Behind-the-Meter Solar + Storage Modeling Tool Comparison

Kathleen Krah, NREL
ASES Solar 2018 – Boulder, CO
August 2, 2018

Background / Motivation

Tool Overview

Modeling Capabilities and Considerations

Tool Comparison

Introduction

Kathleen Krah

Engineer, NREL's Integrated Application Center – Modeling & Analysis Group

- Focus on techno-economic modeling and optimization of distributed energy resources for cost savings, clean energy, and resiliency targets

Background

- BS Chemical & Biomolecular Engineering, University of Notre Dame
- MEngSc Sustainable Energy Engineering, University College Cork (Ireland)
  - Researcher, Energy Policy and Modeling Group

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?
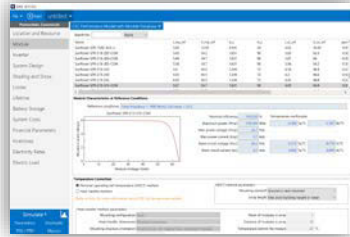- What are the most important tool development and future modeling needs?

Behind-the-meter PV + storage techno-economic modeling tools

REopt Lite
NREL
https://reopt.nrel.gov/tool
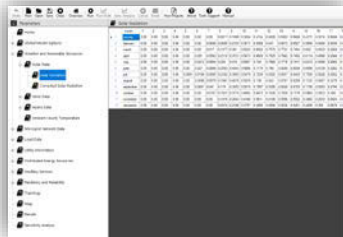

System Advisor Model (SAM)
NREL
https://sam.nrel.gov/

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/
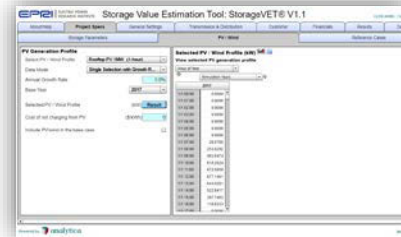
Storage Value Estimate Tool (StorageVET)
EPRI
https://storagevet.com/
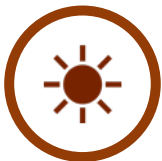
Model Capabilities to Consider

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

ACCESS, INPUTS, OUTPUTS, USABILITY, COMPLEXITY

OTHER

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

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

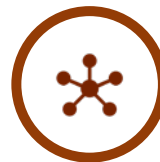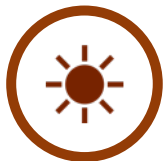**RESILIENCY**

OUTAGES, CRITICAL LOADS, BACKUP GENERATORS

OPTIMIZATION / SIMULATION

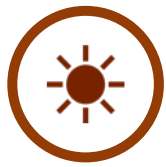SIZING, DISPATCH, FORECASTING, TIME RESOLUTION

USER INTERFACE

INPUTS, OUTPUTS, USABILITY, COMPLEXITY

OTHER

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

SOLAR PV MODELS

SOLAR PV MODELS

- **Solar resource**
  - NSRDB[1] tmy2/tmy3, NASA, others
  - custom
- **PV performance**
  - PV output profile
  - simple efficiency
  - NREL PVWatts[2]
  - specific product lines from manufacturers
  - voltage/current tracking
  - temperature effects
  - losses (%, detailed)
  - shading (%, 3D model)
  - degradation
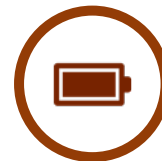 - separate inverter model (DC-to-AC ratio, detailed)
- **Existing PV**

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 or Suneye/other shading data; 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, internal model of PV generation- upcoming release will also allow user to upload PV generation profile. Inverters modeled as piecewise linear function of power in and power out. Considers existing PV.
ESyst	User uploads PVWatts, HelioScope[3], or PVSyst[4] results or generic table of generation; annual % degradation; considers time-based inverter replacement
StorageVET	User uploads PV production profile

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
- **Battery charging constraints**

Tool	BATTERY MODELS
REopt Lite	Basic 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- basic 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, and user-specified maximum charge/discharge power and average temperature. Applies cycling degradation model for Li-ion batteries to calculate capacity. Because set up as typical days in each month, constraint on daily start/finish state of charge.
ESyst	Basic 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	Basic user-specified parameters- charge/discharge capacities and efficiencies, self-discharge, cycling degradation table and calendar degradation (options for default Li-ion parameters). Battery SOC reset daily.

OPTIMIZATION / SIMULATION, RESILIENCY
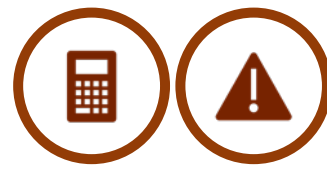
OPTIMIZATION / SIMULATION

- **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 annualized chronological 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	MILP; non-chronological- typical weekday, weekend, and "peak" day profiles for each month, summed up. Value stacking for total system costs/savings. Allows for discrete or continuous system sizing optimization. Objective function can minimize LCC*, minimize CO_2 emissions, or perform a weighted multi-objective optimization. Public version is annualized single year optimization.	✔
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	User specifies system sizes and selects which value streams are considered (frequency regulation, spinning/non-spinning reserve, demand charge reduction, energy arbitrage, backup power (resiliency), demand response). StorageVET optimizes dispatch with MILP to calculate system value. Assumes perfect foresight over 6-day chunks for resetting peak load constraint, co-optimizing with other value streams. User specifies dispatch interval and simulation years (other years interpolated), and whether PV is considered base case or investment case	✔

*MILP: mixed integer linear program. NPV: net present value. LCC: lifecycle costs

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

LOADS

- **Shape**
  - DOE commercial reference buildings[5]
  - other generic load profiles
  - custom load input
  - outputs from UtilityAPI[6], Green Button[7], etc
- **Magnitude**
  - scaling to monthly or annual totals
- **Load growth**

UTILITIES

- **Utility rate**
  - database (URDB[8], Genability[9])
  - 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

RESILIENCY

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

USER EXPERIENCE

- **Access, cost**
- **User account**
- **Inputs (user expertise and data requirements)**
- data requirements and level of detail and expertise desired for stage and emphasis of analysis
- tradeoff between simplicity vs customizability
- **Outputs (content and format)**
- system sizing
- dispatch
- maximum technical potential vs expected savings
- proforma (interactive with formulas vs static)

OTHER

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

[5] https://www.energy.gov/eere/buildings/commercial-reference-buildings;
[6] https://utilityapi.com/;
[7] http://www.greenbuttondata.org/;
[8] https://openei.org/wiki/Utility_Rate_Database;
[9] https://www.genability.com/

Thank you!

www.nrel.gov

Kathleen Krah

kathleen.krah@nrel.gov

NREL/PR-7A40-71804

LOADS, UTILITIES

LOADS

- **Shape**
  - DOE commercial reference buildings[5]
  - other generic load profiles
  - custom load input
  - outputs from UtilityAPI[6], Green Button[7], etc
- **Magnitude**
  - scaling to monthly or annual totals
- **Load growth**

UTILITIES

- **Utility rate**
  - database (URDB[8], Genability[9])
  - 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**

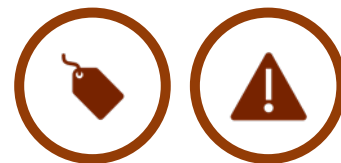| Tool	LOADS	UTILITIES
REopt Lite	Scalable DOE commercial reference buildings, custom, critical load	URDB database; custom rate planned for end of 2018. True net metering option up to net metering limit or annual load.
SAM	DOE commercial reference buildings, custom	URDB database, custom rates; several 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; scalable 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 NEM 2.0 for CA rates. User can select separate post-solar utility rate.
StorageVET	Custom load	Several example rates pre-loaded, otherwise user uploads custom rate. User specifies interconnection/export/net metering constraints.

[5] https://www.energy.gov/eere/buildings/commercial-reference-buildings;
[6] https://utilityapi.com/;
[7] http://www.greenbuttondata.org/;
[8] https://openei.org/wiki/Utility_Rate_Database;
[9] https://www.genability.com/

ECONOMICS, RESILIENCY

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

RESILIENCY

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

Tool	Ownership models	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-, 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, 3rd party/PPA, others	Federal and state income tax, sales tax, property tax, insurance	Overall: federal and state ITC, PTC; federal, state, utility, other direct cash, capacity-based, and production-based incentives- user selects whether taxable and whether reduces depreciation and ITC bases	Overall: 5-, 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-, 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	---	User accounts for in capital costs	User accounts for in capital costs	Planned and unplanned outages, but model has perfect foresight.
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-, 7-yr MACRS, 100% bonus MACRS, straight line	---
StorageVET	Direct (also IPP, IOU, POU/muni, co-op)	Federal and state income tax, property tax	Overall: Federal ITC (user-specified), SGIP, generic capacity-based incentive	Overall: 3-, 5-, 7-, 10-yr MACRS	Value of backup power calculated based on user-specified outage probability, SOC reservation backup power, VoLL. User responsible for sizing system to provide backup.

USER EXPERIENCE & OTHER

USER EXPERIENCE

- **Access, cost**
- **User account**
- **Inputs (user expertise and data requirements)**
  - data requirements and level of detail and expertise desired for stage and emphasis of analysis
  - tradeoff between simplicity vs customizability
- **Outputs (content and format)**
  - system sizing
  - dispatch
  - maximum technical potential vs expected savings
  - proforma (interactive with formulas vs static)

OTHER

- **Other technologies**
- **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 *Other technologies: high concentration PV, wind, biomass, geothermal, solar hot water, CSP, process heat*
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	*Other technologies: wind, CHP, boiler, electric heater, diesel generator* 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.	Annual summaries	Highly customizable; multi-nodal; power flow modeling; emissions modeling; sensitivity studies *Other technologies: solar thermal, wind, hydro, CHP, EVs, thermal storage, controllable loads, HVAC*
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.	Downloadable hourly and summary dispatch and financial tables.	StorageVET is currently implemented for DC coupling of PV + storage + load. Thus, some inputs for behind-the-meter systems are somewhat non-intuitive. *Other technologies: wind* However, StorageVET has extensive value stream modeling capabilities, especially for T&D systems (day ahead and real time energy time shift, resource adequacy capacity, flexible ramping, power quality, investment deferral).

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