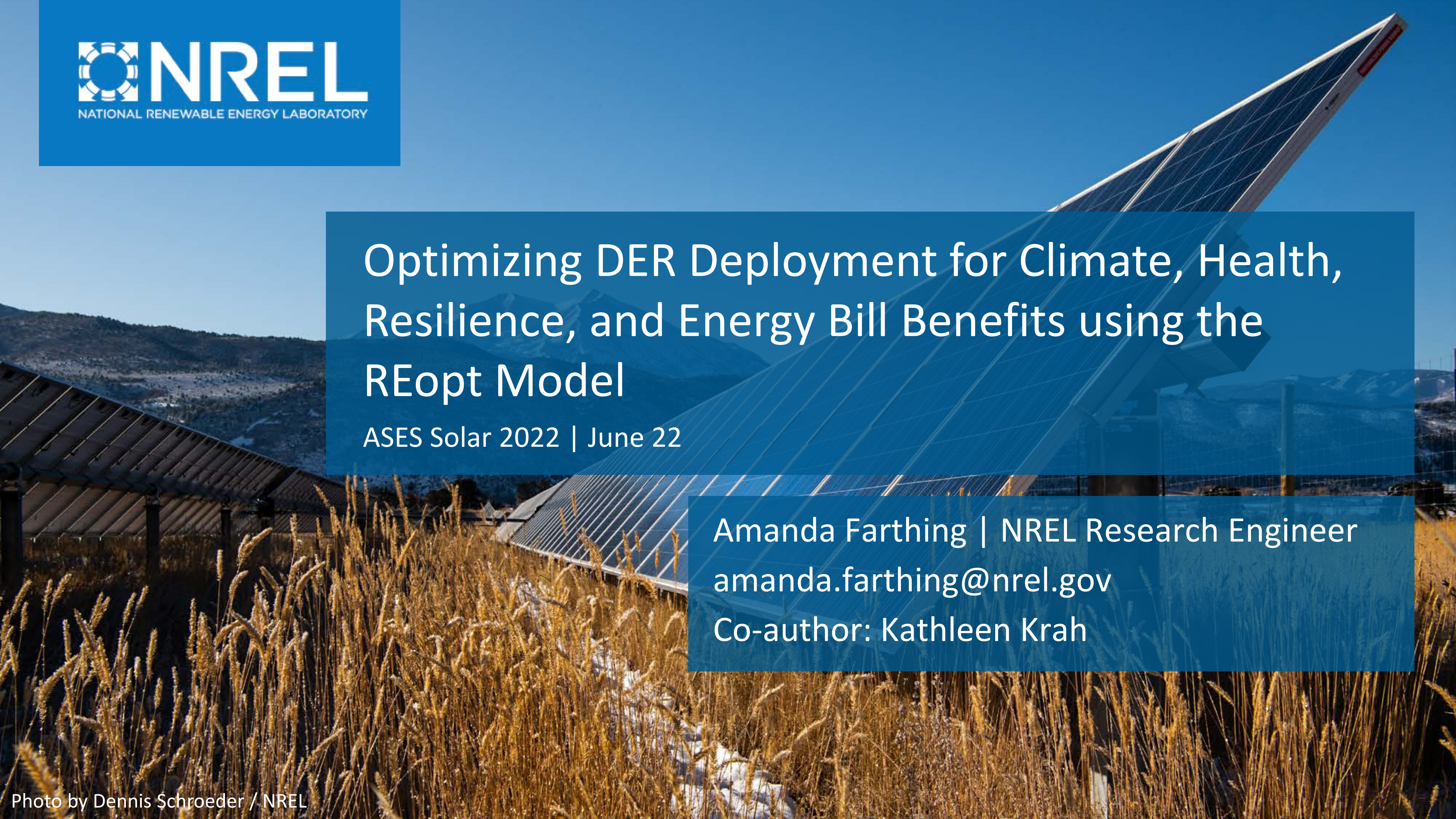


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

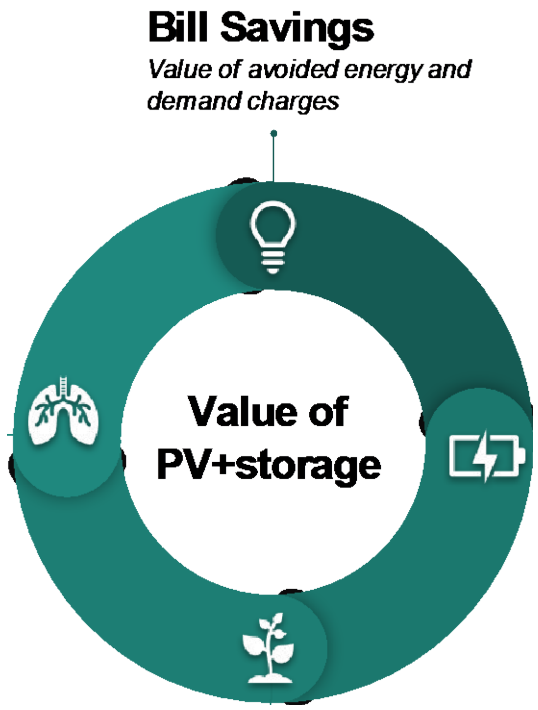
Optimizing DER Deployment for Climate, Health, Resilience, and Energy Bill Benefits using the REopt Model

ASES Solar 2022 | June 22

Amanda Farthing | NREL Research Engineer
amanda.farthing@nrel.gov
Co-author: Kathleen Krah

Photo by Dennis Schroeder / NREL

More entities are looking beyond the energy bill



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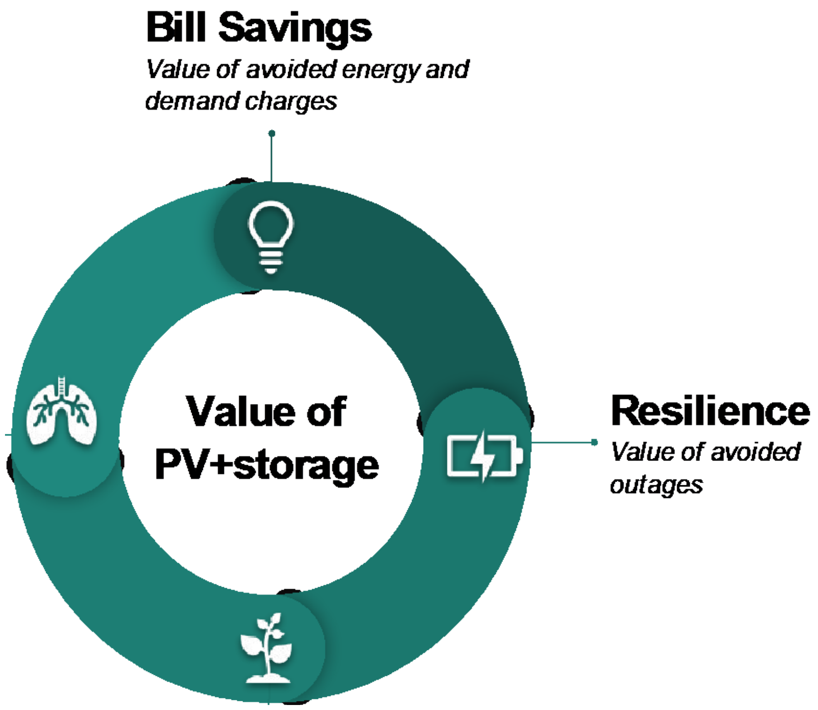
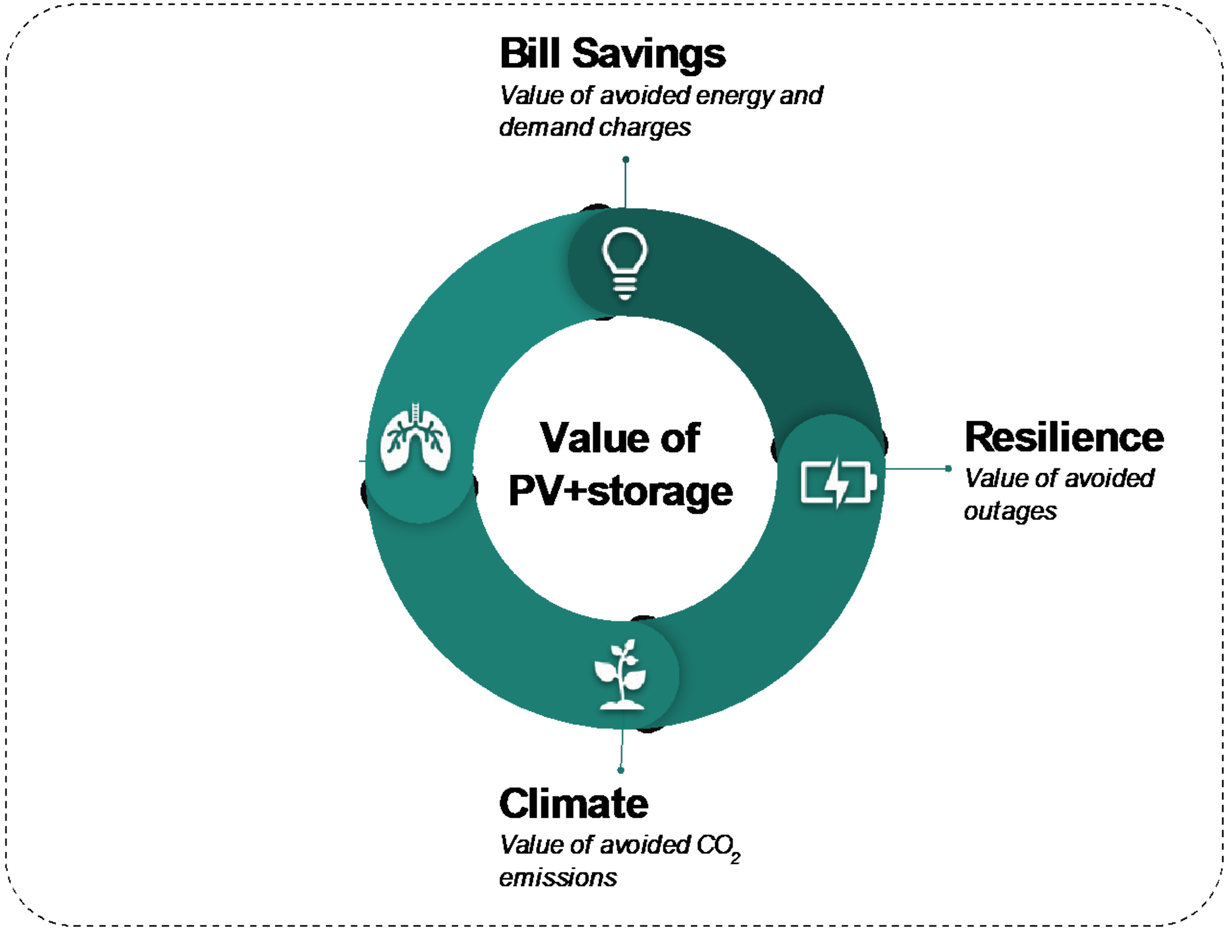


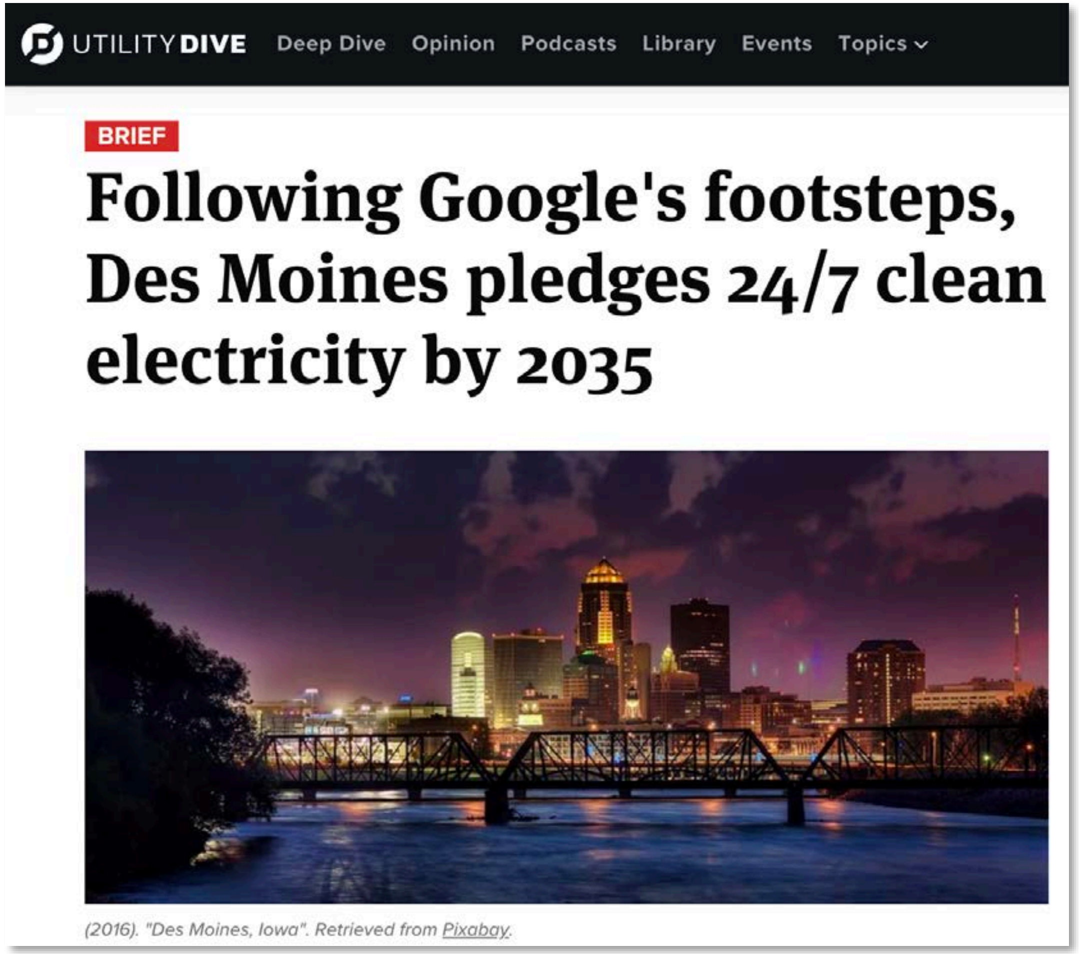
This DC apartment building provides low-income families with solar power and a resilience center

SUSTAINABILITY By Natasha Riddle (Fellow) June 27, 2019 16

Riddle (2019)

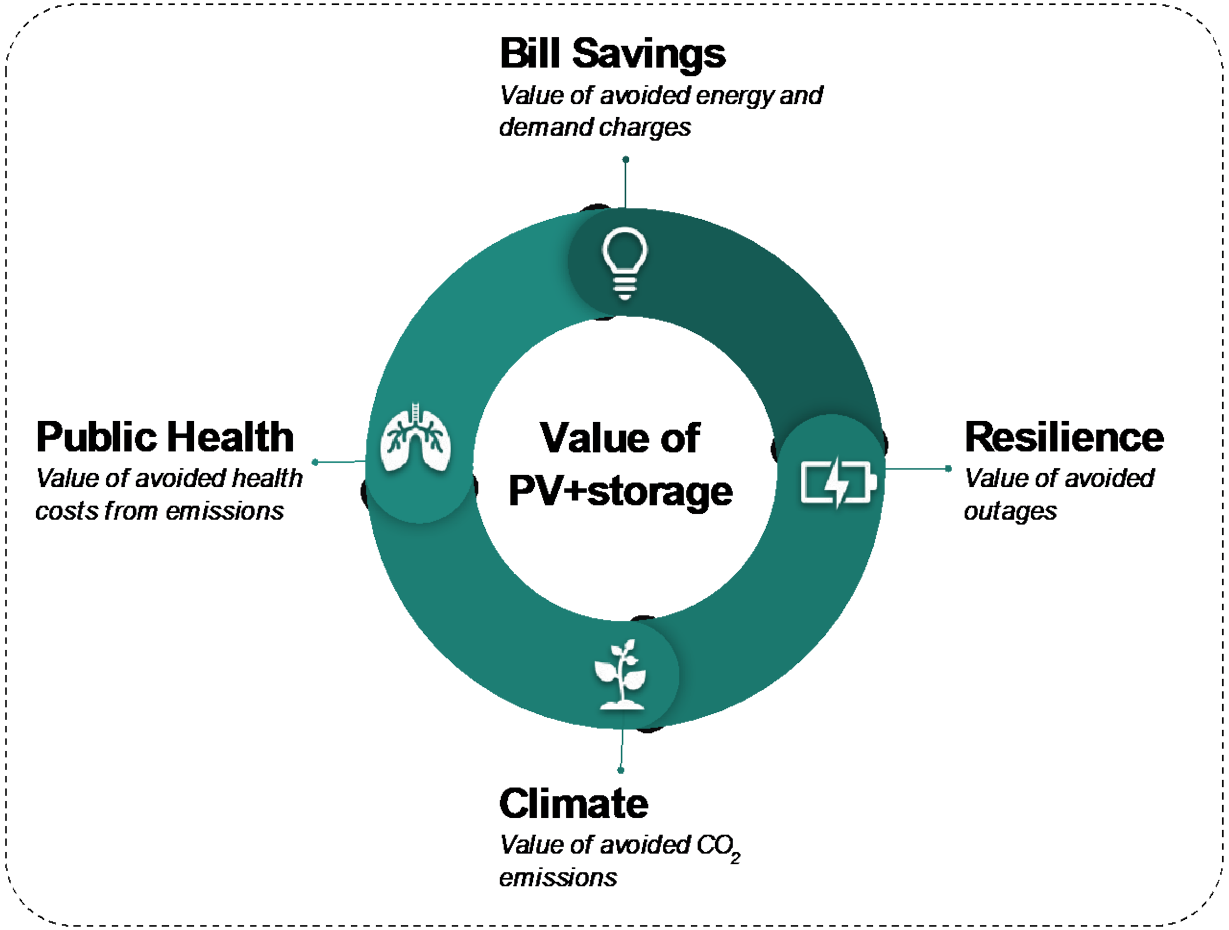
More entities are looking beyond the energy bill

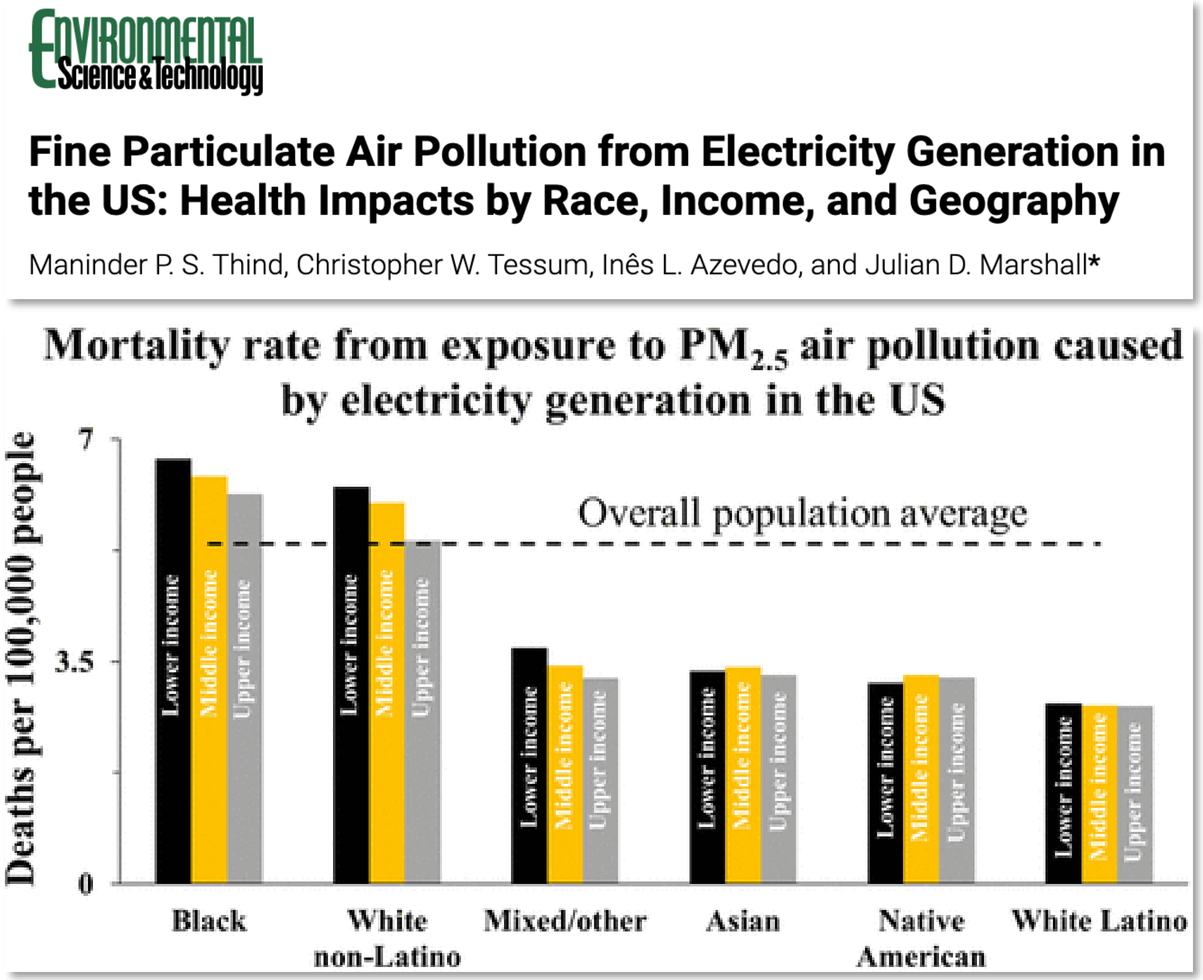




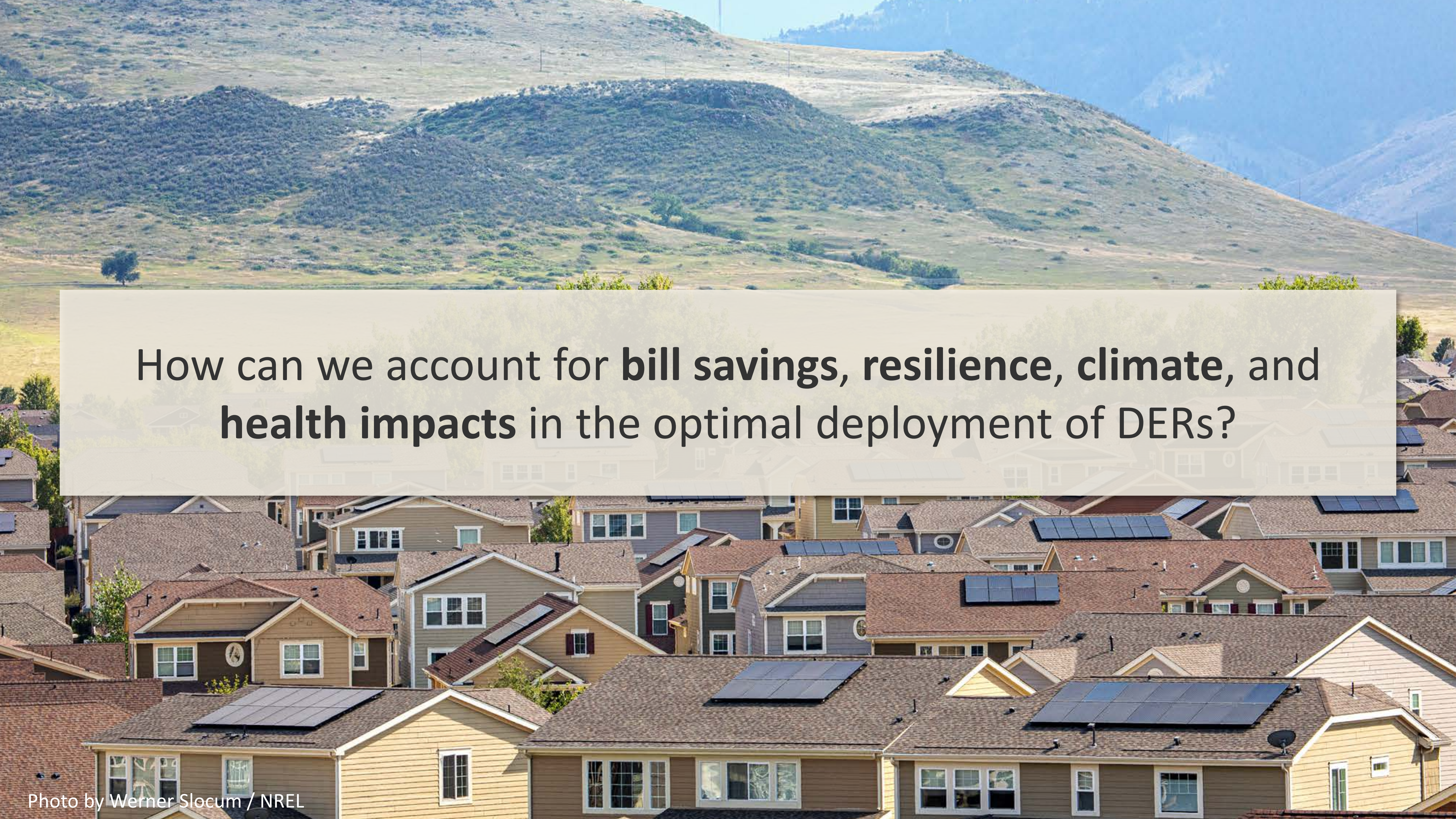
Penrod (2021)

More entities are looking beyond the energy bill





Thind, et al. (2019)



How can we account for **bill savings**, **resilience**, **climate**, and **health impacts** in the optimal deployment of DERs?

Photo by Werner Slocum / NREL

REopt Energy Planning Platform

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

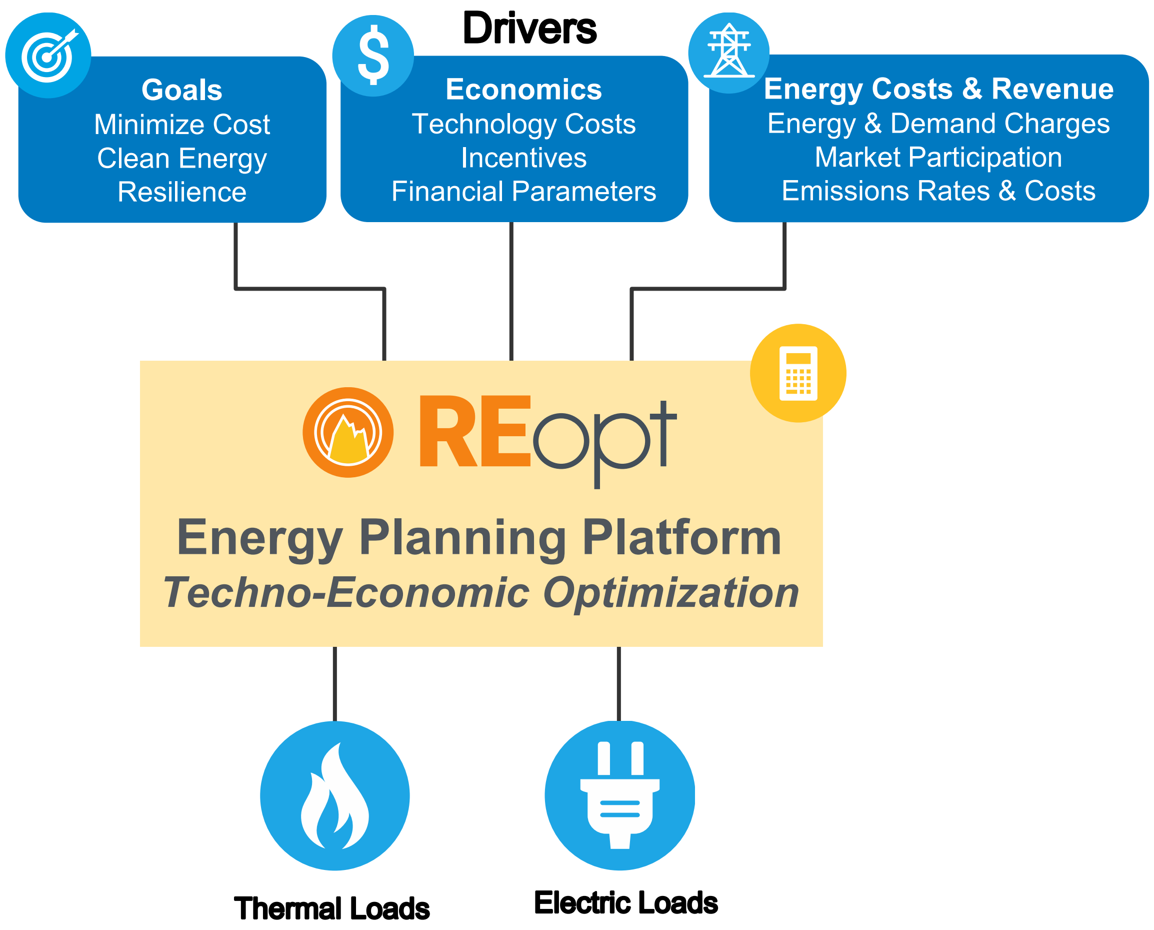
REopt

Energy Planning Platform

Techno-Economic Optimization

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.

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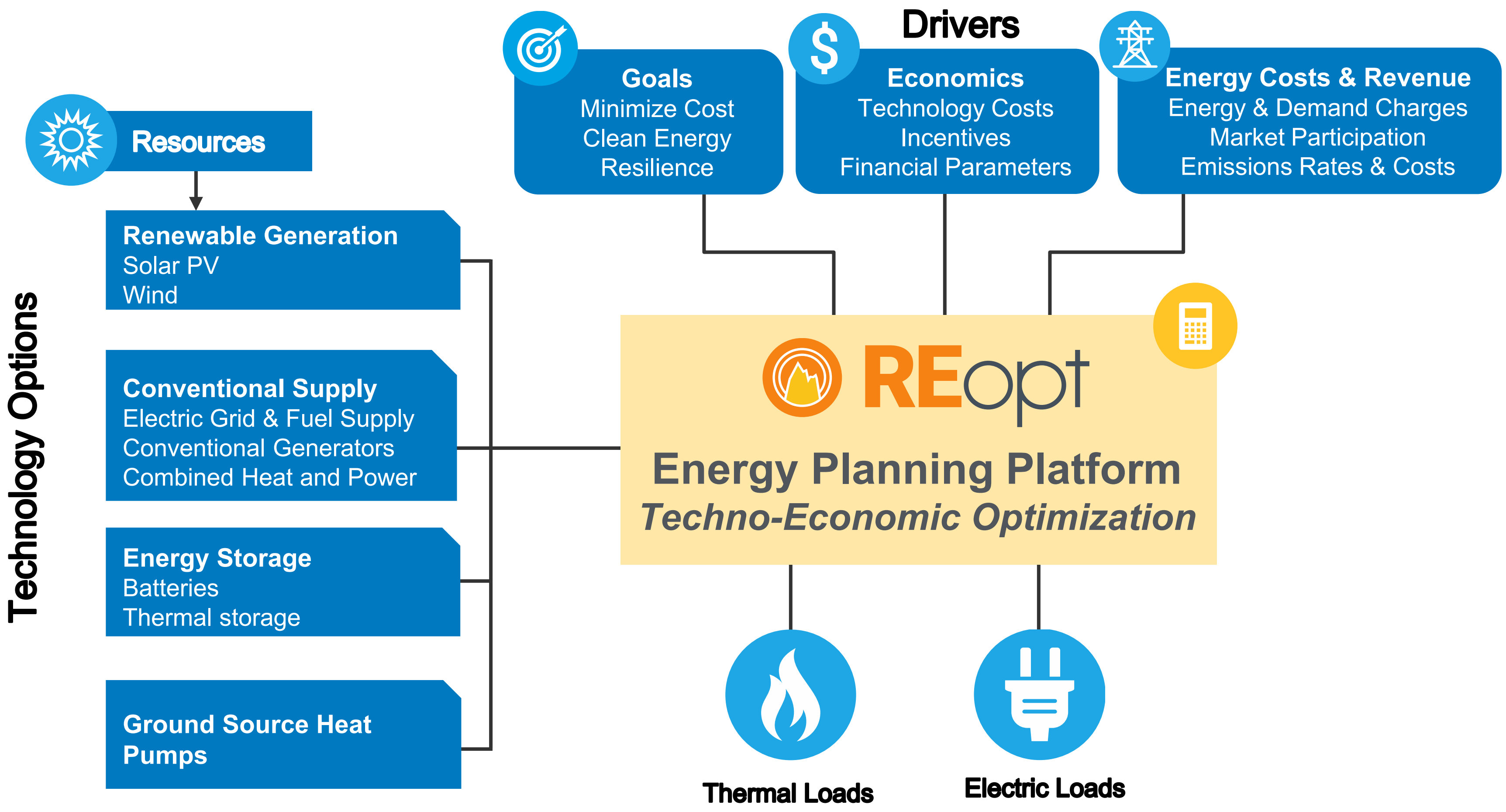

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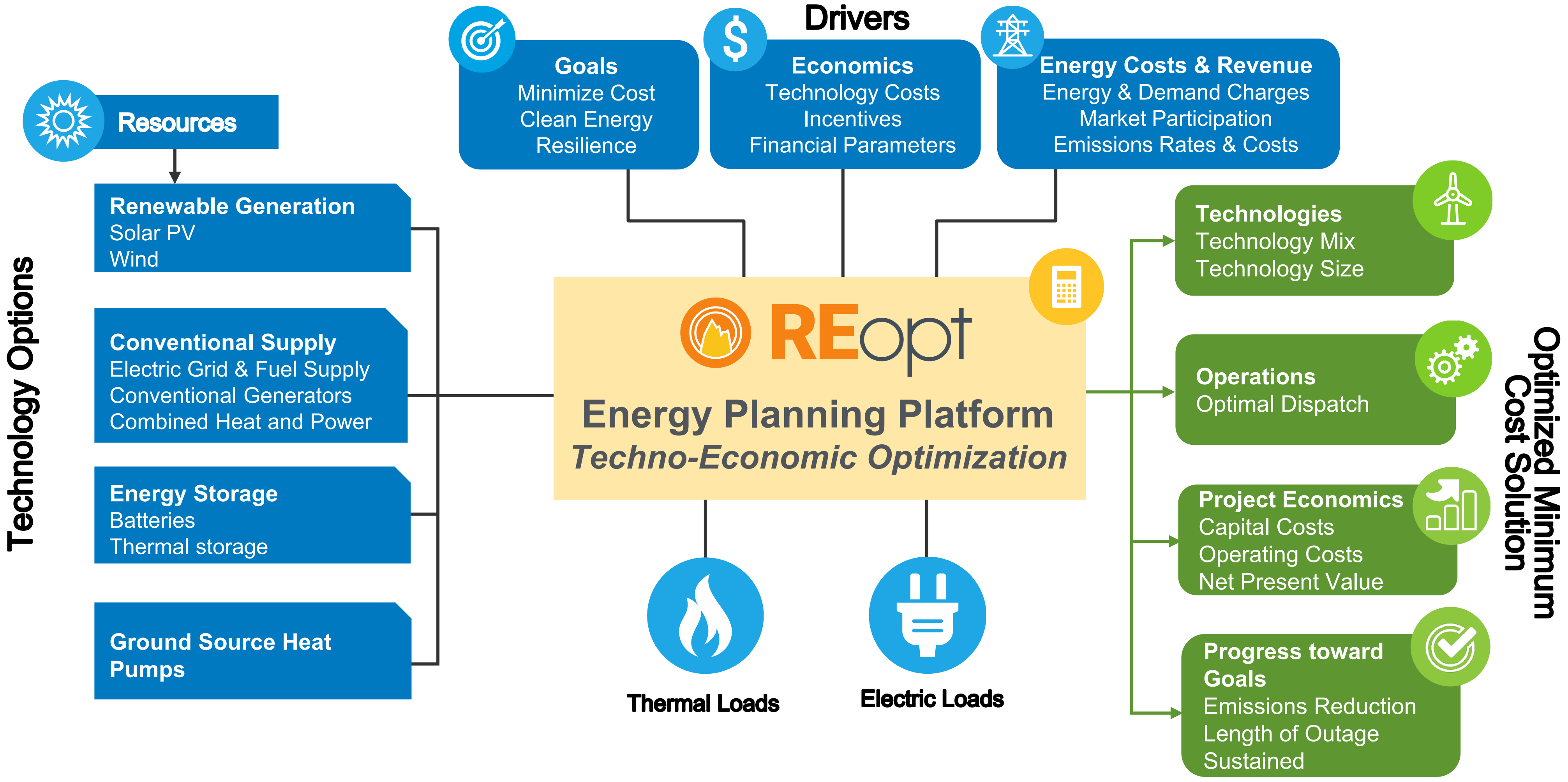

Note some capabilities were developed for specific projects only.

REopt Formulation

REopt is a mixed-integer linear program.

Objective: $minimize\ LCC = C_{cap} + C_{O\&M} + C_{utility} + C_{fuel}$

Life cycle costs | Capital costs | Operations & maintenance | Electricity bill | Fuel

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Life cycle costs | Capital costs | Operations & maintenance | Electricity bill | Fuel | Climate emissions costs | Health emissions costs | Net outage costs

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Life cycle costs | Capital costs | Operations & maintenance | Electricity bill | Fuel | Climate emissions costs | Health emissions costs | Net outage costs

Main decision variables: System sizes, system dispatch

Constraints:

- Load balancing (load met in each timestep)
- Critical loads met during outage
- Technologies' operational constraints
- Available resource (e.g., solar irradiance)
- Utility-related constraints (e.g., limited exports)
- Fuel availability

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- LCC: Life cycle costs
- C_{cap}: Capital costs
- $C_{O\&M}$: Operations & maintenance
- $C_{utility}$: Electricity bill
- C_{fuel}: Fuel
- $C_{climate}$: Climate emissions costs
- C_{health}: Health emissions costs
- C_{outage}: Net outage costs

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Constraints:
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- Utility-related constraints (e.g., limited exports)
- Fuel availability

Net Present Value (NPV)

$$= LCC_{BAU} - LCC_{opt}$$

- LCC_{BAU}: "Business-as-usual" costs; with existing DERs or just grid electricity
- LCC_{opt}: With suggested DERs

For the full formulation, refer to the REopt User Manual

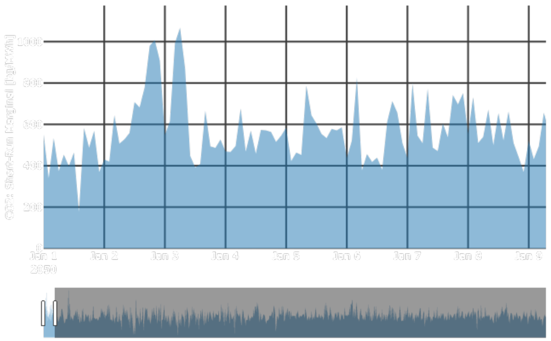
Calculating costs

Emissions cost = Marginal emissions rates (MERs) [t /kWh] * Marginal emissions cost [$/t]

Calculating costs

Emissions cost = Marginal emissions rates (MERs) [t /kWh] * Marginal emissions cost [$/t]

Climate cost = CO_2 MERs [t/kWh] * CO_2 cost [$/t]



- **Source:** EPA's AVERT[1]
- **Type:** Hourly, short-run marginal emissions rates
- **Scale:** 14 regions, continental U.S.
- Projected annual decrease from NREL's Cambium[2]

- Social Cost of Carbon (SC-CO_2)
- Source: U.S. Gov[3]
- $51/t ($2020)

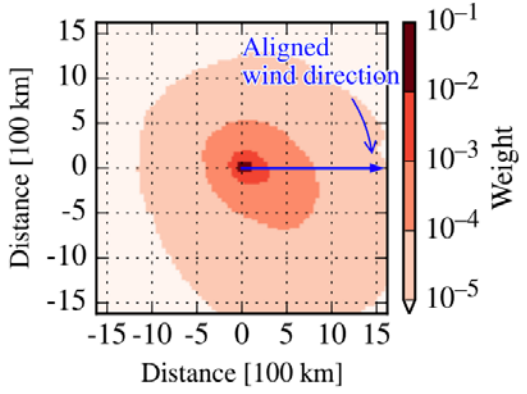
[1]https://www.epa.gov/avert | [2]https://scenarioviewer.nrel.gov | [3]White House Technical Support Document

Calculating costs

Emissions cost = Marginal emissions rates (MERs) [t /kWh] * Marginal emissions cost [$/t]

Climate cost = CO_2 MERs [t/kWh] * CO_2 cost [$/t]

Health cost = $\sum_{NOx,\ SO_2,\ PM2.5}$ MERs [t/kWh] * Health cost [$/t]



(Heo 2017)

- **Source:** EPA's AVERT[1]
- **Type:** Hourly, short-run marginal emissions rates
- **Scale:** 14 regions, continental U.S.
- Projected annual decrease from NREL's Cambium[2]

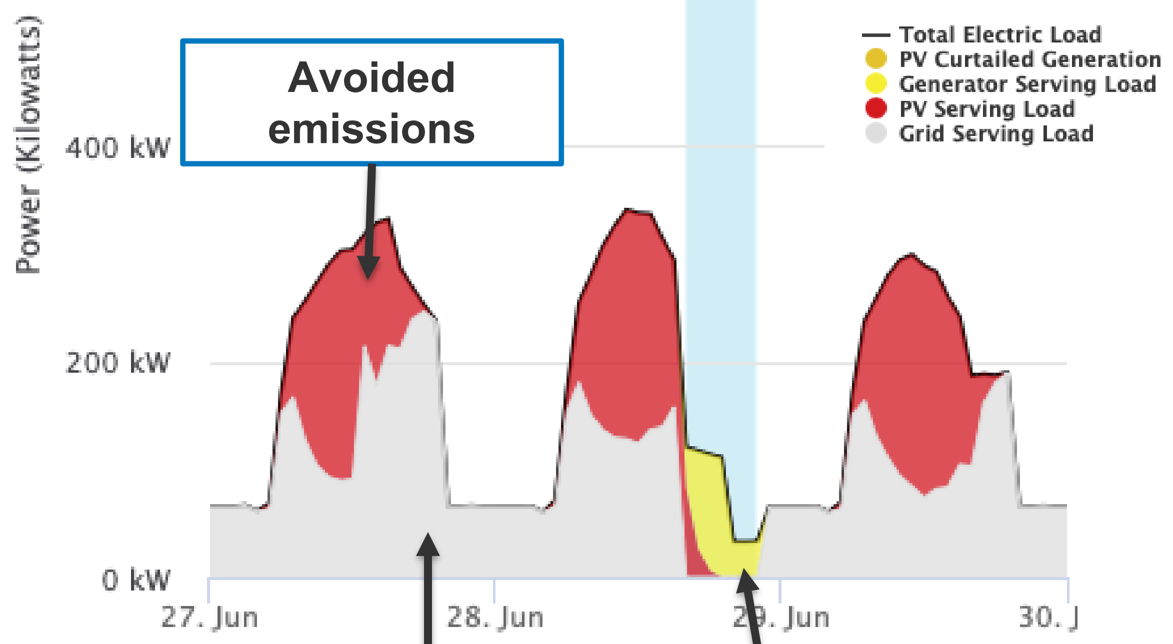
- Source: EASIUR[2] (reduced-form air quality model)
- Location-specific marginal health costs
- Considers **impact of ambient PM2.5 on mortality**

[1]https://www.epa.gov/avert | [2]https://barney.ce.cmu.edu/~jinhyok/easiur/

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.

Emissions impact = BAU emissions (tons and $) – Optimized emissions (tons and $)

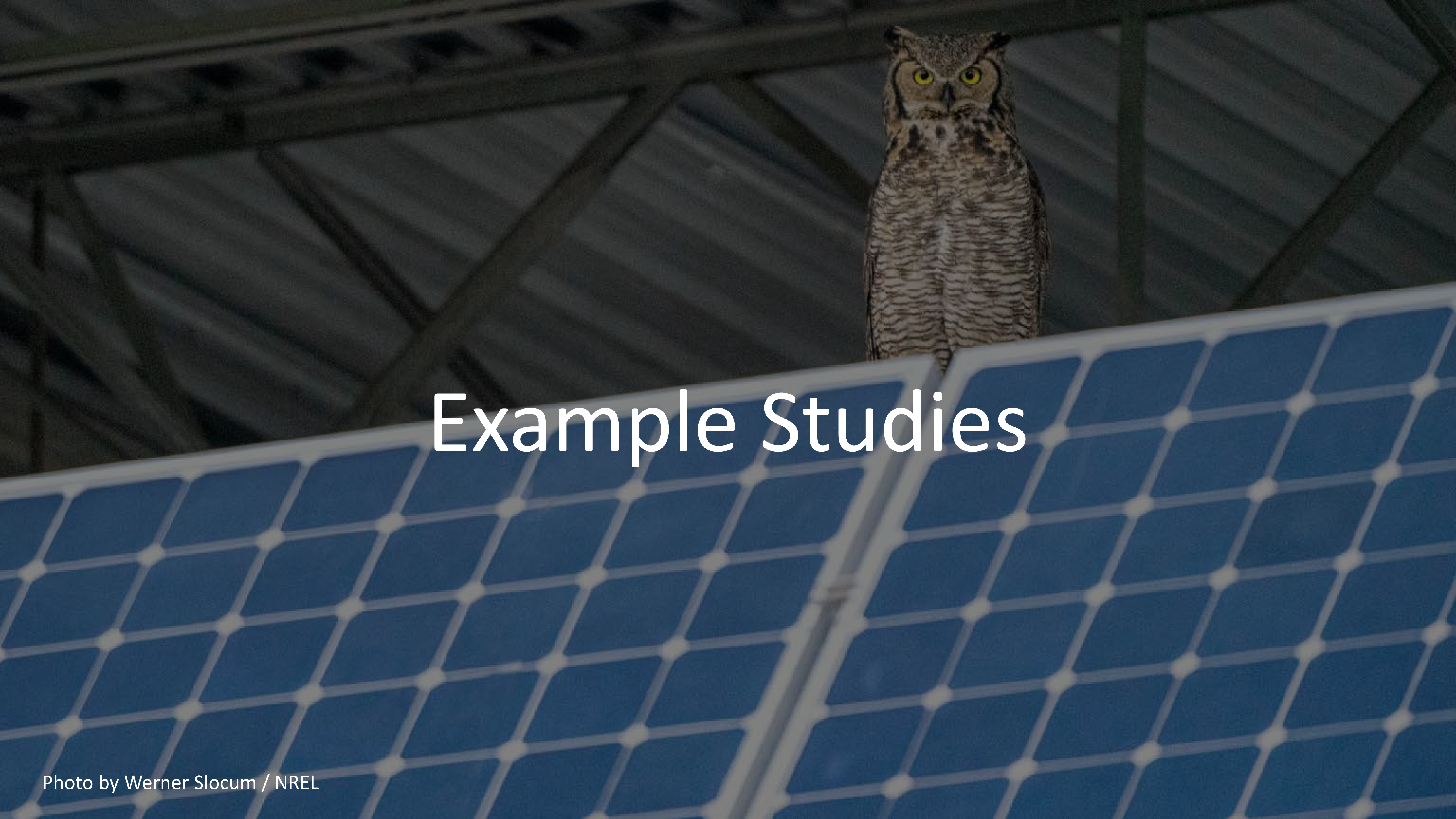


Grid emissions [tons] =
Electric grid purchases [kWh]
x
Marginal emissions intensity [ton/kWh] of the grid (location-specific) in each hour

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

Setting Clean Energy Goals

Capability	Questions answered
Percent onsite **renewable** electricity target	"How do I achieve 25% onsite renewable electricity (annually) at my site at the lowest lifecycle costs?"
Climate emissions reduction target	"How do I reduce my site's CO_2 emissions by 50% with DERs, relative to the BAU scenario?" "What is the breakeven cost per tonne CO_2 to achieve this goal?"
Include **costs of climate and/or health emissions** in the REopt objective function	"How does the cost-optimal system change if I consider the $/tonne costs of climate (CO_2) and health ($PM_{2.5}$, NO_x, SO_2) emissions?"

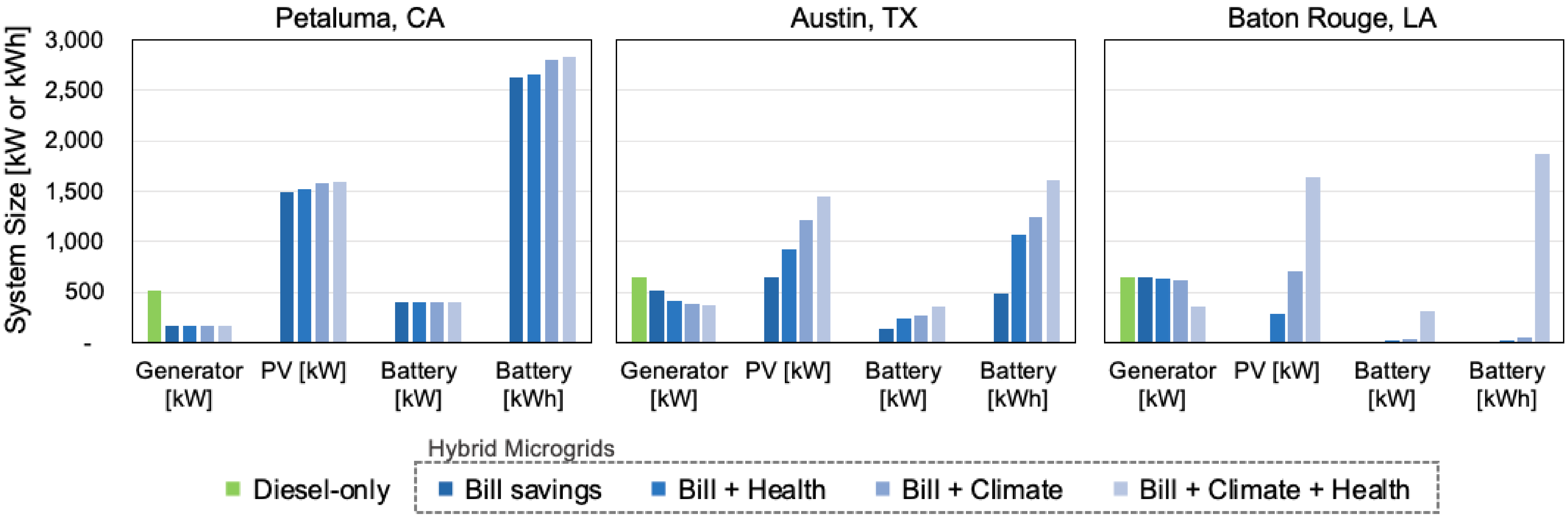


Example Studies

Photo by Werner Slocum / NREL

Impact of Including Emissions Costs on System Sizing

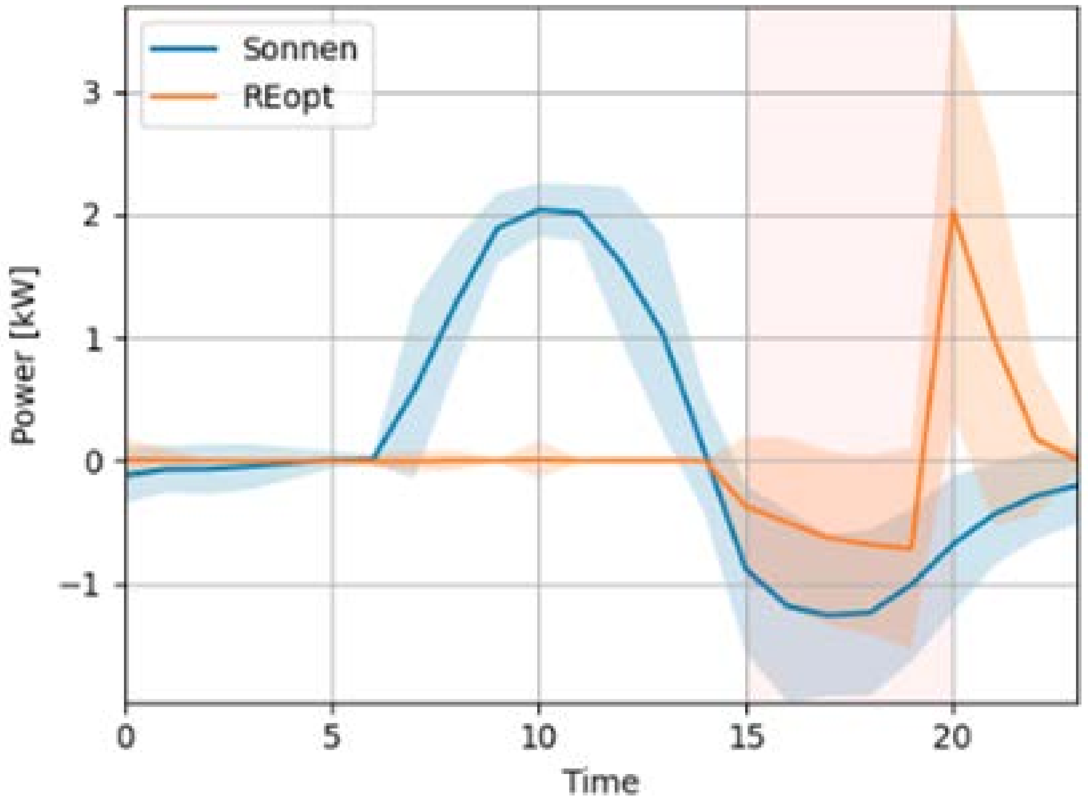
Smaller diesel generators and larger PV and storage systems become cost-optimal as health and climate costs are incrementally included within the lifecycle cost objective function.



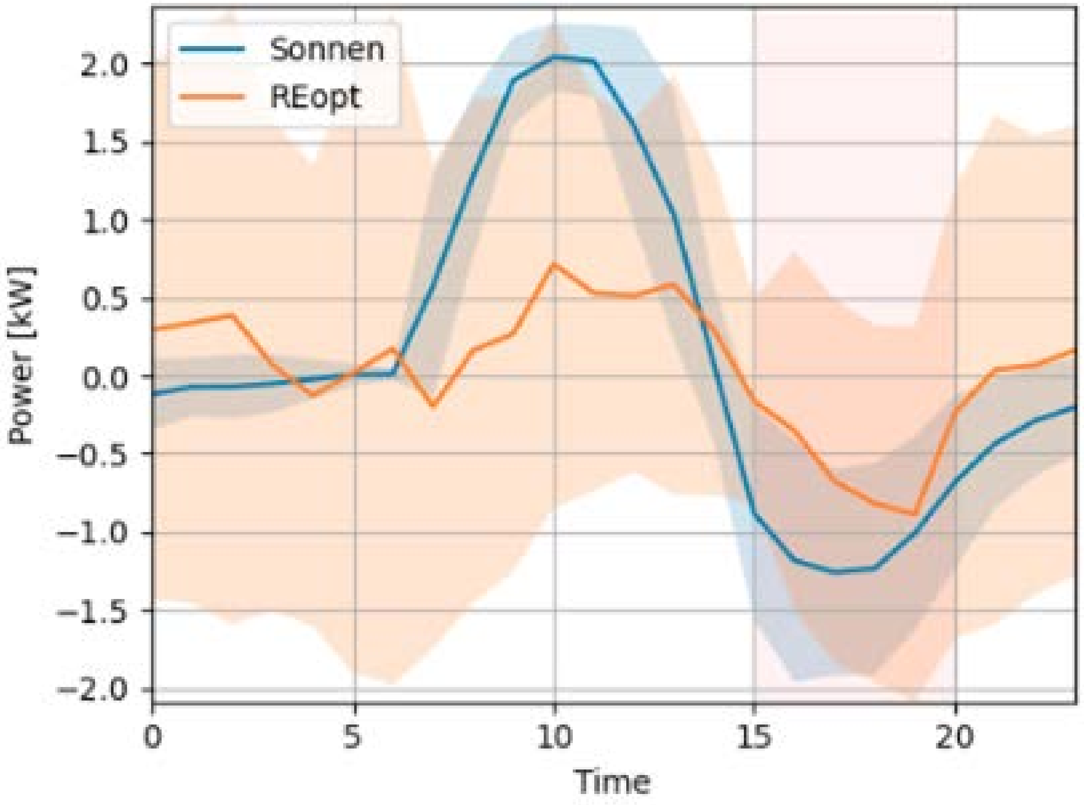
"Looking Beyond Bill Savings to Equity in Renewable Energy Microgrid Deployment" (Anderson, Farthing, Elgqvist, Warren, 2021)

Impacts of Including Emissions Costs on Battery Dispatch

Average REopt battery SOC **without...**



...and **with** CO_2 cost in objective



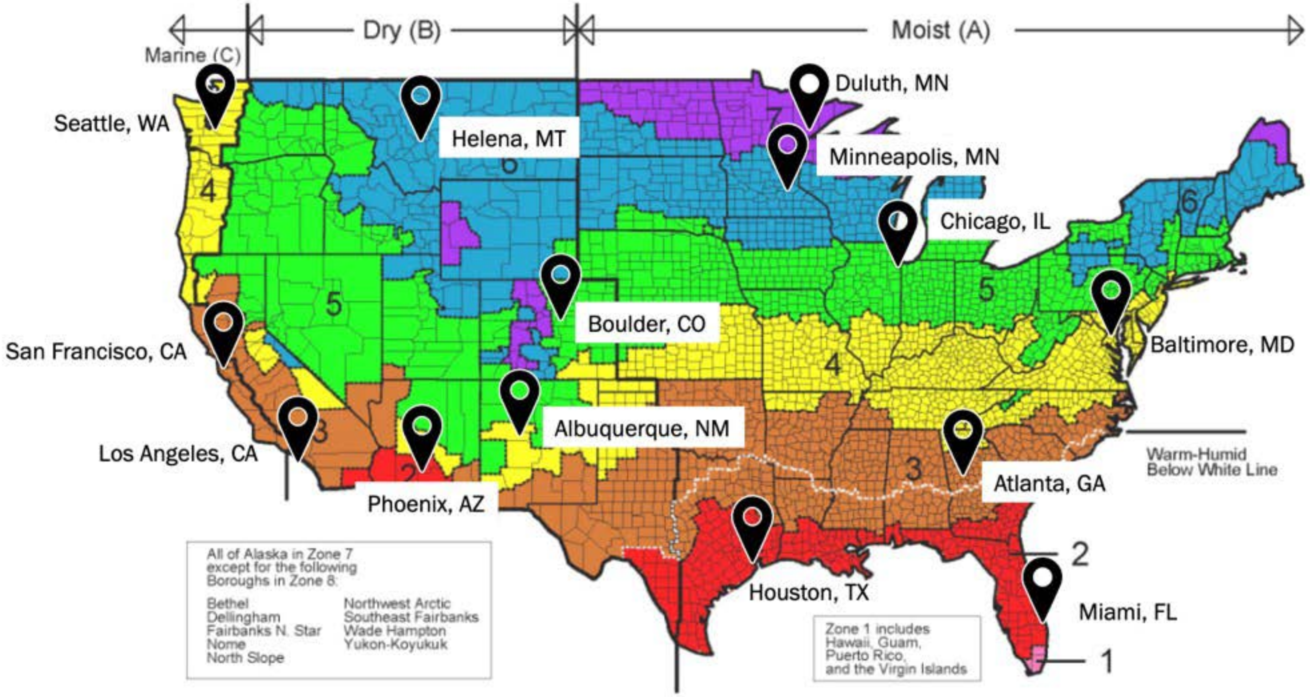
"Savings in Action: Lessons from Observed and Modeled Residential Solar Plus Storage Systems."
(O'Shaughnessy, Cutler, et al. 2022)

Modeled 3 building types across 14 locations in the U.S.

Hospital

School

Warehouse

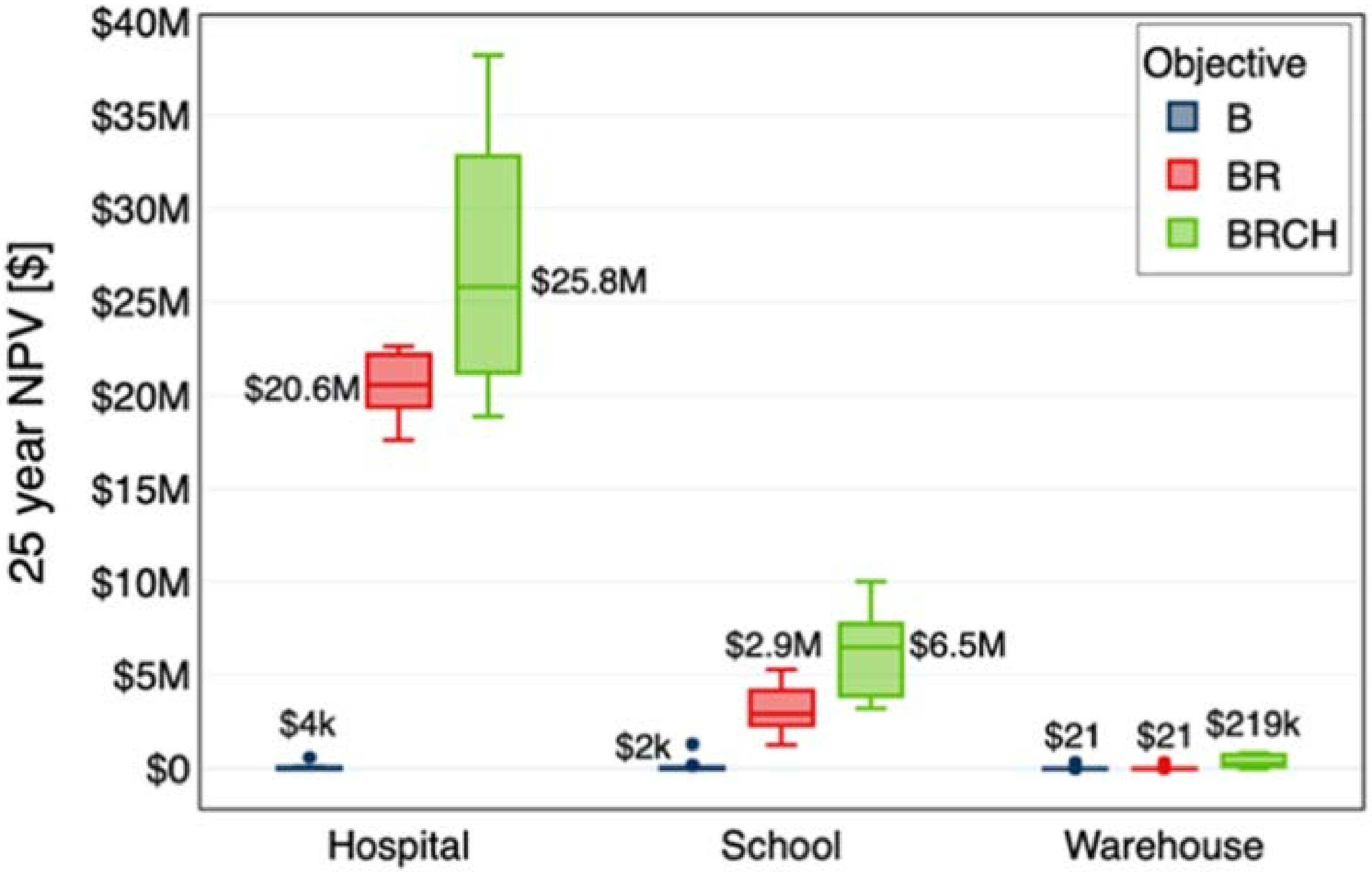


Unique to each location: *Marginal emissions factors (Cambium), health damages*

Unique to each building and location: *Load profiles, utility tariff*

"Optimizing Solar-Plus-Storage Deployment on Public Buildings for Climate, Health, Resilience, and Energy Bill Benefits." (Farthing, Craig, Reames 2021). ASSET Lab, Urban Energy Justice Lab, University of Michigan

Expanding co-optimization from bill and resilience (*BR*) to also include health and climate benefits (*BRCH*) increases the NPV at hospitals, schools, and warehouses by 25%, 124%, and 10,400x, respectively.



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Conclusions

- Co-optimizing for climate & health benefits increases least-cost system sizes and improves solar+storage economics
- Co-optimizing for climate and health also leads to higher utilization of batteries

REopt

Conclusions

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- REopt (free, publicly available) allows users to include a cost of carbon and health-related emissions (NOx, SO_2, $PM_{2.5}$) in their analyses, or to set emissions reductions targets
- A new version of REopt also includes the ability to include the cost of lost load during grid outages within the optimization

REopt

Conclusions

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- A new version of REopt also includes the ability to include the cost of lost load during grid outages within the optimization
- These capabilities can help businesses, government agencies, cities, and other stakeholders make progress towards their climate, health, resilience, and bill savings goals.

Accessing REopt

Interfaces:	
REopt Web Tool	https://reopt.nrel.gov/tool
REopt API (Open Source)	https://github.com/NREL/REopt_API/wiki
Scripts and Notebooks to Run Analyses with API	https://github.com/nrel/reopt-api-analysis/wiki
New REopt Julia Package **(under development; currently distinct from API but same underlying model)**	https://github.com/NREL/REopt.jl
Additional Documentation & Support:	
User Manual	https://reopt.nrel.gov/tool/REopt%20Lite%20Web%20Tool%20User%20Manual.pdf
API Forum	https://github.com/NREL/REopt-API-Analysis/discussions/
Help Desk	reopt@nrel.gov

Thank you!

Questions?

REopt Renewable Energy Integration and Optimization

Amanda Farthing | NREL Research Engineer | amanda.farthing@nrel.gov

REopt website: reopt.nrel.gov

www.nrel.gov

NREL/PR-7A40-82866

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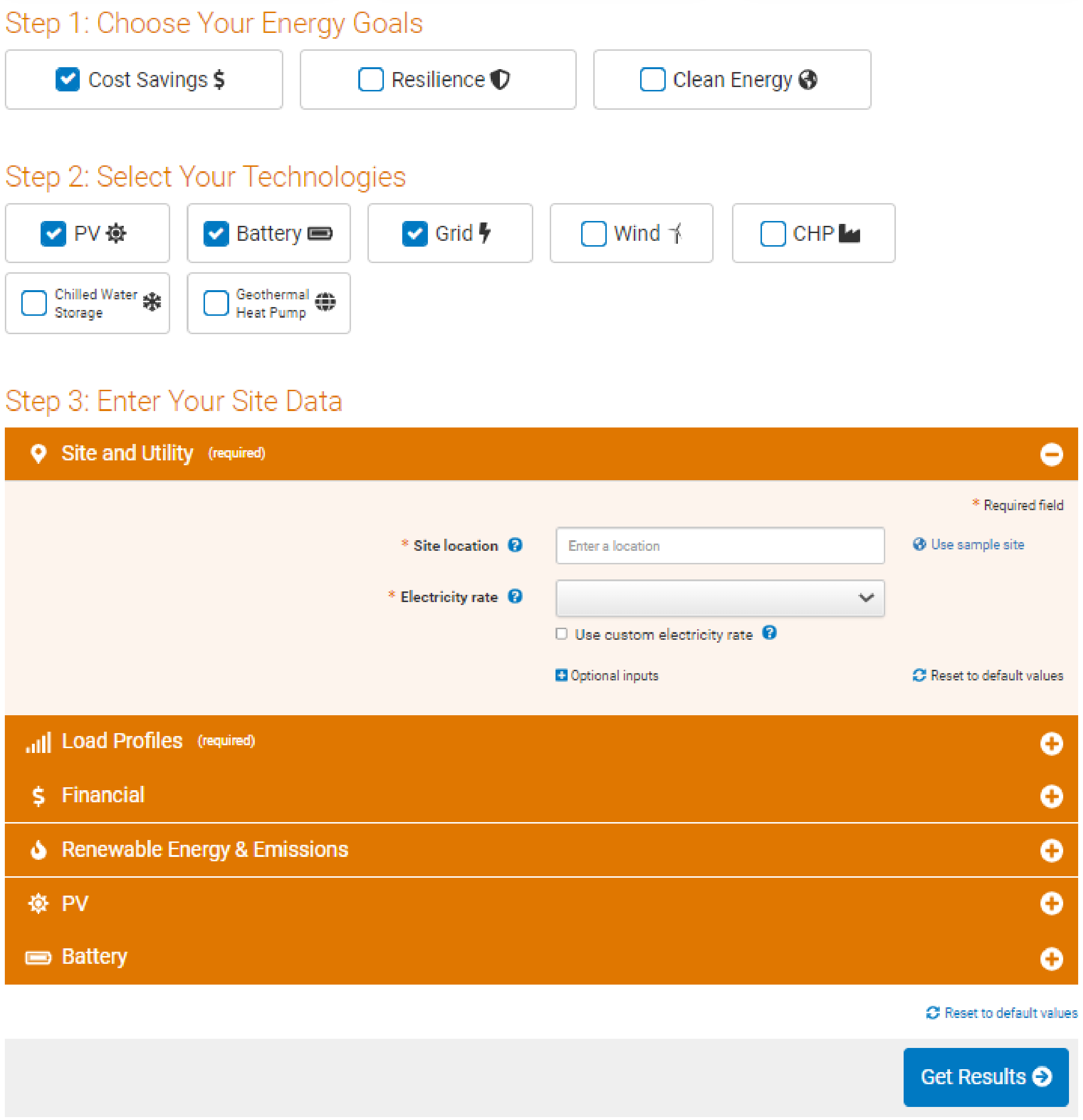
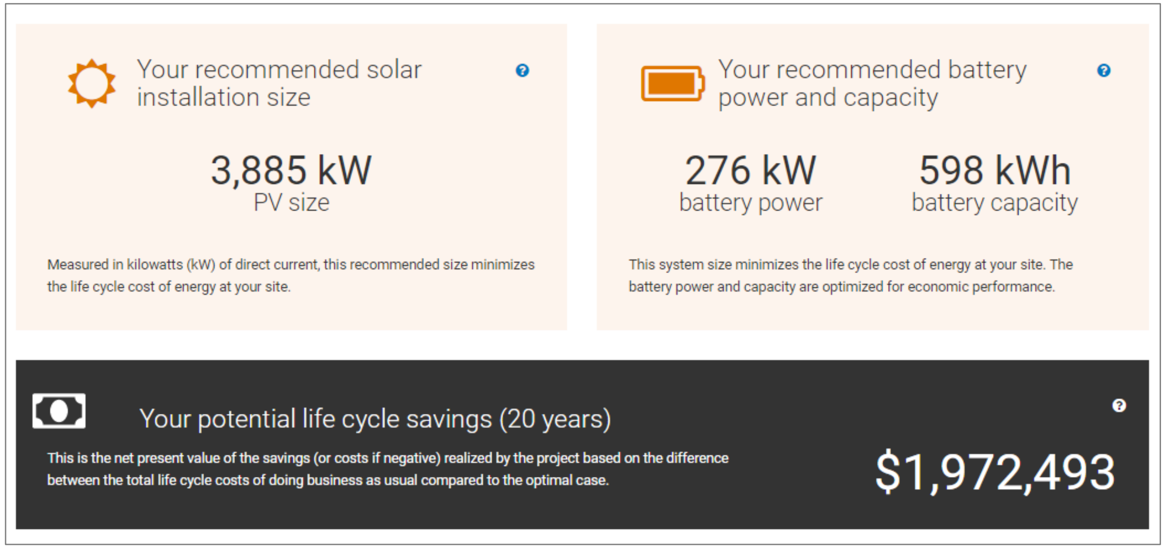
REopt Web Tool User Interface

- **REopt Web Tool** offers a free, publicly available, user-friendly web tool that offers a subset of features available through the API
- Optimizes **PV, wind, CHP, GHP, and energy storage** system sizes and dispatch strategies to **minimize life cycle cost of energy**
- **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
- **Unchecking "Grid"** allow users to model off-grid microgrids of solar, storage, and diesel generators
- Access REopt web tool at reopt.nrel.gov/tool

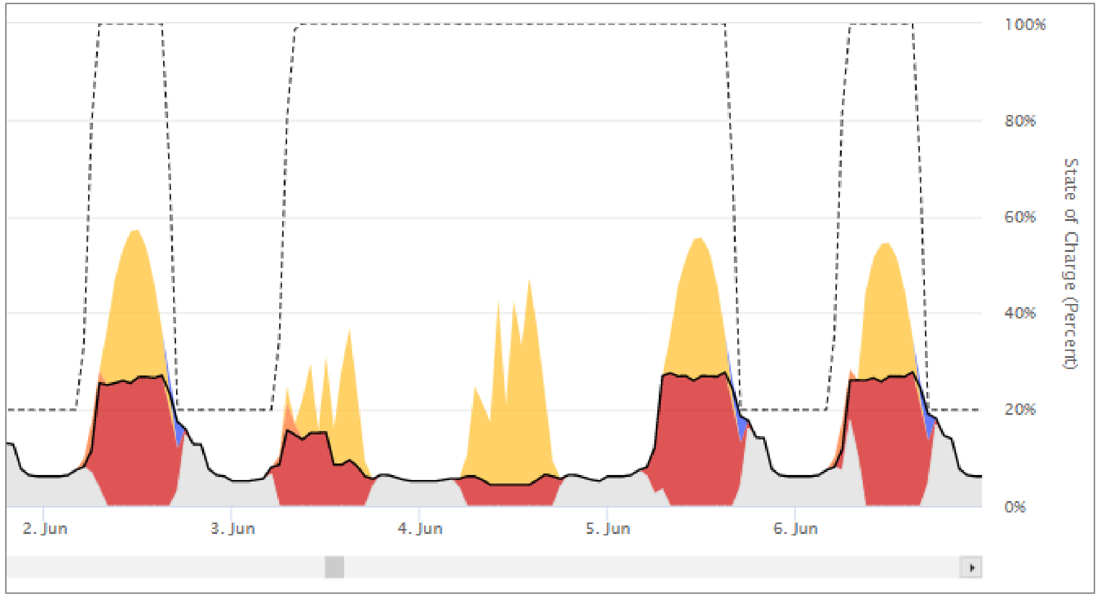
REopt



REopt Web Tool Key Outputs



System Size and NPV



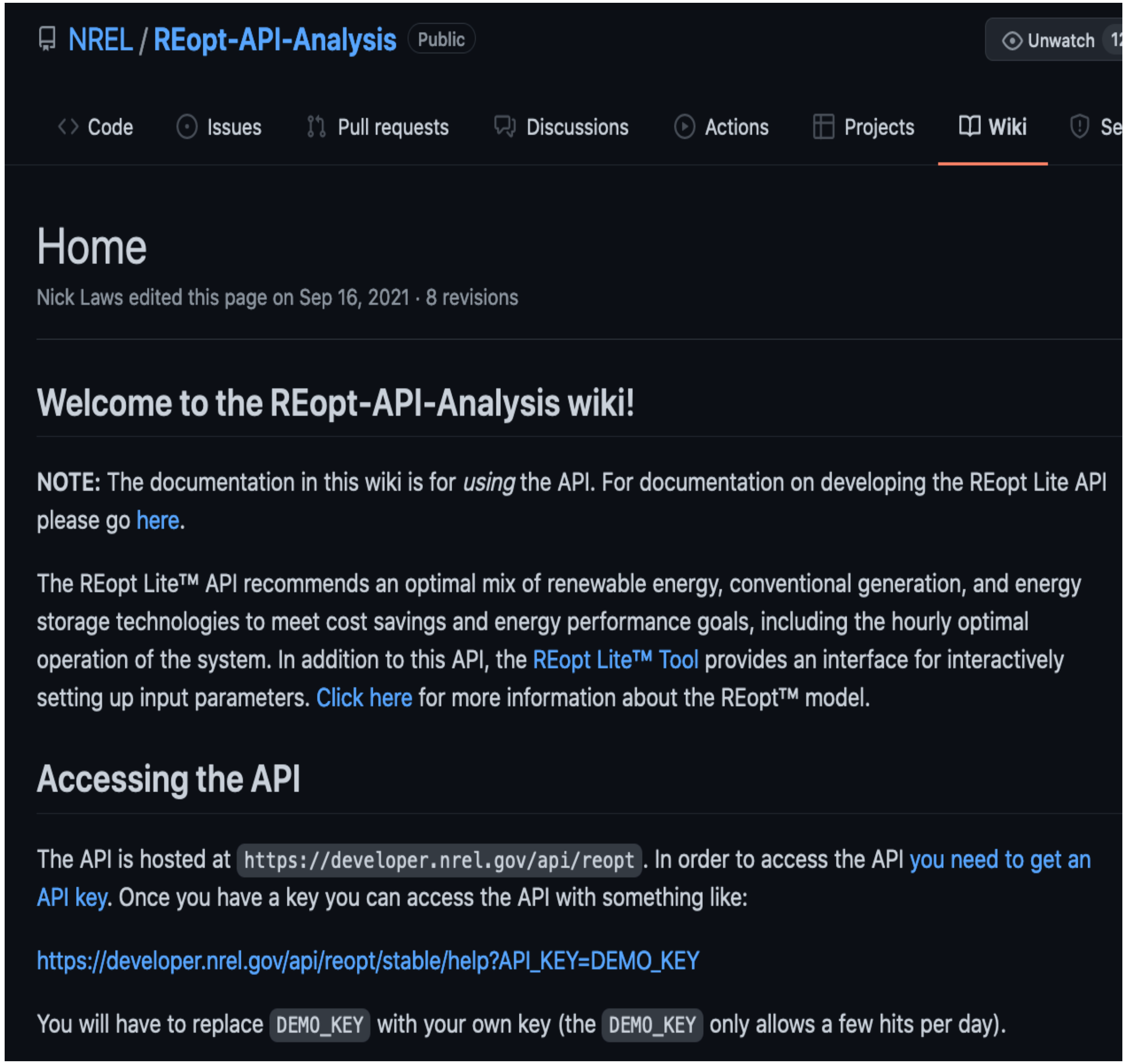
Hourly Dispatch

	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

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

Clean Energy Accounting

For a given project, REopt determines the following:

Climate and health emissions impacts:

- Avoided **climate** (CO_2) and **health** ($PM_{2.5}$, NO_x, SO_2) emissions, as compared to the business-as-usual (BAU) scenario
  - For **grid electricity** *and* **on-site fuel** consumption
  - **Year one** and **Total (analysis period)** emissions
  - Considers future "**greening of the grid**"
- Avoided climate and health emissions **costs**

Renewable energy impacts:

- Site electricity and energy (including heating and cooling) consumption from **on-site renewable sources**

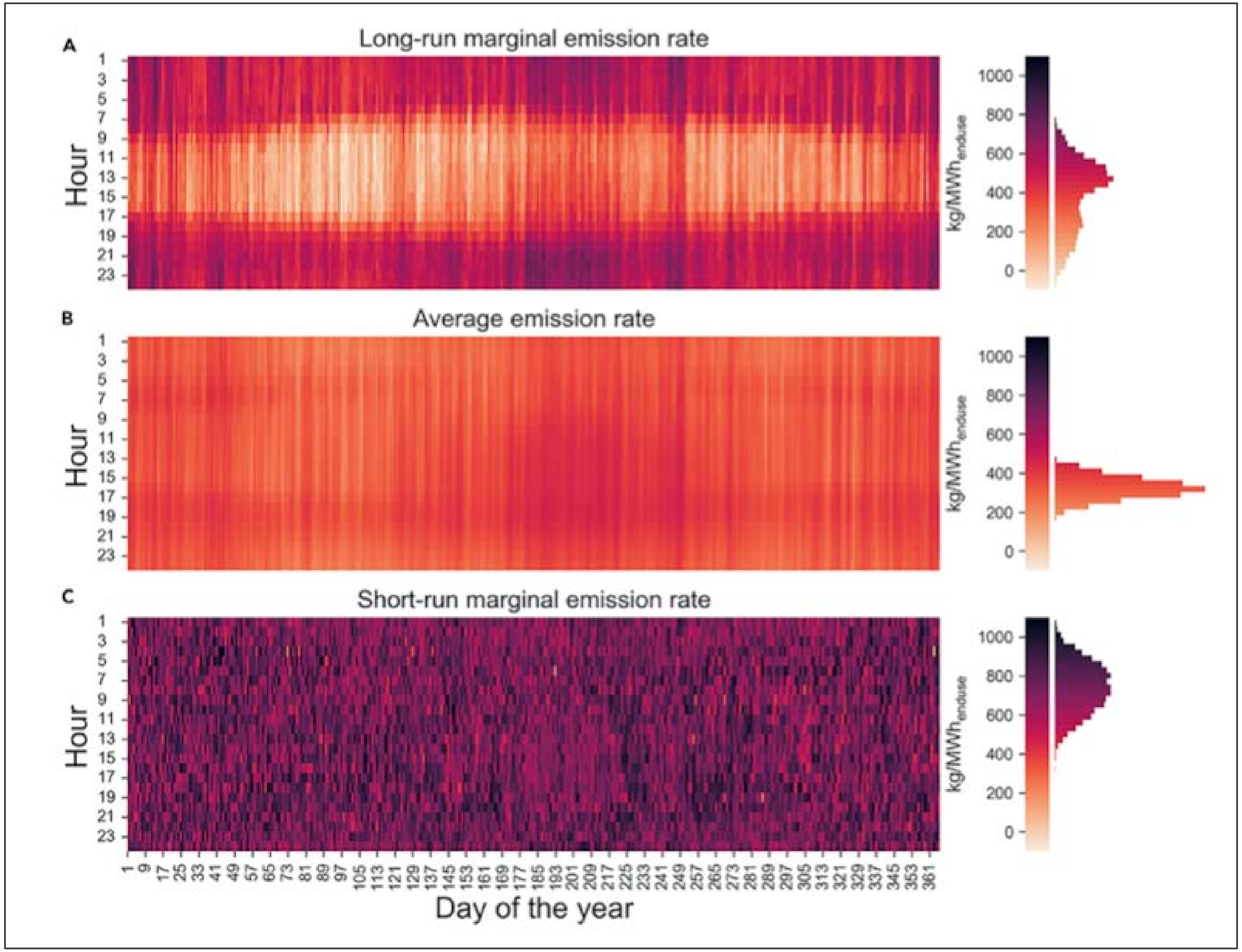
Note:

- Distinction between renewable energy and emissions accounting:
  - Basis for renewable energy accounting is units of energy, e.g. kWh
  - Basis for emissions accounting is units of emissions, e.g. tonnes of CO_2
  - Although a given unit of energy (e.g. kWh) can have a renewable energy attribute and emissions attributes, the accounting of such must be kept separate and follow established guidelines
- Users can **include or exclude** emissions offsets and/or renewable energy credit associated with **exported electricity**

Grid Emissions Rates Considerations

Consideration	Examples
Geographic boundary	State, balancing authority, eGRID subregions
Temporal resolution	Annual, hourly
Timespan	Historic/current rates, future projections
Emissions species	**Climate** (CO_2, CH_4, N_2O, CO_2e) **Health** (PM2.5, NOx, SOx)
Emissions factor type	**Average:** represents entire grid mix; often used for baselining and emissions reporting protocols **Marginal:** represents emissions of generation on the margin; more accurately represents impact of an intervention (e.g., EE, DERs) • **Short-run marginal emissions:** the rate of emissions assuming grid assets remain fixed • **Long-run marginal emissions:** the rate of emissions that would be induced or avoided by a long-term (i.e., more than several years) change in electrical demand, incorporating both operational and structural consequences of the change

Comparison of Emission Factor Types



Cambium data for the contiguous U.S. Central time zone. LRMER are 20-year levelized values, SRMER and AER are single-year values from 2024.

Source: Gagnon & Cole, "Planning for the evolution of the electric grid with a long-run marginal emission rate" (2022). https://doi.org/10.1016/j.isci.2022.103915

Grid Emissions Types and Datasets

Types: Average (entire grid mix) vs. Marginal (marginal generators) emission factors
Different use cases: Emissions reporting protocols (e.g., GHG Protocol) vs. academic/"real impact"
REopt default: Short-run marginal emissions factors from EPA's AVERT

Dataset	First year released	Emissions included							Geographic boundary	Temporal resolution	Type of rates
		CO_2	NOx	SO_2	CH_4	N_2O	CO_2e	PM2.5			
AVERT (EPA)	2014	✓	✓	✓	✗	✗	✗	✓	14 regions, continental U.S.	Hourly	Historical short-run marginal (based on first 1MW reduction in load)
eGRID (EPA)	1996	✓	✓	✓	✓	✓	✓	✗	27 "subregions," entire U.S.	Average annual	Historical average, "non-baseload" as marginal
Cambium (NREL)	2020	✓	✗	✗	✓	✓	✓	✗	Balancing area, 50 states, entire U.S., 20 regions similar to eGRID	Hourly projections 2020-2050	Projected average, short run marginal, long run marginal

Example Study

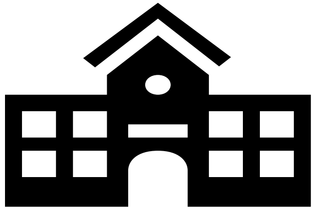
“Optimizing Solar-Plus-Storage Deployment on Public Buildings for Climate, Health, Resilience, and Energy Bill Benefits.” (Farthing, Craig, Reames 2021)
ASSET Lab, Urban Energy Justice Lab, University of Michigan

Photo by Dennis Schroeder / NREL

3 building types modeled using REopt

Hospital

School

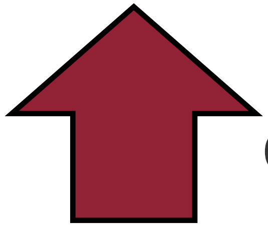


Warehouse

3 building types modeled using REopt

Hospital

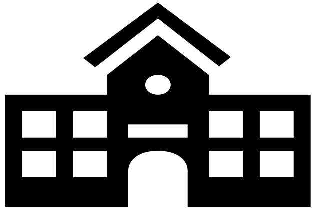
Differing outage impacts

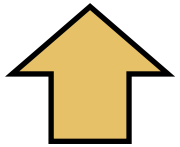


High

Critical Facility

School

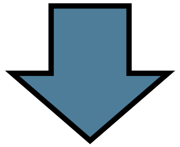




Medium

Resilience Hub

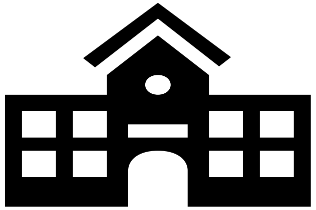
Warehouse



Low

Non-critical

3 building types modeled using REopt

Building	Differing outage impacts		**Value of lost load** ($ per kWh of unserved load during an outage)	**Critical load** (% load that should be powered during outage)
Hospital 	High	Critical Facility	$140	85%
School 	Medium	Resilience Hub	$72	60%
Warehouse 	Low	Non-critical	$4	10%

Expected Outage Characteristics

- **15-hour** outage (average duration of major outages in 2020[1])
- Possible timing: **5% worst possible times for each building**
- Occurs **annually**

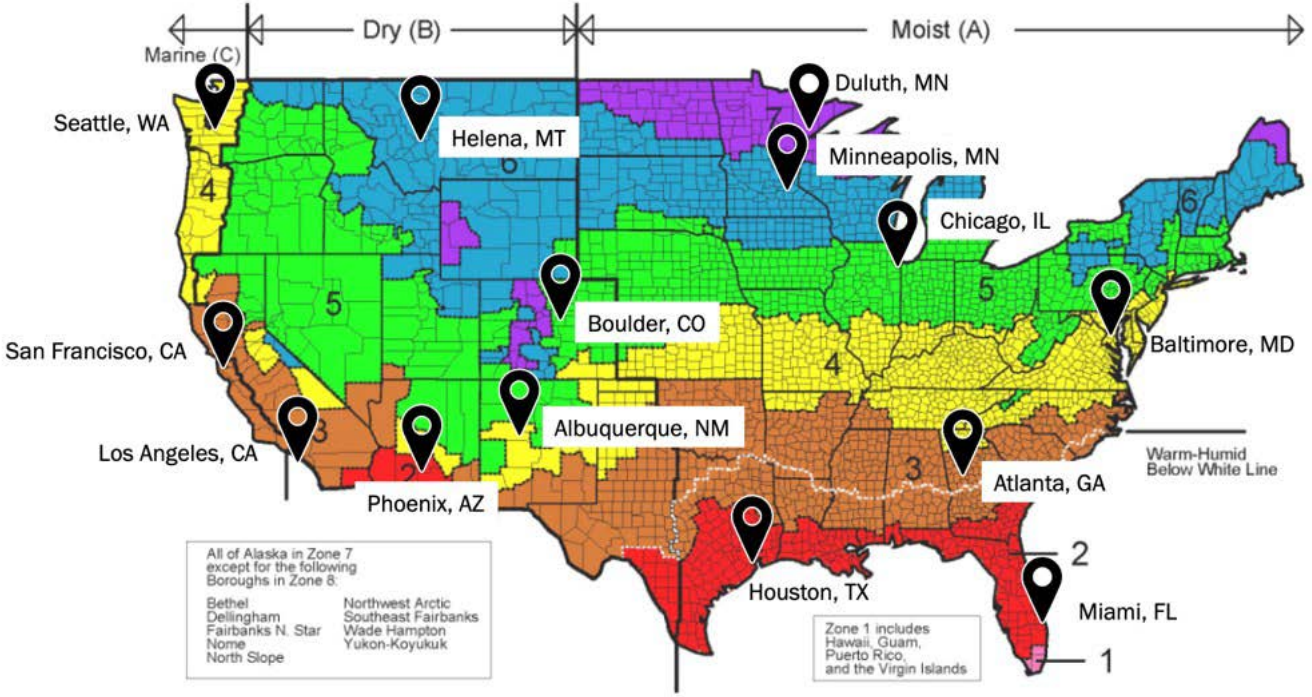
[1]Electric Disturbance Events (OE-417) Annual Summaries

Modeled 3 building types across 14 locations in the U.S.

Hospital

School

Warehouse



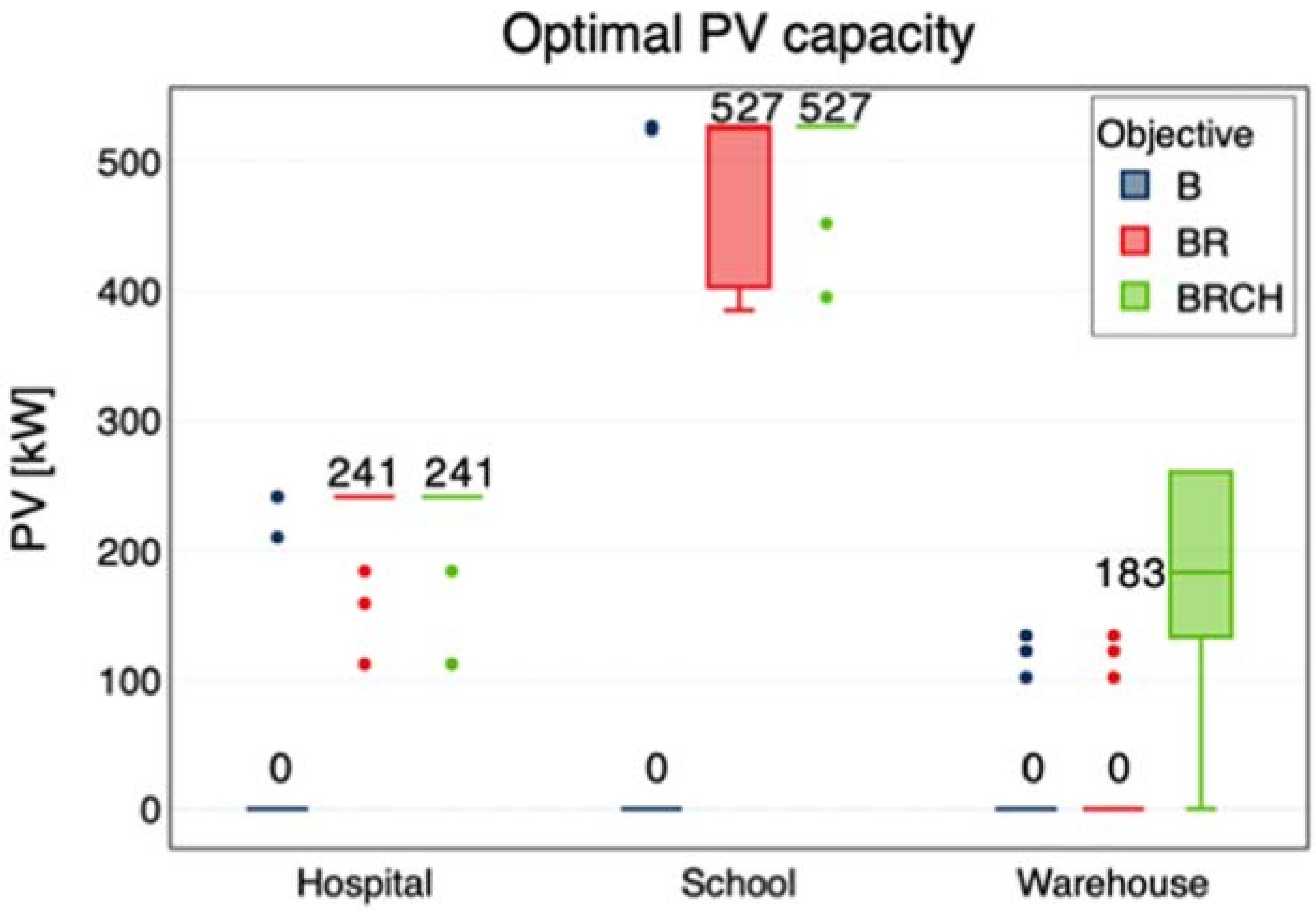
Unique to each location: *Marginal emissions factors (Cambium), health damages*

Unique to each building and location: *Load profiles, utility tariff*

Results

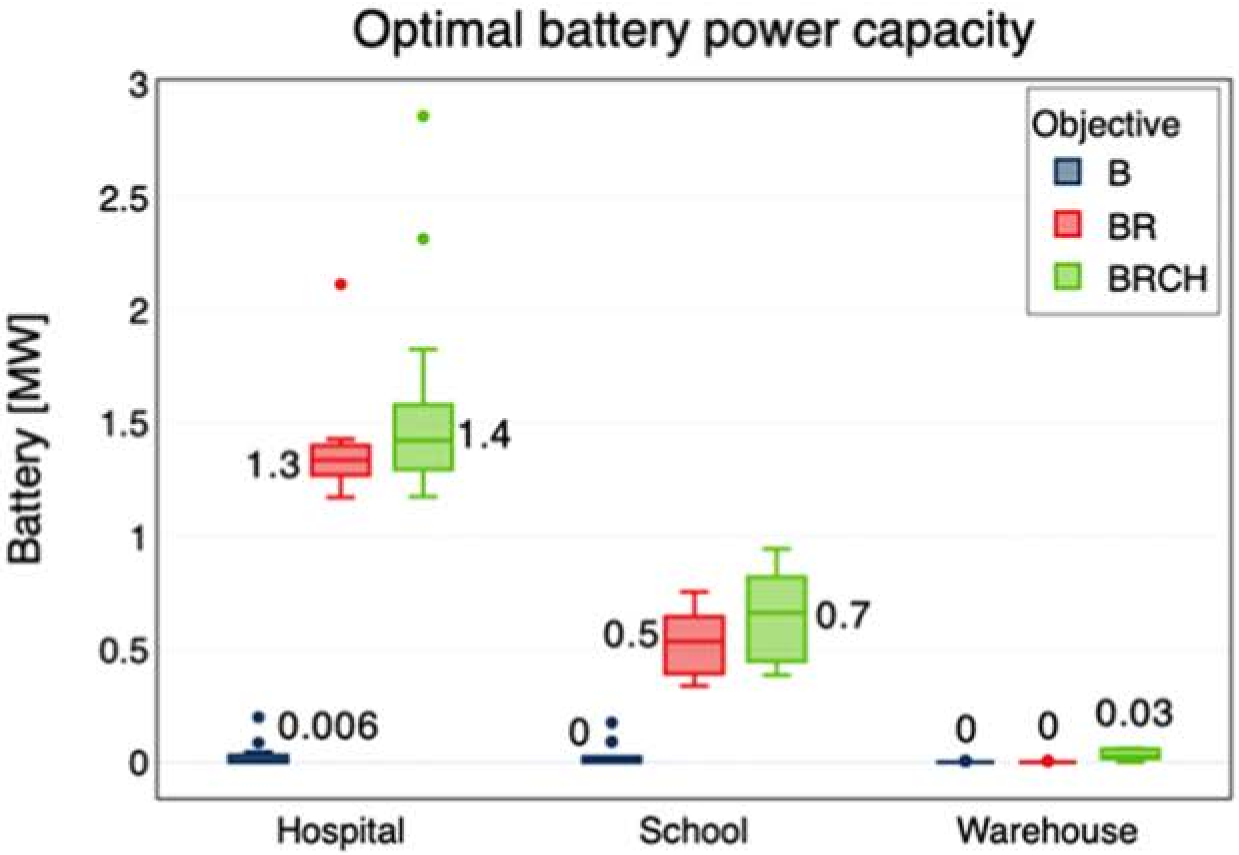
Photo by Dennis Schroeder / NREL

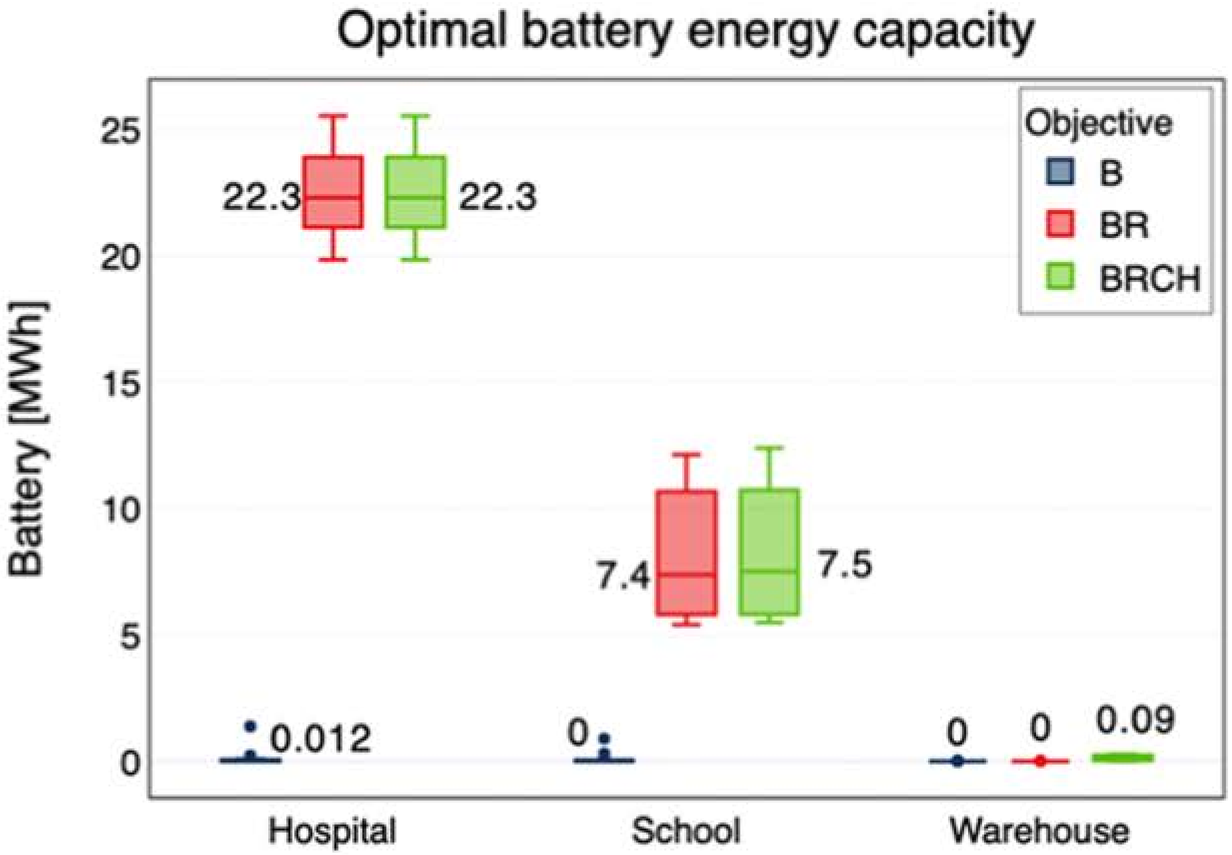
Larger system sizes are cost-optimal when resilience, climate, and health are valued



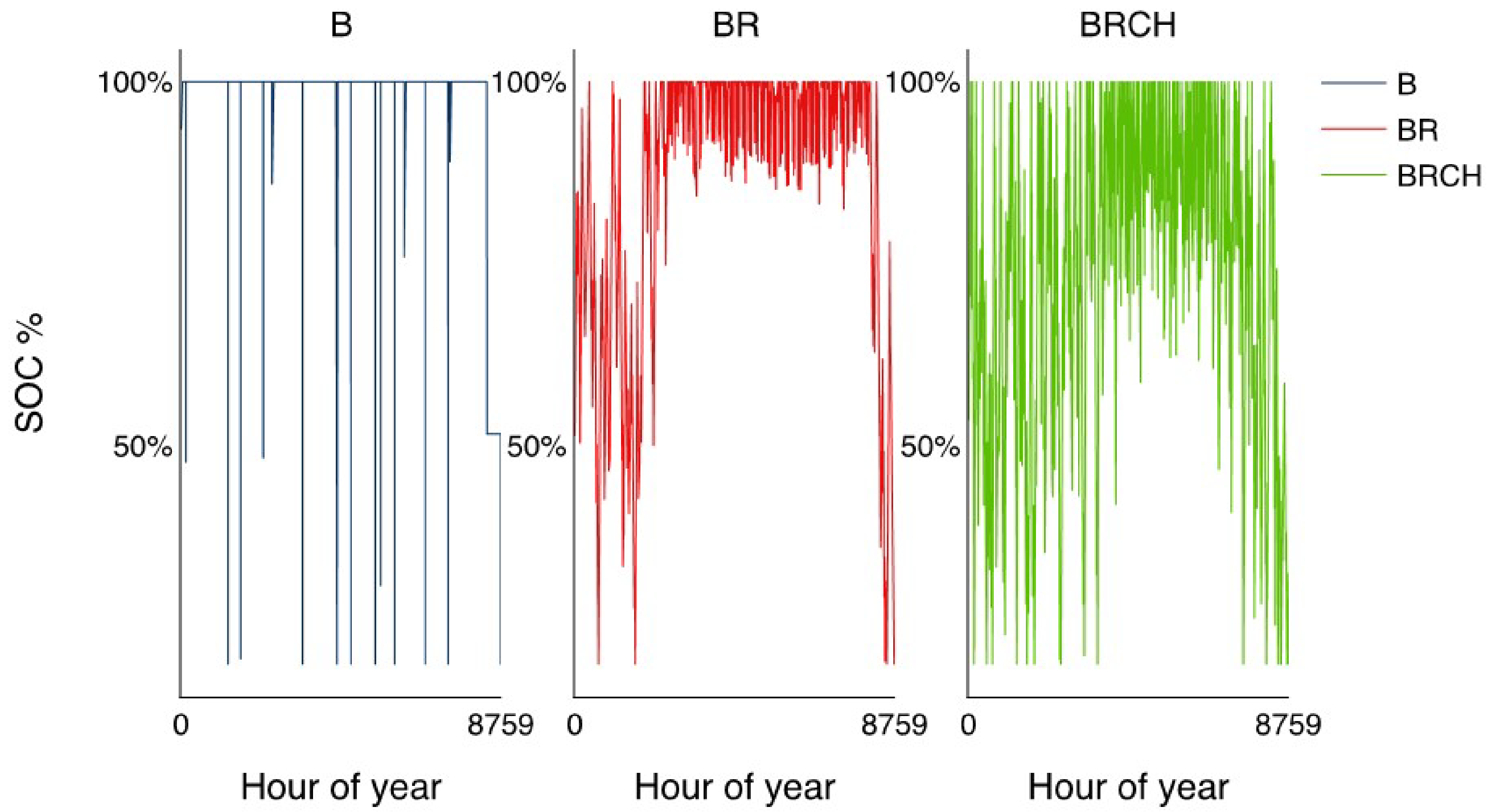
Bill savings
+ Resilience
+ Climate + Health

Larger system sizes are cost-optimal when resilience, climate, and health are valued





Battery operations reflect differing objectives between scenarios, with increasing dispatch from BR to BRCH



Example shown is for the modeled Miami hospital

Expanding co-optimization from bill and resilience (*BR*) to also include health and climate benefits (*BRCH*) increases the NPV at hospitals, schools, and warehouses by 25%, 124%, and 10,400x, respectively.