REopt for Resilient Buildings:

Leveraging Energy Efficiency and Distributed Energy Resources for Resilience Solutions

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reopt.nrel.gov

Integration and Optimization

Photo by Dennis Schroeder, NREL 55200

Contents

Introduction to REopt

The Nation’s Energy Supply Is in the Midst of a Transformation

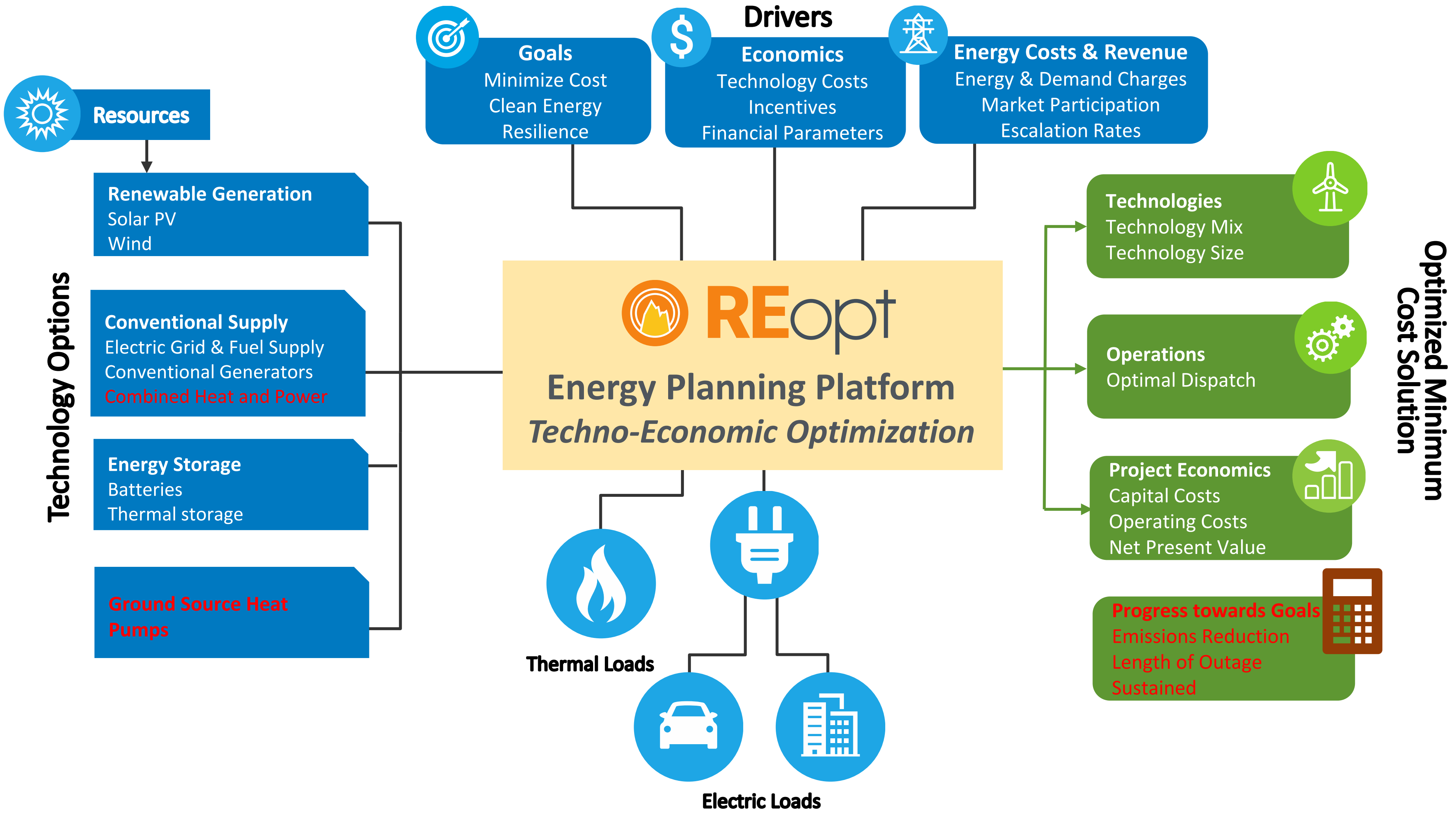
- As costs decrease, renewable energy deployment is growing worldwide
- Generation is increasingly distributed, with 31% of new capacity behind-the-meter
- Distributed energy technologies and demand-response strategies can provide cost savings, resilience, and emissions reduction
- With increasingly integrated and complex systems, back-of-the envelope calculations are no longer sufficient to determine distributed energy project potential

REopt Optimizes Integrated Energy Systems

- NREL's REopt™ platform optimizes planning of generation, storage, and controllable loads to maximize the value of integrated systems
- REopt considers electrical, heating, and cooling loads and technologies simultaneously to identify the optimal technology or mix of technologies
- It transforms complex decisions into actionable results for building owners, utilities, developers, and industry
- REopt analysis guides investment in economic, resilient, sustainable energy technologies

REopt Energy Planning Platform

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



Note some capabilities were developed for specific projects only

Will DERs Work for Your Site?

RE Resource

Technology Costs & Incentives

Site Goals

Utility Cost & Consumption

Financial Parameters

Many factors affect whether distributed energy technologies can provide cost savings and resilience to your site, and they must be evaluated concurrently.

REopt Provides Solutions for a Range of Users

Including researchers, developers, building owners, utilities, and industry

What is the optimal size of DERs to minimize my cost of energy?

How do I optimize system control across multiple value streams to maximize project value?

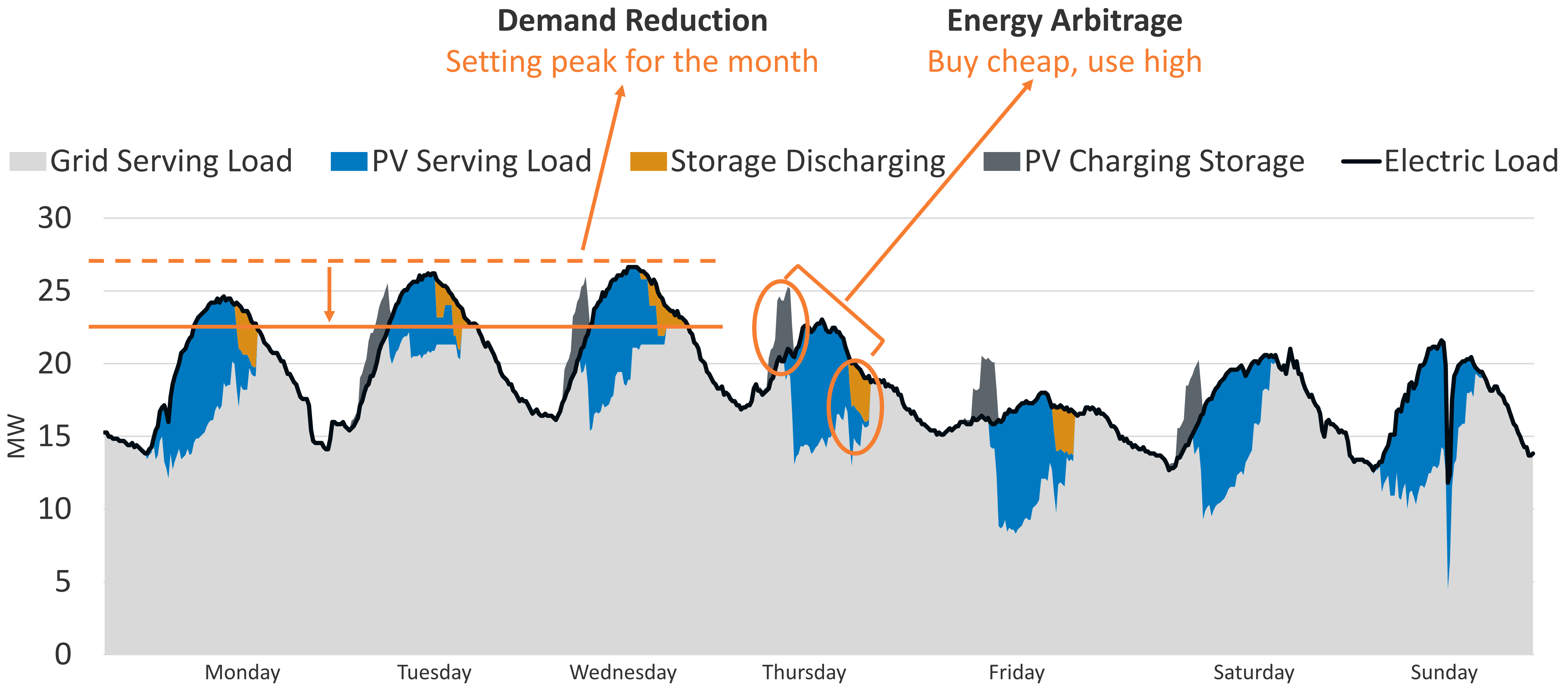
Where do market opportunities for DERs exist? Now and in the future?

What will it cost to meet my sustainability or renewable energy goal?

What is the most cost-effective way to sustain a grid outage spanning 1 day? What about 9 days?

How Does REopt Work?

REopt considers the trade-off between ownership costs and savings across multiple value streams to recommend optimal size and dispatch.



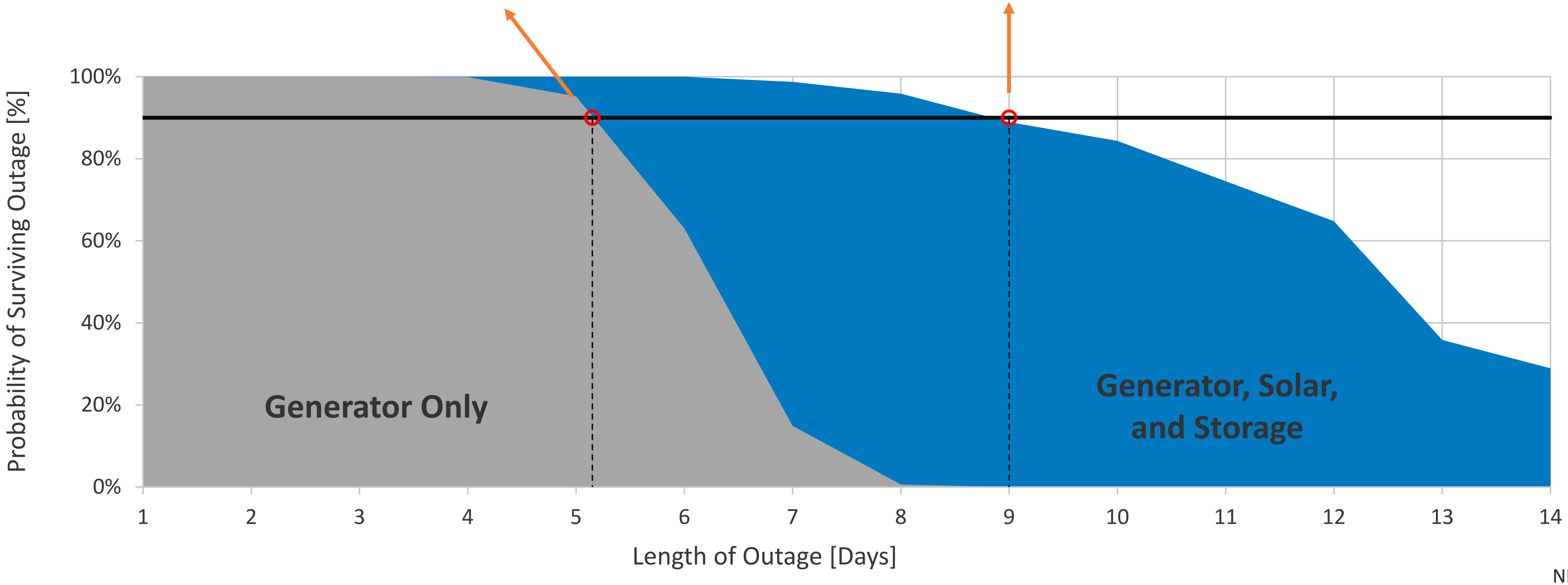
Example of optimal dispatch of PV and BESS

How Does REopt Evaluate Resilience?

REopt finds the system size and dispatch that minimizes life cycle energy costs for grid-connected operations and survives a specified grid outage. It evaluates thousands of random grid outage occurrences and durations to identify the probability of survival.

Existing generator with fixed fuel supply sustains the critical load for 5 days with 90% probability

Adding solar and storage to the existing generator increases survivability from 5 to 9 days by extending fixed diesel fuel supplies and provides utility cost savings while grid-connected.



REopt Capability Development

Capabilities developed by the team are transferred to REopt based on broad use and validation, customer needs, and funding available

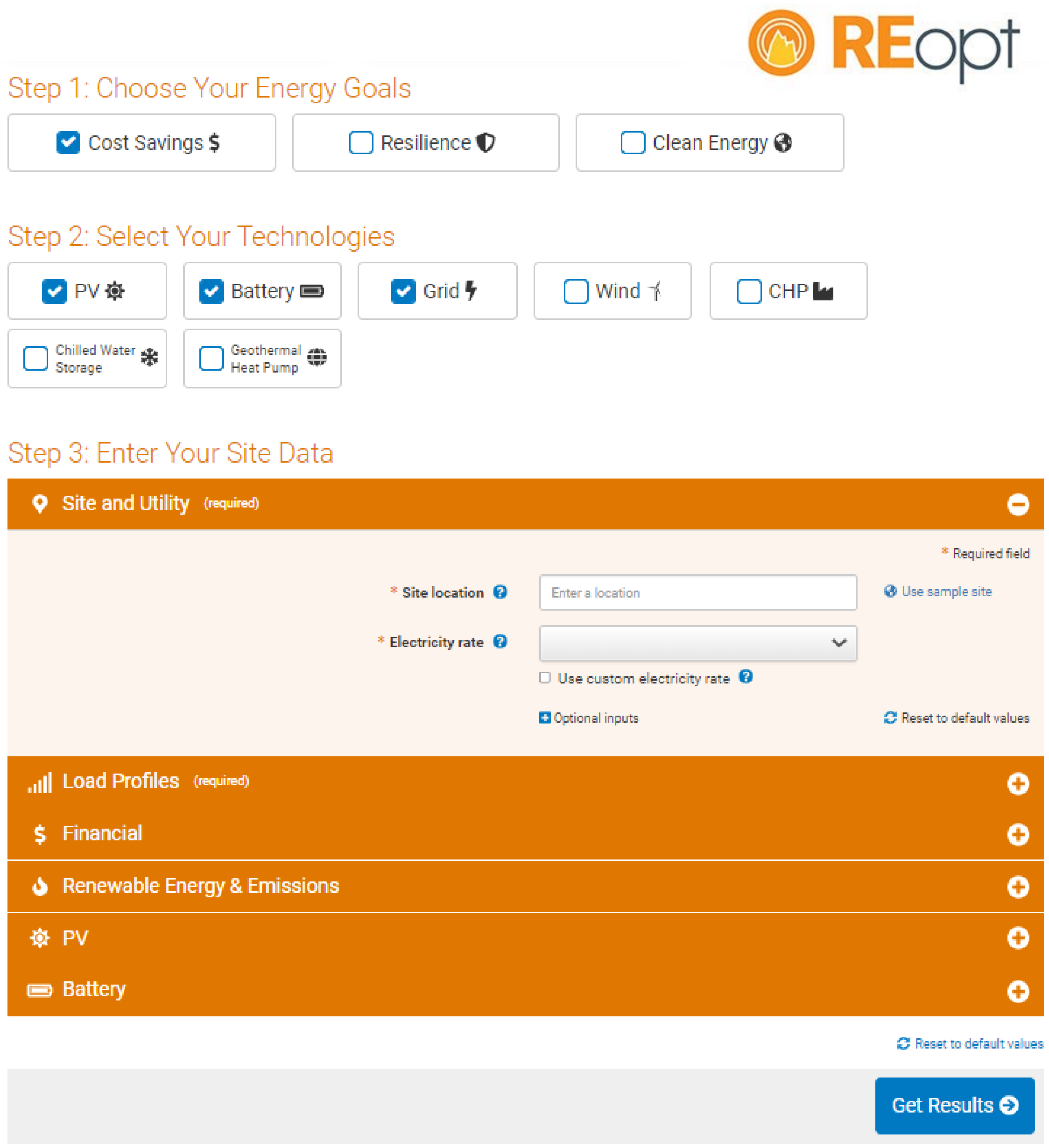
REopt Custom Analysis & Development	• New feature development • Support specific entities
REopt API and O/S	• Additional features with longer run-time • Customizable • Tool integration
REopt Web	• Easy to use web access • Key standardized capabilities

REopt Web Tool

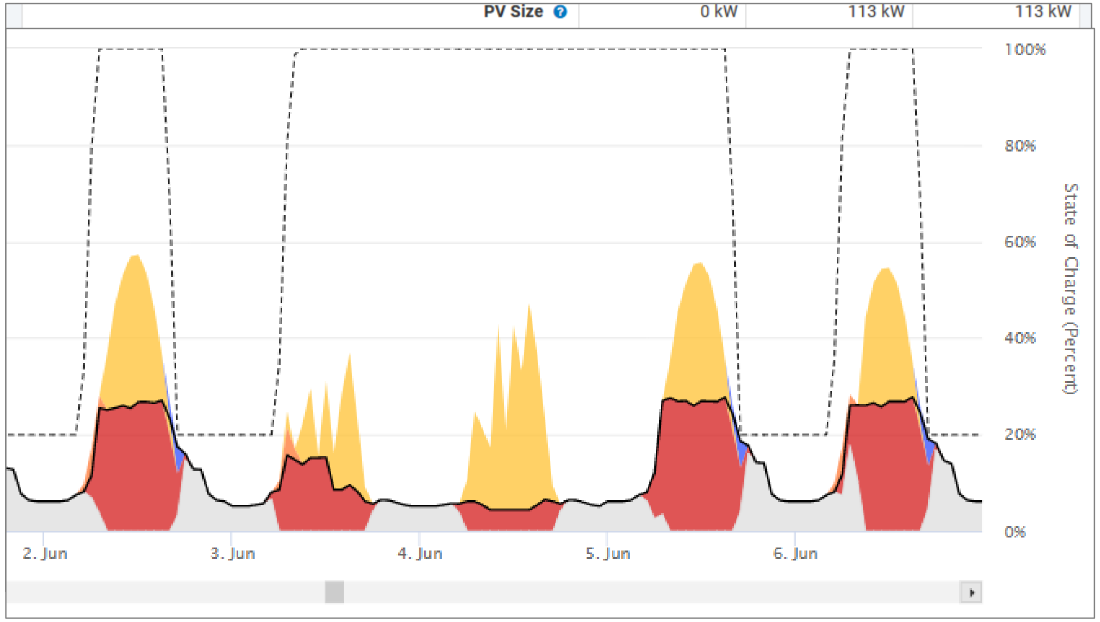
User Interface and Key Results

REopt Web Tool User Interface

- **REopt Web Tool** offers a free, publicly available, user-friendly web tool that offers a subset of NREL's more comprehensive REopt™ model
- Optimizes **PV, wind, CHP, GHP, and battery energy storage system (BESS)** sizes and dispatch strategies to **minimize life cycle cost of energy** while meeting the site loads
- **Resilience mode** optimizes PV, wind, and storage systems, along with backup generators, to sustain critical load during grid outages.
- **Clean energy goals** allow users to consider renewable energy targets, emissions reductions targets, and emissions costs in optimization
- Access REopt web tool at reopt.nrel.gov/tool.



REopt Web Tool Key Outputs - Economic



Hourly Dispatch

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

	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

REopt Web Tool Key Outputs – Resilience

Your recommended solar installation size

13,137 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

1,171 kW
battery power

3,419 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.

Your recommended generator size

7,200 kW
generator size

Measured in kilowatts (kW) of alternating current (AC), this recommended generator size minimizes the life cycle cost of energy at your site during a grid outage.

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.

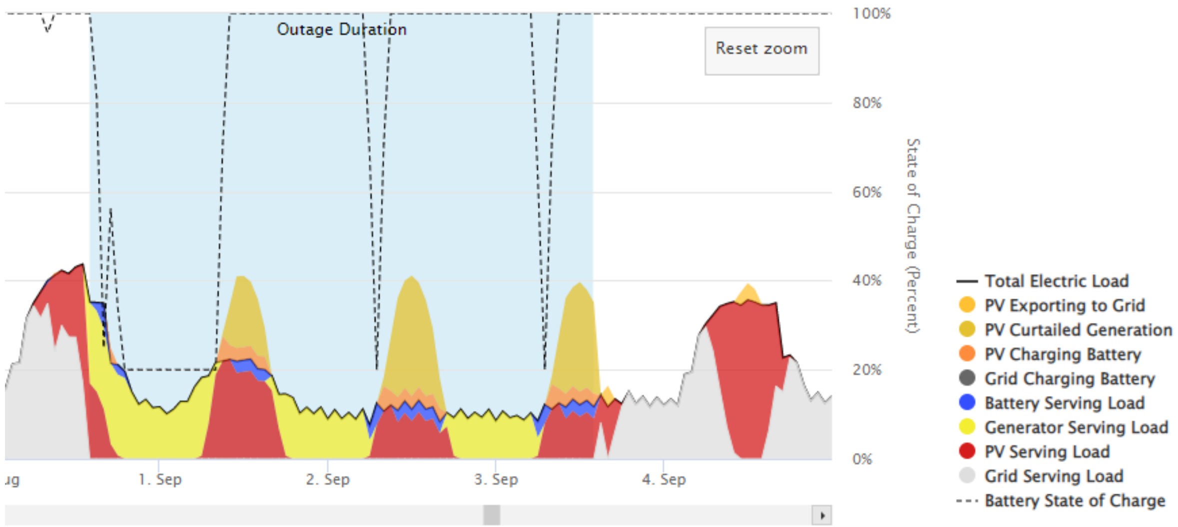
Your potential life cycle savings (25 years)

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.

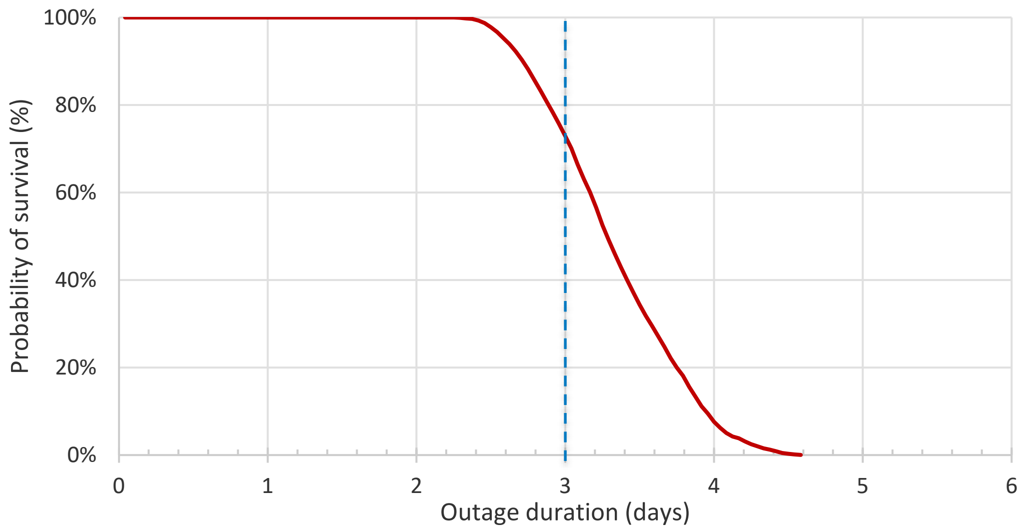
If you did not choose the resilience focus or input minimum required technology sizes for this evaluation, your life cycle cost savings is negative due to the tolerance settings in the model which may result in savings as low as -$3,888,091. In this case, your best solution is business as usual.

-$2,078,711

System Size and NPV



Hourly Dispatch (Outage Duration Highlighted)



Resilience Probability of Survival Curves

Case Study: Community Resilience in Manatee County

Analysis Overview

- This case study leverages REopt to evaluate the **resilience and economic benefits** of energy efficiency (EE), PV, BESS, and backup diesel generators at two municipal facilities in **Manatee County**, Florida.
- The facilities' **resilience goal** was to optimize backup generator, PV and BESS sizes in order to sustain their critical loads during a **three-day** (72-hr) grid outage.
- The analysis considers two separate impacts that EE and PV+BESS may have:
    1. Improving building resilience
    2. Providing economic savings

Facility Name	Public Safety Complex	R. Dan Nolan Middle School
Building Type	Large Office and Hospital	Secondary School
Annual Consumption (kWh)	3,892,560	1,926,144
Peak Load (kW)	928	787
Electric Utility Provider	Florida Power & Light (FPL)	Peace River Electric Cooperative (PRECO)
Critical load (%)	60%	60%
Existing backup generation	Two 1MW generators and two 800 gallons diesel tanks	None (currently renting generator and diesel tank for storm season)

Technologies & Strategies Analyzed

Business-as-usual: Electricity from grid; vulnerable to outages without backup systems

Load reduction through energy efficiency measures

Diesel generator to provide building resilience

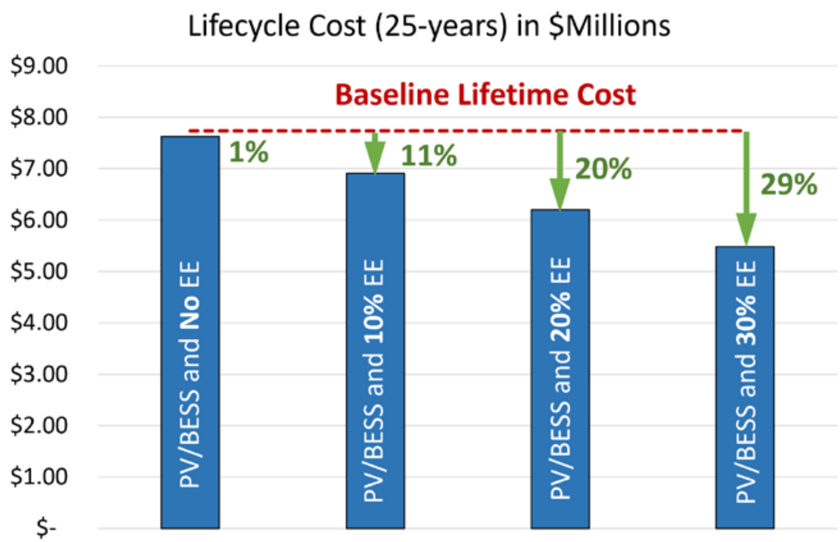
Solar photovoltaics (either rooftop or ground-mount)

Battery electric storage system to provide demand reduction and resilience

Facility information and resilience goals were provided by Manatee County

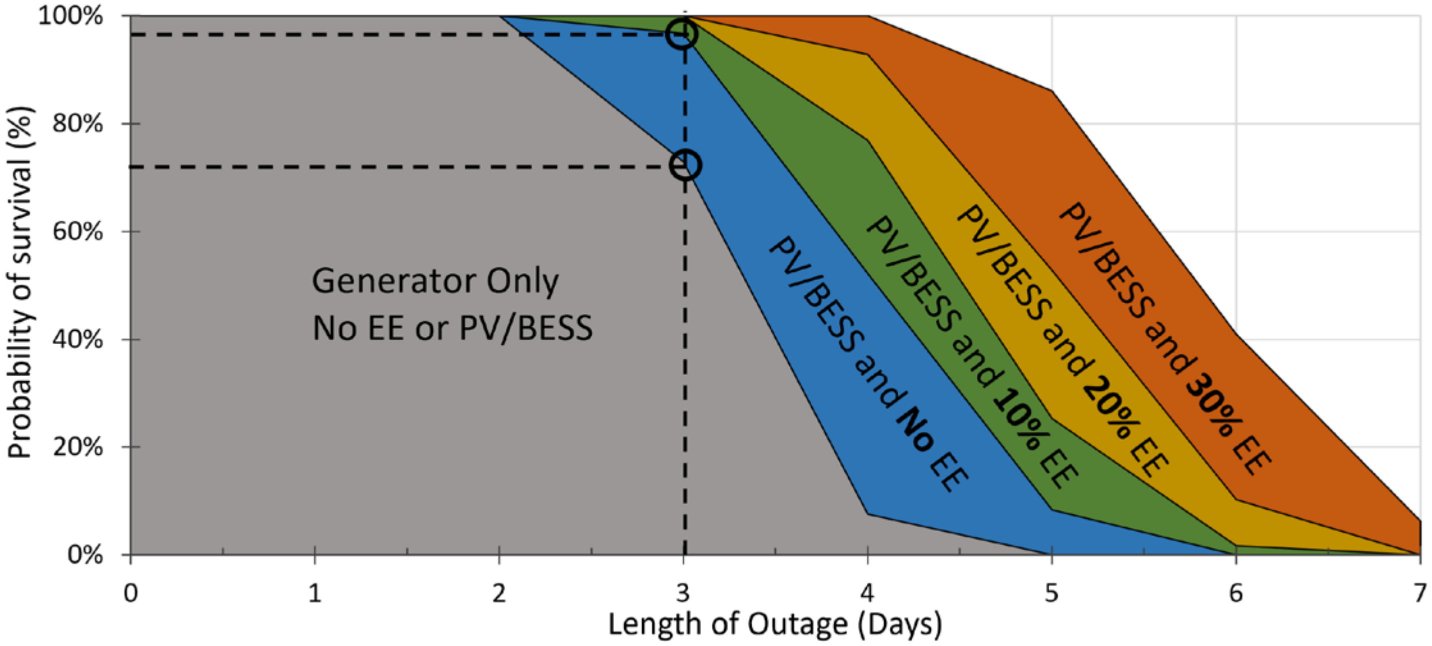
Resilience Benefits of Energy Efficiency and PV+Battery

The **Public Safety Complex** already has 2MW of existing diesel generator. Can EE and PV+BESS **improve** the system resilience and save the site some costs? **Yes!**



Resilience Benefits

- With the existing generator, the system **will not be able to sustain 27%** of all potential grid outages in a year
- Adding PV+BESS **decreases** the unmet outages to **less than 3%**. Adopting 10% EE further decreases those unmet outages to **0%**



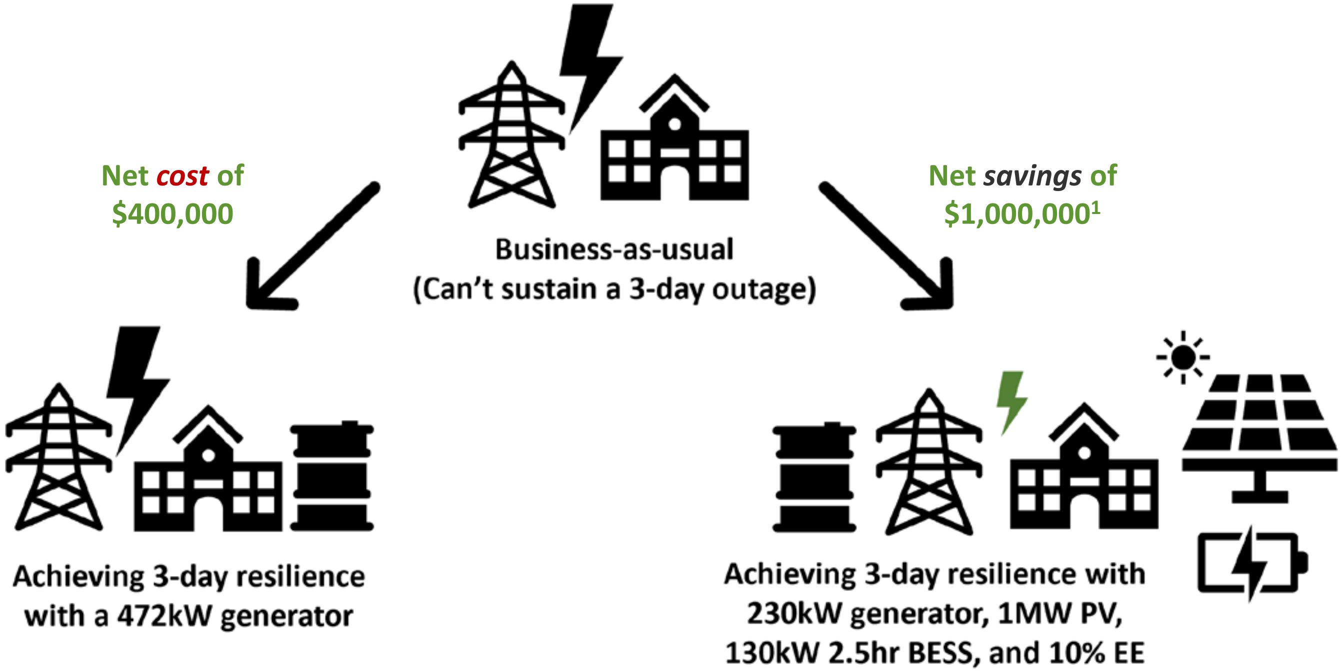
Economic Benefits

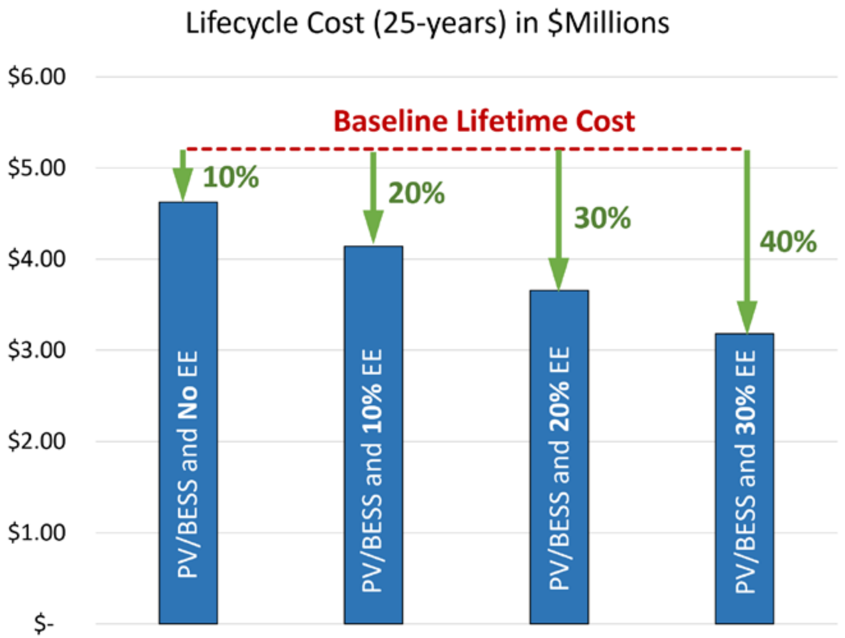
- Each 10% load reduction through EE results in **10% savings (~$700,000)**[1] in lifetime costs compared to business-as usual (i.e.not adopting EE and PV+BESS)
- Savings result mostly from reduction in utility costs

[1]Costs for adopting EE measures are not included in this case study.

Economic Benefits of Energy Efficiency and PV+Battery

The **R. Dan Nolan Middle School** serves as an emergency shelter, and should therefore be resilient to outages from extreme weather. The facility currently **has no backup generator**, so we need to design an optimal system that includes on-site diesel generator. Can EE and PV+BESS **provide economic benefits** compared to installing just a backup generator? Can they provide additional benefits from **resource diversification? Yes!**





Economic Benefits

- Installing cost-optimal PV+BESS results in **10% savings (~$570,000)[1]** in lifetime costs compared to business-as usual (not adopting EE and PV+BESS)
- Each 10% load reduction through EE results in an **additional 10% savings (~$480,000)[1]** in lifetime costs compared to business-as usual
- Savings result from reduction in utility costs and utility (PRECO) a rate structure which incentivizes renewable energy generation (unique to this case)

[1]Costs for adopting EE measures are not included in this case study.

Thank you

REopt website (analysis services and case studies): reopt.nrel.gov
Tool feedback and questions: reopt@nrel.gov

www.nrel.gov

NREL/PR-7A40-83498

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REopt Integration and Optimization

Photo from iStock-627281636

NREL Transforming ENERGY

Appendix: Additional Information

REopt Model Technical Description

Mixed Integer Linear Program

- Mathematical model written in the MOSEL programming language solved using commercial FICO Xpress solver
- Analysis typically requires significant site-specific and client-requested customizations

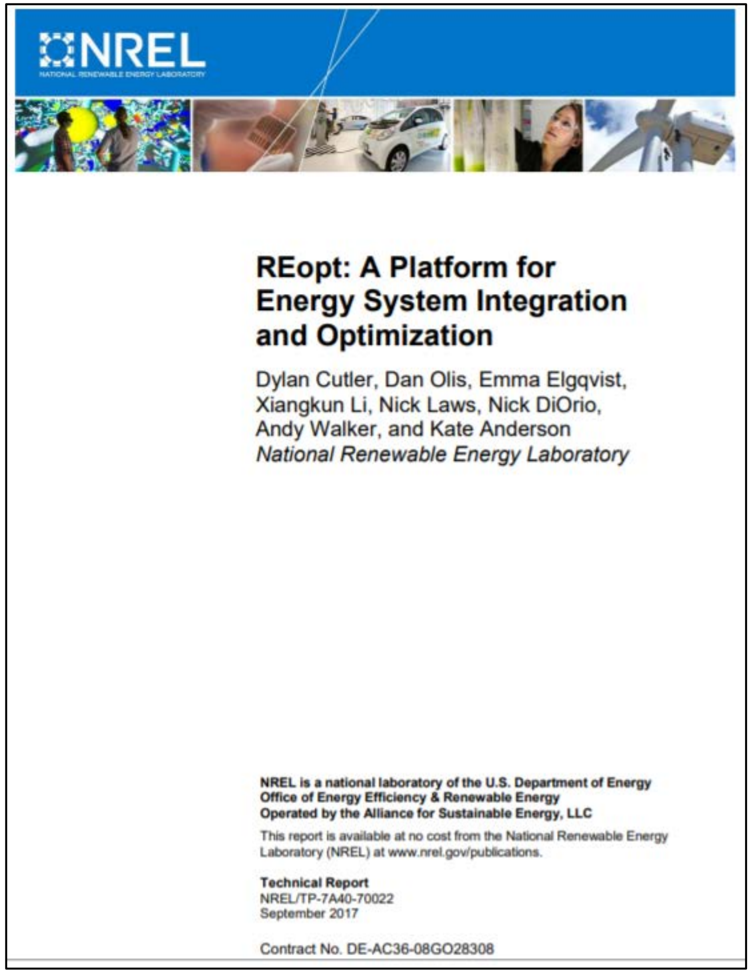
Solves energy balance at every time step for entire year (typically 15-minute or hourly interval)

- Load must be met from some combination of grid purchases, on-site generation, or discharge from storage
- Typically does not consider power flow or transient effects
- Has perfect prediction of upcoming weather and load
- Assumes all years in analysis horizon are the same (typically 25 years)

Technology modules based on empirical operating data

Finds optimal technology sizes (possibly 0) and optimal dispatch strategy subject to resource, operating, and goal constraints

- Objective function is to minimize life-cycle cost of energy
- Resulting life cycle cost is **guaranteed optimal** to within a known gap (typically 0.01%) subject to modeling assumptions


NREL

REopt: A Platform for Energy System Integration and Optimization

Dylan Cutler, Dan Olis, Emma Elgqvist, Xiangkun Li, Nick Laws, Nick DiOrio, Andy Walker, and Kate Anderson
National Renewable Energy Laboratory

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

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Technical Report
NREL/TP-7A40-70022
September 2017

Contract No. DE-AC36-08GO28308

Accessing REopt

The **REopt team works with stakeholders to** provide a suite of trusted techno-economic **decision support services** to optimize energy systems for buildings, campuses, communities, microgrids, and more.

The team also develops publicly available **REopt software**; capabilities developed by the team are transferred to REopt based on broad use and validation, customer needs, and funding available.

REopt Decision Support Services

Allows organizations to work closely with NREL's team of experts on customized analysis, answering complex energy questions using an expanded set of internal modeling capabilities.

REopt Software

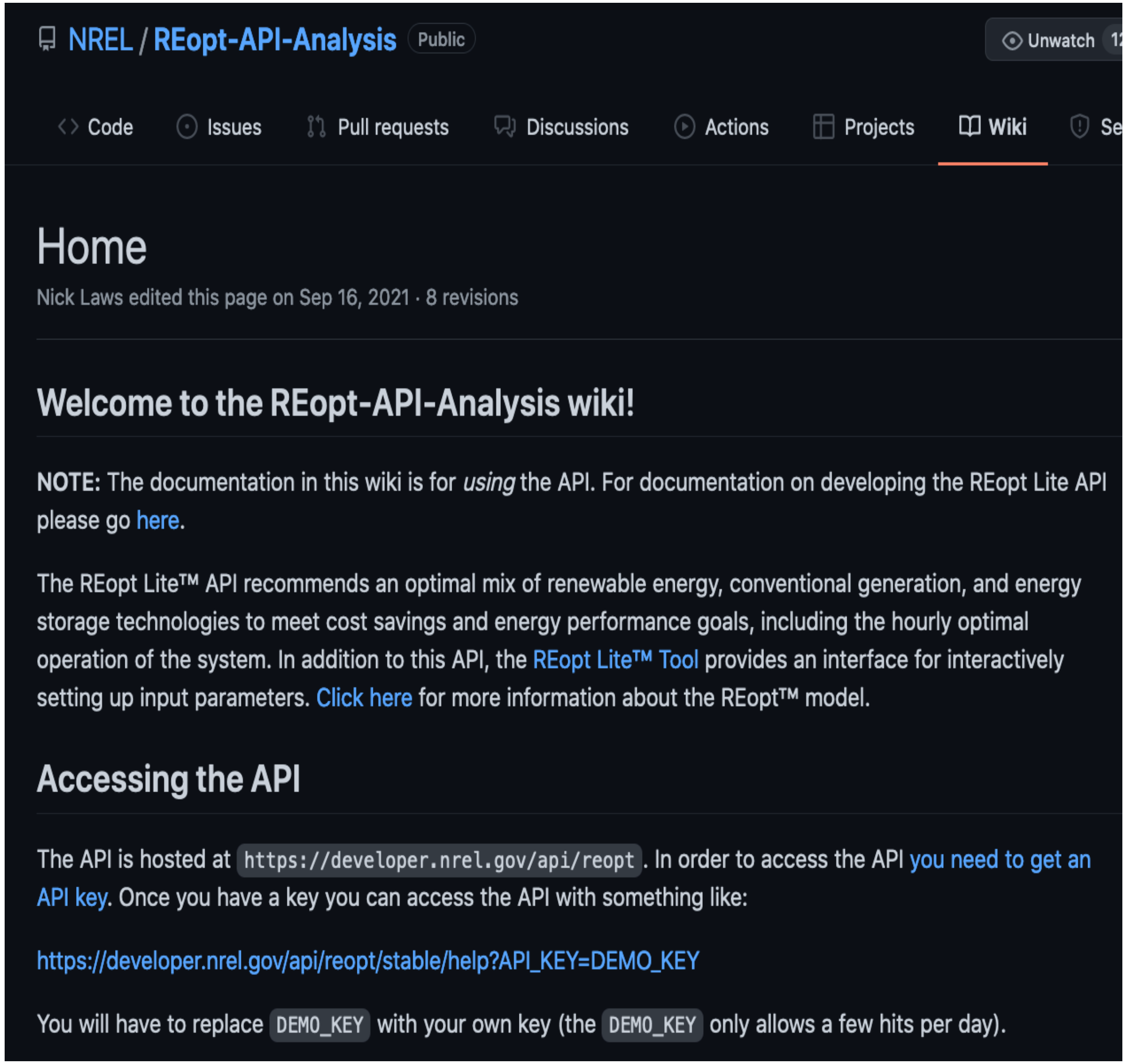
Developed by the REopt team, the tool guides users to the most cost-effective or resilient PV, wind, CHP, and battery storage options at no cost to users. Available via web tool, application programming interface (API), and open source.

NREL. "REopt Lite Web Tool." Accessed April 22, 2020. https://reopt.nrel.gov/tool.
NREL. "REopt Lite API (Version 1)." Accessed April 22, 2020. https://developer.nrel.gov/docs/energy-optimization/reopt-v1/.
GitHub. "REopt Lite API." Accessed April 22, 2020. https://github.com/NREL/REopt_Lite_API.
NREL. "REopt Lite Web Tool: Capabilities and Features." Accessed April 22, 2020. https://www.nrel.gov/docs/fy20osti/76420.pdf.

REopt API

REopt API

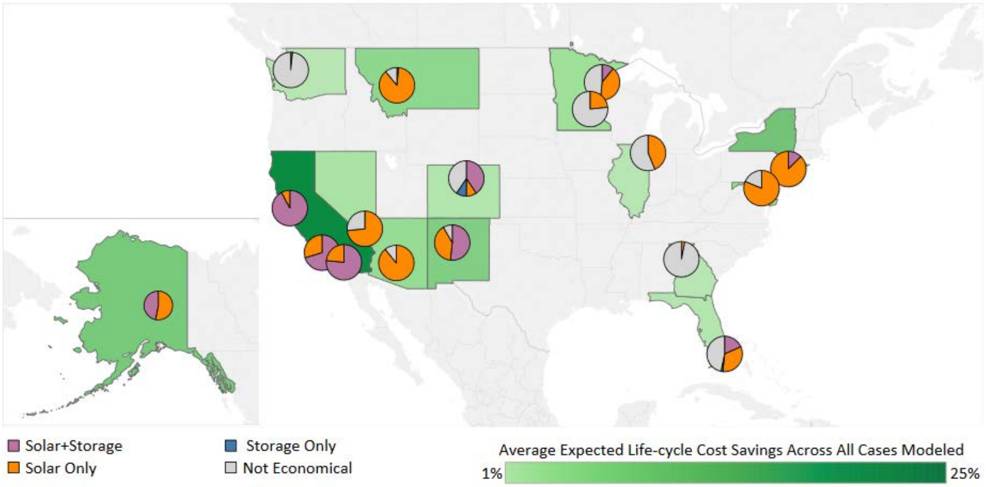
- What is an API?
  - Application Programming Interface
  - Programmatic way of accessing REopt Lite (sending and receiving data from a server)
  - File format used for sending and receiving the data: JSON.
- Advantages:
  - Multiple simulations for different sites can be run programmatically;
  - Scenario analysis can be automated; and
  - Application can be integrated with other programs.



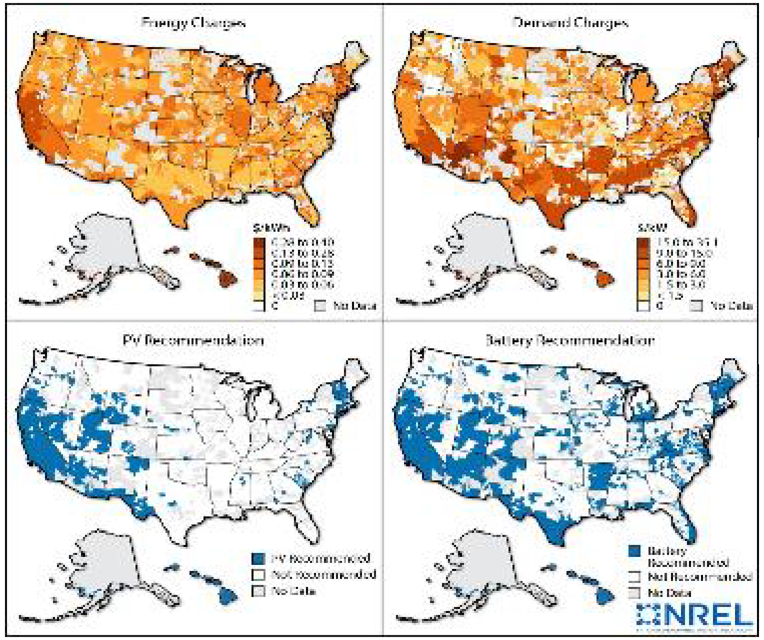
https://github.com/nrel/reopt-api-analysis/wiki

Analysis Enabled by API

- The REopt API enables national-scale analysis of storage economics and impacts on adoption/deployment.
- Analysis questions include:
  - Where in the country is storage (and PV) currently cost-effective?
  - At what capital costs is storage adopted across the United States?
  - How does varying utility rate, escalation rates, and incentive structures impact storage profitability?
  - How (and where) can stationary storage support DC-fast-charging electric vehicle economics and deployment?



Identifying Critical Factors in the Cost-Effectiveness of Solar and Battery Storage in Commercial Buildings
https://www.nrel.gov/docs/fy18osti/70813.pdf



Technology Solutions To Mitigate Electricity Cost for Electric Vehicle DC Fast Charging
https://www.sciencedirect.com/science/article/pii/S0306261919304581

REopt Development Team

- Kathleen Krah, Program Lead
- Dan Olis, Technical Lead
- Bill Becker, Development & Analysis
- Sakshi Mishra, Development & Analysis
- Sean Ericson, Analysis
- Linda Parkhill, Validation and User Support
- Hallie Dunham, Development and Analysis
- Amanda Farthing, Analysis
- Indu Manogaran, Analysis
- Doug Gagne, Analysis
- Rob Eger, UI Development
- Nick Muerdter, UI Development
- Heidi Blakely, Communications
- Andy Walker, Team Advisor

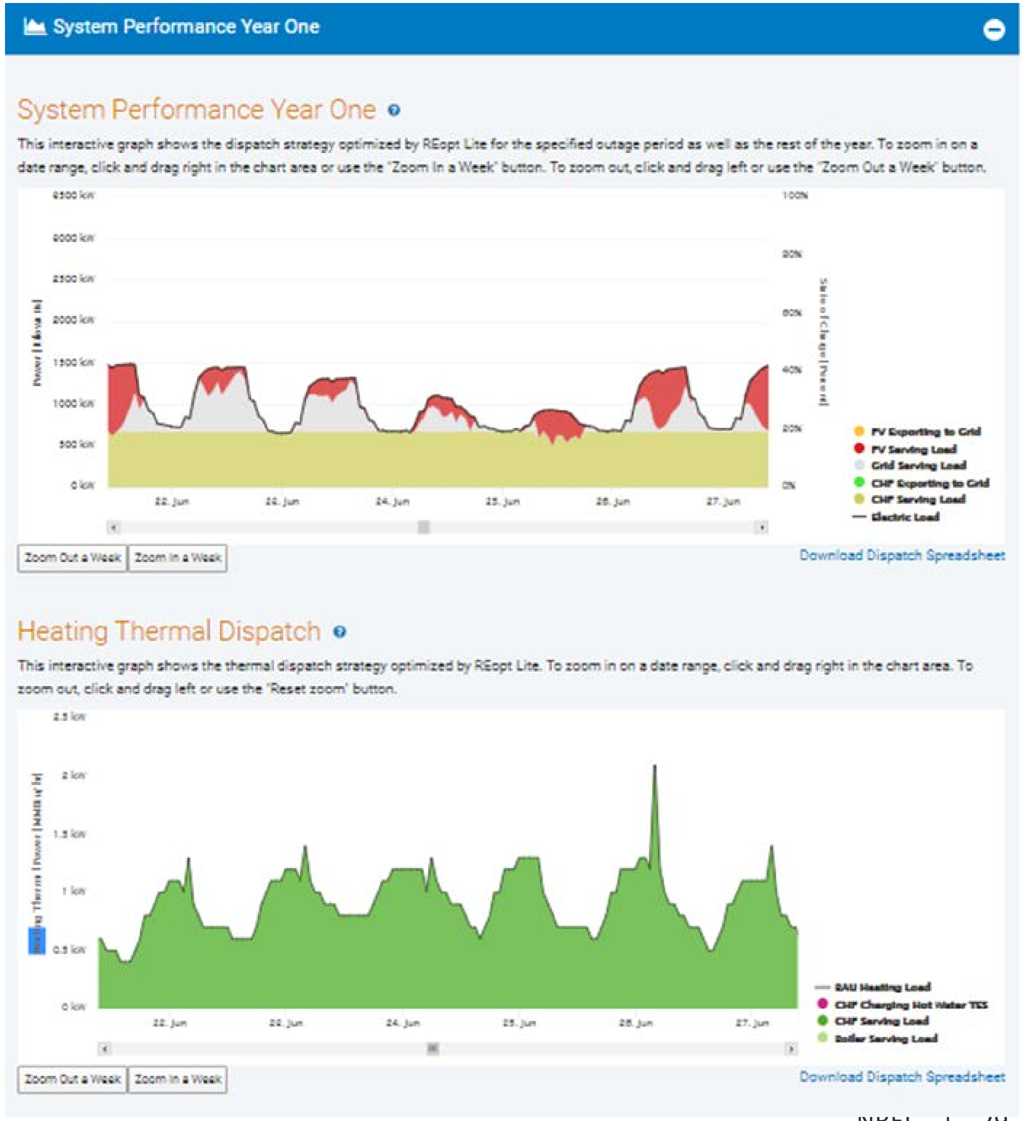
Contact: Kathleen Krah, Kathleen.Krah@nrel.gov
REopt@nrel.gov

https://reopt.nrel.gov/about/team.html

More REopt Capabilities

Thermal Technologies in REopt

- In addition to solar PV, wind power, and battery energy storage systems (BESS), REopt includes combined heat and power (CHP), geothermal heat pumps (GHP), absorption chiller, and thermal energy storage (TES)
- These enable analyses of electric and thermal loads together:
  - Simultaneously serving heating and electricity loads with CHP
  - Switching from heating with fuels to electricity with GHP
  - Switching from generating cooling with electricity to heat with an absorption chiller
  - Value of decoupling thermal loads from when the thermal energy is produced with TES

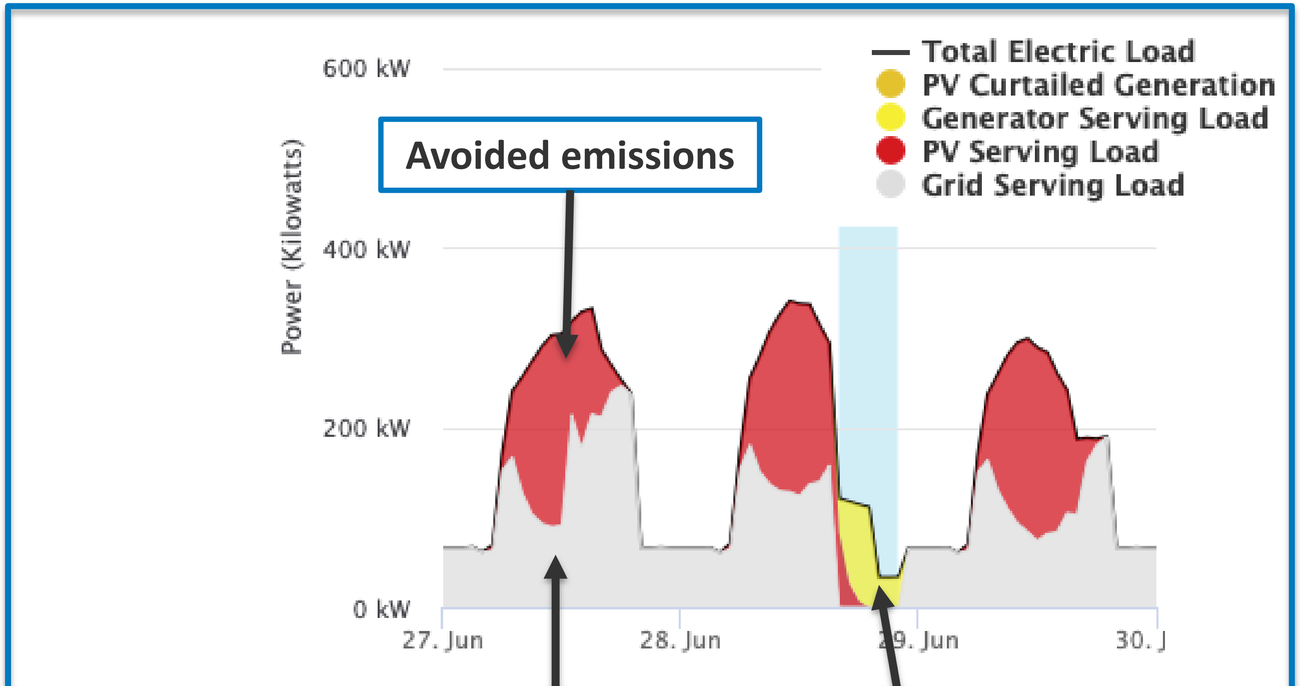


Emissions in REopt

REopt determines the emissions and emissions cost impacts of a DER investment, accounting for the hourly emissions intensity of grid electricity as well as on-site fuel consumption.

Using REopt, users can:

- Quantify **emissions changes** and the **monetary impact** of emissions reductions on **climate** (CO_2) and **health** (NOx, SO_2, PM2.5) outcomes
- Set a **climate emissions reduction target** and allow REopt to determine the cost-optimal DER investment to meet the target
- **Include climate and/or health costs within the optimization objective**, allowing these costs to impact system sizing and dispatch
- Use locational **default** emissions rates and costs or **input custom values**
- Evaluate **lifecycle** emissions, considering future "greening of the grid"



Grid emissions [tons] =
Electric grid purchases [kWh]
x
Marginal emissions intensity [ton/kWh]
of the grid (location-specific) in each hour

Fuel emissions [tons] =
Fuel burned on-site [gal]
x
Fuel emissions intensity
[ton/ gal]

Currently, REopt uses the following defaults:

Grid emissions rates: marginal rates calculated from EPA's AVERT
Grid emission rate change projections: calculated from NREL's Cambium
Climate costs: U.S. Interagency Working Group 2021 social cost of carbon
Health emissions costs: location-specific, obtained from EASIUR model

Case-Study: REopt
Terminology and Definitions

Evaluation Metrics

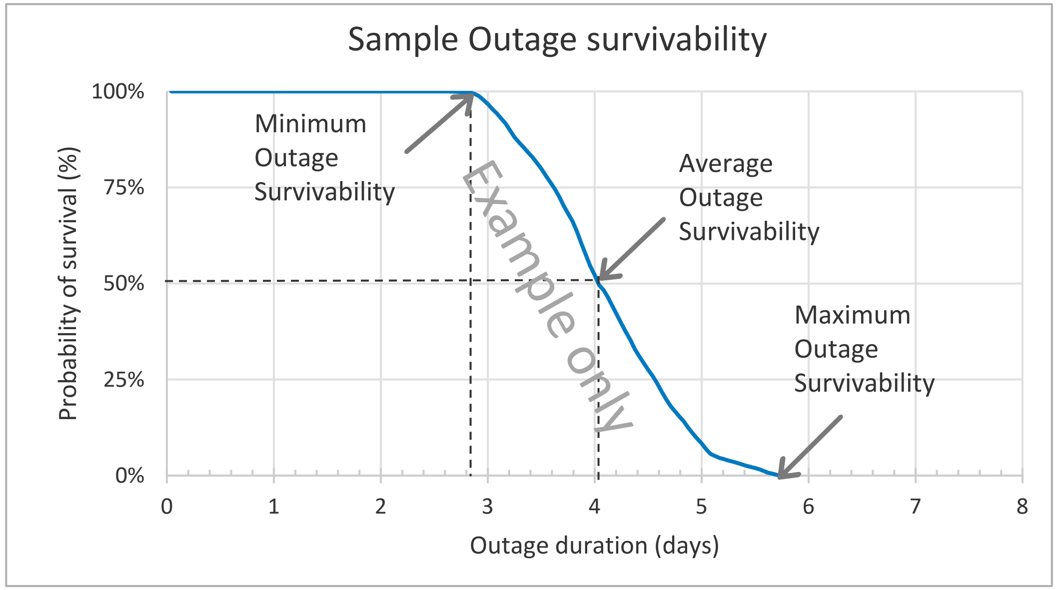
Optimal System Sizes: The least cost system sizes (backup generator size (kW), solar PV capacity (kW) and battery storage capacity (kW/kWh)) required to sustain a 3-day outage starting at facility peak load.

Life Cycle Costs (LCC, $)[1]: All costs (capital costs, O&M costs, fuel costs, utility costs) incurred by the facility, discounted over a 25-year period.

Business-As-Usual (BAU) Case: Baseline costs calculated using current loads (0% EE, no PV/BESS), existing generators, and utility rates.

Net Present Value (NPV, $): Calculated as the difference between the LCC of the scenario being considered and the LCC of BAU case. A negative NPV indicates a net investment into the system or additional costs compared to the BAU case. A positive NPV indicates net savings compared to the BAU case.

Outage Survivability Duration (days): Average outage survivability duration is a measure of resilience corresponding to a 50% probability of survival. Minimum and maximum outage survivability durations indicate durations which have a 100% and 0% probability of survival respectively.



In the sample plot of outages simulated at each hour of the year, the system can survive 100% of outages with duration 2.4 days or less, 50% of all 4-day outages, and 0% of outages with duration 5.8 days or more.

[1]LCCs do not include costs to implement EE measures. Therefore, LCCs and NPV (costs)/savings identified maybe higher/lower respectively.

More REopt Projects

Storage Sizing and Operation

Resilience and Microgrids

Integration of Flexible Loads

Electric Vehicles

Portfolio Optimization

Design Tradeoffs between Economics and Resilience

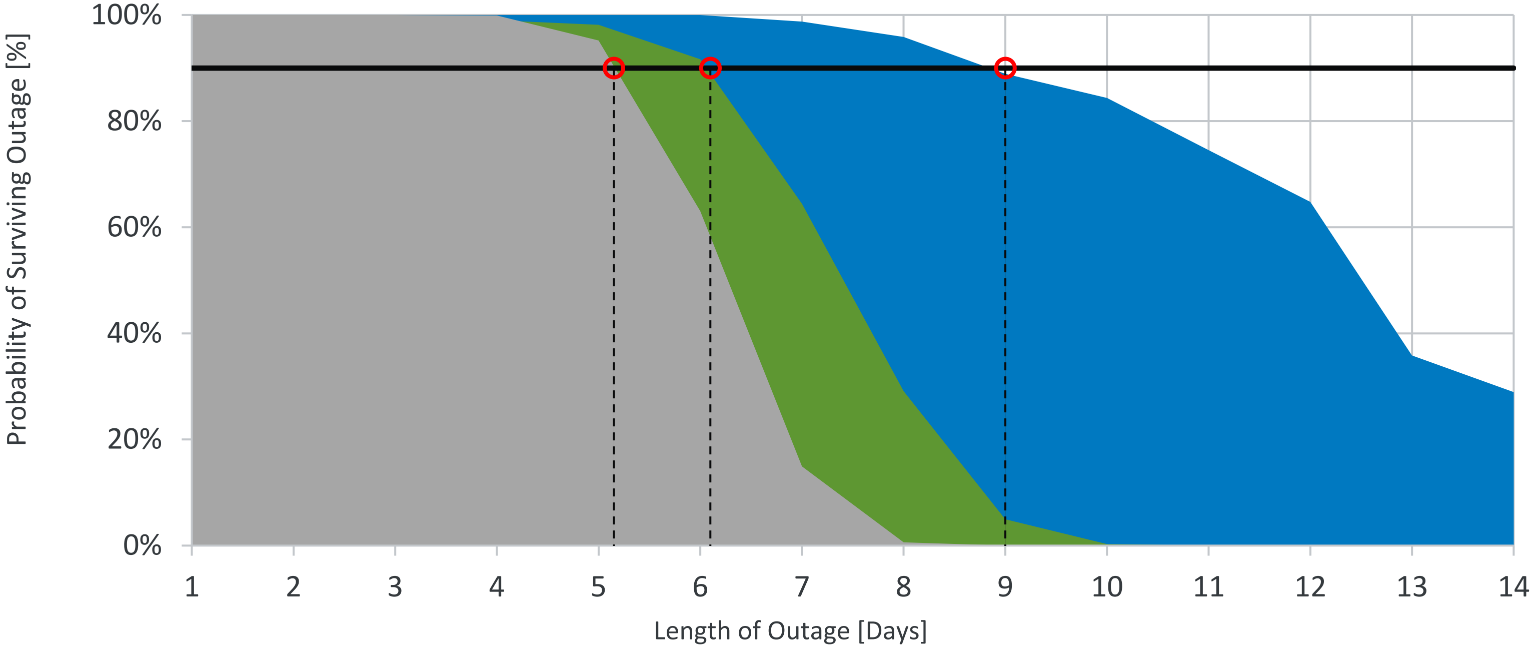
Description: NREL used REopt to evaluate how long existing and proposed backup energy systems could sustain the critical load during an outage at an Army National Guard base. REopt evaluated thousands of random grid outage occurrences and durations and compared hours survived with diesel gensets vs. gensets augmented with PV and battery.

Technology: Solar, storage, diesel generation

Impact: PV and battery can provide savings and resilience. Site can achieve 4 extra days of resilience with no added cost.

Partner: Army National Guard

	Generator	Solar PV	Storage	Lifecycle Cost	Outage
1. Base case	2.5 MW	-	-	$20 million	5 days
2. Lowest cost	2.5 MW	625 kW	175 kWh	$19.5 million	6 days
3. Proposed system	2.5 MW	2 MW	500 kWh	$20 million	9 days



Kate Anderson et al. *Increasing Resiliency Through Renewable Energy Microgrids*. Exton, PA: Journal of Energy Management. August 2017. https://www.nrel.gov/docs/fy17osti/69034.pdf.

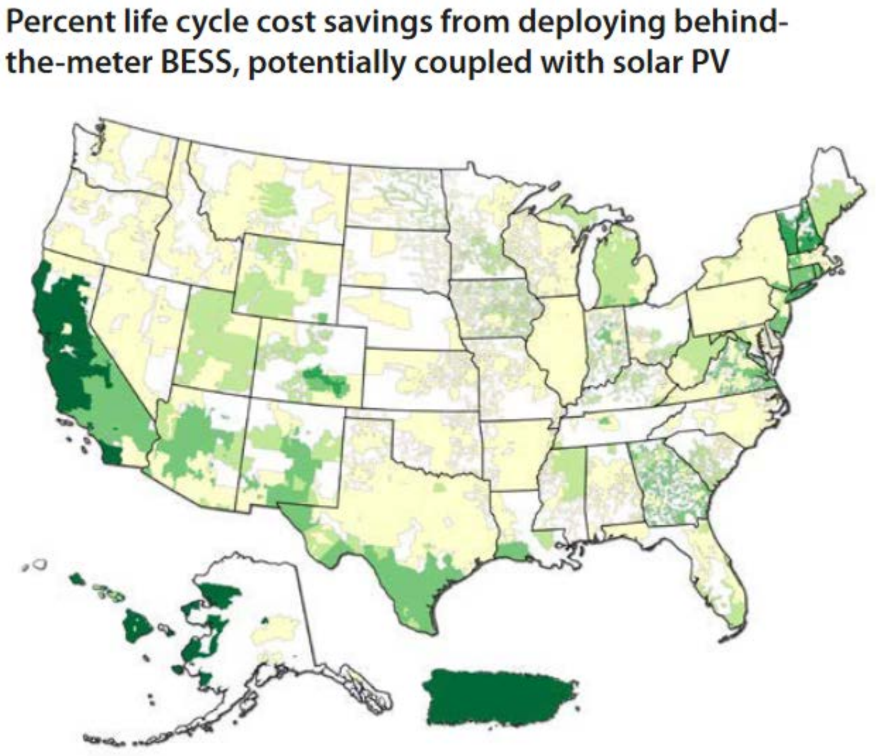
Where Does Solar and Storage Make Sense?

Description: NREL evaluated thousands of combinations of utility territories, solar resources, climate zones, and capital costs to identify scenarios where battery storage is cost-effective across the US.

Technology: Solar PV and Li-Ion battery storage

Impact: Identified cost-effective RE and microgrid projects to meet Time Warner Cable energy goals for reduced energy use, reduced energy cost, and increased resilience.

Partners: Federal Energy Management Program



This map shows where in the United States there is potential for cost savings from implementing a behind-the-meter storage system with solar PV, compared to purchasing all electricity from the utility. Areas in green indicate percent life cycle cost savings (including utility costs as well as capital and operations and maintenance costs) of the deployed systems. Areas in yellow indicate that the area was evaluated, but a system would not provide life cycle cost savings. Image from NREL

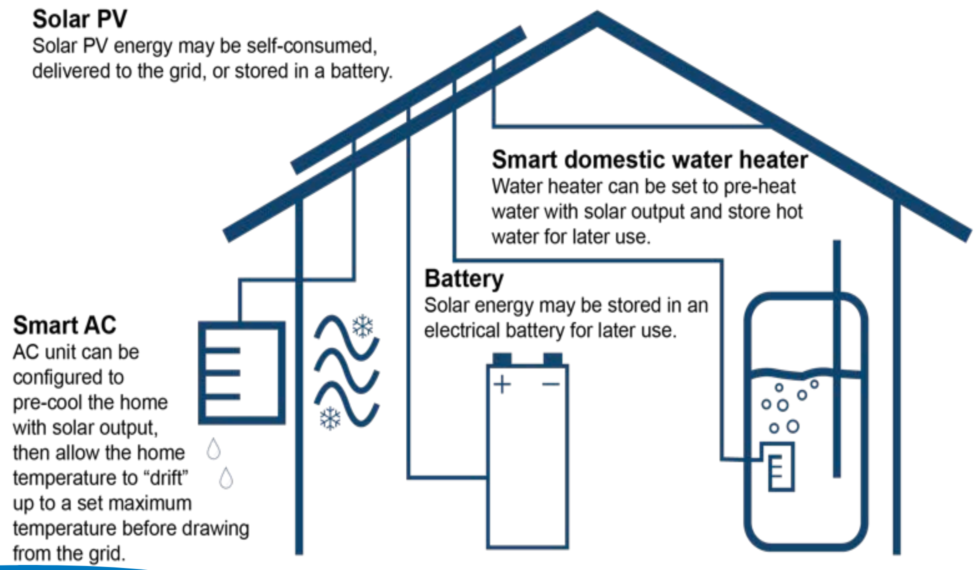
Aligning Generation and Load With Storage and Demand Flexibility

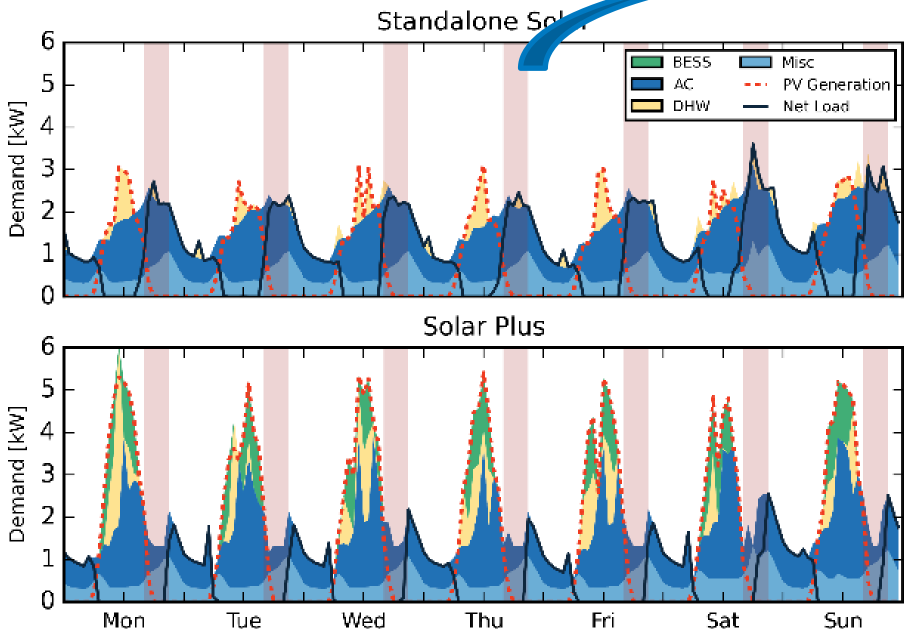
Description: NREL evaluated controllable load and storage options to improve customer economics of solar under post-net metering utility tariffs.

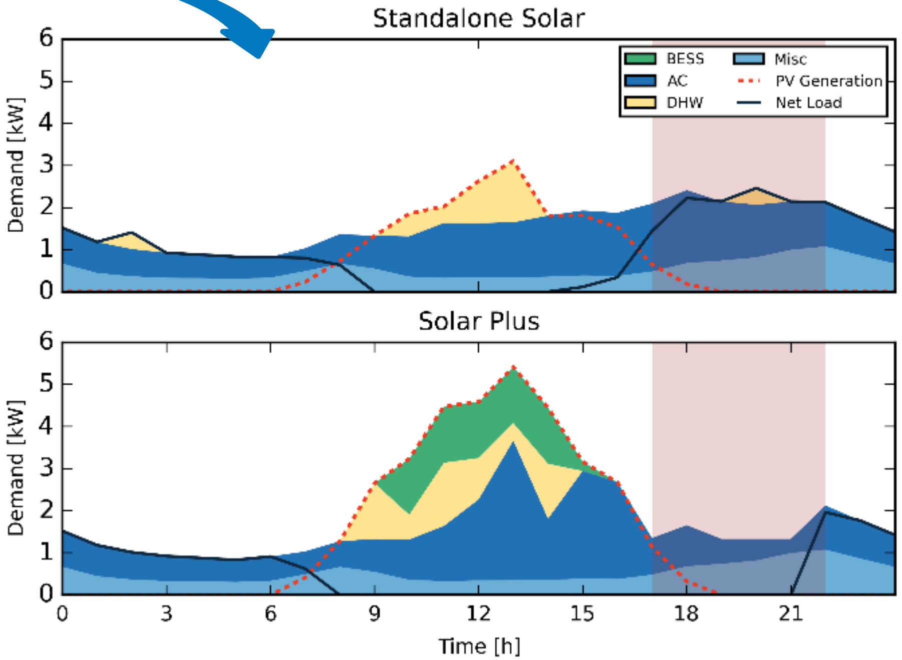
Technology: Solar, storage, buildings

Impact: Flexible loads increase the value of solar by aligning generation to load to maximize value.

Partner: DOE Solar







O'Shaughnessy, Eric, Dylan Cutler, Kristen Ardani, Robert Margolis. *Solar Plus: Optimization of Distributed Solar PV through Battery Storage and Dispatchable Load in Residential Buildings*. United Kingdom: Applied Energy, March 2018. https://doi.org/10.1016/j.apenergy.2017.12.118.

Evaluating Centralized vs. De-centralized Microgrid Options for Military Installations

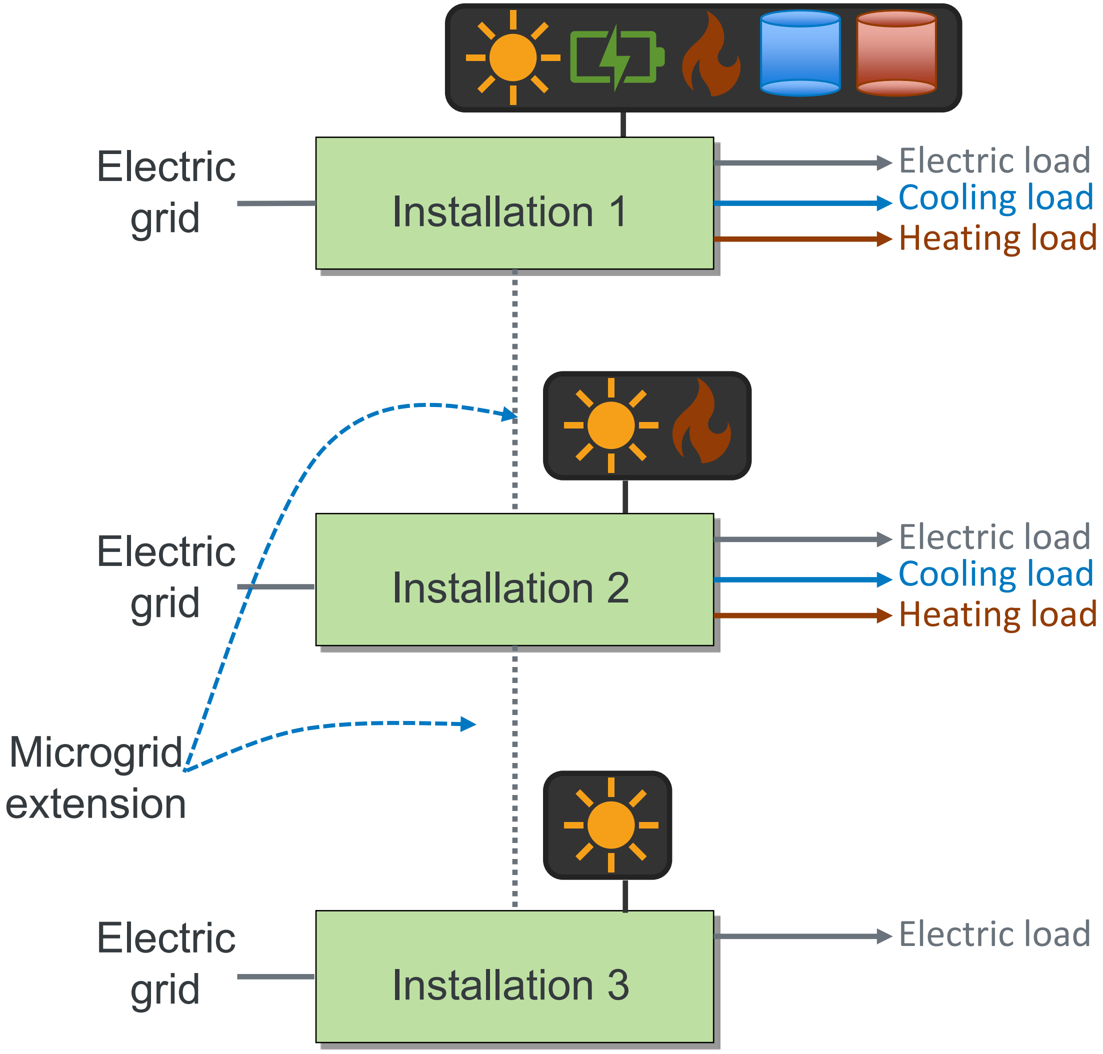
Description: NREL performed an integrated microgrid feasibility analysis for three U.S. military installations to support U.S. Army energy resilience requirements.

Technologies: Solar PV, battery storage, combined heat and power (CHP), chillers (adsorption and centrifugal), hot- and cold-water thermal storage, microgrid components

Impact: Developed conceptual design and cost estimate for integrated microgrids to provide energy cost savings and resilience across the three international U.S. military installations.

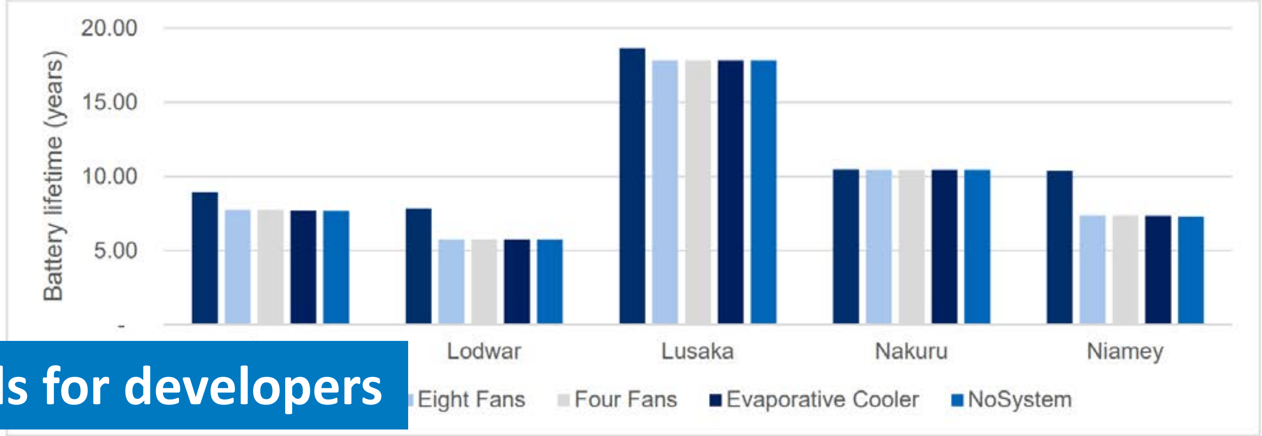
- Addressed electric vs. heat and resiliency vs. cost prioritization for CHP operation
- Resulted in successful RFP for optimized microgrid design.

Partners: United States Army Garrison Italy



NREL. "REopt Identifies and Evaluates Microgrid Options for the U.S. Army Garrison Italy." Accessed April 22, 2020. https://reopt.nrel.gov/projects/case-study-usag-italy.html.

Microgrids for Rural Energy Access In Africa



Tools for developers

Description: NREL used REopt to optimize microgrid designs for systems across sub-Saharan Africa, analyzing the impact of cost trends, technology choices, business models, and regulatory structures to identify least-cost pathways to rural electrification

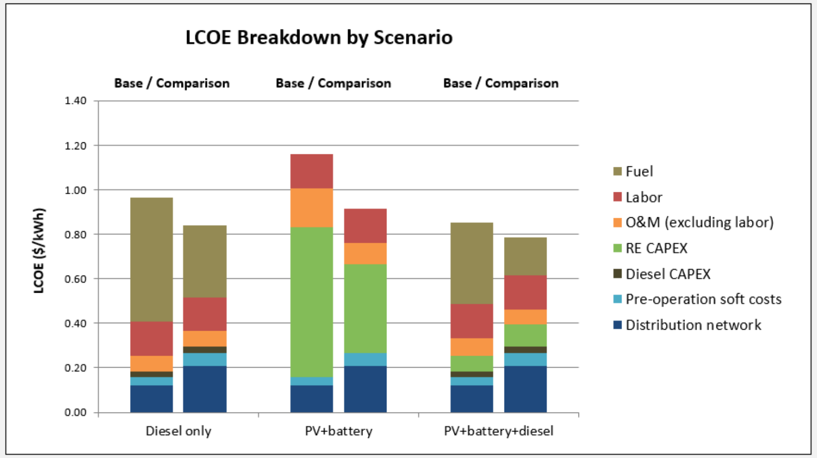
Technology: PV, li-ion and lead-acid batteries, diesel generation

Impact: Informed rural microgrid design decisions and government policies around energy access goals

Partners: USAID, AMDA, individual microgrid developers, national governments in sub-Saharan Africa

Inputs	Base Case		Comparison	
Geographical region	Lodwar, Kenya		Lusaka, Zambia	
Load profile	NREL average		Business heavy	
Percent of load served	100%		85%	
Discount rate	10%		20%	
PV/Battery Costs	High		Low	
Diesel Generator Costs	Medium		Medium	
Diesel Fuel Price	$4.40		$3.20	
Total distribution system costs	Default		Default	
Pre-operating soft costs ($/kW)	Default		Default	
Annual labor costs	Default		Default	
Annual land lease costs	Default		Default	

Assumptions		
Length of analysis	20 years	20 years
Average solar resource (GHI)	6.1 kWh/m2/day	5.3 kWh/m2/day
Installed PV cost [$/kW]	$2,200	$1,400
PV O&M [$/kW]	$44	$28
Useful life	20 years	20 years
Battery storage cost [$/kWh]	$500	$300
Battery useful life	7 years	7 years
Inverter and BOS costs [$/kW]	$1,200	$600
Inverter replacement cost [$/kW]	$600	$300
Battery O&M [$/kWh-installed]	$30	$20
Inverter useful life	10 years	10 years
Diesel genset cost [$/kW]	$400	$400
Useful life	10 years	10 years
Fuel consumption rate [kWh/gal]	10	10
Fuel cost [$/gallon]	$4.40	$3.20
Fuel escalation rate	3%	3%
Total distribution system costs	$20,000	$20,000
Pre-operating soft costs [$/kW]	$1,200	$1,200
Annual labor costs [$/year]	$3,000	$3,000
Annual land lease costs [$/year]	$800	$800



RESULTS SUMMARY	Base case			Comparison		
	Diesel only	**PV+battery**	**PV+battery+diesel**	**Diesel only**	**PV+battery**	**PV+battery+diesel**
PV size	0 kW	27.9 kW	5.5 kW	0 kW	16.8 kW	6.7 kW
Battery size	0 kWh	49 kWh	0 kWh	0 kWh	30.1 kWh	0 kWh
Inverter size	0 kW	5.7 kW	0 kW	0 kW	4 kW	0 kW
Diesel generator size	7 kW	0 kW	7 kW	6 kW	0 kW	6 kW
Total life-cycle cost	$161,800	$194,595	$143,244	$80,557	$87,700	$75,329
Total CAPEX	$30,732	$139,283	$42,898	$28,500	$63,976	$37,881
Total OPEX	$131,068	$55,313	$100,346	$52,057	$23,724	$37,447
LCOE	**$0.96**	**$1.16**	**$0.85**	**$0.84**	**$0.91**	**$0.78**

Eric Lockhart et al. *Comparative Study of Techno-Economics of Lithium-Ion and Lead-Acid Batteries in Micro-Grids in Sub-Saharan Africa*. Golden, CO: NREL. June 2019. https://www.nrel.gov/docs/fy19osti/73238.pdf.

Tim Reber et al. *Tariff Considerations for Micro-Grids in Sub-Saharan Africa*. Golden, CO: NREL. February 2018. https://www.nrel.gov/docs/fy18osti/69044.pdf.

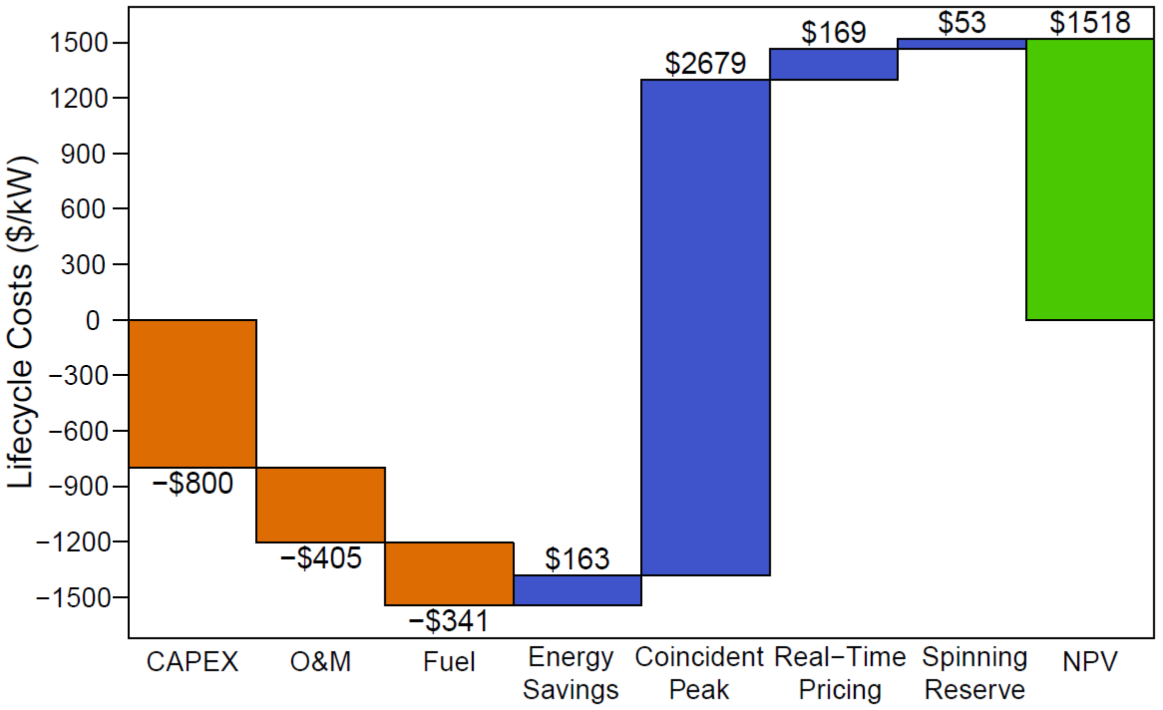
Market Revenues for Backup Generators

Description: NREL evaluated the value backup generators can provide when used for grid-connected economic dispatch. NREL considered potential revenues from tariff switching, peak shaving, energy self-generation, coincident peak reduction, wholesale real-time pricing, spinning reserve markets, and emergency standby programs.

Technology: Natural gas and diesel generators

Impact: The overall cost of back-up generation can be lowered, but opportunities vary across the United States, depending on markets.

Partner: Enchanted Rock



Life cycle costs and revenues ($/kW) for diesel generator providing grid services in Camden, NJ

Generator Type	Diesel			Natural Gas		
Region	TX	FL	NJ	TX	FL	NJ
CAPEX + O&M ($/kW)	-$1,205			-$1,405		
Revenues/savings ($kW)	$968	$1,380	$3,064	$1,091	$1,380	$3,153
Fuel cost for ($/kW)	-$187	$0	-$341	-$199	$0	-$272
NPV ($/kW)	-$425	$175	$1,518	-$513	-$25	$1,476

Net present values by region and by fuel type

Ericson, Sean and Dan Olis. *A Comparison of Fuel Choice for Backup Generators*. Golden, CO: NREL. March 2019. https://www.nrel.gov/docs/fy19osti/72509.pdf

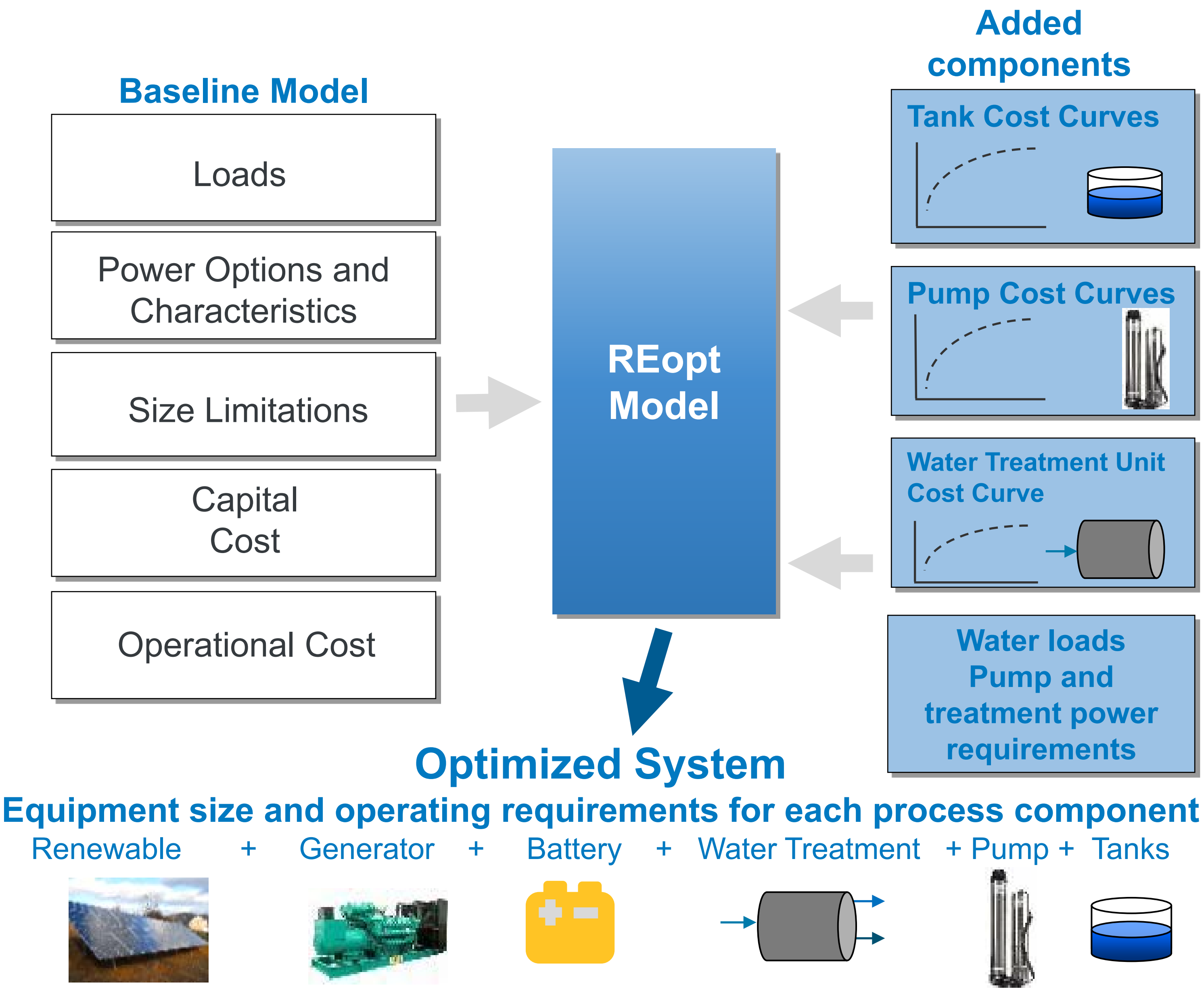
Optimizing Off-Grid Water Treatment and Storage

Description: NREL optimized an off-grid water treatment and storage system on Navajo lands.

Technologies: PV, diesel generator, storage, water treatment and storage

Impact: Identified opportunities to reduce battery size and fuel use by flexing pumping loads and using storage inherent in water tank.

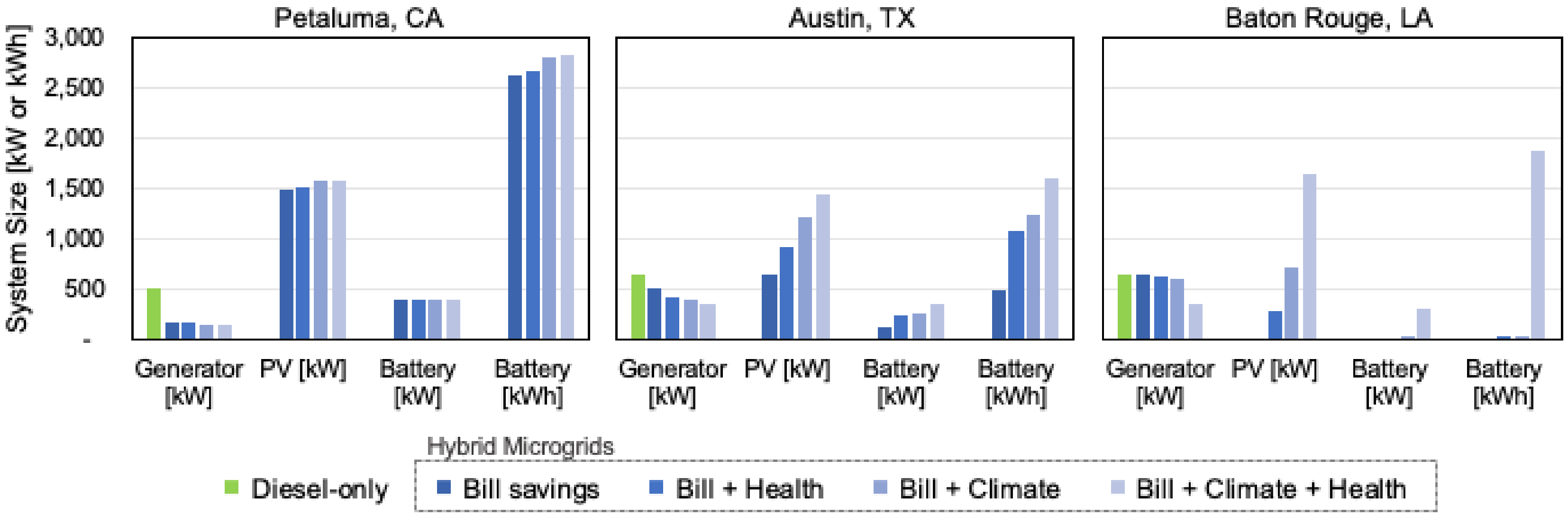
Partner: U.S. Bureau of Reclamation



NREL. "REopt Modeling Informs Design of Off-Grid Water System Under Study for Navajo Nation." Accessed April 22, 2020. https://reopt.nrel.gov/projects/case-study-usbr.html.

Looking Beyond Bill Savings to Equity in Microgrid Deployment

Cost-optimal system sizes across locations and optimization scenarios. Smaller diesel generators and larger PV and storage systems become cost-optimal as health and climate costs are incrementally included within the lifecycle cost calculation.



- **Description:** The value of microgrids is often measured by the economic savings and resilience; here we quantifying broader costs and benefits including utility bill savings, value of resilience, social cost of carbon, public health costs, and jobs associated with the construction and operation of microgrids.
- **Technology:** Solar PV, battery storage, diesel generators
- **Impact:** When climate, health, resilience, and job creation are considered, cost-optimal microgrids include more renewable generation, leading to a 52-82% reduction in emissions and diesel fuel use. The net present values of the grow by $10-16 million, indicating potential for greater microgrid deployment if energy justice values are incorporated in decision making. These findings may be useful to communities as they seek to strengthen resilience to natural disasters while also improving public health, meeting climate goals, and providing economic opportunity for residents.
- **Partners:** Federal Energy Management Program

Kate Anderson, Amanda Farthing, Emma Elgqvist, Adam Warren, “Looking Beyond Bill Savings to Equity in Renewable Energy Microgrid Deployment”, Submitted to *Renewable Energy Focus* journal

Balancing Cost and Resilience with Combined Heat and Power (CHP) at Wastewater Treatment Facility

Northside Wastewater Treatment Plant. Source: CFPUA

Description: NREL evaluated opportunities for CHP and other DERs to provide cost savings and resilience benefits to the Northside wastewater treatment plant, a critical infrastructure susceptible to power outages.

Technology: CHP fueled by free on-site biogas and natural gas, diesel generator, solar PV, battery storage

Impact: Building a hybrid CHP-PV-storage system reduces lifecycle cost of energy for the site by 3% ($301,000 over 25 years). If load can be reduced during the outage by storing and deferring wastewater treatment, required system sizes and costs decrease. 60% of the load can be met in the No-Diesel scenario, and 80-85% in the CHP-Only or All-Technologies scenario, at no additional lifecycle cost compared to the business-as-usual no-outage case.

Partners: DOE Advanced Manufacturing Office