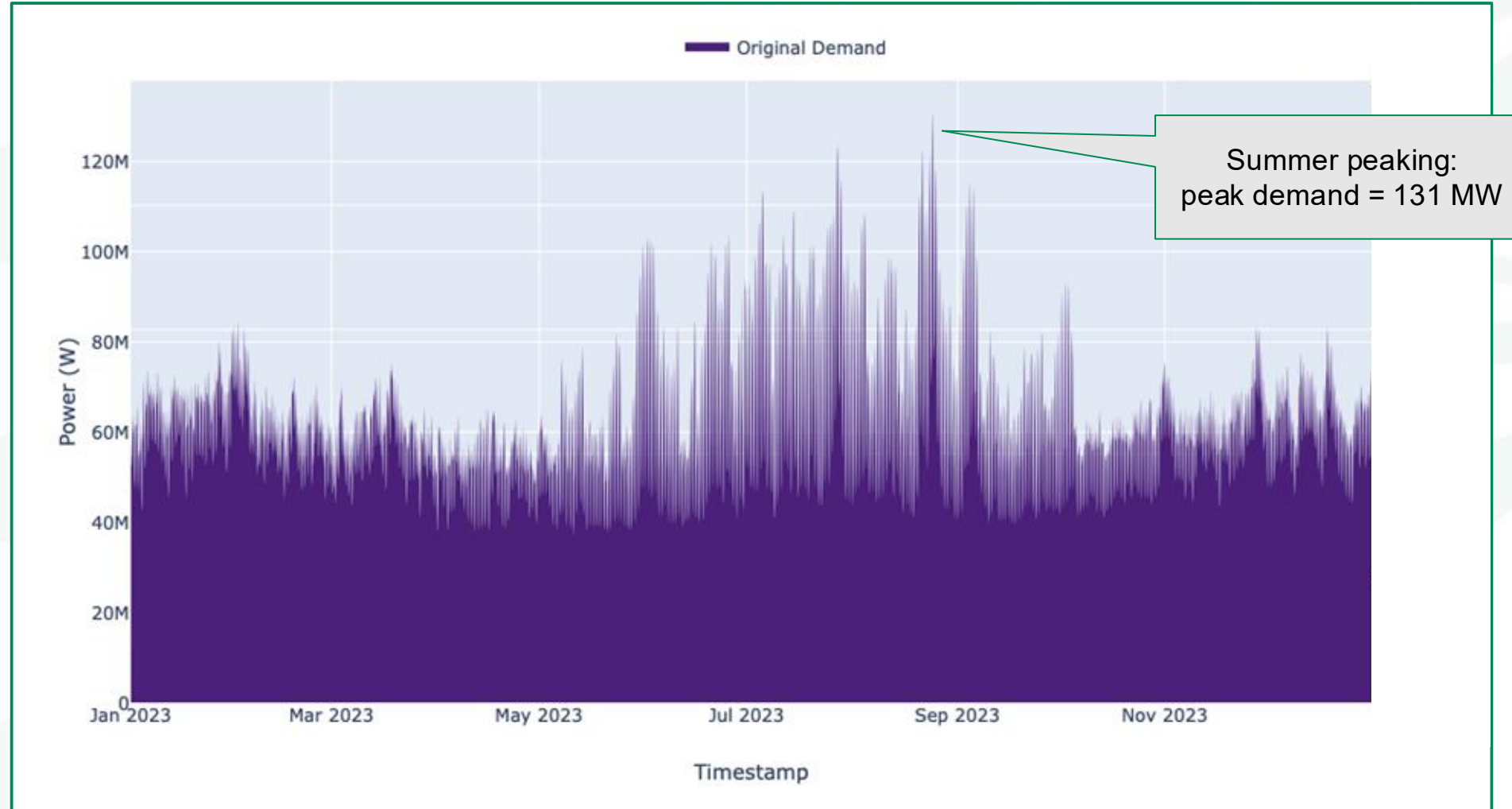


Tipmont's regional climate is considered **"Very-Cold/Cold"** by the EERE's Building America data sets.

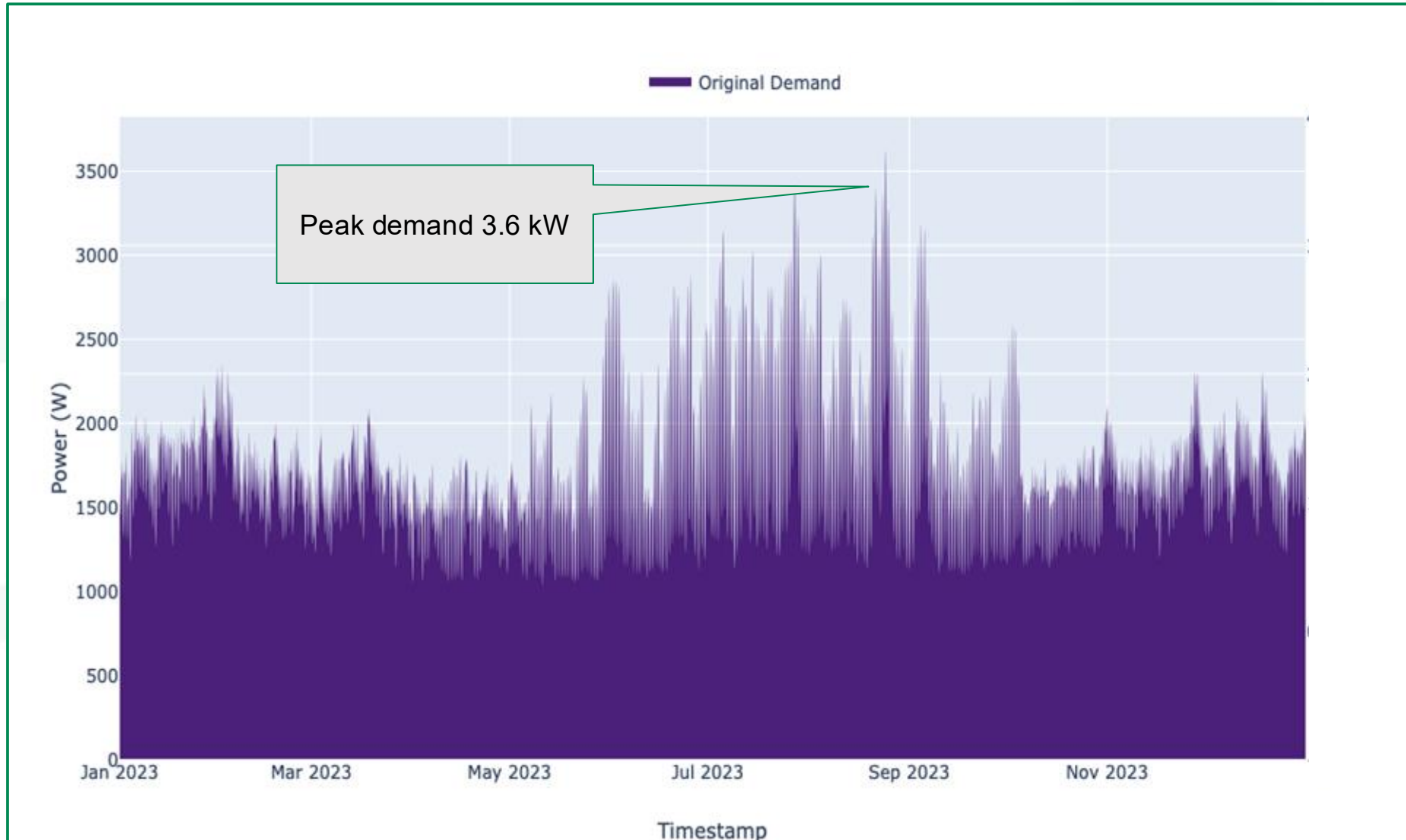
<https://www.energy.gov/eere/buildings/building-america-climate-map>

Tipmont – Annual System Demand

Tipmont's system demand curve is summer peaking, showing 131 MW peak in late August.



Tipmont – Annual Residential Demand



The residential demand curve used as an input in derConsumer was created by scaling the utility's system demand curve down by 36,060 (the total number of meters served).

However, 13% of those meters are non-residential which may need more power than residential ones, so this demand curve is likely larger than a real residential demand curve.

Tipmont – Energy & Demand Tariffs

Wholesale Energy Tariff	
Energy Cost (\$/kWh)	Schedule
0.033489	11pm–5am
0.050489	5am–5pm, 8–11pm
0.061489	5–8pm

Residential TOU Tariff	
Energy Cost (\$/kWh)	Schedule
0.2537	2–8pm weekdays only
0.0825	12am–2pm, 8pm–12am

Wholesale Demand Tariff	
Month	Peak Demand Charge (\$/kW)
Jan	18
Feb	18
Mar	18
April	18
May	18
June	18
July	18
Aug	18
Sept	18
Oct	18
Nov	18
Dec	18

Tipmont derUtilityCost Scenario 1: Base Case

Tipmont – Scenario 1 derUtilityCost Inputs

The Scenario 1 Base Case assumes no subsidies in order to determine the baseline annual value for each DER technology.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Participation Level (out of 31,372 residential meters)
BESS	0	0	1% (314)
GEN	-	-	-
Water Heater	0	0	¹ 34% (10,792)
Heat Pump	0	0	² 3% (1,004)
Air Conditioner	0	0	³ 59% (18,388)

[1] [Table HC8.6 Water heating in U.S. homes, by climate region, 2020](#)

[2] [Table HC6.6 Space heating in U.S. homes, by climate region, 2020](#)

[3] [Table HC7.6 Air conditioning in U.S. homes, by climate region, 2020](#)

Generators will be considered in future work

The participation levels were calculated based on the 2020 Residential Energy Consumption Survey (U.S. Energy Information Administration, Office of Energy Demand and Integrated Statistics, Form EIA-457A)*

*Tipmont's climate is considered "Very-Cold/Cold" for these calculations

All subsidies are set to 0 to determine the base level annual value of all DER technologies

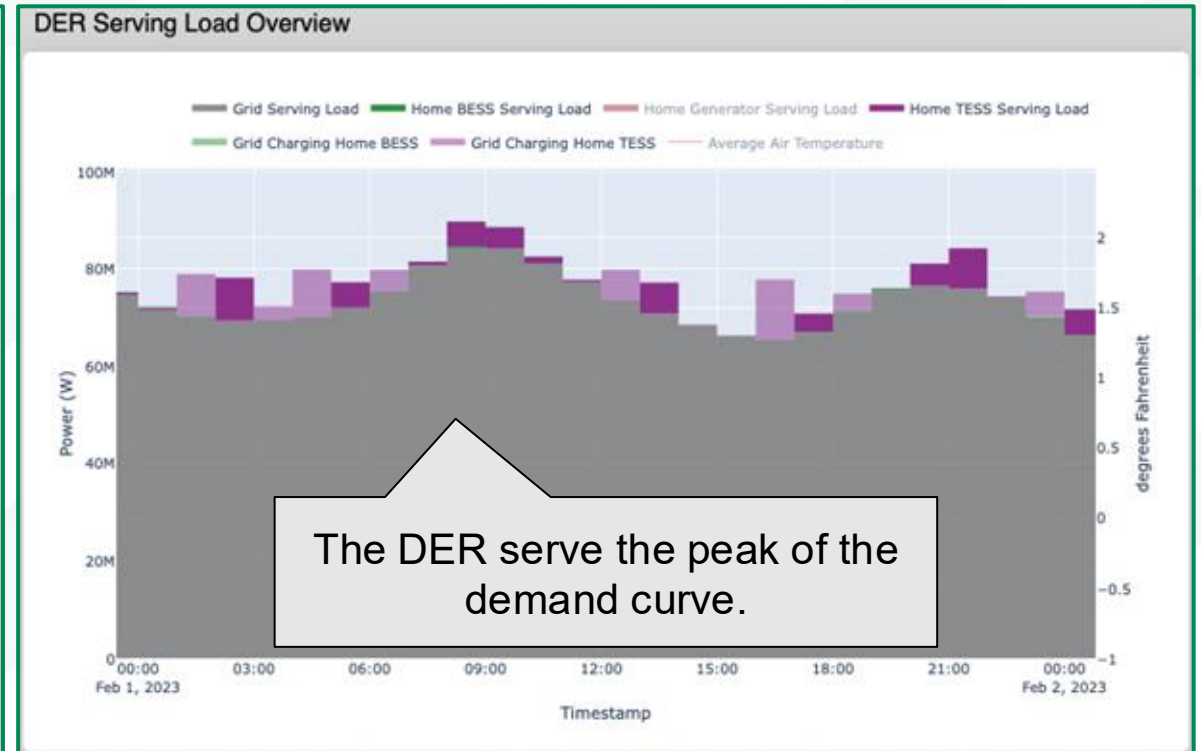
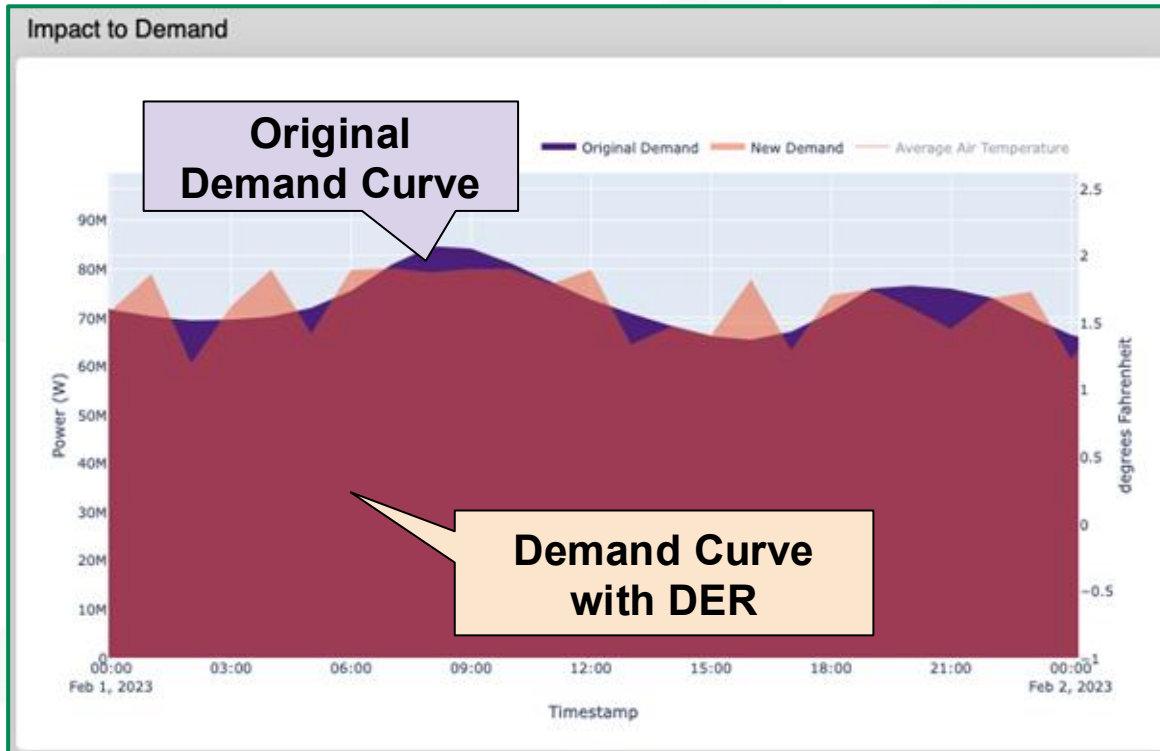
Tipmont – Scenario 1 Inputs

General Model Inputs		
Demand Curve (.csv file) Choose File Tipmont - System Demand_kW	Temperature Curve in °F (.csv file) Choose File Tipmont - Temperature_degF_	Latitude 40.18809
Longitude -86.9039	Year 2023	Use the user-provided random numbers? No
Random Seed - BESS & GEN 2147483647	Random Seed - AC 2147483647	Random Seed - HP 2147483647
Random Seed - WH 2147483647	Random Numbers for Water Heater (.csv file) Choose File example_water_heater_random	
Financial Inputs		
Use Wholesale Energy & Demand Rate Structure (.json) file? ☐	Wholesale Energy & Demand Rate Structure (.json file) Choose File exampleWholesaleRateStructur	(Optional) Wholesale Energy Rate Curve (.csv file) Choose File Tipmont_Wholesale Energy Rat
(Optional) Monthly Demand Charges (.csv file) Choose File Tipmont_Wholesale Demand R	Financial Projection Length (years) 25	Discount Rate (%) 1
Program Startup Costs (\$) 0	Ongoing Operational Costs (\$/month) 0	One-time Operational Costs (\$) 0
Home BESS - Upfront Subsidy Amount (\$) 0	Home BESS - Monthly Recurring Subsidy Amount (\$) 0	Home Heat Pumps - Upfront Subsidy Amount (\$) 0
Home Heat Pumps - Monthly Recurring Subsidy Amount (\$) 0	Home Air Conditioners - Upfront Subsidy Amount (\$) 0	Home Air Conditioners - Monthly Recurring Subsidy Amount (\$) 0
Home Water Heaters - Upfront Subsidy Amount (\$) 0	Home Water Heaters - Monthly Recurring Subsidy Amount (\$) 0	Home Generators - Upfront Subsidy Amount (\$) 0
Home Generators - Monthly Recurring Subsidy Amount (\$) 0		
Home Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Number of Devices 5
Rated Power Capacity (kW) 20	Available Fuel 95	Fuel Cost 3.49

Home Chemical Battery Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Number of Home Chemical Batteries 314	Portion of Charge Used by Utility (%) 20.0
Home Battery Power Capacity (kW) 5.0	Home Battery Energy Capacity (kWh) 13.5	
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Number of Devices 18388	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Number of Devices 1004	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Number of Devices 10792	Rated Power (kW) 4.5
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	
Delete Run Model Share Duplicate		

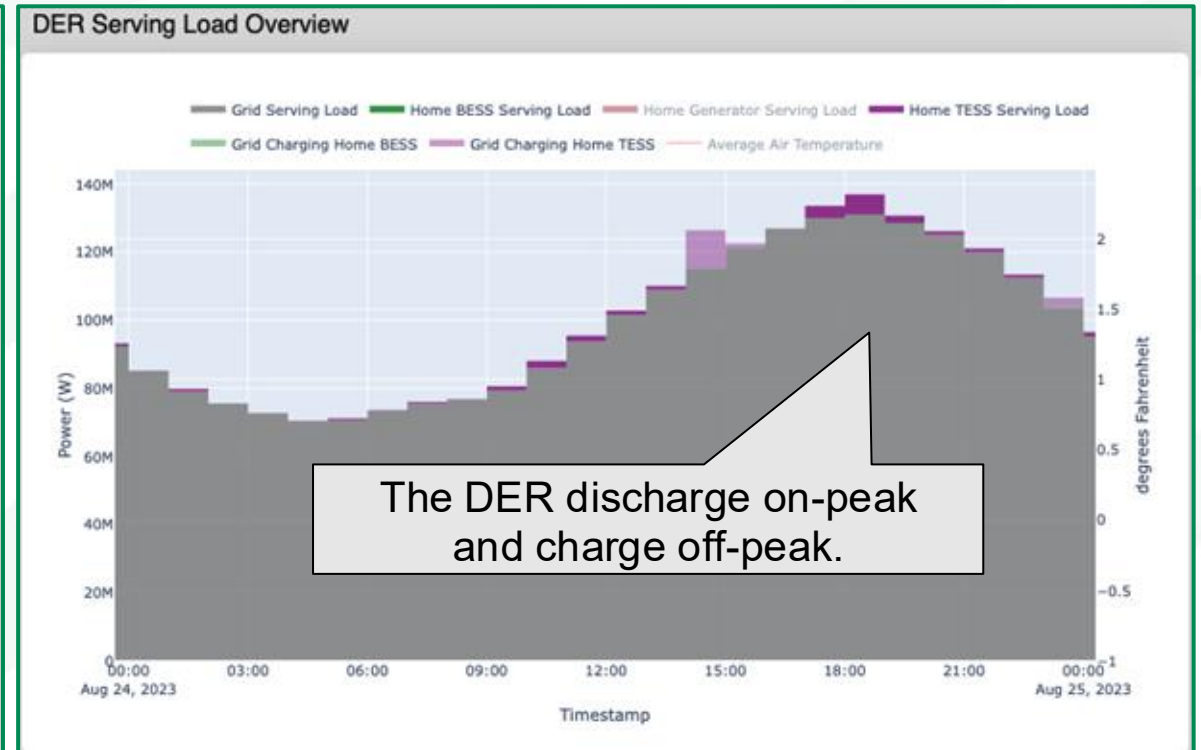
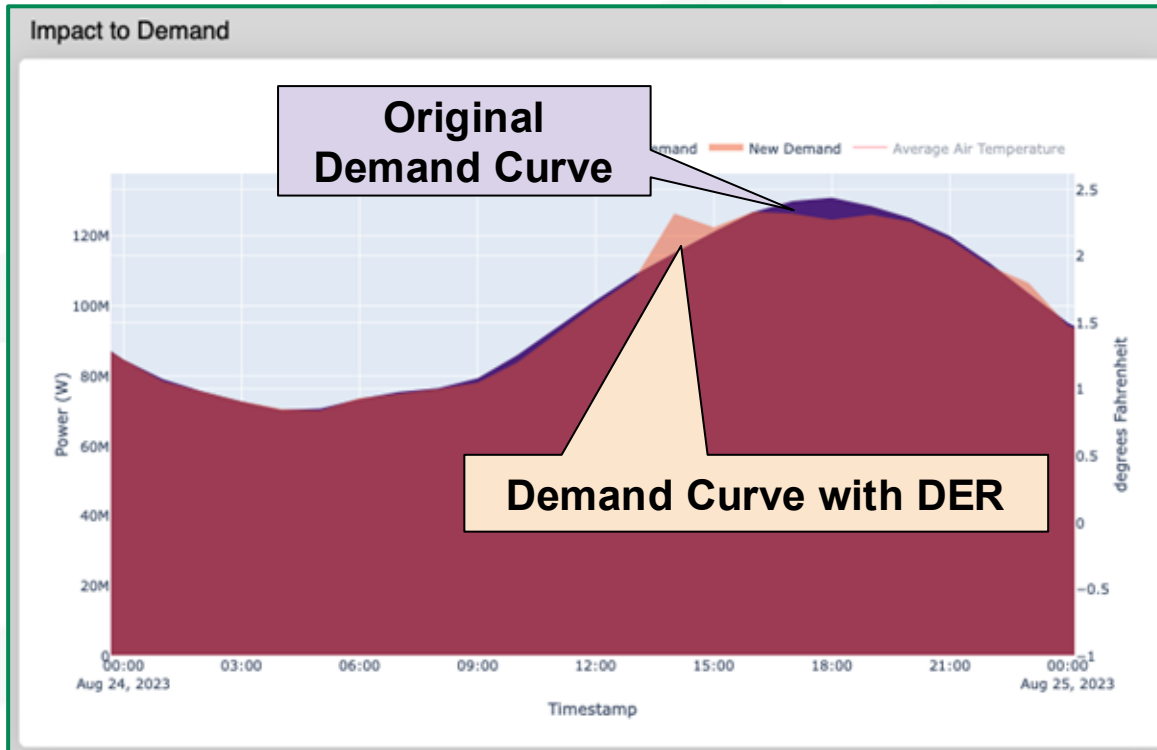
Tipmont – Scenario 1 derUtilityCost Outputs

Winter Peak – February 1, 2023



Tipmont – Scenario 1 derUtilityCost Outputs

Summer Peak – August 24, 2023



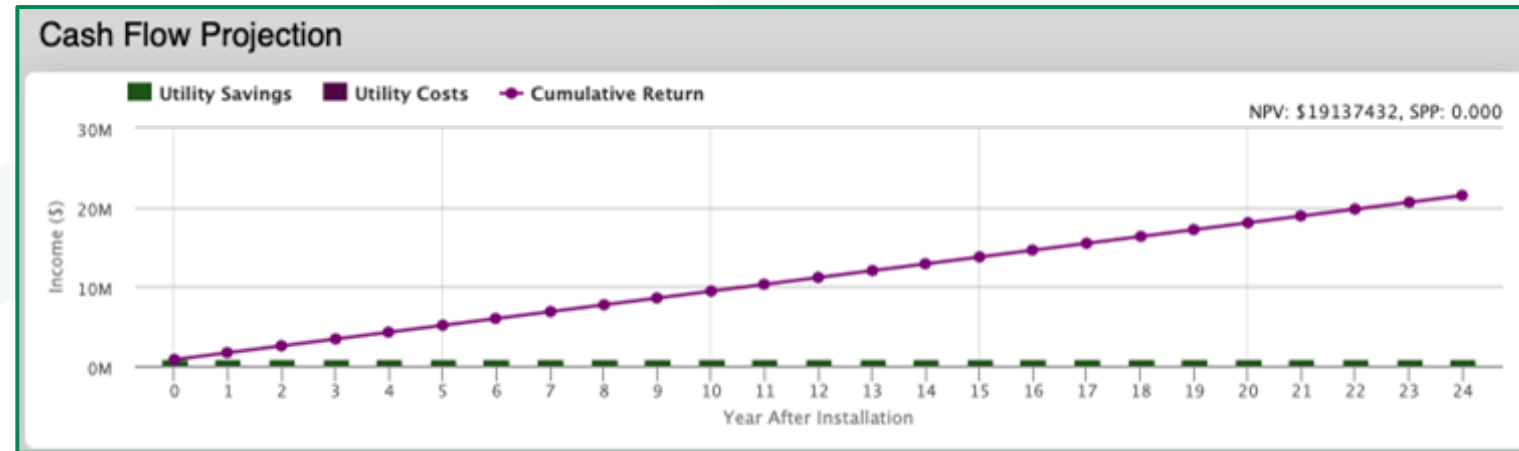
Tipmont – Scenario 1 derUtilityCost Outputs

Monthly Cost Comparison

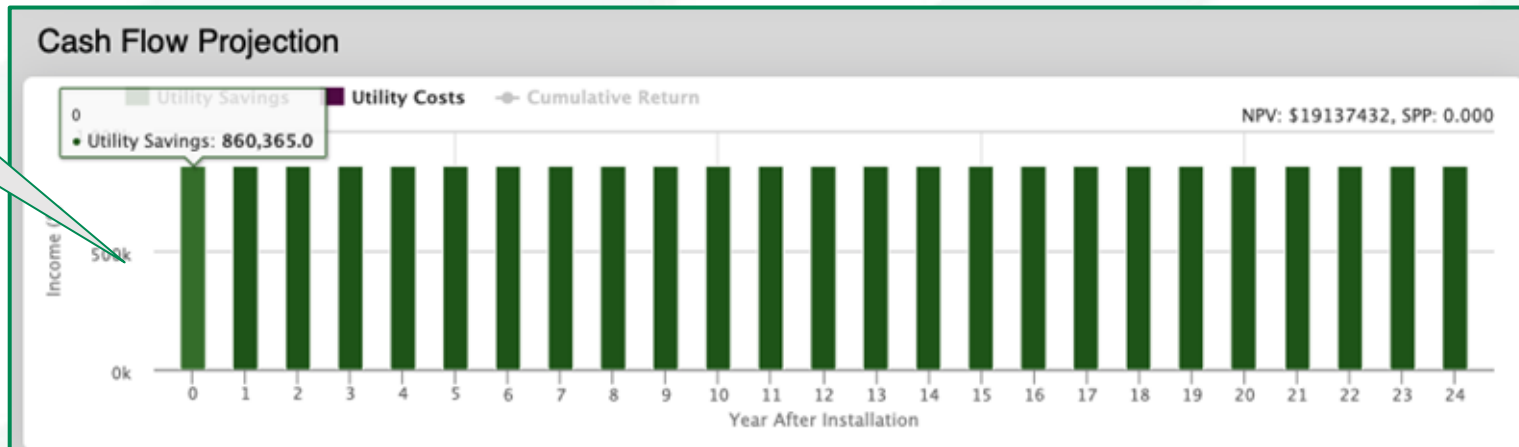
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	83,793	84,665	75,553	65,139	101,145	104,407	123,170	130,960	114,904	93,436	83,130	83,422
Total Adjusted Peak Demand (kW)	78,988	80,152	72,519	62,729	98,138	101,187	119,874	126,933	111,428	90,518	79,026	79,140
Demand Charge (\$)	1,508,272	1,523,977	1,359,952	1,172,509	1,820,612	1,879,333	2,217,063	2,357,278	2,068,278	1,681,848	1,496,345	1,501,599
Adjusted Demand Charge (\$)	1,421,777	1,442,728	1,305,347	1,129,123	1,766,480	1,821,358	2,157,726	2,284,800	2,005,696	1,629,328	1,422,474	1,424,517
Demand Cost Savings (\$)	86,494	81,249	54,606	43,386	54,132	57,975	59,337	72,478	62,582	52,520	73,871	77,082
Energy (kWh)	46,713,696	40,502,584	42,894,312	37,192,238	40,778,165	45,343,286	54,285,296	52,158,444	43,707,842	42,162,538	43,580,034	45,905,578
Adjusted Energy (kWh)	46,651,321	40,441,149	42,835,282	37,152,554	40,676,791	45,206,932	54,072,659	51,977,341	43,589,726	42,090,688	43,506,800	45,839,962
Energy Cost (\$)	2,249,088	1,941,423	2,061,734	1,796,754	1,986,856	2,218,962	2,657,952	2,551,917	2,135,398	2,044,779	2,094,547	2,208,475
Adjusted Energy Cost (\$)	2,244,435	1,935,984	2,057,614	1,791,774	1,980,023	2,209,086	2,645,311	2,541,308	2,127,726	2,038,397	2,088,567	2,203,010
Energy Cost Savings (\$)	4,653	5,439	4,120	4,980	6,834	9,876	12,641	10,609	7,672	6,382	5,980	5,465
Total Cost of Service (\$)	3,757,359	3,465,401	3,421,687	2,969,264	3,807,468	4,098,295	4,875,015	4,909,196	4,203,676	3,726,628	3,590,892	3,710,074
Adjusted Total Cost of Service (\$)	3,666,212	3,378,712	3,362,961	2,920,897	3,746,503	4,030,444	4,803,037	4,826,109	4,133,421	3,667,725	3,511,041	3,627,527
Total Consumer Compensation (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Program Startup and Operational Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Utility Savings (\$)	91,147	86,688	58,726	48,367	60,966	67,851	71,978	83,087	70,255	58,902	79,851	82,547
Total Utility Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Net Utility Savings (\$)	91,147	86,688	58,726	48,367	60,966	67,851	71,978	83,087	70,255	58,902	79,851	82,547

The initial subsidies and startup costs are zero in Scenario 1 to show the Total Utility Savings from DER alone.

Tipmont – Scenario 1 derUtilityCost Outputs

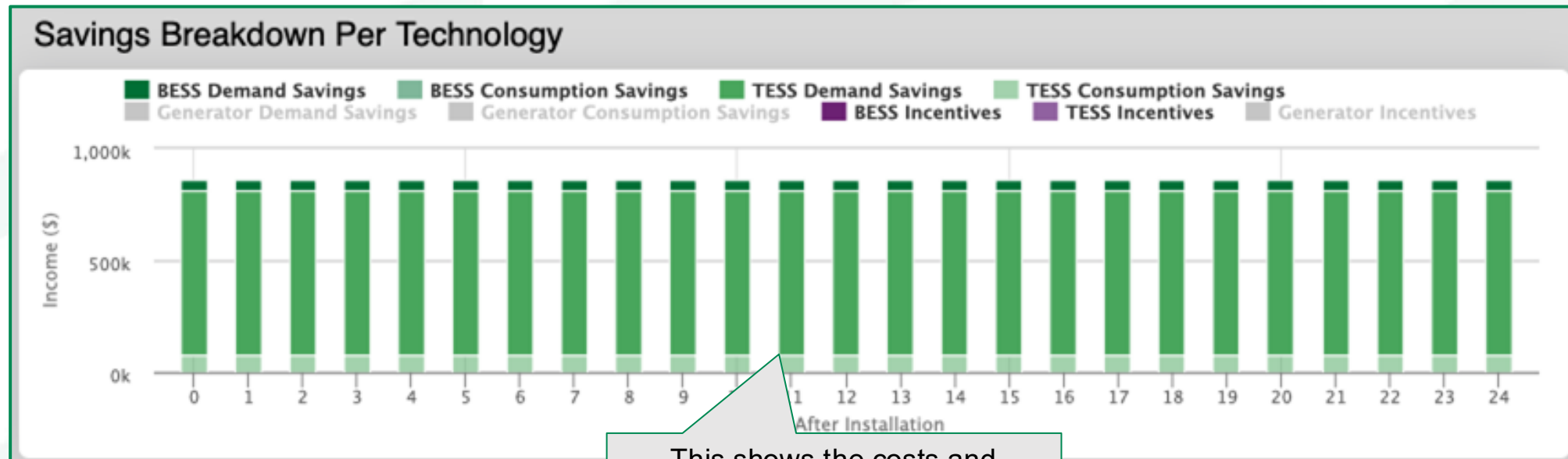


In this Base Scenario, the annual value of all DER is about \$860,365



The Simple Payback Period = 0 years, showing that the program pays itself immediately (since there are no subsidies or costs in this Base Scenario)

Tipmont – Scenario 1 derUtilityCost Outputs



This shows the costs and savings breakdown of the BESS and TESS technologies in terms of kW peak demand savings and kWh consumption savings. Recall that the TESS is a combination of all the thermal devices.

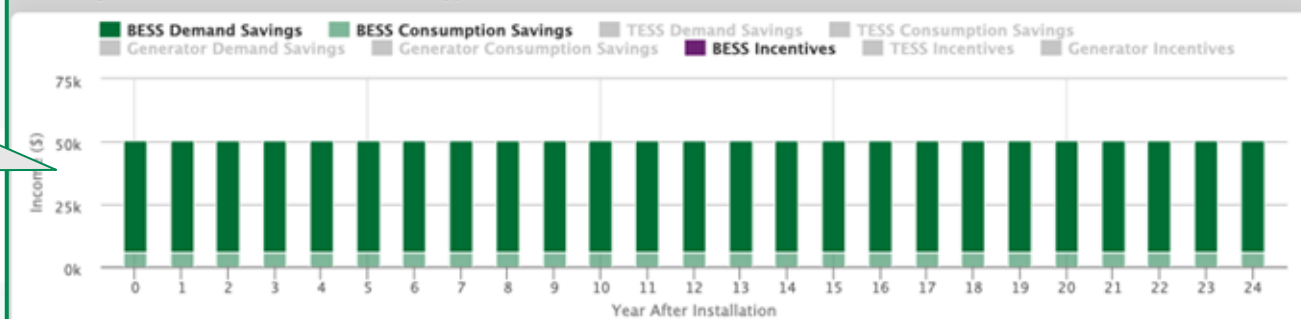
Tipmont – Scenario 1 derUtilityCost Outputs

BESS Savings vs. Incentives

The annual value of the BESS can be determined by adding the Demand Savings and Consumption Savings together. Since Scenario 1 has no subsidies, there are no incentive costs shown.

e.g. Annual BESS Demand Savings + BESS Consumption Savings = \$50,511

Savings Breakdown Per Technology

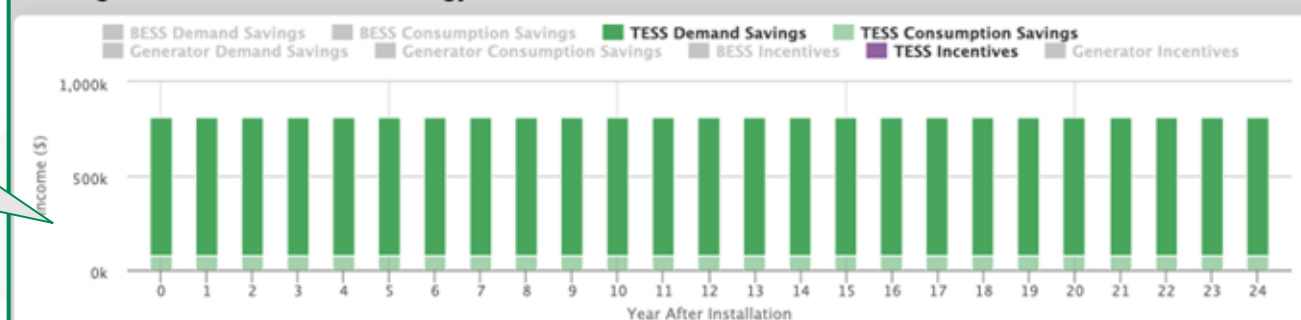


All TESS Savings vs. Incentives

The annual value of the TESS can be determined by adding the Demand Savings and Consumption Savings together. Since Scenario 1 has no subsidies, there are no incentive costs shown.

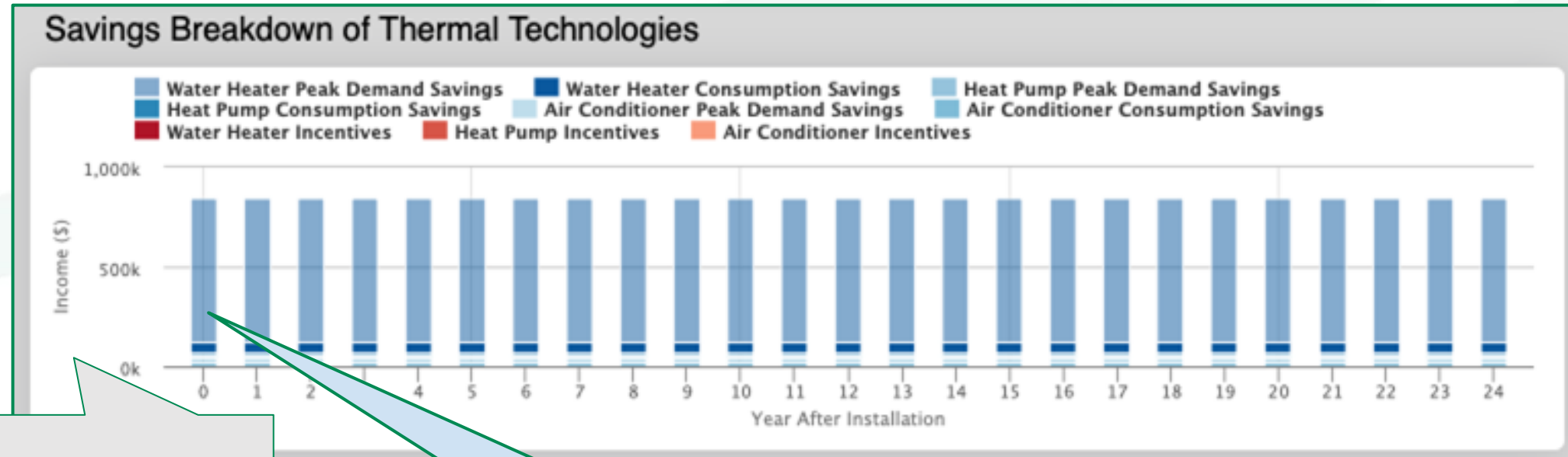
e.g. Annual TESS Demand Savings + TESS Consumption Savings = \$809,854

Savings Breakdown Per Technology



Note: The Y axis scale is not the same between the two plots. See the previous slide for a better side-by-side comparison between TESS and BESS.

Tipmont – Scenario 1 derUtilityCost Outputs



This plot shows the annual breakdown of the costs and savings for all TESS technologies: Water Heaters, Air Conditioners, and Heat Pumps.

Most of the savings come from the Water Heaters, which Tipmont listed as #3 on their preference list

Tipmont's Tech Preferences

- #1 = BESS
- #2 = Generators (propane and natural gas)
- #3 = Water Heater
- #4 = Heat Pump
- #5 = Central AC
- #6 = Resistance Heating

Tipmont – Scenario 1 derUtilityCost Outputs

Water Heater Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$689,358

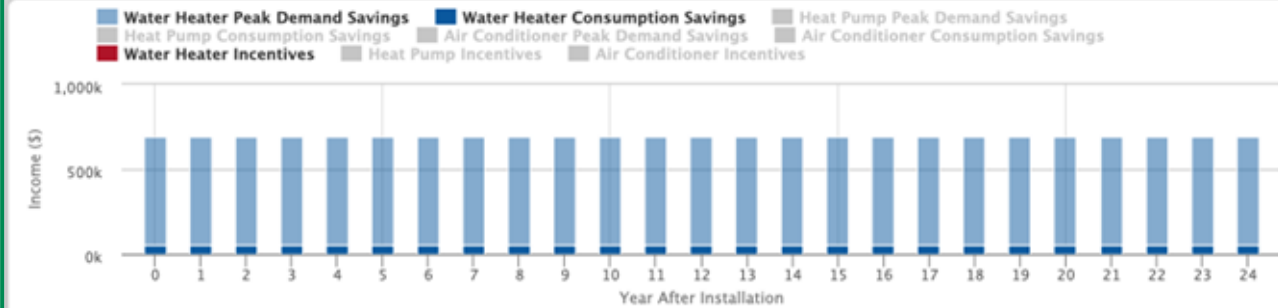
Air Conditioner Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$102,099

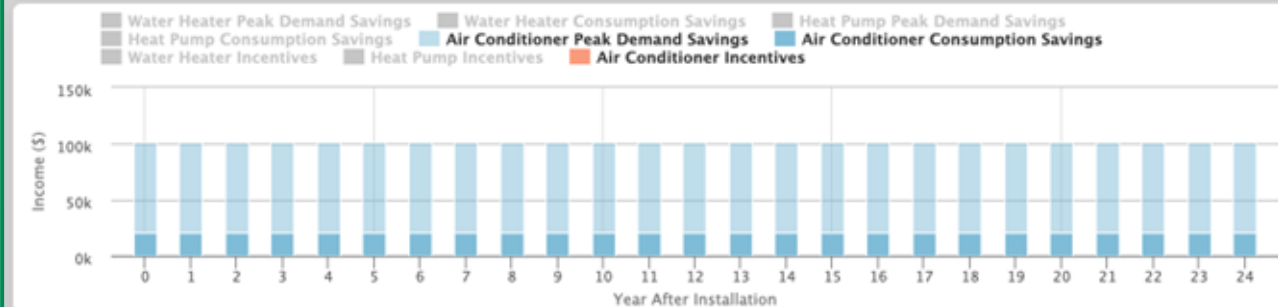
Heat Pump Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$18,397

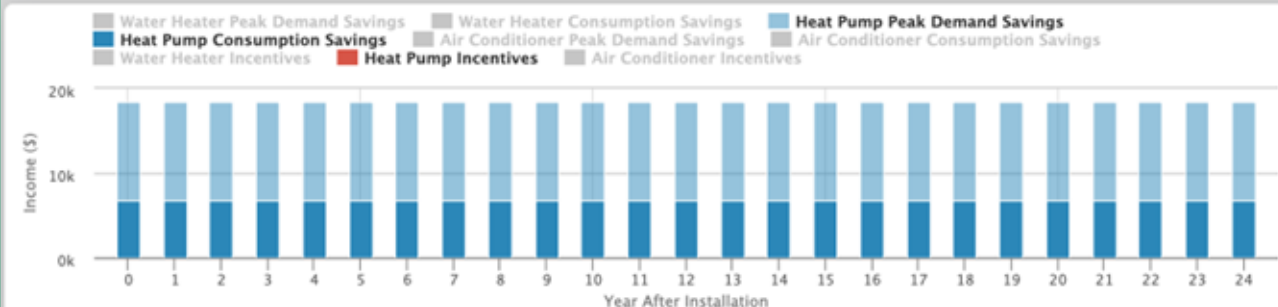
Savings Breakdown of Thermal Technologies



Savings Breakdown of Thermal Technologies



Savings Breakdown of Thermal Technologies



Tipmont – Scenario 1 derUtilityCost Outputs

Tech	Total Annual Savings (kW Demand Savings + kWh Consumption Savings)	Number of Devices	Annual Value of DER per Device	Monthly Subsidy (Total Annual Savings / Number of Devices / 12 months)
BESS	\$50,511	314	\$161	\$13.41
Air Conditioner	\$102,099	18,388	\$6	\$0.46
Water Heater	\$689,358	10,792	\$64	\$5.32
Heat Pump	\$18,397	1,004	\$18	\$1.53

Annual value per device with no subsidies included

These monthly subsidies will be used as inputs in Tipmont's derUtilityCost Scenario 2 and derConsumer

Example Monthly Subsidy calculation:

If Water Heaters saved \$689,358 for the year, then the annual value of water heaters per device would be $\$689,358 / 10,792 \text{ water heaters} = \$64 \text{ per water heater per year}$. That value could be used to determine a monthly subsidy = $\$64 / 12 \text{ months} = \$5.32/\text{month}$ (assuming no upfront subsidies).



Tipmont derUtilityCost Scenario 2: Adjusted Subsidies

Tipmont – Scenario 2 derUtilityCost Inputs

Scenario 2 considers a program where the participation levels remain the same, but the subsidies are adjusted based on the results from Scenario 1.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Participation Level (out of 31,372 residential meters)
BESS	0	\$13.41	1% (314)
Air Conditioner	0	\$0.46	59% (18,388)
Water Heater	0	\$5.32	34% (10,792)
Heat Pump	0	\$1.53	3% (1,004)
GEN	-	-	-

The monthly subsidies calculated from Scenario 1 are used as the starting inputs for Scenario 2.

The participation levels are kept the same

Tipmont – Scenario 2: Adjusted Subsidies

In order to reproduce the same model results as Scenario 1 and only change the subsidies, the random seeds and random numbers in Scenario 2 must be set to the same numbers produced in Scenario 1, which can be found in the outputs at the bottom of the model.

Scenario 1 outputs:

Raw Input and Output Files

random_seeds.csv – water_heater_random_numbers.csv – demand.csv – Scenario_test_POST.json – REoptInputs.json – vbatDispatch_inputs_hp.json – temperature_input_derUtilityCost.csv – reopt_input_scenario.json – vbatDispatch_inputs_wh.json – results.json – vbatDispatch_results_hp.json – Plot_DerServingLoadOverview.html – vbatDispatch_results_wh.json – Plot_NewDemand.html – vbatDispatch_inputs_ac.json – PPID.txt – stderr.txt – PuLP_random_seeds.csv – random_seeds.txt – vbatDispatch_results_ac.json – temperature.csv – wholesale_rate_structure_input_derUtilityCost.json – input_temperature.csv – demand_input_derUtilityCost.csv – input_demand.csv – input_wholesale_rate_structure.json – Plot_ThermalDerServingLoadOverview.html – allInputData.json – allOutputData.json

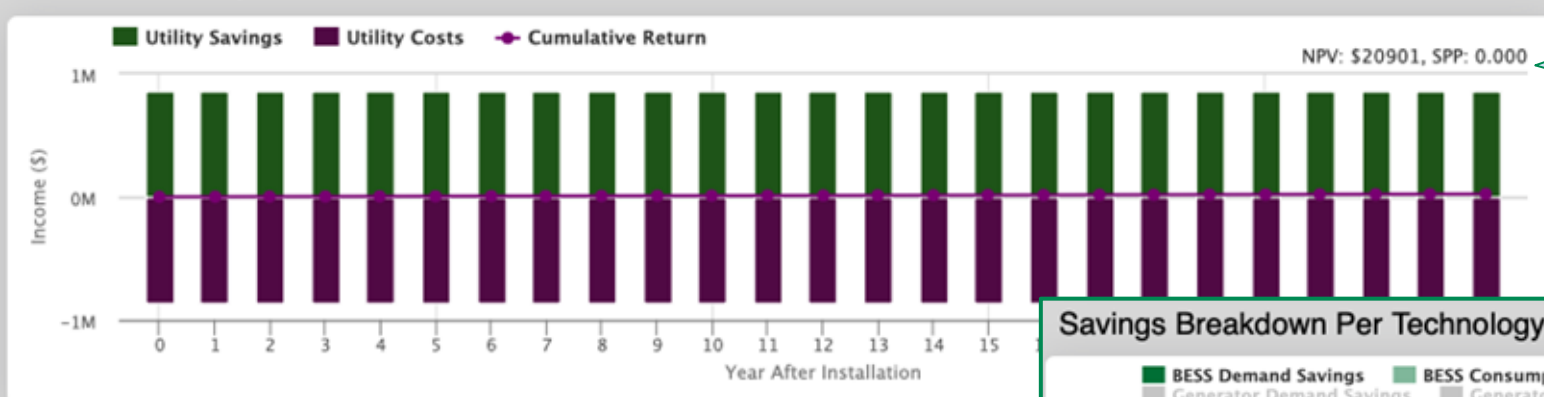
Scenario 2 inputs:

General Model Inputs

Demand Curve (.csv file) Choose File Tipmont - System Demand_kW	Temperature Curve in °F (.csv file) Choose File Tipmont - Temperature_degF_J	Latitude 40.18809
Longitude -86.9039	Year 2023	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 398527171	Random Seed - AC 261076154	Random Seed - HP 692738093
Random Seed - WH 385603020	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_numbers	

Tipmont – Scenario 2 derUtilityCost Outputs

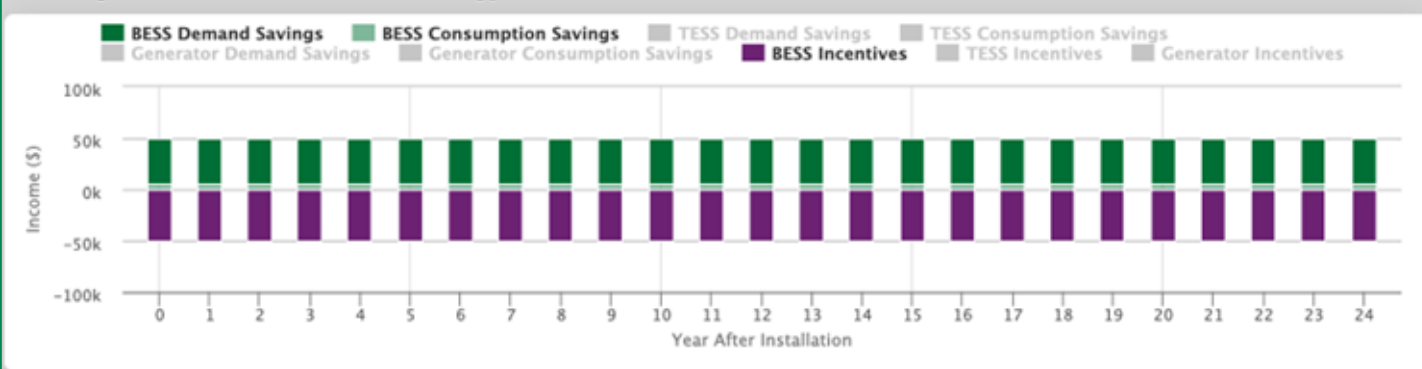
Cash Flow Projection



The SPP is 0 since the subsidy costs are roughly equal to the DER savings, and there are no other initial costs. The NPV, however, is expected to be close to zero for this break-even scenario, but it is nonzero due to rounded numbers and the number of decimal precision in the inputs values.

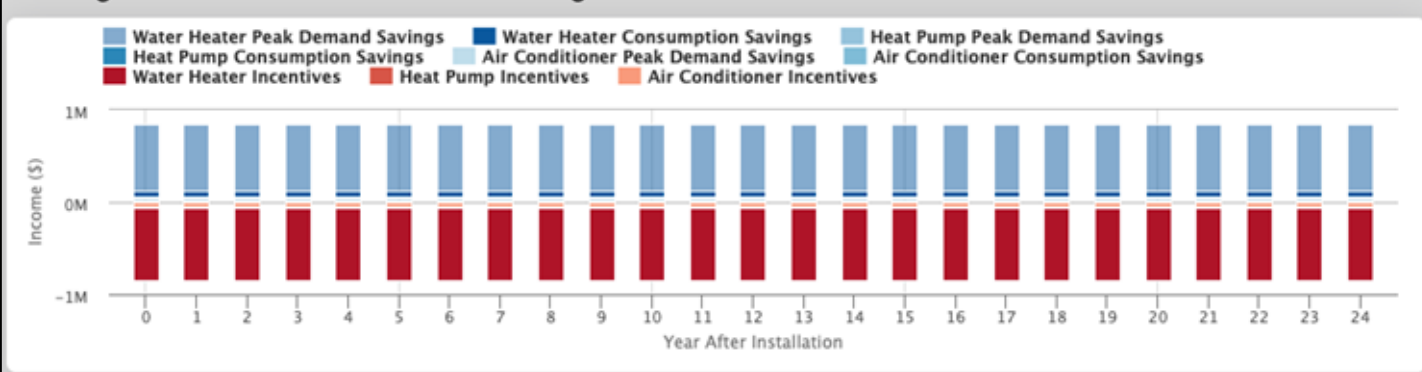
The annual BESS subsidies are roughly comparable to the annual BESS savings

Savings Breakdown Per Technology



The annual TESS subsidies are roughly comparable to the annual TESS savings

Savings Breakdown of Thermal Technologies



Tipmont – Scenario 2 derUtilityCost Outputs

Monthly Cost Comparison

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	83,793	84,665	75,553	65,139	101,145	104,407	123,170	130,960	114,904	93,436	83,130	83,422
Total Adjusted Peak Demand (kW)	78,988	80,152	72,519	62,729	98,138	101,187	119,874	126,933	111,428	90,518	79,026	79,140
Demand Charge (\$)	1,508,272	1,523,977	1,359,952	1,172,509	1,820,612	1,879,333	2,217,063	2,357,278	2,068,278	1,681,848	1,496,345	1,501,599
Adjusted Demand Charge (\$)	1,421,777	1,442,728	1,305,347	1,129,123	1,766,480	1,821,358	2,157,726	2,284,800	2,005,696	1,629,328	1,422,474	1,424,517
Demand Cost Savings (\$)	86,494	81,249	54,606	43,386	54,132	57,975	59,337	72,478	62,582	52,520	73,871	77,082
Energy (kWh)	46,713,696	40,502,584	42,894,312	37,192,238	40,778,165	45,343,286	54,285,296	52,158,444	43,707,842	42,162,538	43,580,034	45,905,578
Adjusted Energy (kWh)	46,651,321	40,441,149	42,835,282	37,152,554	40,676,791	45,206,932	54,072,659	51,977,341	43,589,726	42,090,688	43,506,800	45,839,962
Energy Cost (\$)	2,249,088	1,941,423	2,061,734	1,796,754	1,986,856	2,218,962	2,657,952	2,551,917	2,135,398	2,044,779	2,094,547	2,208,475
Adjusted Energy Cost (\$)	2,244,435	1,935,984	2,057,614	1,791,774	1,980,023	2,209,086	2,645,311	2,541,308	2,127,726	2,038,397	2,088,567	2,203,010
Energy Cost Savings (\$)	4,653	5,439	4,120	4,980	6,834	9,876	12,641	10,609	7,672	6,382	5,980	5,465
Total Cost of Service (\$)	3,757,359	3,465,401	3,421,687	2,969,264	3,807,468	4,098,295	4,875,015	4,909,196	4,203,676	3,726,628	3,590,892	3,710,074
Adjusted Total Cost of Service (\$)	3,666,212	3,378,712	3,362,961	2,920,897	3,746,503	4,030,444	4,803,037	4,826,109	4,133,421	3,667,725	3,511,041	3,627,527
Total Consumer Compensation (\$)	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619
Program Startup and Operational Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Utility Savings (\$)	91,147	86,688	58,726	48,367	60,966	67,851	71,978	83,087	70,255	58,902	79,851	82,547
Total Utility Costs (\$)	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619	71,619
Net Utility Savings (\$)	19,527	15,069	-12,893	-23,252	-10,653	-3,768	35,361	11,468	-1,364	-12,716	8,232	10,929

The Total Utility Savings are the same from Scenario 1, but now we see the Total Utility Costs, which are comprised of the subsidies paid to the consumer

Program Startup and Operational Costs could also be added in future scenarios

Tipmont derConsumer model

Tipmont – derConsumer Inputs

General Model Inputs		
Demand Curve (.csv file) Choose File Tipmont_residentialScaledDem	Temperature Curve in °F (.csv file) Choose File Tipmont - Temperature_degF_	Latitude 40.18809
Longitude -86.9039	Year 2023	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 398527171	Random Seed - AC 261076154	Random Seed - HP 692738093
Random Seed - WH 385603020	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_number	

Financial Inputs		
Use URDB Label? ☐	URDB Label 66a13566e90ecdb7d40581d2	(Optional) Residential Rate Structure (.json file) Choose File Tipmont_Residential Rate-TOU
Discount Rate (%) 1	Financial Projection Length (years) 25	Home BESS - Upfront Subsidy Amount (\$) 0
Home BESS - Monthly Recurring Subsidy Amount (\$) 13.41	Home Heat Pump - Upfront Subsidy Amount (\$) 0	Home Heat Pump - Monthly Recurring Subsidy Amount (\$) 1.53
Home Air Conditioner - Upfront Subsidy Amount (\$) 0	Home Air Conditioner - Monthly Recurring Subsidy Amount (\$) 0.46	Home Water Heater - Upfront Subsidy Amount (\$) 0
Home Water Heater - Monthly Recurring Subsidy Amount (\$) 5.32	Home Generator - Upfront Subsidy Amount (\$) 0	Home Generator - Monthly Recurring Subsidy Amount (\$) 0

Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Rated Power Capacity (kW) 5
Efficiency (%) 35	Retrofit Cost (\$) 0.0	Available Fuel 1000
Fuel Cost 3.80	Generator Replacement Cost (\$/kW) 0.0	Generator Lifetime (years) 15

Chemical Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Battery Power Capacity (kW) 5.0	Battery Energy Capacity (kWh) 13.5
Retrofit Cost (\$) 0.0	Portion of Charge Shared with Utility (%) 20	Battery Replacement Power Cost (\$/kW) 0.0
Battery Replacement Energy Cost (\$/kWh) 0.0	Battery Lifetime (years) 10	Inverter Replacement Cost (\$) 0.0
Inverter Lifetime (years) 10		

Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 150
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	

Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 0
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	

Home Water Heater Device Inputs		
Enable Water Heater? Yes	Rated Power (kW) 4.5	Retrofit Cost (\$) 175
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	

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Tipmont – derConsumer Inputs

The derConsumer model considers the same subsidies that were used in Scenario 2 derUtilityCost to show the member-consumer point of view.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Consumer Retrofit Costs (\$)
BESS	0	\$13.41	0
Air Conditioner	0	\$0.46	150 (Nest Thermostat)
Water Heater	0	\$5.32	175 (Aquila Controller)
Heat Pump	0	\$1.53	0
Generator	-		-

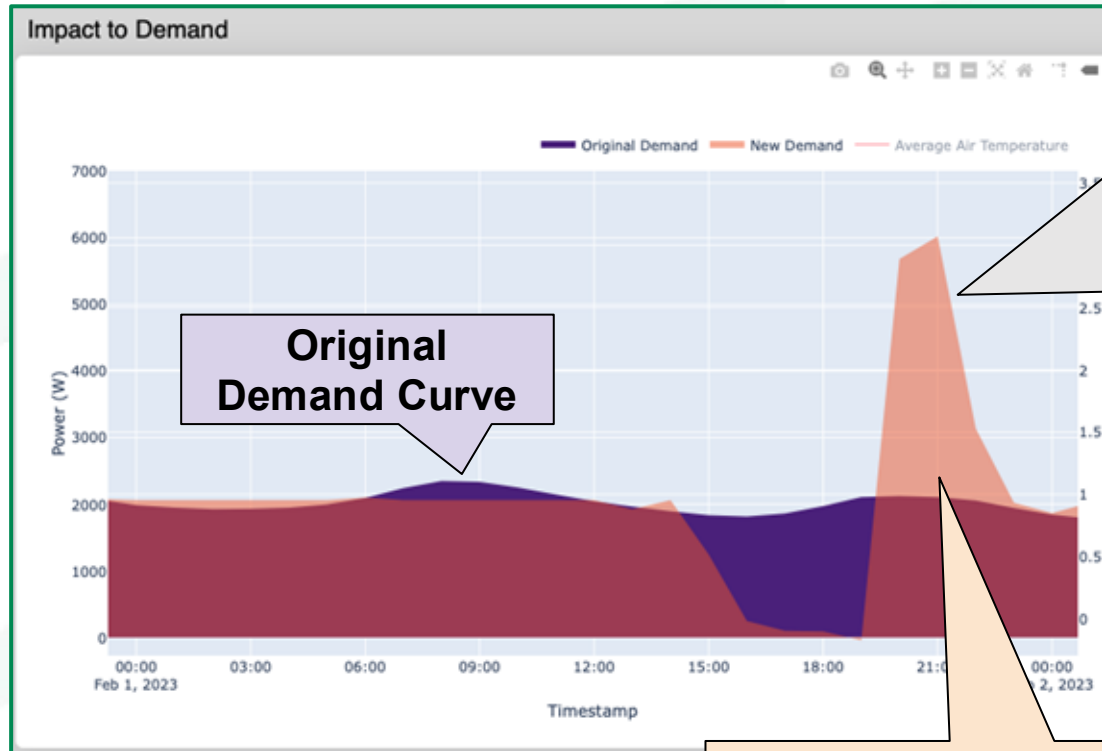
Approx. cost to equip the device to respond to the utility's load control signals. (e.g. Smart Thermostat, Wi-Fi enabled smart plug, etc.) Note: The companies listed here are only examples, not endorsements.

These are the same subsidies used in the derUtilityCost Adjusted Subsidies case. Using them in derConsumer will show how these subsidies look from the perspective of a hypothetical member-consumer.

The Heat Pump retrofit cost is \$0 because it's the same smart thermostat that is used for the Air Conditioner.

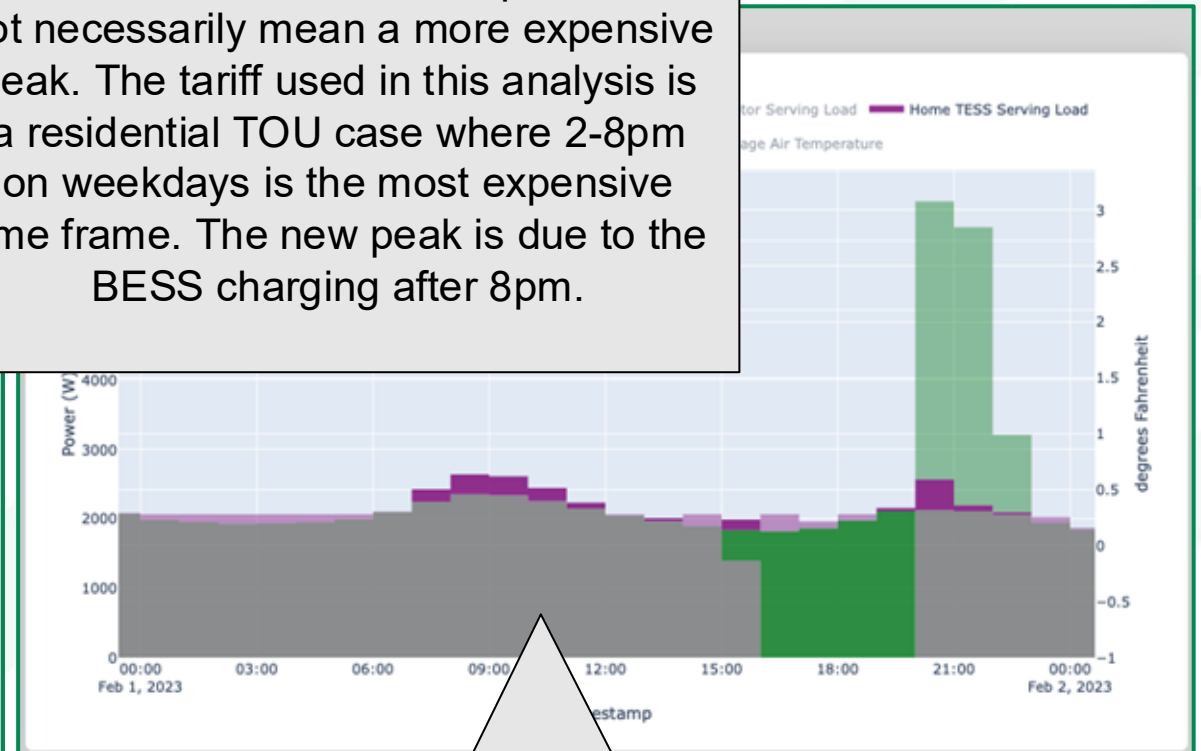
Tipmont – derConsumer Outputs

Winter peak – February 1, 2023



Note that this new demand peak does not necessarily mean a more expensive peak. The tariff used in this analysis is a residential TOU case where 2-8pm on weekdays is the most expensive time frame. The new peak is due to the BESS charging after 8pm.

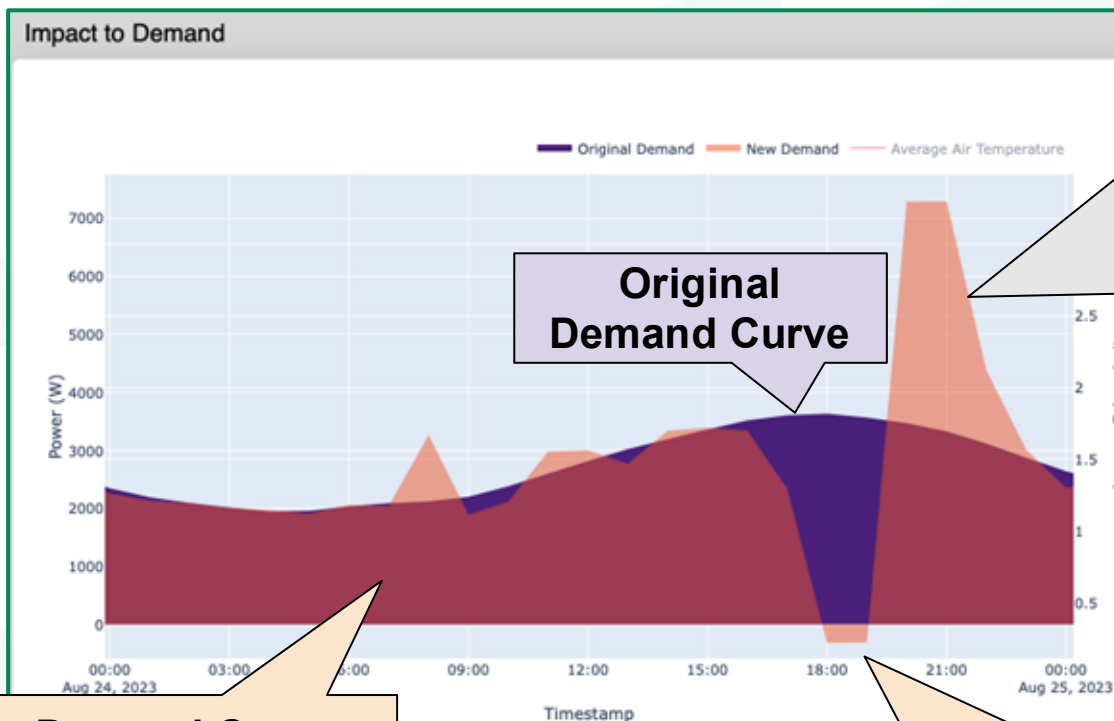
Demand Curve with DER



Some of the BESS and TESS discharge happens on-peak, whereas charging happens off-peak.

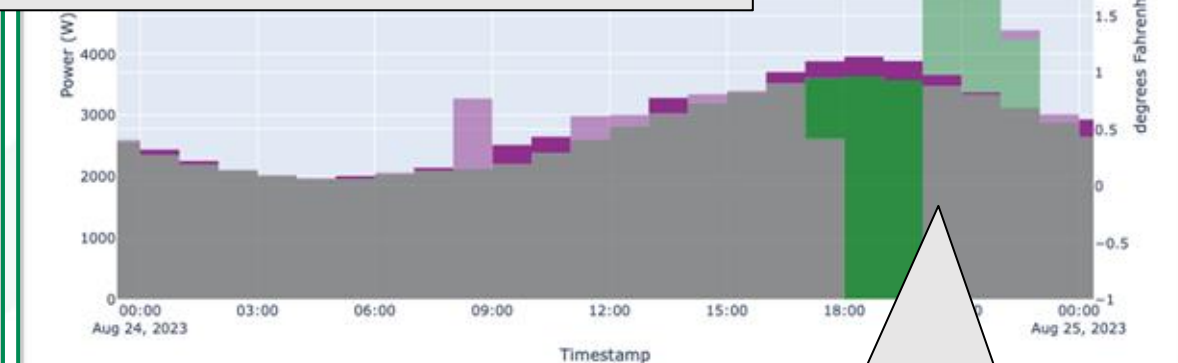
Tipmont – derConsumer Outputs

Summer peak – August 24, 2023



**Demand Curve
with DER**

Note that this new demand peak does not necessarily mean a more expensive peak. The tariff used in this analysis is a residential TOU case where 2-8pm on weekdays is the most expensive time frame. The new peak is due to the BESS charging after 8pm.



The negative New Demand here comes from simulating the BESS and TESS separately, where combining their results make the DER appear to over-serve the load.

BESS performs energy arbitrage; discharging during peak time and charging during off-peak time.



Tipmont – derConsumer Outputs

Monthly Cost Comparison

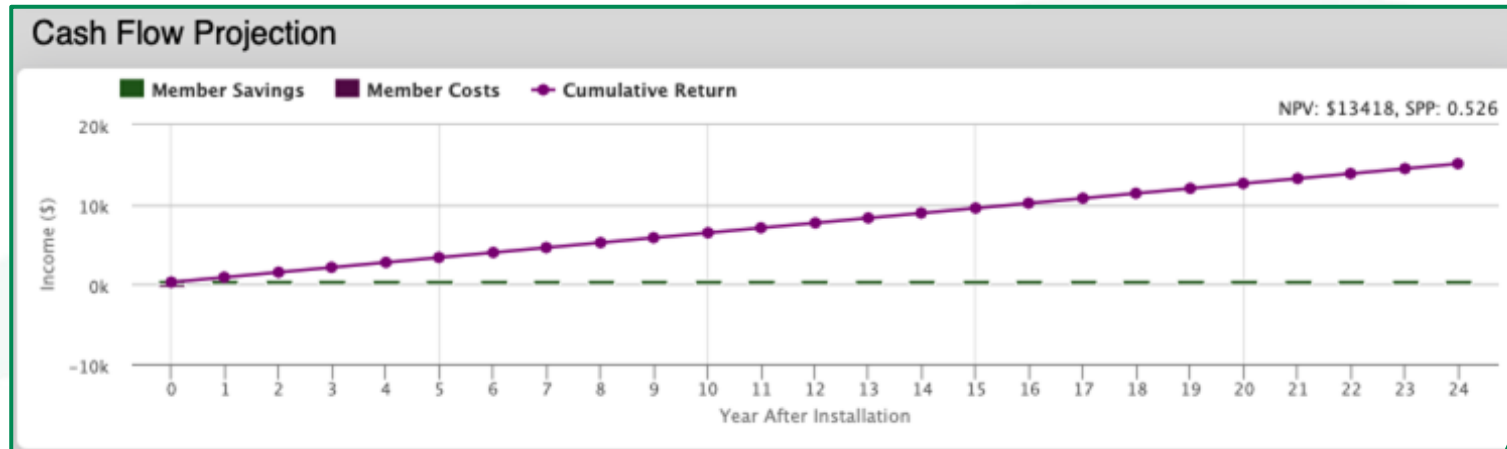
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	2	2	2	2	3	3	3	4	3	3	3	3
Total Adjusted Peak Demand (kW)	6	6	6	6	7	7	7	7	7	6	6	6
Energy (kWh)	1,295	1,123	1,190	1,031	1,131	1,257	1,505	1,446	1,212	1,169	1,169	1,169
Adjusted Energy (kWh)	1,296	1,120	1,188	1,034	1,143	1,270	1,514	1,457	1,224	1,178	1,178	1,178
Energy Cost (\$)	148	127	136	116	136	153	183	178	145	137	137	137
Adjusted Energy Cost (\$)	117	98	103	87	105	123	152	146	115	107	108	113
Energy Cost Savings (\$)	31	29	33	29	31	31	31	33	30	30	31	31
Demand Charge (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Adjusted Demand Charge (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Demand Cost Savings (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Cost of Service (\$)	148	127	136	116	136	153	183	178	145	137	139	144
Adjusted Total Cost of Service (\$)	117	98	103	87	105	123	152	146	115	107	108	113
Generator Fuel Cost (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Utility Subsidies Paid (\$)	21	21	21	21	21	21	21	21	21	21	21	21
Total Consumer Savings (\$)	52	49	54	49	52	51	52	51	50	51	52	52
Total Consumer Costs (\$)	325	0	0	0	0	0	0	0	0	0	0	0
Net Consumer Savings (\$)	-273	49	54	49	52	51	52	51	50	51	52	52

Cost of Service is sometimes increased, sometimes decreased by utility control of DER; This is why a full year is modeled.

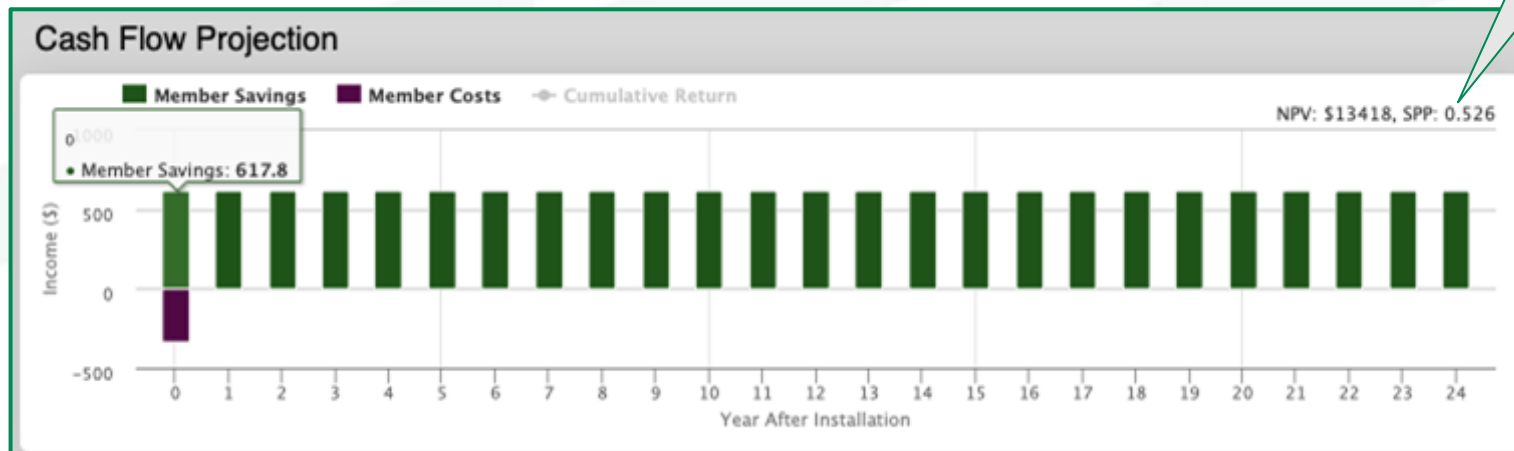
The Total Consumer Costs come from the retrofit and controller device costs.

The Utility Subsidies Paid each month is \$21. The consumer also saves money from having the DER. Overall, only 41% of the consumer's annual savings come from utility subsidies.

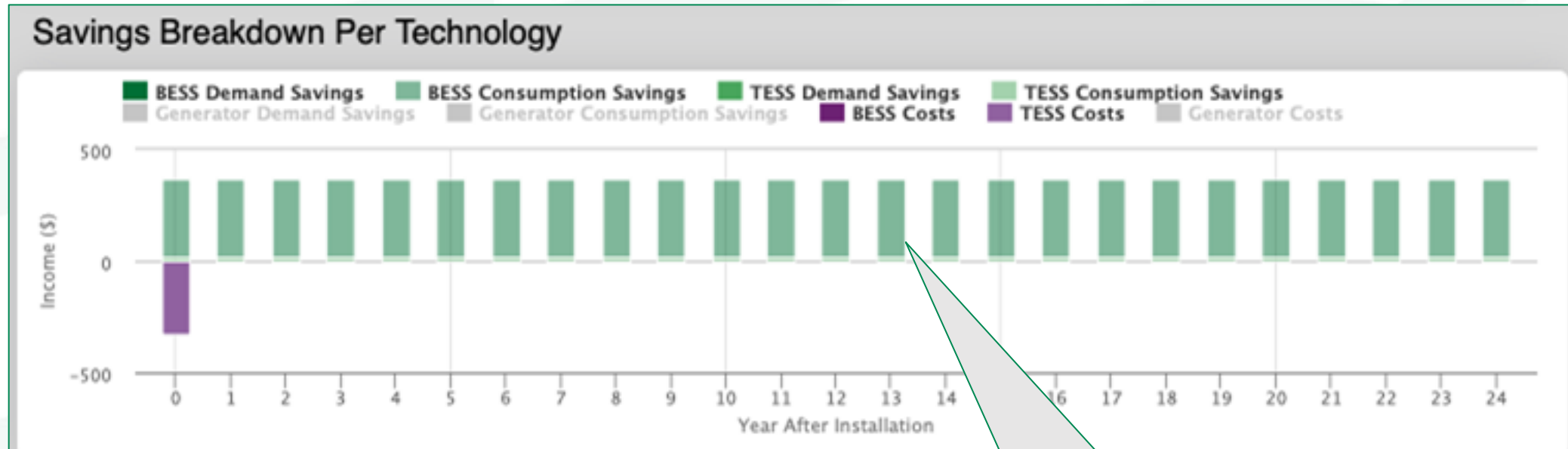
Tipmont – derConsumer Outputs



The SPP is positive, meaning the program will pay the consumer back in just over 6 months since the only costs here are the retrofit device costs.



Tipmont – derConsumer Outputs



Most of the savings come from the BESS Consumption Savings. There are no BESS Demand Savings since Tipmont's residential TOU tariff has no demand component (\$/kW)

Tipmont – derConsumer Outputs

BESS Savings vs. Incentives

Annual BESS Demand Savings + Consumption Savings = \$345/yr

- ★ The consumer can consider enrolling their existing BESS in with the utility's DER sharing program, or consider a new installation. The consumer can also see how quickly a new installation could be paid off over time.

All TESS Savings vs. Incentives

Annual TESS Demand Savings + Consumption Savings = \$24/yr

- ★ The consumer can consider installing a Smart Thermostat and other load control devices and enroll in the utility's DER sharing program to save money on their electric bill.

Savings Breakdown Per Technology

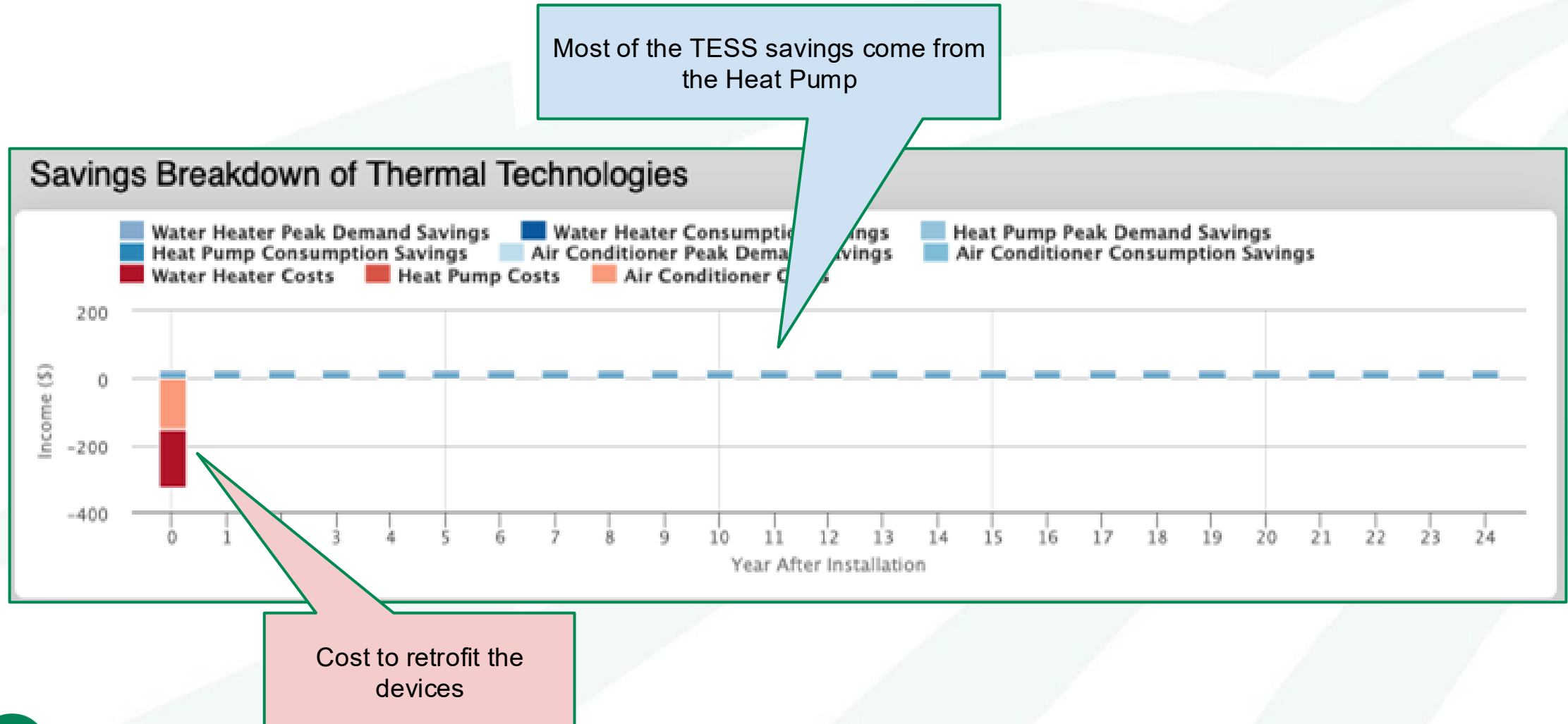


Savings Breakdown Per Technology



Note: The Y axis scale is not the same between the two plots. See the previous slide for a better side-by-side comparison between TESS and BESS.

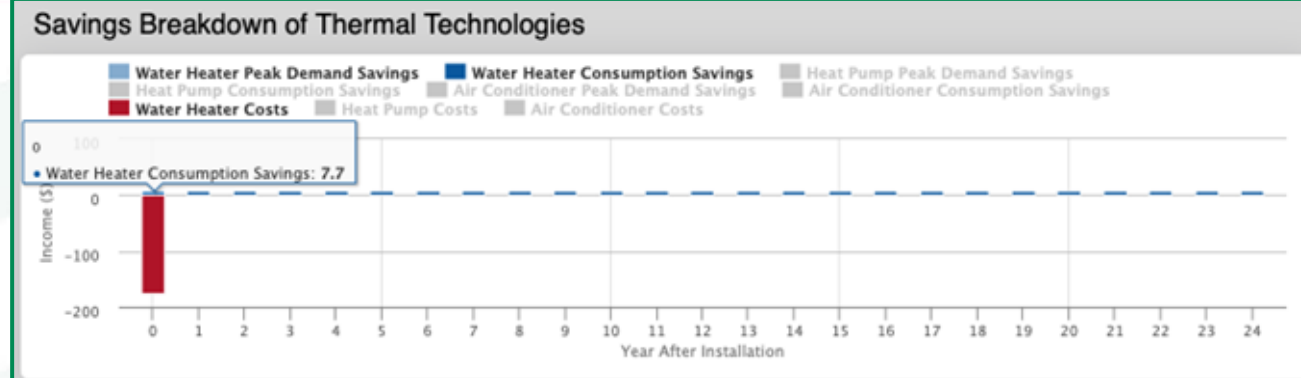
Tipmont – derConsumer Outputs



Tipmont – derConsumer Outputs

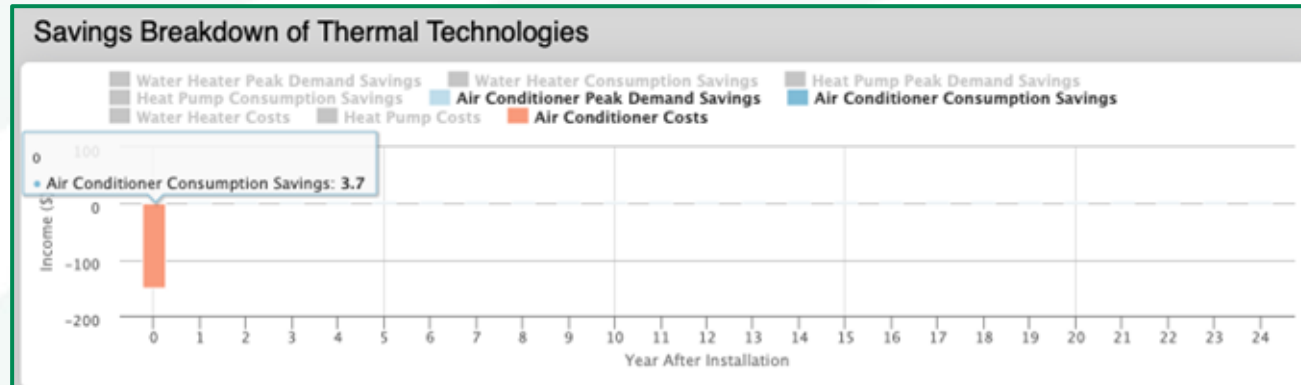
Water Heater Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$8/year



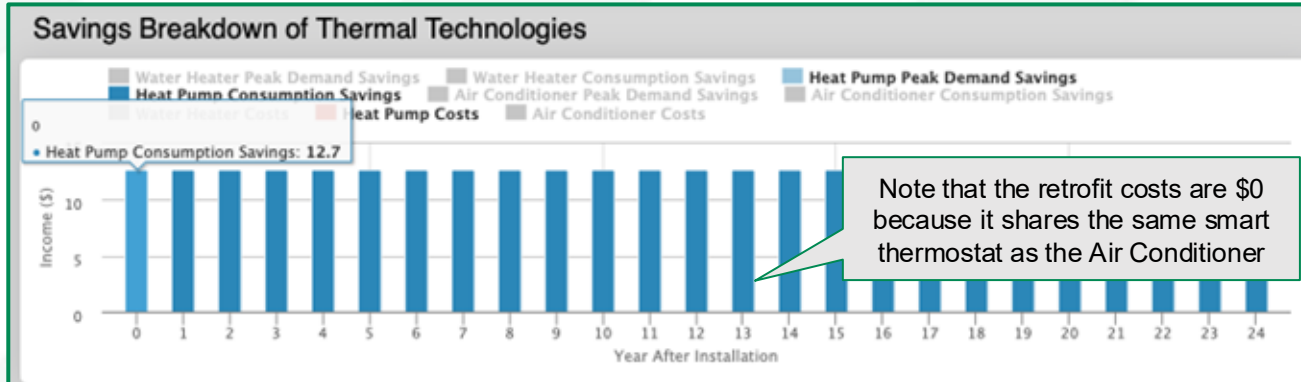
Air Conditioner Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$4/year

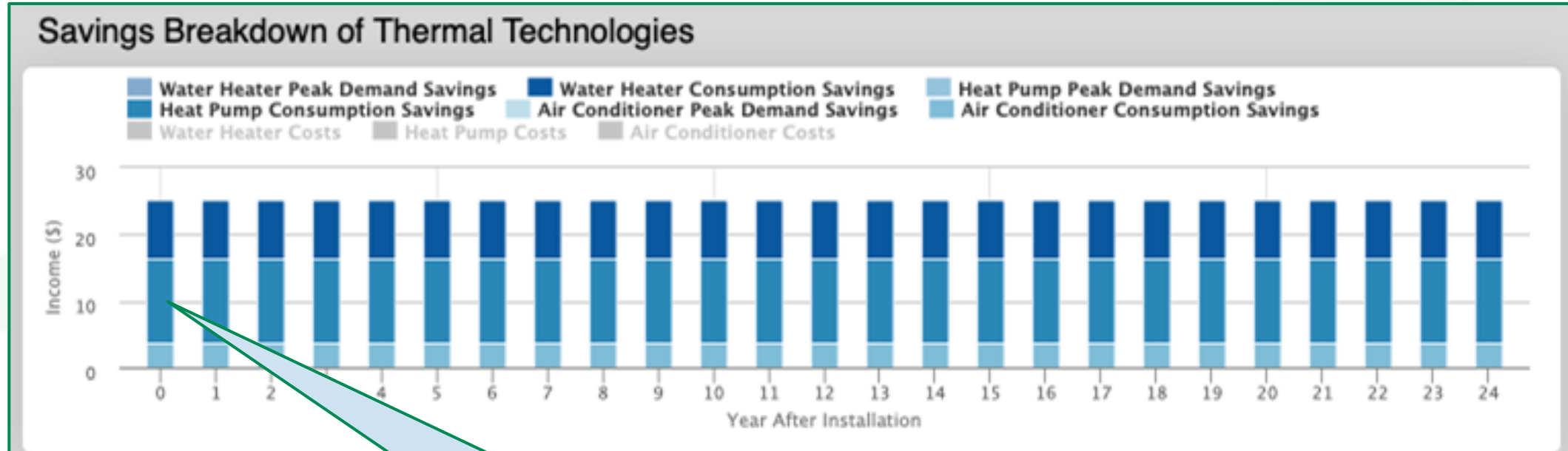


Heat Pump Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$13/year



Tipmont – derConsumer Outputs



Tipmont's Tech Preferences

- #1 = BESS
- #2 = Generators (propane and natural gas)
- #3 = Water Heater
- #4 = Heat Pump
- #5 = Central AC
- #6 = Resistance Heating

Tipmont – Conclusions

Common takeaways from all scenarios:

- BESS and Water Heaters provided the most savings to the utility, whereas BESS and Heat Pumps provided the most benefit to the consumer.
- The BESS provided a monetary benefit to the consumer because of the residential TOU tariff. For a flat residential tariff, the BESS does not offer any savings.
- About 41% of the consumer's monetary benefit came from utility subsidies.

Tipmont – Future Considerations

The utility may want to consider other Scenarios, such as:

- Introducing an up-front subsidy
 - Offering or increasing an up-front subsidy could increase initial participation levels, which could then increase the savings provided by some DER.
- Changing monthly subsidy or participation levels
 - Exploring different levels of monthly incentives or number of enrolled devices can give the utility an idea of what kind of program provides the desired savings to the utility.
- Adding Program Costs
 - Ex. Startup Costs = \$200,000 (estimated)
 - Ongoing Operational Costs = \$1,000/month (provided by Camus)
 - One-time Operational Costs = \$20,000
- Evaluate the consumer perspective using a range of consumption behaviors to guide marketing.
 - Represent the membership using a suite of demand curves to obtain strata-specific subsidies.

Detailed Results: Kenergy Corporation

Detailed Results: Kenergy Corporation



Kenergy Service Area



Kenergy's service area serving several counties in KY.

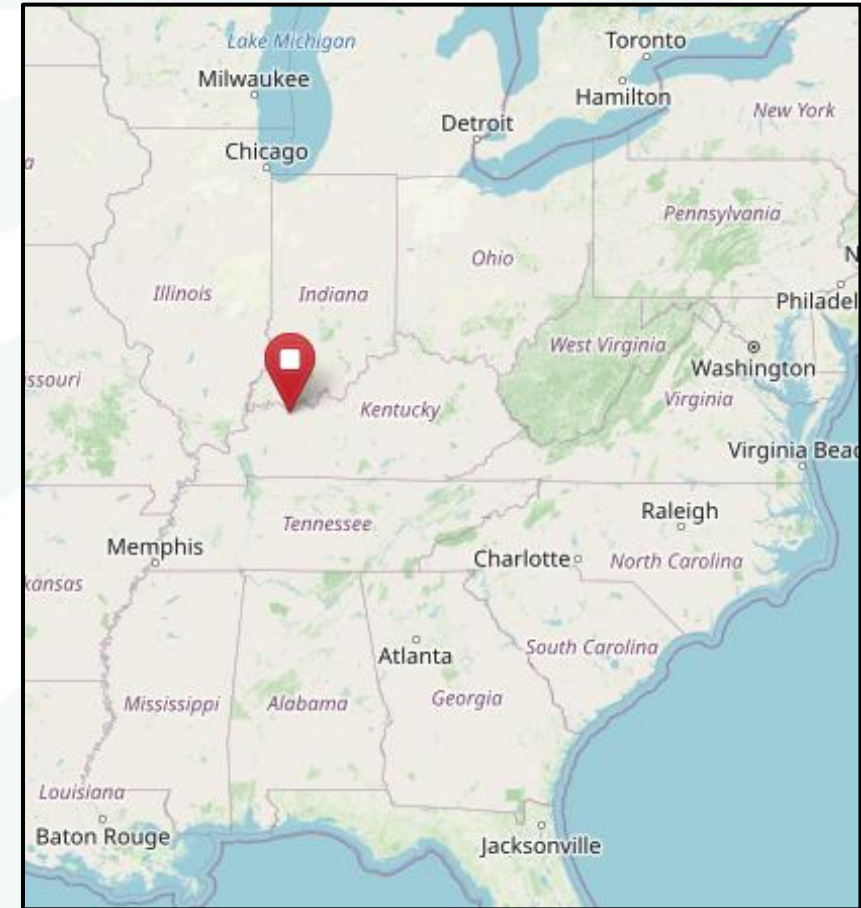
Meters Served: 60,620

Number of Circuits: 194

Annual sales: 6,912 GWh

Peak Demand

- Winter: 1.125 GW
- Summer: 1.153 GW



Kenergy's service area approximate centroid located at (37.760586, -87.127686).

Detailed Results: Kenergy Corporation

Kenergy serves rural Kentucky areas that experience the following grid-stressing weather events:

- Ice Storms & Winter Weather
- Strong Winds
- Heat Waves

Reliability Metrics w/ Major Event Days:

- SAIDI: 385.11
- SAIFI: 3.33
- CAIDI: 115.65

Reliability Metrics w/out Major Event Days:

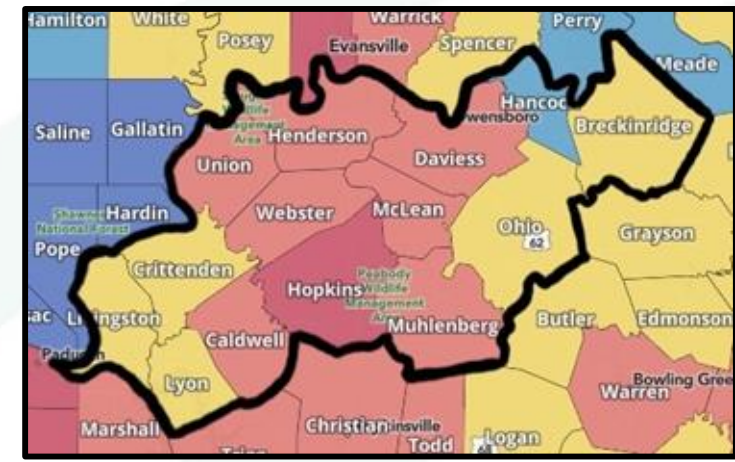
- SAIDI: 115.62
- SAIFI: 1.51
- CAIDI: 76.57



Strong Wind

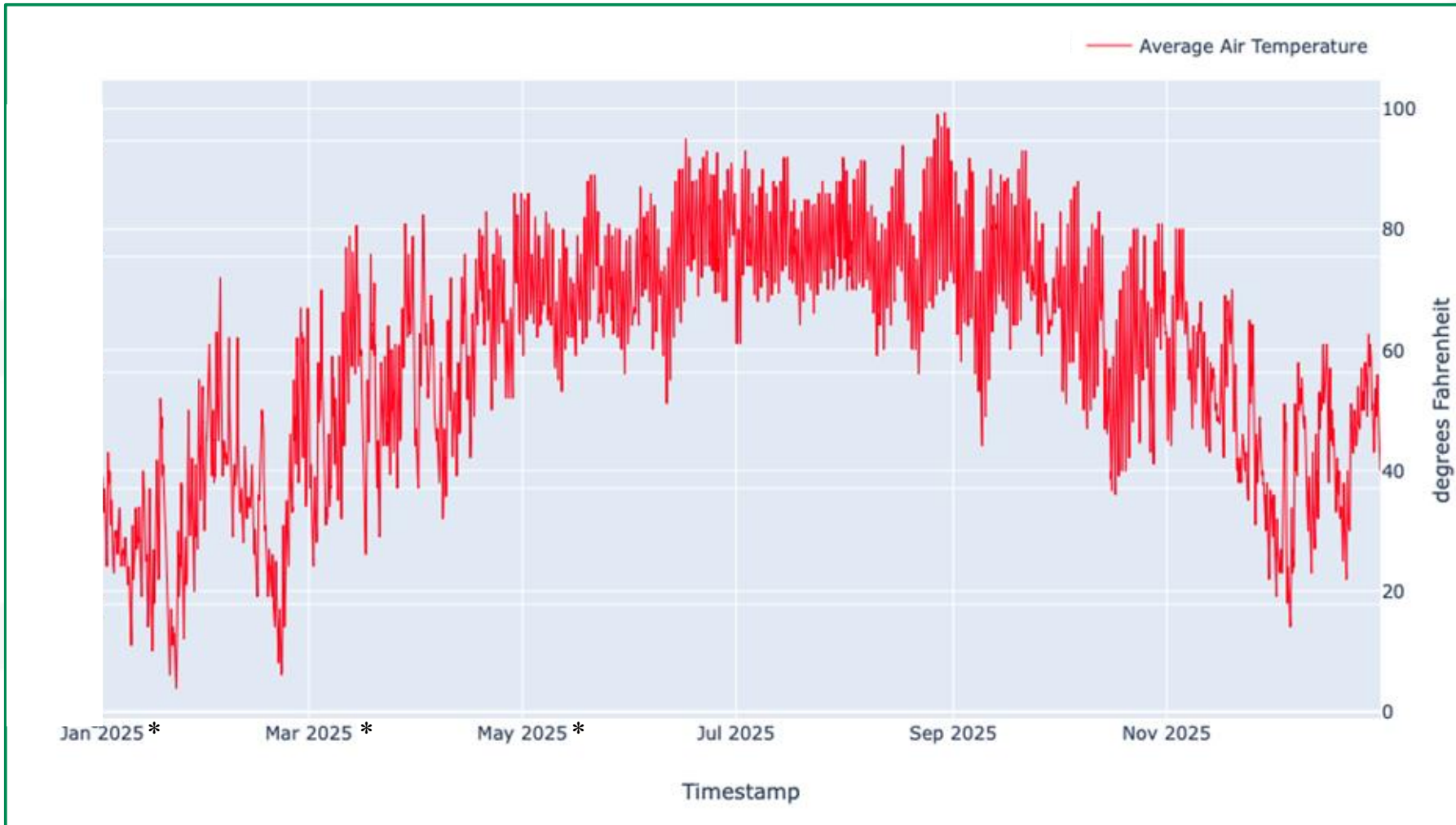


Heat Wave



Ice Storm

Kenergy – Annual Temperature Profile



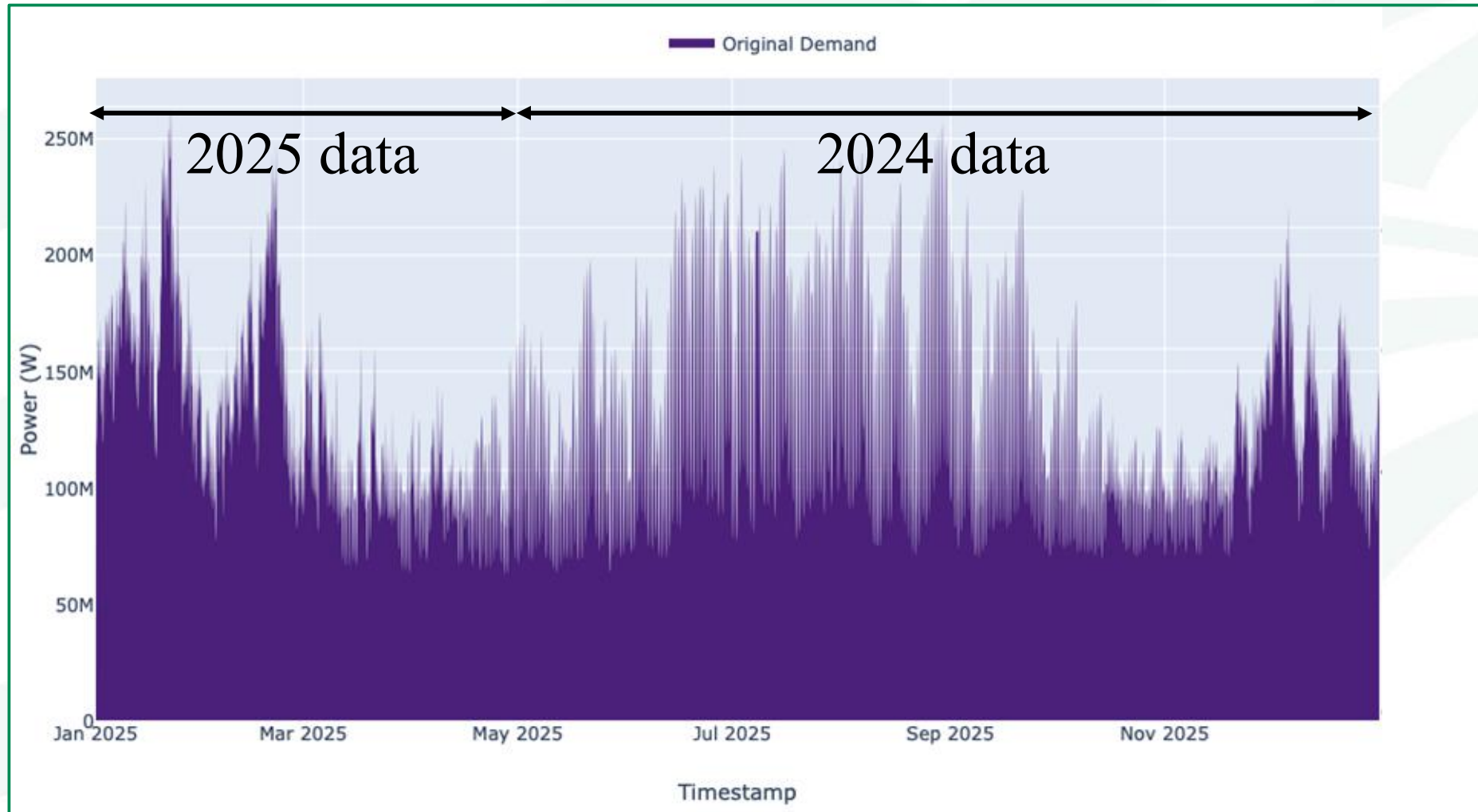
Kenergy's regional climate is considered **"Mixed-Humid"** by the EERE's Building America data sets.

<https://www.energy.gov/eere/buildings/building-america-climate-map>

Kenergy – Annual System-Wide Demand

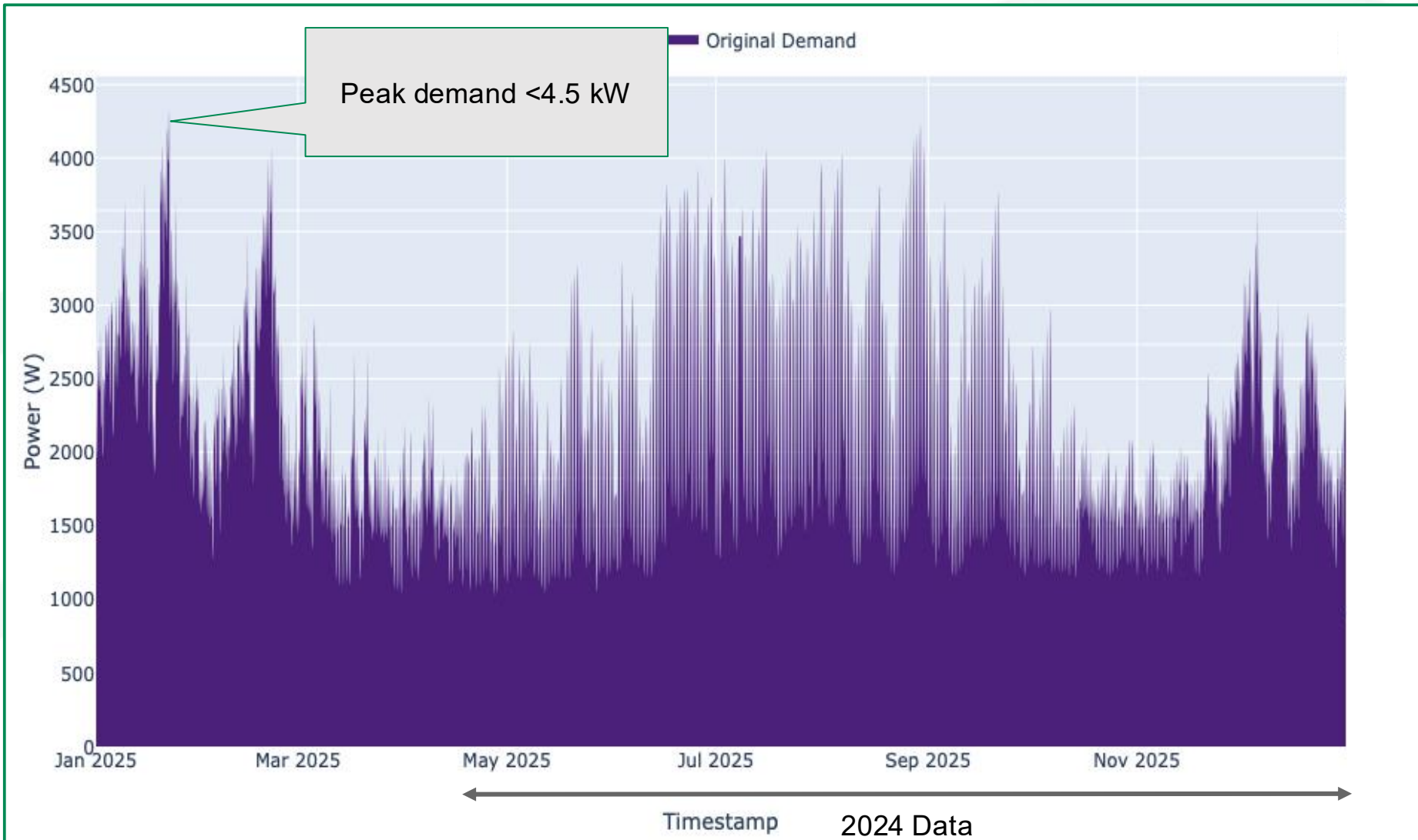
Kenergy's system demand shows two nearly equivalent seasonal peaks. The Summer peak seems to be more predictable than the Winter peak in both time and magnitude.

***Note regarding timestamps:** Kenergy's System Demand Curve data ranged from May 2024 – May 2025. It was rearranged to start on Jan 1 as required by the REopt model. **Because of this, all Kenergy plots show 2025 data for Jan–April, and 2024 data for May–Dec.**



Note: The displayed demand data excludes one high-use industrial customer.

Kenergy – Annual Residential Demand



The residential demand curve for derConsumer was created by scaling the utility's system demand curve down by the total number of meters served – 60,620. However, this includes about 1,371 commercial customers, which tend to need more power than residential ones, so this demand curve is likely larger than an actual residential demand curve.

Kenergy – Energy & Demand Tariffs

Residential Tariff

\$0.110529/kWh
all day, every day

Wholesale Tariff

Month	Peak Demand Charge (\$/kW)	Energy Cost (\$/kWh)
Jan	13.805	0.095526
Feb	13.805	0.089855
Mar	13.805	0.098979
April	13.805	0.095291
May	13.805	0.087899
June	13.805	0.089557
July	13.805	0.092341
Aug	13.805	0.095864
Sept	13.805	0.103616
Oct	13.805	0.104169
Nov	13.805	0.095125
Dec	13.805	0.099309

Kenergy derUtilityCost Scenario 1: Base Case

Kenergy – Scenario 1 derUtilityCost Inputs

The Scenario 1 Base Case assumes no initial subsidies in order to determine the baseline annual value for each DER technology.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Participation Level (out of 59,249 residential meters)
BESS	0	0	1% (592)
GEN	-	-	-
Water Heater	0	0	¹ 53% (31,501)
Heat Pump	0	0	² 19% (11,241)
Air Conditioner	0	0	³ 73% (43,193)

[1] [Table HC8.6 Water heating in U.S. homes, by climate region, 2020](#)

[2] [Table HC6.6 Space heating in U.S. homes, by climate region, 2020](#)

[3] [Table HC7.6 Air conditioning in U.S. homes, by climate region, 2020](#)

Generators will be considered in future work

The participation levels were calculated based on the 2020 Residential Energy Consumption Survey (U.S. Energy Information Administration, Office of Energy Demand and Integrated Statistics, Form EIA-457A) *

*Kenergy's climate is considered "Mixed-Humid" for these calculations

All subsidies are set to 0 to determine the base level annual value of all DER technologies

Kenergy – Scenario 1 Inputs

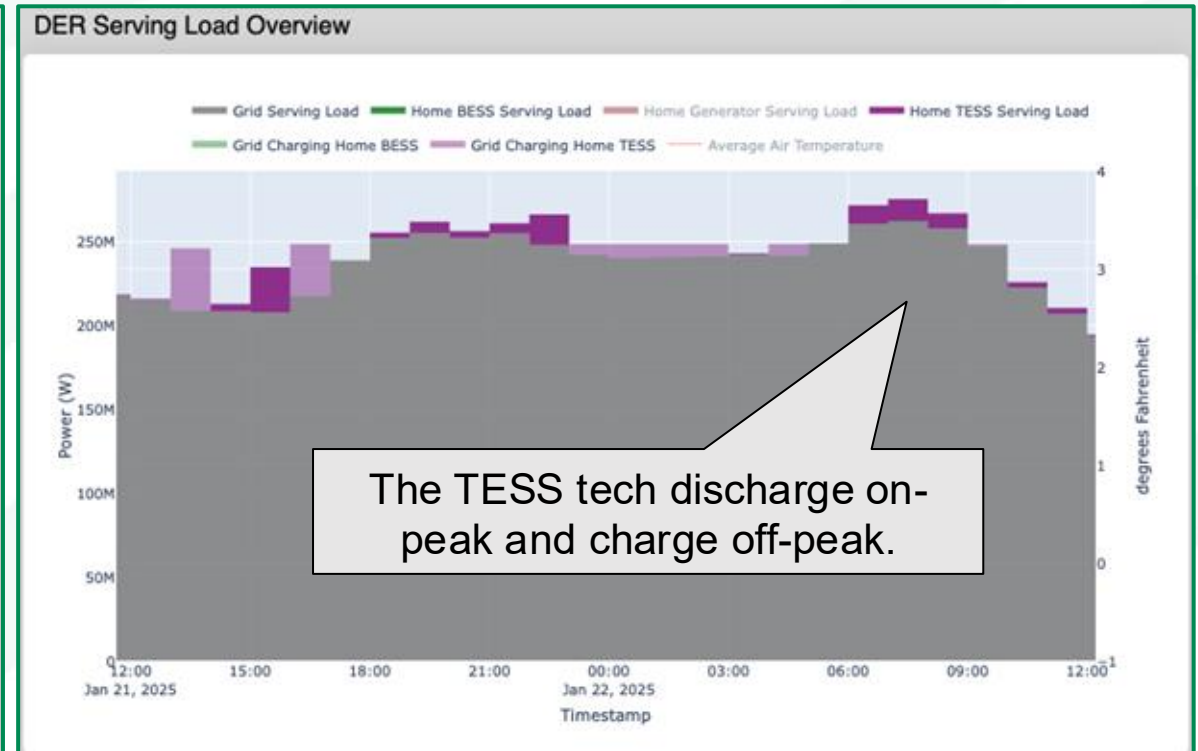
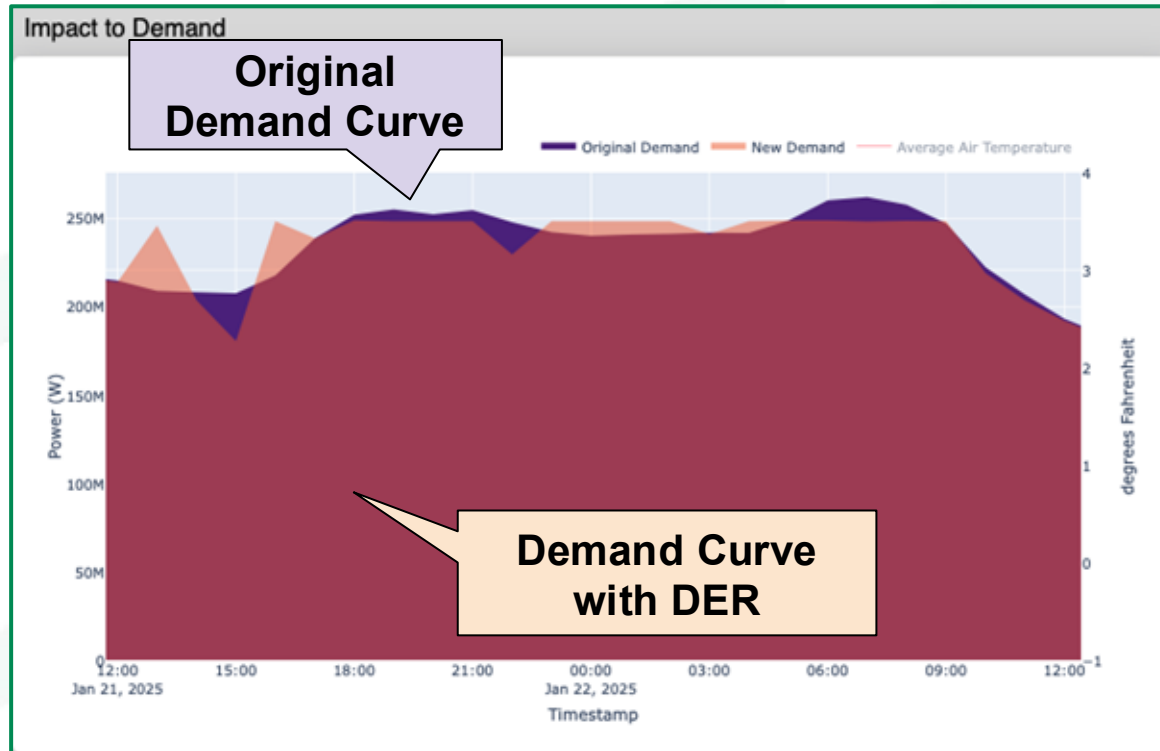
General Model Inputs		
Demand Curve (.csv file) Choose File Kenergy - System Demand_kw	Temperature Curve in °F (.csv file) Choose File Kenergy - Temperature_degF_	Latitude 37.760586
Longitude -87.127686	Year 2025	Use the user-provided random numbers? No
Random Seed - BESS & GEN 2147483647	Random Seed - AC 2147483647	Random Seed - HP 2147483647
Random Seed - WH 2147483647	Random Numbers for Water Heater (.csv file) Choose File example_water_heater_random	
Financial Inputs		
Use Wholesale Energy & Demand Rate Structure (.json) file? ☒	Wholesale Energy & Demand Rate Structure (.json file) Choose File Kenergy_wholesale_tariff.json	(Optional) Wholesale Energy Rate Curve (.csv file) Choose File example_TODRate66a13566e9f
(Optional) Monthly Demand Charges (.csv file) Choose File example_utility_monthly_dema	Financial Projection Length (years) 25	Discount Rate (%) 1
Program Startup Costs (\$) 0	Ongoing Operational Costs (\$/month) 0	One-time Operational Costs (\$) 0
Home BESS - Upfront Subsidy Amount (\$) 0	Home BESS - Monthly Recurring Subsidy Amount (\$) 0	Home Heat Pumps - Upfront Subsidy Amount (\$) 0
Home Heat Pumps - Monthly Recurring Subsidy Amount (\$) 0	Home Air Conditioners - Upfront Subsidy Amount (\$) 0	Home Air Conditioners - Monthly Recurring Subsidy Amount (\$) 0
Home Water Heaters - Upfront Subsidy Amount (\$) 0	Home Water Heaters - Monthly Recurring Subsidy Amount (\$) 0	Home Generators - Upfront Subsidy Amount (\$) 0
Home Generators - Monthly Recurring Subsidy Amount (\$) 0		
Home Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Number of Devices 5
Rated Power Capacity (kW) 20	Available Fuel 95	Fuel Cost 3.49

Home Chemical Battery Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Number of Home Chemical Batteries 592	Portion of Charge Used by Utility (%) 20.0
Home Battery Power Capacity (kW) 5.0	Home Battery Energy Capacity (kWh) 13.5	
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Number of Devices 43193	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Number of Devices 11241	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Number of Devices 31501	Rated Power (kW) 4.5
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	

[Delete](#) [Run Model](#) [Share](#) [Duplicate](#)

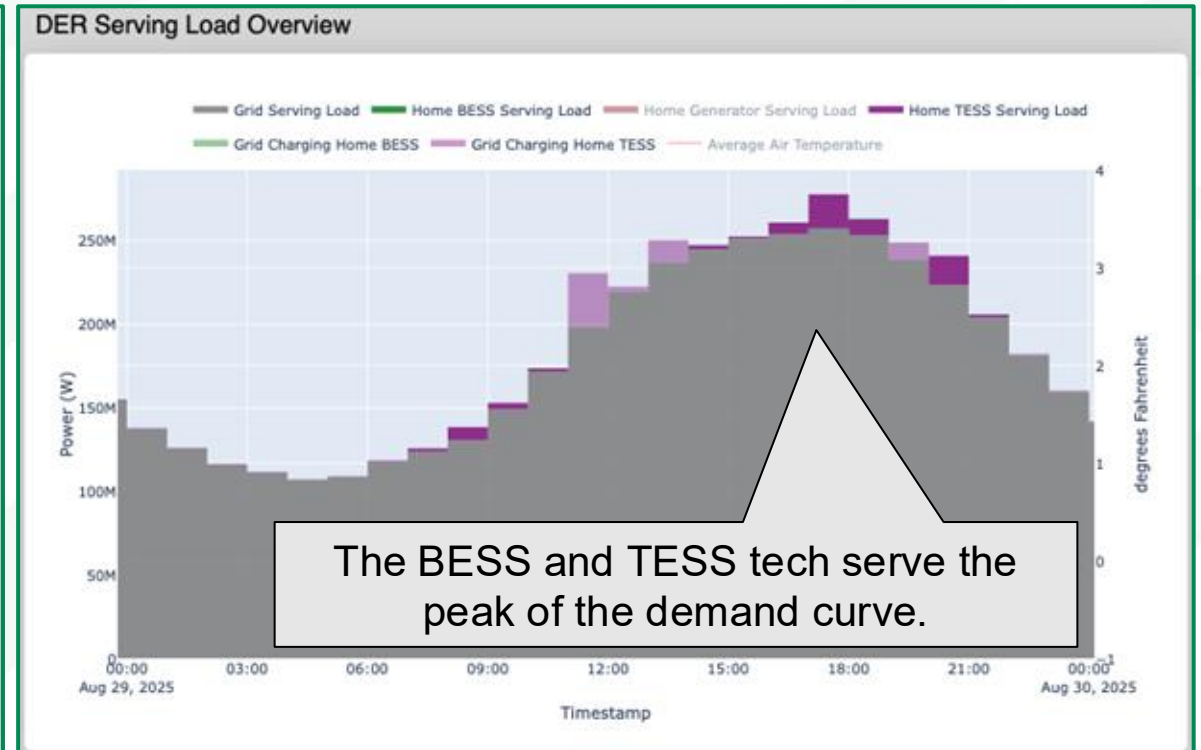
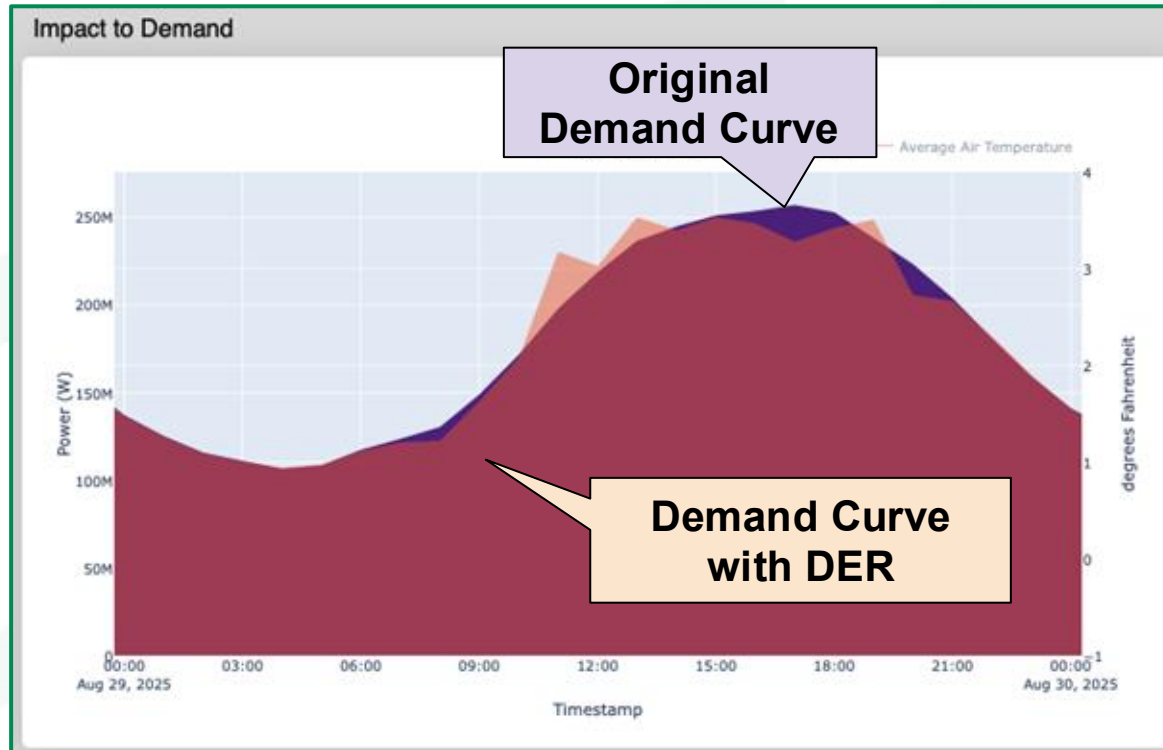
Kenergy – Scenario 1 derUtilityCost Outputs

Winter peak – January 21-22, 2025



Kenergy – Scenario 1 derUtilityCost Outputs

Summer peak – August 29, 2024



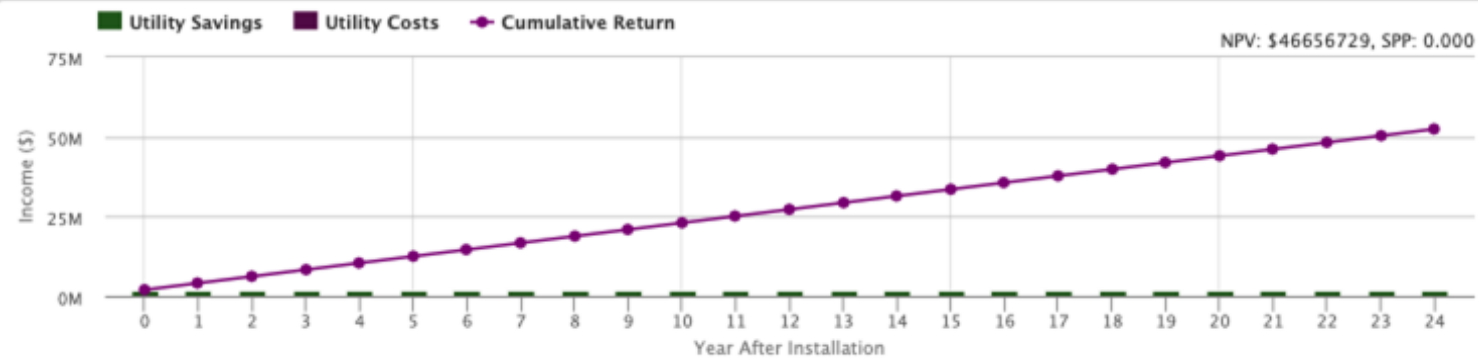
Kenergy – Scenario 1 derUtilityCost Outputs

Monthly Cost Comparison												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	262,328	246,070	176,642	162,319	198,771	238,681	245,600	257,308	228,085	180,078	162,268	221,736
Total Adjusted Peak Demand (kW)	249,096	233,555	165,817	151,813	190,480	230,651	236,983	250,315	219,109	174,904	156,807	202,867
Demand Charge (\$)	3,621,438	3,396,996	2,438,543	2,240,814	2,744,034	3,294,991	3,390,508	3,552,137	3,148,713	2,485,977	2,240,110	3,061,065
Adjusted Demand Charge (\$)	3,438,770	3,224,232	2,289,108	2,095,772	2,629,570	3,184,137	3,271,552	3,455,600	3,024,802	2,414,548	2,164,727	2,800,584
Demand Cost Savings (\$)	182,668	172,764	149,435	145,042	114,464	110,854	118,956	96,536	123,911	71,429	75,382	260,482
Energy (kWh)	122,981,070	96,886,981	78,407,586	70,406,656	81,951,397	100,104,053	112,068,543	109,077,093	89,920,154	74,625,009	76,091,844	98,271,573
Adjusted Energy (kWh)	122,534,485	96,538,522	78,073,901	70,177,346	81,668,739	99,483,536	111,356,688	108,397,175	89,473,390	74,339,638	75,840,400	97,913,779
Energy Cost (\$)	11,747,767	8,705,586	7,760,234	6,708,557	7,203,364	8,964,718	10,348,185	10,456,021	9,316,627	7,773,090	7,237,932	9,759,055
Adjusted Energy Cost (\$)	11,705,107	8,674,276	7,727,208	6,686,708	7,178,519	8,909,149	10,282,454	10,390,845	9,270,338	7,743,365	7,214,015	9,723,524
Energy Cost Savings (\$)	42,660	31,310	33,026	21,849	24,845	55,570	65,731	65,176	46,289	29,725	23,918	35,531
Total Cost of Service (\$)	15,369,205	12,102,582	10,198,777	8,949,371	9,947,398	12,259,710	13,738,693	14,008,158	12,465,341	10,259,067	9,478,042	12,820,121
Adjusted Total Cost of Service (\$)	15,143,876	11,898,508	10,016,316	8,782,480	9,808,089	12,093,285	13,554,006	13,846,445	12,295,140	10,157,913	9,378,742	12,524,107
Total Consumer Compensation (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Program Startup and Operational Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Utility Savings (\$)	225,328	204,074	182,461	166,891	139,309	166,424	184,687	161,713	170,201	101,154	99,300	296,013
Total Utility Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Net Utility Savings (\$)	225,328	204,074	182,461	166,891	139,309	166,424	184,687	161,713	170,201	101,154	99,300	296,013

The initial subsidies and startup costs are zero in Scenario 1 to show the Total Utility Savings from DER alone.

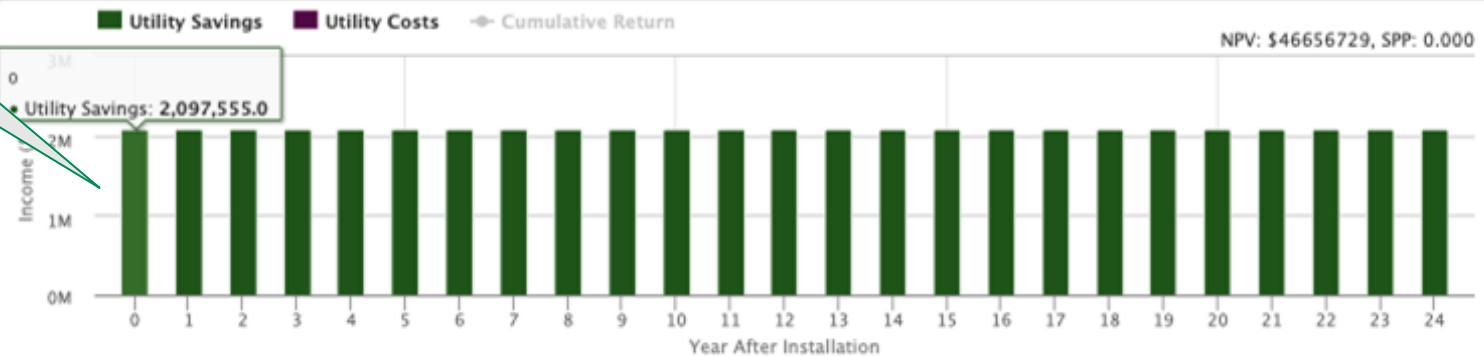
Kenergy – Scenario 1 derUtilityCost Outputs

Cash Flow Projection



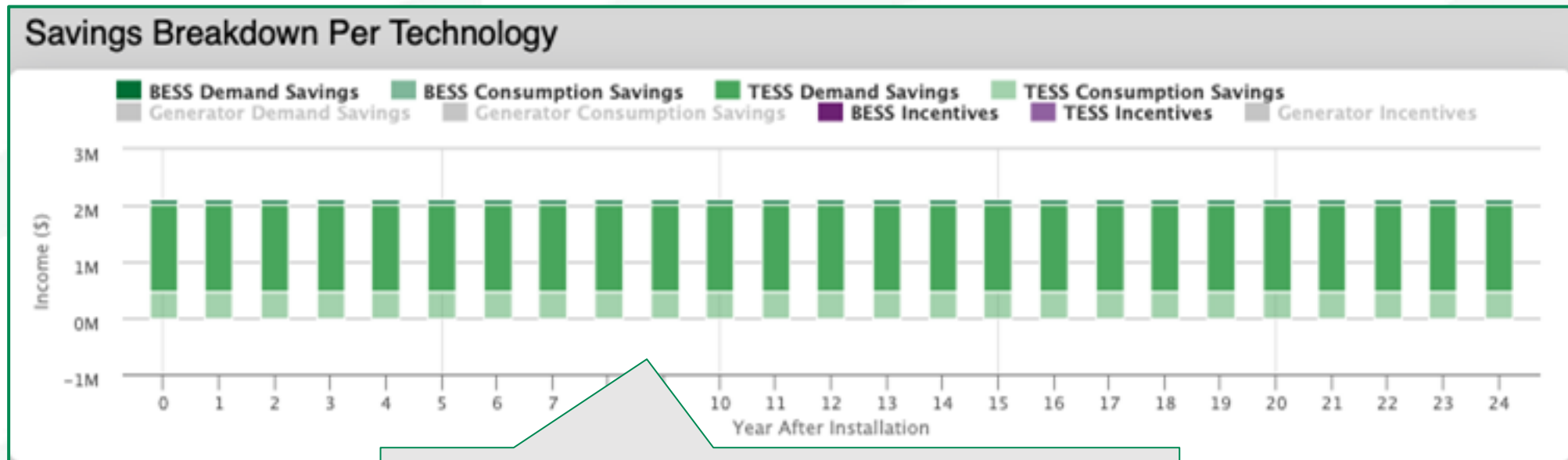
In this Scenario, the annual value of all DER is about \$2,097,555

Cash Flow Projection



The Simple Payback Period = 0 years, showing that the program pays itself immediately (since there are no subsidies or costs in this Scenario)

Kenergy – Scenario 1 derUtilityCost Outputs



This shows the costs and savings breakdown of the BESS and TESS technologies in terms of peak demand savings and kWh consumption savings. Recall that the TESS is a combination of all the thermal devices.

Kenergy – Scenario 1 derUtilityCost Outputs

BESS Savings vs. Incentives

The annual value of the BESS can be determined by adding the Demand Savings and Consumption Savings together. Since Scenario 1 has no subsidies, there are no incentive costs shown.

e.g. Annual BESS Demand Savings + BESS Consumption Savings = \$67,070

Savings Breakdown Per Technology

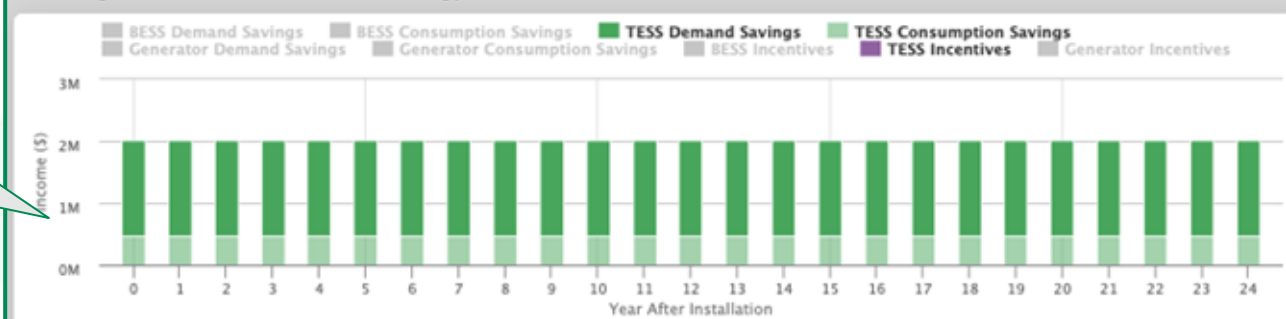


All TESS Savings vs. Incentives

The annual value of the TESS can be determined by adding the Demand Savings and Consumption Savings together. Since Scenario 1 has no subsidies, there are no incentive costs shown.

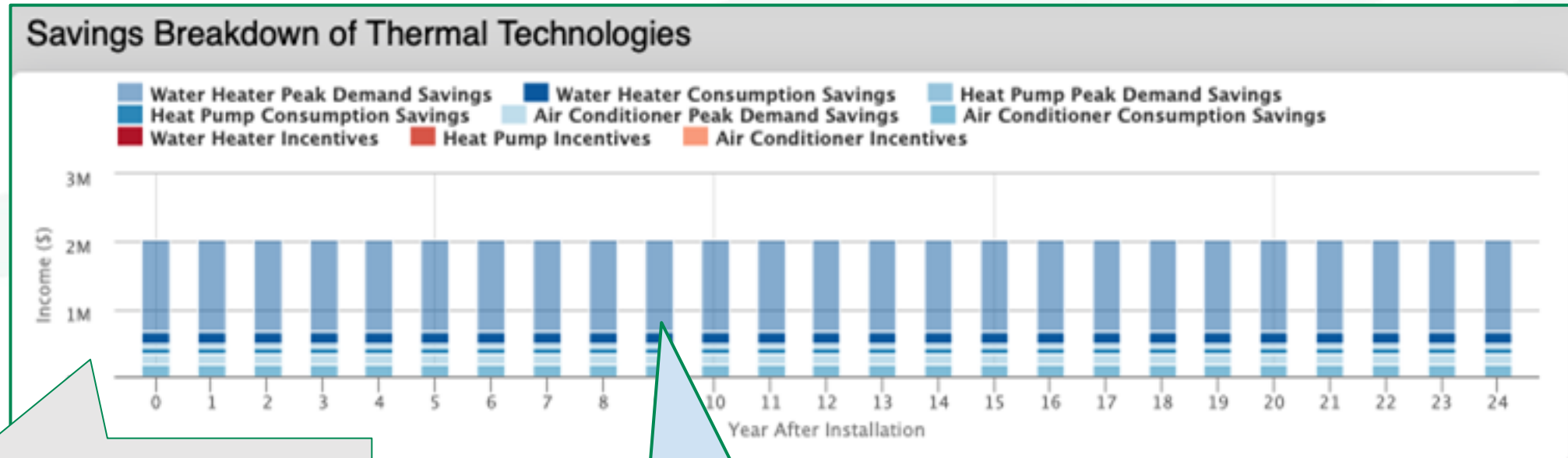
e.g. Annual TESS Demand Savings + TESS Consumption Savings = \$2,030,484

Savings Breakdown Per Technology



Note: The Y-axis scale is not the same between the two plots. See the previous slide for a better side-by-side comparison between TESS and BESS.

Kenergy – Scenario 1 derUtilityCost Outputs



This shows the annual breakdown of the costs and savings for all TESS technologies: Water Heaters, Air Conditioners, and Heat Pumps.

Most of the savings come from the Water Heaters, which Kenergy listed as #3 in the Tech Preferences

Kenergy's Tech Preferences

- #1 = Heat Pump (and Resistance Heating)
- #2 = Central AC
- #3 = Water Heater
- #4 = Fossil Fuel Generators
- #5 = BESS

Kenergy – Scenario 1 derUtilityCost Outputs

Water Heater Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$1,547,744

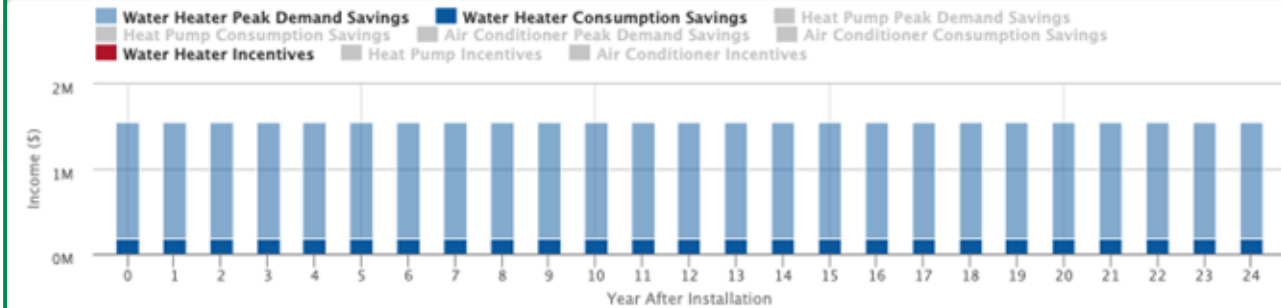
Air Conditioner Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$335,860

Heat Pump Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$146,881

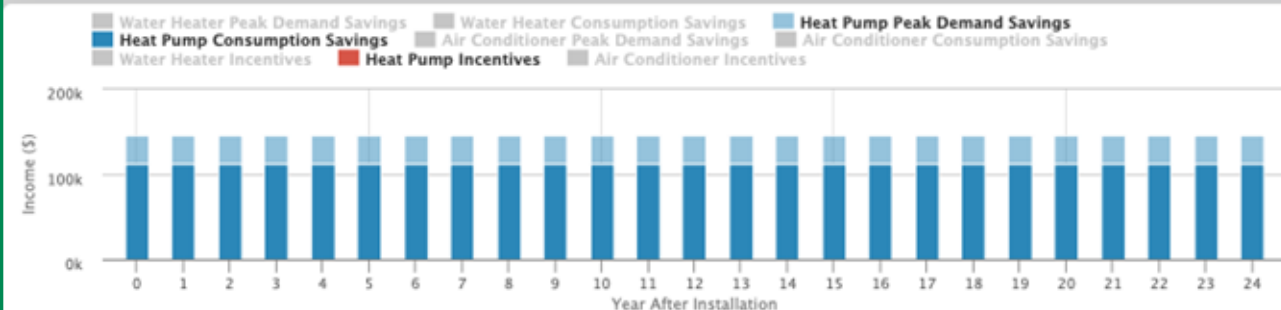
Savings Breakdown of Thermal Technologies



Savings Breakdown of Thermal Technologies



Savings Breakdown of Thermal Technologies



Kenergy – Scenario 1 derUtilityCost Outputs

Tech	Total Annual Savings (kW Demand Savings + kWh Consumption Savings)	Number of Devices	Annual Value of DER per device	Monthly Subsidy (Total Annual Savings / Number of Devices / 12 months)
BESS	\$67,070	592	\$113	\$9.44
Air Conditioner	\$335,860	43193	\$8	\$0.65
Water Heater	\$1,547,744	31501	\$49	\$4.09
Heat Pump	\$146,881	11241	\$13	\$1.09

Annual value per device with no subsidies included

These monthly subsidies will be used as inputs in Kenergy's derUtilityCost Scenario 2 and derConsumer runs

Example Monthly Subsidy calculation:

If Water Heaters saved \$1,547,744 for the year, then the annual value of water heaters per device would be $\$1,547,744 / 31,501$ water heaters = \$49 per water heater per year. That value could be used to determine a monthly subsidy = $\$49 / 12$ months = \$4.09/month (assuming no upfront subsidies).

Kenergy derUtilityCost Scenario 2: Adjusted Subsidies

Kenergy – Scenario 2: Adjusted Subsidies

Scenario 2 consiDER a program where the participation levels remain the same, but the subsidies are adjusted based on the results from Scenario 1.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Participation Level (out of 59,249 residential meters)
BESS	0	\$9.44	1% (592)
Air Conditioner	0	\$0.65	73% (43,193)
Water Heater	0	\$4.09	53% (31,501)
Heat Pump	0	\$1.09	19% (11,241)
GEN	-	-	-

The monthly subsidies calculated from Scenario 1 are used as the starting inputs for Scenario 2.

The participation levels are kept the same

Kenergy – Scenario 2: Adjusted Subsidies

In order to reproduce the same model results as Scenario 1 and only change the subsidies, the random seeds and random numbers in Scenario 2 must be set to the same numbers produced in Scenario 1, which can be found in the outputs at the bottom of the model.

Scenario 1 outputs:

Raw Input and Output Files

random_seeds.csv – water_heater_random_numbers.csv – demand.csv – Scenario_test_POST.json – REoptInputs.json – vbatDispatch_inputs_hp.json – temperature_input_derUtilityCost.csv – reopt_input_scenario.json – vbatDispatch_inputs_wh.json – results.json – vbatDispatch_results_hp.json – Plot_DerServingLoadOverview.html – vbatDispatch_results_wh.json – Plot_NewDemand.html – vbatDispatch_inputs_ac.json – PPID.txt – stderr.txt – PuLP_random_seeds.csv – random_seeds.txt – vbatDispatch_results_ac.json – temperature.csv – wholesale_rate_structure_input_derUtilityCost.json – input_temperature.csv – demand_input_derUtilityCost.csv – input_demand.csv – input_wholesale_rate_structure.json – Plot_ThermalDERServingLoadOverview.html – allInputData.json – allOutputData.json

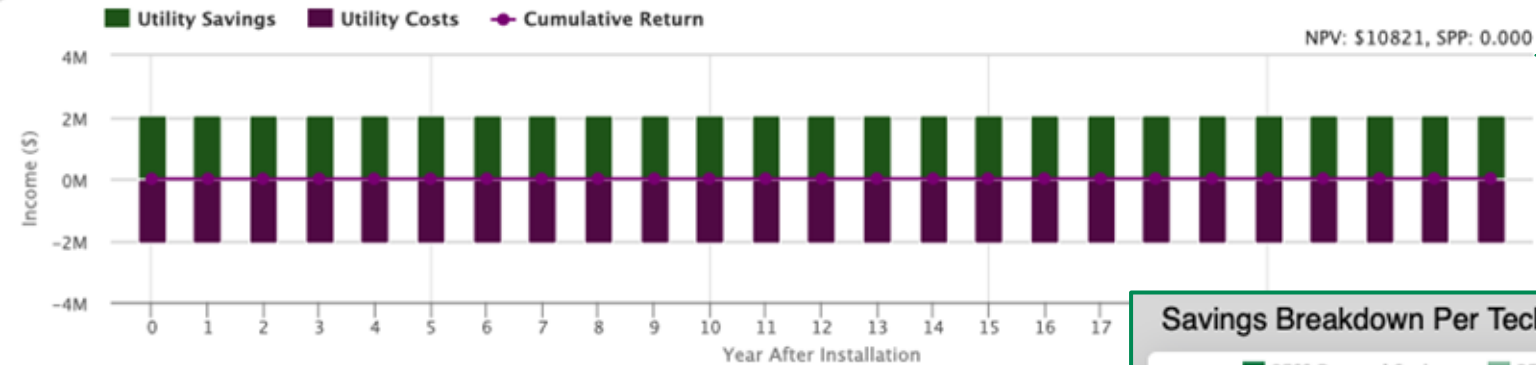
Scenario 2 inputs:

General Model Inputs

Demand Curve (.csv file) Choose File Kenergy - System Demand_kw_	Temperature Curve in °F (.csv file) Choose File Kenergy - Temperature_degF_J	Latitude 37.760586
Longitude -87.127686	Year 2025	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 274512714	Random Seed - AC 546948094	Random Seed - HP 258532281
Random Seed - WH 1706383983	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_numbers	

Kenergy – Scenario 2 derUtilityCost Outputs

Cash Flow Projection



The SPP is 0 since the subsidy costs are roughly equal to the DER savings, and there are no other initial costs. The NPV, however, is expected to be close to zero for this break-even scenario, but it is nonzero due to rounded numbers and the number of decimal precision in the input values.

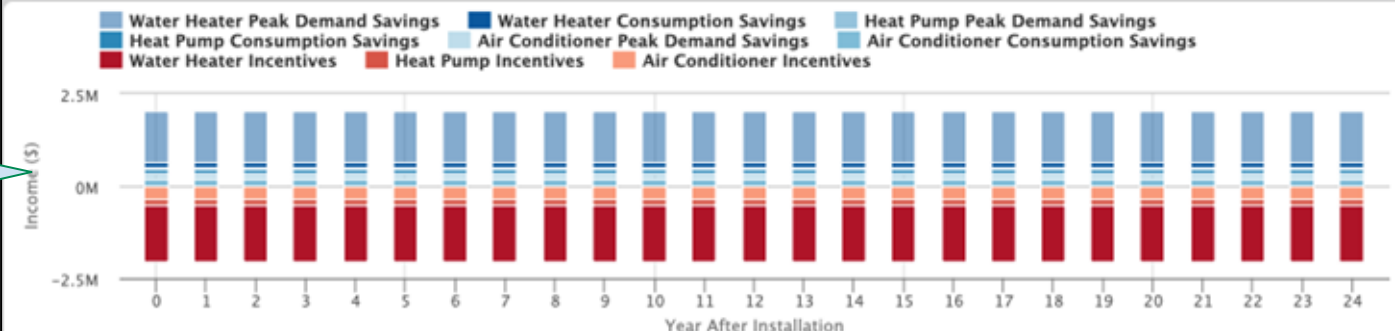
The annual BESS subsidies are roughly comparable to the annual BESS savings

Savings Breakdown Per Technology



The annual TESS subsidies are roughly comparable to the annual TESS savings

Savings Breakdown of Thermal Technologies



Kenergy – Scenario 2 derUtilityCost Outputs

Monthly Cost Comparison

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	262,328	246,070	176,642	162,319	198,771	238,681	245,600	257,308	228,085	180,078	162,268	221,736
Total Adjusted Peak Demand (kW)	249,096	233,555	165,817	151,813	190,480	230,651	236,983	250,315	219,109	174,904	156,807	202,867
Demand Charge (\$)	3,621,438	3,396,996	2,438,543	2,240,814	2,744,034	3,294,991	3,390,508	3,552,137	3,148,713	2,485,977	2,240,110	3,061,065
Adjusted Demand Charge (\$)	3,438,770	3,224,232	2,289,108	2,095,772	2,629,570	3,184,137	3,271,552	3,455,600	3,024,802	2,414,548	2,164,727	2,800,584
Demand Cost Savings (\$)	182,668	172,764	149,435	145,042	114,464	110,854	118,956	96,536	123,911	71,429	75,382	260,482
Energy (kWh)	122,981,070	96,886,981	78,407,586	70,406,656	81,951,397	100,104,053	112,068,543	109,077,093	89,920,154	74,625,009	76,091,844	98,271,573
Adjusted Energy (kWh)	122,534,485	96,538,522	78,073,901	70,177,346	81,668,739	99,483,536	111,356,688	108,397,175	89,473,390	74,339,638	75,840,400	97,913,779
Energy Cost (\$)	11,747,767	8,705,586	7,760,234	6,708,557	7,203,364	8,964,718	10,348,185	10,456,021	9,316,627	7,773,090	7,237,932	9,759,055
Adjusted Energy Cost (\$)	11,705,107	8,674,276	7,727,208	6,686,708	7,178,519	8,909,149	10,282,454	10,390,845	9,270,338	7,743,365	7,214,015	9,723,524
Energy Cost Savings (\$)	42,660	31,310	33,026	21,849	24,845	55,570	65,731	65,176	46,289	29,725	23,918	35,531
Total Cost of Service (\$)	15,369,205	12,102,582	10,198,777	8,949,371	9,947,398	12,259,710	13,738,693	14,008,158	12,465,341	10,259,067	9,478,042	12,820,121
Adjusted Total Cost of Service (\$)	15,143,876	11,898,508	10,016,316	8,782,480	9,808,089	12,093,285	13,554,006	13,846,445	12,295,140	10,157,913	9,378,742	12,524,107
Total Consumer Compensation (\$)	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756
Program Startup and Operational Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Utility Savings (\$)	225,328	204,074	182,461	166,891	139,309	166,424	184,687	161,713	170,201	101,154	99,300	296,013
Total Utility Costs (\$)	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756	174,756
Net Utility Savings (\$)	50,573	29,318	7,705	-7,864	-35,447	-8,331	9,931	-13,043	-4,555	-73,602	-75,456	121,258

The Total Utility Savings are the same from Scenario 1, but now we see the Total Utility Costs, which are comprised of the subsidies paid to the consumer

Program Startup and Operational Costs could also be added in future scenarios

Kenergy derConsumer model

Kenergy – derConsumer Inputs

General Model Inputs		
Demand Curve (.csv file) Choose File residential_Kenergy_kw_Jan20	Temperature Curve in °F (.csv file) Choose File Kenergy - Temperature_degF_	Latitude 37.760586
Longitude -87.127686	Year 2025	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 274512714	Random Seed - AC 546948094	Random Seed - HP 258532281
Random Seed - WH 1706383983	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_number	
Financial Inputs		
Use URDB Label? ☐	URDB Label 66a13566e90ecdb7d40581d2	(Optional) Residential Rate Structure (.json file) Choose File Kenergy - Residential_tariff.json
Discount Rate (%) 1	Financial Projection Length (years) 25	Home BESS - Upfront Subsidy Amount (\$) 0
Home BESS - Monthly Recurring Subsidy Amount (\$) 9.44	Home Heat Pump - Upfront Subsidy Amount (\$) 0	Home Heat Pump - Monthly Recurring Subsidy Amount (\$) 1.09
Home Air Conditioner - Upfront Subsidy Amount (\$) 0	Home Air Conditioner - Monthly Recurring Subsidy Amount (\$) 0.65	Home Water Heater - Upfront Subsidy Amount (\$) 0
Home Water Heater - Monthly Recurring Subsidy Amount (\$) 4.09	Home Generator - Upfront Subsidy Amount (\$) 0	Home Generator - Monthly Recurring Subsidy Amount (\$) 0
Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Rated Power Capacity (kW) 5
Efficiency (%) 35	Retrofit Cost (\$) 0.0	Available Fuel 1000
Fuel Cost 3.80	Generator Replacement Cost (\$/kW) 0.0	Generator Lifetime (years) 15

Chemical Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Battery Power Capacity (kW) 5.0	Battery Energy Capacity (kWh) 13.5
Retrofit Cost (\$) 0.0	Portion of Charge Shared with Utility (%) 20	Battery Replacement Power Cost (\$/kW) 0.0
Battery Replacement Energy Cost (\$/kWh) 0.0	Battery Lifetime (years) 10	Inverter Replacement Cost (\$) 0.0
Inverter Lifetime (years) 10		
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 150
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 0
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Rated Power (kW) 4.5	Retrofit Cost (\$) 175
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	
Delete Run Model Share Duplicate		

Kenergy – derConsumer Inputs

The derConsumer model provides the member-consumer point of view. The results shown here reflect the adjusted subsidies obtained through derUtilityCost under scenario 2.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Consumer Retrofit Costs (\$)
BESS	0	\$9.44	0
Air Conditioner	0	\$0.65	150 (<u>Nest Thermostat</u>)
Water Heater	0	\$4.09	175 (<u>Aquanta Controller</u>)
Heat Pump	0	\$1.09	0
Generator	-		-

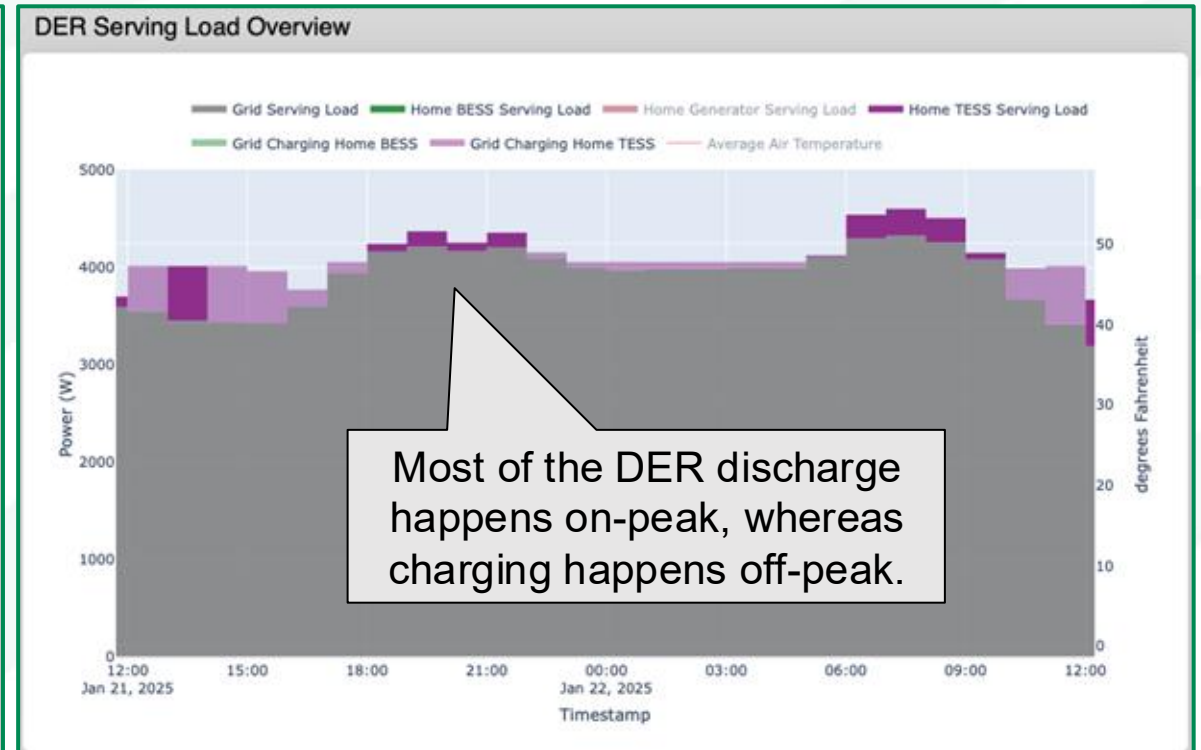
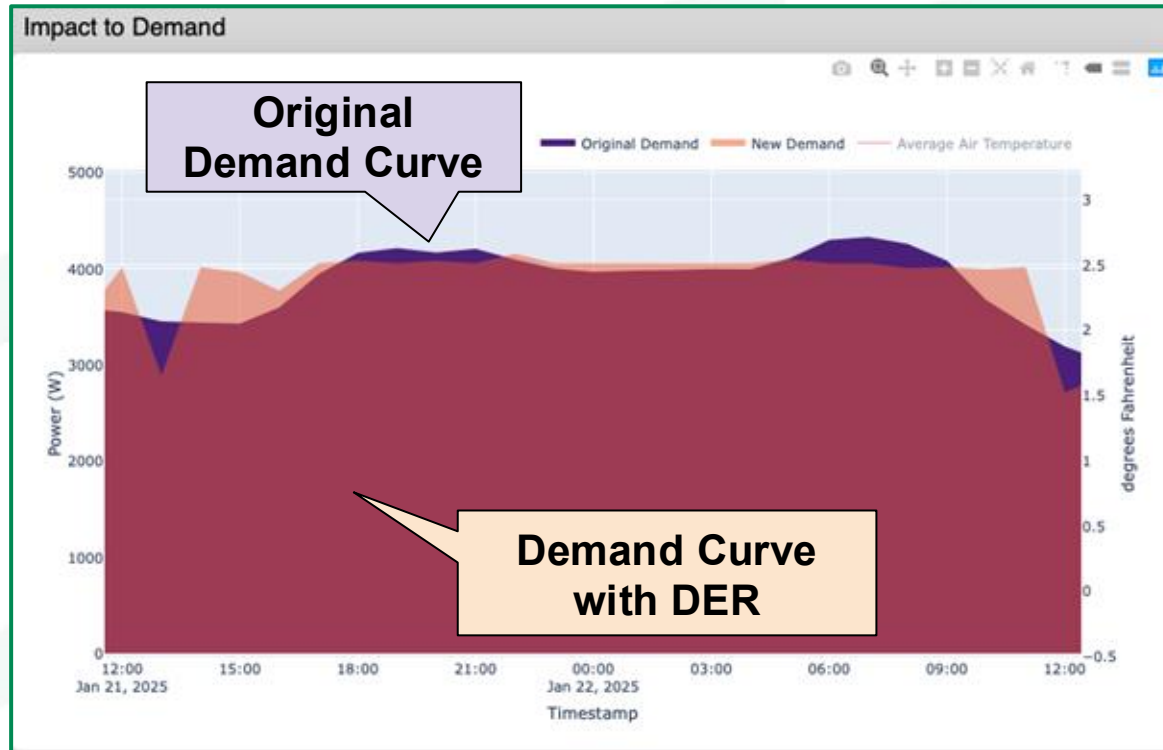
Approx. cost to equip the device to respond to the utility's load control signals. (e.g. Smart Thermostat, Wi-Fi enabled smart plug, etc.) Note: The companies listed here are only examples, not endorsements.

These are the same subsidies used in the derUtilityCost Adjusted Subsidies case. Using them in derConsumer will show how these subsidies look from the perspective of a hypothetical member-consumer.

The Heat Pump retrofit cost is \$0 because it's the same smart thermostat that is used for the Air Conditioner.

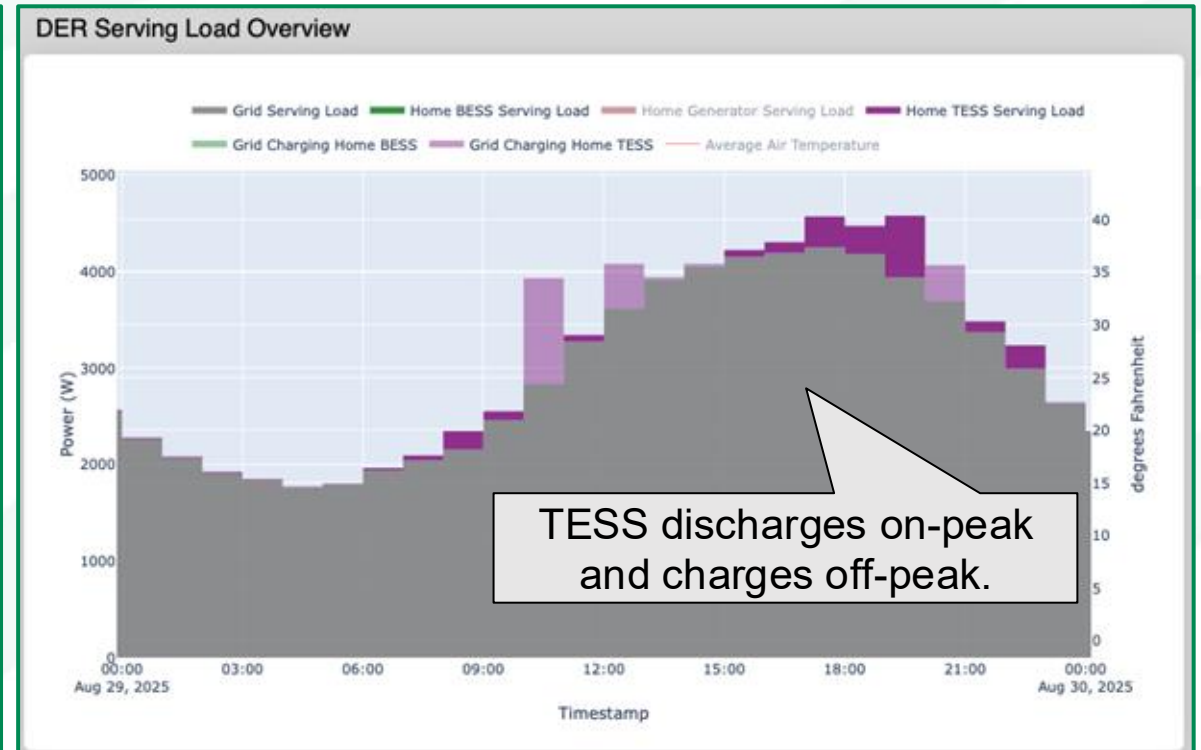
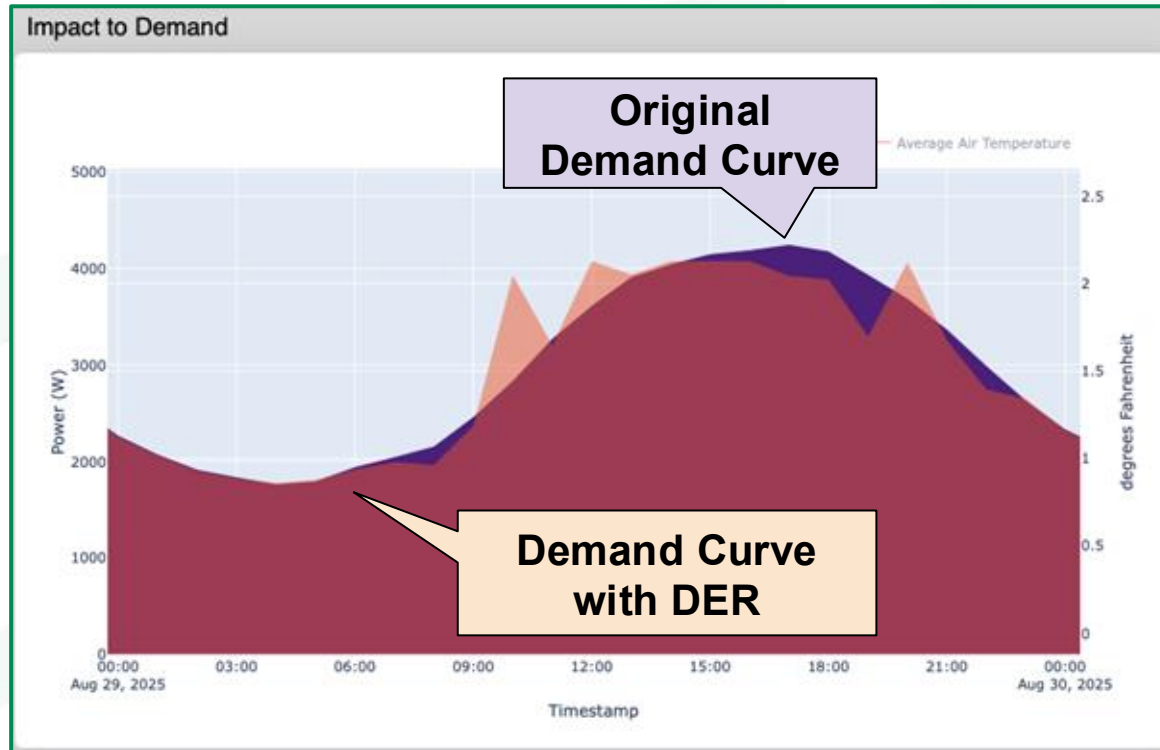
Kenergy – derConsumer Outputs

Winter peak – January 21-22, 2024

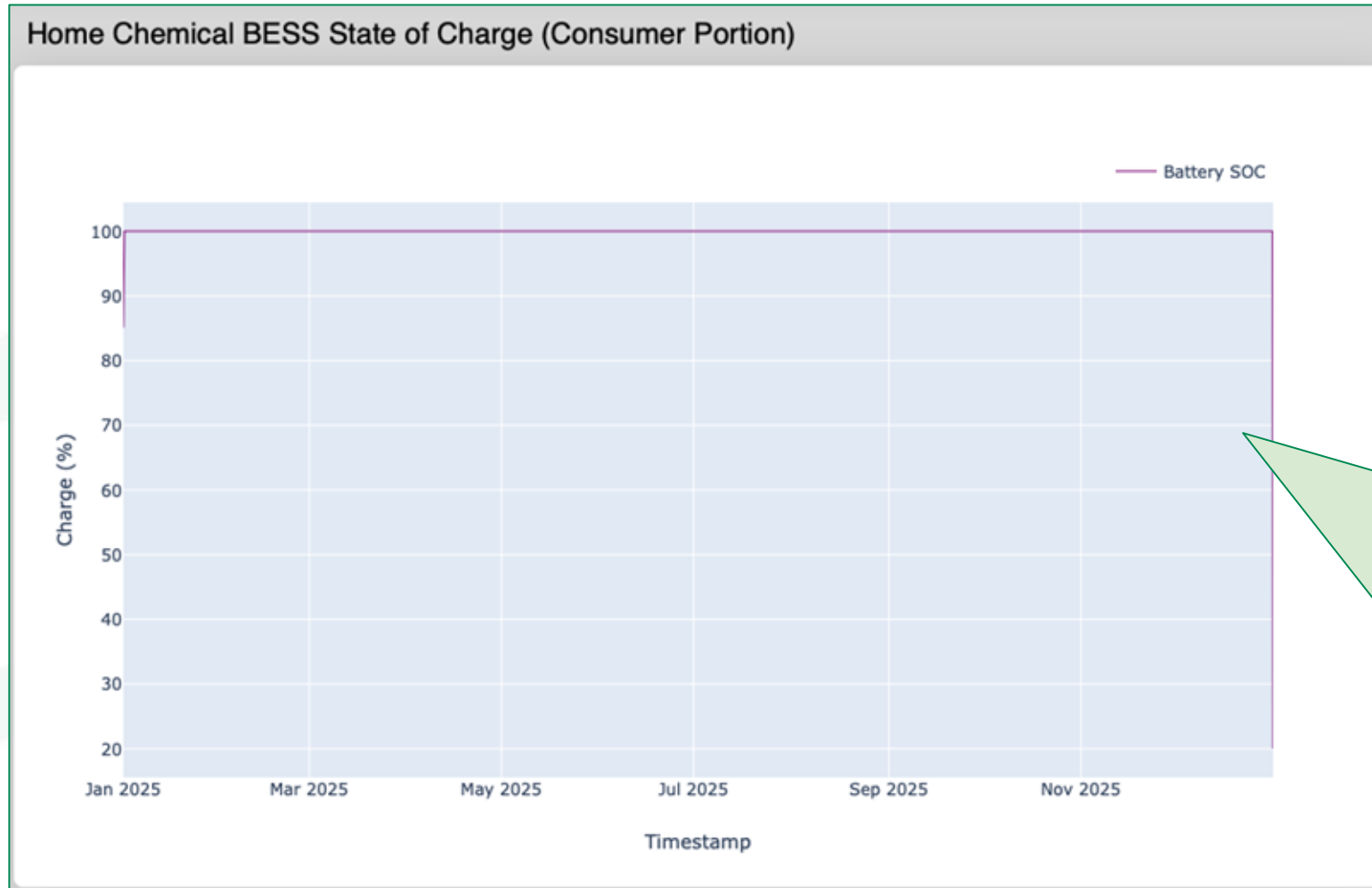


Kenergy – derConsumer Outputs

Summer peak – August 29, 2025



Kenergy – derConsumer Outputs



The consumer BESS results show no usage throughout the year (except for the beginning and end of the year, which might be an artifact from REopt's optimization code).

This is likely because Kenergy's residential tariff is a flat rate per month with no opportunity for energy arbitrage while also considering round trip energy losses.

Kenergy also listed BESS as their least preferred DER technology in this analysis.

Kenergy – derConsumer Outputs

Monthly Cost Comparison

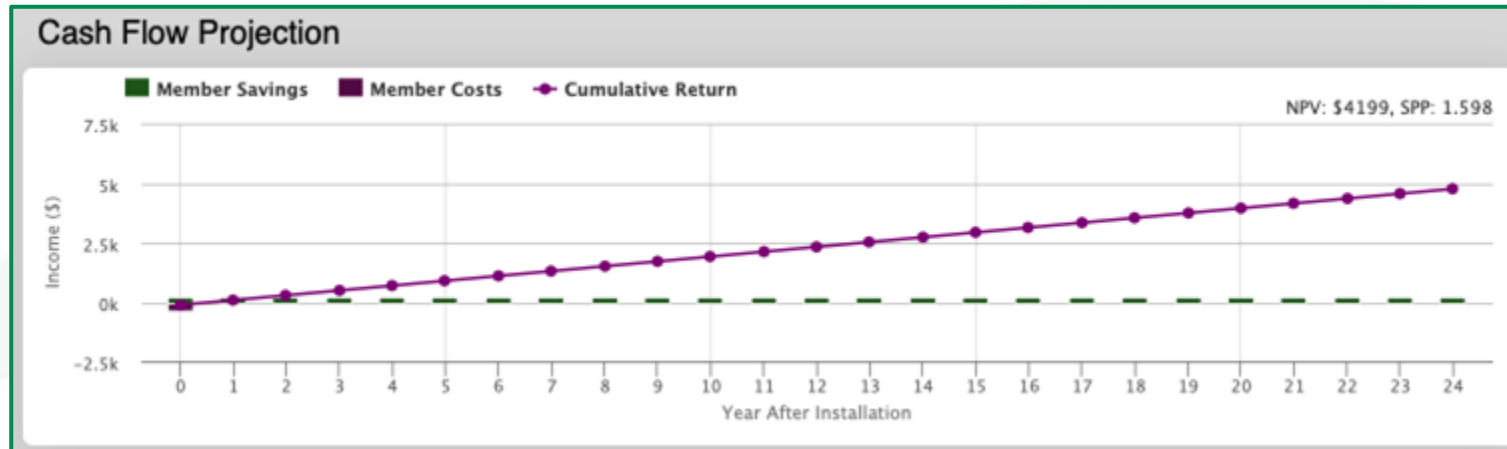
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	4	4	3	3	3	4	4	4	4	3	3	4
Total Adjusted Peak Demand (kW)	6	4	3	2	3	4	4	4	4	3	3	3
Energy (kWh)	2,029	1,598	1,293	1,161	1,352	1,651	1,849	1,799	1,483	1,231	1,255	1,621
Adjusted Energy (kWh)	2,006	1,576	1,279	1,152	1,347	1,636	1,833	1,784	1,473	1,223	1,242	1,590
Energy Cost (\$)	224	177	143	128	149	183	204	199	164	136	139	179
Adjusted Energy Cost (\$)	222	174	141	127	149	181	203	197	163	135	137	176
Energy Cost Savings (\$)	3	2	2	1	1	2	2	2	1	1	1	3
Demand Charge (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Adjusted Demand Charge (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Demand Cost Savings (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Cost of Service (\$)	224	177	143	128	149	183	204	199	164	136	139	179
Adjusted Total Cost of Service (\$)	222	174	141	127	149	181	203	197	163	135	137	176
Generator Fuel Cost (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Utility Subsidies Paid (\$)	15	15	15	15	15	15	15	15	15	15	15	15
Total Consumer Savings (\$)	18	18	17	16	16	17	17	17	16	16	17	19
Total Consumer Costs (\$)	325	0	0	0	0	0	0	0	0	0	0	0
Net Consumer Savings (\$)	307	18	17	16	16	17	17	17	16	16	17	19

Cost of Service is sometimes increased, sometimes decreased by utility control of DER; This is why a full year is modeled.

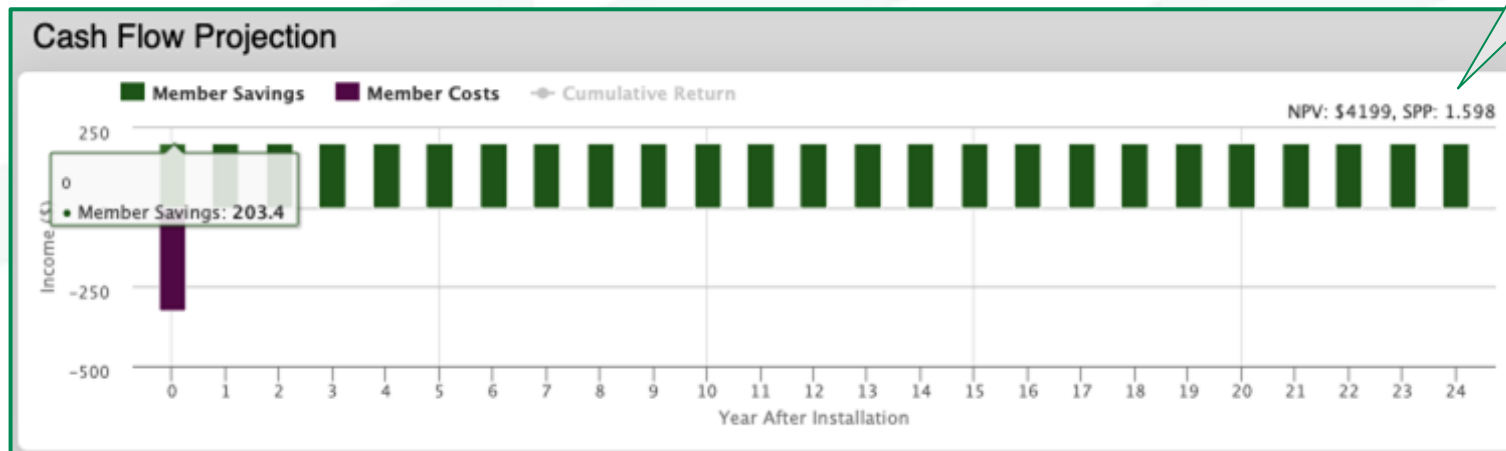
The Total Consumer Costs come from the retrofit and controller device costs.

The Utility Subsidies Paid each month is roughly \$15. The consumer also saves money from having the thermal DER. Overall, 88% of the consumer's overall annual savings came from utility subsidies.

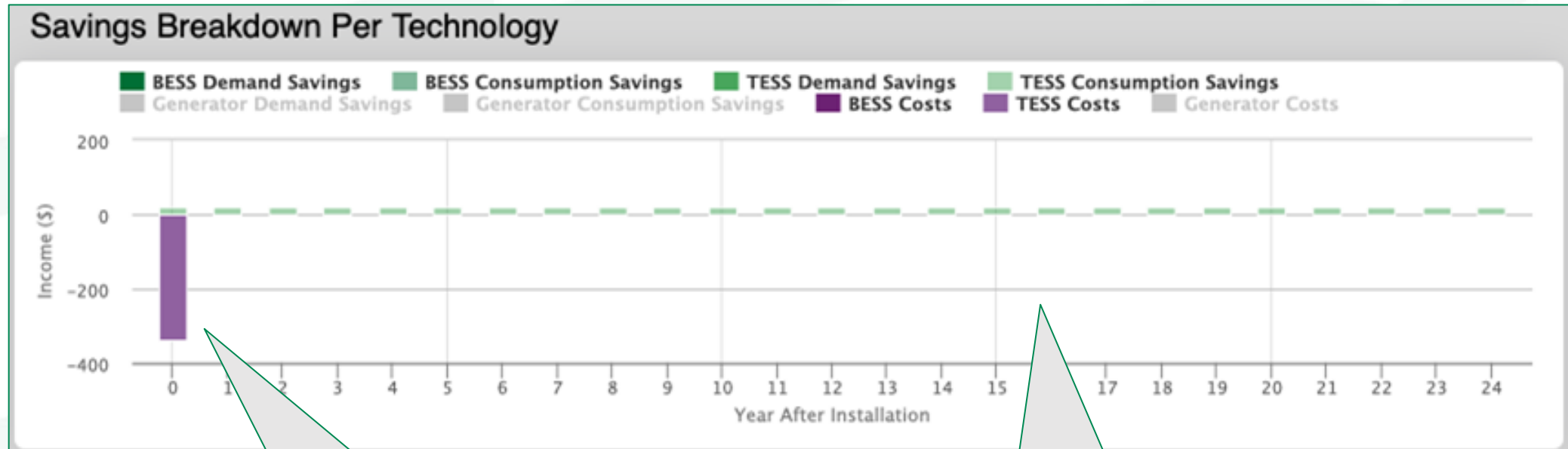
Kenergy – derConsumer Outputs



The SPP is positive, meaning the program will pay the consumer back in about 1.6 years.



Kenergy – derConsumer Outputs



Thermal DER retrofit costs

Most of the savings come from the thermal DER

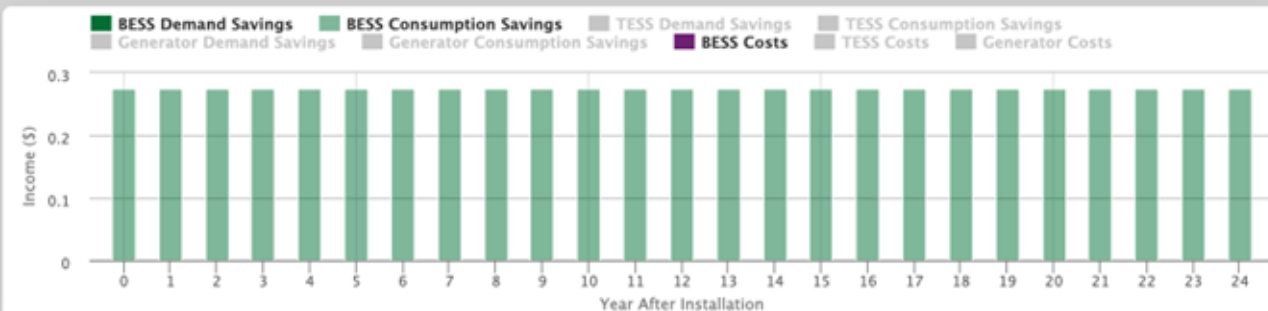
Kenergy – derConsumer Outputs

BESS Savings vs. Incentives

Annual BESS Consumption Savings = \$0.30/yr

- ★ Because Kenergy's residential tariff is a flat rate, the BESS did not contribute to the consumer savings. The \$0.30/year saved is likely from the anomalous discharge at the very beginning and end of the year, which are likely an artifact from the REopt optimization code. For non-flat tariff structures like TOU cases, the derConsumer model would show BESS usage and savings for the consumer.

Savings Breakdown Per Technology



All TESS Savings vs. Incentives

Annual TESS Consumption Savings = \$20/yr

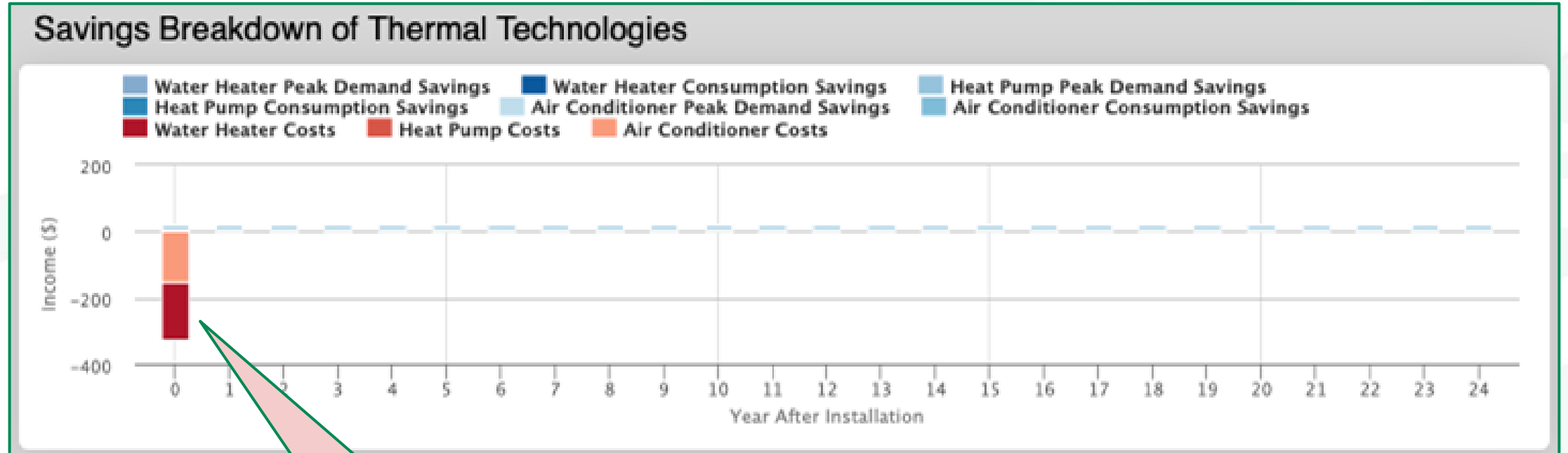
- ★ The consumer could consider installing a Smart Thermostat and/or other load control devices and enroll in the utility's DER sharing program to save money on their electric bill.

Savings Breakdown Per Technology



Note: The Y axis scale is not the same between the two plots. See the previous slide for a better side-by-side comparison between TESS and BESS.

Kenergy – derConsumer Outputs

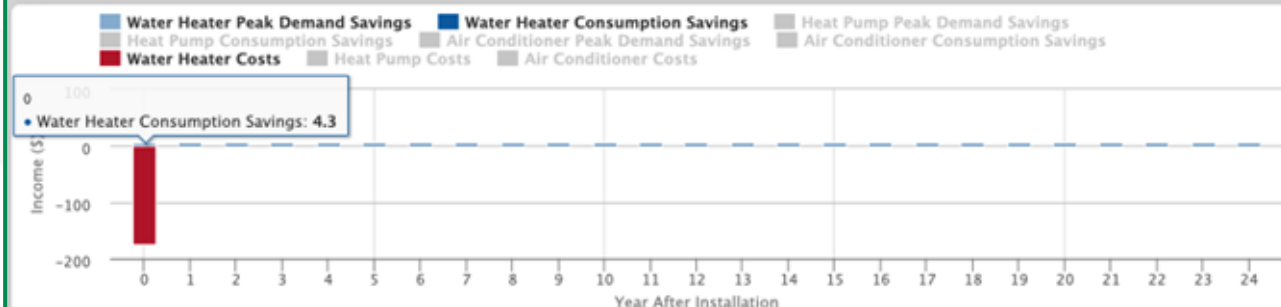


Kenergy – derConsumer Outputs

Water Heater Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$4/year

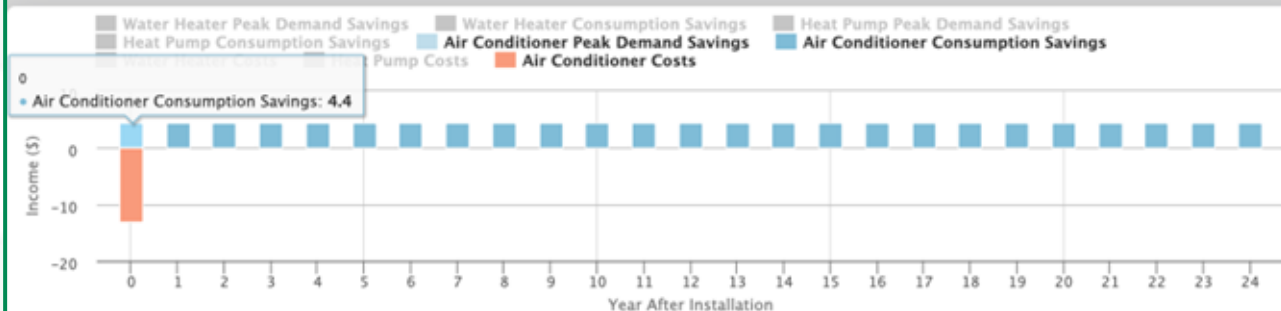
Savings Breakdown of Thermal Technologies



Air Conditioner Savings vs. Incentives

★ Annual Demand + Consumption Savings = \$4/year

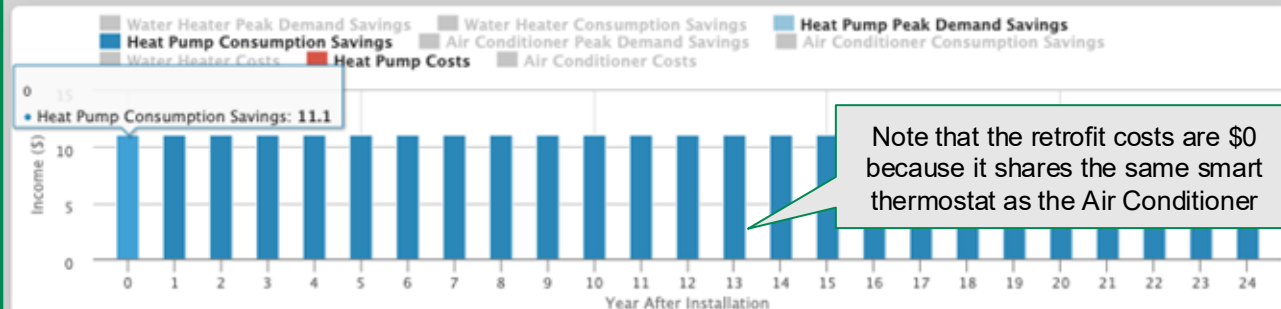
Savings Breakdown of Thermal Technologies



Heat Pump Savings vs. Incentives

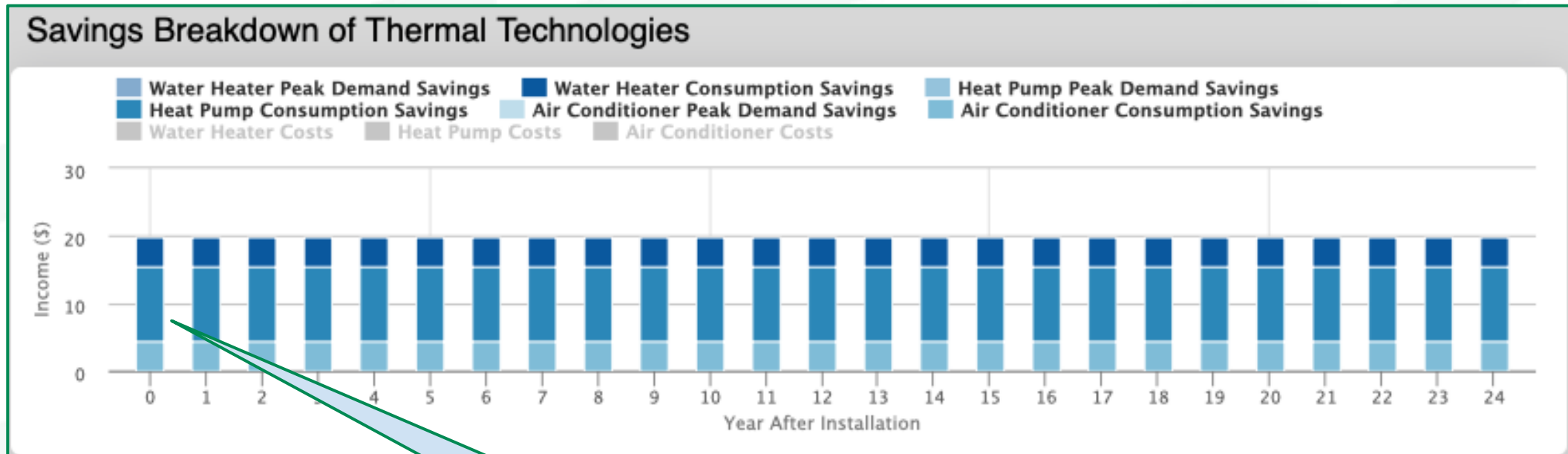
★ Annual Demand + Consumption Savings = \$11/year

Savings Breakdown of Thermal Technologies



Note that the retrofit costs are \$0 because it shares the same smart thermostat as the Air Conditioner

Kenergy – derConsumer Outputs



Heat Pumps provided the most savings out of all thermal DER, which Kenergy listed as #1 on their tech preference list.

Kenergy's Tech Preferences

- #1 = Heat Pump (and Resistance Heating)
- #2 = Central AC
- #3 = Water Heater
- #4 = Fossil Fuel Generators
- #5 = BESS

Kenergy – Conclusions

Common takeaways from all scenarios:

- Water Heaters contributed the most peak demand and consumption savings for the utility (water heaters are prioritized over other thermal DER in the code), whereas Heat Pumps contributed the most benefit to the consumer.
- Although Kenergy selected Heat Pumps as their top technology of interest, the model results suggest that Water Heaters were more advantageous to the utility, but Heat Pumps were more advantageous to the consumer.
- The BESS provided some savings to the utility, but no savings for the consumer. This is likely because the residential tariff is a flat rate per month, with no opportunity for energy arbitrage for the consumer.
- 88% of the consumer's annual monetary benefit came from utility subsidies.

Kenergy – Future Considerations

The utility may want to consider other model scenarios, such as:

- Introducing an up-front subsidy
 - Offering or increasing an up-front subsidy could increase initial participation levels, which could then increase the savings provided by some DER.
- Changing monthly subsidy or participation levels
 - Exploring different levels of monthly incentives or number of enrolled devices can give the utility an idea of what kind of program provides the desired savings to the utility.
- Adding Program Costs
 - Ex. Startup Costs = \$200,000 (estimated)
 - Ongoing Operational Costs = \$1,000/month (provided by Camus)
 - One-time Operational Costs = \$20,000
- Evaluate the consumer perspective using a range of consumption behaviors to guide marketing.
 - Represent the membership using a suite of demand curves to obtain strata-specific subsidies.

Detailed Results: Flathead Electric Cooperative

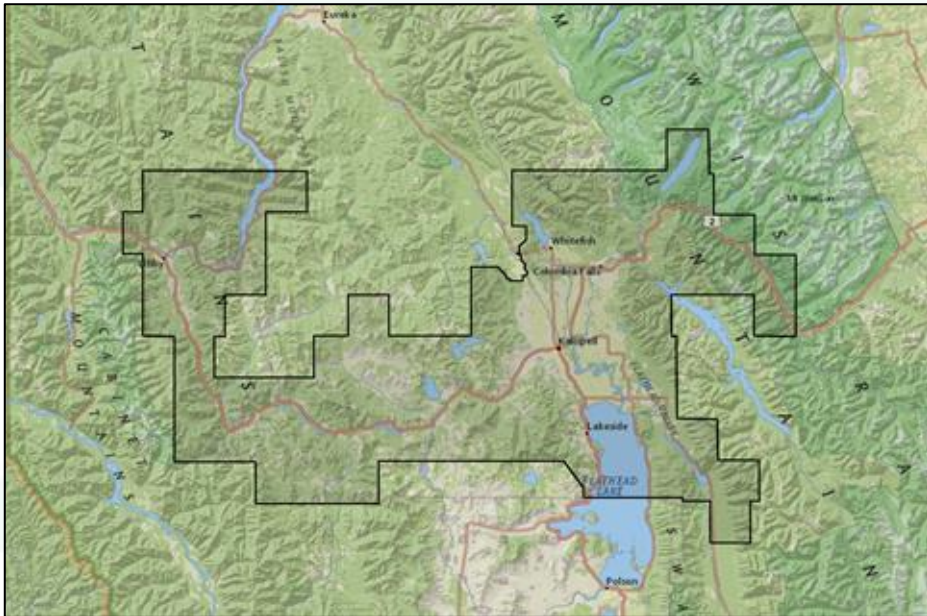


FLATHEAD ELECTRIC
— COOPERATIVE —

Detailed Results: Flathead

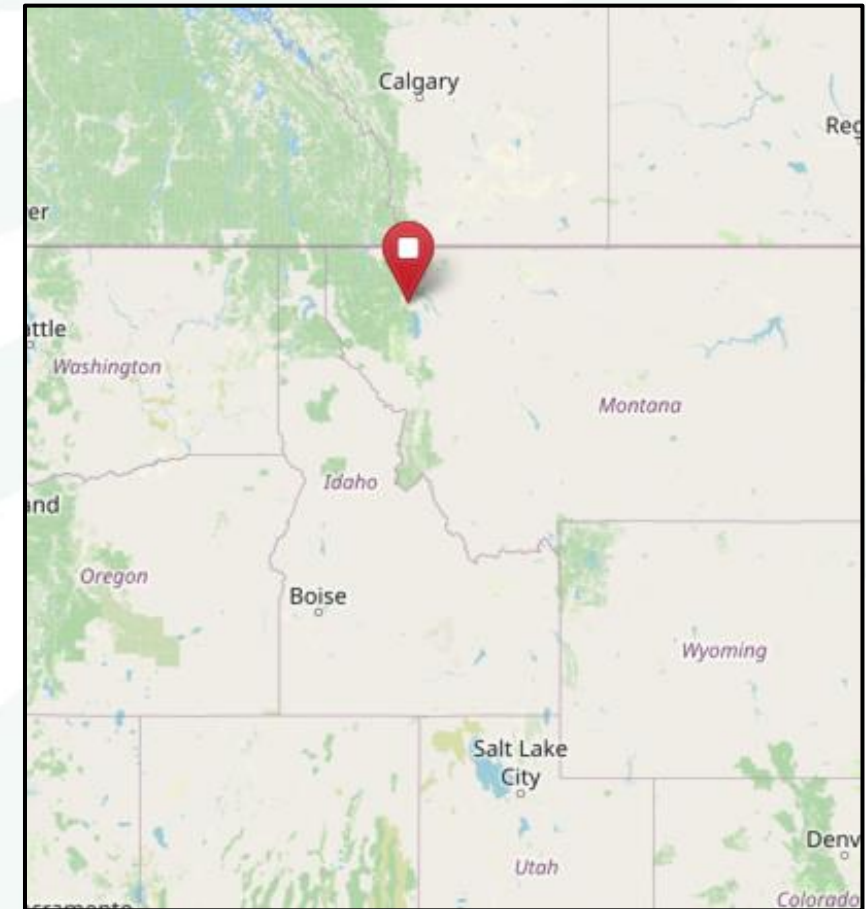


FLATHEAD ELECTRIC
— COOPERATIVE —



Flathead's service area spanning Flathead and Lincoln counties in MT.

- Meters Served:** 81,545
Number of Circuits: 91
Annual sales: 1,588 GWh
Peak Demand
- Winter: 374.3 MW
 - Summer: 206.0 MW



Flathead's service area approximate centroid located at (48.197777, -114.316109).

Detailed Results: Flathead

Flathead serves rural Montana areas that experience the following grid-stressing weather events:

- Cold Waves & Winter Weather
- Wildfires
- Landslides

Reliability Metrics w/ Major Event Days:

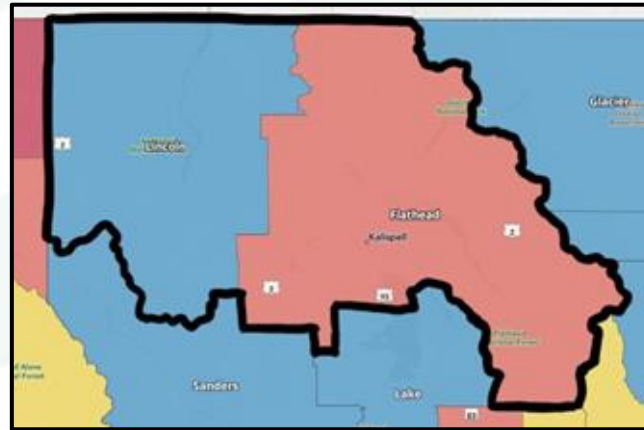
- SAIDI: 692.240
- SAIFI: 2.720
- CAIDI: 254.500

Reliability Metrics w/out Major Event Days:

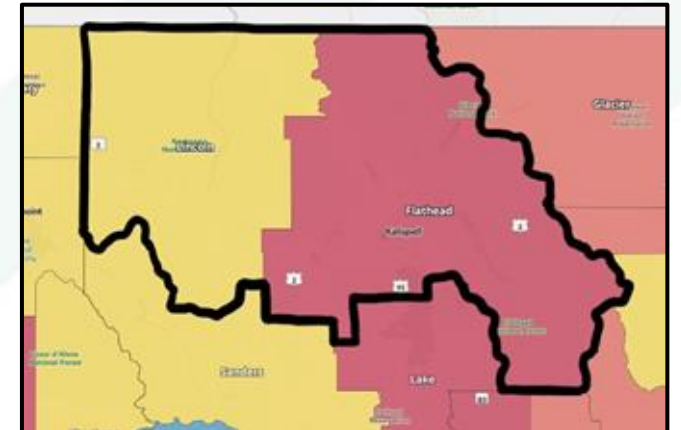
- SAIDI: 222.950
- SAIFI: 1.820
- CAIDI: 122.500



Wildfires

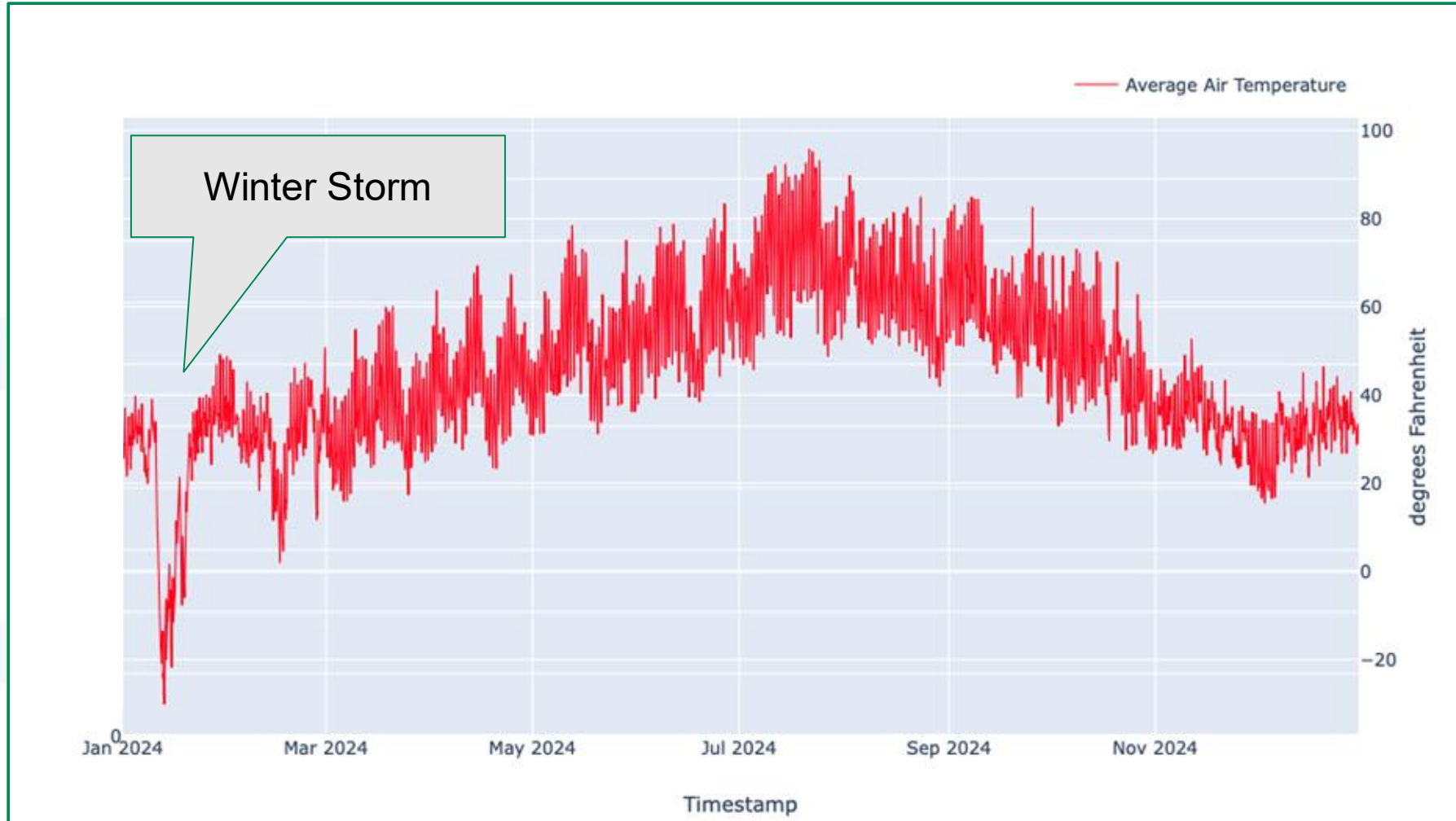


Landslides



Cold Waves

Flathead – Annual Temperature Profile

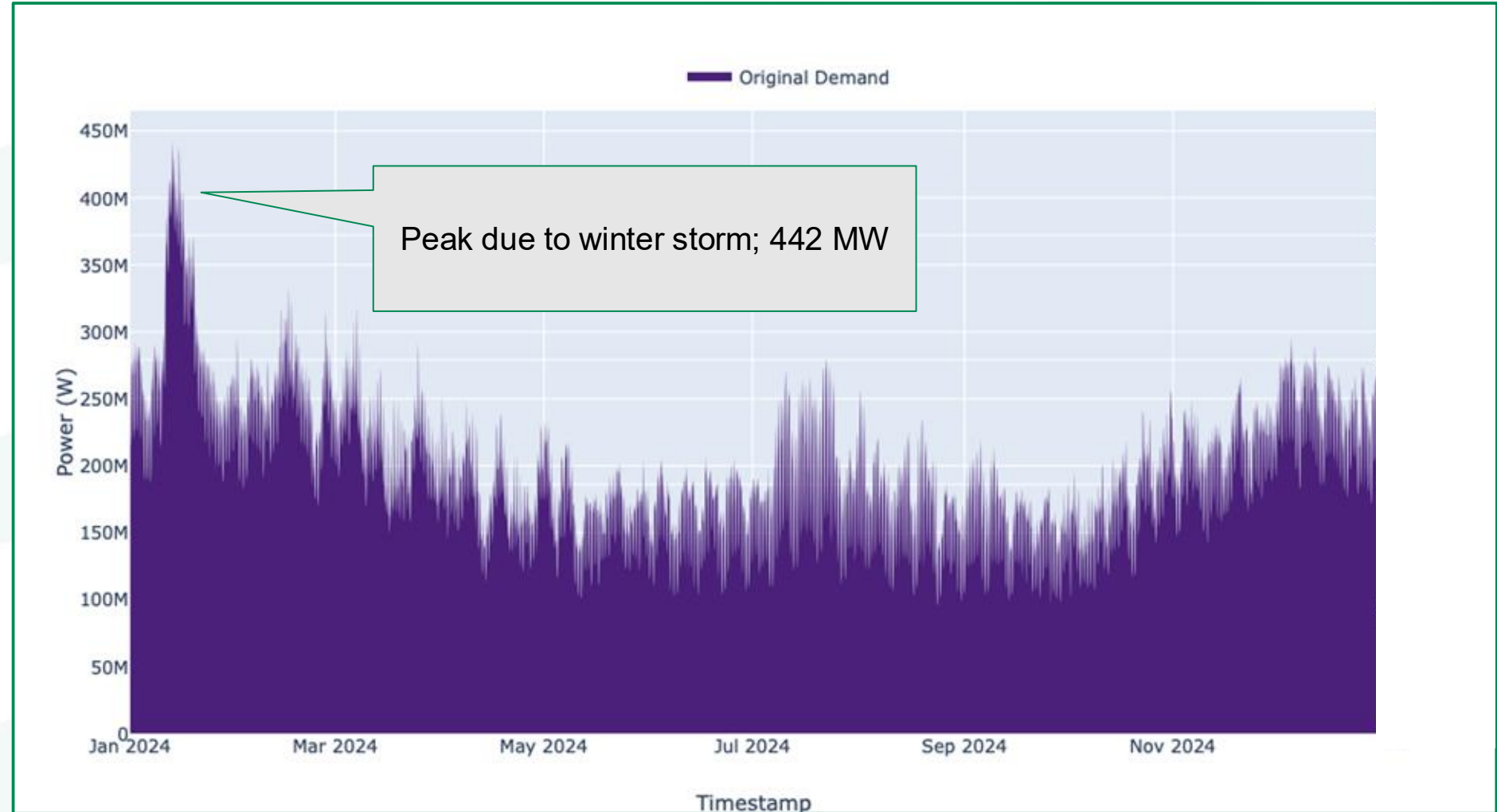


Flathead's regional climate is considered **“Very-Cold/Cold”** by the EERE's Building America data sets.

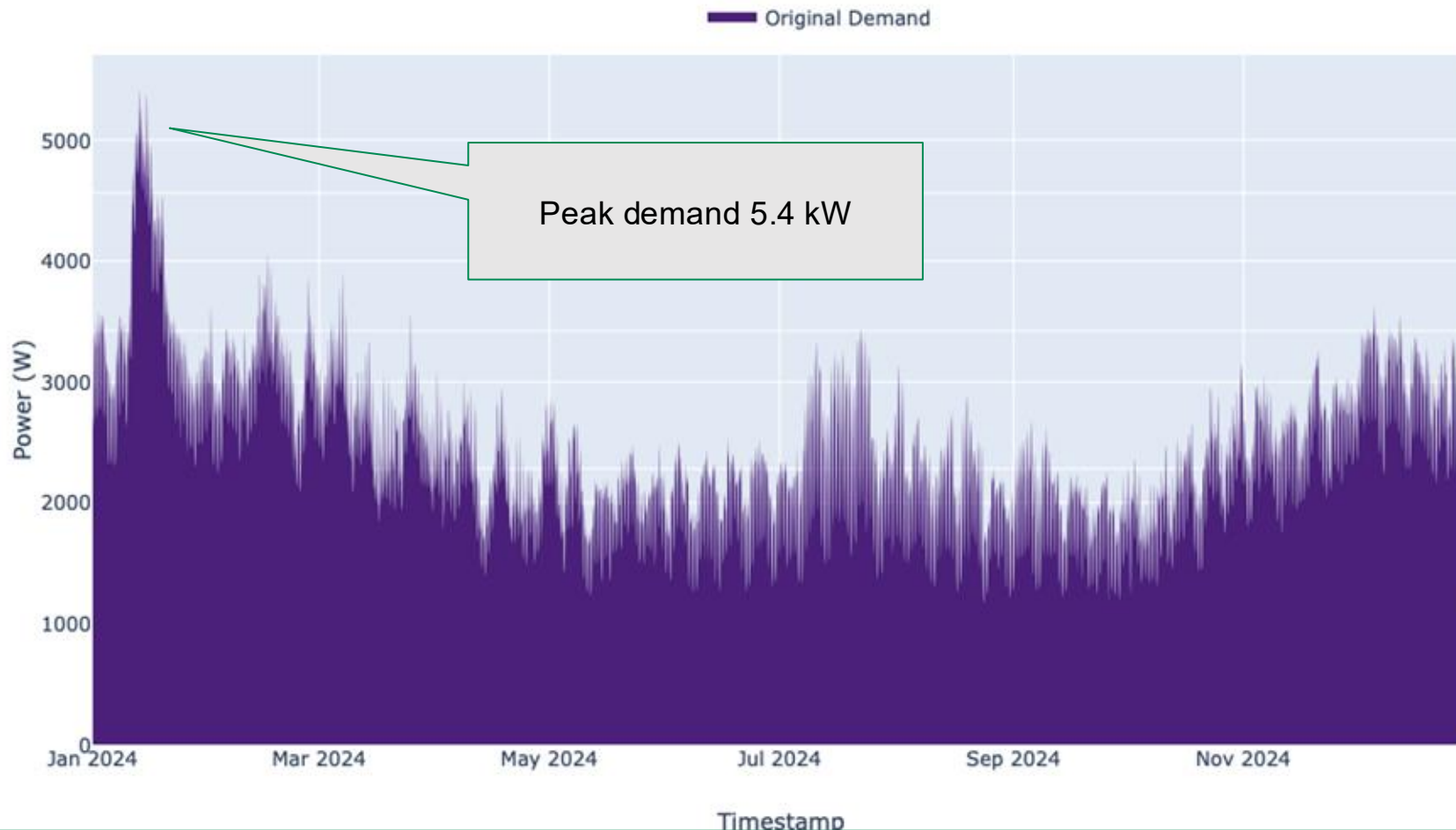
<https://www.energy.gov/eere/buildings/building-america-climate-map>

Flathead – Annual System Demand

Flathead's system demand curve shows a 442 MW peak due the winter storm in 2023.



Flathead – Annual Residential Demand



The residential demand curve was created by scaling the utility's system demand curve down by 81,545 (the total number of meters served).

However, 20% of those meters are non-residential which may need more power than residential ones, so this demand curve is likely larger than a real residential demand curve.

Flathead – Wholesale Energy & Demand Tariffs

	Wholesale Energy Rate (\$/kWh)		Wholesale Demand Rate (\$/kW)
Month	<i>Heavy Load Hours</i> (6am–10am Mon–Sat)	<i>Light Load Hours</i> (10pm–6am Mon–Sat, all day on Sundays)	
Jan	0.04356	0.04380	11.88
Feb	0.04543	0.04918	12.339
Mar	0.02919	0.03454	7.97
Apr	0.02233	0.02709	6.09
May	0.00860	0.01273	2.35
Jun	0.01510	0.01608	4.12
Jul	0.05098	0.04806	13.91
Aug	0.05380	0.05032	14.67
Sep	0.06051	0.05906	16.51
Oct	0.05063	0.04885	13.81
Nov	0.03953	0.04164	10.78
Dec	0.04763	0.04879	12.99

Flathead – Residential Energy & Demand Tariffs

Northwest Montana Summary

Residential Service Rates

[Residential Service Rates \(PDF\)](#) – effective June 1, 2025

(all residential services, see rate schedule for Rules and Regulations)

- **Basic Charge (single-phase service):** \$24.83 per month
- **Basic Charge (three-phase service):** \$36.28 per month
- **Demand Charge:** \$4.04/kW during peak hours
 - Peak hours occur Monday through Friday from 7 to 10 a.m. and 5 to 8 p.m. There are no demand charges on weekends or major federal holidays, including New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving, and Christmas. In the event that the holiday occurs on Sunday, there are no demand charges on the following Monday.
- **Energy Charge:**
 - \$0.0549 per kWh (for the first 600 kWh per month)
 - \$0.0653 per kWh (for 601-3,500 kWh per month)
 - \$0.1002 per kWh (for 3,501 and over kWh per month)

Flathead derUtilityCost Scenario 1: Base Case

Flathead – Scenario 1 derUtilityCost Inputs

The Scenario 1 Base Case assumes no subsidies in order to determine the baseline annual value for each DER technology.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Participation Level (out of 65,236 residential meters)
BESS	0	0	1% (652)
GEN	-	-	-
Water Heater	0	0	¹ 34% (22,441)
Heat Pump	0	0	² 3% (2,088)
Air Conditioner	0	0	³ 59% (38,236)

[1] [Table HC8.6 Water heating in U.S. homes, by climate region, 2020](#)

[2] [Table HC6.6 Space heating in U.S. homes, by climate region, 2020](#)

[3] [Table HC7.6 Air conditioning in U.S. homes, by climate region, 2020](#)

Generators will be considered in future work

The participation levels were calculated based on the 2020 Residential Energy Consumption Survey (U.S. Energy Information Administration, Office of Energy Demand and Integrated Statistics, Form EIA-457A)*

*Flathead's climate is considered "Very-Cold/Cold" for these calculations

All subsidies are set to 0 to determine the base level annual value of all DER technologies

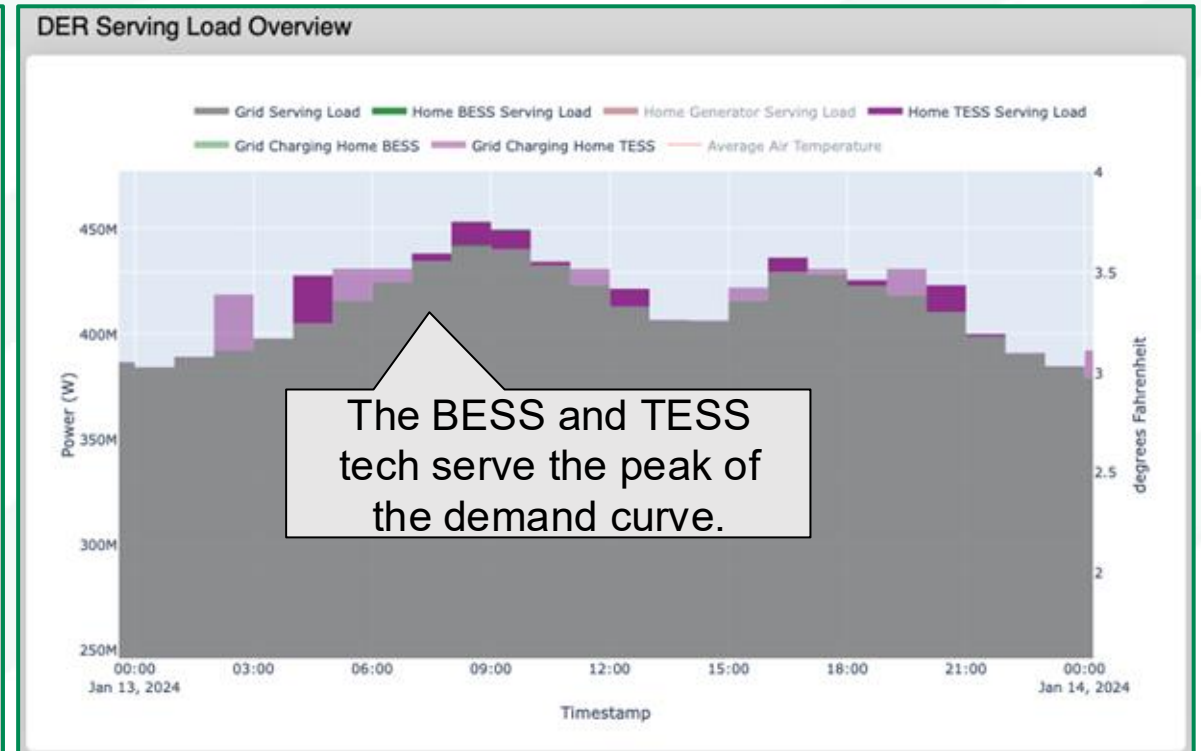
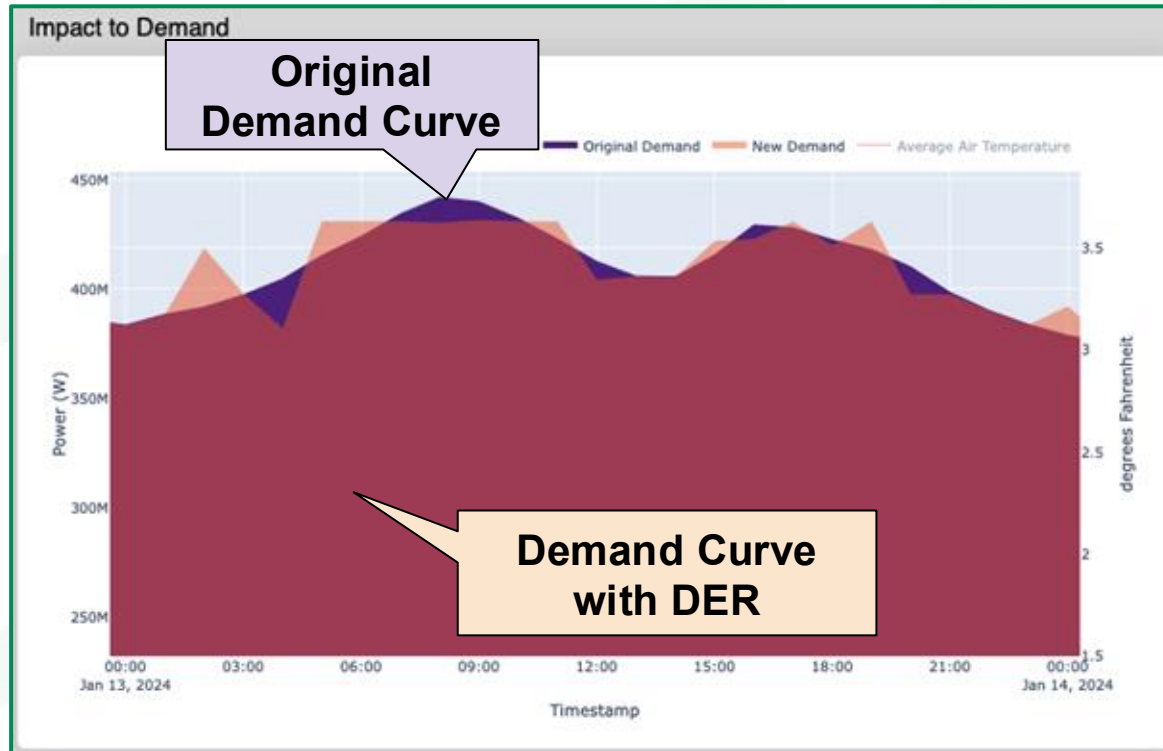
Flathead – Scenario 1 Inputs

General Model Inputs		
Demand Curve (.csv file) Choose File 8760_Flathead-SystemDemand	Temperature Curve in °F (.csv file) Choose File 8760_Flathead_Temperature_c	Latitude 48.197777
Longitude -114.316109	Year 2024	Use the user-provided random numbers? No
Random Seed - BESS & GEN 2147483647	Random Seed - AC 2147483647	Random Seed - HP 2147483647
Random Seed - WH 2147483647	Random Numbers for Water Heater (.csv file) Choose File example_water_heater_random	
Financial Inputs		
Use Wholesale Energy & Demand Rate Structure (.json) file? ☐	Wholesale Energy & Demand Rate Structure (.json file) Choose File exampleWholesaleRateStructur	(Optional) Wholesale Energy Rate Curve (.csv file) Choose File input_wholesale_rate_curve.cs
(Optional) Monthly Demand Charges (.csv file) Choose File input_monthly_demand_charg	Financial Projection Length (years) 25	Discount Rate (%) 1
Program Startup Costs (\$) 0	Ongoing Operational Costs (\$/month) 0	One-time Operational Costs (\$) 0
Home BESS - Upfront Subsidy Amount (\$) 0	Home BESS - Monthly Recurring Subsidy Amount (\$) 0	Home Heat Pumps - Upfront Subsidy Amount (\$) 0
Home Heat Pumps - Monthly Recurring Subsidy Amount (\$) 0	Home Air Conditioners - Upfront Subsidy Amount (\$) 0	Home Air Conditioners - Monthly Recurring Subsidy Amount (\$) 0
Home Water Heaters - Upfront Subsidy Amount (\$) 0	Home Water Heaters - Monthly Recurring Subsidy Amount (\$) 0	Home Generators - Upfront Subsidy Amount (\$) 0
Home Generators - Monthly Recurring Subsidy Amount (\$) 0		
Home Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Number of Devices 5
Rated Power Capacity (kW) 20	Available Fuel 95	Fuel Cost 3.49

Home Chemical Battery Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Number of Home Chemical Batteries 652	Portion of Charge Used by Utility (%) 20.0
Home Battery Power Capacity (kW) 5.0	Home Battery Energy Capacity (kWh) 13.5	
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Number of Devices 38236	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Number of Devices 2088	Rated Power (kW) 5.6
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Number of Devices 22441	Rated Power (kW) 4.5
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	
Delete Run Model Share Duplicate		

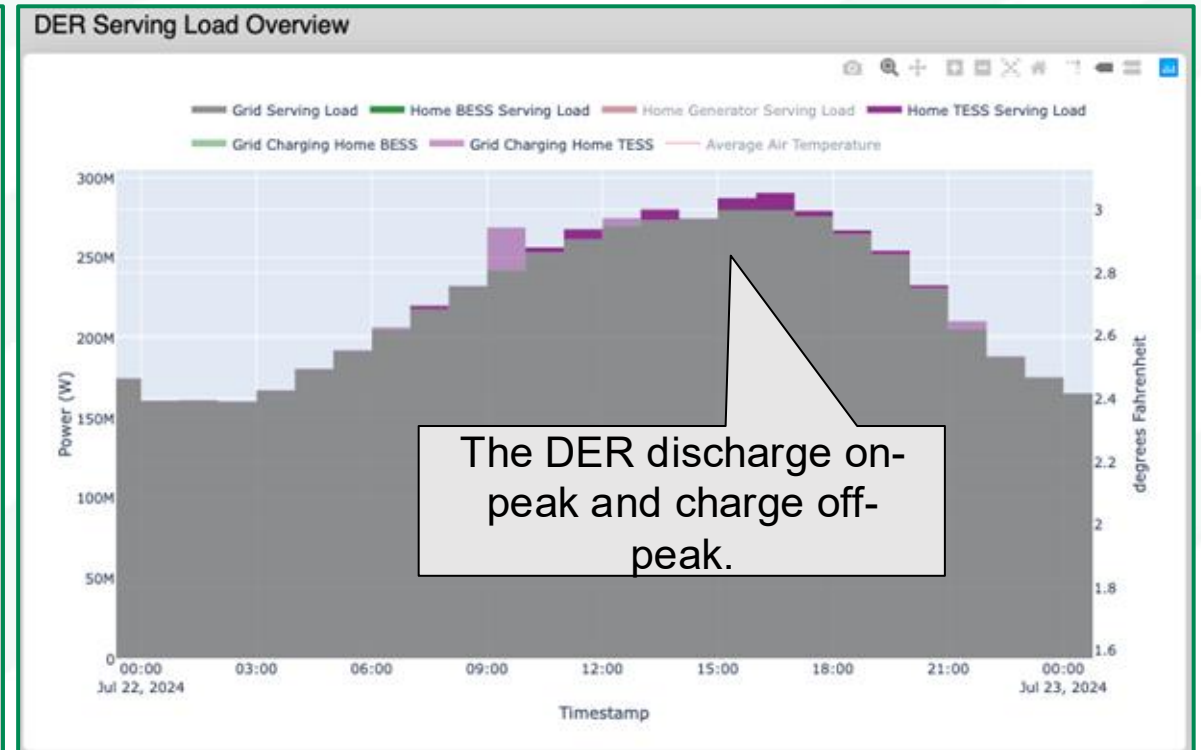
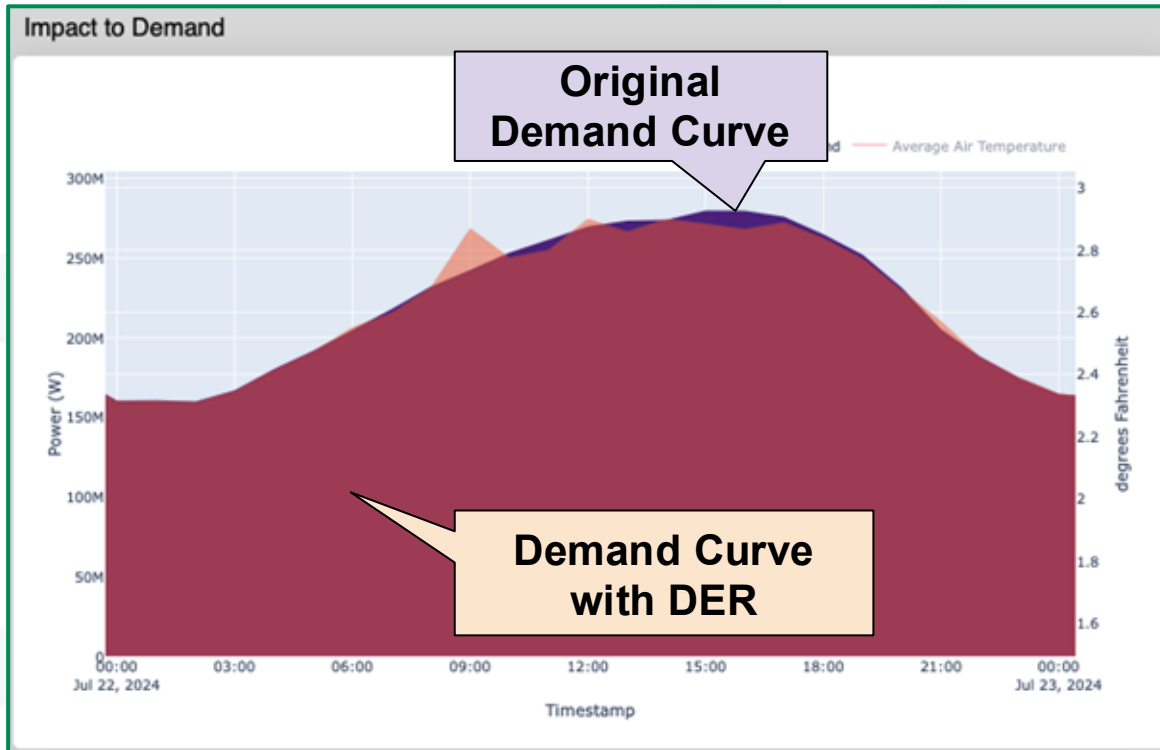
Flathead – Scenario 1 derUtilityCost Outputs

Winter peak – January 13, 2024



Flathead – Scenario 1 derUtilityCost Outputs

Summer peak – July 22, 2024



Flathead – Scenario 1 derUtilityCost Outputs

Monthly Cost Comparison

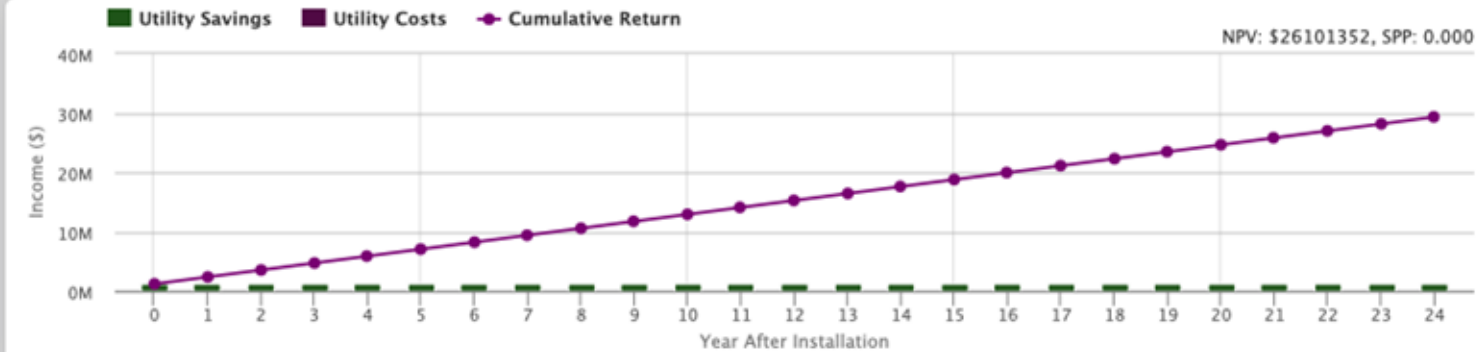
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	441,907	330,858	320,977	251,675	233,105	209,156	279,814	256,170	219,521	258,060	265,689	295,045
Total Adjusted Peak Demand (kW)	431,364	318,242	304,342	247,228	224,264	197,556	274,731	246,344	211,543	256,702	257,363	285,074
Demand Charge (\$)	5,249,856	4,099,337	2,558,188	1,532,699	547,797	861,721	3,892,207	3,758,019	3,624,289	3,563,803	2,864,124	3,832,638
Adjusted Demand Charge (\$)	5,124,601	3,943,024	2,425,603	1,505,621	527,021	813,932	3,821,504	3,613,873	3,492,576	3,545,053	2,774,373	3,703,105
Demand Cost Savings (\$)	125,254	156,313	132,585	27,079	20,776	47,789	70,703	144,146	131,713	18,750	89,751	129,533
Energy (kWh)	209,795,407	170,259,979	159,544,148	126,524,861	120,550,964	114,101,209	138,442,678	120,737,667	108,820,235	125,195,856	147,662,193	169,451,623
Adjusted Energy (kWh)	209,684,397	170,107,221	159,392,743	126,386,566	120,443,795	113,976,604	138,053,202	120,550,108	108,663,818	125,055,131	147,528,148	169,330,449
Energy Cost (\$)	9,156,894	7,969,256	4,993,489	3,048,419	1,214,780	1,764,293	6,925,516	6,356,901	6,526,731	6,259,372	5,947,606	8,145,383
Adjusted Energy Cost (\$)	9,152,066	7,962,916	4,989,030	3,045,819	1,213,727	1,762,606	6,905,533	6,346,404	6,517,109	6,251,901	5,942,729	8,139,748
Energy Cost Savings (\$)	4,829	6,340	4,459	2,601	1,053	1,687	19,982	10,497	9,622	7,471	4,876	5,635
Total Cost of Service (\$)	14,406,750	12,068,593	7,551,677	4,581,119	1,762,577	2,626,014	10,817,723	10,114,920	10,151,020	9,823,175	8,811,729	11,978,021
Adjusted Total Cost of Service (\$)	14,276,667	11,905,940	7,414,633	4,551,439	1,740,749	2,576,538	10,727,037	9,960,277	10,009,685	9,796,954	8,717,102	11,842,854
Total Consumer Compensation (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Program Startup and Operational Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Utility Savings (\$)	130,083	162,653	137,044	29,679	21,829	49,476	90,685	154,643	141,335	26,221	94,627	135,167
Total Utility Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Net Utility Savings (\$)	130,083	162,653	137,044	29,679	21,829	49,476	90,685	154,643	141,335	26,221	94,627	135,167

The initial subsidies and startup costs are zero in Scenario 1 to show the Total Utility Savings from DER alone.

Flathead – Scenario 1 derUtilityCost Outputs

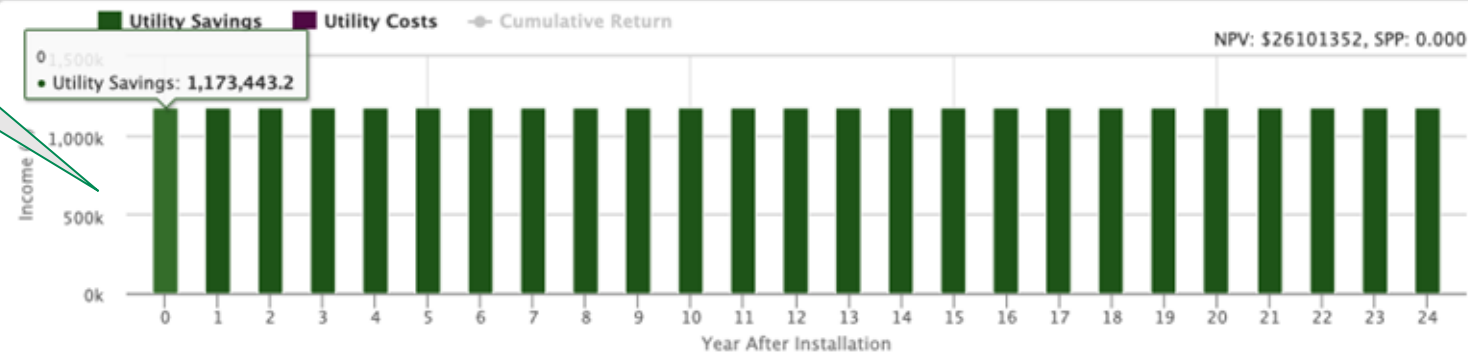
In this Scenario, the annual value of all DER is about \$1,173,443

Cash Flow Projection

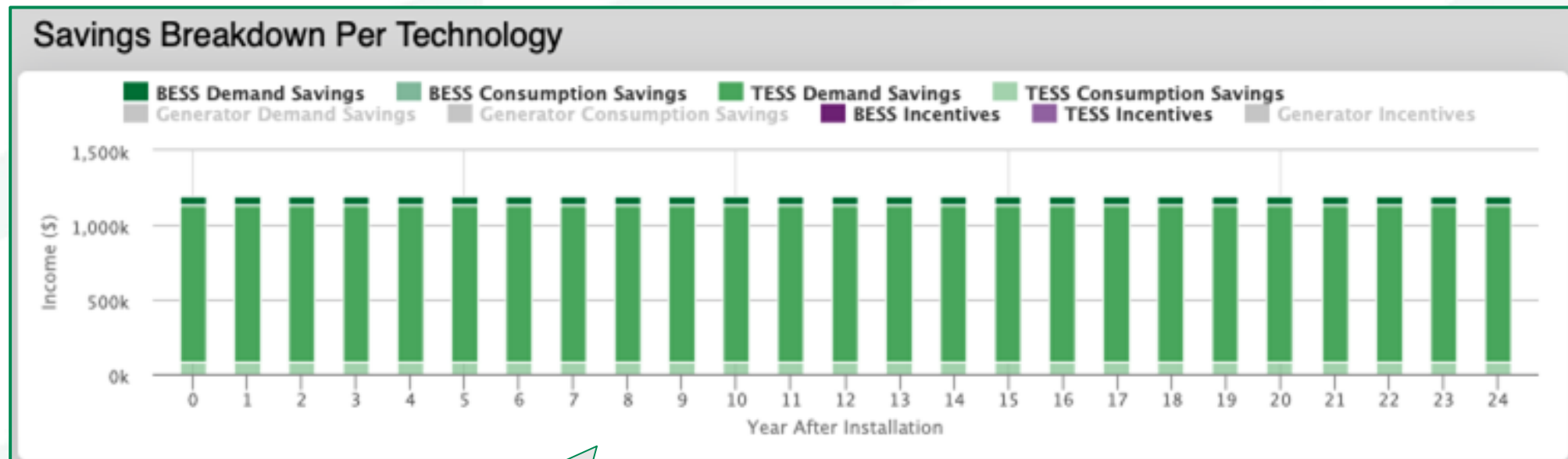


The Simple Payback Period = 0 years, showing that the program pays itself immediately (since there are no subsidies or costs in this Scenario)

Cash Flow Projection



Flathead – Scenario 1 derUtilityCost Outputs



This shows the costs and savings breakdown of the BESS and TESS technologies in terms of peak demand (kW) savings and consumption (kWh) savings. Recall that the TESS is a combination of all the thermal devices.

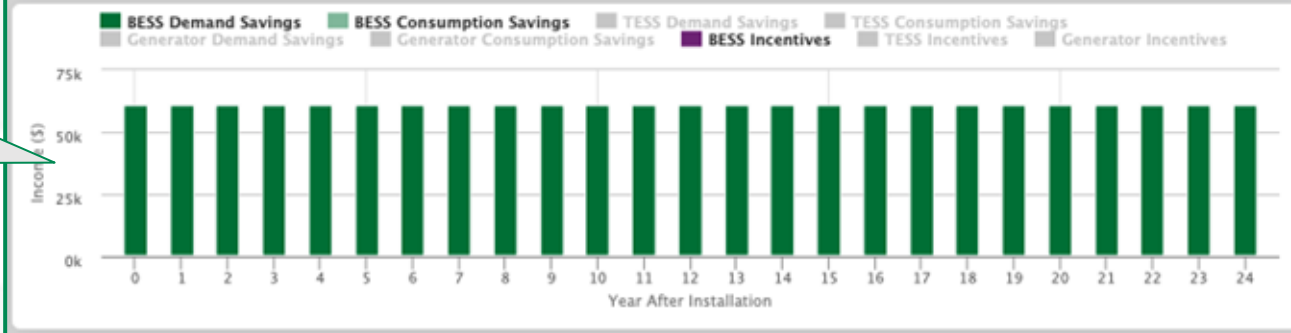
Flathead – Scenario 1 derUtilityCost Outputs

BESS Savings vs. Incentives

The annual value of the BESS can be determined by adding the Demand Savings and Consumption Savings together. Since Scenario 1 has no subsidies, there are no incentive costs shown.

e.g. Annual BESS Demand Savings + BESS Consumption Savings = \$57,880

Savings Breakdown Per Technology



All TESS Savings vs. Incentives

The annual value of the TESS can be determined by adding the Demand Savings and Consumption Savings together. Since Scenario 1 has no subsidies, there are no incentive costs shown.

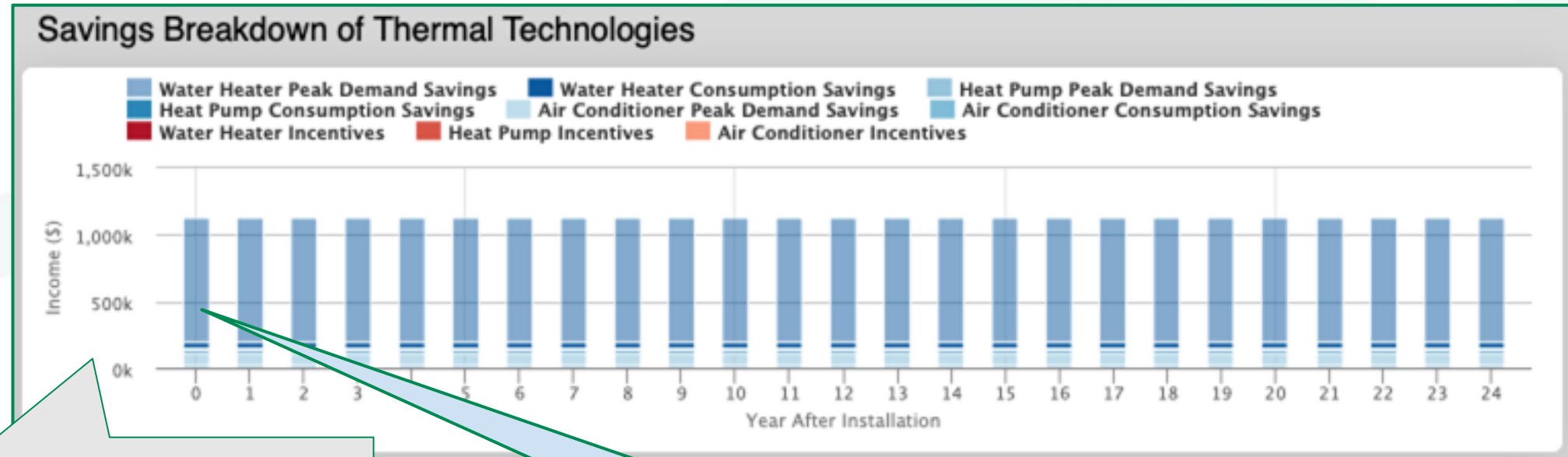
e.g. Annual TESS Demand Savings + TESS Consumption Savings = \$1,115,564

Savings Breakdown Per Technology



Note: The Y axis scale is not the same between the two plots. See the previous slide for a better side-by-side comparison between TESS and BESS.

Flathead – Scenario 1 derUtilityCost Outputs



This shows the annual breakdown of the costs and savings for all TESS technologies: Water Heaters, Air Conditioners, and Heat Pumps.

Most of the savings come from the Water Heater, which Flathead listed as #2 on their technology preference list.

Flathead's Tech Preferences

- #1 = Central Air Conditioner
- #2 = Water Heater
- #3 = Heat Pump
- #4 = BESS
- #5 = GEN

Flathead – Scenario 1 derUtilityCost Outputs

Water Heater Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$969,020

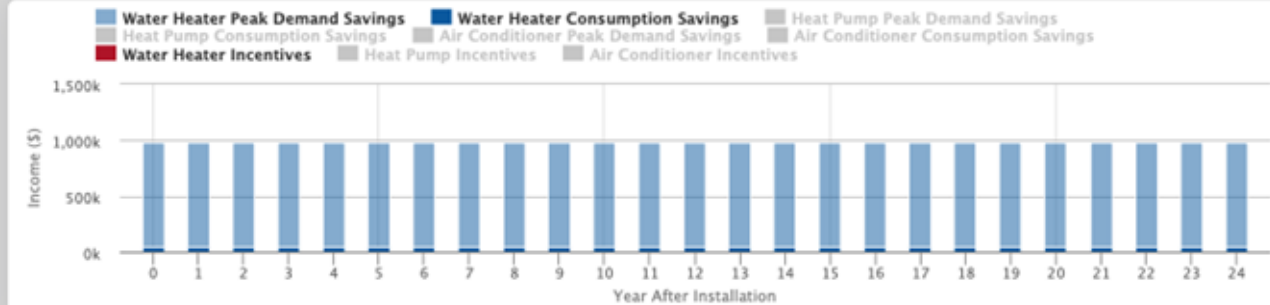
Air Conditioner Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$38,236

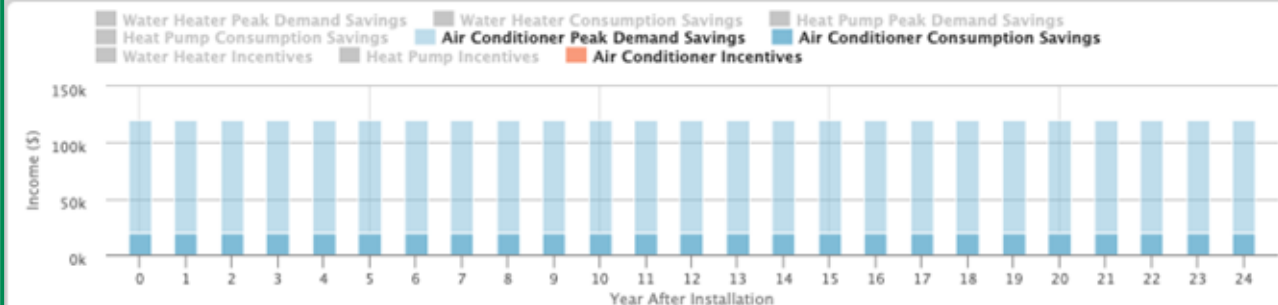
Heat Pump Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$28,644

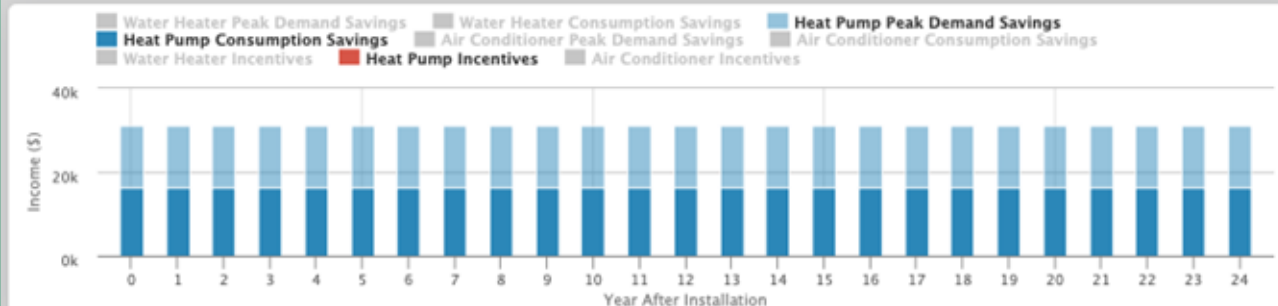
Savings Breakdown of Thermal Technologies



Savings Breakdown of Thermal Technologies



Savings Breakdown of Thermal Technologies



Flathead – Scenario 1 derUtilityCost Outputs

Tech	Total Annual Savings (kW Demand Savings + kWh Consumption Savings)	Number of Devices	Annual Value of DER per Device	Monthly Subsidy (Total Annual Savings / Number of Devices / 12 months)
BESS	\$57,880	652	\$89	\$7.40
Air Conditioner	\$117,899	38,236	\$3	\$0.26
Water Heater	\$969,020	22,441	\$43	\$3.60
Heat Pump	\$28,644	2,088	\$14	\$1.14

Annual value per device not including subsidies

These monthly subsidies will be used as inputs in Flathead's derUtilityCost Scenario 2 and derConsumer

Example Monthly Subsidy calculation:

If Water Heaters saved \$969,020 for the year, then the annual value of water heaters per device would be $\$969,020 / 22,441 \text{ water heaters} = \$43 \text{ per water heater per year}$. That value could be used to determine a monthly subsidy = $\$43 / 12 \text{ months} = \$3.60/\text{month}$ (assuming no upfront subsidies).



Flathead derUtilityCost Scenario 2: Adjusted Subsidies

Flathead – Scenario 2: Adjusted Subsidies

Scenario 2 considers a program where the participation levels remain the same, but the subsidies are adjusted based on the results from Scenario 1.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Participation Level (out of 65,236 residential meters)
BESS	0	\$7.40	1% (652)
Air Conditioner	0	\$0.26	59% (38,236)
Water Heater	0	\$3.60	34% (22,441)
Heat Pump	0	\$1.14	3% (2,088)
GEN	-	-	-

The monthly subsidies calculated from Scenario 1 are used as the starting inputs for Scenario 2.

The participation levels are kept the same

Flathead – Scenario 2 derUtilityCost Inputs

In order to reproduce the same model results as Scenario 1 and only change the subsidies, the random seeds and random numbers in Scenario 2 must be set to the same numbers produced in Scenario 1, which can be found in the outputs at the bottom of the model.

Scenario 1 outputs:

Raw Input and Output Files

random_seeds.csv – water_heater_random_numbers.csv – demand.csv – Scenario_test_POST.json – REoptInputs.json – vbatDispatch_inputs_hp.json – temperature_input_derUtilityCost.csv – reopt_input_scenario.json – vbatDispatch_inputs_wh.json – results.json – vbatDispatch_results_hp.json – Plot_DerServingLoadOverview.html – vbatDispatch_results_wh.json – Plot_NewDemand.html – vbatDispatch_inputs_ac.json – PPID.txt – stderr.txt – PuLP_random_seeds.csv – random_seeds.txt – vbatDispatch_results_ac.json – temperature.csv – wholesale_rate_structure_input_derUtilityCost.json – input_temperature.csv – demand_input_derUtilityCost.csv – input_demand.csv – input_wholesale_rate_structure.json – Plot_ThermalDERServingLoadOverview.html – allInputData.json – allOutputData.json

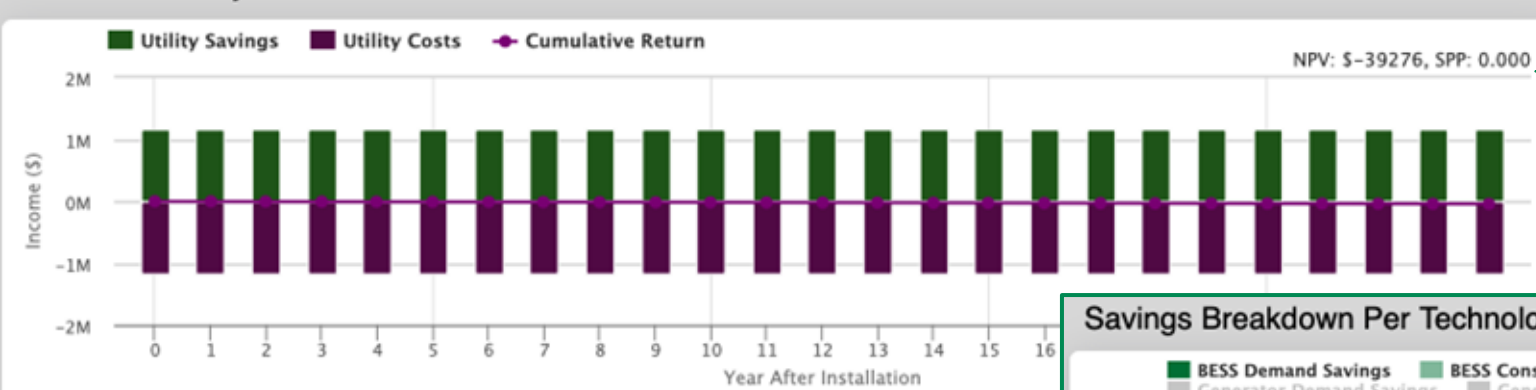
Scenario 2 inputs:

General Model Inputs

Demand Curve (.csv file) Choose File 8760_Flathead-SystemDemand	Temperature Curve in °F (.csv file) Choose File 8760_Flathead_Temperature_d	Latitude 48.197777
Longitude -114.316109	Year 2024	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 413403184	Random Seed - AC 533407496	Random Seed - HP 400836215
Random Seed - WH 1464832581	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_numbers	

Flathead – Scenario 2 derUtilityCost Outputs

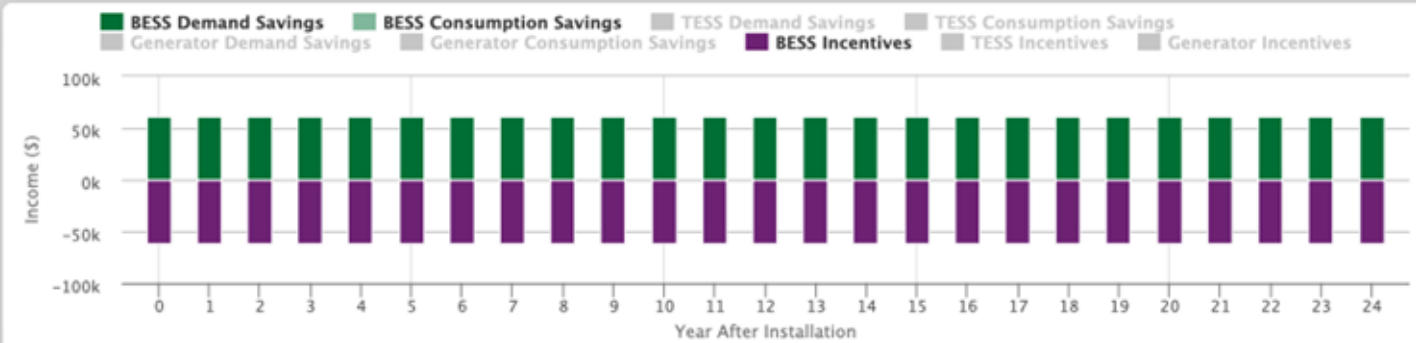
Cash Flow Projection



The SPP is 0 since the subsidy costs are roughly equal to the DER savings, and there are no other initial costs. The NPV, however, is expected to be close to zero for this break-even scenario, but it is nonzero due to the number of decimal places in the subsidy input values.

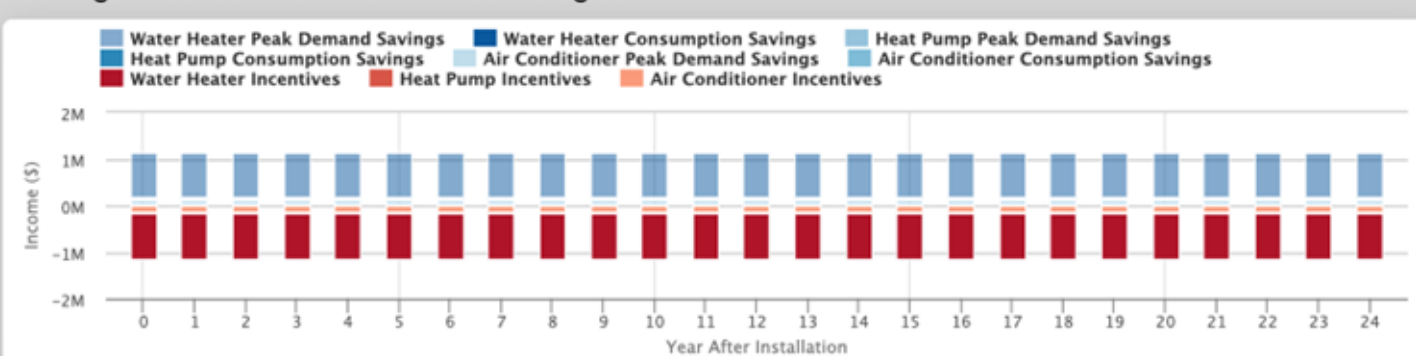
The annual BESS subsidies are roughly comparable to the annual BESS savings

Savings Breakdown Per Technology



The annual TESS subsidies are roughly comparable to the annual TESS savings

Savings Breakdown of Thermal Technologies



Flathead – Scenario 2 derUtilityCost Outputs

Monthly Cost Comparison

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	441,907	330,858	320,977	251,675	233,105	209,156	279,814	256,170	219,521	258,060	265,689	295,045
Total Adjusted Peak Demand (kW)	431,364	318,242	304,342	247,228	224,264	197,556	274,731	246,344	211,543	256,702	257,363	285,074
Demand Charge (\$)	5,249,856	4,099,337	2,558,188	1,532,699	547,797	861,721	3,892,207	3,758,019	3,624,289	3,563,803	2,864,124	3,832,638
Adjusted Demand Charge (\$)	5,124,601	3,943,024	2,425,603	1,505,621	527,021	813,932	3,821,504	3,613,873	3,492,576	3,545,053	2,774,373	3,703,105
Demand Cost Savings (\$)	125,254	156,313	132,585	27,079	20,776	47,789	70,703	144,146	131,713	18,750	89,751	129,533
Energy (kWh)	209,795,407	170,259,979	159,544,148	126,524,861	120,550,964	114,101,209	138,442,678	120,737,667	108,820,235	125,195,856	147,662,193	169,451,623
Adjusted Energy (kWh)	209,684,397	170,107,221	159,392,743	126,386,566	120,443,795	113,976,604	138,053,202	120,550,108	108,663,818	125,055,131	147,528,148	169,330,449
Energy Cost (\$)	9,156,894	7,969,256	4,993,489	3,048,419	1,214,780	1,764,293	6,925,516	6,356,901	6,526,731	6,259,372	5,947,606	8,145,383
Adjusted Energy Cost (\$)	9,152,066	7,962,916	4,989,030	3,045,819	1,213,727	1,762,606	6,905,533	6,346,404	6,517,109	6,251,901	5,942,729	8,139,748
Energy Cost Savings (\$)	4,829	6,340	4,459	2,601	1,053	1,687	19,982	10,497	9,622	7,471	4,876	5,635
Total Cost of Service (\$)	14,406,750	12,068,593	7,551,677	4,581,119	1,762,577	2,626,014	10,817,723	10,114,920	10,151,020	9,823,175	8,811,729	11,978,021
Adjusted Total Cost of Service (\$)	14,276,667	11,905,940	7,414,633	4,551,439	1,740,749	2,576,538	10,727,037	9,960,277	10,009,685	9,796,954	8,717,102	11,842,854
Total Consumer Compensation (\$)	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934
Program Startup and Operational Costs (\$)	0	0	0	0	0	0	0	0	0	0	0	0
Total Utility Savings (\$)	130,083	162,653	137,044	29,679	21,829	49,476	90,685	4,643	141,335	26,221	94,627	135,167
Total Utility Costs (\$)	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934	97,934
Net Utility Savings (\$)	32,149	64,719	39,110	5,555	-76,105	-48,458	-7,249	9,249	43,401	-71,713	-3,307	37,233

The Total Utility Savings are the same from Scenario 1, but now we see the Total Utility Costs, which are comprised of the subsidies paid to the consumer

Program Startup and Operational Costs could also be added in future scenarios

Flathead derConsumer model

Flathead – derConsumer Inputs

General Model Inputs		
Demand Curve (.csv file) Choose File scaledDown_by_81545meters_1	Temperature Curve in °F (.csv file) Choose File 8760_Flathead_Temperature_d	Latitude 48.197777
Longitude -114.316109	Year 2024	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 413403184	Random Seed - AC 533407496	Random Seed - HP 40083621E
Random Seed - WH 1464832581	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_numbers	
Financial Inputs		
Use URDB Label? ☐	URDB Label 66a13566e90ecdb7d40581d2	(Optional) Residential Rate Structure (.json file) Choose File Flathead-residential_energy-de
Discount Rate (%) 1	Financial Projection Length (years) 25	Home BESS - Upfront Subsidy Amount (\$) 0
Home BESS - Monthly Recurring Subsidy Amount (\$) 7.4	Home Heat Pump - Upfront Subsidy Amount (\$) 0	Home Heat Pump - Monthly Recurring Subsidy Amount (\$) 1.14
Home Air Conditioner - Upfront Subsidy Amount (\$) 0	Home Air Conditioner - Monthly Recurring Subsidy Amount (\$) 0.26	Home Water Heater - Upfront Subsidy Amount (\$) 0
Home Water Heater - Monthly Recurring Subsidy Amount (\$) 3.60	Home Generator - Upfront Subsidy Amount (\$) 0	Home Generator - Monthly Recurring Subsidy Amount (\$) 0
Fossil Fuel Generator Device Inputs		
Enable Use of Fossil Fuel Generator? No	Fuel Type Diesel	Rated Power Capacity (kW) 5
Efficiency (%) 35	Retrofit Cost (\$) 0.0	Available Fuel 1000
Fuel Cost 3.80	Generator Replacement Cost (\$/kW) 0.0	Generator Lifetime (years) 15

Chemical Energy Storage Device Inputs		
Enable Use of Home Chemical BESS? Yes	Battery Power Capacity (kW) 5.0	Battery Energy Capacity (kWh) 13.5
Retrofit Cost (\$) 0.0	Portion of Charge Shared with Utility (%) 20	Battery Replacement Power Cost (\$/kW) 0.0
Battery Replacement Energy Cost (\$/kWh) 0.0	Battery Lifetime (years) 10	Inverter Replacement Cost (\$) 0.0
Inverter Lifetime (years) 10		
Home Air Conditioner Device Inputs		
Enable Air Conditioner? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 150
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 2.5
Temperature Setpoint (°F) 72	Temperature Deadband (°F) 1	
Home Heat Pump Device Inputs		
Enable Heat Pump? Yes	Rated Power (kW) 5.6	Retrofit Cost (\$) 0
Thermal Capacitance (kWh/°C) 2	Thermal Resistance (°C/kW) 2	Coefficient of Performance 3.5
Temperature Setpoint (°F) 67	Temperature Deadband (°F) 1	
Home Water Heater Device Inputs		
Enable Water Heater? Yes	Rated Power (kW) 4.5	Retrofit Cost (\$) 175
Thermal Capacitance (kWh/°C) 0.4	Thermal Resistance (°C/kW) 120	Coefficient of Performance 1
Temperature Setpoint (°F) 119.3	Temperature Deadband (°F) 5.4	
Delete Run Model Share Duplicate		

Flathead – derConsumer Inputs

The derConsumer model considers the same subsidies that were used in Scenario 2 derUtilityCost to show the member-consumer point of view.

	Upfront Subsidy (\$)	Ongoing Subsidy (\$/month)	Consumer Retrofit Costs (\$)
BESS	0	\$7.40	0
Air Conditioner	0	\$0.26	150 (Nest Thermostat)
Water Heater	0	\$3.60	175 (Aquila Controller)
Heat Pump	0	\$1.14	0
Generator	-		-

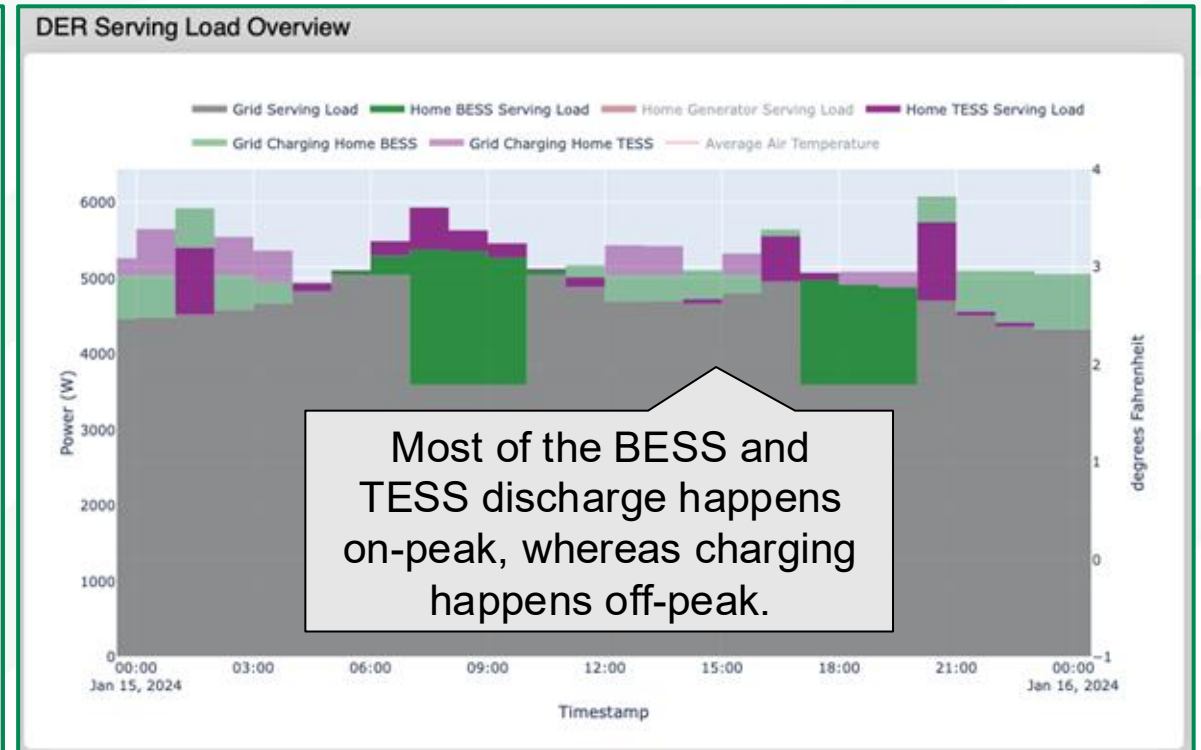
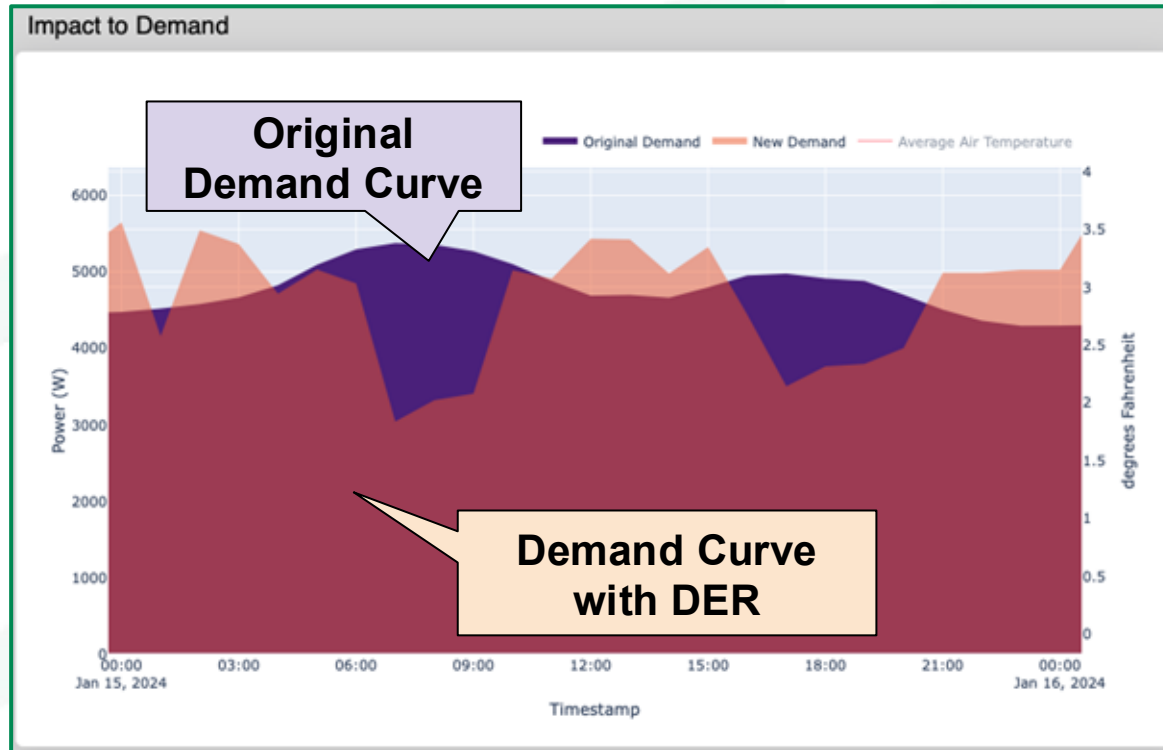
Approx. cost to equip the device to respond to the utility's load control signals. (e.g. Smart Thermostat, Wi-Fi enabled smart plug, etc.)
Note: The companies listed here are only examples, not endorsements.

These are the same subsidies used in the derUtilityCost Adjusted Subsidies case. Using them in derConsumer will show how these subsidies look from the perspective of a hypothetical member-consumer.

The Heat Pump retrofit cost is \$0 because it's the same smart thermostat that is used for the Air Conditioner.

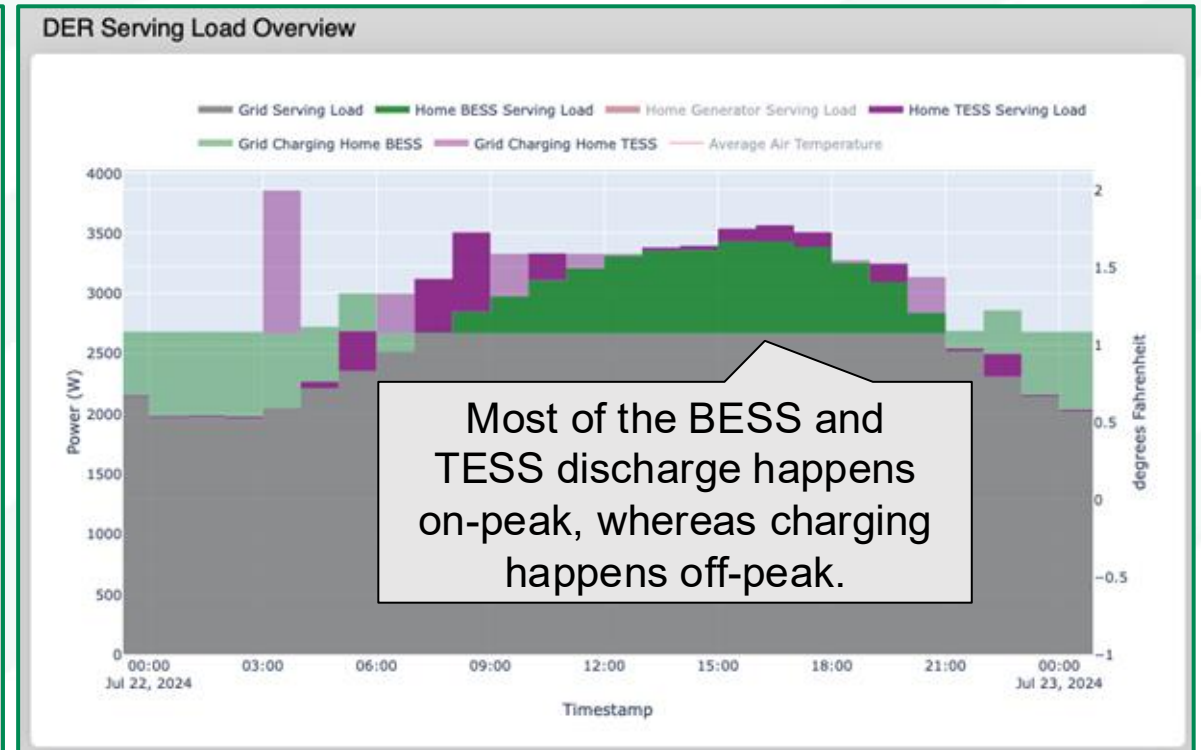
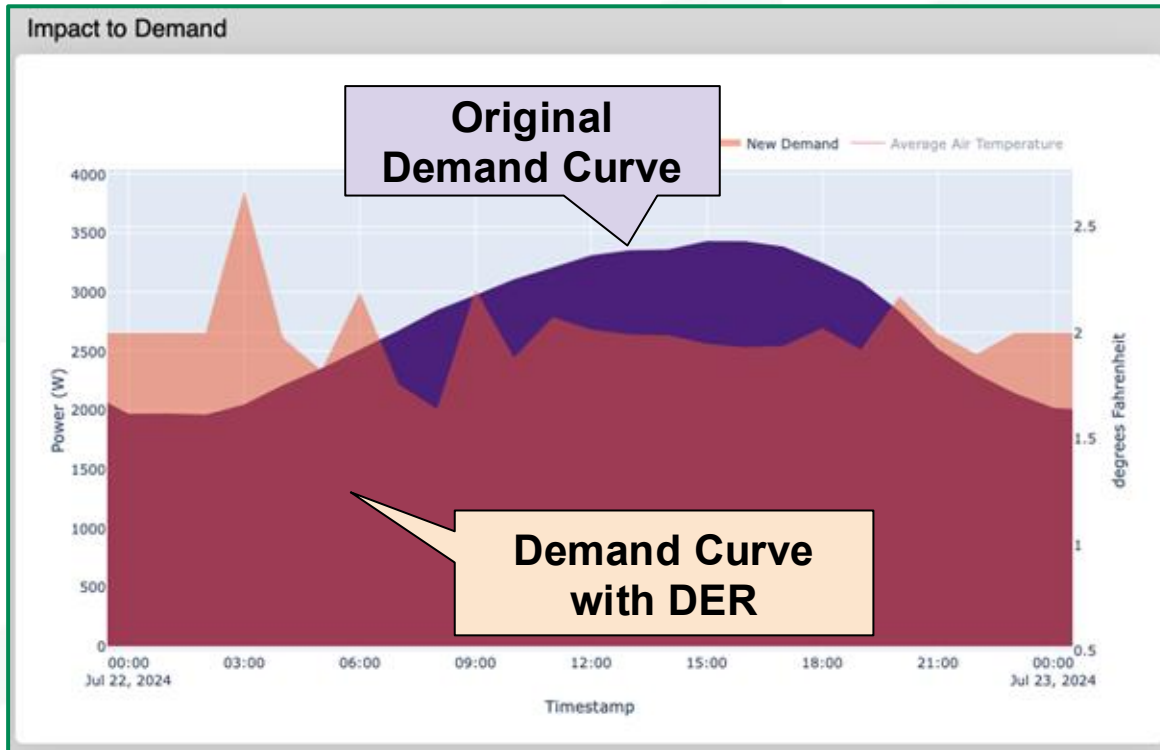
Flathead – derConsumer Outputs

Winter peak – January 15, 2024



Flathead – derConsumer Outputs

Summer peak – July 22, 2024



Flathead – derConsumer Outputs

Monthly Cost Comparison

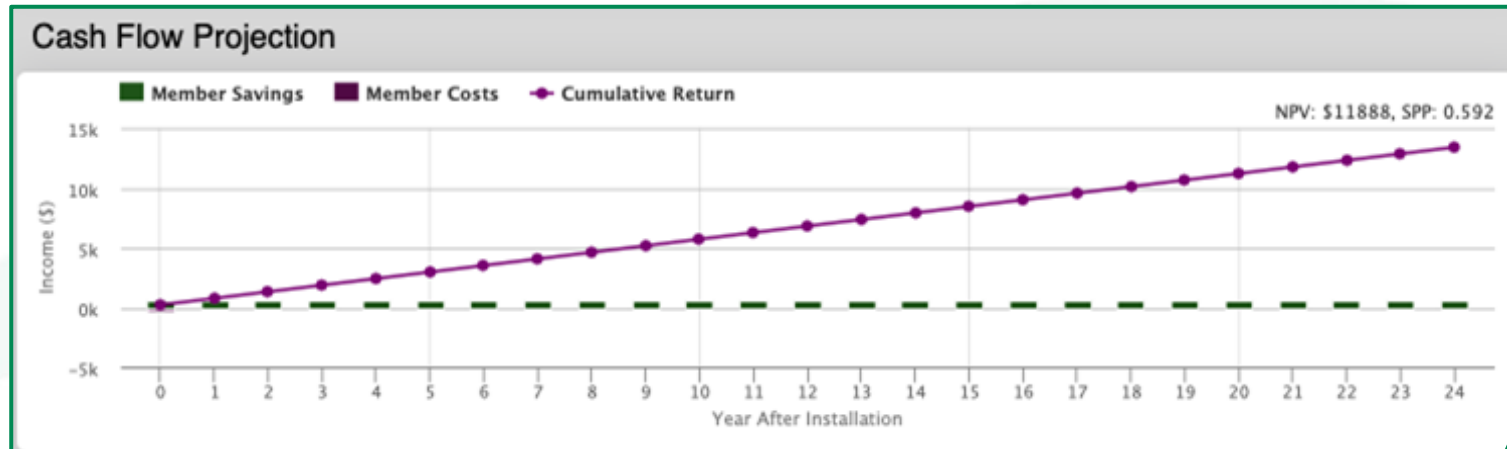
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Total Peak Demand (kW)	347	283	253	218	210	182	248	207	183	222	242
Total Adjusted Peak Demand (kW)	363	309	284	230	230	166	278	244	210	251	263
Energy (kWh)	2,573	2,088	1,957	1,552	1,478	1,399	1,698	1,481	1,334	1,535	1,811
Adjusted Energy (kWh)	2,557	2,062	1,935	1,552	1,495	1,412	1,689	1,481	1,331	1,512	1,793
Energy Cost (\$)	162	130	122	95	90	85	105	90	81	94	112
Adjusted Energy Cost (\$)	161	129	120	95	91	86	104	90	81	93	111
Energy Cost Savings (\$)	1	2	1	-0	-1	-1	1	0	0	1	1
Demand Charge (\$)	697	566	501	431	417	363	491	411	363	442	483
Adjusted Demand Charge (\$)	678	598	510	281	153	163	536	461	403	487	508
Demand Cost Savings (\$)	18	-32	-8	150	265	200	-45	-50	-39	-45	-26
Total Cost of Service (\$)	858	696	623	526	508	448	596	501	444	536	595
Adjusted Total Cost of Service (\$)	839	727	630	376	244	249	641	552	483	580	619
Generator Fuel Cost (\$)	0	0	0	0	0	0	0	0	0	0	0
Utility Subsidies Paid (\$)	12	12	12	12	12	12	12	12	12	12	12
Total Consumer Savings (\$)	33	-18	6	162	276	211	-32	-38	-27	-31	-12
Total Consumer Costs (\$)	325	0	0	0	0	0	0	0	0	0	0
Net Consumer Savings (\$)	-292	-18	6	162	276	211	-32	-38	-27	-31	-12

Cost of Service is sometimes increased, sometimes decreased by utility control of DER; This is why a full year is modeled.

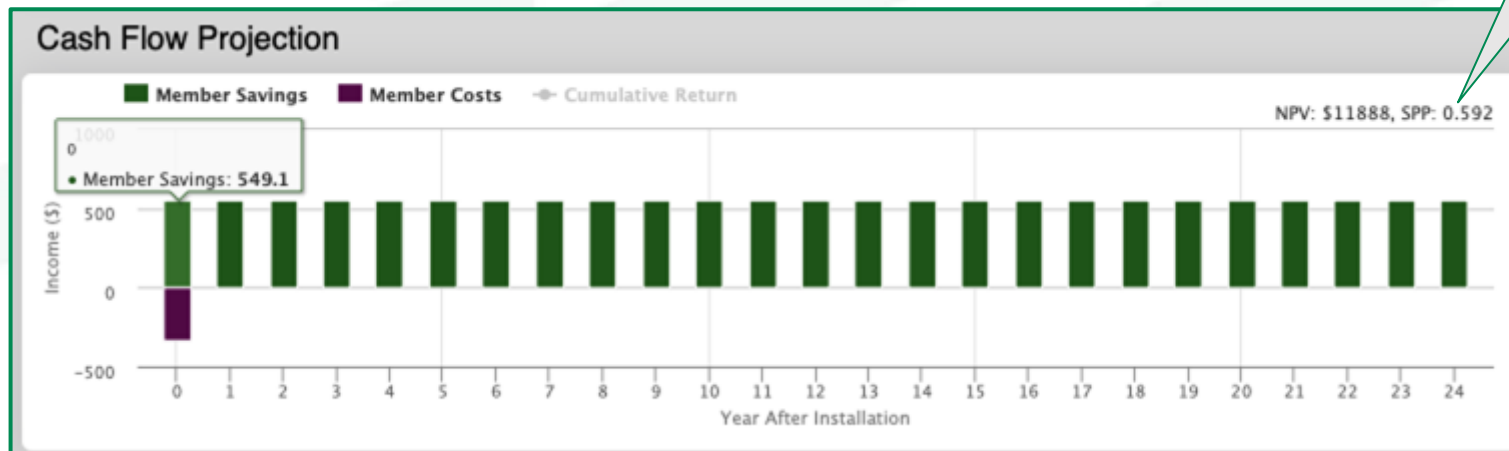
The Total Consumer Costs come from the retrofit and controller device costs.

The Utility Subsidies Paid each month is about \$12. The consumer also saves money from having the DER. Overall, only about 26% of the consumer's annual savings come from utility subsidies.

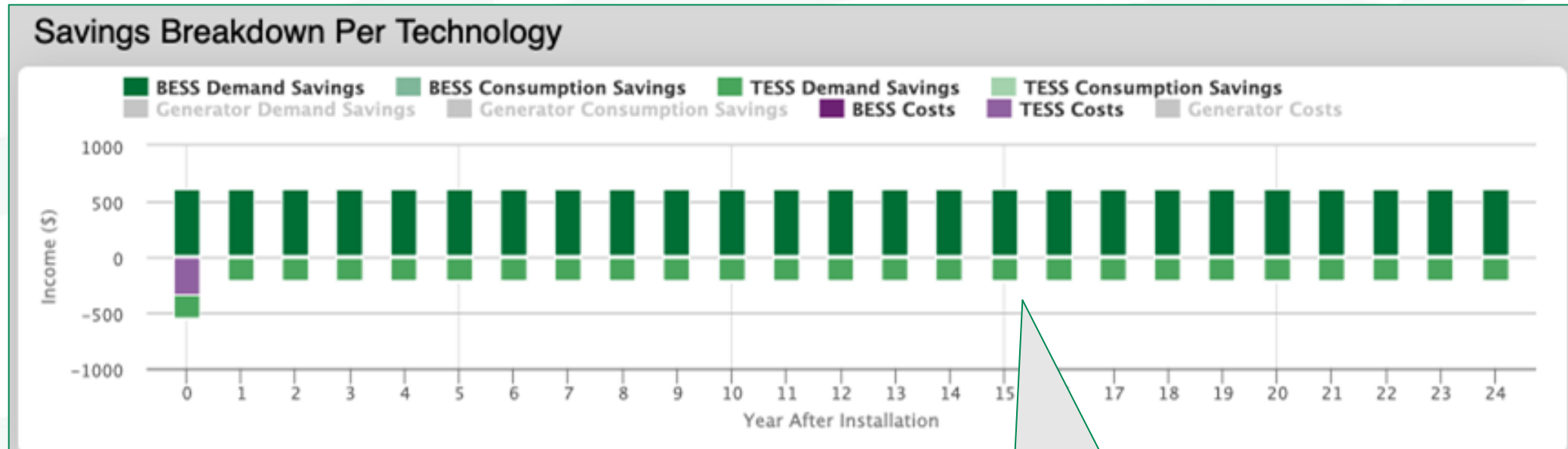
Flathead – derConsumer Outputs



The SPP is positive, meaning the program will pay the consumer back in just over 7 months since the only costs here are the retrofit device costs.



Flathead – derConsumer Outputs



Most of the DER savings come from the BESS, whereas most of the costs come from the TESS technologies

Flathead – derConsumer Outputs

BESS Savings vs. Incentives

Annual BESS Demand Savings + Consumption Savings = \$596/yr

- ★ The consumer can consider enrolling their existing BESS in with the utility's DER sharing program, or consider a new installation. The consumer can also see how quickly a new installation could be paid off over time.

All TESS Savings vs. Incentives

Annual TESS Demand Savings + Consumption Savings = -\$195/yr

- ★ The consumer can consider installing a Smart Thermostat and other load control devices and enroll in the utility's DER sharing program, but these results suggest that it may be more expensive for the consumer.

Savings Breakdown Per Technology



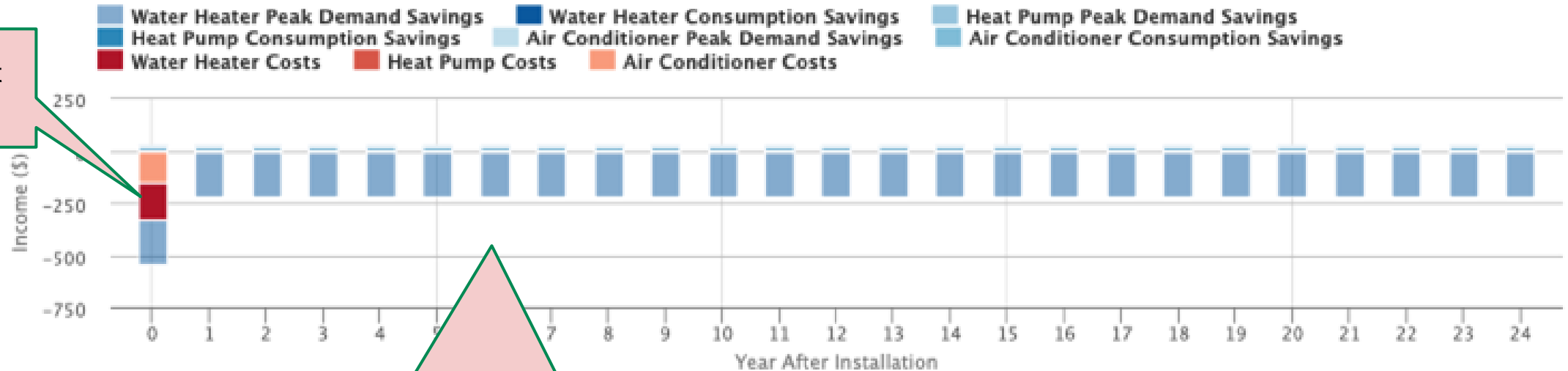
Savings Breakdown Per Technology



Note: The Y axis scale is not the same between the two plots. See the previous slide for a better side-by-side comparison between TESS and BESS.

Flathead – derConsumer Outputs

Savings Breakdown of Thermal Technologies



Cost to retrofit the devices

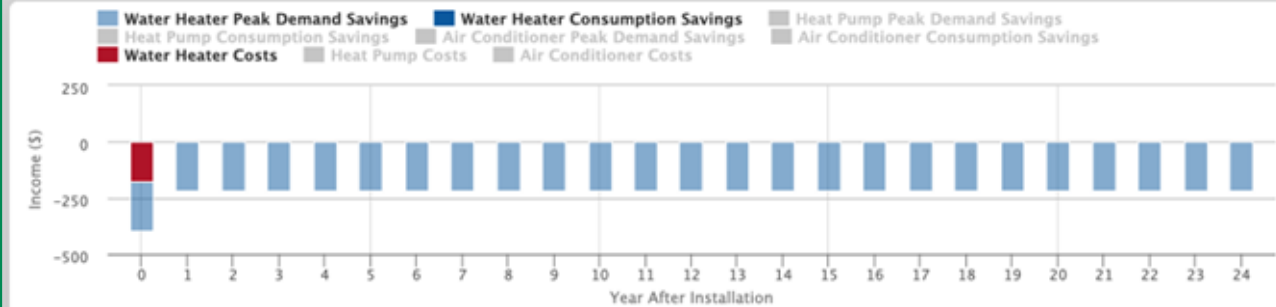
The Water Heater Peak Demand Savings are negative, indicating that this technology is probably charging during the most expensive monthly peak times. This is likely because the thermal optimization code currently does not account for energy or demand tariff information, which would change the time that the thermal technologies are dispatched.

Flathead – derConsumer Outputs

Water Heater Savings vs. Incentives

☆ Annual Demand + Consumption Savings = **-\$217/year**

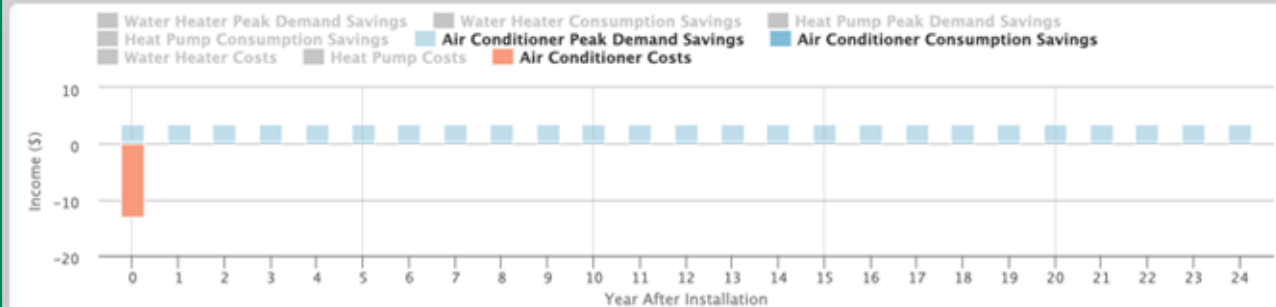
Savings Breakdown of Thermal Technologies



Air Conditioner Savings vs. Incentives

☆ Annual Demand + Consumption Savings = \$4/year

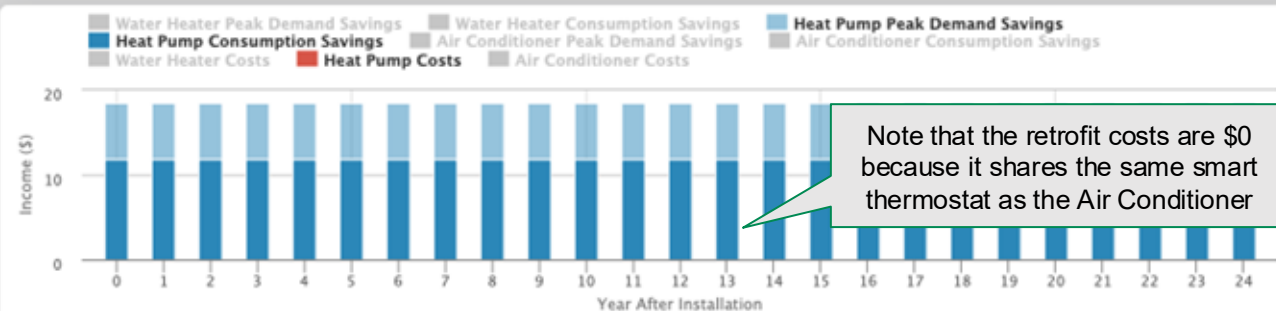
Savings Breakdown of Thermal Technologies



Heat Pump Savings vs. Incentives

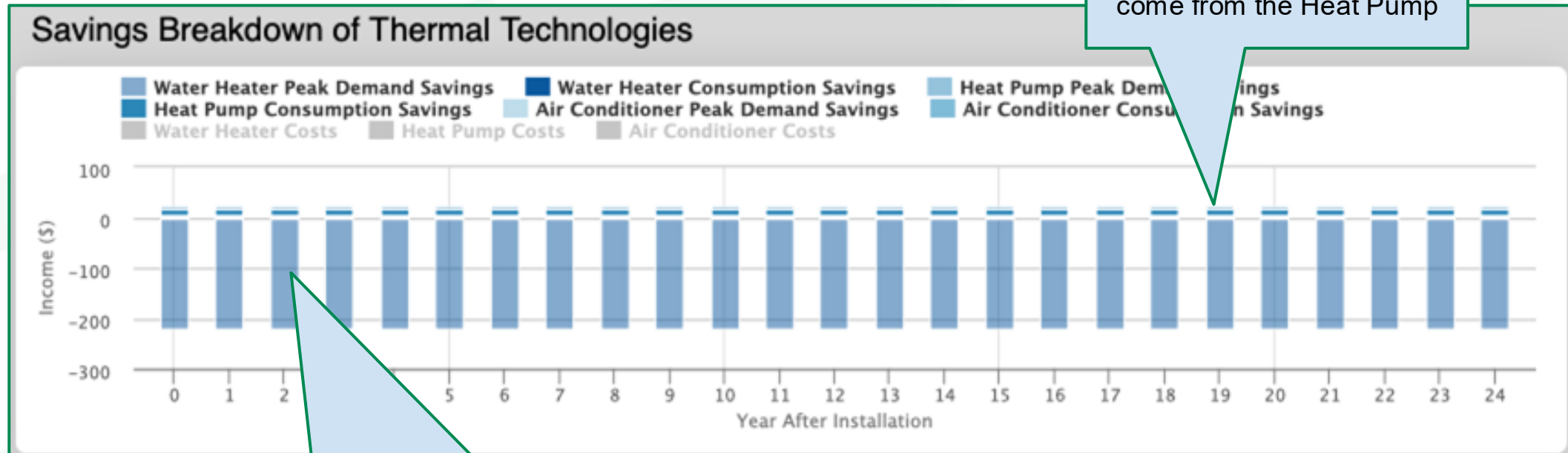
☆ Annual Demand + Consumption Savings = \$18/year

Savings Breakdown of Thermal Technologies



Note that the retrofit costs are \$0 because it shares the same smart thermostat as the Air Conditioner

Flathead – derConsumer Outputs



Water Heaters were listed as Flathead's #2 technology preference, but provided the least amount of savings to the consumer out of all the thermal DER. This negative savings result may stem from the vbatDispatch model not knowing the rate structure information currently, and thus the water heaters "charge" at expensive peak times.

Flathead's Tech Preferences

- #1 = Central Air Conditioner
- #2 = Water Heater
- #3 = Heat Pump
- #4 = BESS
- #5 = GEN

Flathead – Conclusions

Common takeaways from all scenarios:

- BESS and Heat Pumps provided the most monetary benefit to the consumer, whereas Water Heaters provided the most benefit to the utility.
- Water Heaters appear to cost the consumer money, likely due to the current state of the thermal DER optimization code which does not account for any tariff information that would change when the thermal DER were dispatched (e.g. thermal energy arbitrage).
- About 26% of the consumer's monetary benefit came from utility subsidies.

Flathead - Future Considerations

The utility may want to consider other model scenarios, such as:

- Introducing an up-front subsidy
 - Offering or increasing an up-front subsidy could increase initial participation levels, which could then increase the savings provided by some DER.
- Changing monthly subsidy or participation levels
 - Exploring different levels of monthly incentives or number of enrolled devices can give the utility an idea of what kind of program provides the desired savings to the utility.
- Adding Program Costs
 - Ex. Startup Costs = \$200,000 (estimated)
 - Ongoing Operational Costs = \$1,000/month (provided by Camus)
 - One-time Operational Costs = \$20,000
- Evaluate the consumer perspective using a range of consumption behaviors to guide marketing.
 - Represent the membership using a suite of demand curves to obtain strata-specific subsidies.

Model Adjustments Based on Feedback

Reworking Metrics

Priorities for defining outage impact are likely to vary between service areas. To address this, the resilientCommunity model was expanded to use a customizable metric called **Outage Impact Potential (OIP)** in place of FEMA's Social Vulnerability Index (SVI).

OIP aggregates customer variables and weather hazard variables in each census blockgroup along with user-defined weights to determine their importance in one of two ways:

- **Average** can be used if the user wants same-weighted values to be prioritized equally.
- **Root-mean-square (RMS)** can be used if the user wants larger values of the same weight to be prioritized more.

$$\text{Average}$$
$$\text{OIP}_b = \frac{\sum_{v \in V} w_v n_{v,b}}{\sum_{v \in V} w_v}$$

$$\text{RMS}$$
$$\text{OIP}_b = \sqrt{\frac{\sum_{v \in V} w_v n_{v,b}^2}{\sum_{v \in V} w_v}}$$

OIP_b , the OIP Score for a blockgroup, b .
 V , the set of variables used to calculate OIP.
 w_v , the weight assigned to a variable v .
 $n_{v,b}$, the normalized value of a variable v for blockgroup b .

Each variable is normalized so that its minimum value is 0 and its maximum value is 1 before aggregating, referred to in this model as “**Min-Max-Normalized**”. This allows variables of different scales to be meaningfully combined.

Reworking Metrics

To reflect independence from SVI, the Community Criticality Score (CCS) has been renamed to **Locational Criticality Score (LCS)**. The calculation of equipment LCS now parallels that of equipment BCS for more consistency in how the metrics can be interpreted.

$$LCS_{Load} = BCS_{Load} \times OIP_b \quad LCS_{Equipment} = \sum_{Load \in Loads} LCS_{Load}$$

The **Base Criticality Score (BCS)** remains unchanged.

$$BCS_{Load} = \frac{kva_{Load}}{\left(\frac{pd}{N}\right)} \quad BCS_{Equipment} = \sum_{Load \in Loads} BCS_{Load}$$

kva_{Load} , the demand at $Load$.

pd , the peak demand (in kva) for the average load served by the system.

N , the average number of occupants for a household in the area.

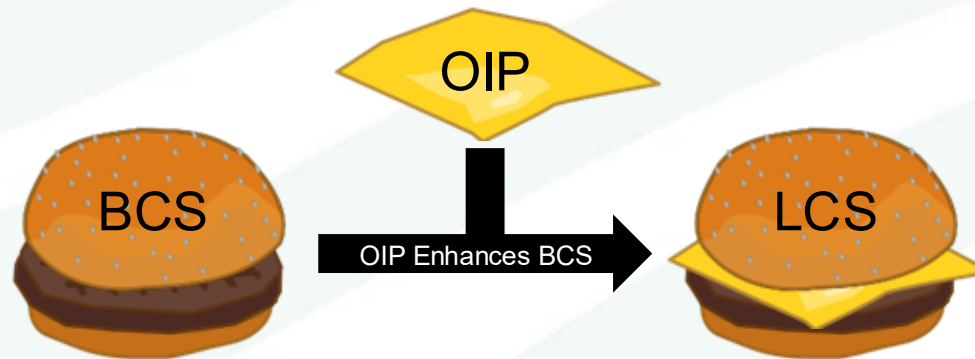
$\left(\frac{pd}{N}\right)$, the estimated demand contribution per person

$Loads$, the set of all loads served by a piece of equipment: *Equipment*

Reworking Metrics

BCS estimates the number of people served at a load or by a piece of equipment.

LCS estimates the potential for outage impact on a number of people served at a load or by a piece of equipment.



Rather than thinking of **BCS** and **LCS** as two totally different metrics, **OIP** can be thought of as a special ingredient that enhances **BCS** to create **LCS**.

Expanding Functionality

- OIP is designed to be the aggregate of 12 customer variables and 13 weather hazard variables, each weighted by the user and optionally excluded by using a weight of 0.
- OIP expands the possibilities formerly enabled by SVI by including most of the variables used to calculate SVI in the 12 customer variables alongside the 13 other variables users may prioritize.

Open Modeling Framework • resilientCommunity • "Demo resCom mostly ag After OIP"

Model Input

Model Type Help?	Model Name	User
resilientCommunity	Demo resCom mostly ag After OIP	admin
Created	Run Time	
2025-11-04 11:59:15.932522	0:00:07	

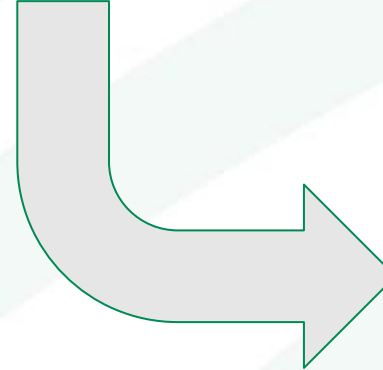
System Parameters

Feeder	Customer Information (.csv file)	Equipment Lifetime (.csv file)
Open Editor	Choose File restorationLoads ORIGINAL.csv	Choose File equipLifeExample.csv
Average Peak Demand (kW)	Feeder Map Coloring By	
2.0	Feeder Sections	

Include in Analysis

Lines	Transformers	Fuses
Yes	No	No

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Open Modeling Framework • resilientCommunity • "Demo resCom mostly ag After OIP"

Model Input

Model Type Help?	Model Name	User
resilientCommunity	Demo resCom mostly ag After OIP	admin
Created	Run Time	
2025-11-04 11:59:15.932522	0:00:10	

System Parameters

Feeder	Customer Information (.csv file)	Equipment Lifetime (.csv file)
Open Editor	Choose File restorationLoads ORIGINAL.csv	Choose File equipLifeExampleEMPTY.csv
Feeder Map Coloring By	Average Peak Demand (kW)	Average Number of Occupants
Base Criticality Index	2.0	4.0

Include in Analysis

Lines	Transformers	Fuses
Yes	No	No

Outage Impact Potential (OIP)

Aggregation Method: Average of Min-Max Normalized

Outage Impact Potential - Customer Variables

% Age 16+ Employed	Weight	1
% Age 65+	Weight	1
% Crowding	Weight	1
% Individuals Below Poverty Level	Weight	1
% Individuals Disabled	Weight	1
% Limited English Speaking Households	Weight	1
% Mobile Home	Weight	1
% Multi-Unit Structure	Weight	1
% No Vehicle	Weight	1
% Non-HS Grads	Weight	1
% Non-Institutionalized Below Age 19	Weight	1
Avg Aggregate Household Income (USD)	Weight	1

Outage Impact Potential - Weather Hazards Annualized Frequency

Avalanche	Weight	1
Cold Wave	Weight	1
Drought	Weight	1
Earthquake	Weight	1
Hail	Weight	1
Heat Wave	Weight	1
Hurricane	Weight	1
Ice Storm	Weight	1
Landslide	Weight	1
Lightning	Weight	1
Strong Wind	Weight	1
Wildfire	Weight	1
Winter Weather	Weight	1

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Expanding Functionality

Because of the robust way user input contributes to OIP, the Restoration model was changed so that instead of referencing resilientCommunity internally, resilientCommunity now generates an output that users can upload as an input to enhance the restoration analysis.

This keeps the functionality and inputs of the individual models more separate but still allows the functionality of one model to enhance the other.

Open Modeling Framework » restoration » "testing new resto"

Model Input

Model Type Help?	Model Name	User
restoration	testing new resto	admin

Created: 2025-11-17 14:10:21.698191 Run Time: 0:00:50

Model Specifications

Feeder Open Editor	Event Information (.json file) Choose File iowa240_dwp_22.events.json	Solution Fidelity Medium
Load Priorities (.json file) Choose File iowa240_dwp_22.loadPriority.ba	Microgrid Tagging (.csv file) Choose File iowa240_dwp_22.microgridTaggi	Impact of CCI High

Outage Cost Parameters

Customer Information (.csv file) Choose File customerInfoExample.csv	Restoration Cost (\$/hr) 100	Hardware Cost (\$) 550
---	---------------------------------	---------------------------

Energy Sales Margin: 0.03

[Delete](#) [Run Model](#)



Open Modeling Framework » restoration » "testing new resto"

Model Input

Model Type Help?	Model Name	User
restoration	testing new resto	admin

Created: 2025-11-17 14:10:21.698191 Run Time: 0:00:50

Model Specifications

Feeder Open Editor	Event Information (.json file) Choose File iowa240_dwp_22.events.json	Solution Fidelity Medium
Load Priorities (.json file) Choose File iowa240_dwp_22.loadPriority.ba	Microgrid Tagging (.csv file) Choose File iowa240_dwp_22.microgridTaggi	

Outage Cost Parameters

Customer Information (.csv file) Choose File customerInfoExample.csv	Restoration Cost (\$/hr) 100	Hardware Cost (\$) 550
---	---------------------------------	---------------------------

Energy Sales Margin: 0.03

Include Locational Data in Analysis

Load LCI Data (.json file) Choose File rescomOutputForIowa240.json	Use LCI Yes	Impact of LCI High
---	----------------	-----------------------

[Delete](#) [Run Model](#)

Advantages of Min-Max-Scaling

SVI was calculated by taking the percentile rankings of each variable, then for a particular block group, summing those percentile rankings to create a **Social Vulnerability Score**. Those **Social Vulnerability Scores** for each blockgroup were then ranked against each other to create **SVI**.

Instead of percentile ranking variables, **OIP** uses **Min-Max-Normalization** before aggregating them into an **OIP Score**. The **OIP Score** for each blockgroup can then be ranked against each other to create **OIP Index**.

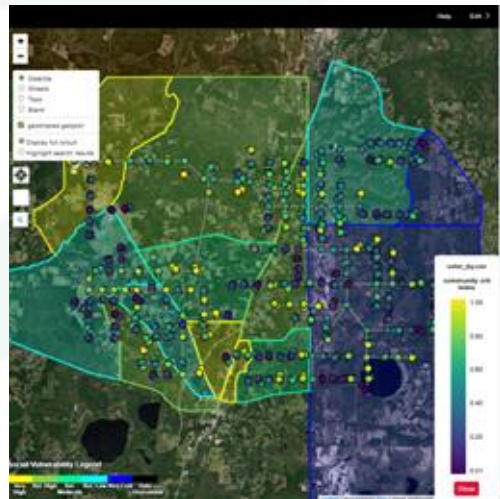
Both percentile ranking and **Min-Max-Normalization** force values between 0 and 1 but only **Min-Max-Normalization** preserves relative distance between values while percentile ranking erases that information. Performing further calculations on percentile rankings carries forward that loss of information, making it less ideal for use before the last step in a calculation.

Example Variable Name	Example Values (1 per blockgroup)	Min-Max-Normalizations	Percentile Rankings
% Age 65+	(1, 2, 3, 11)	(0, 0.1, 0.2, 1)	(0.25, 0.5, 0.75, 1)
% Individuals Disabled	(1, 7, 10, 13)	(0, 0.5, 0.75, 1)	(0.25, 0.5, 0.75, 1)

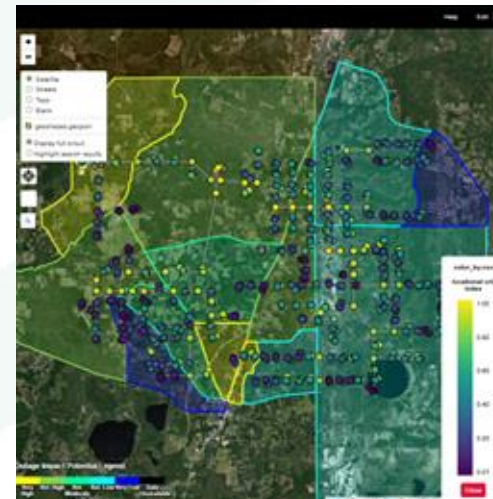
Advantages of Min-Max-Scaling

The effects of using **Min-Max-Scaling** versus percentile ranking can be visualized by comparing two identical feeders where one feeder map is made using **SVI** and the other is made using **OIP Index** calculated with the same variables as **SVI** and aggregated by **Average of Min-Max-Normalization**.

Because the number of variables being averaged is the same across every blockgroup, averaging variables and then ranking results is equivalent to summing variables and then ranking results. Thus, the only difference between **SVI** and **OIP Index** in these maps is the method used to force their variables between 0 and 1 before aggregation.



Resilient Community Map using SVI

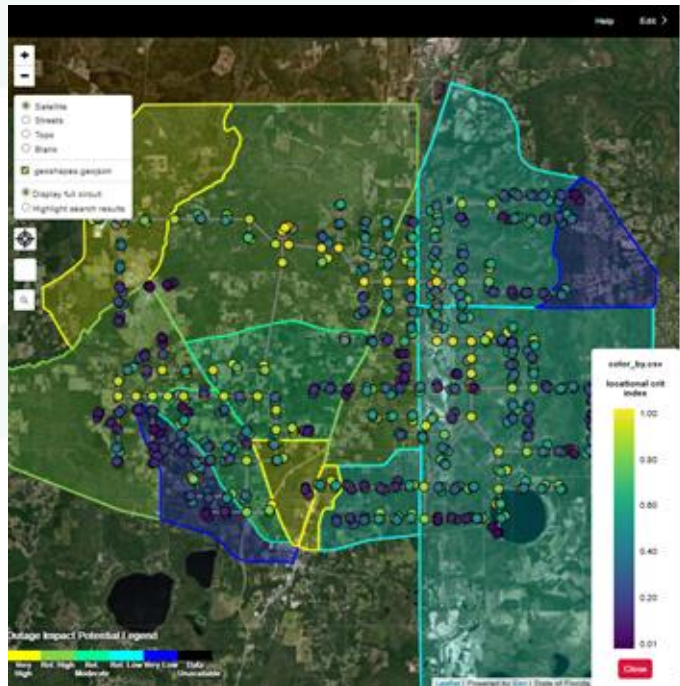


Resilient Community Map using OIP Aggregated via
Avg of Min-Max-Normalized Customer Variables

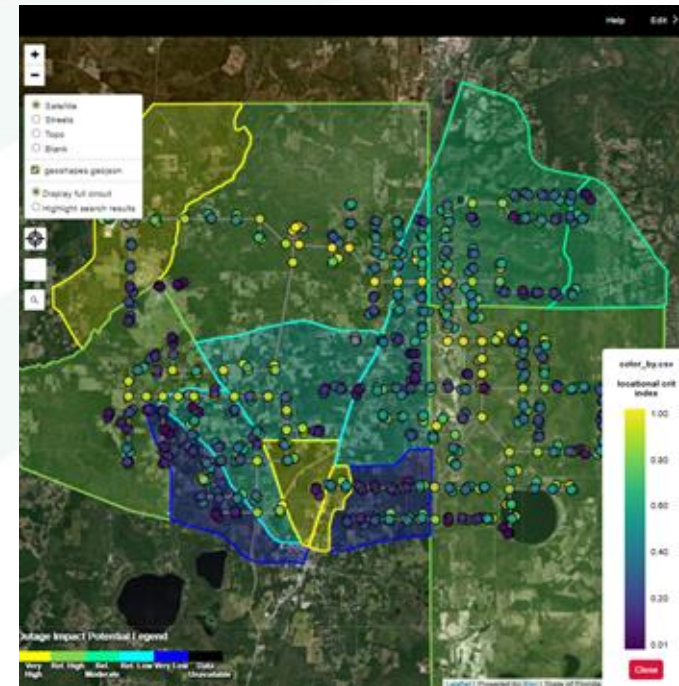
We can see from these maps that the loss of information inherent to SVI makes a noticeable difference in the ranking of blockgroups on the feeder.

Advantages of New Aggregation Methods

While the **Average of Min-Max-Normalized** aggregation method (left) is used as the default because it prioritizes same-weighted variables evenly, the **RMS of Min-Max-Normalized** method (right) can be effective for identifying blockgroups which have more extreme values for their variables. This can be particularly useful when used with a smaller subset of variables enabled to identify the places that most need particular kinds of support when resources are constrained.



Resilient Community Map using OIP Aggregated via Avg of Min-Max-Normalized Customer Variables



Resilient Community Map using OIP Aggregated via RMS of Min-Max-Normalized Customer Variables

Flexibility of OIP

The ability to control the weights of each variable and exclude variables by setting weights to 0 introduces a new level of flexibility to how resilientCommunity can be used.

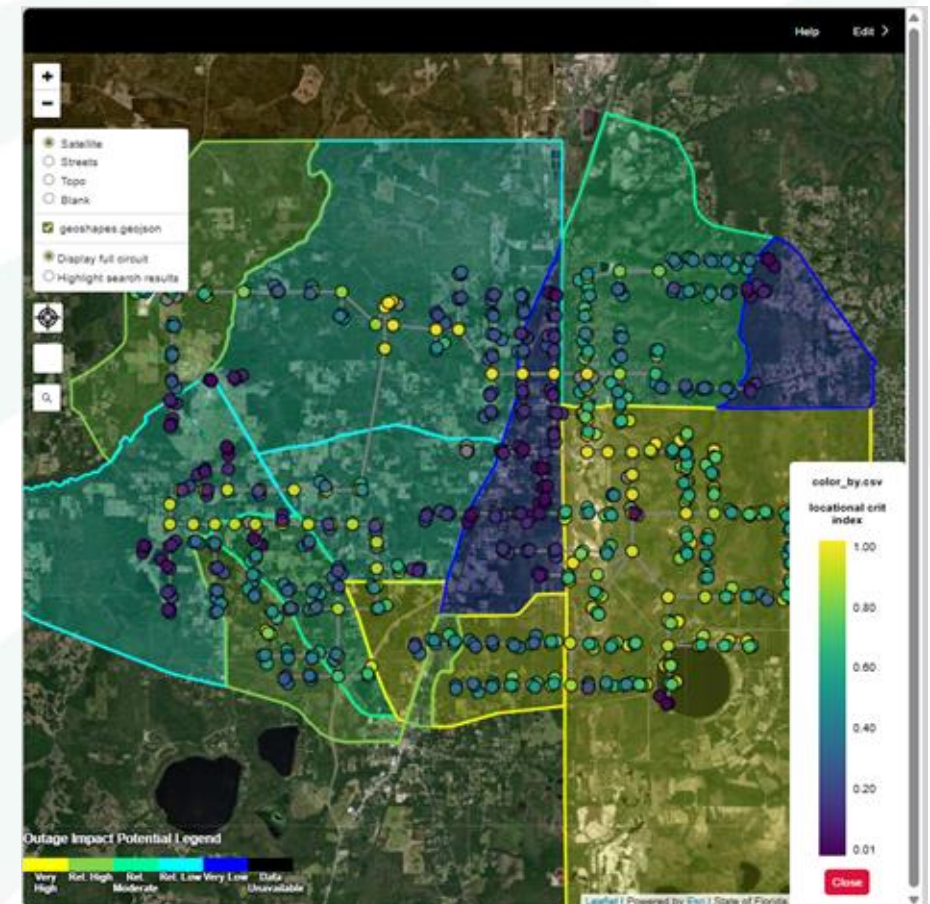
Consider the example where someone specifically wants to identify areas where more people are likely to be reliant on durable medical equipment.

With OIP, they could set all weights to 0 except for “% Age 65+” and “% Individuals Disabled” then look for yellow “very high” OIP Index areas on the map output.

Outage Impact Potential - Customer Variables		
% Age 16+ Employed	Weight	0
% Age 65+	Weight	1
% Crowding	Weight	0
% Individuals Below Poverty Level	Weight	0
% Individuals Disabled	Weight	1
% Limited English Speaking Households	Weight	0
% Mobile Home	Weight	0
% Multi-Unit Structure	Weight	0
% No Vehicle	Weight	0
% Non-HS Grads	Weight	0
% Non-Institutionalized Below Age 19	Weight	0
Avg Aggregate Household Income (USD)	Weight	0

Outage Impact Potential - Weather Hazards Annualized Frequency		
Avalanche	Weight	0
Cold Wave	Weight	0
Drought	Weight	0
Earthquake	Weight	0
Hail	Weight	0
Heat Wave	Weight	0
Hurricane	Weight	0
Ice Storm	Weight	0
Landslide	Weight	0
Lightning	Weight	0
Strong Wind	Weight	0
Wildfire	Weight	0
Winter Weather	Weight	0

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Resilient Community Changes: # Occupants

In the resilientCommunity model, the accuracy of **BCS** to estimate the total number of persons served at a load or by a piece of equipment was improved by using average number of household occupants at a blockgroup-resolution, rather than using one value for the whole system.

Because Resilient Community now dynamically retrieves average number of household occupants from the US Census database, users no longer have to estimate a system-wide “Average Number of Occupants” input. Instead, they can actually use the model to gain that knowledge for each blockgroup.

System Parameters

Feeder [Open Editor](#)

Customer Information (.csv file) [Choose File](#) restorationLoads.csv

Equipment Lifetime (.csv file) [Choose File](#) equipLifeExample.csv

Feeder Map Coloring By: Base Criticality Index

Average Peak Demand (kva) 2.0

~~Average Number of Occupants 4~~



System Parameters

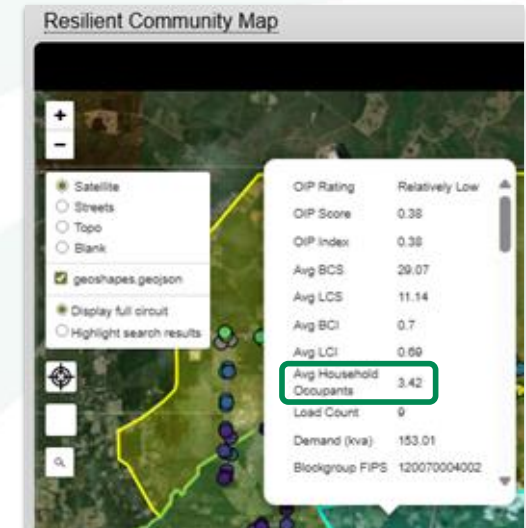
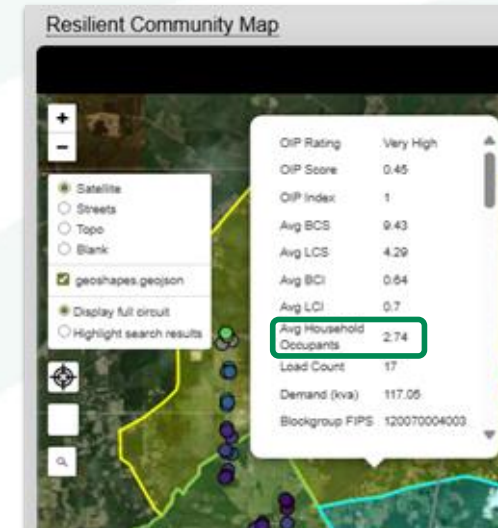
Feeder [Open Editor](#)

Customer Information (.csv file) [Choose File](#) restorationLoads.csv

Equipment Lifetime (.csv file) [Choose File](#) equipLifeExample.csv

Feeder Map Coloring By: Base Criticality Index

Average Peak Demand (kva) 2.0



Restoration Changes: Demand Served

- Performed extensive testing to verify what Demand Served Plot variables taken from PowerModelsONM output represent.
- It became apparent during testing that names used weren't explanatory enough without accompanying definitions.
- Created new variable names based on understanding built through verification testing and official documentation.

— Total Demand — Feeder Demand — Microgrid Demand — Bonus Demand via Microgrid



— % Total Demand Served
— % Microgrid Demand Served

— % Non-Microgrid Demand Served By Grid
— % Non-Microgrid Demand Served By Microgrids

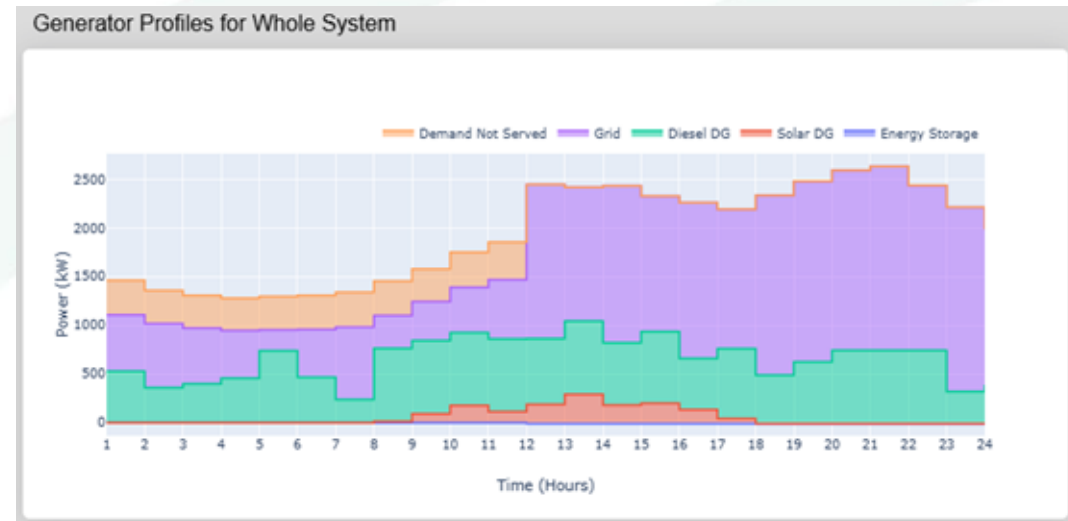
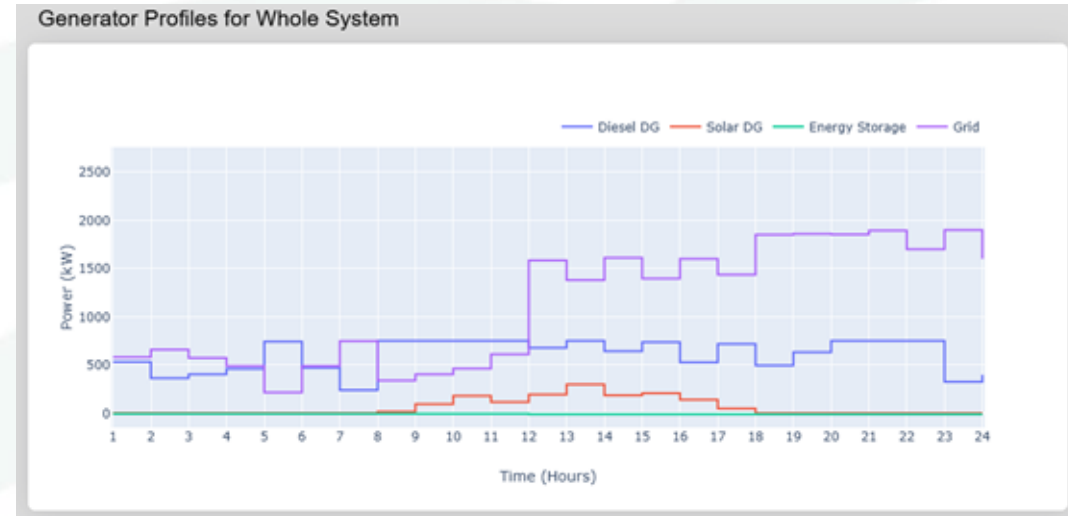
Restoration Changes: Generator Profiles

Old:

- Horizontal line chart with overlapping variables
- Hard to visualize total generation
- No visualization of Demand Not Served due to outages

New:

- Stacked area chart
- Total generation visualized by line tracing the top of stacked generation areas
- Estimation of Demand Not Served added atop other areas (calculated based on demand scheduled via loadshape and base kW for each load experiencing outage)



Restoration Changes: Utility Outage Cost

- Removed Restoration Labor Cost and Restoration Hardware Cost because they were over-simplified estimations.
- Took what was most important in Utility Outage Cost and expanded it out into a more informative plot.

Model Specifications

Feeder [Open Editor](#)

Event Information (.json file) [Choose File](#) iowa240_dwp_22.eventsONLY2C

Solution Fidelity

Load Priorities (.json file) [Choose File](#) iowa240_dwp_22.loadPriority.ba

Microgrid Tagging (.csv file) [Choose File](#) iowa240_dwp_22.microgridTaggi

Outage Cost Parameters

Customer Information (.csv file) [Choose File](#) customerInfoExample.csv

Restoration Cost (\$/hr)

Hardware Cost (\$)

Energy Sales Margin

Include Locational Data in Analysis

Load LCI Data (.json file) [Choose File](#) rescomOutputForIowa240.json

Use LCI

Impact of LCI

[Delete](#) [Run Model](#) [Share](#) [Duplicate](#)



Model Specifications

Feeder [Open Editor](#)

Customer Information (.csv file) [Choose File](#) customerInfoExample.csv

Event Information (.json file) [Choose File](#) iowa240_dwp_22.eventsONLY2C

Solution Fidelity

Load Priorities (.json file) [Choose File](#) iowa240_dwp_22.loadPriority.ba

Microgrid Tagging (.csv file) [Choose File](#) iowa240_dwp_22.microgridTaggi

Include Locational Data in Analysis

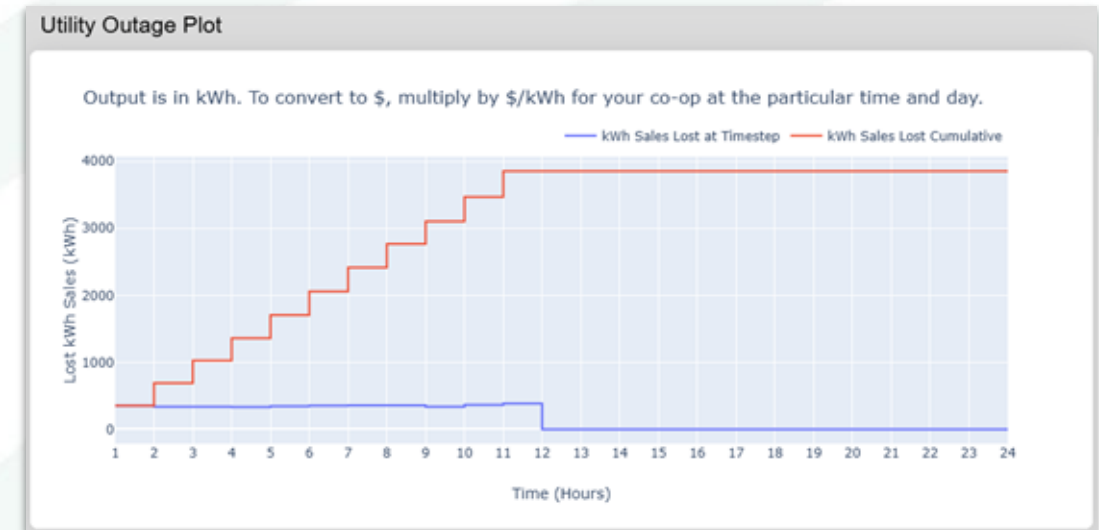
Load LCI Data (.json file) [Choose File](#) rescomOutputForIowa240.json

Use LCI

Impact of LCI

[Delete](#) [Run Model](#) [Share](#) [Duplicate](#)

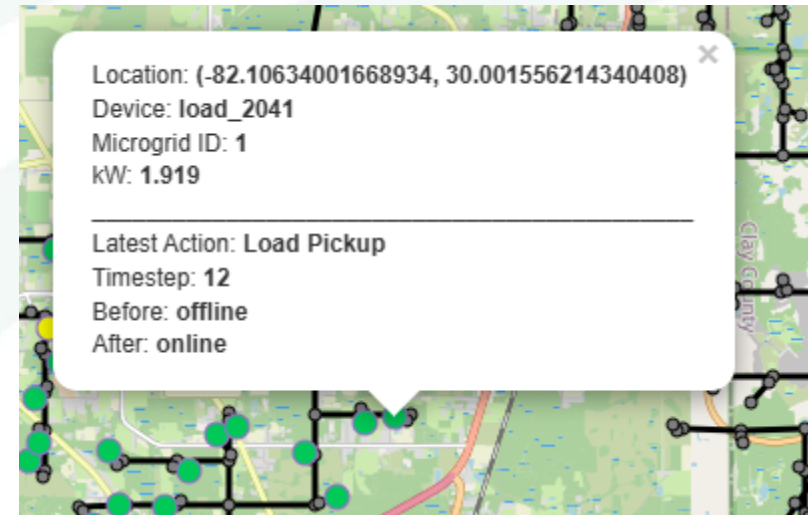
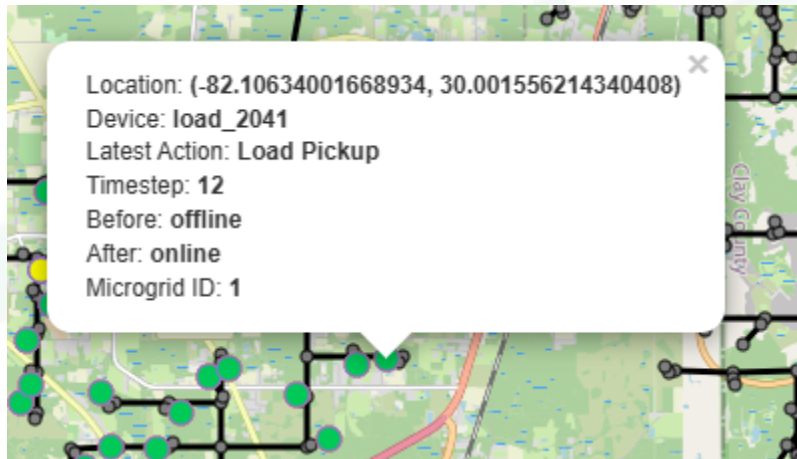
Utility Outage Cost			
Lost kWh Sales	Restoration Labor Cost	Restoration Hardware Cost	Utility Outage Cost
265.68	\$2,400.00	\$550.00	\$3,215.68



Restoration Changes: Outage Map

Updated popup on outage map for each object on the circuit:

- Separated static values for each object from dynamic values that occur at timesteps in the simulation.
- Added base kW to static values in map popup for quick reference.



Clarified Monthly Cost Comparison Chart

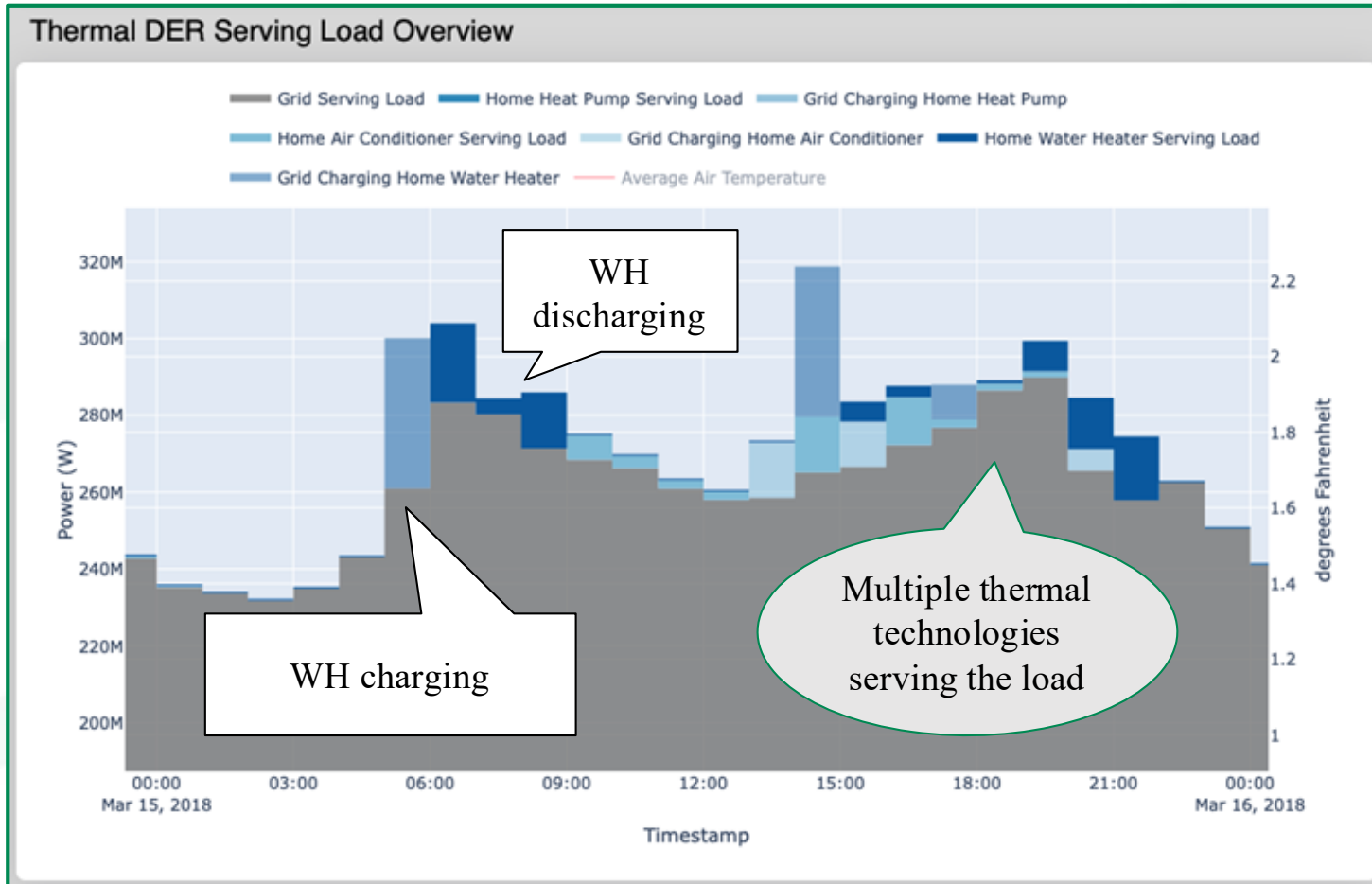
The utility's total costs, savings, and net savings were added to the Monthly Cost Comparison Chart to provide a more concise picture of the value of a DER sharing program from month to month.

This addition shows which months of the year are least/most profitable, depending on things like seasonal weather variations, the utility's consumption at different times of the year, and what DER are serving the load at any given time.

Monthly Cost Comparison												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Peak Demand (kW)	328,568	329,601	312,643	303,527	383,522	459,433	476,507	434,832	432,229	326,931	307,627	340,568
Total Adjusted Peak Demand (kW)	298,695	298,542	287,279	280,606	328,058	414,330	414,488	375,617	369,945	282,211	286,800	303,168
Demand Charge (\$)	16,428,400	16,480,050	15,632,150	15,176,350	19,176,100	22,971,650	23,825,350	21,741,600	21,611,450	16,346,550	15,381,350	17,028,400
Adjusted Demand Charge (\$)	14,934,769	14,927,095	14,363,952	14,030,318	16,402,920	20,716,517	20,724,390	18,780,832	18,497,264	14,110,564	14,339,991	15,158,420
Demand Cost Savings (\$)	1,493,631	1,552,955	1,268,198	1,146,032	2,773,180	2,255,133	3,100,960	2,960,768	3,114,186	2,235,986	1,041,359	1,869,980
Energy (kWh)	202,900,008	185,231,888	194,820,114	185,376,600	198,356,499	214,256,681	243,553,144	227,990,388	206,254,073	192,262,680	179,604,045	203,503,708
Adjusted Energy (kWh)	203,784,643	186,017,113	195,099,008	185,431,558	198,900,618	215,307,443	244,384,619	228,825,092	207,014,596	192,496,117	180,408,130	204,459,573
Energy Cost (\$)	18,730,877	17,063,856	17,906,685	17,094,318	18,689,999	20,651,090	23,531,252	22,065,762	19,829,106	17,813,020	16,621,772	18,883,179
Adjusted Energy Cost (\$)	17,982,772	16,473,959	17,273,873	16,487,022	17,527,575	19,578,343	22,408,553	20,953,803	18,738,524	17,114,707	15,770,038	18,066,750
Energy Cost Savings (\$)	748,104	589,897	632,811	607,296	1,162,424	1,072,747	1,122,699	1,111,959	1,090,581	698,313	851,734	816,429
Total Cost of Service (\$)	35,159,277	33,543,906	33,538,835	32,270,668	37,866,099	43,622,740	47,356,602	43,807,362	41,440,556	34,159,570	32,003,122	35,911,579
Adjusted Total Cost of Service (\$)	32,917,541	31,401,054	31,637,826	30,517,340	33,930,495	40,294,860	43,132,943	39,734,635	37,235,789	31,225,271	30,110,029	33,225,170
Total Consumer Compensation (\$)	4,279,420	1,418,812	1,434,083	1,427,807	1,549,371	1,534,923	1,540,916	1,543,647	1,536,628	1,453,263	1,476,785	1,467,665
Program Startup and Operational Costs (\$)	221,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Total Utility Savings (\$)	2,241,736	2,142,852	1,901,009	1,753,328	3,935,603	3,327,880	4,223,659	4,072,727	4,204,767	2,934,299	1,893,093	2,686,409
Total Utility Costs (\$)	4,500,420	1,419,812	1,435,083	1,428,807	1,550,371	1,535,923	1,541,916	1,544,647	1,537,628	1,454,263	1,477,785	1,468,665
Net Utility Savings (\$)	-2,258,684	723,040	465,926	324,521	2,385,233	1,791,957	2,681,744	2,528,080	2,667,140	1,480,037	415,308	1,217,744

Added **Total Utility Savings (\$)**, **Total Utility Costs (\$)**, and **Net Utility Savings (\$)** to the Monthly Cost Comparison Chart.

Thermal DER Serving Load Overview Plot



A new plot was added to the model to show a more detailed breakdown of the thermal DER technologies (Water Heater, Air Conditioner, and Heat Pump) that serve the utility's load throughout the year.

Previously, all thermal technologies were combined into a single "TESS" series, analogous to a virtual battery.

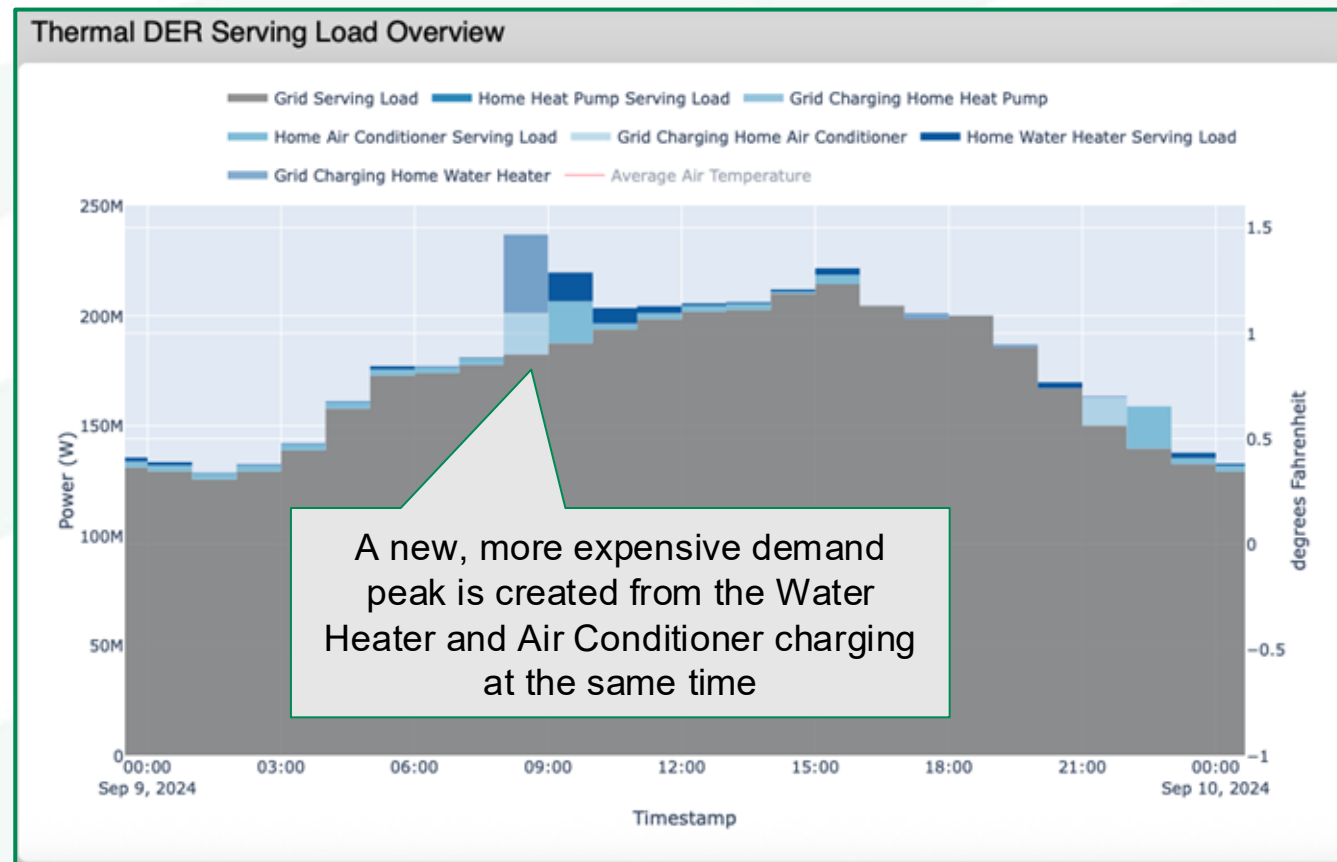
This new, detailed view of the thermal technologies allows a utility to analyze behavior for a specific technology during a specific hour, day, or month of the year.

Thermal DER Charge Prioritization

Each thermal technology (i.e. WH, AC, HP) is calculated independently from the others because the vbatDispatch model can only model one thermal DER at a time.

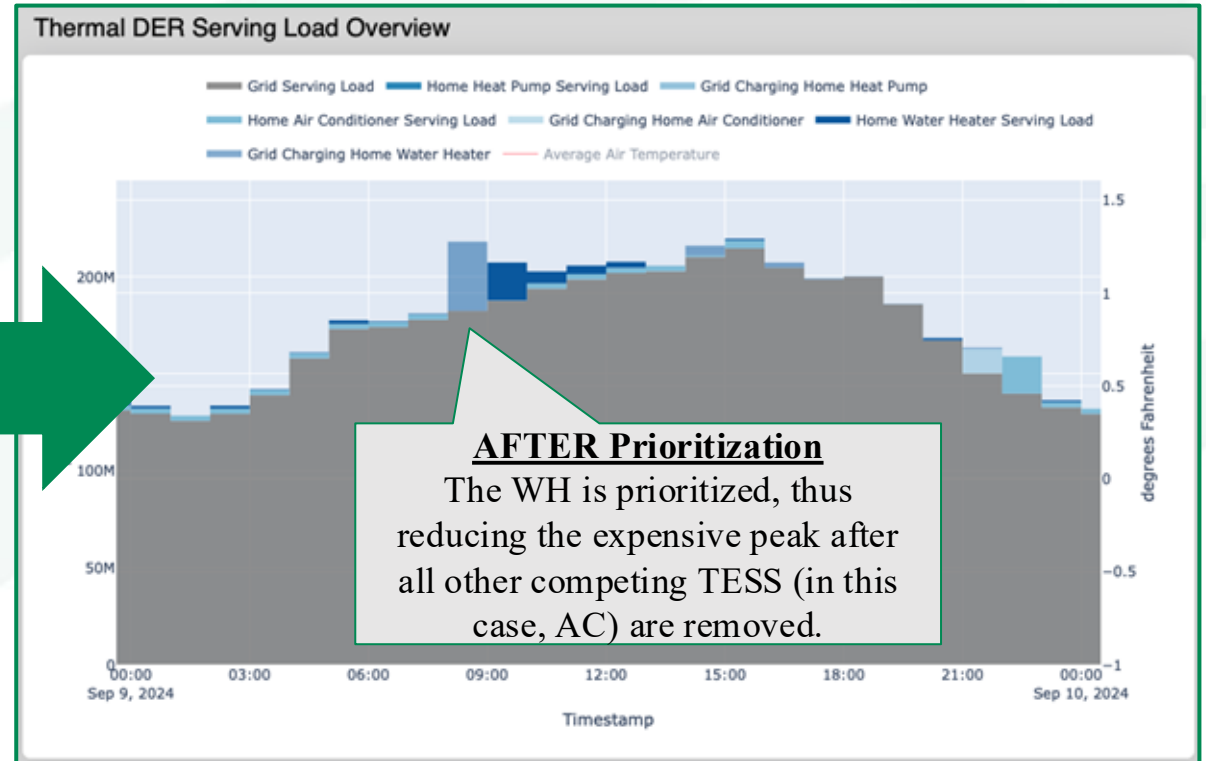
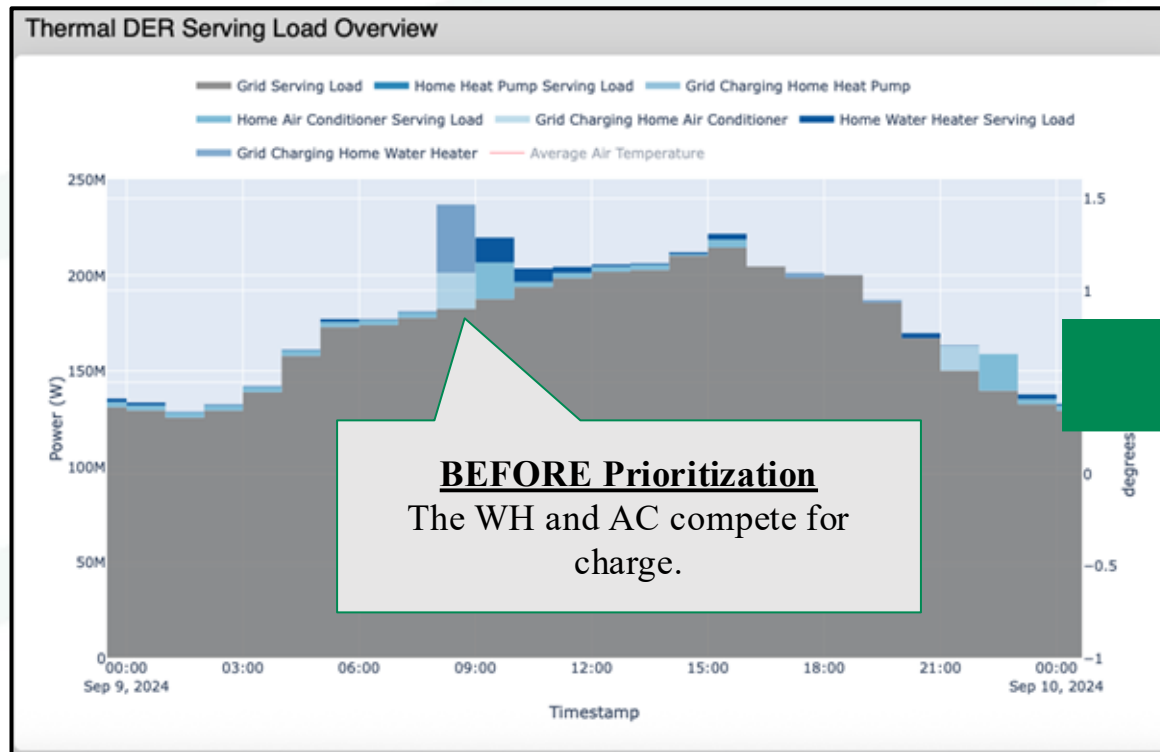
After collecting and combining the individual thermal DER results, instances of two or more thermal DER with coinciding charge times appeared to create a larger peak kW expense for the utility (see figure on the right).

To address this, a thermal DER prioritization plan was introduced into the derUtilityCost and derConsumer models to only allow one thermal DER to charge at any given time.



Thermal DER Charge Prioritization

The prioritization order is fixed where Water Heaters are prioritized first, followed by Air Conditioners, then Heat Pumps. All technologies that are not the top priority at a given time are not allowed to charge. The figures below show the results before and after the prioritization is implemented.



Control over TESS variability

In order to reproduce the same model results as Scenario 1 and only change the subsidies, the random seeds and random numbers in Scenario 2 must be set to the same numbers produced in Scenario 1, which can be found in the outputs at the bottom of the model.

Scenario 1 outputs:

Raw Input and Output Files

random_seeds.csv — water_heater_random_numbers.csv — demand.csv — Scenario_test_POST.json — REoptInputs.json — vbatDispatch_inputs_hp.json — temperature_input_derUtilityCost.csv — reopt_input_scenario.json — vbatDispatch_inputs_wh.json — results.json — vbatDispatch_results_hp.json — Plot_DerServingLoadOverview.html — vbatDispatch_results_wh.json — Plot_NewDemand.html — vbatDispatch_inputs_ac.json — PPID.txt — stderr.txt — PuLP_random_seeds.csv — random_seeds.txt — vbatDispatch_results_ac.json — temperature.csv — wholesale_rate_structure_input_derUtilityCost.json — input_temperature.csv — demand_input_derUtilityCost.csv — input_demand.csv — input_wholesale_rate_structure.json — Plot_ThermalDerServingLoadOverview.html — allInputData.json — allOutputData.json

Scenario 2 inputs:

General Model Inputs

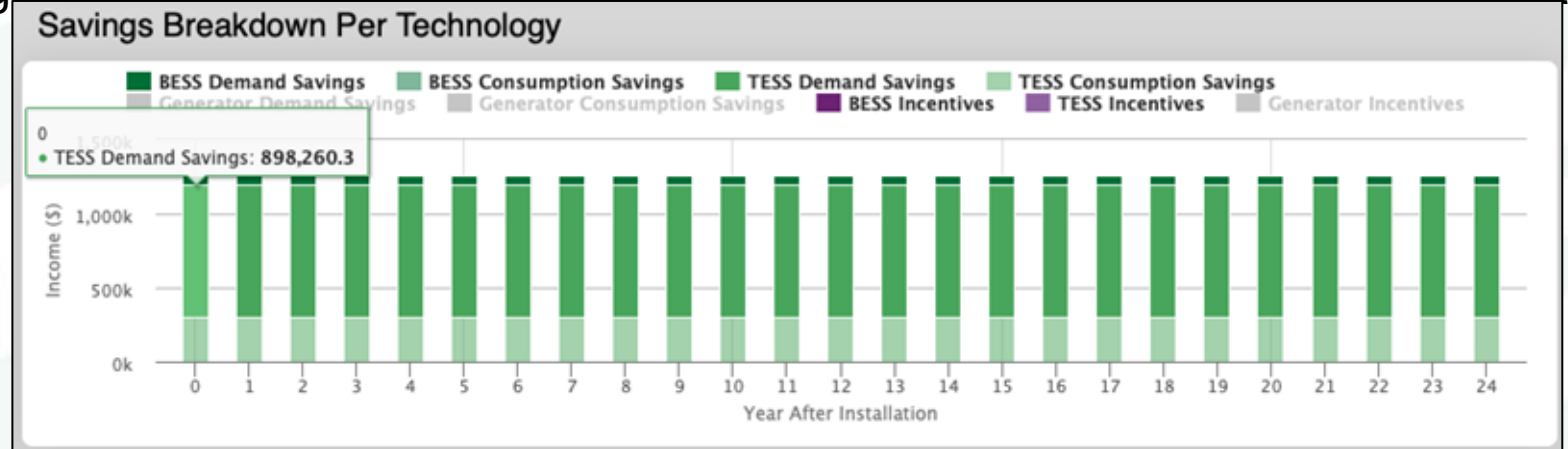
Demand Curve (.csv file) Choose File 8760_Flathead-SystemDemand	Temperature Curve in °F (.csv file) Choose File 8760_Flathead_Temperature_d	Latitude 48.197777
Longitude -114.316109	Year 2024	Use the user-provided random numbers? Yes
Random Seed - BESS & GEN 413403184	Random Seed - AC 533407496	Random Seed - HP 400836215
Random Seed - WH 1464832581	Random Numbers for Water Heater (.csv file) Choose File water_heater_random_numbers	

Control over TESS variability

The demand savings and consumption savings for each technology remain the same, allowing the user to hone in on a changed input of interest (e.g. how changing the Water Heater ongoing monthly subsidy affects the cost/savings output).

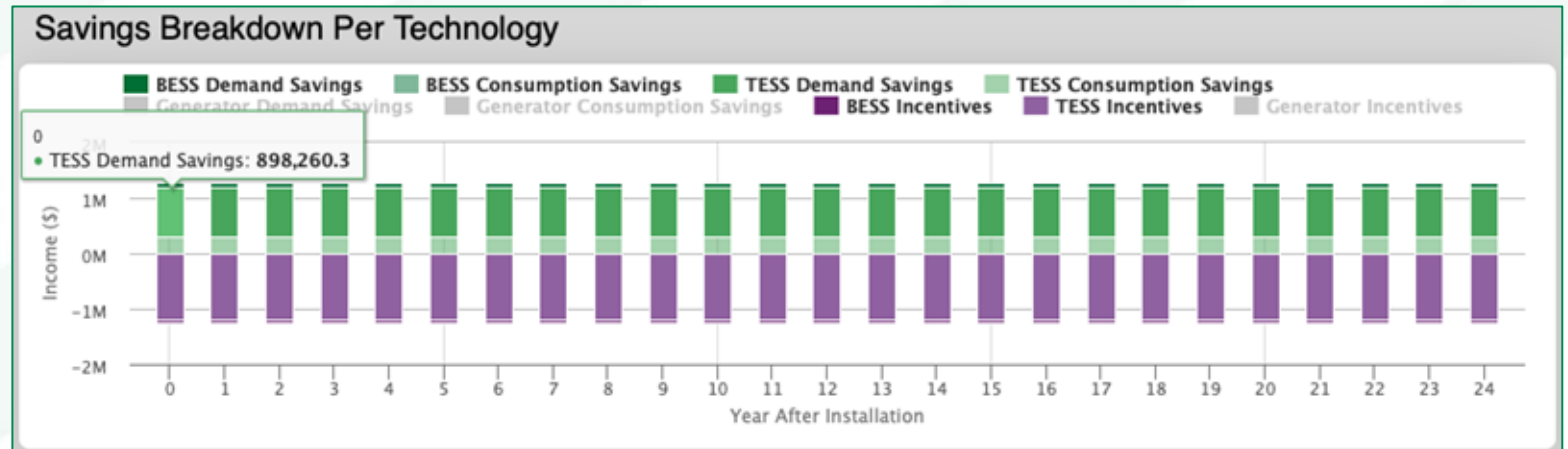
Previous model results:

TESS Demand Savings = \$898,260 with no subsidies (hence no Incentives shown on this plot).



New model results:

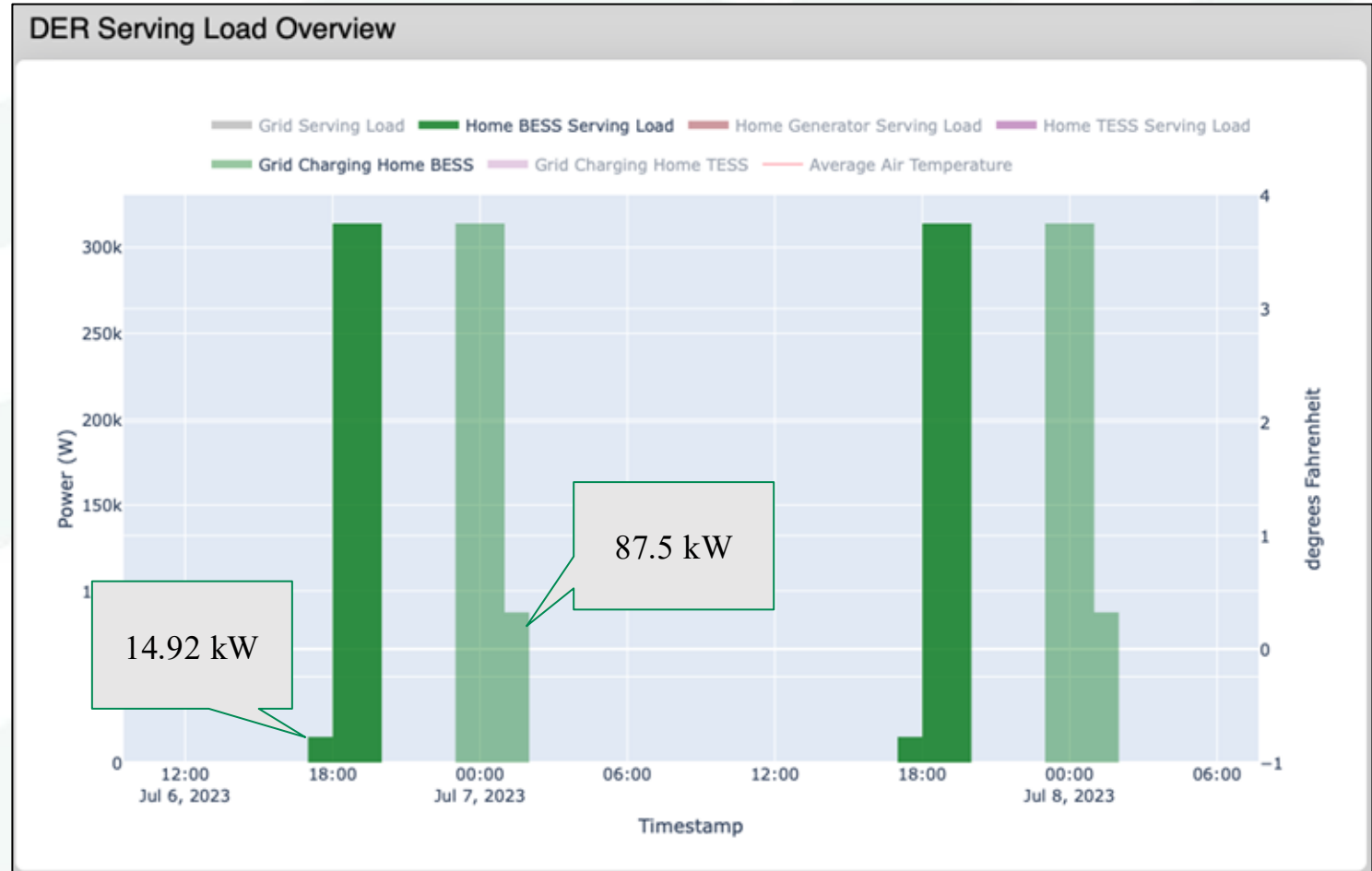
TESS Demand Savings = \$898,260, successfully reproducing the previous model results. In this model run, subsidies were added for all technologies and the user can directly compare the two model runs.



Further Analysis

REopt Behaviors

- This is output from Tipmont's Scenario 2: Adjusted Subsidies.
- There are 314 5.0kW BESS defined, with an allowed 20% depth-of-discharge. This configuration provides a total possible power of 314kW.
- The area under the curve for many of the charge/discharge cycles is greater than 314kW.
- Where is the extra charge going/coming from?



Additional Analysis

Many additional scenarios may be of interest. Further modeling with derUtilityCost and derConsumer could include:

- Tightening deployment levels to better match the specific characteristics of the membership,
- varying participation rates,
- subsidizing consumer' retrofit costs or BESS installation costs,
- considering different tariffs (e.g. TOU vs. Flat rates),
- assessing how fossil fuel generators affect cost-benefit ratios (preliminary results suggest they might be significant demand savers for co-ops).

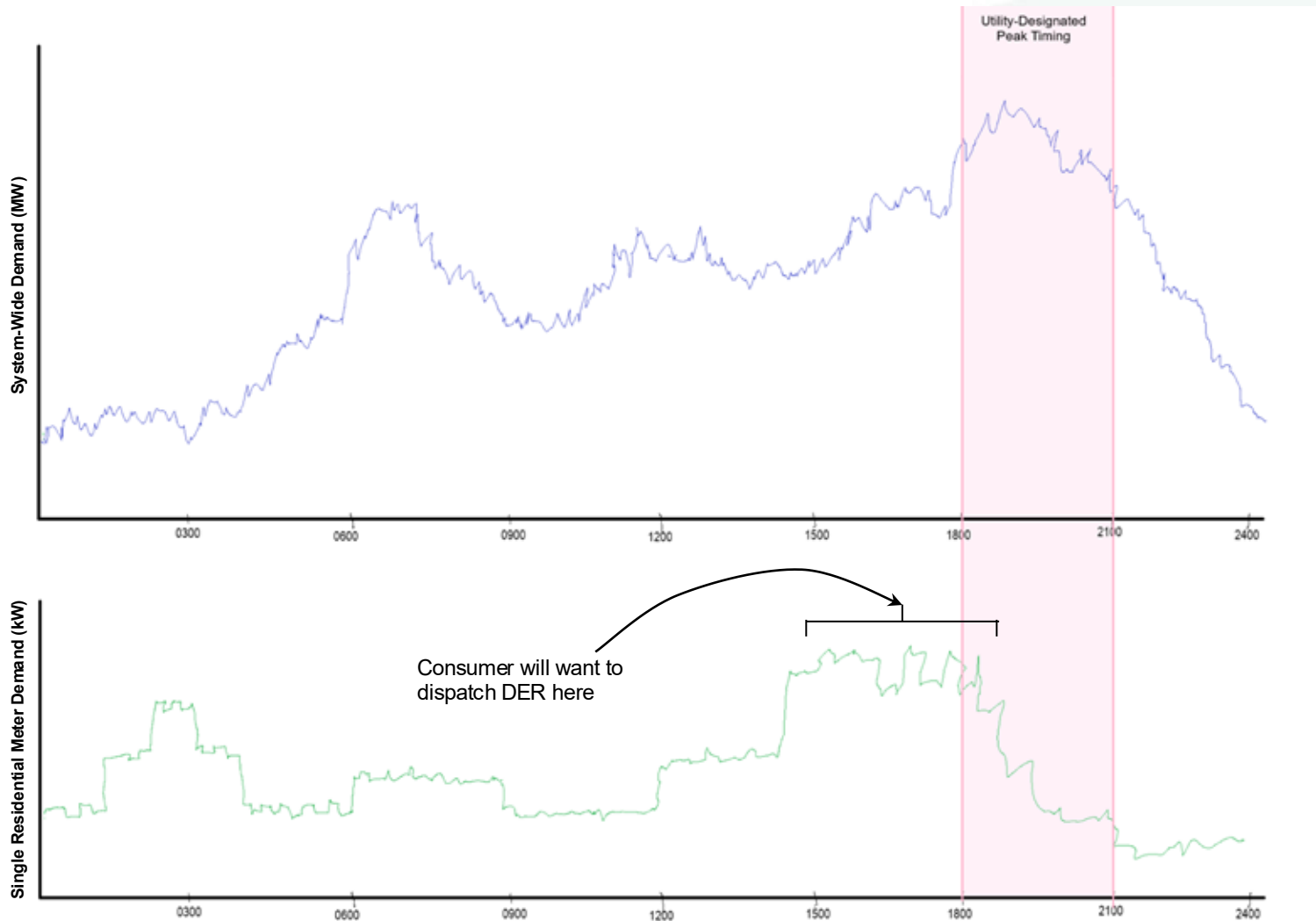
Model Enhancements

The test consumer was previously a scaled version of the co-op's system demand profile. This means the peaks were aligned in time.

It is possible that the consumer peaks do not align in time to utility peaks.

This misalignment results in desired DER dispatch at different times.

Model Enhancements



- derConsumer model only gets consumer curve, but needs info from utility curve.
- csv input:
 - Needed info from the top can be communicated as start/end of utility-designated peak periods.
 - hourly csv using 'y' or 'n' to designate on- or off-peak times, respectively.
- Can the consumer demand curve or tariff get modified such that REopt considers this scenario? Nope :(
- **Solution: create a new model that considers both sides at once and shows results from each perspective. Remove the time-coupling by removing the \$/kWh compensation type.**