REopt® Model Overview and Example Use Cases

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REopt Integration and Optimization

The Renewable Energy Integration and Optimization platform (REopt)

What is it?

- A mathematical model formulated as mixed-integer linear optimization.
- Model has evolved over time from an Excel workbook to web accessible API, user-friendly webtool, and customizable Julia package.

What does it do?

- Performs a cost-minimization on the cost of serving electrical and thermal loads at a site.
- Identifies onsite behind-the-meter (BTM) distributed energy resources (DER) system sizes and dispatch strategies to minimize energy costs.

The Renewable Energy Integration and Optimization platform (REopt)

Why use REopt?

- Offers a quick and low-effort way to understand if DERs are cost-effective at a site.
- Can determine system sizes that meet resilience targets and/or emissions goals while minimizing life cycle cost.

When is it used?

- Used in the initial planning phases of a project.
- Results from this model can help sites identify cost-effective technologies and inform detailed downstream analyses.

The Renewable Energy Integration and Optimization platform (REopt)

How can REopt be used?

- **Web accessible** tool (https://reopt.nrel.gov) offers a user friendly GUI to provide inputs to REopt. User manual available at https://reopt.nrel.gov/tool/reopt-user-manual.pdf.
- **REopt API** (https://github.com/NREL/REopt_API/wiki) provides API access to the model along with some added flexibility of inputs. The API leverages NREL computational resources.
- **REopt Julia** package (https://github.com/NREL/REopt.jl) offers the most flexibility in inputs, allows mathematical model customization.
  - Users must use an open-source solver or bring their own solver.

The Renewable Energy Integration and Optimization platform (REopt)

Clean energy or resilience goals

- REopt allows energy cost minimization with site specific min/max emissions reduction or min/max renewable electricity requirement
  - Location-based emissions factors from NREL's Cambium database
- Model can require an identified cost-optimal system to serve critical site loads for a predefined duration.
  - Can optionally include value of lost load (VoLL, *$/kWh_unserved*)
  - Resilience simulation: given a system sizing and critical loads, what is the likelihood of site surviving an outage of duration X?

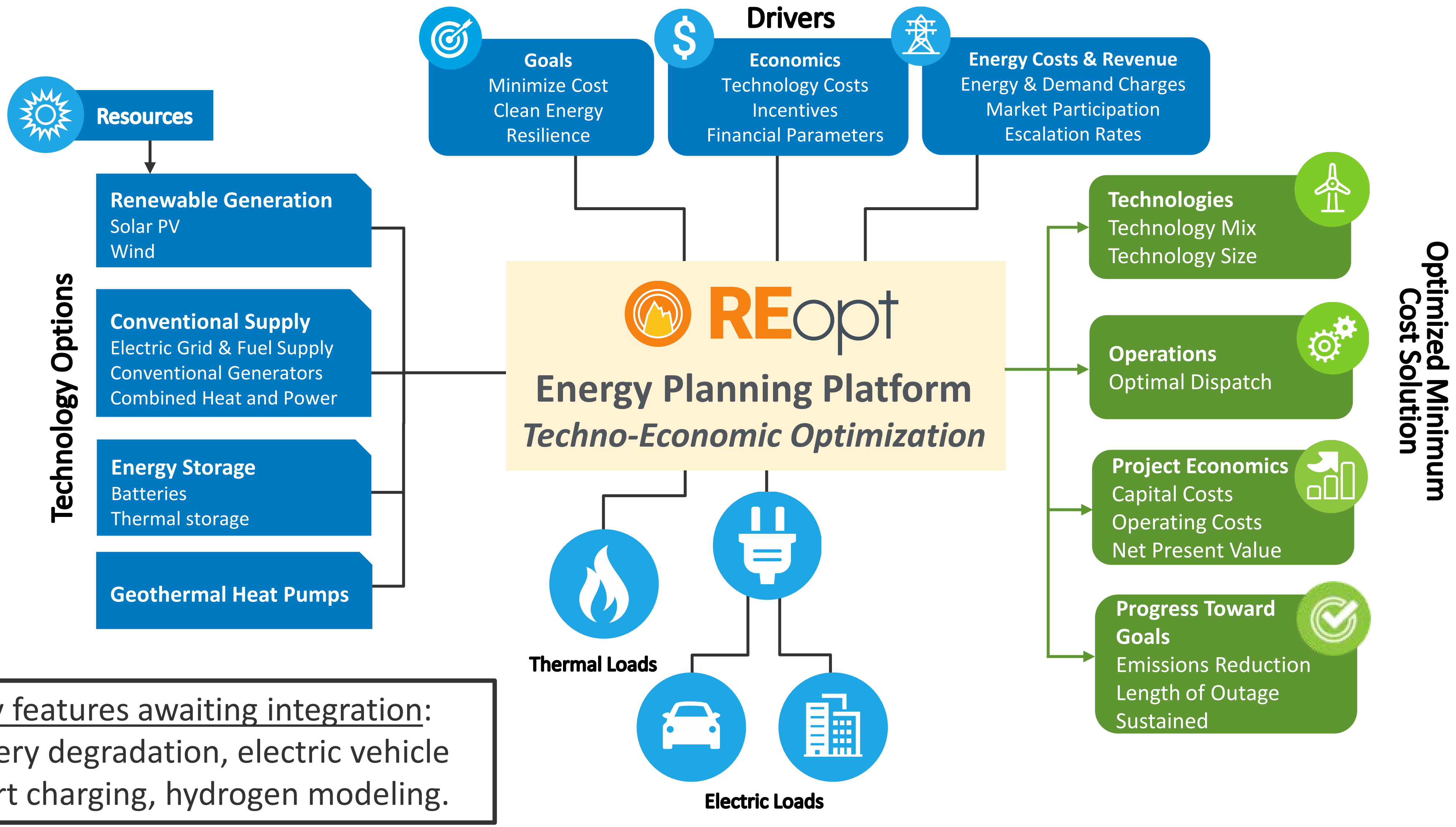
The Renewable Energy Integration and Optimization platform (REopt)

Key caveats

- Model only considers real power consumption and takes a BTM perspective
- Model is a price taker, and not a price setter
- Dispatch of any identified systems is performed with perfect foresight into future loads and renewables generation
- Variations in model inputs can have large changes in the optimization results.
- Memory growth issue if considering large batch runs: https://discourse.julialang.org/t/memory-consumption-growth-with-many-large-milps-in-jump/61895.

REopt Energy Planning Platform

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

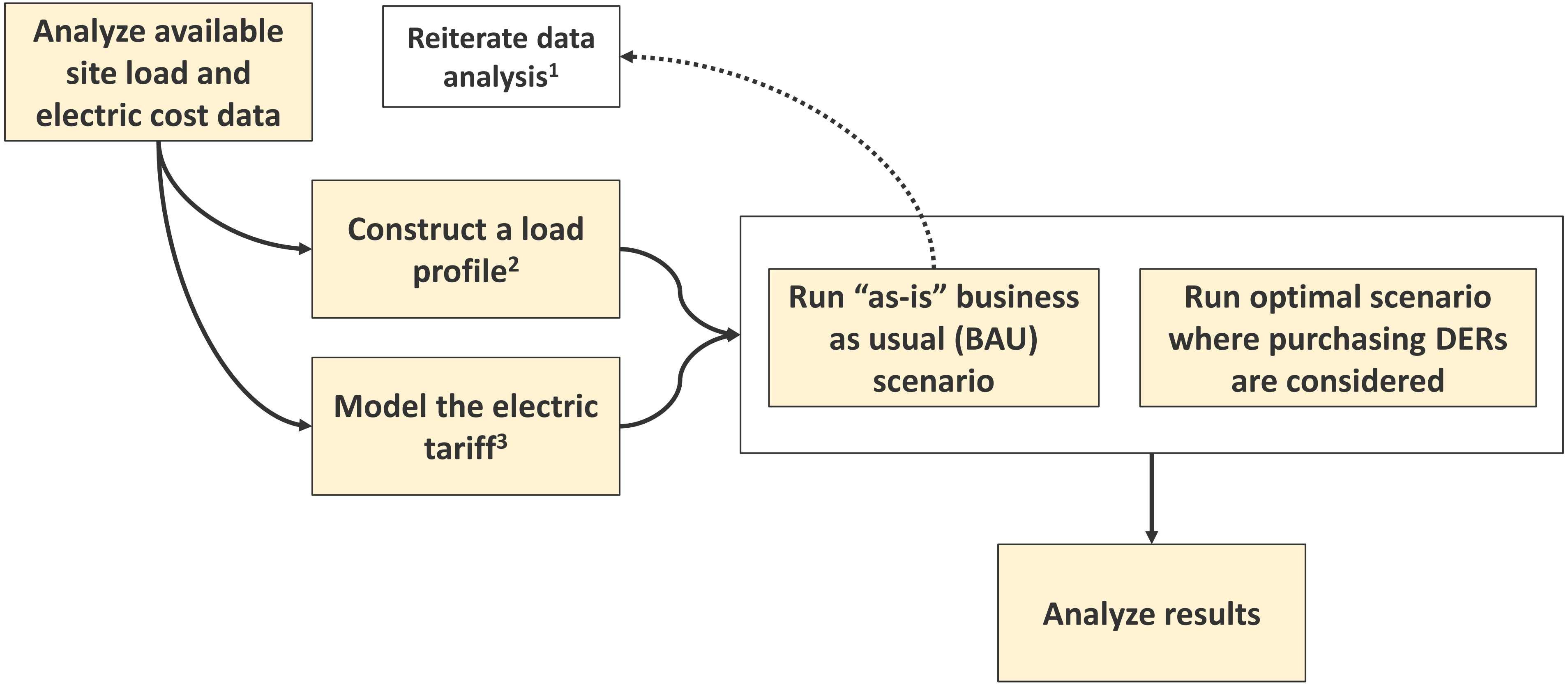


<u>Key features awaiting integration</u>:
Battery degradation, electric vehicle smart charging, hydrogen modeling.

Model Inputs and Outputs

A summary of key inputs, how the model works, and key outputs

REopt modeling workflow



Lifecycle cost (LCC) *includes the present cost of all capital (& battery replacement) costs, O&M costs, value of available incentives, and electric grid purchases throughout the 25-year analysis period*

Net present value (NPV) *is calculated as the LCC savings in the investment case relative to the business-as-usual (BAU) case*

[1] The BAU scenario output results can be compared with provided site electric bills to determine if any adjustments need to be made to the input data to achieve better alignment between the BAU results and billing data

[2] Provided load profiles are converted to vectors of length 8760, 17520, or 35,040 elements, and then fed into REopt.

[3] Electric tariff is not considered when modeling off-grid sites. Users can build their own rates in the webtool.

REopt minimizes the life cycle cost of energy

- **Life cycle cost (LCC)** of energy: The present value of all costs of energy at the site throughout the analysis period.

$$LCC = \text{Capital Costs} - \text{Available Incentives} + \text{O\&M Costs} + \text{Electric Grid Purchases} + \text{Fuel Purchases}$$

- **Net present value (NPV)** of DER system: The life cycle cost savings (difference in LCC) between the business-as-usual (BAU) case and the optimized (OPT) case.

$$NPV = LCC_{BAU} - LCC_{OPT}$$

If NPV > 0, the project provides cost savings relative to the BAU case.
If NPV < 0, the project is more expensive than the BAU case.

REopt identifies the **life cycle cost-optimal** DER system that achieves the site's energy goals (**cost savings**, **decarbonization**, and/or **resilience**).

Key model outputs and results interpretation

Results for Your Site

These results from REopt summarize the economic viability of PV, wind, battery storage, CHP, prime generator and/or GHP at your site. You can edit your inputs to see how changes to your energy strategies affect the results.

Copy | Download PDF

Your recommended solar installation size

System sizes and electricity cost savings, expected exports to the grid, progress towards goals

2,361 kW
PV size

M… …mmended size minimizes the life cycle cost of energy at your site.

This … 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)

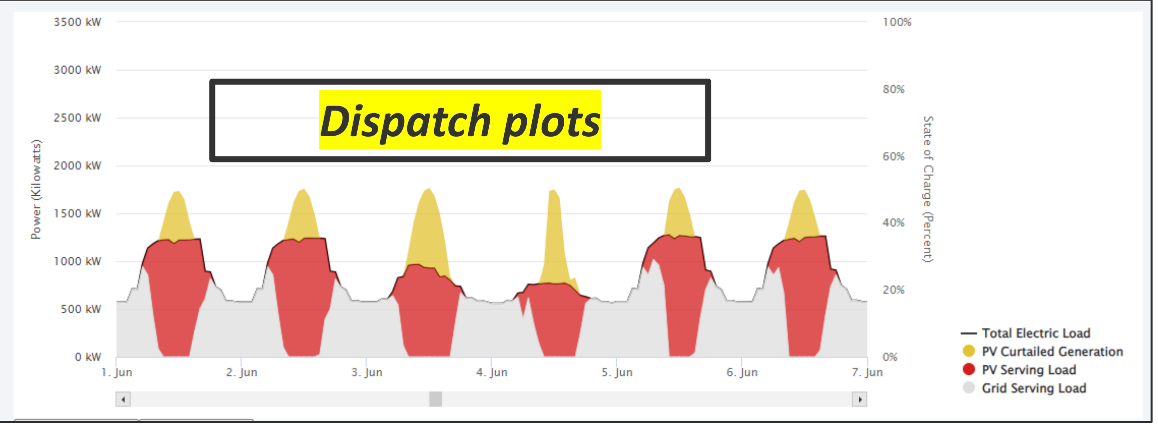
This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the total life cycle costs of doing business as usual compared to the optimal case.

$3,259,370

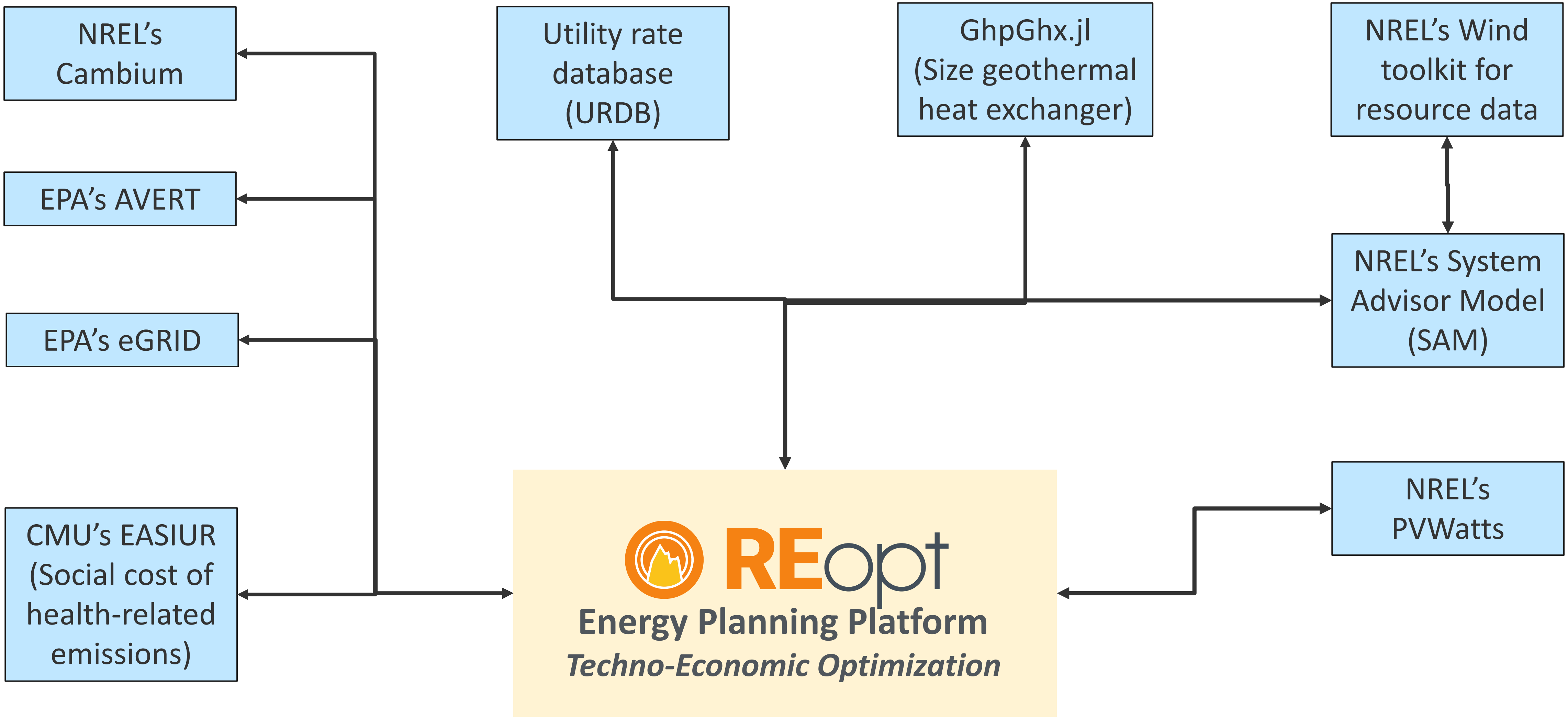
View citation

Proforma excel with cash flow calculations

RESULTS		
Business as usual LCC, $	23,247,307	
Optimal LCC, $	17,192,868	NOTE: A negative LCC indic…
NPV, $	6,054,439	NOTE: This NPV can differ s…
IRR, %	15.15%	
Simple Payback Period, years	5.44	



What external databases does REopt interact with and why?



Electric tariff modeling

- Model utilizes detailed electric tariffs as basis of cost minimization
- User entered vectors or a rate identified in OpenEI's Utility Rate Database (URDB, https://openei.org/wiki/Utility_Rate_Database)
- Rates can vary in complexity and are a driver of cost savings.

Rate component:	What it is:	What it would mean in terms of driving:
Energy charges [$/kWh]	Cost per unit of energy consumed over a month	A charge per mile traveled on a trip.
Demand charges [$/kW]	Cost on quickest rate of energy consumption during a month	A charge on the fastest speed observed during the trip
Tiered charges	Variable pricing based on how much energy/power was used	Variable charge based on how much distance traveled / top speed achieved
Time of use (TOU) charges	Variable pricing based on when energy/power were used	Variable charge based on when distance is covered or top speed is achieved
System peak based charges (4CP, 5CP)	Extra charges based on usage when the entire system's peak occurred	A charge on speed observed when all surrounding cars were going fastest.

Electric load modeling

- A snapshot in time of power consumption at a site
- Important to capture time of day and seasonal variations in power consumption
- Users can provide input in following ways:
  - **Upload** site usage data timeseries as a CSV
  - Model **one** Department of Energy (**DOE**) Commercial Reference Building (**CRB,** https://www.energy.gov/eere/buildings/commercial-reference-buildings) load profile, such as small hotels.
  - Model a **blend** of various **DOE CRB** load profiles for buildings with multiple end uses, such as airport terminals (a blend of 24x7 operations, restaurants, office loads, shops).
- Note: optimization timesteps should match electric utility demand measurement timesteps for accurate demand charge calculations.

Thermal load modeling

- Thermal loads such as space heating loads, cooling loads, and domestic hot water heating loads can be:
  - Specified using DOE CRB load profiles
  - Fuel loads time series in MMBtu/timestep
    - Fuel costs ($/MMBtu) may be required in with thermal technologies

Demo scenarios

Interactive session to use REopt Julia package

Demo site scenario

1. Webtool example
2. Walk through API analysis repo (https://github.com/NREL/REopt-Analysis-Scripts)
3. Cost-optimal base case scenario
4. Adding an emissions constraint
5. Off grid scenarios to mimic remote isolated locations
6. Thermal loads with a heat pump

Techno-economic assumptions

Economic assumptions

Input	Assumption
Technologies evaluated	Photovoltaics, Battery Storage, GHP
Objective	Minimize lifecycle cost
Ownership models	Direct Purchase via appropriations – Government owned Third-party ownership – private ownership
Analysis period	25 years (standard analysis period and conservative life estimate)
Inflation rate	1.2% per National Institute of Standards and Technology (NIST) Handbook 135
Discount rates (nominal)	Direct ownership: 4.2% per NIST Handbook 135 Third party ownership: 6.38% per 2023 NREL Annual Technology Baseline
Electricity cost escalation rate (nominal)	National average provided by Energy Information Agency (EIA) Annual Energy Outlook 2023: 1.7%/year Region specific rates can be calculated using NIST Energy Escalation Rate Calculator (EERC)
Effective tax rate	System host/offtaker: 0% if federal or tax-exempt state entity System owner/developer: 26% if private third-party entity
Interconnection limit	Unlimited

https://www.nist.gov/publications/energy-price-indices-and-discount-factors-life-cycle-cost-analysis-2024-annual
https://pages.nist.gov/eerc/
https://www.eia.gov/outlooks/aeo/
https://atb.nrel.gov/electricity/2023/index

Technology assumptions: Solar PV

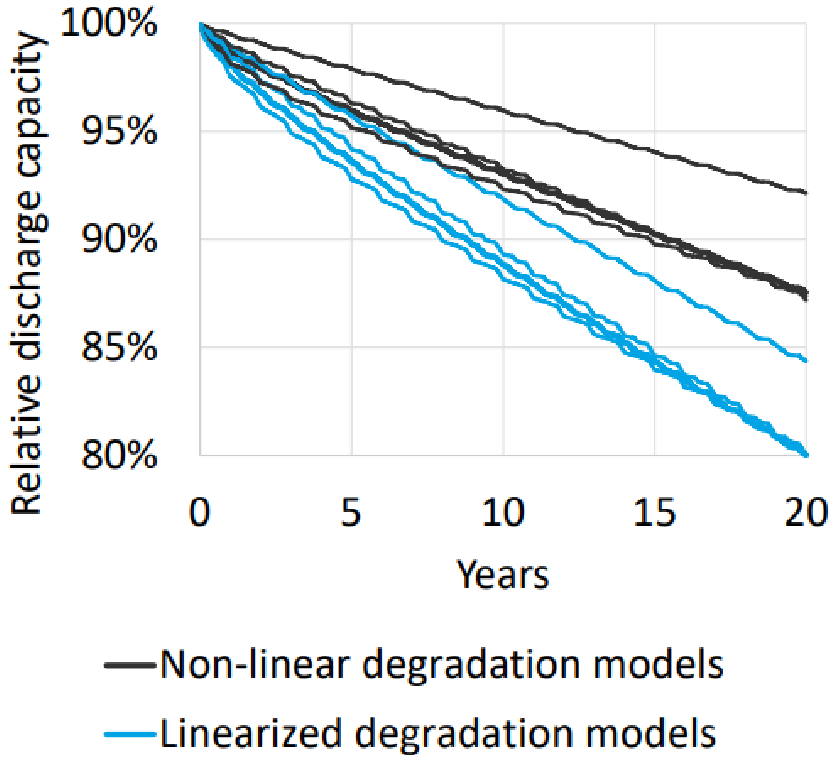
Solar PV Inputs	Assumptions
System capital cost	$1,790/kWdc
System O&M cost	$18/kWdc/year
PV Module type	Standard / premium / thin-film
Array type	Ground mount fixed / Roof mount fixed / Ground mount single axis tracking → Carport style PV can be modeled as rooftop PV with different tilt angles and capital costs.
Azimuth	180 degrees (south facing)
Tilt	20 degrees
DC to AC ratio	Default of 1.2
System losses	14%
Solar resource data (location specific)	PVWatts API v8, which utilizes 2020 solar resource TMY data from National Solar Radiation Database (NSRDB). Manual upload of PV production timeseries (units of kWhac/kWdc)
Incentives available	30% investment tax credit (ITC) Asset value depreciation using Modified Accelerated Cost Recovery System (MACRS) 5 year schedule Bonus depreciation: 60% in year 1 State, utility and production based incentives can also be modeled.

Technology assumptions: stationary battery energy storage systems (BESS)

Input	Assumption
Battery type	Lithium-ion (REopt's default battery type – efficient and long lasting)
AC-AC round trip efficiency	89.9% (97.5% internal, 96% inverter, 96% rectifier)
Minimum state of charge	20% (battery charge is managed to stay above this typical minimum)
Initial state of charge	50% (the charge at the start of the analysis period – before system charging begins)
Capital costs	$910/kW + $455/kWh
Scheduled replacement costs	$715/kW + $455/kWh in Year 10
Allow the utility grid to charge the Battery along with PV?	Yes
Incentives	30% investment tax credit (ITC) Asset value depreciation using Modified Accelerated Cost Recovery System (MACRS) 5 or 7 year schedule Bonus depreciation: 60% in year 1 Capacity and power discharged based incentives can also be modeled.

BESS degradation methodologies in REopt

Input	Assumption
Scheduled replacement	Replace the BESS energy capacity and power electronics in a predetermined year with identical system. New system is assumed to last until end of analysis period.
Degradation based replacement strategy	Replace the BESS energy capacity if its state of health (SOH) drops below 80% and keep replacing at that frequency. Account for the salvage value of BESS towards end of lifecycle.
Degradation based augmentation strategy	Replace the degraded SOH regularly (modeled as daily).



Linearized degradation model overestimates degradation, variance in degradation observed across different battery chemistry types is preserved.

https://www.nrel.gov/docs/fy23osti/85472.pdf

Useful Links

1. REopt model home page: https://www.nrel.gov/reopt/
2. REopt webtool: https://reopt.nrel.gov
3. REopt webtool user manual: https://reopt.nrel.gov/tool/reopt-user-manual.pdf
4. REopt API Wiki: https://github.com/NREL/REopt_API/wiki
5. REopt API analysis scripts: https://github.com/NREL/REopt-Analysis-Scripts
6. REopt Julia package: https://github.com/NREL/REopt.jl
7. REopt Julia package documentation: https://nrel.github.io/REopt.jl/dev/
8. NREL's Cambium database: https://www.nrel.gov/analysis/cambium.html
9. EPA AVERT database: https://www.epa.gov/avert
10. EPA eGRID database: https://www.epa.gov/egrid
11. CMU'sEASIUR tool: https://barney.ce.cmu.edu/~jinhyok/easiur/
12. URDB for electric tariffs: https://apps.openei.org/USURDB/
13. GhpGhx.jl repository: https://github.com/NREL/GhpGhx.jl
14. NREL's Wind toolkit: https://www.nrel.gov/grid/wind-toolkit.html
15. NREL's System Advisor Model (SAM): https://sam.nrel.gov/
16. DOE's Commercial Reference Building load profiles: https://www.energy.gov/eere/buildings/commercial-reference-buildings (available in web tool).
17. NIST Handbook 135: https://www.nist.gov/publications/energy-price-indices-and-discount-factors-life-cycle-cost-analysis-2024-annual
18. NIST EERC tool: https://pages.nist.gov/eerc/
19. EIA's Annual Energy Outlook: https://www.eia.gov/outlooks/aeo/
20. NREL's 2023 Annual Technology Baseline: https://atb.nrel.gov/electricity/2023/index
21. National Solar Resource Database: https://nsrdb.nrel.gov/data-viewer
22. Tax credits for business: https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses

Publications focusing on REopt

- Prefeasibility Analysis of Behind-the-Meter Distributed Energy Resources in Highland Park, MI: https://www.nrel.gov/docs/fy24osti/87988.pdf
- Optimization of energy storage system economics and controls by incorporating battery degradation costs in REopt: https://www.nrel.gov/docs/fy23osti/85472.pdf
- Towards a greener Antarctica: https://www.nrel.gov/docs/fy24osti/89240.pdf
- Impacts of Regional Air Mobility and Electrified Aircraft on Airport Electricity Infrastructure and Demand: https://www.nrel.gov/docs/fy23osti/84176.pdf
- Federal Aviation Administration Vertiport Electrical Infrastructure Study: https://www.nrel.gov/docs/fy24osti/86245.pdf

Thank you!

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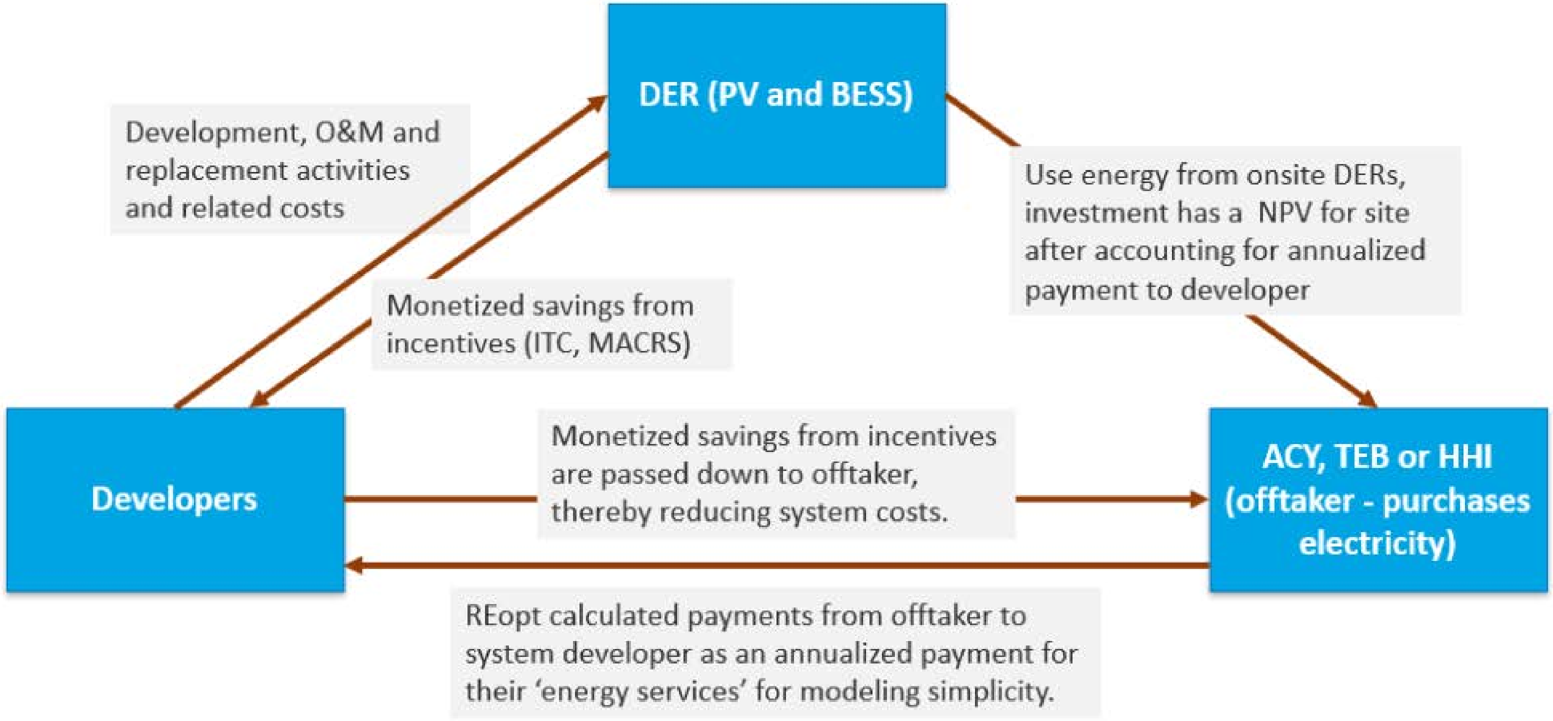
Extra slides

Third-party ownership model in REopt



The model assumes that all cost savings from incentives utilized by the third-party developer are passed down to the offtaker, or system host. The annual payment to developer from energy offtaker includes new infrastructure capital costs, O&M costs, replacement costs and developer rate of return.

Image source: Solanki, Bharatkumar, Peyton Sanders, Eric Miller, Priti Paudyal, Bhavesh Rathod, Sherinn Ann Abraham, Michael Young, Andre Fernandes Tomon Avelino, Harsha Vardhana Padullaparti, Scott Cary, Chris Hallock, Kristi Moriarty, Grant Ellwood, Jiyu Wang, Francisco Flores-Espino, Jayaraj Rane, Tony Markel, and Anuj Sanghvi. 2023. Federal Aviation Administration Vertiport Electrical Infrastructure Study. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5R00-86245. https://www.nrel.gov/docs/fy24osti/86245.pdf.

How do economic incentives come together?

Investment of $1M (tax basis) with 30% ITC, 5-year MACRS, 40% bonus depreciation, 26% effective tax rate, discount rate 6.38%.

- Reduced tax liability in year 1 after ITC: 30% of $1M = $300k
- MACRS depreciable basis after ITC = $1M*(1-50%(30%)) = $850k
- Bonus depreciation basis in year 1 = 0.4*$850k = $340k

In present value terms

Year	Depreciation rate [%]	Depreciable basis after bonus	Accelerated depreciation deduction	Net depreciation deductions (A)	Impact on tax liability (A * 0.26)
1	20%	$850k-$340k = $510k	$102k	$102k+$340k = $442k	$114.9k+$300k ITC
2	32%	$510k	$163.2k	$163.2k	$37.5k
3	19%	$510k	$96.9k	$96.9k	$20.9k
4	12%	$510k	$61.2k	$61.2k	$12.4k
5	12%	$510k	$61.2k	$61.2k	$11.7k
6	6%	$510k	$30.1k	$30.1k	$5.4k
Total tax write off present value (ITC + depreciation write offs):					*~$502.8k*

More information on incentives can be located at https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses, https://www.nrel.gov/docs/legosti/old/5173.pdf, https://www.energy.gov/sites/prod/files/2020/01/f70/Guide%20to%20the%20Federal%20Investment%20Tax%20Credit%20for%20Commercial%20Solar%20PV.pdf, https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses, REopt's economic model https://reopt.nrel.gov/tool/reopt-user-manual.pdf (Section 4)