



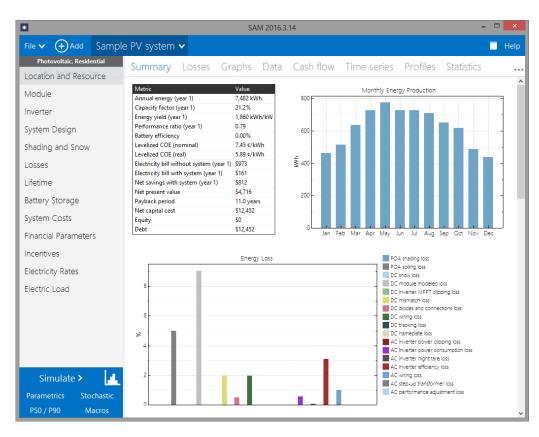
Recent updates to the System Advisor Model (SAM)

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9th PV Performance Modeling Workshop December 5, 2017

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

Free software that combines detailed performance and financial models to estimate the cost of energy for systems



http://sam.nrel.gov/download

Offerings

Desktop application Scripting Software Development Kit (SDK) Open source code

Technologies

Photovoltaics (detailed & PVWatts) Battery storage Concentrating solar power Wind Multiple other technologies

Financials

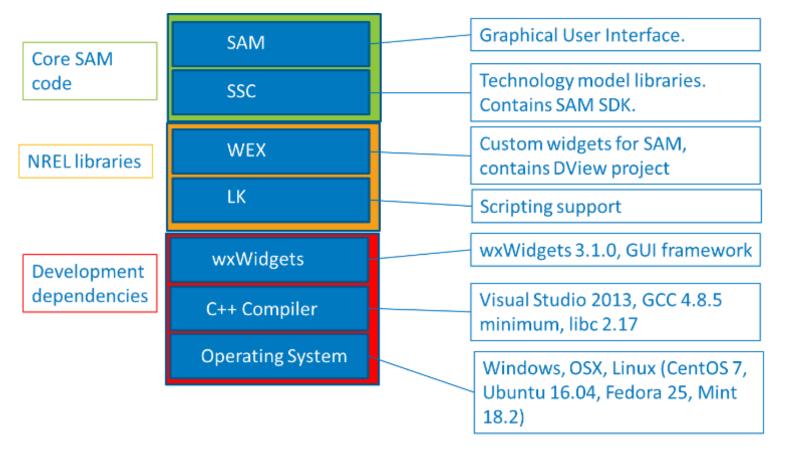
Behind-the-meter Power purchase agreements Simple LCOE calculator

Platforms

Windows, Mac OSX, Linux

- NREL open sourced the SAM code in August 2017 on GitHub
- Permissive corporate license. Non-profits must keep code changes publicly available.
- NREL still actively developing and supporting official releases
- This is the newest in the many ways to interact with SAM, including scripting, the SDK, etc.
- Increased transparency, flexibility, and collaboration opportunities.
- We are excited to continue working on SAM and fostering a new community of contributors.

Open Source Code



- Open-sourced all four NREL repositories
- Comprehensive build instructions

Code Locations

wxWidgets	https://www.wxwidgets.org/downloads/
GoogleTest	https://github.com/google/googletest
LK	https://github.com/NREL/lk
WEX	https://github.com/NREL/wex
SSC	https://github.com/NREL/ssc
SAM	https://github.com/NREL/SAM

NRFL / SAM		⊕ Watch + 5 ★ Unstar 1 ÿfork	
O Code 🛛 🕅	ues D 📋 Pull requests D 🔃 Projects D 🔛 Wild In	nights +	
stern Advisor M	siid (SAM)		
(F 1,882 (onnits ¥ 31 branches	© 0 releases	
kan bahada per	Reception period	Coste une Sie Uphoal Sies Find Sie Onne in doordood -	
👷 sjanzou commit	ed on GitiHub Merge pull request this from NBEL/dearup, warnings	Latest commit sources 5 hours ago	
Sanda	Adding linux Sandia bin files to fix linux build	5 hours age	
buildJinus	SAM opensource branch clean up for public release	9 daya ago	
build_ox	Add git attributes to ignore ownen directories from linguist. 5 days ago		
build_ve2018	Add more notes to bettery UI	4 days ago	
deploy	usability	4 days ago	
resource	Gean-op SAM repeatory, more doc like to SAM-documentation, etc. 13 days ag		
shadecale	Merge problems, forcing files to be the GiHub head a month ag		
src	Merge branch 'develop' into cleanup_warnings	5 hours ago	
) gitattributes	Add git attributes to ignore certain directories from linguist	5 days ago	

If you are new to Git and GitHub, please checkout: <u>https://guides.github.com/</u> IEC61853 Single Diode Model 🗸

★ Irradiance

Transposition using Isotropic, HDKR, or Perez Measured plane of array (POA) input

Shading

Irregular obstruction shading from 3D scene Self-shading for regularly spaced rows

External input from SunEye, Solar Pathfinder

Snow cover loss model

Module

Simple efficiency model

Single diode model (CEC database or datasheet)

Extended single diode model (for IEC-61853 tests)

Sandia PV Array Performance Model

Inverter

Sandia/CEC grid-tied inverter model

Datasheet part-load efficiency curve

System

Sizing wizard or electrical layout
 Multiple subarrays

Fixed, 1 axis, backtracking, azimuth axis, 2 axis

★ Battery storage

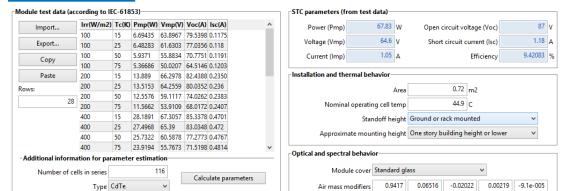
Degradation

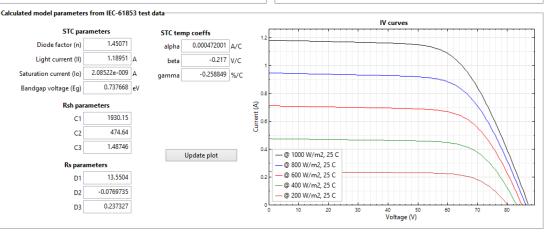
Extrapolated single year

Lifetime simulation of all years

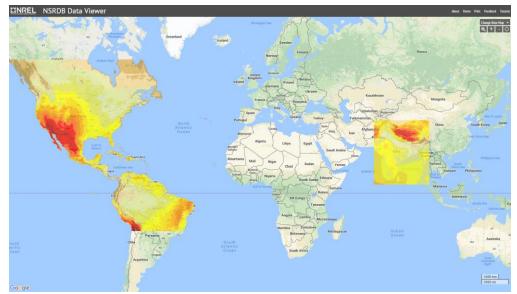
Simulation

1 minute to 1 hour time steps





Integration with NSRDB data



National Solar Radiation Database

- Collection of hourly and half-hourly solar irradiation and meteorological data
- U.S data 4x4 km spatial resolution, 30 minute temporal resolution from 1998-2014. Older data available.
- International data available in Mexico and Central and South America, South Asia.

SAM Integration

- Simple interface
- Options for choosing specific data sets

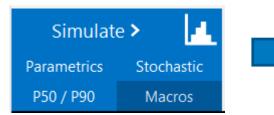
PVWatts Integration

- Upcoming
- Will replace TMY2 as standard dataset

* SAM 2017.9.5

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rcial	NREL National Solar Radiation Database (NSRDB)	
		r most long-term cash flow analyse:
	Download a weather file for your location Choose files to download (advanced)	Map on NSRDB website
		SAM weather data website
		solar resource library.
	Enter your location as a street address or latitude and longitude, for example: 15031 denver west parkway golden co	,
	40.1,-109.3	
	The email address you used to register SAM will be sent to the NSRDB at NREL. If you do not want share your email addr	ress with the NSRDB, click Cancel n
		OK Cancel
	cial	NREL National Solar Radiation Database (NSRDB) Download the latest weather files from the NSRDB to add to your solar resource library: Download a typical-year (TMY) file for choose files to download for single-year or P50/P90 analyses. See Help for details. Download a weather file for your location Download Typical-year (TMY) Weather File from NSRDB Use this window to download a typical-year (TMY) file from the NSRDB to a folder on your computer and add it to your Enter your location as a street address or latitude and longitude, for example: 15031 denver west parkway golden co

PV System Sizing



Append	Snow	Data
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System Sizing Information

Download Electric Load

Value of RE System

Run macro 🗲		View code
System Sizing Information	Light Induced Degradation (%):	1
	Annual Panel Degradation (%):	1
This macro provides information to help in sizing your system.	Suggestions for other modules:	1) From same manufacturer 🗸
It also provides suggestions for: (1) number of strings (2) other modules (from CEC Module database and Sandia Module database) to reduce the clipping losses	Allowable clipping time (hrs):	100

Sizing goals

- For current system, optimize the number of modules per string and strings in parallel to reduce clipping losses
- Allowable clipping is user-specified

Instructions:

- 1. Provide the Light Induced Degradation value and Annual Panel Degradation
- 2. Specify whether suggestions for other modules should be from the same manufacturer or all the manufacturers
- 3. Specify threshold for allowable clipping time.

PV System Sizing Results

Inverter Sizing Results

String Sizing Information

Sizing information reported for case: Sizing Macro

Tips for system design

The maximum voltage produced by the array under open circuit condition is 831.387 V

This is ok as it is below the inverter's maximum voltage rating.

You have 12 modules per string. The maximum number of modules per string should be 14 for the given case.

1401.18 kWh is being clipped.

Suggestions for reducing clipping time.

1. By reducing number of strings:

The number of strings should be reduced by 7 to reduce clipping losses

2. By changing the modules used in string

Module suggestions to reduce clipping loss

- SunPower PL-SUNP-SPR-305

DC-AC Ratio

 The effective Year 25 DC-AC ratio is computed after light-induced degradation and annual m

 Nameplate DC-AC Ratio
 1.22279

 Effective DC-AC Ratio, Year 1
 1.21057

 Effective DC-AC Ratio, Year 25
 0.941603

First Year Inverter Clipping Losses

	Power Limiting	MPPT Voltage Limiting
Number of Hours Clipped	195	919
Total kWh (AC) lost	1401.18	348.693
% of AC Power lost	0.335863	0.0837934
% of DC Power lost	0.32962	0.069696

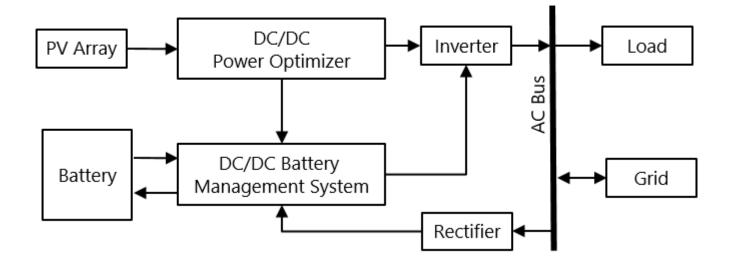
Inverter MPPT Performance

Inverter Specifications	V	Actual System Voltages	Subarray 1
MPPT Voltage Minimum	570	Actual Voltage Minimum	570
MPPT Voltage Maximum	800	Actual Voltage Maximum	683.539
Maximum Allowable Voltage	1000	Actual Maximum Voltage	683.539

Results summary

- Recommended layout of modules
- Options for modules that could reduce clipping
- System properties and metrics

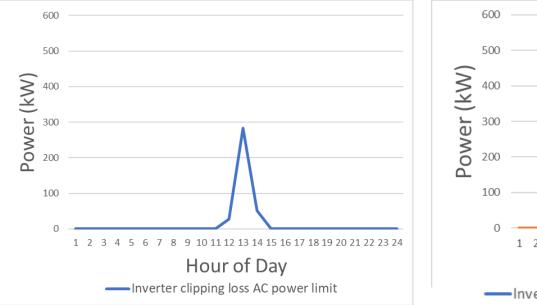
Photovoltaics with DC-connected batteries



Possible reasons for connecting battery on DC-side

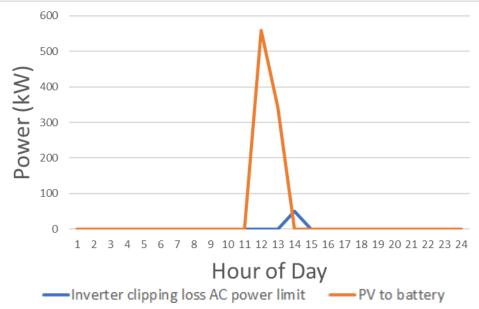
- Leverage existing PV power electronics
- Install higher DC-AC ratio systems
 - capture energy from PV array which would otherwise be clipped
 - Discharge battery during times of low PV production
- PV Grid integration in locations encouraging self consumption (no NEM).
- Powering a DC-microgrid

Capturing clipped power



PV clipping with no battery

PV clipping with DC-connected battery



- Strategically discharge battery to:
 - Level off PV output
 - Reduce state-of-charge and prepare to accept clipped PV power

Upcoming 2017 and 2018 improvements

- Addition of Sandia and NREL developed Bifacial model
- Support for multiple MPPT inputs
- Inverter thermal modeling
- Continued improvement of dispatch controllers
 - Automated dispatch for DCconnected battery storage systems



 $\circ~$ Integration with NREL REopt

- Website:
 - o sam.nrel.gov
- Open source code:
 - o https://github.com/NREL/SAM

Thank You!

www.nrel.gov



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Extra Slides

www.nrel.gov



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REopt Lite: reopt.nrel.gov

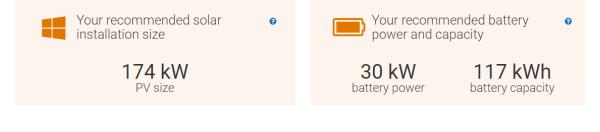
Web app and upcoming API that optimizes solar plus storage combination, size, and dispatch to minimize lifecycle costs.

Results for Your Site

G Edit Inputs

These results from REopt Lite summarize the economic viability of PV and battery storage at your site. You can edit your inputs to see how changes to your energy strategies affect the results.





Accessing REopt	Link
Website	https://reopt.nrel.gov/tool

API will be available in the next few months. See the REopt website to learn more.

Technologies

Photovoltaics Battery Storage

Financials

Behind-the-meter

Inputs:

Location (uses PVWatts for PV) Electric load Utility rate (uses URDB for rates) Site financial information PV and storage costs

Outputs:

Optimal system sizes Annual savings Financial metrics Optimal dispatch graph Annual cash flow

Transparency

• Look at the underlying code of a model that you are interested in.

Flexibility

- Change the way a model works for research purposes
- Change electricity rate models to be specific to your country

Collaboration

- Add new technology models
- Add a new battery dispatch model

We'd love to learn how you use SAM's open-source code! It helps us tailor our efforts.

Code licenses (LK and WEX)

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 - Want to encourage companies to use SSC and SAM as a foundation for growing their business in a fairly unrestricted way.
 - Want to encourage research institutions to share back any new innovations or make them publicly available so that the community as a whole benefits.
- Please see full license here:
 - <u>https://github.com/NREL/SAM/blob/develop/LICENSE.md</u>