

Behind-the-Meter Solar + Storage Modeling Tool Comparison

Kathleen Krah, NREL
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Background / Motivation

Tool Overview

Tool Capabilities and Considerations

Tool Comparison

Big Picture: Energy Modeling of BTM solar + storage

Introduction

Kathleen Krah

- Engineer, NREL's Integrated Application Center – Modeling & Analysis Team
 - Focus on techno-economic modeling and optimization of distributed energy resources for cost savings, clean energy, and resiliency targets
- BS Chemical & Biomolecular Engineering, University of Notre Dame
- MEngSc Sustainable Energy Engineering, University College Cork (Ireland)





Motivation

We've been receiving – and asking ourselves – many questions about:

- What tools should we use for different analyses?
- What assumptions are being made by the tools we're using, and how accurate are they to the actual system we're modeling?
- Where do our tools fit into the suite of tools available?
- What are the most important tool development and future modeling needs?

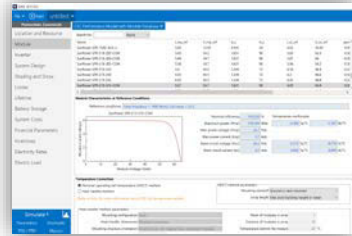
Behind-the-meter PV + storage technoeconomic modeling tools



REopt Lite

NREL

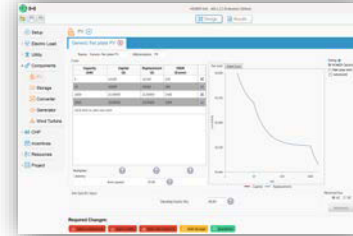
<https://reopt.nrel.gov/tool>



System Advisor Model (SAM)

NREL

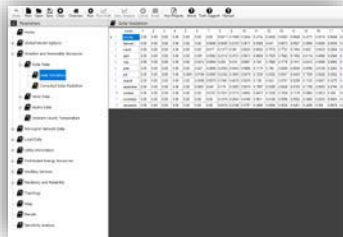
<https://sam.nrel.gov/>



HOMER Grid

HOMER Energy

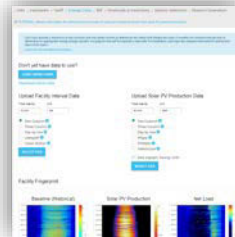
<https://www.homerenergy.com/products/grid/index.html>



**Distributed Energy Resources –
Customer Adoption Model
(DER-CAM)**

LBNL

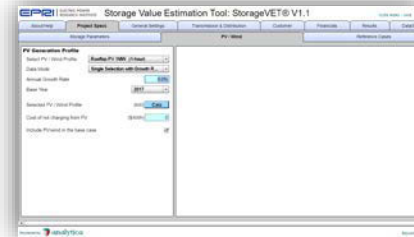
<https://building-microgrid.lbl.gov/projects/der-cam>



ESyst

Geli

<https://esyst.geli.net/>

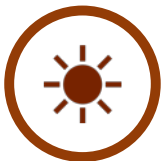


**Storage Value Estimate Tool
(StorageVET)**

EPRI

<https://storagevet.com/>

Model Capabilities to Consider



SOLAR PV MODEL

RESOURCE,
PERFORMANCE



BATTERY MODEL

PERFORMANCE,
DEGRADATION,
REPLACEMENT



UTILITIES

RATES, NET METERING,
COST ESCALATION, GRID
SERVICES



LOADS

SIMULATION,
CUSTOMIZATION, LOAD
GROWTH



ECONOMICS

COSTS, OWNERSHIP,
INCENTIVES,
DEPRECIATION, TAX



RESILIENCY

OUTAGES, CRITICAL
LOADS, BACKUP
GENERATORS



OPTIMIZATION / SIMULATION

SIZING, DISPATCH,
FORECASTING, TIME
RESOLUTION



USER INTERFACE

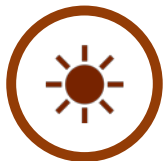
INPUTS, OUTPUTS,
USABILITY, COMPLEXITY



OTHER

EMISSIONS, POWER
FLOW, SINGLE/MULTI-
NODAL, SENSITIVITY
STUDIES, OTHER
TECHNOLOGIES

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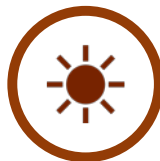
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SOLAR PV MODELS



SOLAR PV MODELS

- **Solar resource**

- NSRDB tmy2/tmy3, NASA, others
- custom

- **PV performance**

- PV output profile
- simple efficiency
- NREL PVWatts¹
- specific product lines from manufacturers
- voltage/current tracking
- temperature effects
- losses (% , detailed)
- shading (% , 3D model)
- degradation
- separate inverter model (DC-to-AC ratio, detailed)

- **Existing PV**

| Tool | SOLAR PV MODELS |
|-------------------|--|
| REopt Lite | User enters location, tool calls PVWatts using NSRDB tmy3 data. Considers existing PV. |
| SAM | Two options: 1) detailed PV model- NSRDB or custom resource data; 3D shading model and detailed losses; tracks PV module and inverter current, voltage, temperature effects, and degradation (% annual degradation); applies actual manufacturer PV and inverter specs. 2) PVWatts model- NSRDB or custom resource data; tool calls PVWatts |
| HOMER Grid | Pulls solar resource data from NREL or NASA database; HOMER synthesizes solar radiation using V.A. Graham algorithm for daily/hourly variability applied to downloaded or user-defined monthly averages. Generation calculated using equation considering generic or specific PV cell characteristics, incident solar radiation, PV cell temp, and derating factor |
| DER-CAM | Custom solar resource data. how do they calculate PV output? Inverters modeled as piecewise linear function of power in and power out- DC to AC ratio?? Considers existing PV. |
| ESyst | User uploads PVWatts, HelioScope, or PVSyst results or generic table of generation; annual % degradation; considers time-based inverter replacement |
| StorageVET | |

¹ <https://pwwatts.nrel.gov/pwwatts.php>

BATTERY MODELS



BATTERY MODELS

•Battery performance

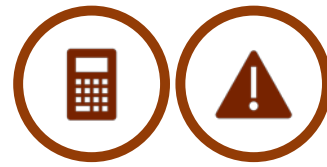
- simple efficiency
- voltage/current tracking
- temperature effects on capacity and lifetime
- battery chemistries
- specific battery product lines from manufacturers
- maximum charge/discharge rates
- strings/paralleling of batteries
- ancillary equipment losses

•Degradation

- calendar degradation
- cycling degradation
- replacement

| Tool | BATTERY MODELS |
|------------|---|
| REopt Lite | Simple roundtrip efficiency with time-based replacement |
| SAM | Two options: 1) detailed PV model- considers current and voltage measurements and constraints; temperature effects, operating point on I-V curve, maximum charge/discharge rates; different battery chemistries for voltage models and degradation; cycling and calendar degradation with option to replace based on either; applies specific manufacturer specs. 2) PVWatts model- simple roundtrip efficiency and % degradation, doesn't track current, voltage, temperature effects, operating point, etc. |
| HOMER Grid | Three models: simple battery model, kinetic battery model, modified kinetic battery model (option to consider temperature effects on capacity and lifetime); considers voltage and maximum charge/discharge power, and batteries in strings and in parallel; user selects generic or specific batteries; cycling and calendar degradation with option to replace based on either or both |
| DER-CAM | Considers efficiency, self-discharge, temperature effects? , user-specified maximum charge/discharge power. Applies cycling degradation model for Li-ion batteries to calculate capacity. replacement? AccurateBattChargeDischarge? |
| ESyst | Simple roundtrip efficiency (user-specified or from specific battery manufacturer info); User-specified calendar degradation rate + internally calculated cycling degradation model (based on information directly from battery manufacturers); replace when effective capacity reaches 80% or in calendar-based replacement year, whichever occurs first |
| StorageVET | |

OPTIMIZATION / SIMULATION, RESILIENCY



OPTIMIZATION / SIMULATION

- **Sizing**
- **Dispatch**
 - peak shaving / demand charge reduction
 - energy arbitrage
 - load control
- **Forecasting / lookahead**
- **Maximum technical potential vs expected savings**
- **Chronology and resolution of data and analysis**
- **Objective function**
 - costs (lifecycle costs, NPV, electricity costs)
 - emissions
- **Type of optimization** (MILP, grid search, simulation only)

RESILIENCY

- **Outages** (frequency, duration, planned/unplanned)
- **Critical loads** (% of full load, custom load, prioritization of load curtailment, value of lost loads)
- **Backup generators** (fuel rates, minimum load, fuel availability)

| Tool | OPTIMIZATION / SIMULATION | RESILIENCY |
|-------------------|---|------------|
| REopt Lite | MILP; optimizes PV and battery storage sizes to maximize system NPV using energy arbitrage and demand charge reduction; assumes perfect forecasting for maximum technical potential; optimization performed on one year of chronological annualized data applied to project lifetime | ✓ |
| SAM | Simulation only, parametrics for pseudo-optimization; day-ahead or day-behind peak-shaving or custom dispatch strategy- currently minimizes grid purchases, but in future will consider utility rate | --- |
| HOMER Grid | Grid search or proprietary non-derivative optimization; currently models 1 year of chronological timesteps- planned implementation of multi-year analysis in Q3 of 2018. | ✓ |
| DER-CAM | | ✓ |
| ESyst | Maximize savings on the utility bill based on interval data, PV data, and utility tariff using same algorithms used in run-time controls (forecasting/optimization/dispatch). User selects between optimal (theoretical maximum) savings, estimated savings (more realistic based on Geli load forecaster and demand charge management), and conservative savings (like estimated, but with a more conservative demand charge management) | --- |
| StorageVET | | --- |

LOADS, UTILITIES, ECONOMICS, RESILIENCY, USER EXPERIENCE, OTHER



LOADS

- **Shape**
 - DOE commercial reference buildings²
 - other generic load profiles
 - custom load input
 - outputs from UtilityAPI³, Green Button⁴, etc
- **Magnitude**
 - scaling to monthly or annual totals
- **Load growth**

UTILITIES

- **Utility rate**
 - database (URDB⁵, Genability⁶)
 - custom utility rate inputs
 - energy and demand charges; TOU, tiered, real-time, seasonal, weekend/ weekday/holiday etc.
 - post-solar rate study
- **Net metering**
 - net metering limit
 - export limitations
 - true net metering vs avoided cost payments
 - net metering accounting
- **Energy cost escalation rates**

ECONOMICS

- **Costs considered** (capital, O&M)
- **Ownership models** (direct purchase, 3rd party/PPA, etc.)
- **Financial parameters considered** (discount rates, inflation, cost escalation rates)
- **Incentives**
 - capital-based (%), such as federal ITC
 - capacity-based (\$/kW)
 - production-based (\$/kWh)
 - federal, state, utility/local
 - depreciation (straight line, MACRS, bonus MACRS)
- **Tax models**
 - income, property, sales, etc.
 - Interplay between tax and incentives

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- **Outputs (content and format)**
 - system sizing
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OTHER

- **Other technologies**
- **Emissions modeling**
- **Power flow modeling**
- **Single or multi-nodal analyses**
- **Sensitivity study capabilities**

² <https://www.energy.gov/eere/buildings/commercial-reference-buildings>;

³ <https://utilityapi.com/>; ⁴ <http://www.greenbuttondata.org/>;

⁵ https://openei.org/wiki/Utility_Rate_Database; ⁶ <https://www.genability.com/>

Thank you!

www.nrel.gov

kathleen.krah@nrel.gov

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Tool Overview

| Tool | REopt Lite | System Advisor Model (SAM) | HOMER Grid | DER-CAM | ESyst | StorageVET |
|---------------------------------|--|--|--|---|--------------------------|---------------------------------|
| Organization | NREL | NREL | HOMER Energy | Desktop | Web | Web |
| Type of application | Web | Desktop; Software development kit; Open source code | Desktop | Web and desktop | Web | Web |
| Cost/Access | Free, Publicly available | Free; Open source | For purchase | Free, Publicly available | Free, Publicly available | Free, Publicly available |
| Optimization/ Simulation | MILP | Simulation; Parametric for pseudo-optimization | - Enhanced grid search - Proprietary derivative-free optimization | MILP | Simulation | Simulation |
| Technologies | PV, battery, diesel generator, existing PV | PV, high concentration PV, wind, biomass, geothermal, solar hot water, CSP, process heat | PV, wind, CHP, boiler, electric heater, diesel generator, battery | PV, solar thermal, wind, hydro, CHP, energy storage (battery, EVs, thermal), controllable loads, HVAC | PV, battery | PV, wind, battery |
| Technology location(s) | Behind-the-meter; Resiliency (outages) | Behind-the-meter | Behind-the-meter; Resiliency (outages) | Behind-the-meter; Resiliency (outages) | Behind-the-meter | Behind-the-meter, utility-scale |

LOADS, UTILITIES, ECONOMICS



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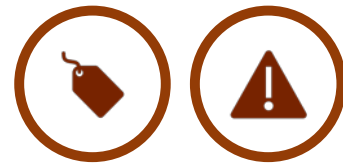
| Tool | LOADS | UTILITIES |
|------------|---|--|
| REopt Lite | DOE commercial reference buildings, custom, critical load | URDB database; custom rate planned for end of 2018. True net metering option up to net metering limit or annual load. |
| SAM | DOE commercial reference buildings, custom | URDB database, custom rates; several net metering options |
| HOMER Grid | DOE commercial reference buildings; generic commercial, industrial, residential, community loads; custom; critical load | Genability database for commercial North American tariffs; detailed custom tariff builder. Net metering based on rate. User can also set a kW grid sale limit. |
| DER-CAM | Typical weekday, weekend, and “peak day” load for each month; load database based on ASHRAE regions- DOE commercial reference buildings? | Limited options for representative existing rates in select cities. Also custom rate input option- TOU, tiered, or hourly energy charges, coincident, non-coincident, and TOU daily and monthly demand charges. |
| ESyst | Custom load, incl. UtilityAPI and Green Button outputs | Genability database for commercial North American tariffs; custom rate planned for upcoming release. Net metering based on rate, with NEM and NEM2.0 for CA rates. User can select separate post-solar utility rate. |
| StorageVET | | |

² <https://www.energy.gov/eere/buildings/commercial-reference-buildings>;

³ <https://utilityapi.com/>; ⁴ <http://www.greenbuttondata.org/>;

⁵ https://openei.org/wiki/Utility_Rate_Database; ⁶ <https://www.genability.com/>

ECONOMICS & RESILIENCY



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| | Ownership model | Tax models | Incentives | Depreciation | Resiliency |
|-------------------|---|--|--|---|---|
| REopt Lite | Direct | One overall rate | PV: federal, state, utility-capital/capacity-based; total production-based. Battery: federal % capital | PV, storage: 5-yr, 7-yr MACRS, none | Recommends system sizes to meet critical load during outage(s); outage modeled as annual or once per system lifetime; considers existing backup generator |
| SAM | Direct; 3 rd party/PPA; others | Sales, | Overall: federal and state ITC, PTC; federal, state, utility, other direct cash, capacity-based, and production-based incentives- user select whether taxable and whether reduces depreciation and ITC bases | Overall: 5-yr, 7-yr MACRS, straight line, custom | --- |
| Homer Grid | Direct | Individual marginal tax rate applied to each incentive | PV, wind, storage: ITC; SGIP; custom capital/capacity-based and production-based; user selects portion eligible for each incentive | PV, wind, storage: 5-yr, 7-yr MACRS, bonus MACRS, straight line, custom, none | User-defined outage duration and frequency- for outage frequency, models with and without outage and calculates weighted average of LCC |
| DER-CAM | Direct | --- | | | |
| ESyst | Direct | Federal and state income tax; state and city/county sales tax; utility tax | PV, overall: ITC. Overall: custom direct cash, capacity-based, production-based | Overall: federal and state 5-yr, 7-yr MACRS, 100% bonus MACRS, straight line | --- |
| StorageVET | Direct | | | | |

USER EXPERIENCE & OTHER



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- **Emissions modeling**
- **Power flow modeling**
- **Single or multi-nodal analyses**
- **Sensitivity study capabilities**

| Tool | ACCESS | OUTPUTS | OTHER |
|------------|---|--|--|
| REopt Lite | Web interface, free. | Interactive proforma and annual/lifecycle costs summary | REopt Lite is a simplified version of a highly customizable desktop model that includes other technologies, developed and used at NREL for optimization analyses |
| SAM | Desktop interface with software development kit and open source code, free. | Interactive proforma and annual/lifecycle costs summary with detailed D-VIEW plots and CSVs of hourly, monthly, annual, lifecycle data | Sensitivity studies, P50/P90 analyses <i>Other technologies: high concentration PV, wind, biomass, geothermal, solar hot water, CSP, process heat</i> |
| HOMER Grid | Desktop interface, paid license. | Interactive proforma and annual/lifecycle costs summary with detailed D-VIEW plots and CSVs of hourly, monthly, annual, lifecycle data | <i>Other technologies: wind, CHP, boiler, electric heater, diesel generator</i> HOMER Energy's other tool, HOMER Pro, focuses on off-grid systems, while HOMER Grid focuses on behind-the-meter systems |
| DER-CAM | Web and desktop interfaces, free. User account saves models. | Outputs | Multi-nodal; power flow modeling; emissions modeling; sensitivity studies <i>Other technologies: solar thermal, wind, hydro, CHP, EVs, thermal storage, controllable loads, HVAC</i> |
| ESyst | Web interface, free. User account saves models and results. | Interactive proforma and PDF report with visuals illustrating costs/benefits | Geli maintains commercial relationships with system integrators and provides a path forward beyond ESyst for users looking for hardware quotes and deploying an energy storage project |
| StorageVET | Web interface, free. User account with saved models. | XXX | <i>Other technologies: wind</i> XXX |