



REopt Lite Tutorial: Resilience Outputs

This tutorial explains the resilience modeling outputs in the [REopt Lite™ web tool](#). Find additional REopt Lite [tutorials](#).

The following example uses the same input data as provided in the “sample site” option within the web tool, with a 168-hour (7-day) outage that started at midnight on January 4.

Results

Technology Recommendations

For the tutorial example scenario in the previous steps, the technology recommendations are a 729-kilowatt (kW) solar photovoltaic (PV) system, and 220 kW of battery storage (Figure 1).

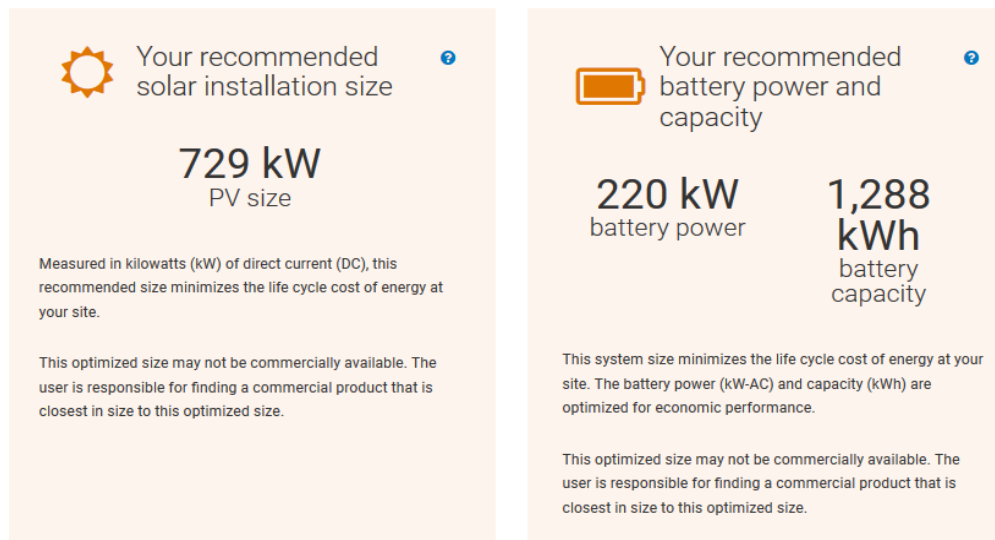


Figure 1. REopt Lite site recommendations for a resilience analysis

Your Potential Life Cycle Savings

The net present value (NPV) of life cycle savings for this example is $-\$107,073$. This means that installing the recommended technologies to reduce utility costs during grid-connected operation and to meet the critical load during the specified outage period will result in a negative NPV and will cost the site $\$107,073$ over the 25-year life cycle (Figure 2).

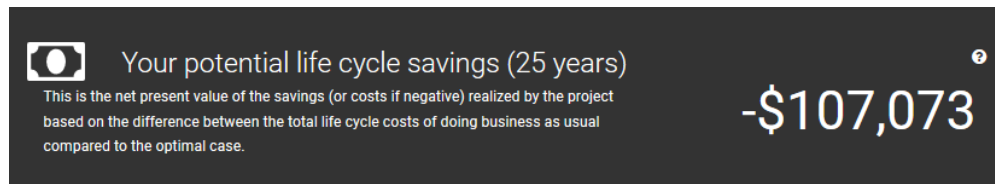


Figure 2. The net present value of your resilience scenario



Your Potential Resilience

The benefit of this system is the resilience it can provide to the site. REopt Lite is optimizing to survive the specified 7-day outage starting on January 4.

While the system is optimized to sustain the load during the one outage period at lowest cost, as specified by the user, the simulation also shows how the system will perform during 7-day outages starting at other times of the year. Outage survivability will change depending on the load and solar resource at the time of the outage.

This particular system has a 72% probability of meeting the critical load during a 7-day outage any time of the year (Figure 3).



Figure 3. The potential resilience benefit of your modeled system

System Performance Year One

The outage event that was specified is highlighted in blue. The load is represented by the solid black line. It is lower during the outage time period, because the critical load specified was only 75% of the typical load (Figure 4).

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.

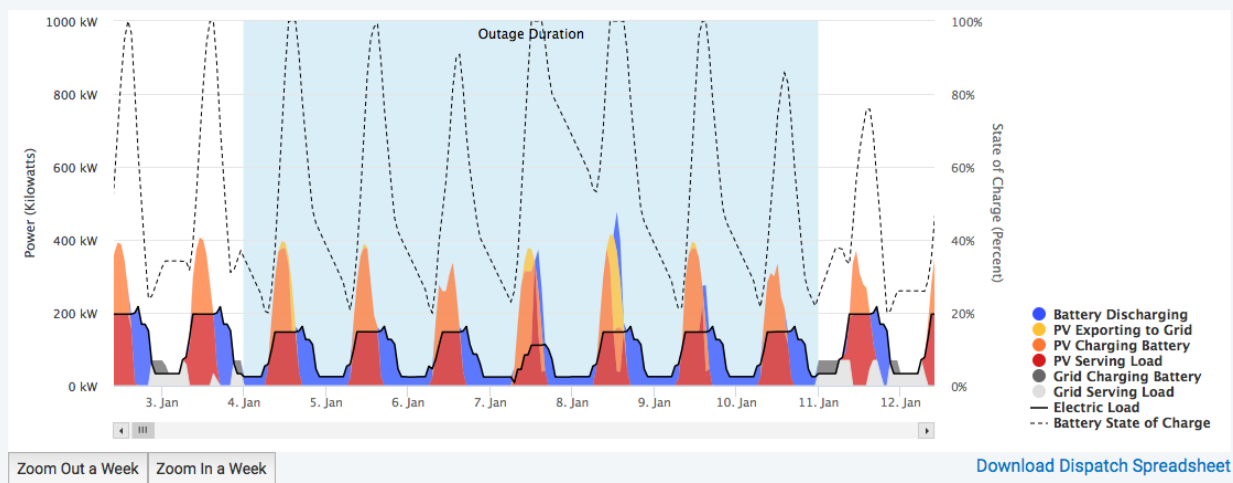


Figure 4. Interactive system performance and dispatch strategy graph, including your modeled grid outage



During this time period, the load is being met exclusively by the PV and storage that REopt Lite selected. As soon as the outage ends, the site goes back to purchasing grid electricity.

Because the system is designed to meet the critical load during the entire period specified, there are times where there is excess PV generation that is above the amount needed to meet the load or charge the battery.

An important consideration here is the critical load percentage specified. For example, if the critical load were estimated to be only 10% of the typical load, a smaller system would be needed to meet the resilience requirement.

Resilience Versus Financial Benefits

The Resilience Benefits table compares a system designed for resilience to a system designed for economics in terms of system size, NPV, and outage survivability. Note the lower NPV of the larger system, which is sized to meet the resilience requirement. This is due to higher capital costs that won't be completely recuperated during the grid-connected portion of the year (Figure 5).

Resilience Benefits

This system was designed to sustain the critical load during the outage period specified at lowest cost. The results below show how the system performs during outages occurring at other times of the year. Outages are simulated starting at every hour of the year and amount of time the system can sustain the critical load during each outage is calculated. The resilient system is compared to the business as usual system and a system designed for maximum financial benefits.

	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

Figure 5. Compare the business-as-usual case to the resilience case and the financial case



In the Business as Usual (BAU) case, where no existing generator or PV system is specified, the system cannot survive the outage. If an existing PV and/or generator is specified, a simulation is performed to check whether the existing systems can sustain the critical load for the full outage period. A similar simulation is performed to check whether the financial system can sustain the specified outage. The “Survives Specified Outage” row indicates the result of this resilience check.

The resilience system has been sized by the REopt Lite optimization to sustain the specified outage if it is technically feasible (i.e., there are technologies and/or fuel supply to meet the load). The average, minimum, and maximum hours survived are calculated from a simulation, described in the Outage Simulation section below.

Outage Simulation

Click the “simulate outage” button to run the outage simulation.

The simulator runs 8,760 cases (an outage starting at each hour of the year) and calculates the number of hours the critical load is sustained for each case (Figure 6). Due to time constraints, the simulation uses an algorithmic load-following dispatch strategy instead of a full optimization of the 8,760 scenarios. See the [REopt Lite Web Tool User Manual](#) for more details.

Outage Simulation

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

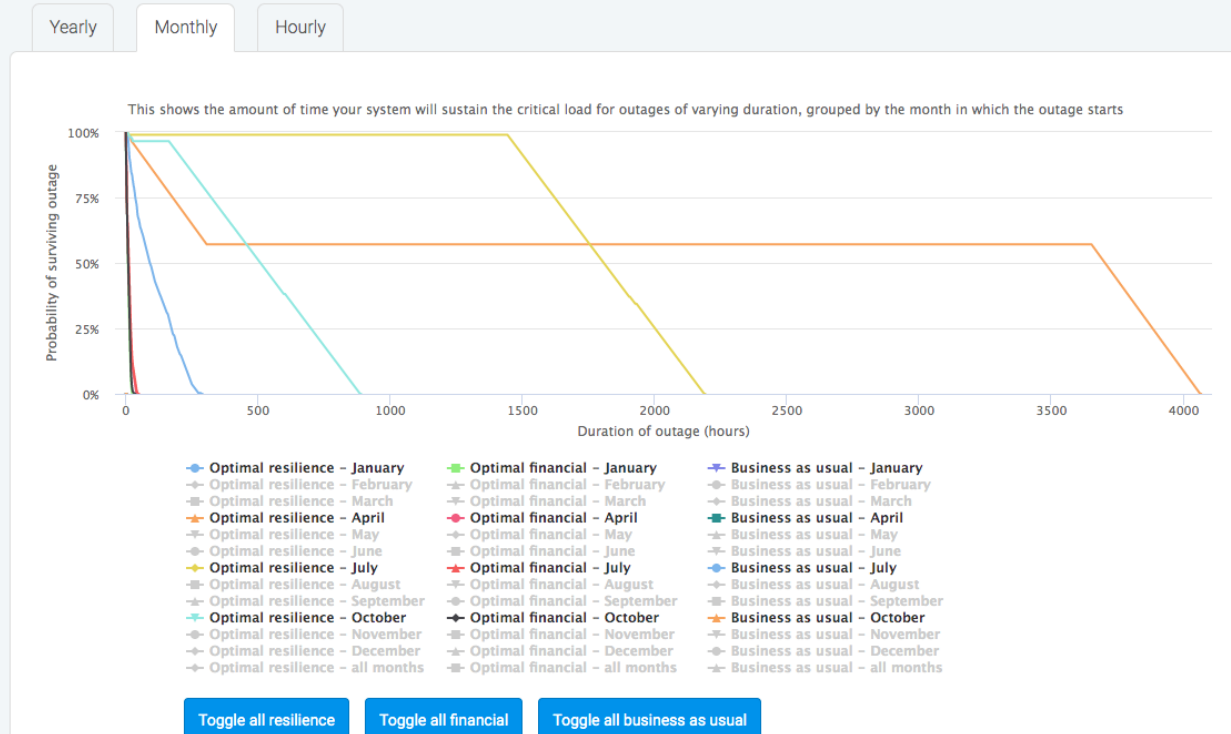


Figure 6. REopt Lite outage simulation results, including yearly, monthly, and hourly graphs



Yearly, monthly, and hourly graphs show how survivability varies from the annual average for outages starting at different months of the year and different hours of the day. Probabilities by month and by hour of the day are calculated by finding the average survival duration for the given month (from 1 to 12) or the given hour (from 1 to 24).

The y-axis shows the probability of sustaining an outage of the length shown on the x-axis. The example evaluation only includes the grid in the BAU case, which means BAU won't survive any outage. The financial case can survive only a very short outage. For the resilience case, notice how the probability of surviving an outage decreases as the outage duration increases.

You can view values from month to month, which can vary depending on the both the differences in load and in the generation from the PV system in different months. Click the "toggle all resilience" button to see how the results vary by month for this system. For example, in the month of May, the system has the highest probability of surviving an outage. If the 7-day outage occurs during this month, it could survive close to 3,000 hours. Notice that the outage month selected, January, has the lowest probability of surviving an outage.

Finally, you can explore the impacts of the timing of an outage starting at various hours of the day.

Results Comparison

As with the financial evaluation, REopt Lite presents a comparison of the costs and savings for the BAU case, the resilience case, and the financial case. See [REopt Lite Tutorial: Financial Outputs](#) for more information about the Results Comparison table.

For a resilience evaluation, the BAU case displayed pertains to the resilience scenario. The resilience scenario and financial scenario have slightly different BAU costs. The resilience scenario BAU utility costs do not include the cost of purchasing energy during the outage period, because the grid is unavailable. In the financial scenario, no outage is modeled, so the financial scenario BAU totals include the cost of purchasing utility energy during all hours. The financial scenario BAU is not displayed on the tables in the resilience evaluation results.

The resilience case NPV is the difference between the resilience scenario life cycle cost and the resilience scenario BAU life cycle cost. The financial case NPV is the difference between the financial scenario life cycle cost and the larger financial scenario BAU life cycle cost.



Effect of Resilience Cost and Benefits

This section allows you to explore the impact of additional costs and values that are not included in the optimization.

In order for this system to provide power during an outage, additional upgrades to the electrical infrastructure may be required. The “Microgrid Upgrade Cost” slider allows you to explore the impact of the cost of those upgrades as a percentage of the total installed cost of the system (Figure 7).

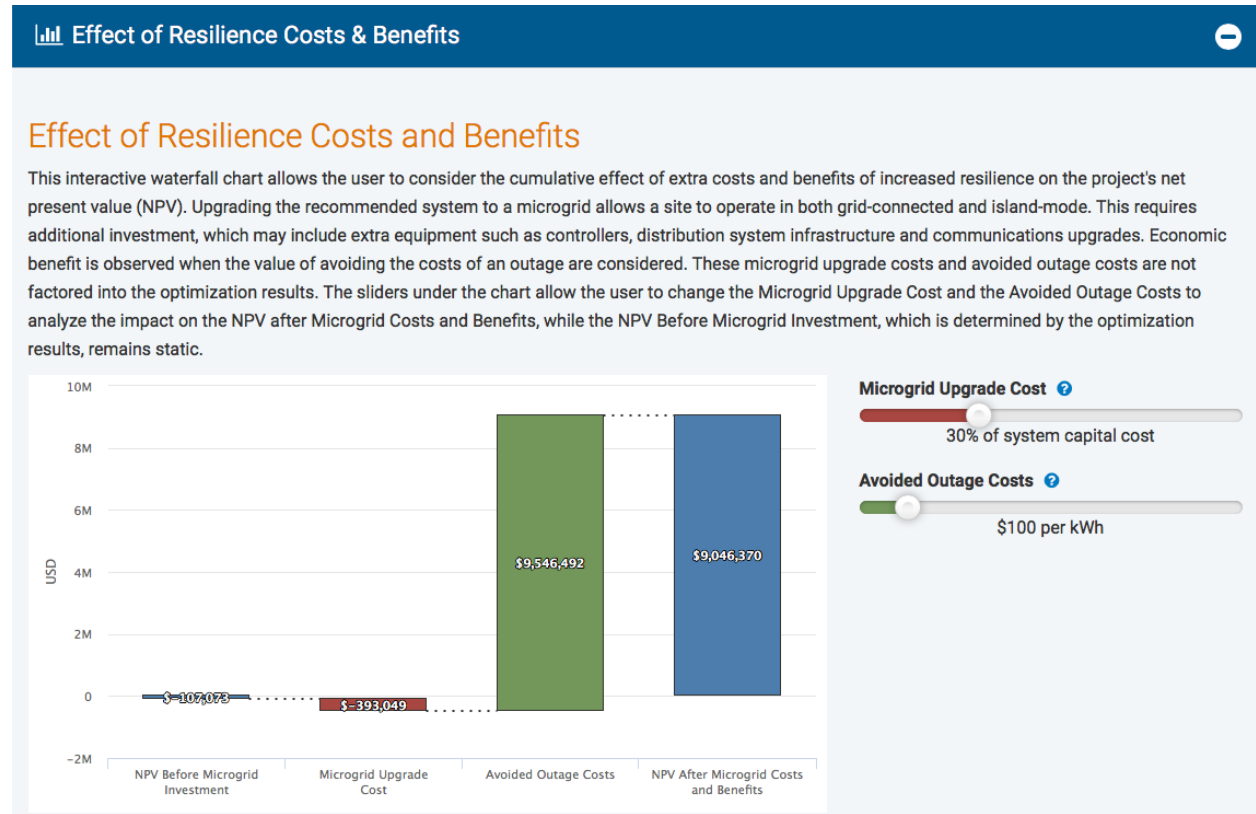


Figure 7. Interactive resilience costs and benefits waterfall chart



A system that can sustain an outage features one additional value stream that is not included in the optimization—the monetary resilience benefit. This value can be particularly challenging to quantify. Not only does it vary from building to building, but sometimes there is not a readily available value for all of the monetary effects of the loss of grid power. Here you can use the “Avoided Outage Costs” slider to explore how attributing varying values to an avoided outage will impact the NPV of the resilience system.

Learn More

For more information on tool inputs and default values, please see the [REopt Lite Web Tool User Manual](#).

Find additional REopt Lite tutorial documents and videos on reopt.nrel.gov/user-guides.html.



NREL’s REopt Lite web tool helps users evaluate the economic viability of grid-connected PV, wind, and battery storage systems at a site. It identifies system sizes and battery dispatch strategies to minimize energy costs, and estimates how long a system can sustain the site’s critical load during a grid outage.

Learn more about REopt Lite at reopt.nrel.gov/tool.

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