U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB

Techno-Economic Analysis Using REopt for Community Solar on Multifamily Affordable Housing Properties

Amanda Farthing and Emma Elgqvist, NREL

May 2022

Portfolio Screening Steps

Multifamily affordable housing providers can identify and prioritize properties in their portfolios for which community solar development is feasible by taking the following steps.

Focus of these slides

- Site List and Associated Data Generation
- Policy Workbook and Screening
- Solar Technical Potential
- Financial Analysis
- Techno-Economic Analysis

  This step can be performed using NREL's REopt Web Tool

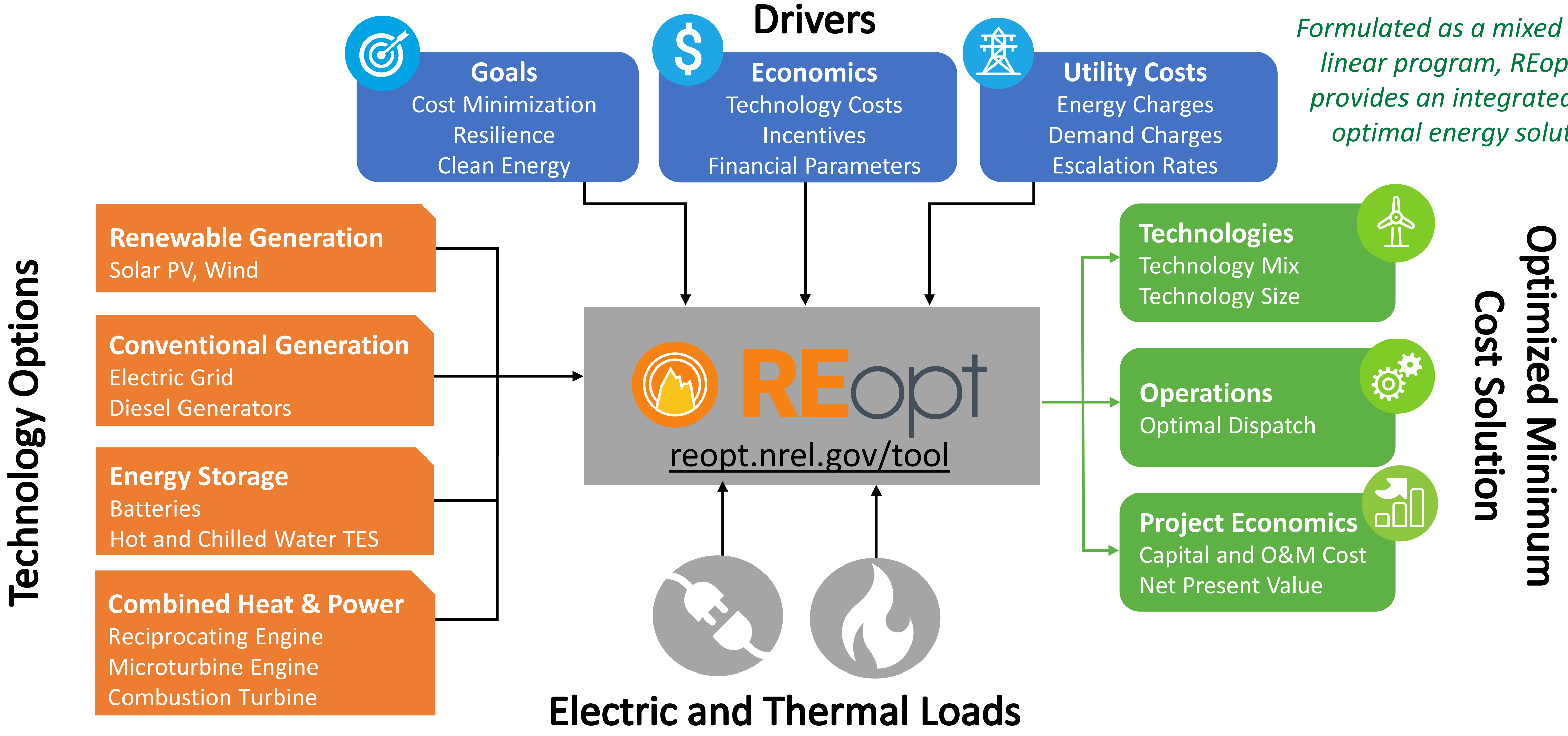
  REopt

See NREL's companion publication, *Multifamily Affordable Housing Portfolio Screening Approach Fact Sheet and Case Study,* on the MFAH Collaborative page of the NCSP website for a detailed description of this approach.

Techno-Economic Analysis Using REopt

- **Purpose of this step:** Conduct more detailed analyses for a select number of sites to assess how distributed energy resources (DERs) such as solar plus storage can help meet your goals
- **Tool:** REopt (https://reopt.nrel.gov/tool) is a free techno-economic optimization model that determines DER sizes and dispatch strategies that minimize the life cycle cost of energy at a site
- **Example questions that REopt can help answer:**
  - What size solar PV system will result in the most energy bill savings at this site?
  - What size solar-plus-storage system would be needed to power critical loads through a utility grid outage?
  - What is the financial impact of rate switching, net metering, and/or meter aggregation?
  - What percentage of the site's load can be offset with renewable energy? What are the emissions benefits of this renewable generation?

REopt: Free Web Tool To Optimize Economic and Resilience Benefits of Distributed Energy Resources

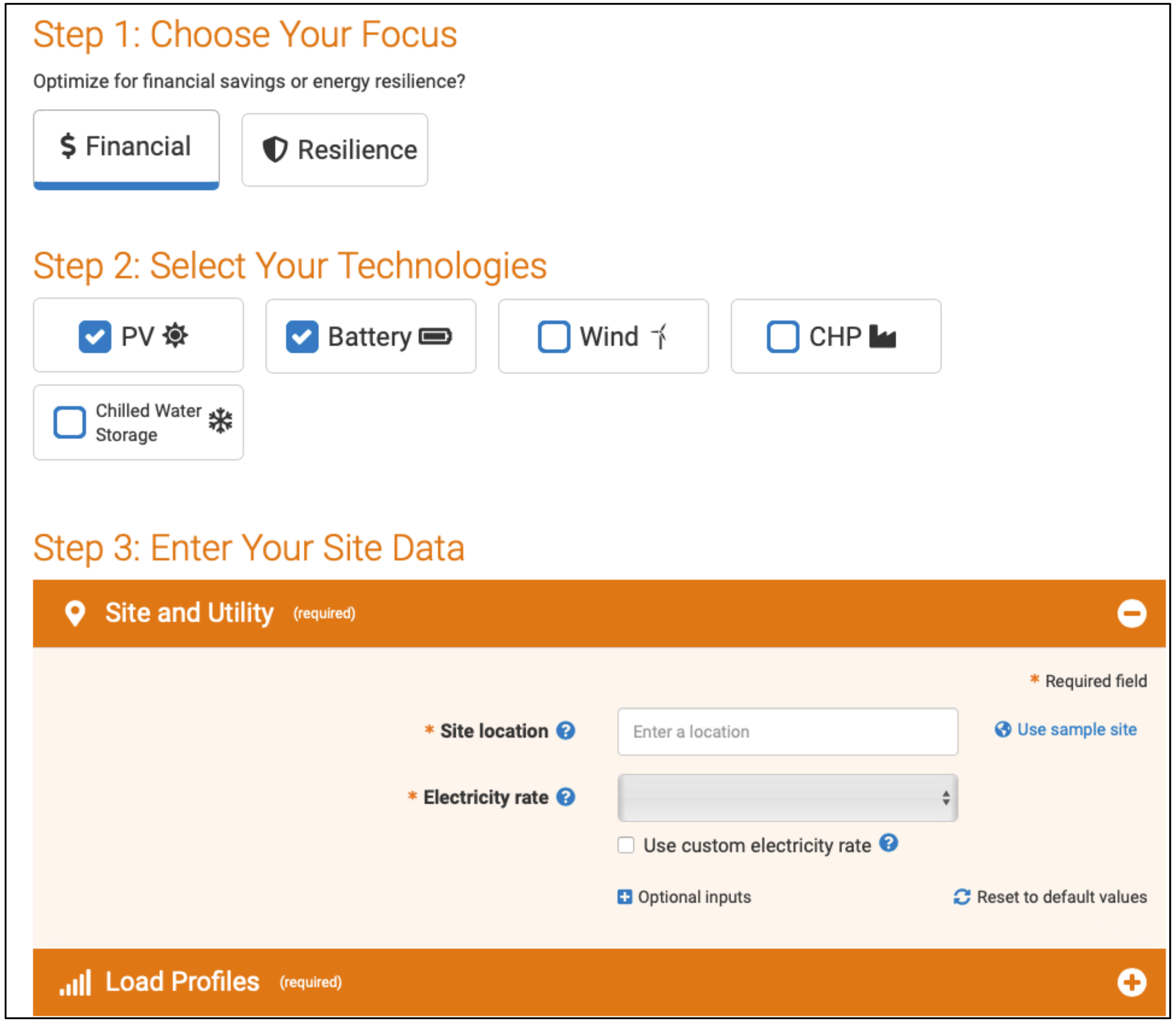


Formulated as a mixed integer linear program, REopt Lite provides an integrated cost-optimal energy solution.

REopt Web Tool

The **REopt Lite web tool** is a free, publicly available tool to evaluate and optimize the economic viability of DERs

- **Financial mode** optimizes DERs and dispatch strategy to minimize life cycle cost of energy
- **Resilience mode** optimizes DERs to sustain critical load during grid outages
- **DERs included:** Solar PV, battery storage, wind, combined heat and power (CHP), generator, and chilled water storage
- **Access REopt** at reopt.nrel.gov/tool
- **Access the user manual** [here]()



REopt Key Outputs

Your recommended solar installation size

3,885 kW
PV size

Measured in kilowatts (kW) of direct current, this recommended size minimizes the life cycle cost of energy at your site.

Your recommended battery power and capacity

276 kW
battery power

598 kWh
battery capacity

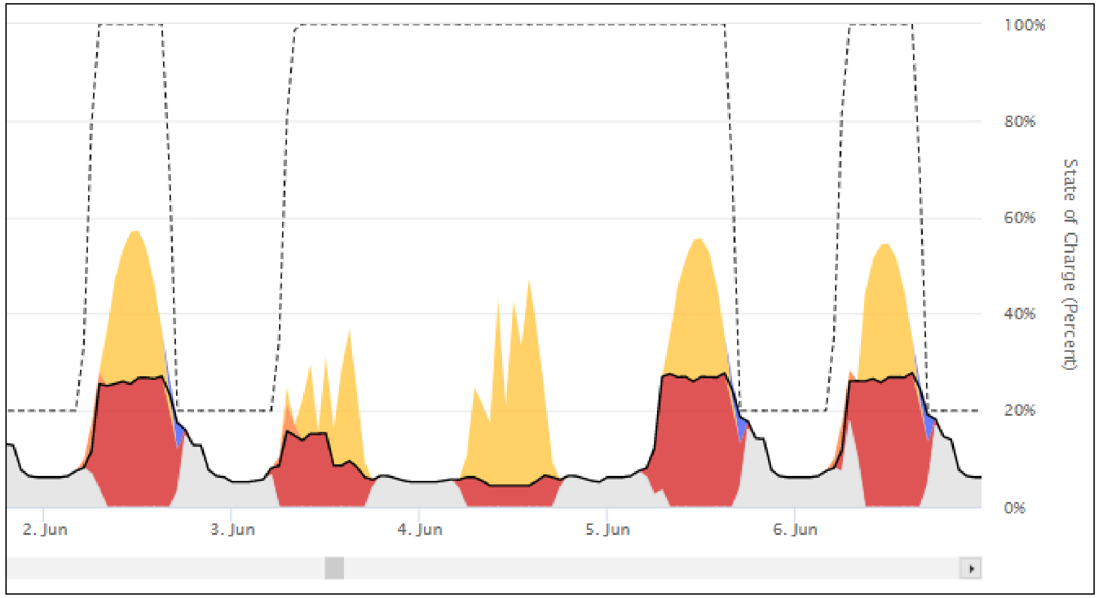
This system size minimizes the life cycle cost of energy at your site. The battery power and capacity are optimized for economic performance.

Your potential life cycle savings (20 years)

This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the total life cycle costs of doing business as usual compared to the optimal case.

$1,972,493

System Size and NPV



Hourly Dispatch

	Business As Usual	Financial	Difference
System Size, Energy Production, and System Cost			
PV Size	0 kW	113 kW	113 kW
Annualized PV Energy Production	0 kWh	132,000 kWh	132,000 kWh
Battery Power	0 kW	0 kW	0 kW
Battery Capacity	0 kWh	0 kWh	0 kWh
Net CAPEX + Replacement + O&M	$0	$133,318	$133,318
Energy Supplied From Grid in Year 1	132,000 kWh	65,384 kWh	66,616 kWh
Year 1 Utility Cost — Before Tax			
Utility Energy Cost	$18,112	-$404	$18,515
Utility Demand Cost	$0	$0	$0
Utility Fixed Cost	$0	$0	$0
Utility Minimum Cost Adder	$0	$0	$0

Detailed Financial Outputs

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB

How To Use REopt for Techno-Economic Analysis of Community Solar for Multifamily Affordable Housing

Step 1: Establish Goals

Define goals related to solar deployment at your site(s). These goals will influence the analyses you run in REopt. Goals can include:

Maximize
cost savings

Reach clean energy
targets

Provide resilience
to grid outages

Step 2: Gather the Following Data for Sites for Which REopt Will Be Used

- Site location (address)
- Available roof and land space for solar
- Electricity rate *for meter(s) to which solar generation will be tied*
- Load profile *for meter(s) to which solar generation will be tied*
- Financial parameters (discount rates, escalation rates, etc.)
- State and utility policies (incentives, net metering, etc.)

Step 2 (cont.): Consider the Following for Each Site

Data points to keep in mind as you explore community solar options

Financial

Financial Barriers to project implementation

Applicable Incentives or Grants

Utility Rates: Commercial vs. residential, rate variation between building accounts

Utility Bills: Paid by tenants or property owner?

Net Metering and Virtual Net Metering Rules

Step 2 (cont.): Consider the Following for Each Site

Data points to keep in mind as you explore community solar options

Organizational

Building Ownership

System Ownership: Direct or third-party?

Program Management: In-house or outsourced?

Step 2 (cont.): Consider the Following for Each Site

Data points to keep in mind as you explore community solar options

Technical

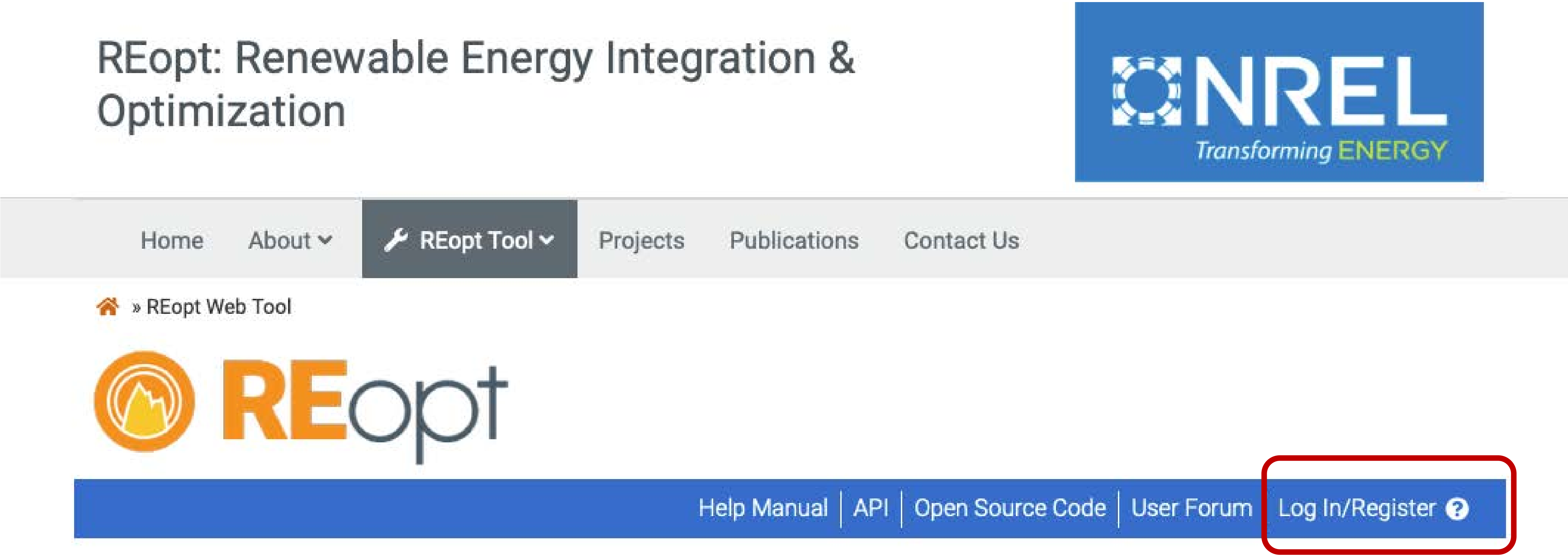
Metering Configuration: Master-metered or multi-metered?

Electric Load To Serve With Solar: Common areas, individual units, other?

System Location: On-site or off-site?

Step 3: Conduct REopt Analyses for Each Site

Navigate to reopt.nrel.gov



Click Log In/Register to be able to save evaluations.

Choose Your Focus and Technologies

Step 1: Choose Your Focus

Optimize for financial savings or energy resilience?

$ Financial | Resilience

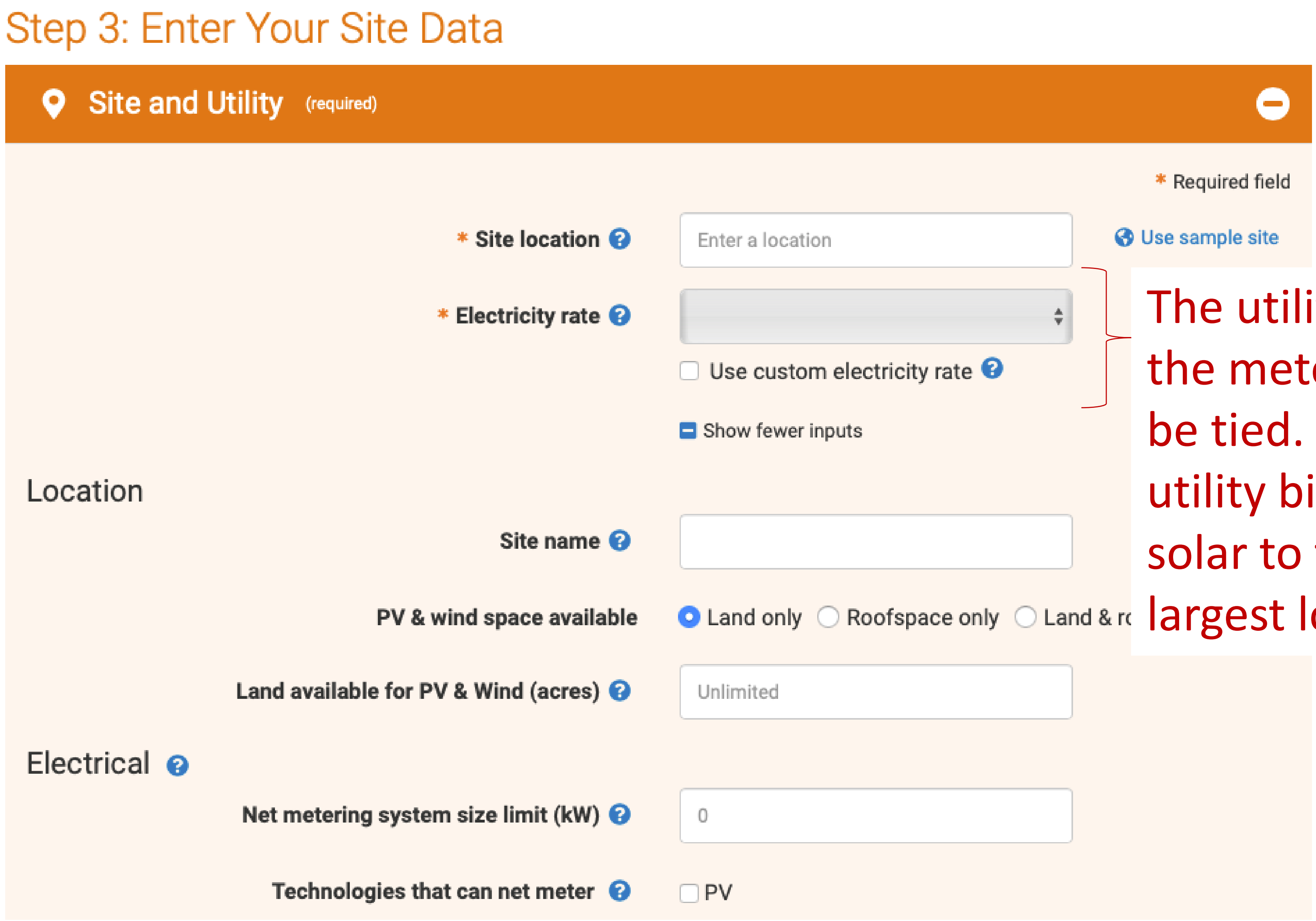
Choose whether meeting resilience goals is an objective for this site.

Step 2: Select Your Technologies

- [x] PV
- [x] Battery
- [ ] Wind
- [ ] CHP
- [ ] Chilled Water Storage

Choose the technologies that you'd like to consider for this site.

Enter Site and Utility Inputs



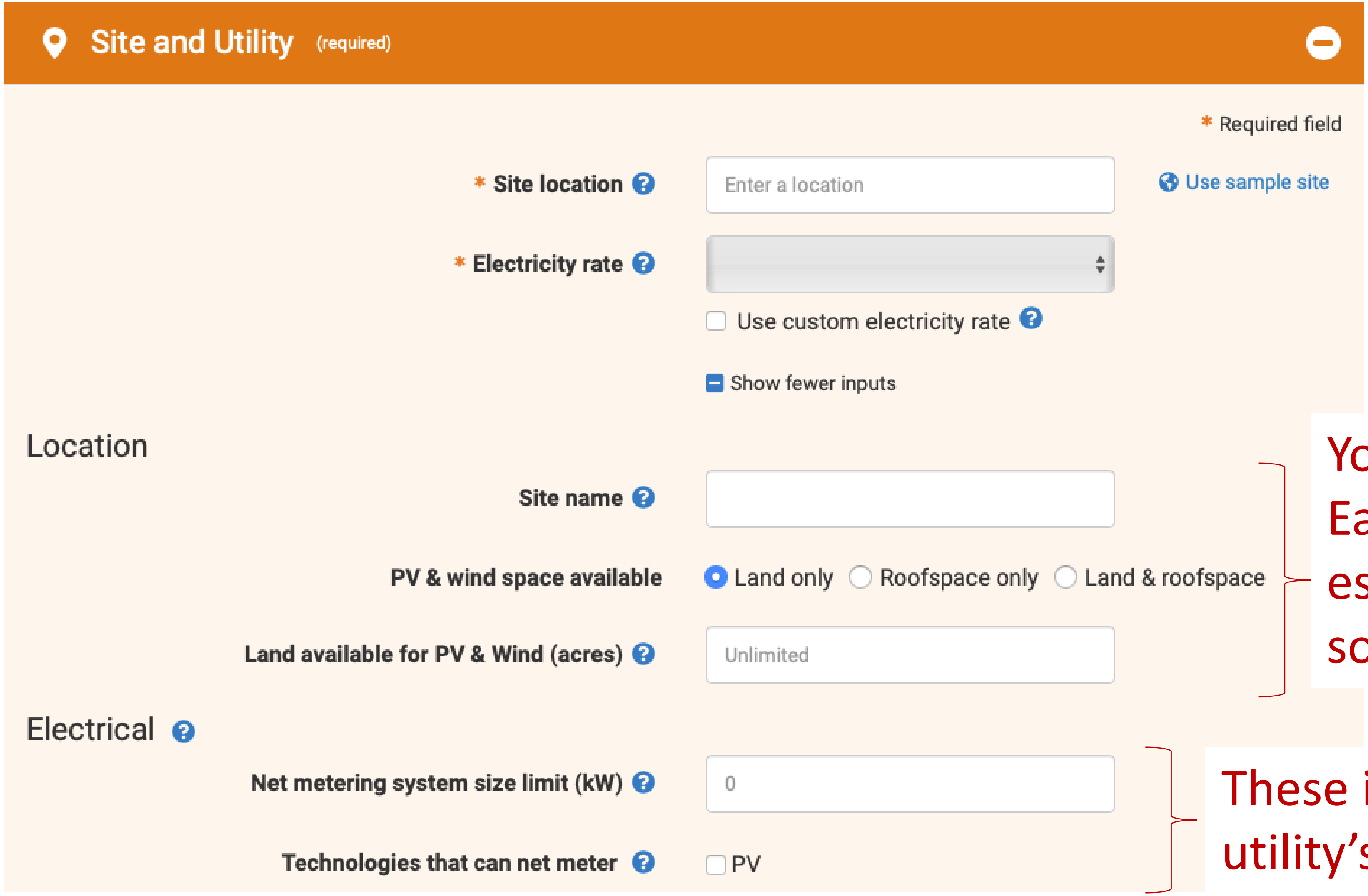
The utility rate typically corresponds to the meter to which the solar output will be tied. This is usually listed on your utility bill. You will likely want to tie solar to the meter associated with the largest load or highest utility bill.

Note: Default values are provided for most inputs, but tailoring these inputs to your sites will provide more accurate results.

(not all inputs are shown here)

Enter Site and Utility Inputs

Step 3: Enter Your Site Data

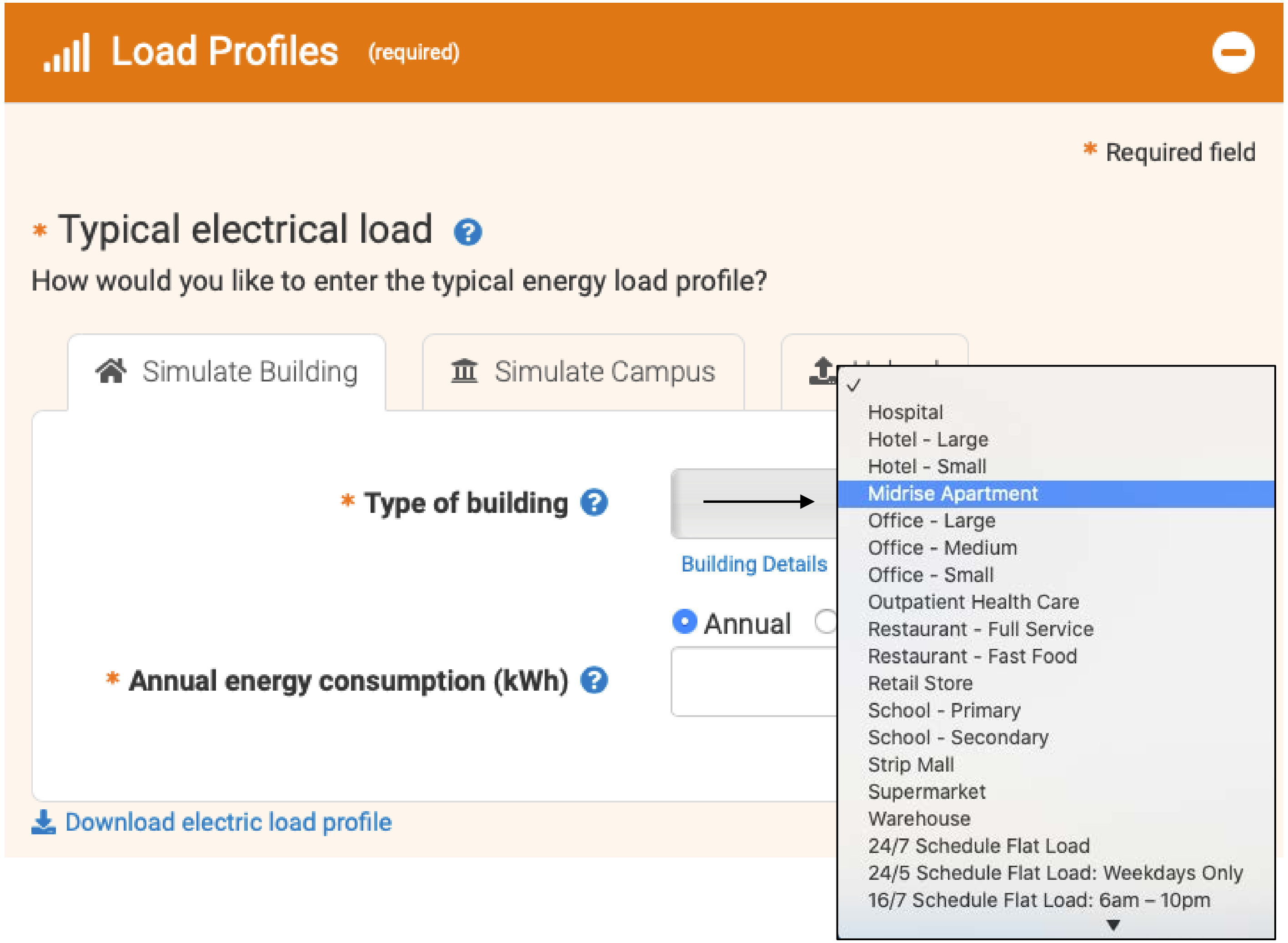


You can use PVWatts, Google Earth, or Project Sunroof to estimate the available space for solar.

These inputs will be based on the utility's net metering rules.

(not all inputs are shown here)

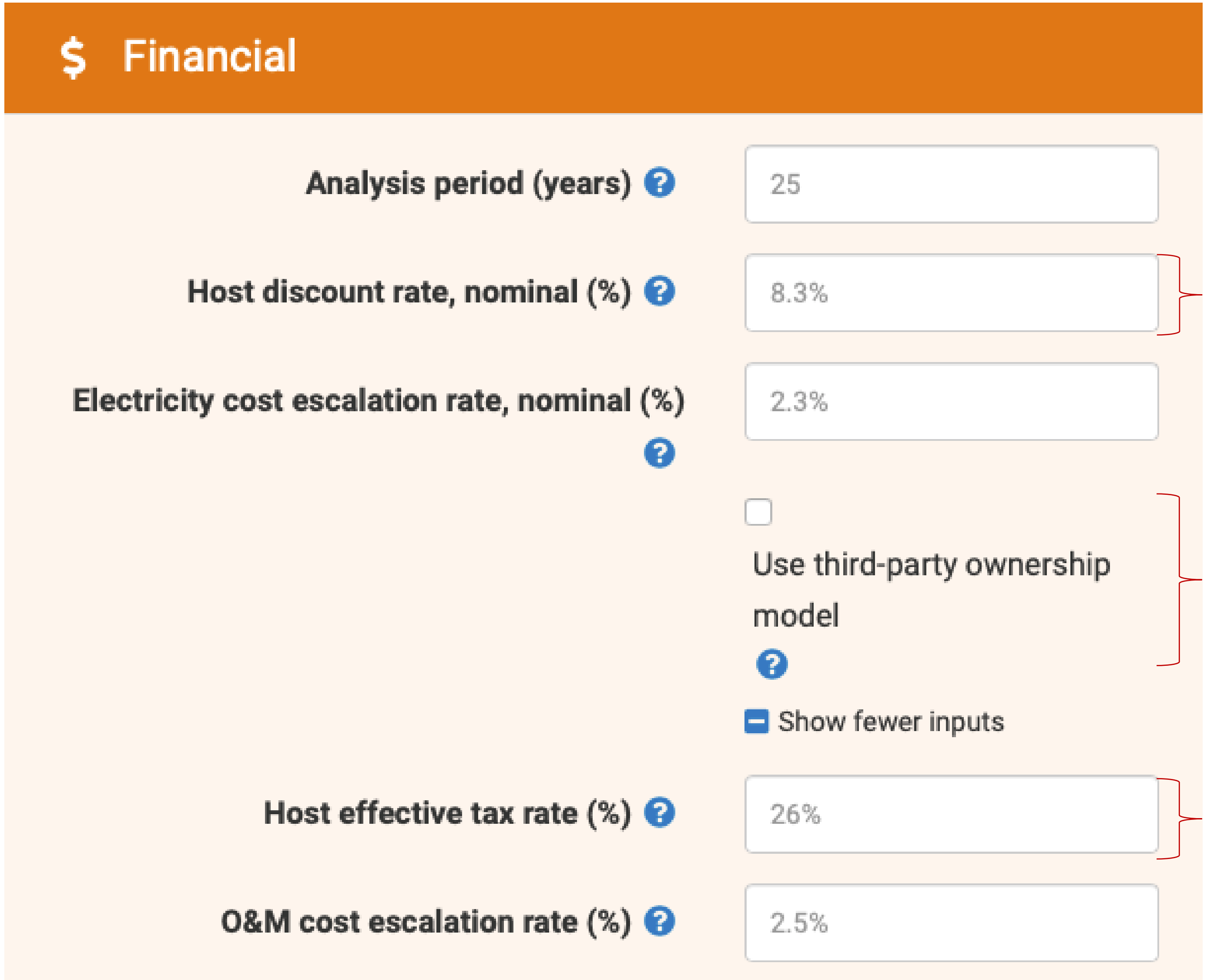
Enter Load Profile Inputs



- Typically, the load profile entered in REopt should correspond to the meter/utility account to which solar generation will be tied
  - *Possible exceptions: the off-taker pursues virtual net metering, meter aggregation, community solar, or another similar agreement. In this case, enter the aggregate load to be served.**
- Obtaining 15-minute to hourly load data (from your utility company) will result in the most accurate REopt results (use the "Upload" tab)
- Alternatively, you can select the building type that most closely corresponds to the loads on the selected utility account and scale this load profile to the annual energy consumption on that account.

**Check applicable program rules to determine the correct load to use in REopt.*

Enter Load Profile Inputs

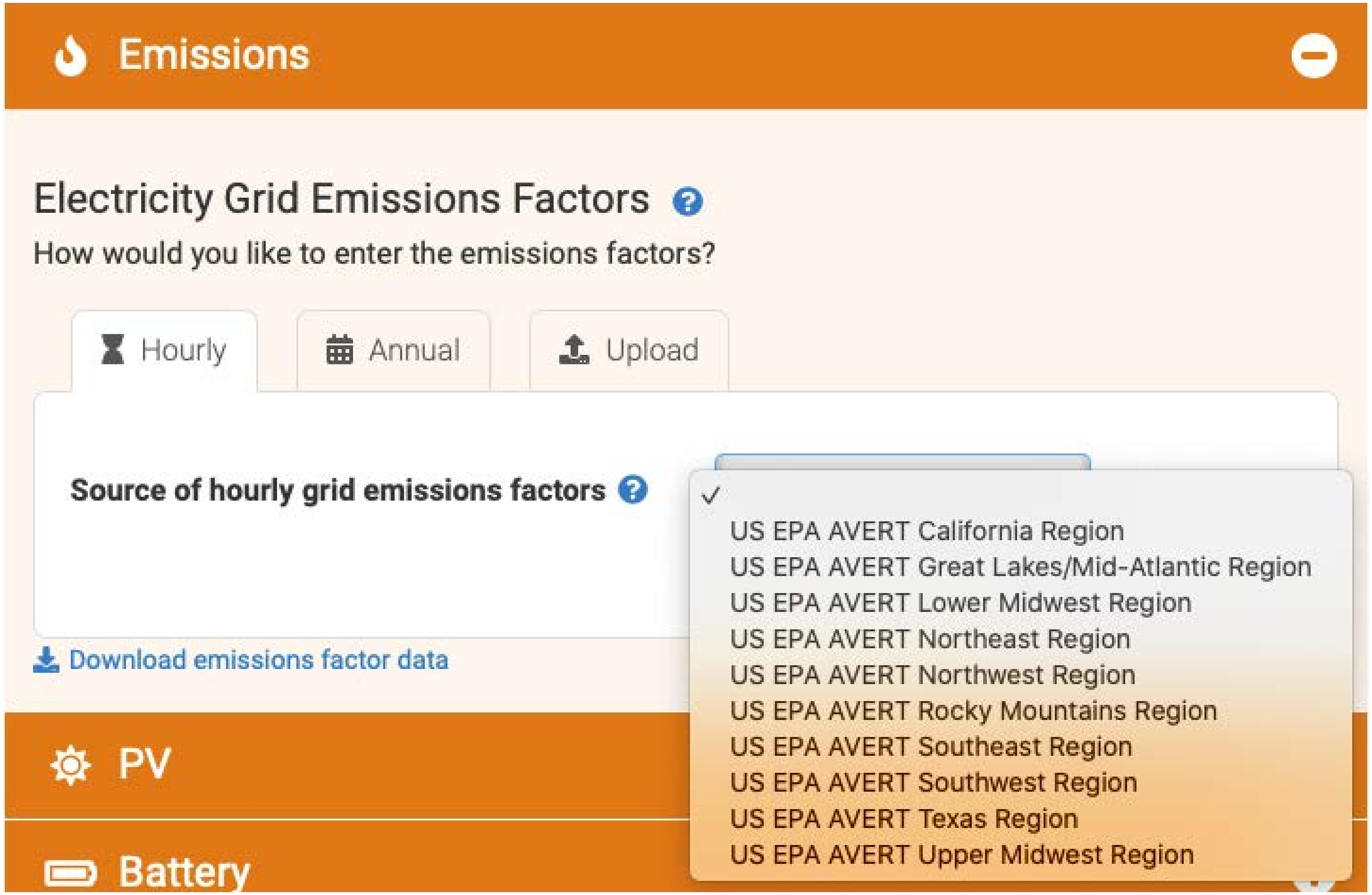


The discount rate is the rate at which the host discounts the value of future costs and savings. Nonprofit entities may have lower discount rates than the private sector (e.g., 3%).

A third-party ownership model may be desirable if, for instance, your entity cannot monetize tax-based incentives (e.g., federal ITC), or to minimize upfront capital expenses.

Government and nonprofit entities should reduce the host effective tax rate to 0%.

Enter Emissions Inputs



The default emissions region will appear once a location is entered. REopt will determine the grid emissions offset from on-site generation as well as the emissions impacts of on-site fuel burn. Alternatively, you can provide a constant annual emissions factor or upload a custom emissions profile.

Enter PV Inputs

PV

System capital cost ($/kW DC): $1,600

Existing PV system?

Minimum new PV size (kW DC): 0

Maximum new PV size (kW DC): Unlimited

Show fewer inputs

PV Costs

O&M cost ($/kW per year): $16

PV System Characteristics

Module type: Standard

Array type: Ground Mount, Fixed

Array azimuth (deg): 180

Array tilt (deg): 10

DC to AC size ratio: 1.2

System losses (%): 14%

PV generation profile: Choose File no file selected

PV Station Search Radius (mi): Unlimited

Be sure to select the appropriate array type.

Enter PV Inputs (cont.)

Determine whether your entity can monetize the federal Investment Tax Credit (ITC). If it cannot, and you are not modeling third-party financing, reduce the "Federal" incentive to 0%...

...and set the MACRS schedule to "No MACRS."

PV Incentives and Tax Treatment

Capital Cost or System Size Based Incentives

Database of state incentives for renewables

	Incentive based on percentage of cost (%)	Maximum dollar amount for incentive based on percentage of cost ($)	Rebate based on system size ($/kW)	Maximum dollar amount for rebate based on system size ($)
Federal	26%	Unlimited	$0	Unlimited
State	0%	Unlimited	$0	Unlimited
Utility	0%	Unlimited	$0	Unlimited

Production Based Incentives

	Production incentive ($/kWh)	Incentive duration (yrs)	Maximum incentive ($)	System size limit (kW)
Total	$0	1	Unlimited	Unlimited

Tax Treatment

MACRS schedule 5 years

MACRS bonus depreciation 100%

Reset to default values

If you plan to sell RECs associated with PV generation at this site, you can enter the REC value as a production incentive ($/kWh) or rebate ($/kW), depending on the REC contract structure.

Enter Battery Inputs (If Applicable)

REopt separately sizes battery energy [kWh] and power [kW] capacity.

Battery

Energy capacity cost ($/kWh)	$420
Power capacity cost ($/kW AC)	$840
Allow grid to charge battery	Yes
Minimum energy capacity (kWh)	0
Maximum energy capacity (kWh)	Unlimited

Show fewer inputs

Battery Costs

Energy capacity replacement cost ($/kWh)	$200
Energy capacity replacement year	10
Power capacity replacement cost ($/kW AC)	$410
Power capacity replacement year	10

Battery Characteristics

Minimum power capacity (kW AC)	0
Maximum power capacity (kW AC)	Unlimited

A battery can help reduce peak demand or time-of-use electricity charges and can help provide resilience to grid outages.

(not all inputs are shown here)

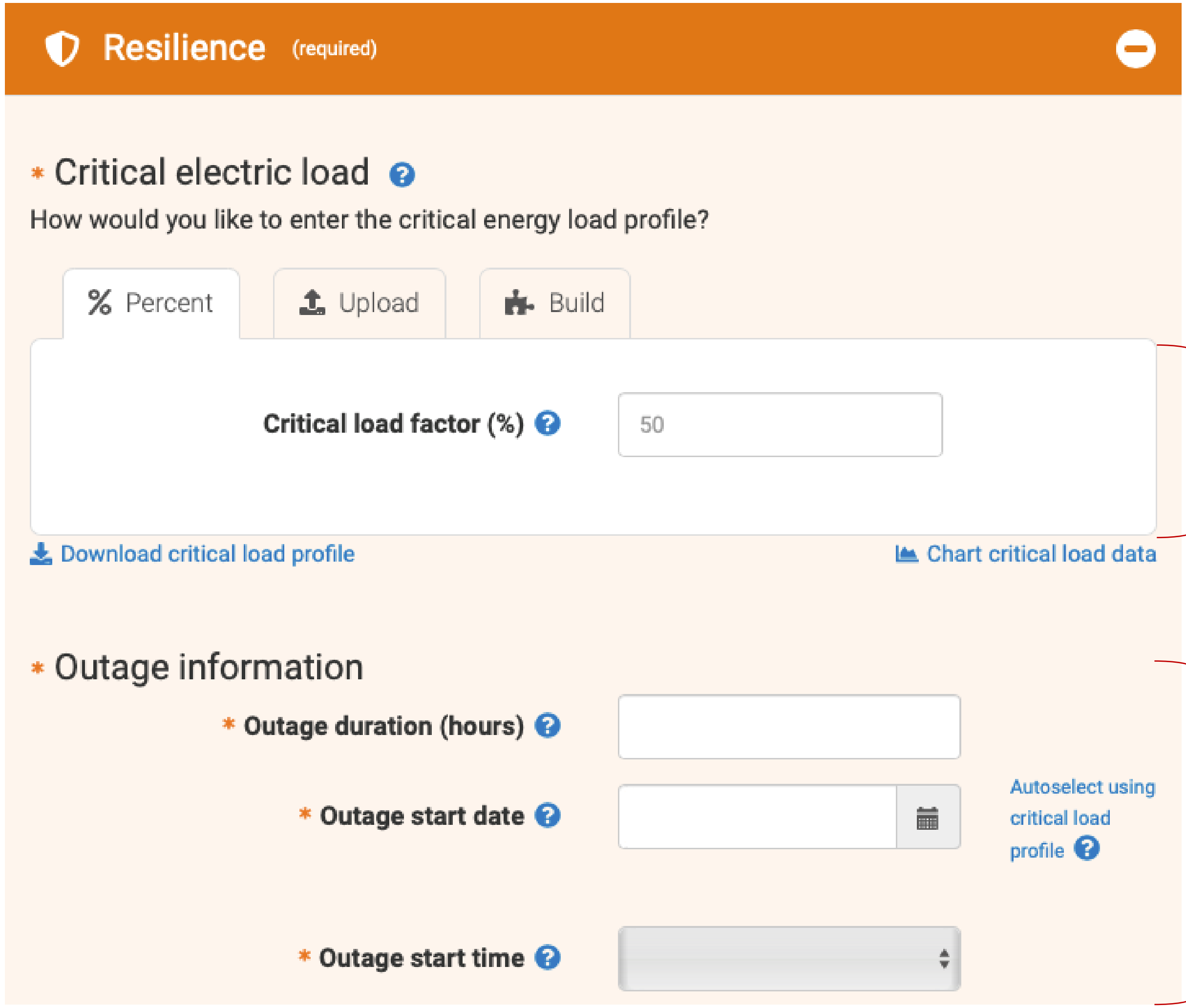
Enter Battery Inputs (If Applicable)

The percentage-based incentive is treated as a tax-based incentive to model the federal Investment Tax Credit (ITC). Whether the grid or solar PV charges the battery will impact the owner's ability to take advantage of the ITC. The default for percentage-based incentives is 0%, corresponding to the default of the battery charging from the grid.

Without a renewable energy system installed, or if the battery is charged by renewable energy less than 75% of the time, the battery system is eligible for the 7-year MACRS depreciation schedule. If the battery system is charged by the renewable energy system more than 75% of the time, the battery should qualify for the 5-year MACRS schedule.

See the REopt Help Manual and the Internal Revenue Service for more details and to check the latest tax laws.

Enter Resilience Inputs (If Applicable)



The critical load % is relative to the load profile information entered above.

System sizes must be at least large enough to power critical loads through the specified outage.

(not all inputs are shown here)

Get Results

Key Results: System Sizes and Savings

Your recommended solar installation size

361 kW
PV size

Measured in kilowatts (kW) of direct current (DC), this recommended size minimizes the life cycle cost of energy at your site.

This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size.

Your recommended battery power and capacity

78 kW
battery power

253 kWh
battery capacity

This system size minimizes the life cycle cost of energy at your site. The battery power (kW-AC) and capacity (kWh) are optimized for economic performance.

This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size.

Optimal system sizes are outputs of the tool.

Battery power (kW) and energy (kWh) are sized independently.

Your potential life cycle savings (25 years)

This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the total life cycle costs of doing business as usual compared to the optimal case.

$209,418

Net present value of savings after capital and operations and maintenance (O&M) costs.

Additional Results: Economics Summary

	Business As Usual	Financial	Difference
System Size, Energy Production, and System Cost			
PV Size	0 kW	361 kW	361 kW
Annualized PV Energy Production	0 kWh	577,409 kWh	577,409 kWh
Battery Power	0 kW	78 kW	78 kW
Battery Capacity	0 kWh	253 kWh	253 kWh
Net CAPEX + Replacement + O&M	$0	$532,744	$532,744
Energy Supplied From Grid in Year 1	1,000,000 kWh	448,266 kWh	551,734 kWh
Year 1 Utility Cost — Before Tax			
Utility Energy Cost	$74,602	$31,430	$43,172
Utility Demand Cost	$80,133	$45,853	$34,280
Utility Fixed Cost	$5,551	$5,551	$0
Utility Minimum Cost Adder	$0	$0	$0
Life Cycle Utility Cost — After Tax			
Utility Energy Cost	$714,851	$301,166	$413,685
Utility Demand Cost	$767,851	$439,375	$328,476
Utility Fixed Cost	$53,191	$53,191	$0
Utility Minimum Cost Adder	$0	$0	$0
Total System and Life Cycle Utility Cost — After Tax			
Total Life Cycle Costs	$1,535,894	$1,326,476	$209,418
Net Present Value	$0	$209,418	$209,418

Download ProForma Spreadsheet

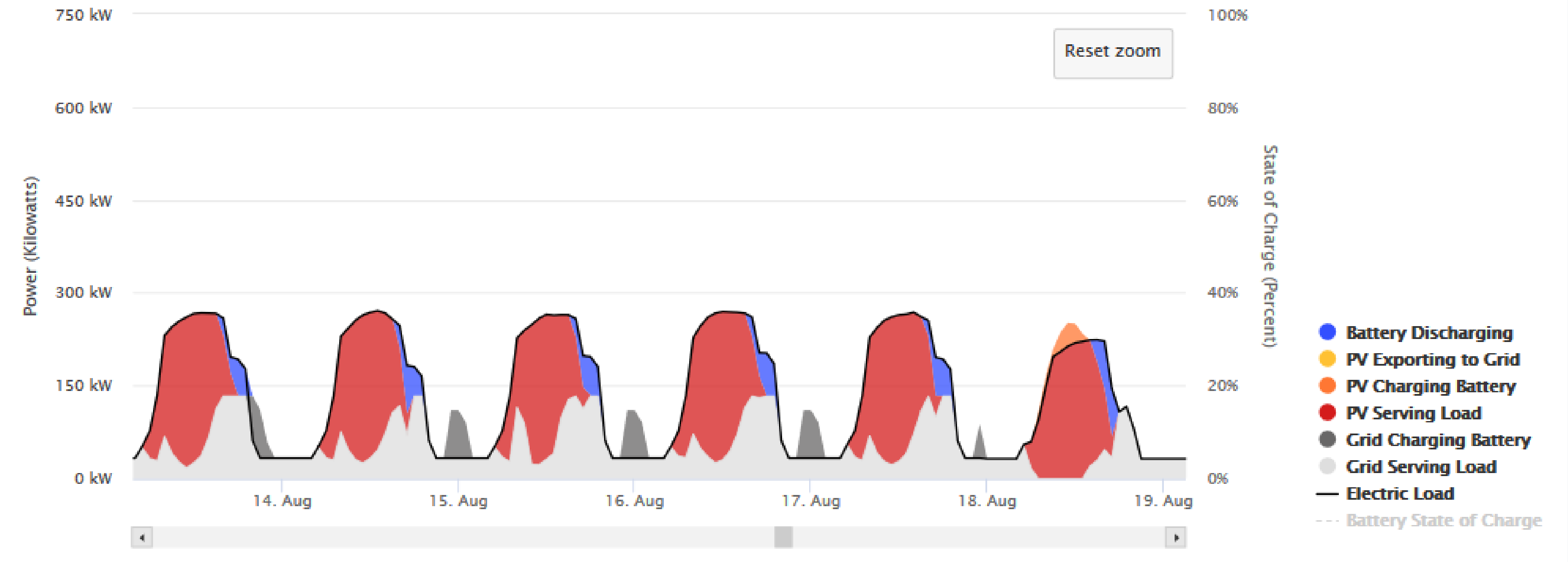
Compare the business-as-usual (BAU) case with the optimal results from REopt.

Download ProForma for more detailed financial results.

Additional Results: Hourly Dispatch Graph

System Performance Year One

This interactive graph shows the dispatch strategy optimized by REopt Lite for the specified outage period as well as the rest of the year. To zoom in on a date range, click and drag right in the chart area or use the "Zoom In a Week" button. To zoom out, click and drag left or use the "Zoom Out a Week" button.



Zoom Out a Week | Zoom In a Week

Download Dispatch Spreadsheet

Turn technologies on or off.

Zoom in and out to look at a day, week, and year.

Download hourly data.

Resilience Outputs: System Sized To Meet Outage

Your Potential Resilience

This system sustains the 75% critical load during the specified outage period, from January 4 at 12am to January 11 at 12am.

System survives specified 168-hour outage

This system sustains the critical load for 72% of all potential 168 hour outages throughout the year.

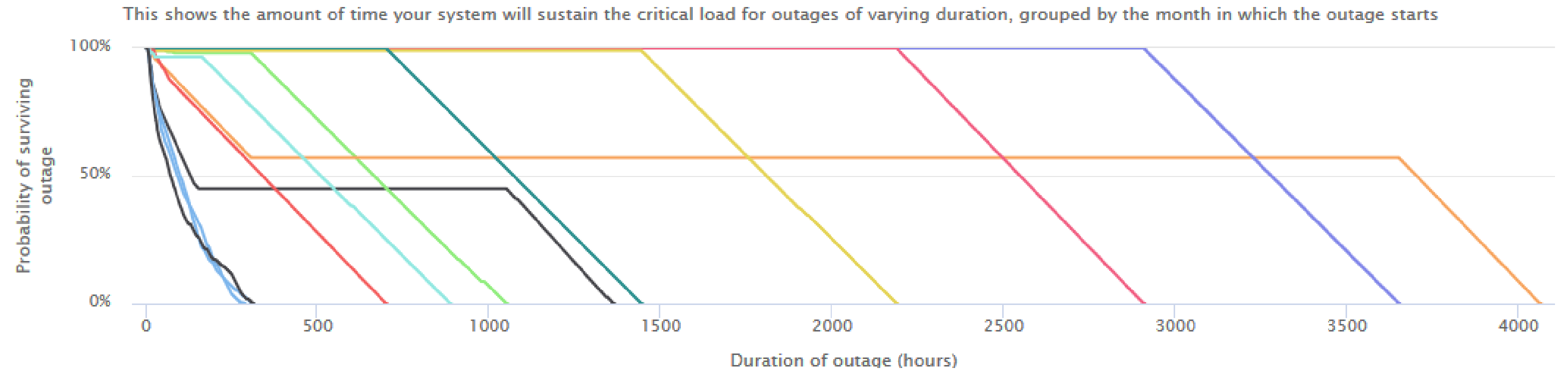
72% System survives 72% of 168-hour outages

REopt optimizes system size and dispatch to survive specified outage.

Outage Simulation

Evaluate the amount of time that your system can survive grid outages.

Yearly | Monthly | Hourly

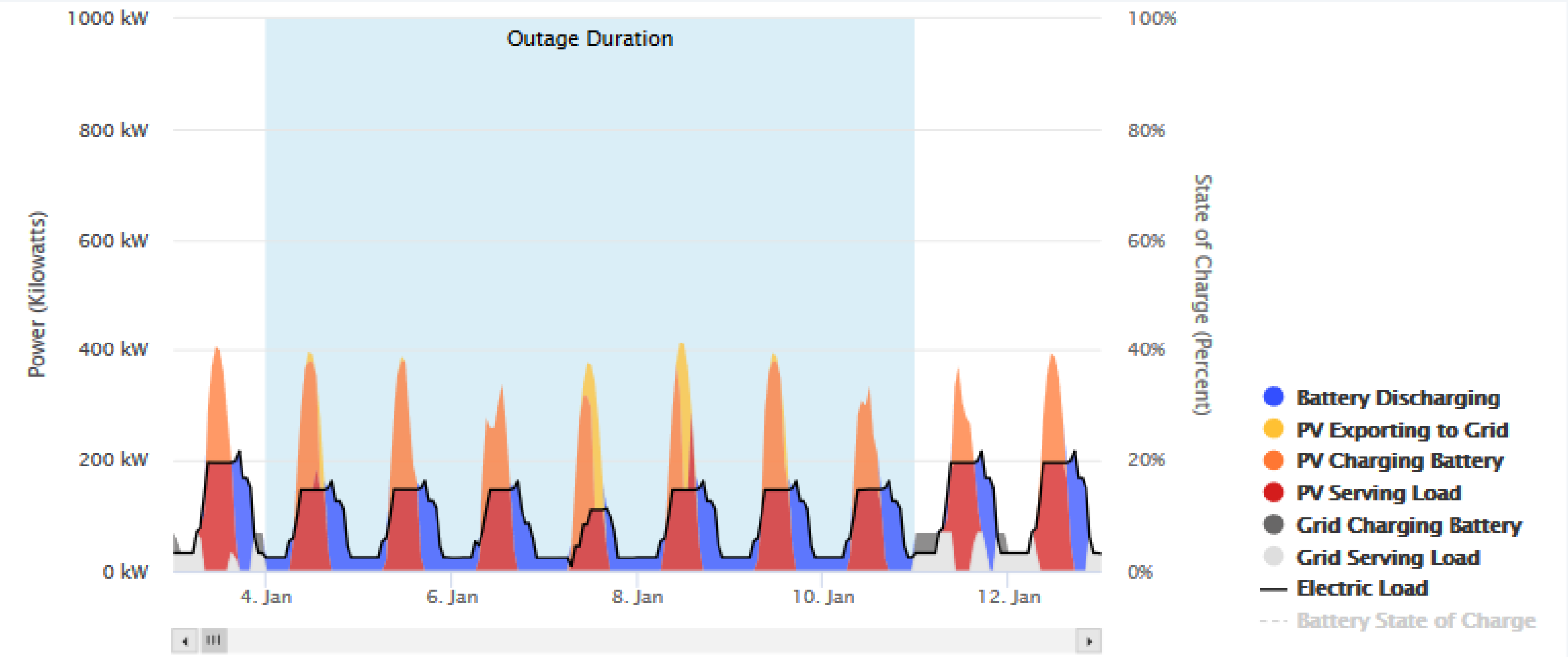


REopt simulates outages of varying lengths throughout the year.

Resilience Outputs: Dispatch During Outage

System Performance Year One

This interactive graph shows the dispatch strategy optimized by REopt Lite for the specified outage period as well as the rest of the year. To zoom in on a date range, click and drag right in the chart area or use the "Zoom In a Week" button. To zoom out, click and drag left or use the "Zoom Out a Week" button.



Zoom Out a Week | Zoom In a Week

Download Dispatch Spreadsheet

The specified outage event is highlighted in blue (lower load).

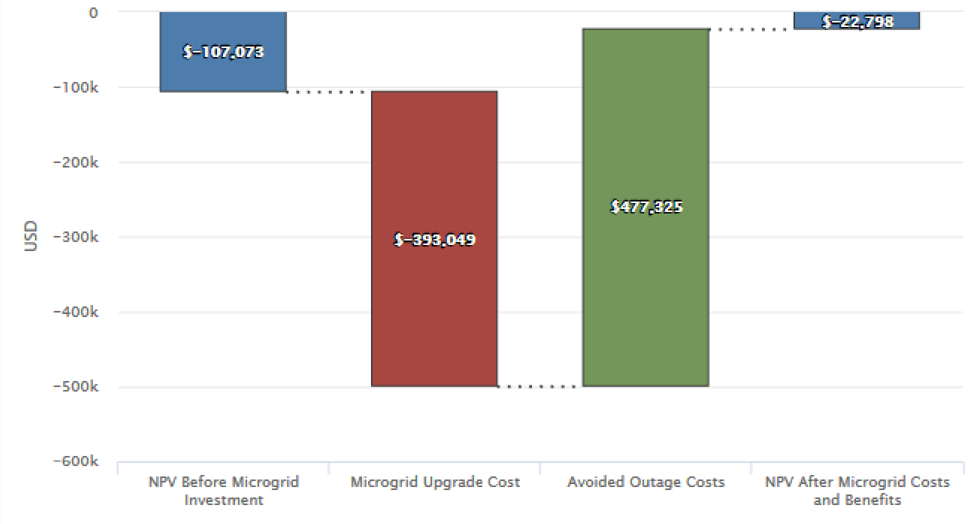
The load is met exclusively by the cost-optimal DERs (as determined by REopt).

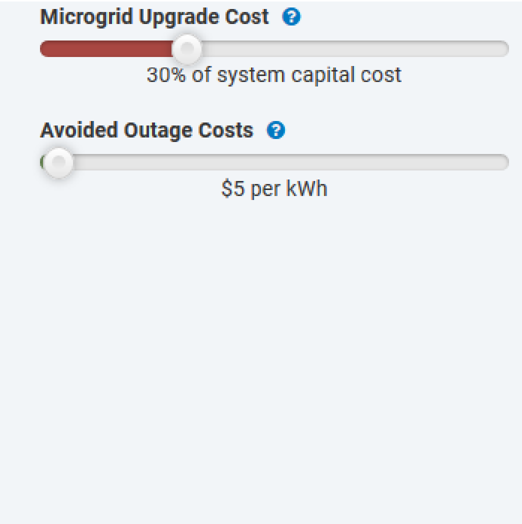
As soon as the outage ends, the site goes back to purchasing grid electricity.

Resilience Output: Comparison to Financial Optimal (Without Resilience) and Cost Sliders

	Business As Usual	Resilience	Financial
System	None	729 kW PV 220 kW Battery 1,288 kWh Battery	361 kW PV 78 kW Battery 253 kWh Battery
NPV	$0	-$107,073	$209,419
Survives Specified Outage	No	Yes	No
Average	0 hrs	1,115 hrs	10 hrs
Minimum	0 hrs	4 hrs	0 hrs
Maximum	0 hrs	4,061 hrs	63 hrs

Compare results of resilience analysis to results for the optimal configuration in the absence of resilience requirements.





Explore impact of microgrid upgrade costs and value of avoiding an outage.

Important Questions To Answer Before and/or With REopt Analyses

- Which account(s) may be tied to solar generation?
- Will the maximum PV generation at this site greatly exceed the annual load at the meter to which it will be tied?
  - If so, should consider net metering, meter aggregation, and/or shared solar options
  - Without these options, solar sizing may be capped at the annual load of the meter to which solar is tied
- What are the net metering rules?
  - Must the PV be sized to load?
  - What compensation will the system receive for exported PV?
- Will hourly load data be key to accurate calculation of utility bill benefits?
- Is meter aggregation/virtual net metering possible?
  - If so, this may be the easiest option to realize the maximum solar potential possible
- Is shared solar or community solar possible?
- Can the site be compensated for the sale of RECs?

Potential Scenarios To Run Using the REopt Web Tool

- Bill-savings (financial) optimal vs. resilience optimal
- Standard NEM (solar output tied to single meter) vs. community solar or virtual net metering (solar output tied to multiple accounts)
- Selling RECs vs. retaining RECs
- Owner-financed vs. third-party-financed
- PV tied to meter A vs. meter B

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB

Using REopt for Multifamily Affordable Housing: Example Analysis

Hypothetical Case

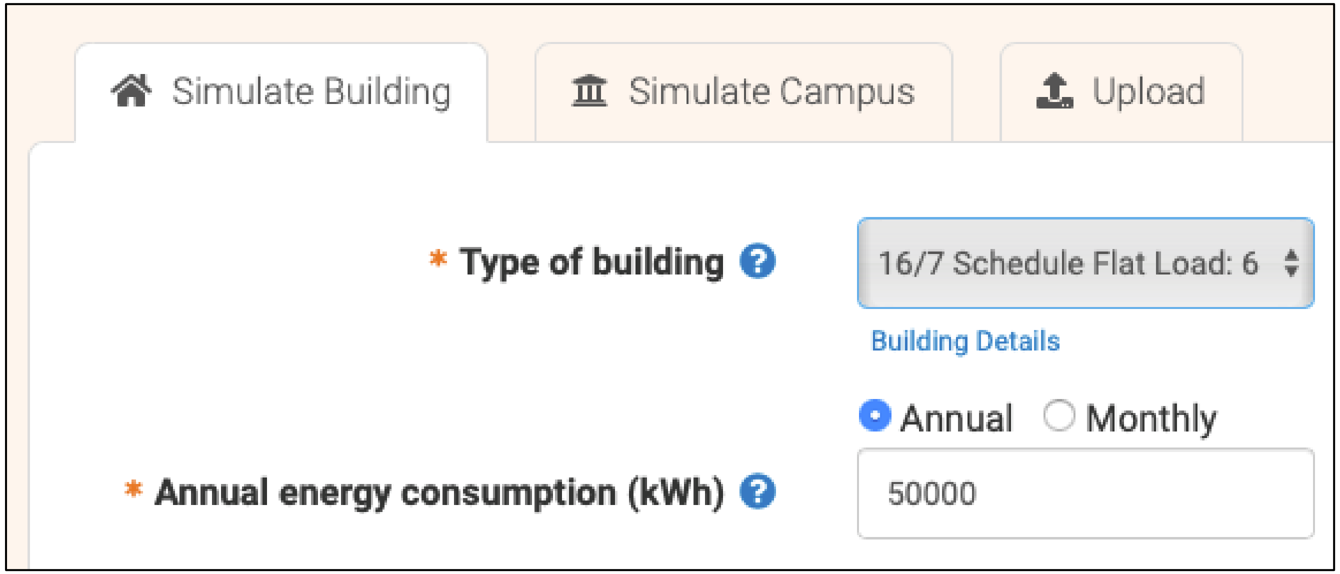
- Sol Housing, a nonprofit multifamily affordable housing provider in Providence, RI, is interested in **installing solar PV** on one of its properties in order to reduce tenants' utility bills
- Sol Housing is also interested in creating a resilience shelter for long-duration outages, and therefore will consider a scenario with **solar PV plus storage to meet a 2-day outage**
- This example will step through key inputs and scenarios that Sol Housing should consider when running REopt analyses for this site

Key Site Inputs

Input	Value
Location	Providence, RI
Available space for solar	8,000 sf (rooftop)
Utility company/electricity supplier	National Grid/Constellation Energy, Inc.
Utility account to be tied to solar generation	Common area meter
Utility rate	Basic residential rate
Energy charges	**$0.21/kWh** (calculated from utility bill, based on *combined delivery and supply charges*. Note that the Utility Rate Database (URDB) rate often does not include supply charges, if a separate supply rate exists)
Demand charges	None

Load Profile

- Solar PV will be tied to the **common area meter**/utility account
- The common area refrigerators, hallway lighting, welcome center, and elevators are tied to this meter
- The **annual load is 50,000 kWh**, and the load is expected to be relatively flat from 6 a.m. to 10 p.m. daily



Financial Inputs

Parameter	Site Input
Financing mechanism	Direct ownership
Off-taker (host) discount rate (nominal)	3%
O&M cost escalation rate (nominal)	2.50%
Electricity cost escalation rate (nominal)	2.30%
Host effective tax rate (%)	0% (non-profit)
PV incentives	None
Project life	25 years

See the REopt User Manual for more details on these inputs.

Solar PV Inputs

Parameter	Site Input
Maximum PV size	80 kW (based on available roof space)
PV type	Rooftop, fixed
Azimuth	180 degrees (south)
Technology resource	TMY2 weather file from National Solar Resource Database (NSRDB)[1]
Tilt	10 degrees
DC to AC ratio	1.2
Capital cost	$1.60/W-DC per NREL ATB[2]
Fixed technology O&M	$16/kW-PV/year per NREL ATB
Useful life	25 years

See the REopt User Manual for more details on these inputs.

Net Metering Considerations

- The maximum solar size is 80 kW (based on available roof space)
- The expected output from an 80-kW system in Providence, RI, is **96,000 kWh/year**[1]
- The estimated load for the common area meter is **50,000 kWh/year**
- Since the **maximum PV output is ~2x the annual load**, it is important to consider **net metering options**

[1] PVWatts: https://pvwatts.nrel.gov/pvwatts.php

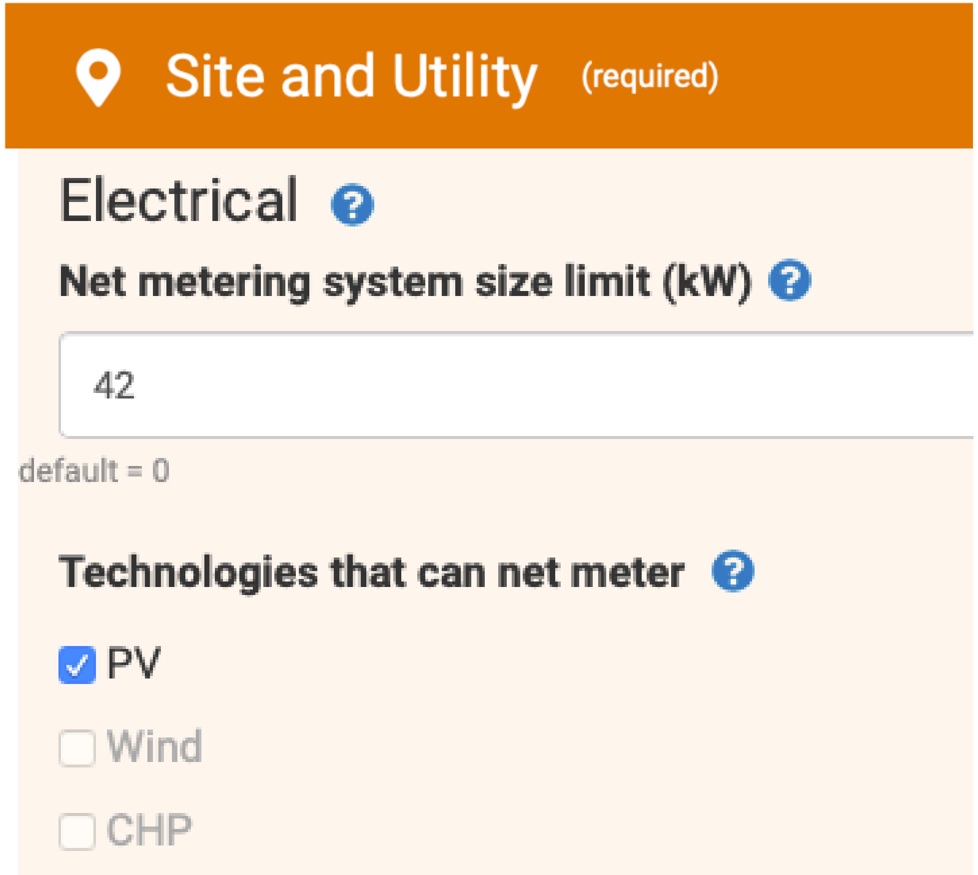
Net Metering Options (Hypothetical)

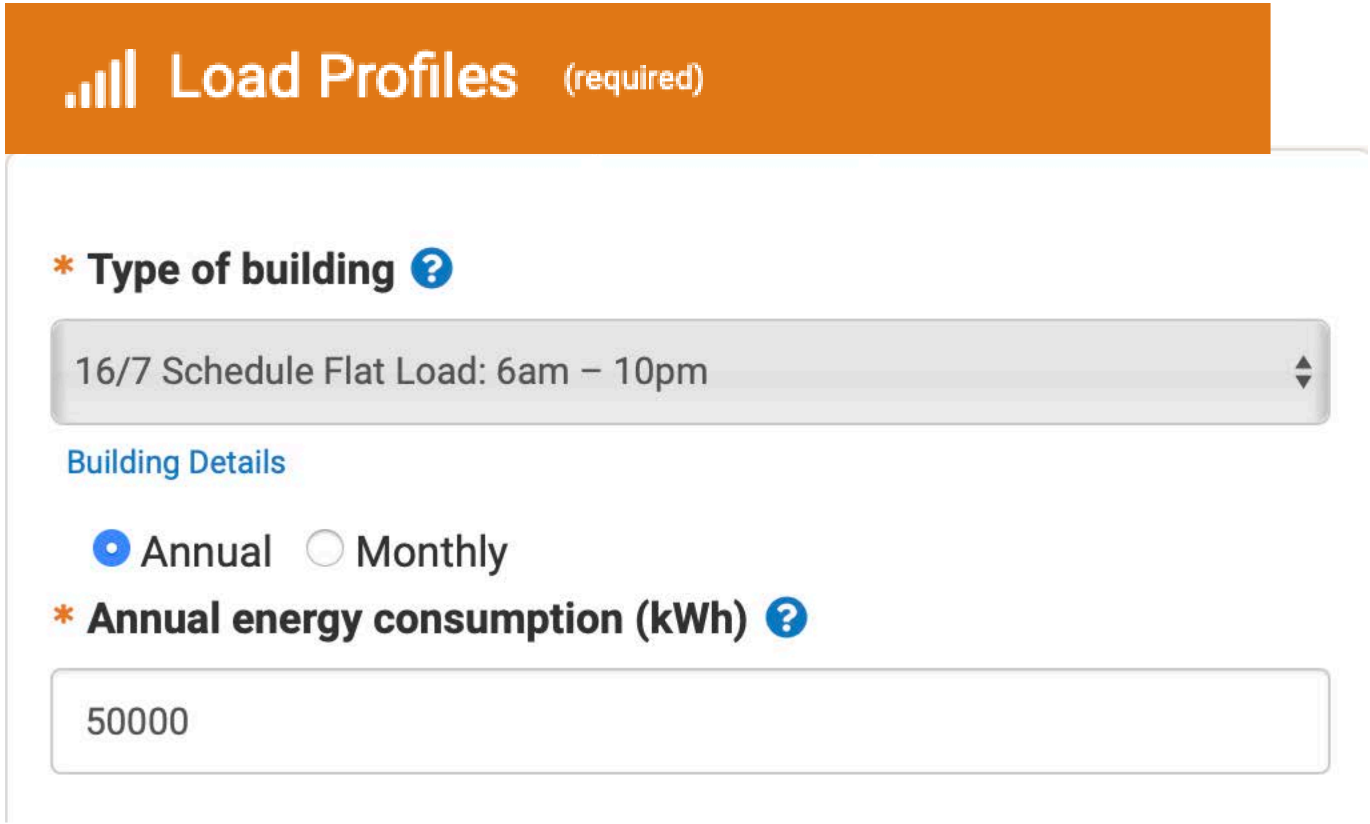
- Option 1: **Standard net metering**
  - Compensated for exports at NEM credit rate of **$0.21/kWh**
  - System must be sized to **not exceed the common area annual load** (**42 kW max**)
- Option 2: **Shared Solar Program**
  - Per program rules, all solar generation compensated at **$0.21/kWh**
  - System size limited only by roof capacity (**80 kW max**)
  - Compensation distributed to multiple accounts
  - Must complete competitive application process

Sol Housing would like to evaluate the added value of pursuing the Shared Solar Program as opposed to standard net metering

Net Metering Options (Hypothetical)

- Option 1: **Standard net metering**





Projects sized up to the net metering limit will receive credit for any exported energy at the electric retail rate at the time of export, up to the annual site load.

Net Metering Options (Hypothetical)

- Option 2: **Shared Solar Program**

Site and Utility (required)

Electrical

Net metering system size limit (kW)

80

default = 0

Technologies that can net meter

- [x] PV
- [ ] Wind
- [ ] CHP

Load Profiles (required)

*** Type of building**

16/7 Schedule Flat Load: 6am – 10pm

Building Details

(•) Annual ( ) Monthly

*** Annual energy consumption (kWh)**

100000

Increase the annual energy consumption to the **aggregate load of all accounts to be served.**

Projects sized up to the net metering limit will receive credit for any exported energy at the electric retail rate at the time of export, up to the annual site load.

Scenario 1 & 2 Results

Your recommended solar installation size

42 kW
PV size

Your recommended solar installation size

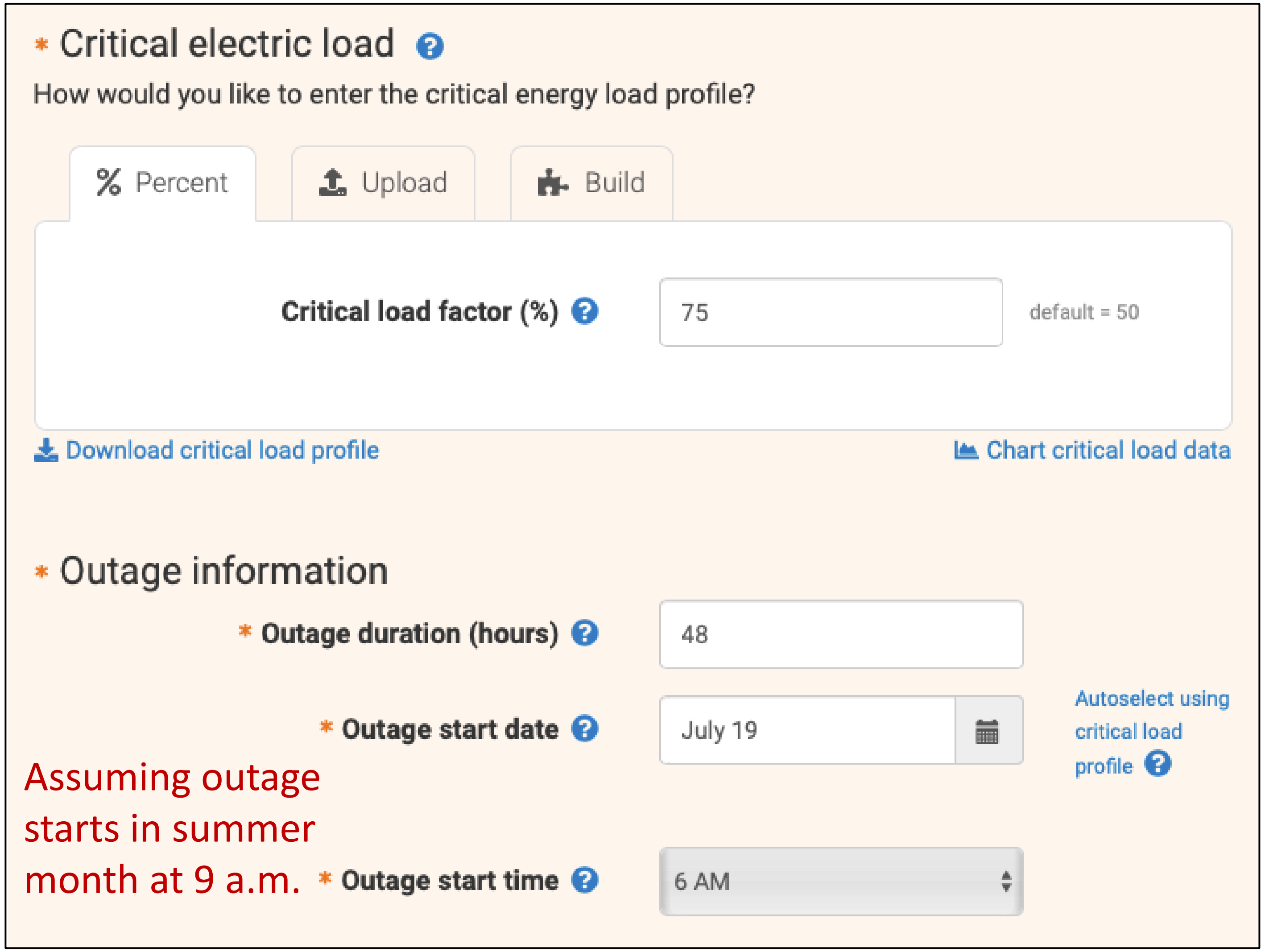
80 kW
PV size

Parameter	Scenario 1 (standard NEM)	Scenario 2 (Shared Solar)
Net present value (NPV)	$146,525	$279,105
Capital costs	$67,200	$128,000
Life cycle O&M costs	$15,780	$30,057
Life cycle utility bill savings	$229,505	$437,344
Internal rate of return (IRR)	15.9%	15.9%
PV production relative to load	95%	182%

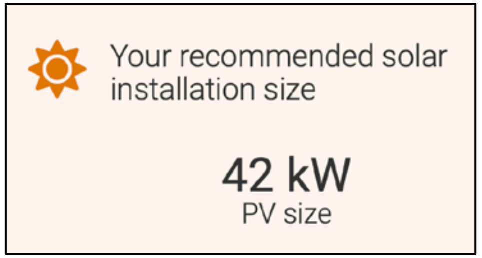
Resilience Analysis

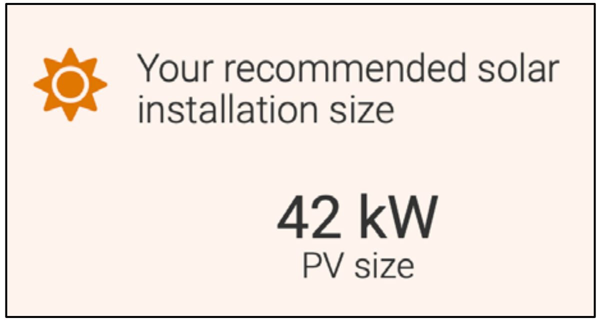
Scenario 3:

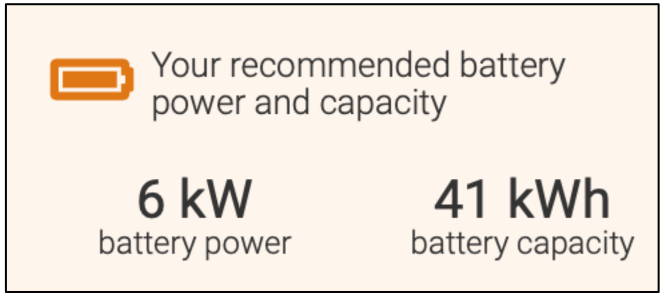
- Standard net metering pursued (Scenario 1)
- *Additionally*, would like to provide resilience for a **48-hour outage**
- **75%** of the common area loads are deemed critical
- Solar PV plus battery microgrid desired (no generator)



Scenario 1 & 3 Results

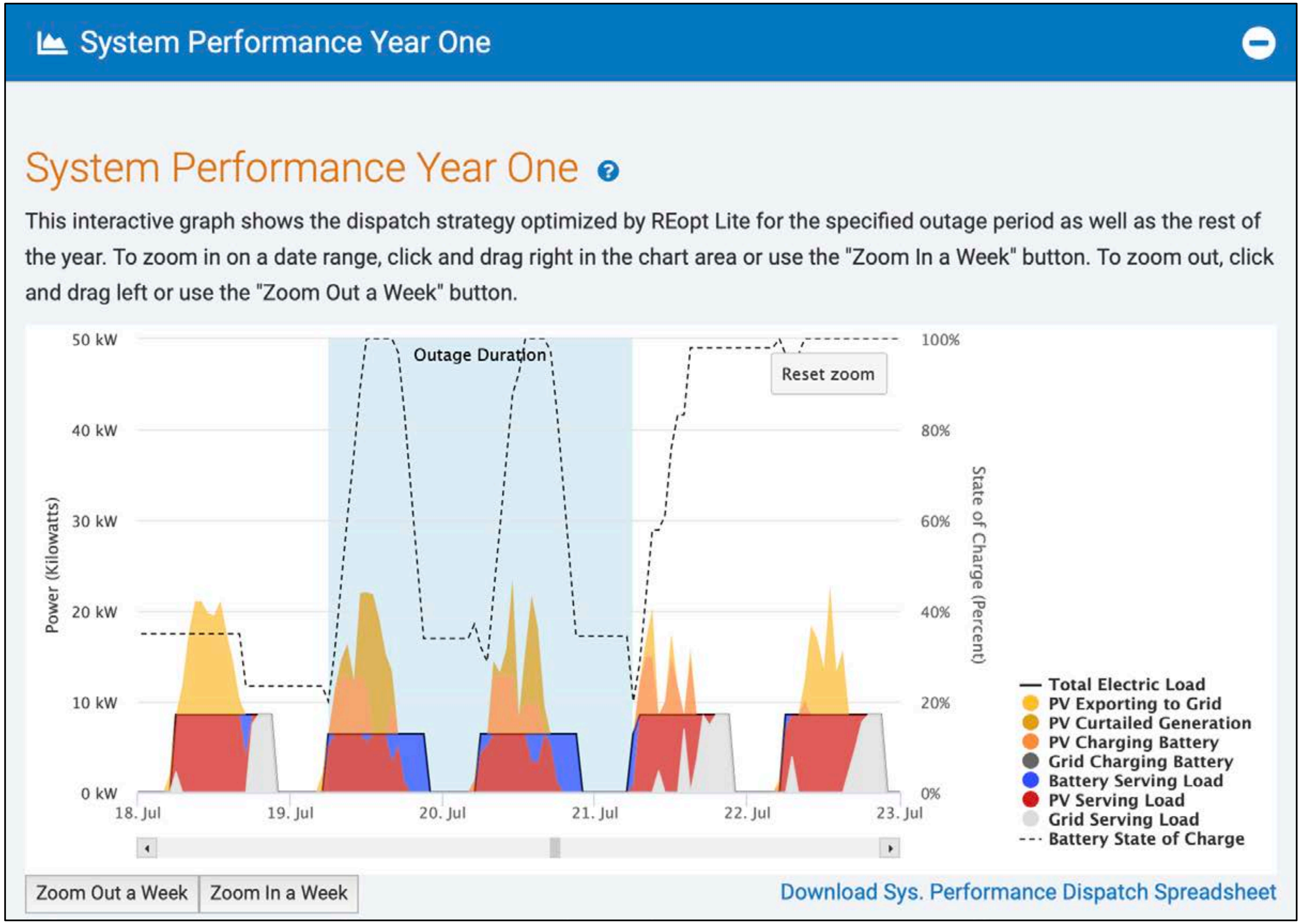






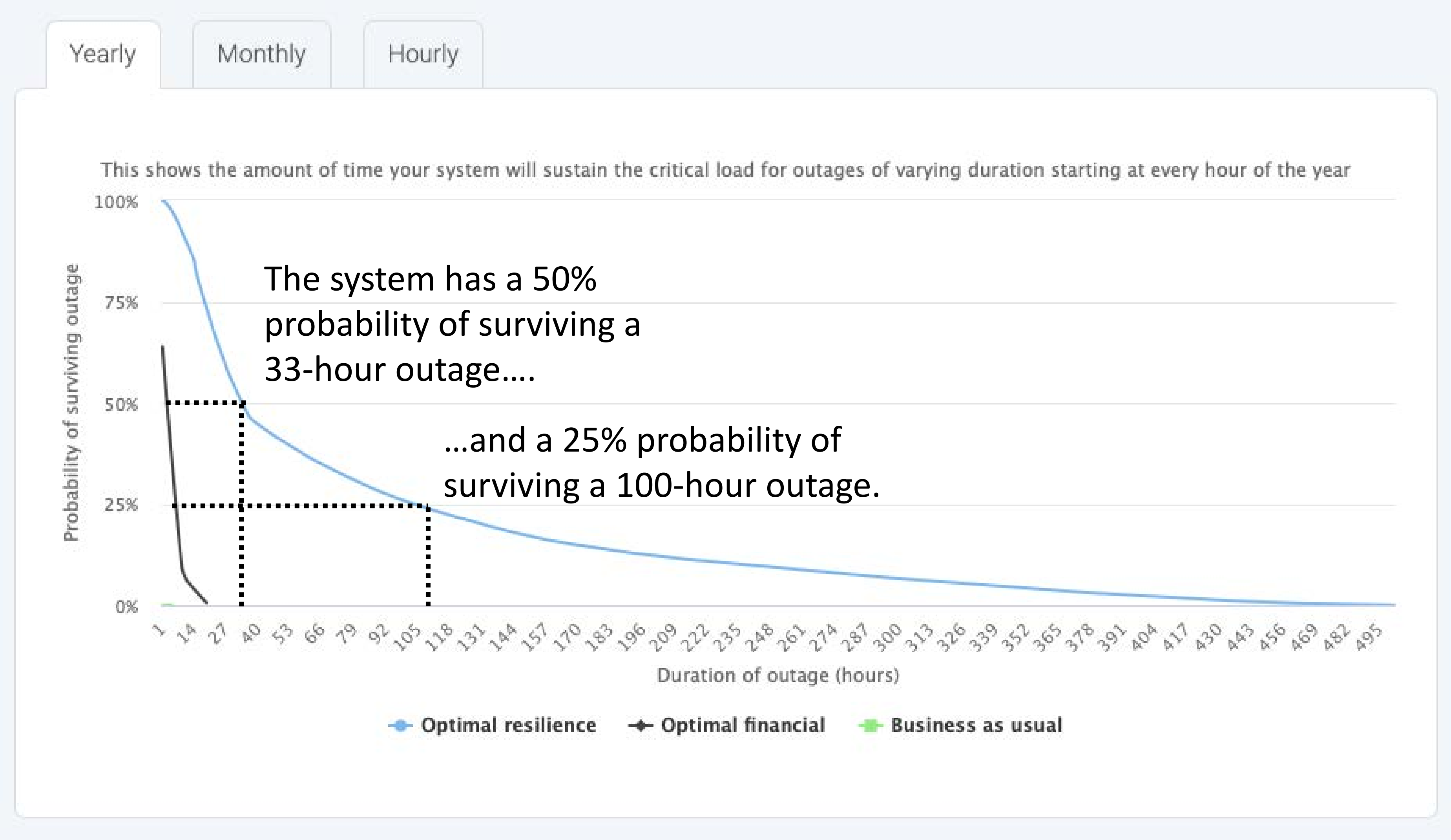
Parameter	Scenario 1 (standard NEM)	Scenario 3
Net present value (NPV)	$146,525	$114,036
Capital costs	$67,200	$89,920
Life cycle O&M + replacement costs	$15,780	$23,878
Life cycle utility bill savings	$229,505	$227,834
Internal rate of return (IRR)	15.9%	11.1%
PV production relative to load	95%	95%

Additional Resilience Results (Scenario 3)



The 42-kW solar, 6-kW/41-kWh battery microgrid system can meet the specified two-day outage.

Additional Resilience Results (Scenario 3)



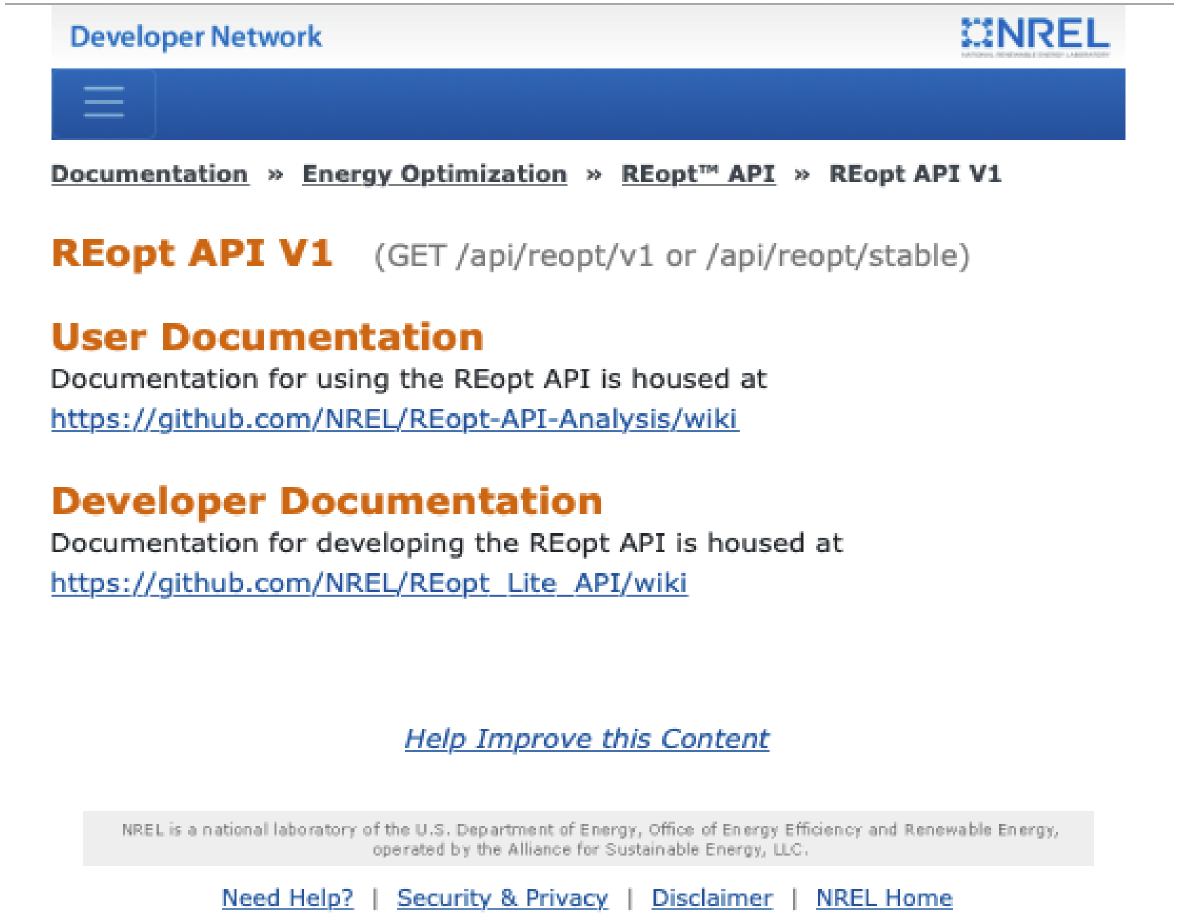
REopt API

What is an API?

- Application programming interface
- Programmatic way of accessing REopt (sending and receiving data from a server)
- File format used for sending and receiving the data: JSON.

Why might MFAH users want to use the API?

- Evaluation of multiple sites and multiple scenarios can be automated (can save time if a significant number of evaluations are needed)
- Application can be integrated with other programs


Developer Network NREL

Documentation » Energy Optimization » REopt™ API » REopt API V1

REopt API V1 (GET /api/reopt/v1 or /api/reopt/stable)

User Documentation

Documentation for using the REopt API is housed at https://github.com/NREL/REopt-API-Analysis/wiki

Developer Documentation

Documentation for developing the REopt API is housed at https://github.com/NREL/REopt_Lite_API/wiki

Help Improve this Content

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Need Help? | Security & Privacy | Disclaimer | NREL Home

https://developer.nrel.gov/docs/energy-optimization/reopt/v1/

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB

This resource was developed by NREL for the National Community Solar Partnership (NCSP) Multifamily Affordable Housing (MFAH) Collaborative

For more information about the NCSP and technical assistance offerings, including collaboratives, visit:

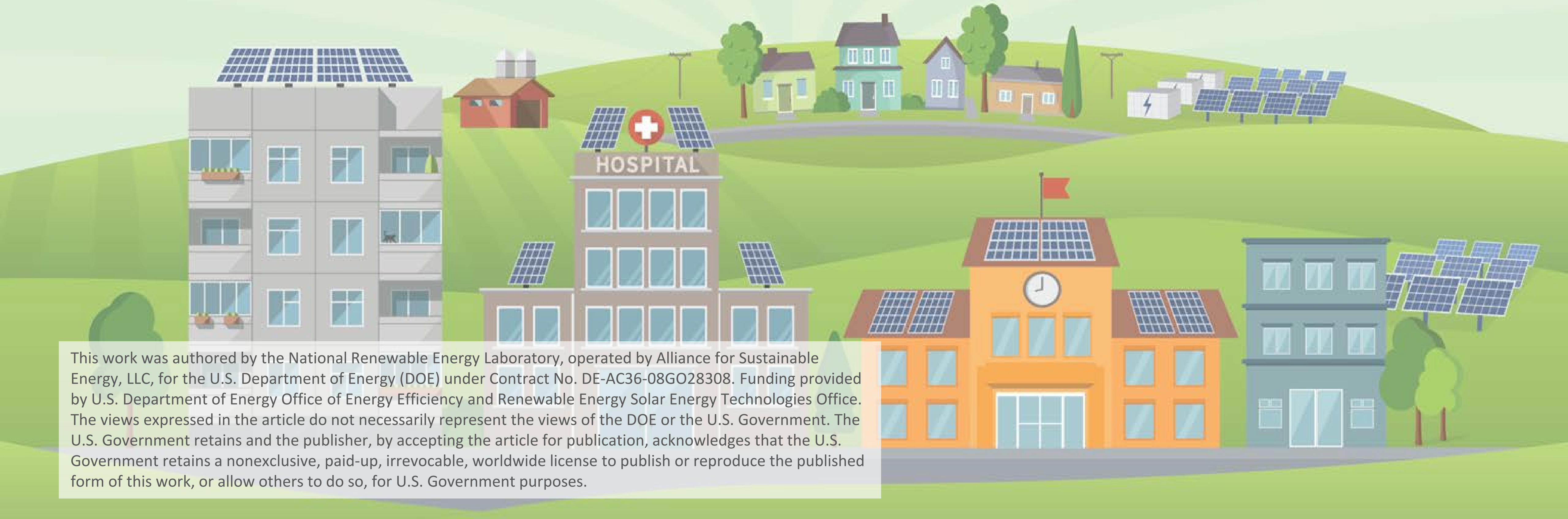
https://www.energy.gov/communitysolar/community-solar

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB



This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.