



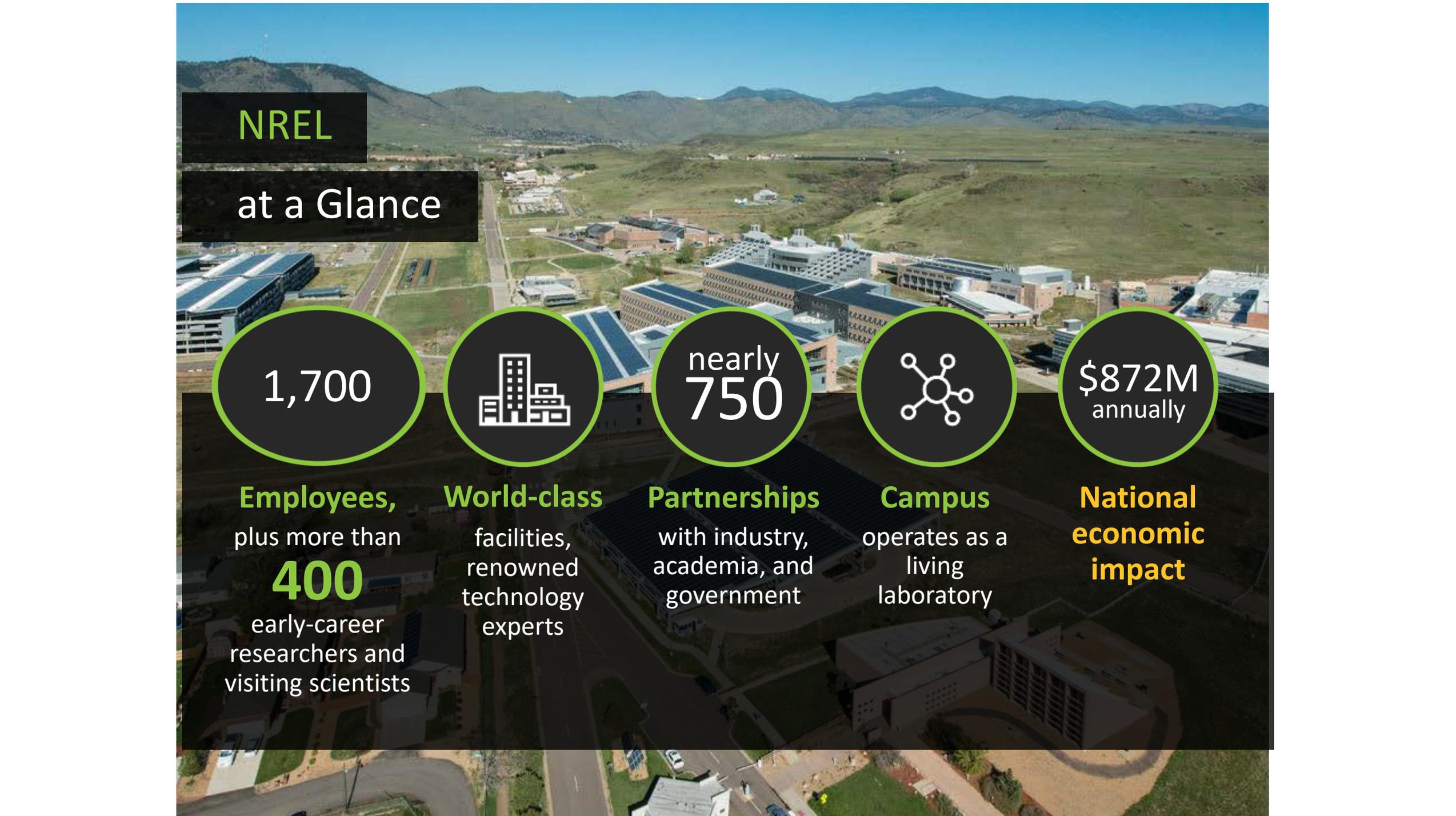
Solar System Modeling at NREL

Solar Power International 2018

Nick DiOrio

September 24, 2018

NREL/PR-6A20-72547



NREL

at a Glance

1,700

Employees,
plus more than
400
early-career
researchers and
visiting scientists



World-class
facilities,
renowned
technology
experts

nearly
750

Partnerships
with industry,
academia, and
government



Campus
operates as a
living
laboratory

\$872M
annually

**National
economic
impact**

Science Drives Innovation



Renewable Power

Solar
Wind
Water
Geothermal



Sustainable Transportation

Bioenergy
Vehicle Technologies
Hydrogen



Energy Efficiency

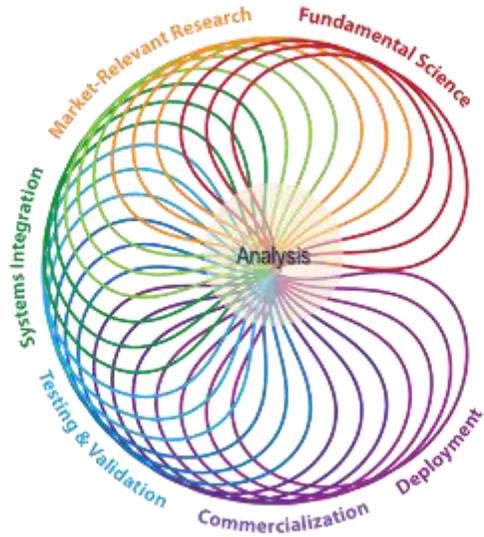
Buildings
Advanced Manufacturing
Government Energy Management



Energy Systems Integration

High-Performance Computing
Data and Visualizations

Partnerships are key



**Leveraging
Knowledge and
Knowhow to
Address Energy
Challenges**



Workshop agenda

8:00	Workshop introduction	Nick DiOrio (NREL)
8:10	Introduction to NREL tools and data	Nate Blair (NREL)
8:25	PVWatts – Overview and demo	Janine Freeman (NREL)
8:45	National Solar Radiation Database (NSRDB)	Aron Habte (NREL)
9:15	REopt Lite Introduction	Nick DiOrio (NREL)
9:25	RdTools	Nick DiOrio (NREL)
9:55	Break	
10:10	SAM bifacial and battery modeling	Nick DiOrio (NREL)
11:10	Additional NREL tools	Nate Blair (NREL)
11:40	American-Made Challenge Solar Price	Debbie Brodt-Giles (NREL)
11:45	Questions and break out	

Questions

Slido - Audience Interaction Mac x +

https://www.sli.do

Product Use cases Pricing Resources

LOG IN SIGN UP

Every Question Matters.

The Ultimate Q&A and Polling Platform for Company Meetings and Events

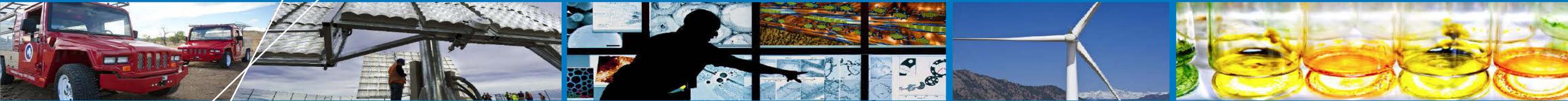
NRELSPI JOIN or SIGN UP

By using this app I agree to the [Acceptable Use Policy](#) [request a demo](#)

www.sli.do

[#NRELSPI](https://twitter.com/NRELSPI)

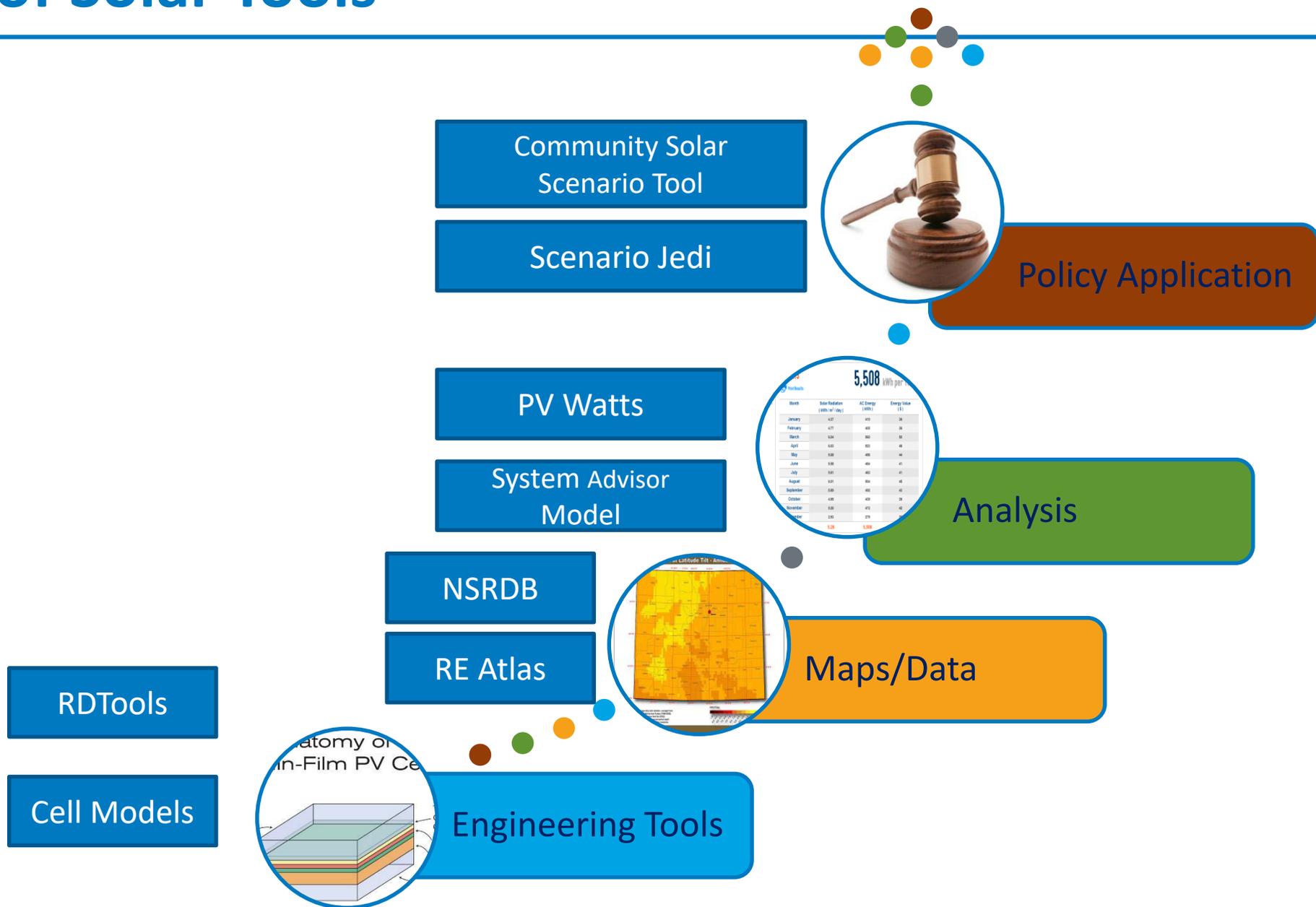
Overview of NREL Solar Data and Tools



Nate Blair

Group Manager

Range of Solar Tools



Types of Questions

- **Data – cost comparisons between technologies**
- **Data – How good is the resource?**
- **Analysis – How much will PV produce here?**
- **Analysis – what's the impact of energy efficiency option for my house?**
- **Policy – How many jobs will this project create?**

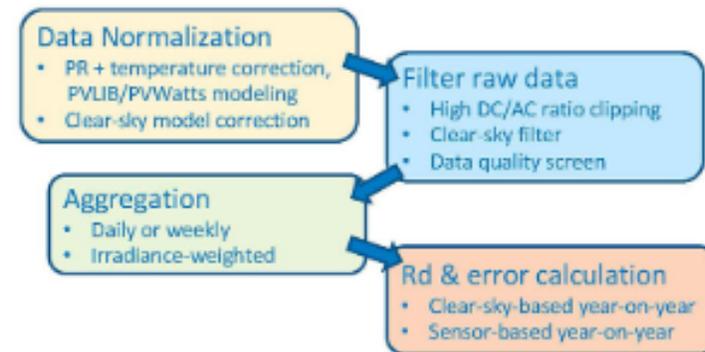
Engineering Model Example

Accurate Degradation Rate Calculation with RdTools

Tool enables accurate time-series photovoltaic data and new insights into technology performance.

RdTools is a set of Python scripts and software for analysis of photovoltaic time-series data. The open-source tools were developed in collaboration with industry to bring together best practices and years of degradation research from NREL. Although the toolkit can be used for many useful PV analysis purposes, the primary use is to evaluate degradation rates over time.

The software can be accessed from the [GitHub repo](https://www.nrel.gov/pv/rdtools.html) with installation instructions and usage examples provided.

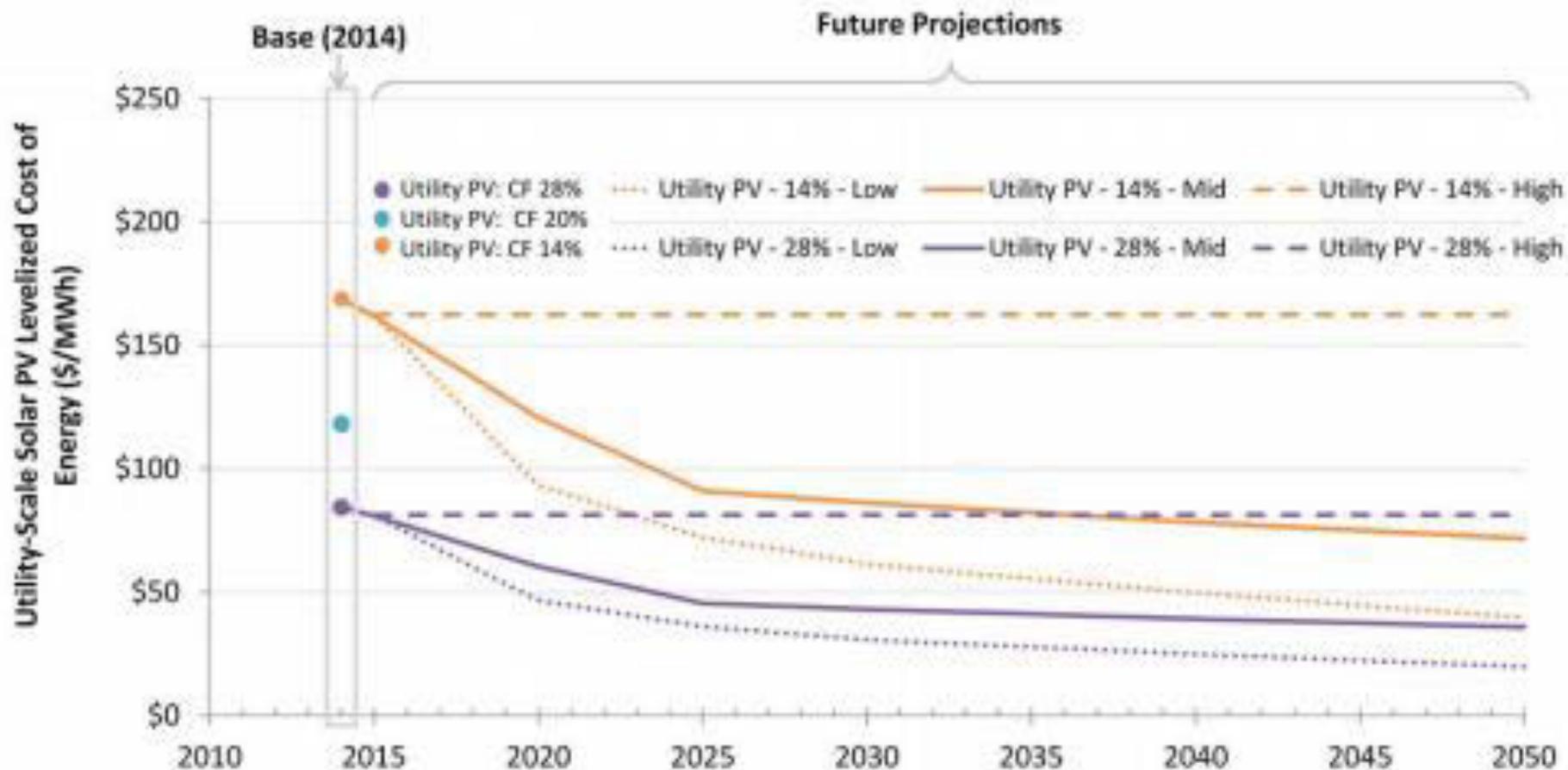


RdTools workflow involves four major steps: Data Normalization, Data Filtering, Aggregation and Degradation rate calculation.

<https://www.nrel.gov/pv/rdtools.html>

Annual Technology Baseline (Solar PV example)

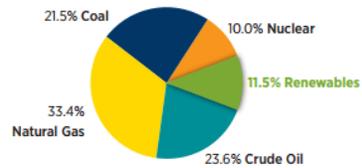
http://www.nrel.gov/analysis/data_tech_baseline.html



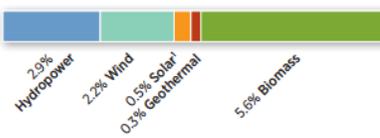
- In general, the degree of adoption of a range of technology innovations distinguishes between the low, mid and high cost cases.
- The range of LCOE in 2050 associated with variation in solar resource across the U.S. is reduced from \$81-163/MWh for High Cost to \$20-40/MWh for Low Cost reduction scenarios.

U.S. Energy Production and Consumption (2015)

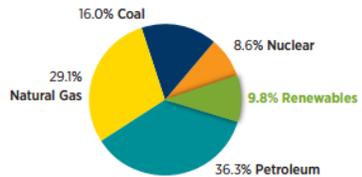
U.S. Energy Production (2015): 83.5 Quadrillion Btu



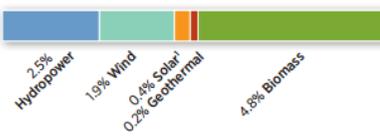
U.S. Renewable Energy Production: 9.6 Quadrillion Btu



U.S. Energy Consumption (2015): 97.7 Quadrillion Btu



U.S. Renewable Energy Consumption: 9.6 Quadrillion Btu

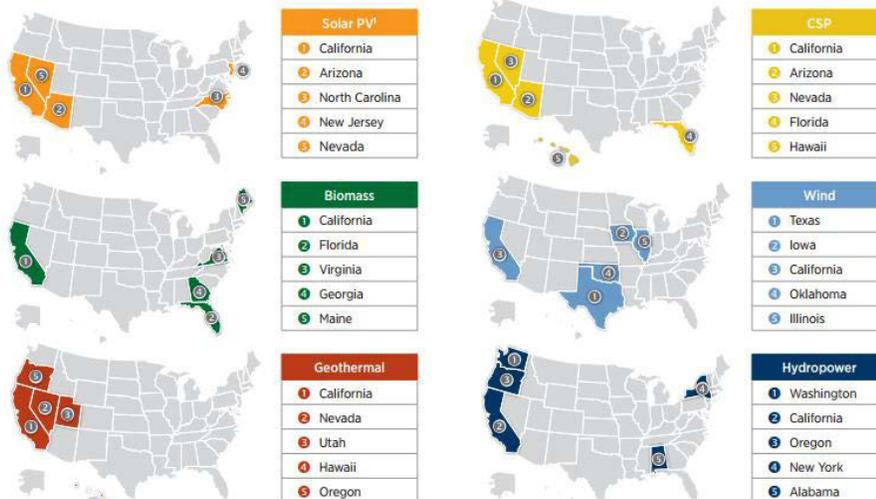


Source: U.S. Energy Information Administration (EIA)

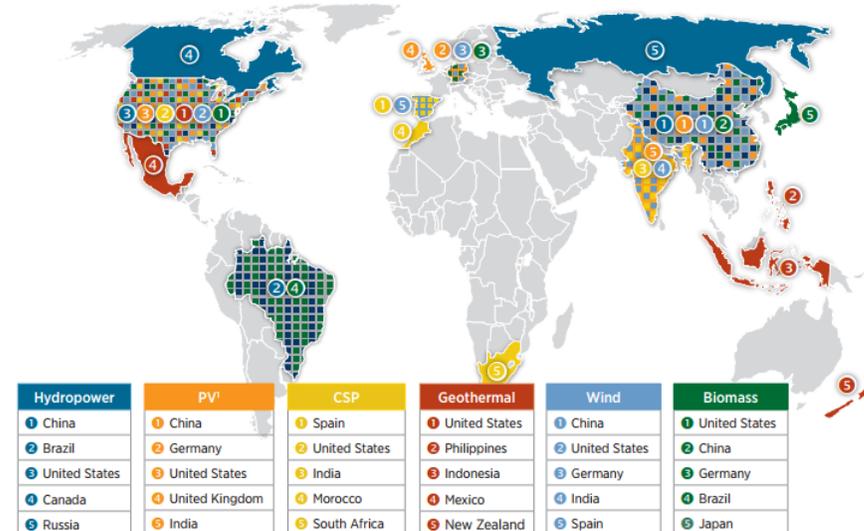
U.S. RE Capacity as % of Total Generating Capacity

Year	Hydropower	Solar PV ¹	CSP	Wind	Geothermal	Biomass	Total Renewables
2005	7.4%	0.0%	0.0%	0.9%	0.3%	1.1%	9.7%
2006	7.3%	0.0%	0.0%	1.1%	0.3%	1.1%	9.9%
2007	7.3%	0.0%	0.0%	1.6%	0.3%	1.1%	10.3%
2008	7.2%	0.1%	0.0%	2.3%	0.3%	1.2%	11.1%
2009	7.1%	0.1%	0.0%	3.2%	0.3%	1.2%	11.9%
2010	7.0%	0.1%	0.0%	3.6%	0.3%	1.2%	12.2%
2011	6.9%	0.3%	0.0%	4.1%	0.3%	1.2%	12.8%
2012	6.8%	0.5%	0.0%	5.2%	0.3%	1.2%	14.1%
2013	6.8%	0.8%	0.1%	5.3%	0.3%	1.3%	14.6%
2014	6.8%	1.2%	0.1%	5.7%	0.3%	1.3%	15.5%
2015	6.8%	1.7%	0.2%	6.4%	0.3%	1.4%	16.7%

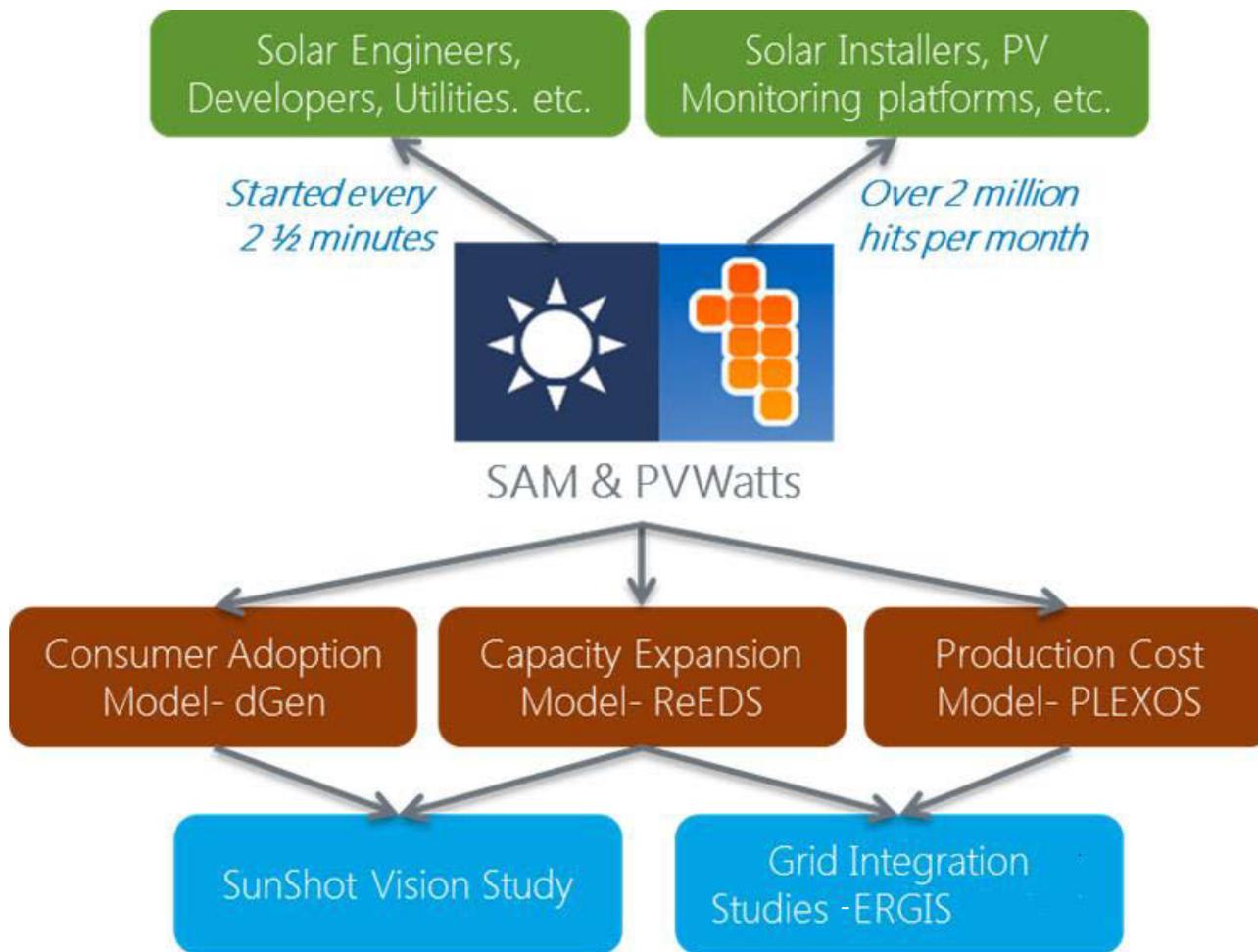
Top States for RE Installed Capacity (2015)



Top Countries for Installed Renewable Generation (2015)



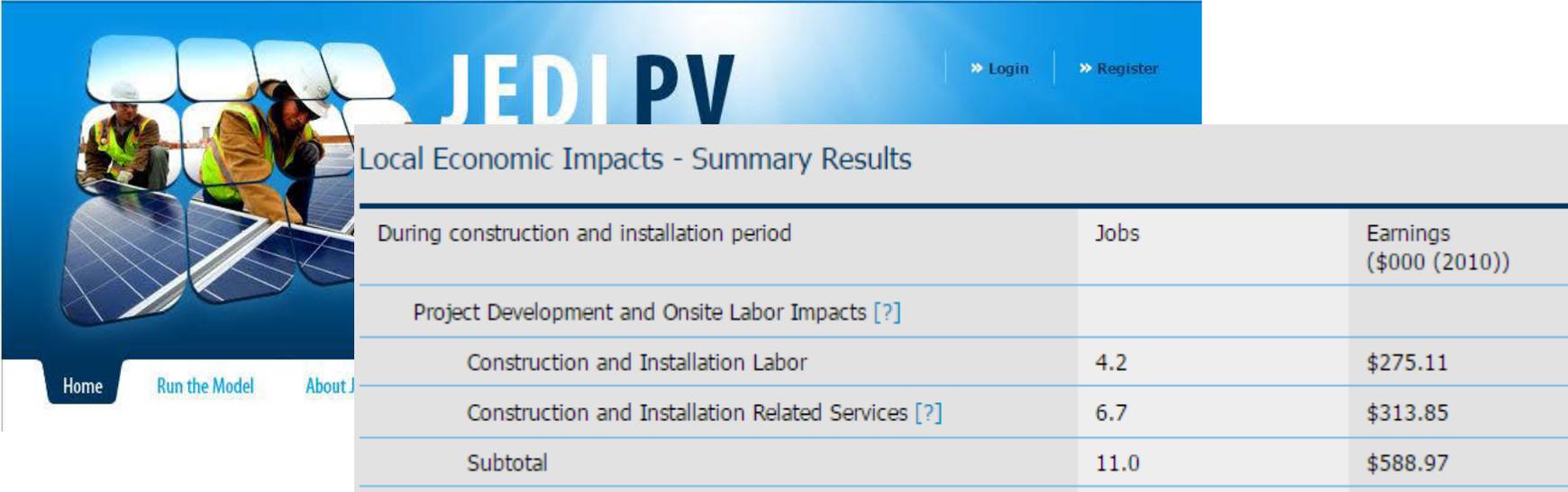
Foundational PV + Battery + Financial Modeling



14

JEDI PV – Jobs and Economic Development

- **NOTE:** JEDI models exist for wind, biofuels, Solar CSP, Coal, Hydropower, Geothermal, Marine Hydrokinetic, Petroleum, Transmission as well as PV
- **PURPOSE:** Estimate the economic impacts of constructing and operating photovoltaic power generation at the local and state levels.
- **TYPE:** Spreadsheet-based impact model (PV has a web version as well)
- **TAKEAWAY:** Economic impacts for one, or, a portfolio of projects
- **CONTACT:** JEDISupport@nrel.gov



The screenshot displays the JEDI PV web interface. On the left, there is a navigation menu with links for 'Home', 'Run the Model', and 'About'. The main content area features a header with the 'JEDI PV' logo and 'Login' and 'Register' buttons. Below the header, a table titled 'Local Economic Impacts - Summary Results' is shown. The table has three columns: 'During construction and installation period', 'Jobs', and 'Earnings (\$000 (2010))'. The data rows are: 'Project Development and Onsite Labor Impacts [?]', 'Construction and Installation Labor' (4.2 jobs, \$275.11 earnings), 'Construction and Installation Related Services [?]' (6.7 jobs, \$313.85 earnings), and a 'Subtotal' row (11.0 jobs, \$588.97 earnings).

During construction and installation period	Jobs	Earnings (\$000 (2010))
Project Development and Onsite Labor Impacts [?]		
Construction and Installation Labor	4.2	\$275.11
Construction and Installation Related Services [?]	6.7	\$313.85
Subtotal	11.0	\$588.97

<http://www.nrel.gov/analysis/jedi/download.html>



PVWatts

Solar Power International 2018

Janine Freeman

September 24, 2018

Outline

- **What is PVWatts?**
- **How can I access PVWatts?**
- **Live demonstration**
- **Questions**

What is PVWatts?

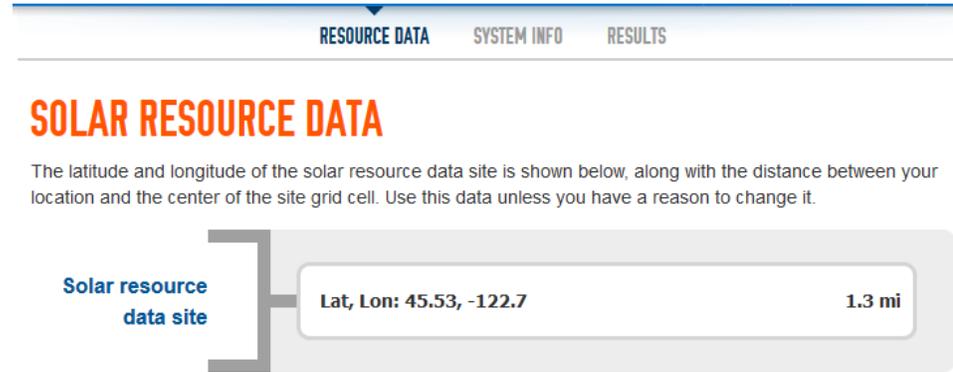
What is PVWatts?

The screenshot shows the PVWatts Calculator website. At the top, there is a navigation bar with the NREL logo and the text "PVWatts® Calculator". Below this is a "Get Started:" section with a search input field containing "portland, or" and a "GO >>" button. To the right of the search field are links for "HELP" and "FEEDBACK", and a dropdown menu for "ALL NREL SOLAR TOOLS". The main content area features a large blue box with the text: "A free online calculator for photovoltaic systems, developed and distributed by the U.S. Department of Energy's National Renewable Energy Laboratory." To the left of this text is a graphic of a solar panel array. Below the main text is a yellow box with the following text: "PVWatts now uses solar resource data from the latest **NREL National Solar Radiation Database**. The data covers the Americas including Hawaii between about 21° South latitude (about 300 km North of Sao Paulo, Brazil) to about 60° North (about 200 km south of Anchorage, Alaska), and the Indian subcontinent and parts of Central Asia. We recommend that you use the new data, but you can still use legacy data if needed. We also changed some labels, updated a few default values, and revised the Help documentation. See **What's New** above for details." To the right of the yellow box is a "What's New" button and a "Follow @PVWattsatNREL" button. At the bottom of the page, there is a footer with the following text: "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. PVWatts® is a registered trademark by Alliance for Sustainable Energy, LLC in Golden, CO, 80401. Version 6.1.0. Need Help? | Security & Privacy | Disclaimer | NREL Home".

Simply put...

What is PVWatts?

PVWatts requires a few simple inputs to describe the location...



The screenshot shows the 'SOLAR RESOURCE DATA' section of the PVWatts interface. At the top, there are three tabs: 'RESOURCE DATA', 'SYSTEM INFO', and 'RESULTS'. Below the tabs, the title 'SOLAR RESOURCE DATA' is displayed in orange. A paragraph of text explains that the latitude and longitude of the solar resource data site are shown, along with the distance between the user's location and the center of the site grid cell. Below this text, there is a grey box containing a label 'Solar resource data site' on the left, and a white box with rounded corners on the right. The white box contains the text 'Lat, Lon: 45.53, -122.7' and '1.3 mi'.

RESOURCE DATA SYSTEM INFO RESULTS

SOLAR RESOURCE DATA

The latitude and longitude of the solar resource data site is shown below, along with the distance between your location and the center of the site grid cell. Use this data unless you have a reason to change it.

Solar resource data site

Lat, Lon: 45.53, -122.7 1.3 mi

What is PVWatts?

and the system...

RESOURCE DATA **SYSTEM INFO** RESULTS

SYSTEM INFO

Modify the inputs below to run the simulation.

DC System Size (kW):	<input type="text" value="4"/>	i
Module Type:	<input type="text" value="Standard"/>	i
Array Type:	<input type="text" value="Fixed (open rack)"/>	i
System Losses (%):	<input type="text" value="14.08"/>	i Loss Calculator
Tilt (deg):	<input type="text" value="20"/>	i
Azimuth (deg):	<input type="text" value="180"/>	i

What is PVWatts?

to estimate the monthly and annual electrical output of a photovoltaic system.

Month	Solar Radiation (kWh / m ² / day)	AC Energy (kWh)	Value (\$)
January	1.48	151	16
February	2.86	260	28
March	3.35	334	36
April	4.85	446	48
May	5.48	519	56
June	5.90	526	56
July	7.04	614	66
August	6.42	570	61
September	5.21	454	49
October	3.18	305	33
November	1.88	179	19
December	1.41	145	15
Annual	4.09	4,503	\$ 483

RESOURCE DATA

SYSTEM INFO

RESULTS

RESULTS

 Print Results

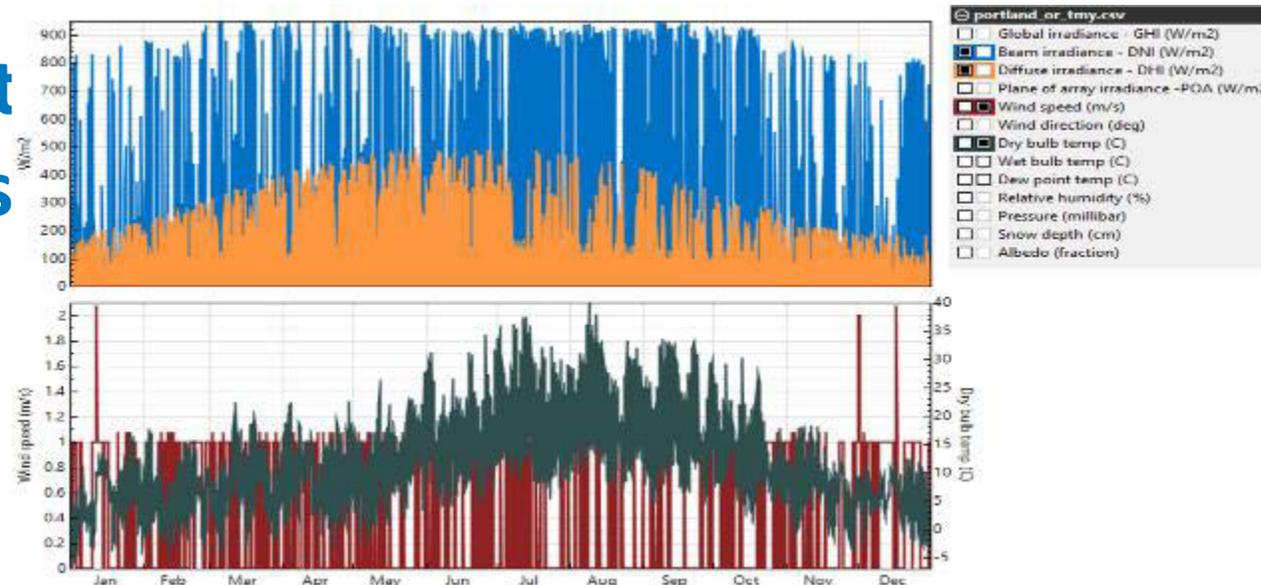
4,503 kWh/Year*

System output may range from 4,220 to 4,743 kWh per year near this location.
Click [HERE](#) for more information.

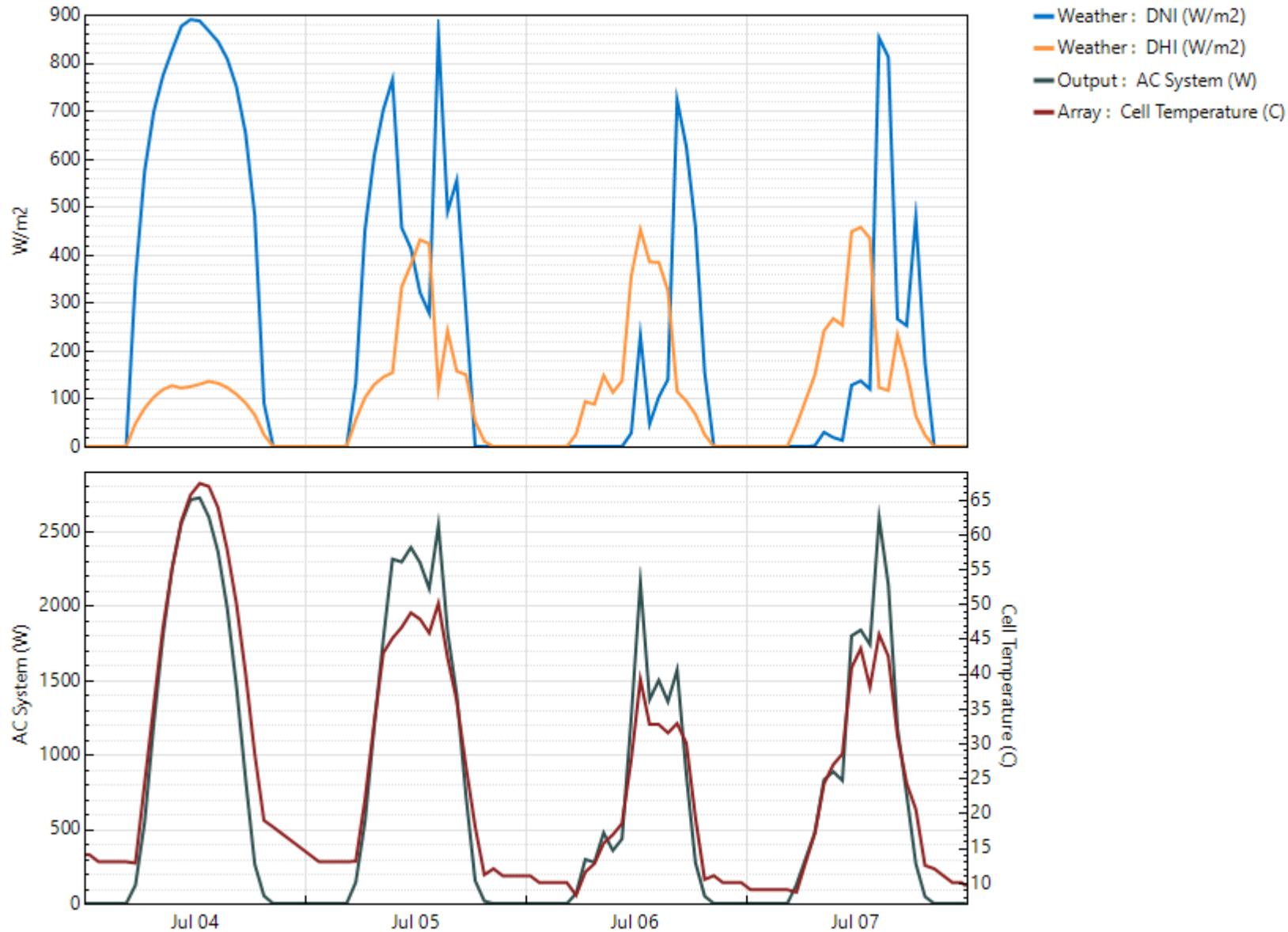
A little more detail...

What is PVWatts?

- Production estimates are based on an hour-by-hour simulation for one full year.
- Estimates account for solar irradiance, cell temperature, module cover optical characteristics.
- Other effect
System Loss



Hourly outputs include array DC output, system AC outputs, and cell temperature.



How to Access PVWatts?

The screenshot shows the PVWatts Calculator website. At the top, the browser address bar displays "https://pvwatts.nrel.gov/index.php". The page header includes the "PVWatts® Calculator" title and the NREL logo (National Renewable Energy Laboratory). A navigation bar contains a "Get Started:" section with a text input field containing "portland, or" and a "GO >>" button. To the right are "HELP" and "FEEDBACK" links, and a dropdown menu for "ALL NREL SOLAR TOOLS".

The main content area features a large blue banner with a grid of orange squares on the left. The text reads: "NREL's PVWatts® Calculator. Estimates the energy production and cost of energy of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, small building owners, installers and manufacturers to easily develop estimates of the performance of potential PV installations." A "What's New" button is positioned on the right side of the banner.

A yellow callout box in the center of the banner contains the following text: "Welcome to the updated PVWatts Calculator! PVWatts now uses solar resource data from the latest **NREL National Solar Radiation Database**. The data covers the Americas including Hawaii between about 21° South latitude (about 300 km North of Sao Paulo, Brazil) to about 60° North (about 200 km south of Anchorage, Alaska), and the Indian subcontinent and parts of Central Asia. We recommend that you use the new data, but you can still use legacy data if needed. We also changed some labels, updated a few default values, and revised the Help documentation. See **What's New** above for details." A "Follow @PVWattsatNREL" button is located at the bottom right of the banner.

At the bottom of the page, a grey footer box contains the text: "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." Below this, it states: "PVWatts® is a registered trademark by Alliance for Sustainable Energy, LLC in Golden, CO, 80401. Version 6.1.0". At the very bottom, there are links for "Need Help?", "Security & Privacy", "Disclaimer", and "NREL Home".

System Advisor Model for cost and financial analysis: <https://sam.nrel.gov>

SAM 2017.9.5

File

+ Add

4 kW Residential

PVWatts, Residential

Location and Resource

System Design

System Costs

Lifetime

Financial Parameters

Incentives

Electricity Rates

Electric Load

System Parameters

System nameplate size kWdc

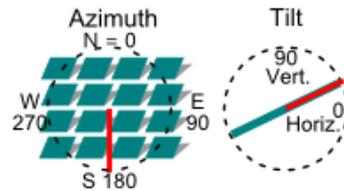
Module type

DC to AC ratio

Rated inverter size kWac

Inverter efficiency %

Orientation



Array type

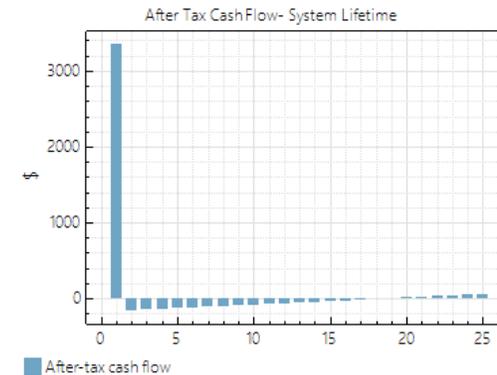
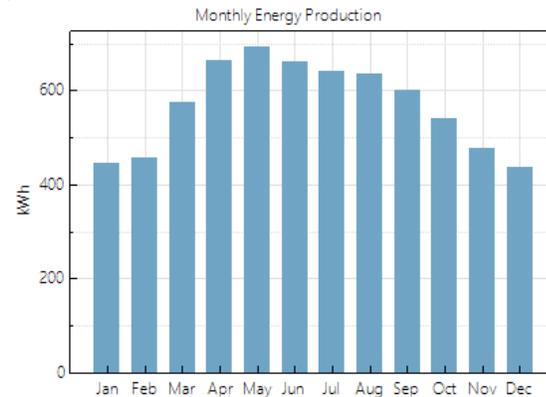
Tilt degrees

Azimuth degrees

Ground coverage ratio

Summary Data tables Graphs Cash flow Time series Profiles Statistics Heat map PDF / CDF Notices

Metric	Value
Annual energy (year 1)	6,832 kWh
Capacity factor (year 1)	19.5%
Energy yield (year 1)	1,708 kWh/kW
Levelized COE (nominal)	10.75 ¢/kWh
Levelized COE (real)	8.51 ¢/kWh
Electricity bill without system (year 1)	\$973
Electricity bill with system (year 1)	\$205
Net savings with system (year 1)	\$768
Net present value	\$2,299
Payback period	14.4 years
Discounted payback period	NaN
Net capital cost	\$11,727
Equity	\$0
Debt	\$11,727



API for web service on developer.nrel.gov

https://developer.nrel.gov/docs/solar/pvwatts/v6/

Developer Network

HOME DOCUMENTATION COMMUNITY

Documentation » Solar » PVWatts » PVWatts V6

PVWatts V6

(GET /api/pvwatts/v6)

PVWatts Version 6 is an update that uses different weather data by default than Version 5. Version 6 uses the NREL Physical Solar Model (PSM) TMY from the NREL National Solar Radiation Database (NSRDB) by default, however you can select to use NREL NSRDB 1991-2005 TMY3 data, international data, or a 10km gridded dataset covering all of India. PVWatts Version 6 also updates the default DC to AC ratio to 1.2 instead of 1.1, but you can still specify the DC to AC ratio that you wish to use in your simulation.

[Examples](#)

The algorithms used to calculate energy output have not changed. See [Dobos, A. P. PVWatts Version 5 Manual](#). NREL/TP-6A20-62641

JSON Output Format

- Request URL
- Request Parameters
- Response Fields
 - Station Info Fields
 - Output Fields
- Examples
 - JSON Output Format
 - XML Output Format
- Rate Limits
- Errors

```
GET /api/pvwatts/v6.json?api_key=DEMO_KEY&lat=40&lon=-105&system_capacity=4&azimuth=180&tilt=40&array_type=1&module_type=1&losses=10
```

```
{
  "inputs": {
    "system_capacity": "4",
    "lat": "40",
    "lon": "-105",
    "azimuth": "180",
    "tilt": "40",
    "array_type": "1",
    "module_type": "1",
    "losses": "10"
  },
  "errors": [],
  "warnings": [],
  "version": "1.4.0",
  "seo_info": {
    "version": "45",
    "build": "Linux 64 bit GNU/C++ Jul 7 2015 14:24:09"
  },
  "station_info": {
    "lat": 40.084983215333,
    "lon": -105.019968430884,
    "elev": 1981.039969203135,
    "tz": -7,
    "location": "Horse",
    "city": "",
    "state": "Colorado",
    "solar_resource_file": "W10502N4001.csv",
    "distMoe": 2029
  },
  "outputs": {
    "ac_monthly": [
      474.4326171875,
      484.3903503417969,
      505.7704487773438,
      550.0558365234375,
      591.2682353518425,
      593.3538208007812,
      583.2352405273438,
      566.459350585375,
      494.0131713861188,
      561.72814458125,
      406.12603709765625,
      445.68817138671875
    ],
    "dc_monthly": [
      141.48084177246094,
      145.57119750974562,
      154.70526100585938,
      164.83932450195312,
      173.97338800784375,
      174.1074515039375,
      173.24151500984375,
      168.37557850573438,
      153.5096420016289,
      173.64470500753906,
      128.7797685034375,
      143.91383150934375
    ]
  }
}
```

Request URL

GET /api/pvwatts/v6.format?parameters

Request Parameters

Parameter	Required	Value
format	Yes	Type: string Default: None Options: json, xml
api_key	Yes	Type: string Your developer API key. See API keys for more information.

API for SAM Simulation Core (SSC) in SAM Software Development Kit: <https://sam.nrel.gov>

The screenshot shows the SAM 2017.9.5 software interface. The 'File' menu is open, and the 'Generate code...' option is highlighted. A 'Code Language' dialog box is open, showing a list of languages: JSON for inputs, LK for SDKtool, C, MATLAB, Python 2, Python 3 (selected), Java, Android Studio (Android), C#, and VBA. Below the dialog box, a file explorer shows the generated files:

Name	Size
__init__.py	
4_kW_Residential.py	
load.csv	160 KB
PySSC.py	8 KB
ssc.dll	15,745 KB
sscapi.h	14 KB
ur_ts_sell_rate.csv	18 KB

```
1 #Created with SAM version 2017.9.5
2 import string, sys, struct, os
3 from ctypes import *
4 c_number = c_float # must be c_double or c_float depending on how defined in
5
6 class PySSC:
7     def __init__(self):
8         if sys.platform == 'win32' or sys.platform == 'cygwin':
9             self.pdll = CDLL("C:/Users/gaobo/Desktop/Temp/python/ssc.dll")
10        elif sys.platform == 'darwin':
11            self.pdll = CDLL("C:/Users/gaobo/Desktop/Temp/python/ssc.dylib")
12        elif sys.platform == 'linux2':
13            self.pdll = CDLL('C:/Users/gaobo/Desktop/Temp/python/ssc.so')
14        else:
15            print ('Platform not supported ', sys.platform)
16
17    INVALID=0
18    STRING=1
19    NUMBER=2
20    ARRAY=3
21    MATRIX=4
22    INPUT=1
23    OUTPUT=2
24    INOUT=3
25
26    def version(self):
27        self.pdll.ssc_version.restype = c_int
28        return self.pdll.ssc_version()
29
30    def build_info(self):
31        self.pdll.ssc_build_info.restype = c_char_p
32        return self.pdll.ssc_build_info()
33
34    def data_create(self):
35        self.pdll.ssc_data_create.restype = c_void_p
36        return self.pdll.ssc_data_create()
37
38    def data_free(self, p_data):
39        self.pdll.ssc_data_free( c_void_p(p_data) )
40
41    def data_clear(self, p_data):
42        self.pdll.ssc_data_clear( c_void_p(p_data) )
43
44    def data_unassign(self, p_data, name):
45        self.pdll.ssc_data_unassign( c_void_p(p_data), c_char_p(name) )
46
47    def data_query(self, p_data, name):
```

C++ source code on github.com/nrel/sam

```
// cell temperature
pvt = (*tccalc)( poa, wspd_corr, tdry );

// dc power output (Watts)
dc = dc_nameplate*(1.0+gamma*(pvt-25.0))*tpoa/1000.0;

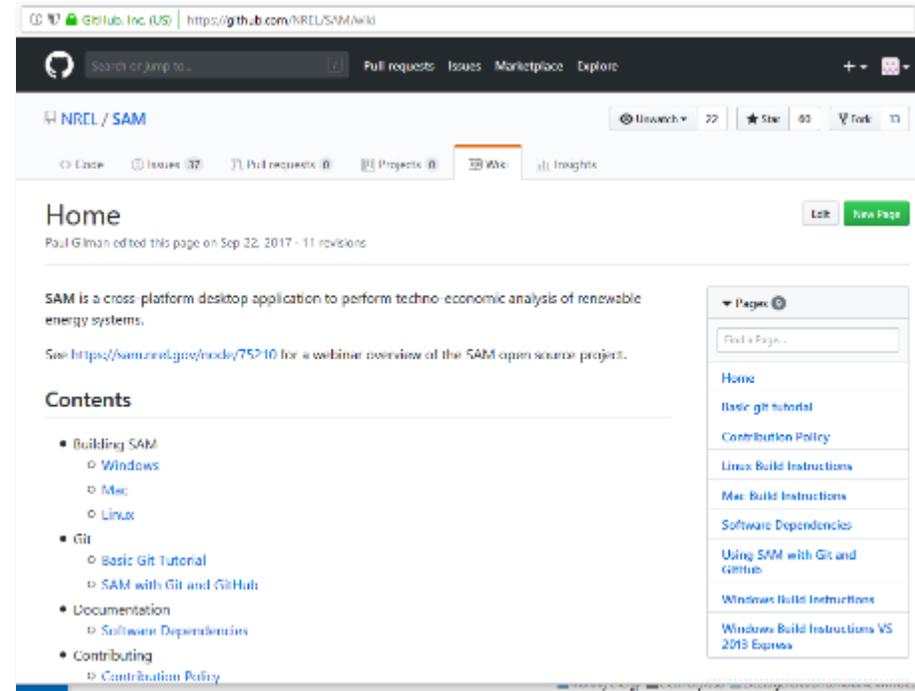
// dc losses
dc = dc*(1-loss_percent/100);

// inverter efficiency
double etanom = inv_eff_percent/100.0;
double etaref = 0.9637;
double A = -0.0162;
double B = -0.0059;
double C = 0.9858;
double pdc0 = ac_nameplate/etanom;
double plr = dc / pdc0;
ac = 0;

if ( plr > 0 )
{ // normal operation
    double eta = (A*plr + B/plr + C)*etanom/etaref;
    ac = dc*eta;
}

if ( ac > ac_nameplate ) // clipping
    ac = ac_nameplate;

// make sure no negative AC values (no parasitic nighttime losses calculated)
if ( ac < 0 ) ac = 0;
```



https://github.com/NREL/ssc/blob/develop/ssc/cmod_pvwattsV5.cpp

References

<https://pvwatts.nrel.gov>

2018 PVWatts webinar for Green Home Institute:

https://www.youtube.com/watch?time_continue=2&v=4JQ1PZbFPwY

Dobos, A. (2014). PVWatts Version 5 Manual. NREL Report No. TP-6A20-62641. ([PDF 714 KB](#))

Dobos, A.; (2013). PVWatts Version 1 Technical Reference. 11 pp.; NREL Report No. TP-6A20-60272. ([PDF 487 KB](#))

Marion, B. et al. (2005). Performance Parameters for Grid-Connected PV Systems. NREL Report No. CP-520-37358. ([PDF 816 KB](#))

MacAlpine, S., Deline, Chris. (2015). Modeling Microinverters and DC Power Optimizers in PVWatts. NREL Report No. TP-5J00-6346. ([PDF 360 KB](#))

Live Demonstration

Thank you!

www.nrel.gov





THE NATIONAL SOLAR RADIATION DATABASE (1998-2016)

Presenter: Aron Habte,

Dr. Manajit Sengupta, Aron Habte, Dr. Yu Xie, Anthony Lopez, Dr. Galen Maclaurin, NREL

Dr. Michael J. Foster, CIMMS, University of Wisconsin

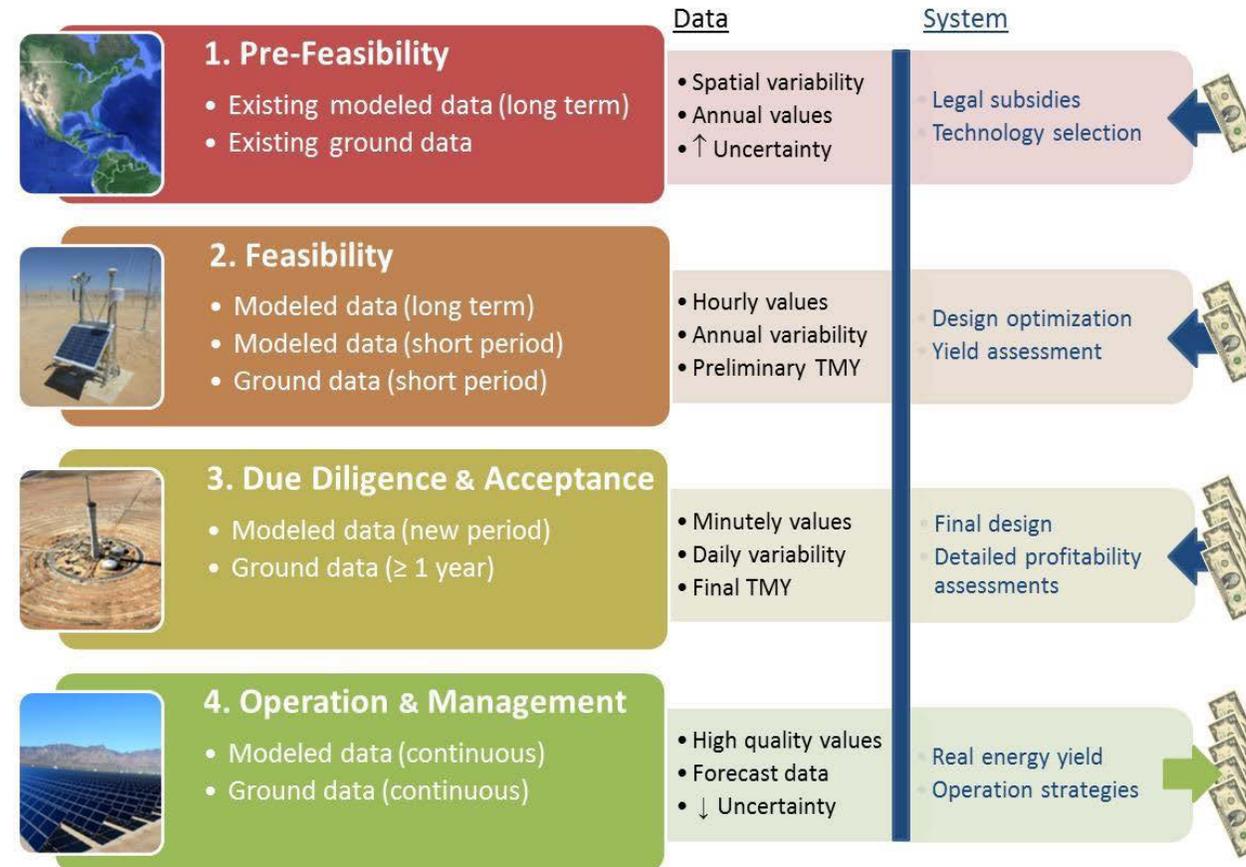
Dr. Andrew Heidinger, NOAA/NESDIS, Madison, Wisconsin

Dr. Christian Gueymard, Solar Consulting Services

Solar Power International Educational Workshop, September 24-27, 2018

Application of Solar Resource Information

Support the U.S. Department of Energy (DOE) SunShot goal of reducing solar deployment and financing costs through improving accuracy in solar resource modeling.
Funded by the SI subprogram of DOE EERE Solar Energy Technology Program

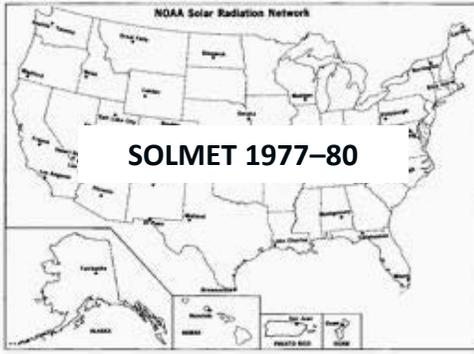


Source: <https://www.nrel.gov/docs/fy18osti/68886.pdf>

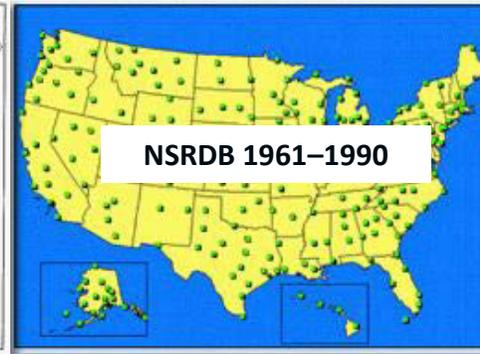
Outline

- **Evolution of NSRDB**
- **The Physical Solar Model (PSM)**
- **What's new in NSRDB Version 3**
- **Validation of the NSRDB**
- **Spectral data**
- **Typical Meteorological Year (TMY)**
- **Accessing NSRDB and available parameters**
- **Future Work**

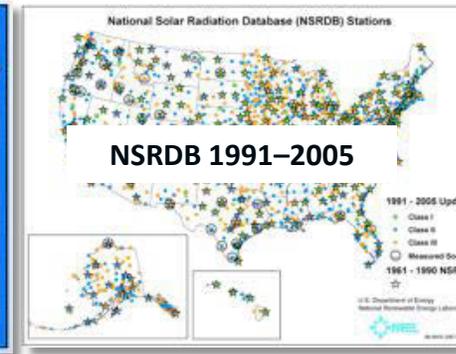
Evolution of the National Solar Radiation Database (NSRDB)



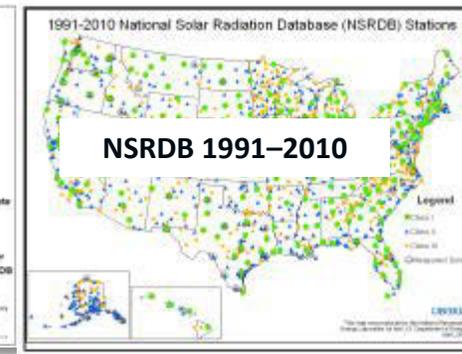
248 weather stations with 26 **Solar measurement** stations [ERDA, NOAA, 1979]



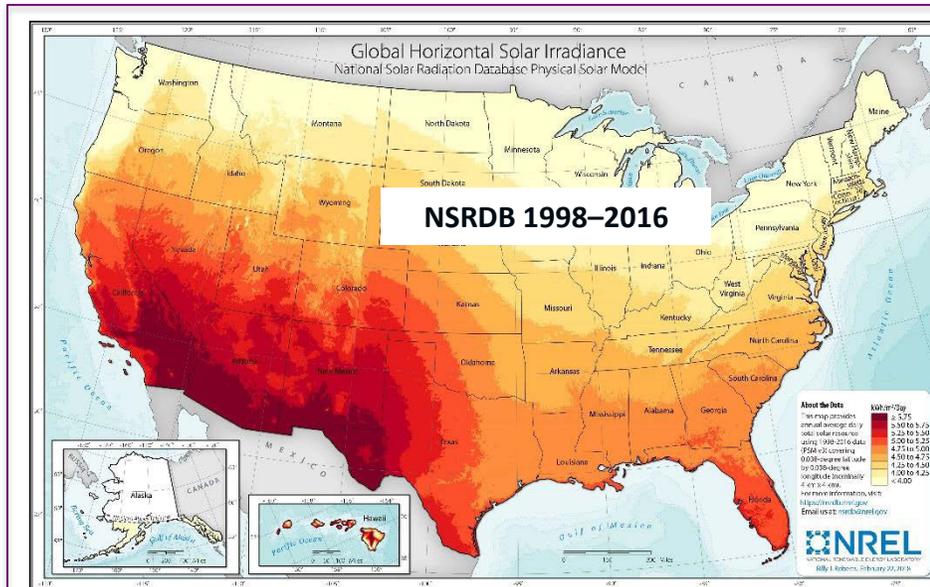
239 **modeled** stations with 56 partial measurement stations [DOE, NOAA, 1994]



1,454 **modeled** locations [DOE, SUNY-A, NOAA, 2007]



1,454 **modeled** locations [DOE, CPR, 2012]



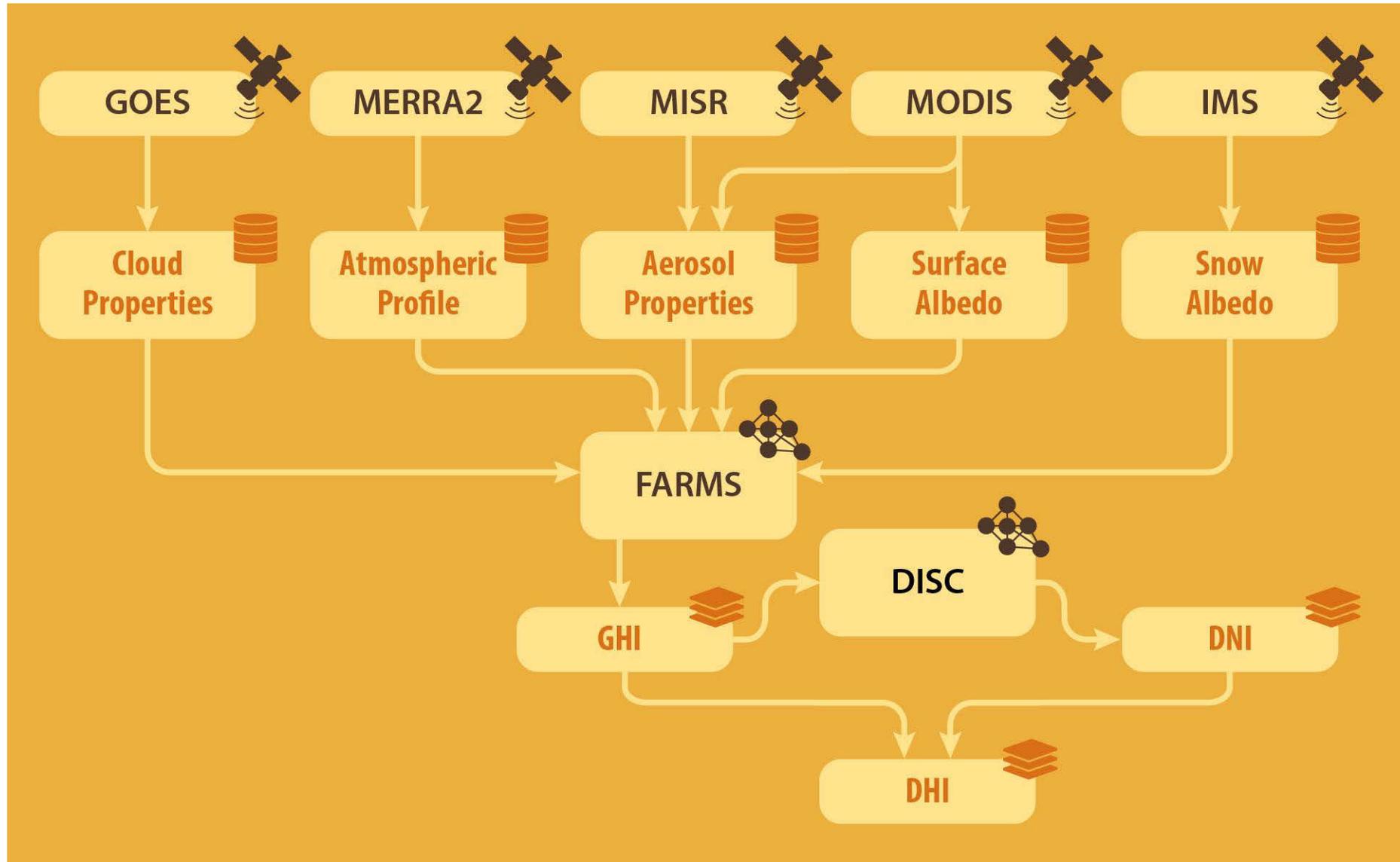
Satellite-based, gridded, 4 km x 4 km, half-hourly [DOE, NOAA, UW, SCS 2016]

NREL National Solar Radiation Database (NSRDB)
Home About Data Sets Resources Contact

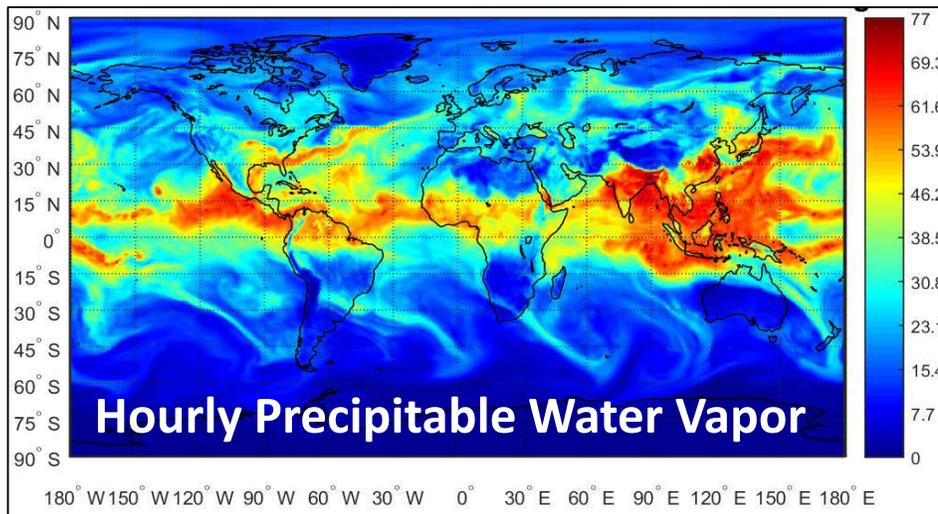
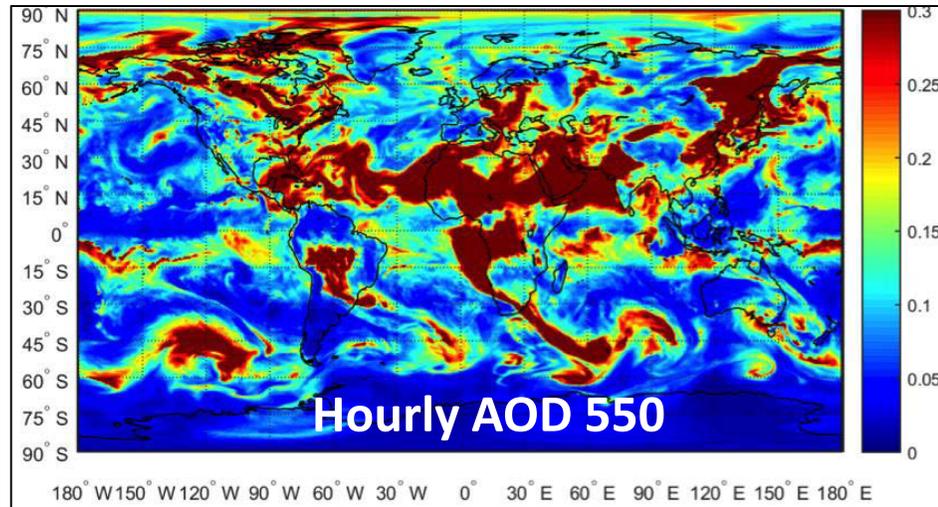
See: Global Horizontal Irradiance
Location: North, North America
Date: March 31, 2012
Time: 12:00 hours, Mountain Time Zone
Spatial Resolution: 4 km

<http://nsrdb.nrel.gov>

Physical Solar Model (PSM) Framework

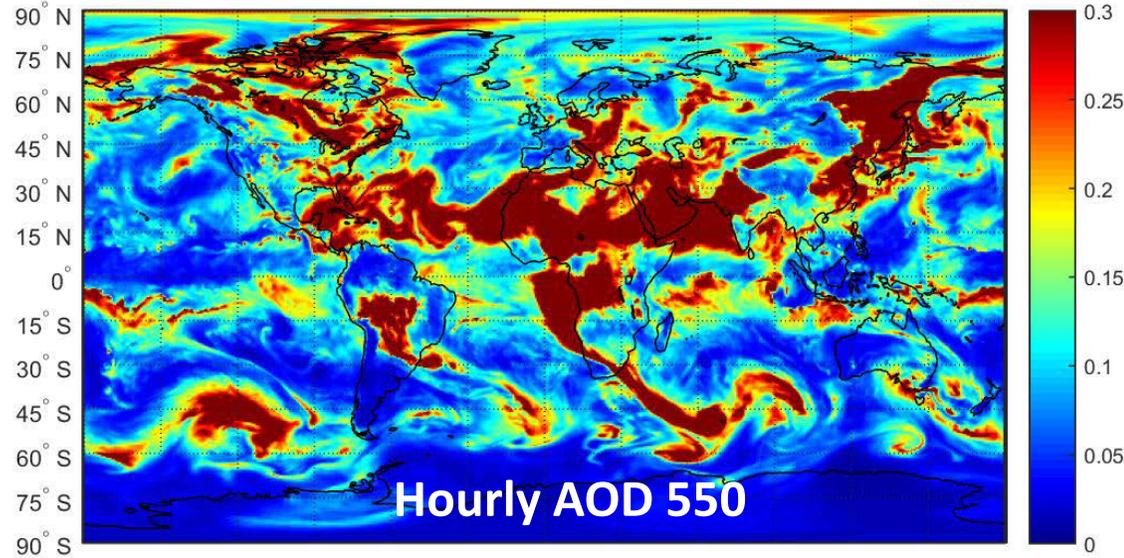


NSRDB (PSM-V3): What's New

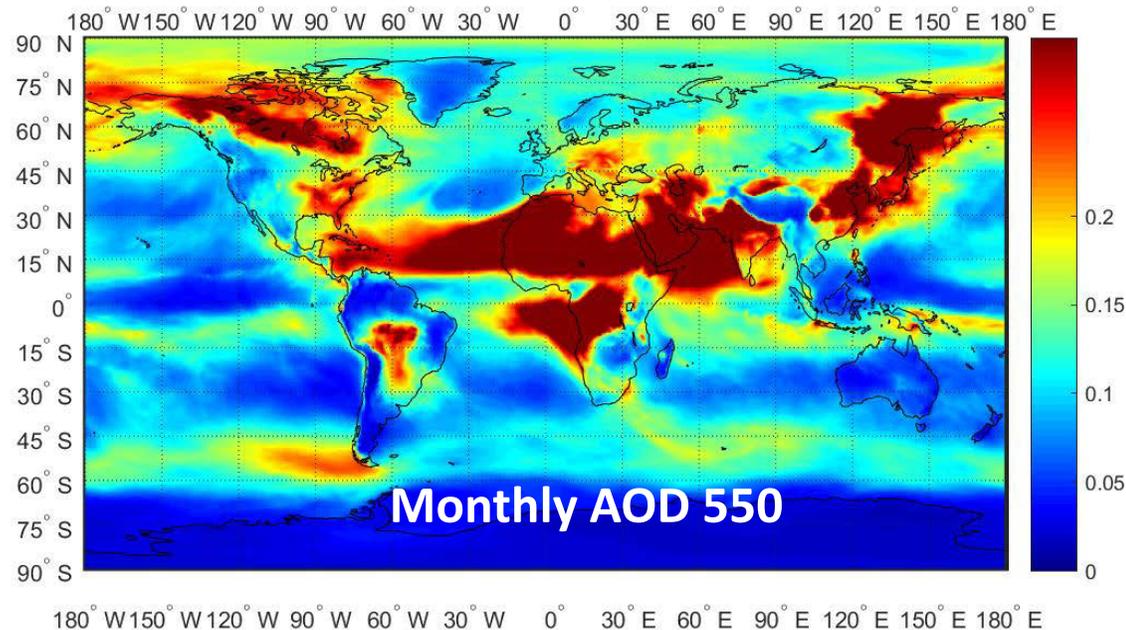


- Hourly aerosol optical depth (1998-2016) from Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA2).
- Snow-free Surface Albedo from MODIS (2001-2015) (MCD43GF CMG Gap-Filled Snow-Free Products from University of Massachusetts, Boston).
- Snow cover from Integrated Multi-Sensor Snow and Ice Mapping System (IMS) daily snow cover product (National Snow and Ice Data Center).
- Ancillary data (pressure, humidity, wind speed etc.) from MERRA2.

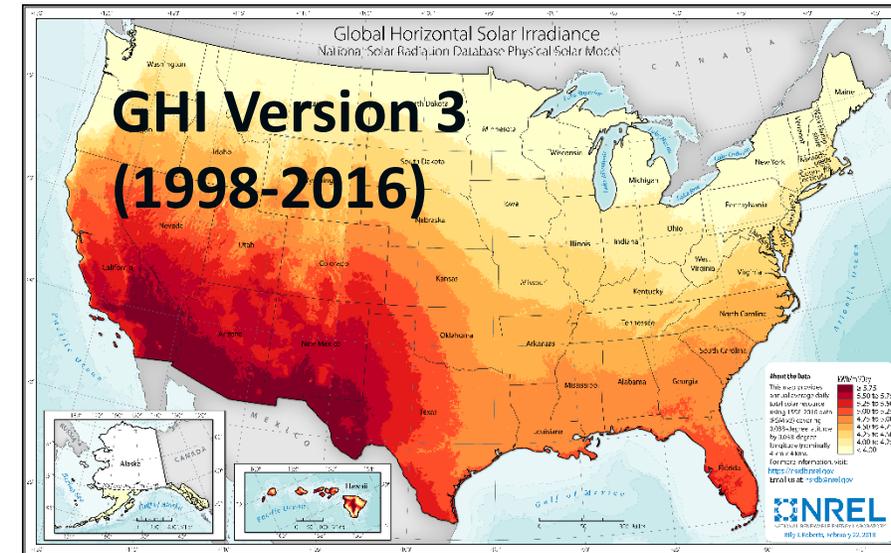
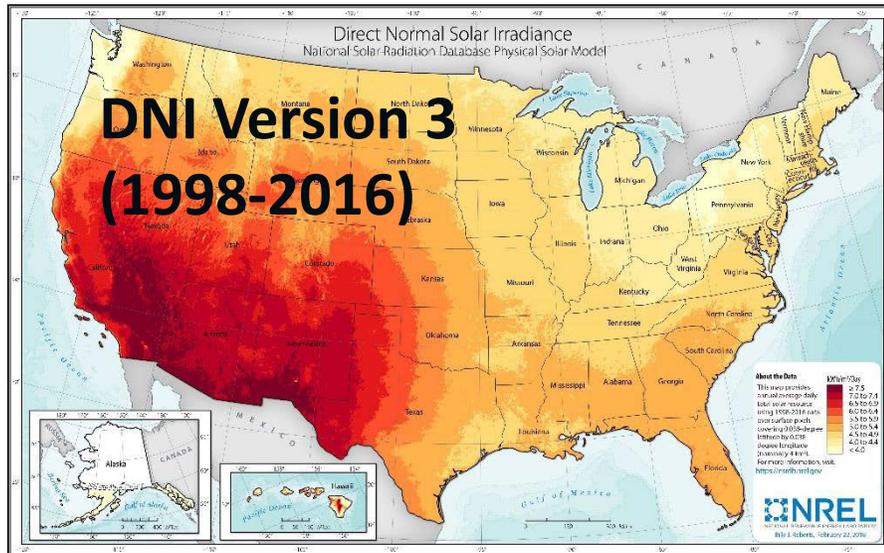
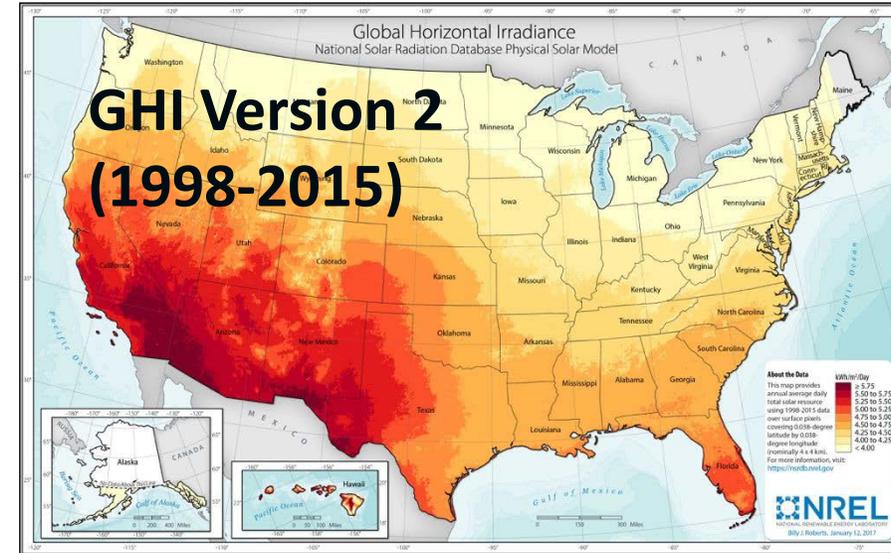
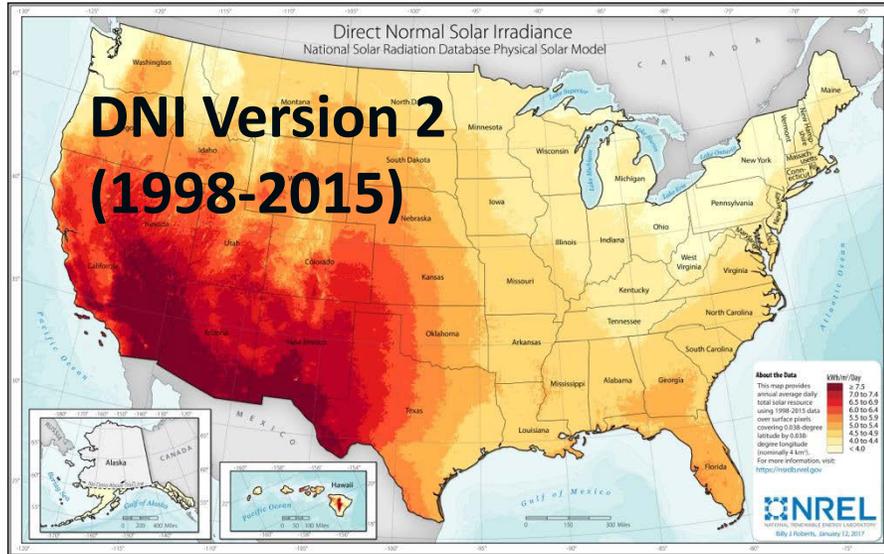
NSRDB (PSM-V3): What's New



Hourly AOD for one time stamp in July 1998 (Top) versus monthly AOD for July 1998 (Bottom)

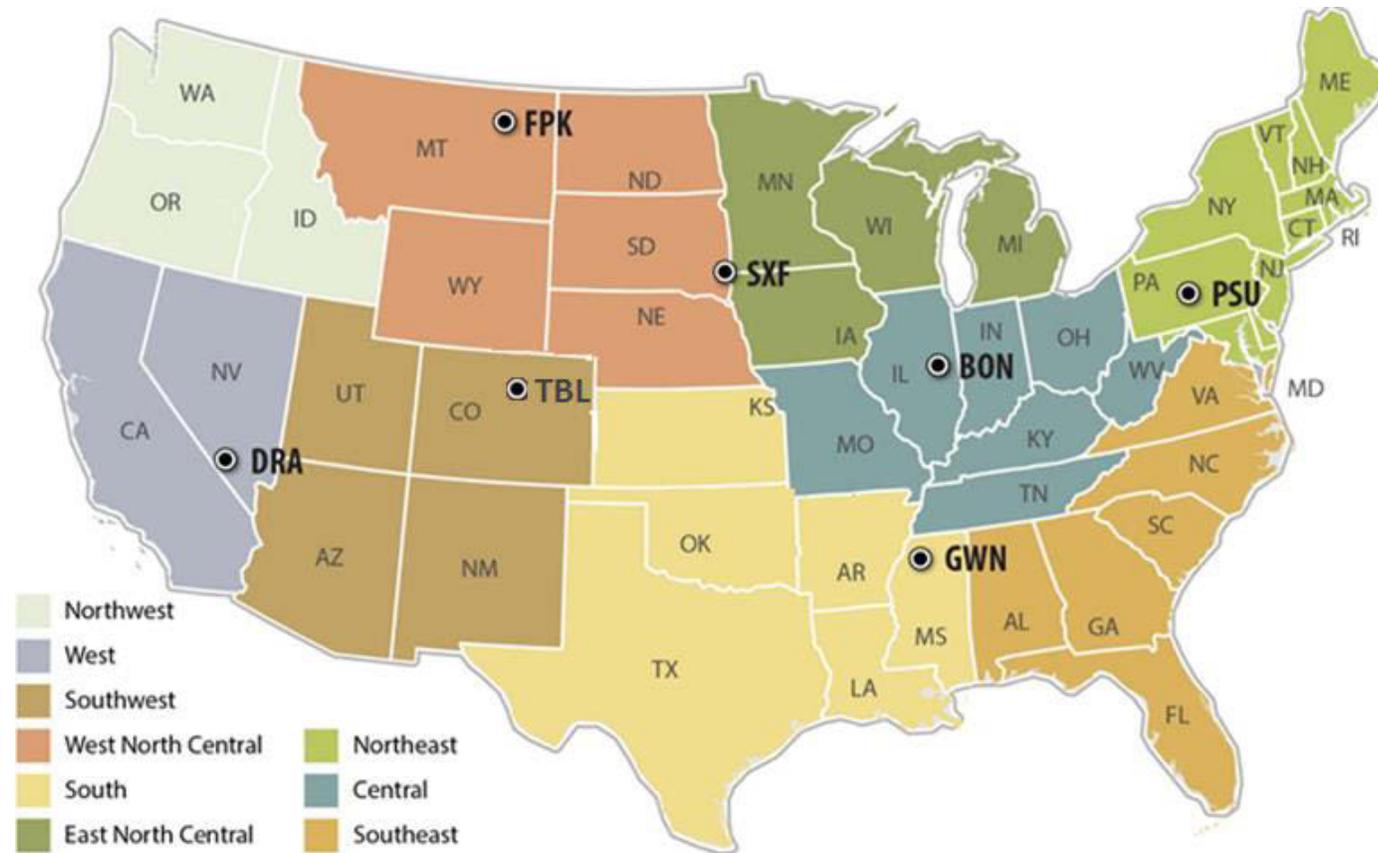


NSRDB Version 2 and 3 Comparison



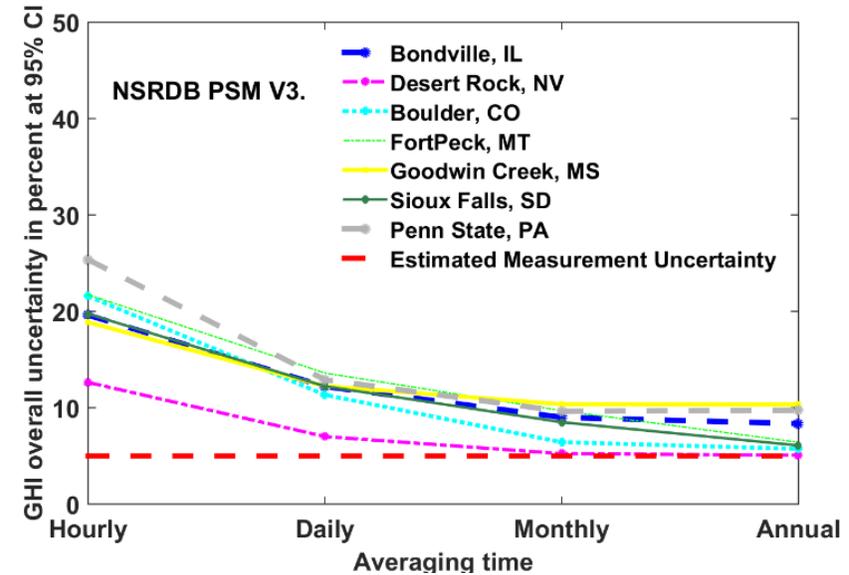
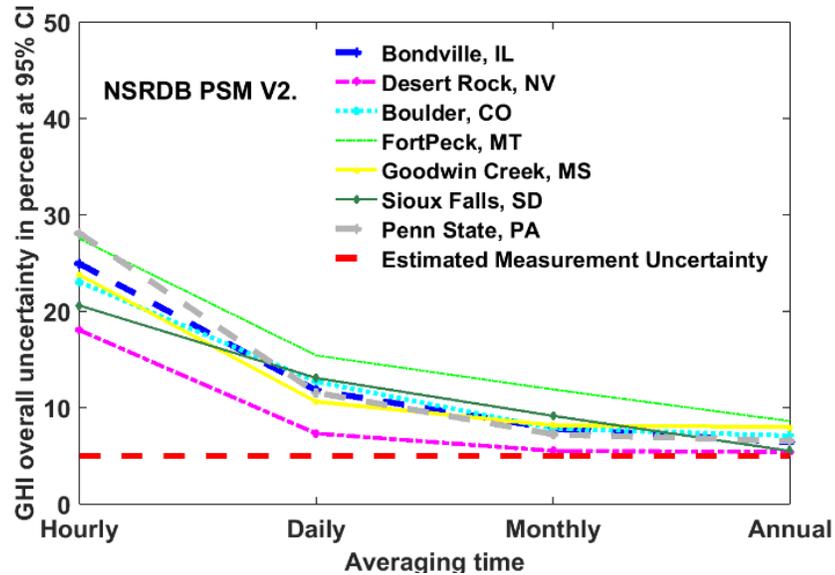
Validation of NSRDB Using Surface-Based Measurements

Surface Radiation (SURFRAD) Network



Validation of NSRDB Using Surface-Based Measurements

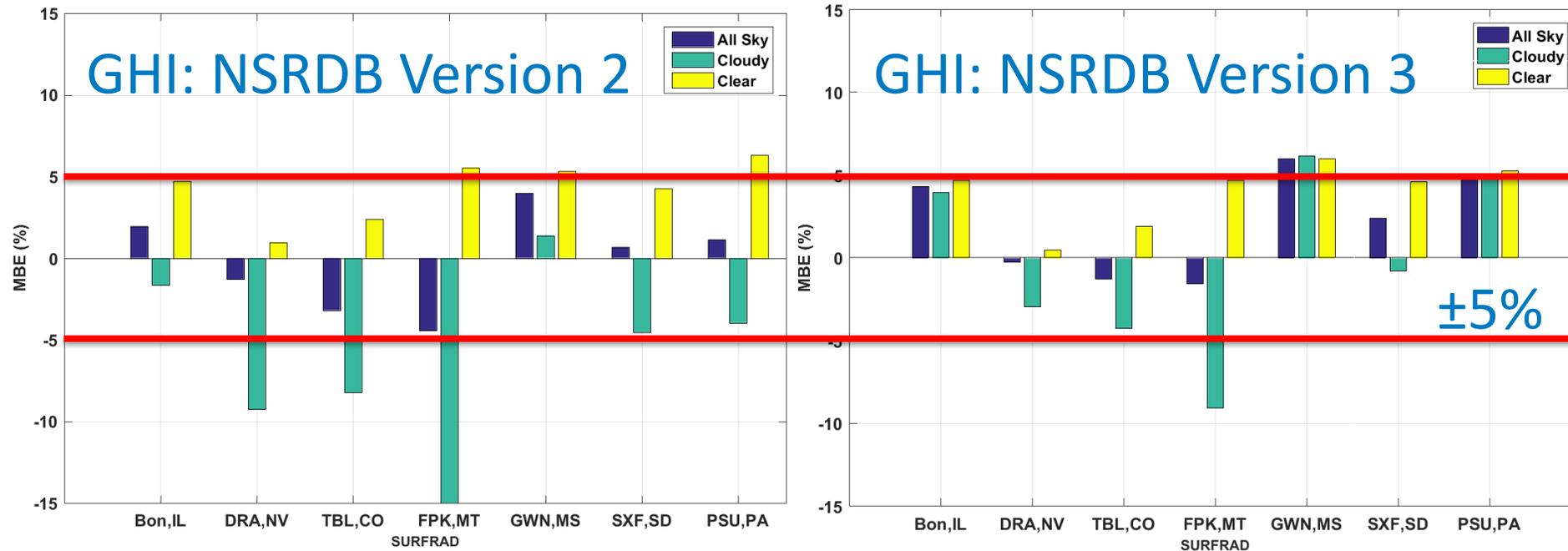
GHI: Overall estimated uncertainty—NSRDB (1998–2015)



Uncertainty estimation includes:

- MBE
- RMSE
- Surface measurement uncertainty.

Validation of NSRDB Using Surface-Based Measurements



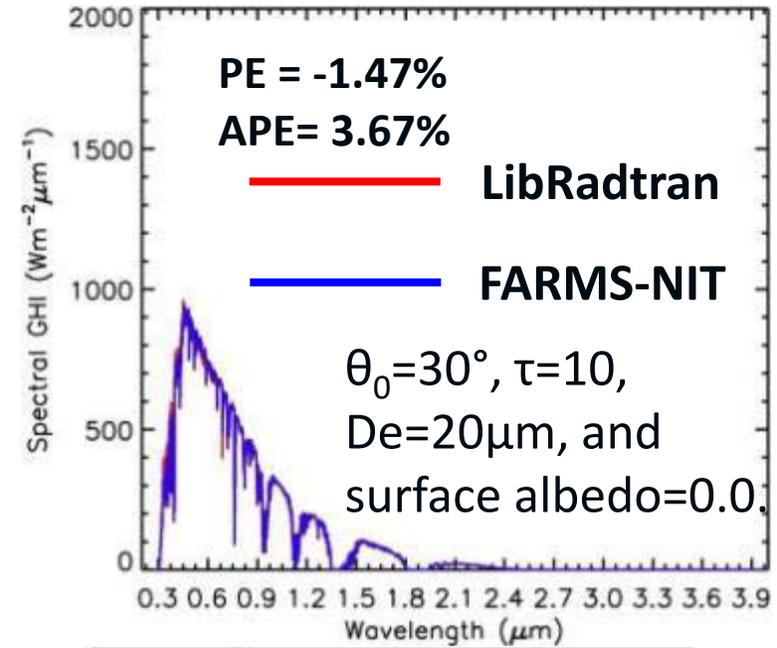
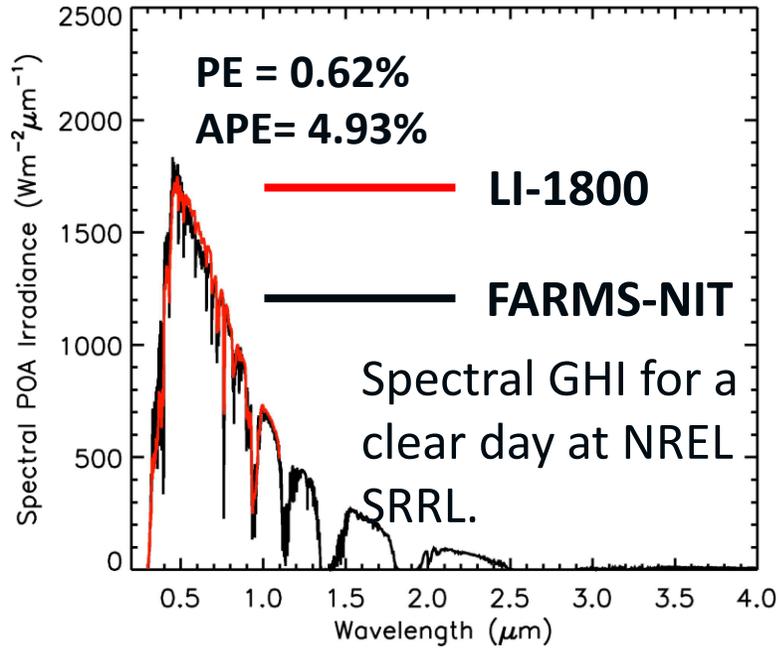
Difference between the two versions:

- MERRA-2 AOD vs climatological AOD
- Precipitable water vapor from MERRA2
- Surface Albedo from MODIS and Snow Cover from IMS
- Some of downscaling calculations for ancillary variables

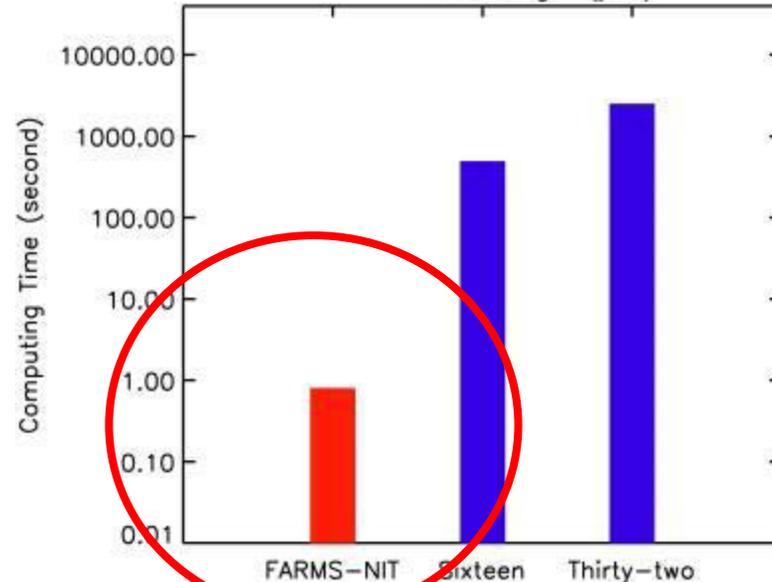
Spectral Data from NSRDB

- **New capability to provide spectral POA on demand for any fixed-tilt or single-axis tracking orientation.**
- **POA irradiances are efficiently computed for 2002 wavelength bands (0.28-4.0 μm) from the radiances.**
- **Spectral radiances are computed by using lookup table of cloud transmittance and solving the radiative transfer equation.**
- **POA irradiance is computed by integrating radiances over inclined surfaces.**

Uncertainty of Spectral Model



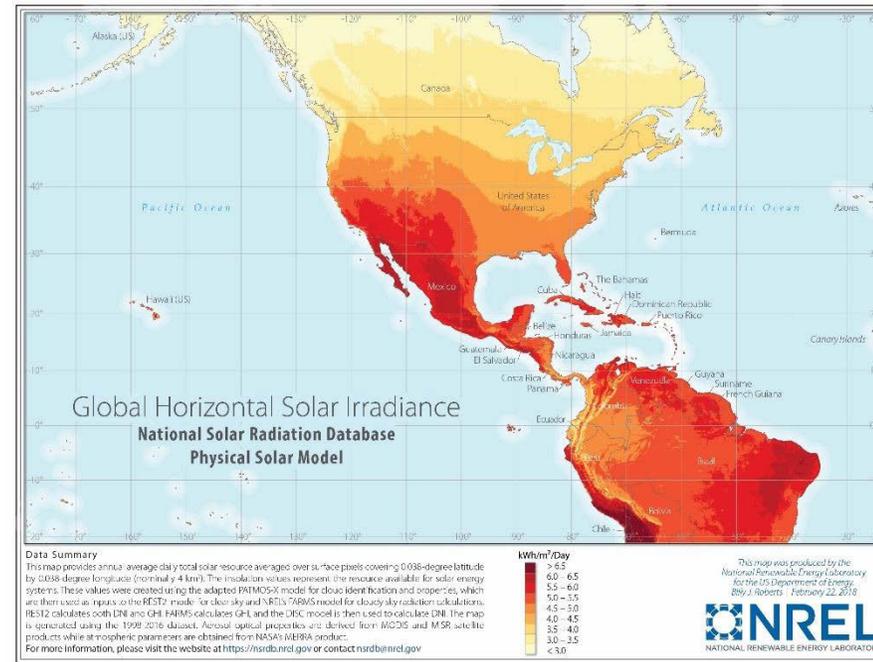
FARMS-NIT: 0.8 second.
LibRadtran (16 stream):
492 seconds.
LibRadtran (32 stream):
2493 seconds.



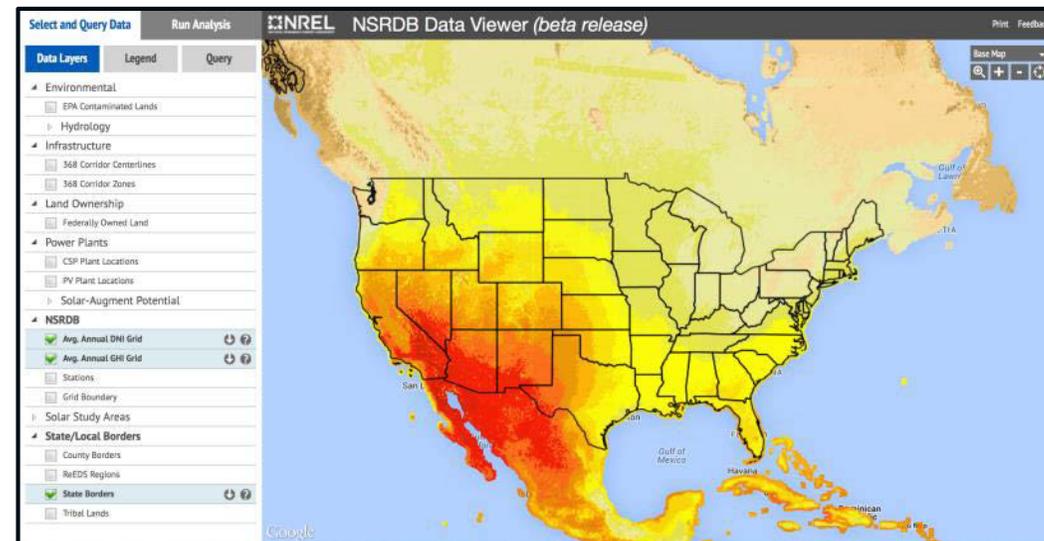
What's Available

USA and North and South America:

- Current product (4-km, half-hourly) available from 1998–2016 (Model V3)
- Typical meteorological year (TMY) product is also available.
- Multiple summary products are available with current data sets.
- Spectral data



<https://nsrdb.nrel.gov>



What's Available

15 Variables are Delivered Publicly:

Dataset in the NSRDB	
Data used in PSM	Publicly available datasets
<ul style="list-style-type: none"> • <u>MERRA-2</u> ○ Atmospheric pressure ○ Surface albedo ○ Aerosols ○ Aerosol optical thickness ○ Single scattering albedo ○ Aerosol Angstrom parameter. ○ Total ozone ○ Precipitable water. • <u>GOES (PATMOS-X retrievals)</u> ○ Cloud effective radius ○ Cloud optical depth ○ Cloud type. • <u>Moderate Resolution Imaging Spectroradiometer/National Snow and Ice Data Center</u> ○ Surface albedo. 	<ul style="list-style-type: none"> • Global horizontal irradiance (GHI) • Direct normal irradiance (DNI) • Diffuse horizontal irradiance (DHI) • Clear-sky GHI, DNI, and DHI • Cloud type • Dew point** • Air temperature* • Atmospheric pressure • Relative humidity** • Solar zenith angle • Precipitable water* • Wind direction** • Wind speed.**
<p>* From MERRA-2 ** Recalculated from MERRA-2</p>	

TMY Data Set

- Step 1
 - For each month of the calendar year, 5 candidate months with cumulative distribution functions (CDFs) for the daily indices that are closest to the long-term (30 years for the NSRDB) CDFs are selected.
- Step 2
 - The 5 candidate months are ranked with respect to closeness of the month to the long-term mean and median.
- Step 3
 - The persistence of mean dry bulb temperature and daily global horizontal radiation are evaluated by determining the frequency and run length above and below fixed long-term percentiles.
- Step 4
 - The 12 selected months are concatenated to make a complete year and smooth discontinuities at the month interfaces for 6 hours each side using curve-fitting techniques.

Weighting Parameters for the TMY, TDY, and TGY Data Sets (Modified from Wilcox and Marion 2008)

Index	TMY	TDY	TGY
Max Dry Bulb Temp	1/20	0	0
Min Dry Bulb Temp	1/20	0	0
Mean Dry Bulb Temp	2/20	0	0
Max Dew Point Temp	1/20	0	0
Min Dew Point Temp	1/20	0	0
Mean Dew Point Temp	2/20	0	0
Max Wind Velocity	1/20	0	0
Mean Wind Velocity	1/20	0	0
GHI	5/20	0	20/20
DNI	5/20	20/20	0

TMY: Typical meteorological year

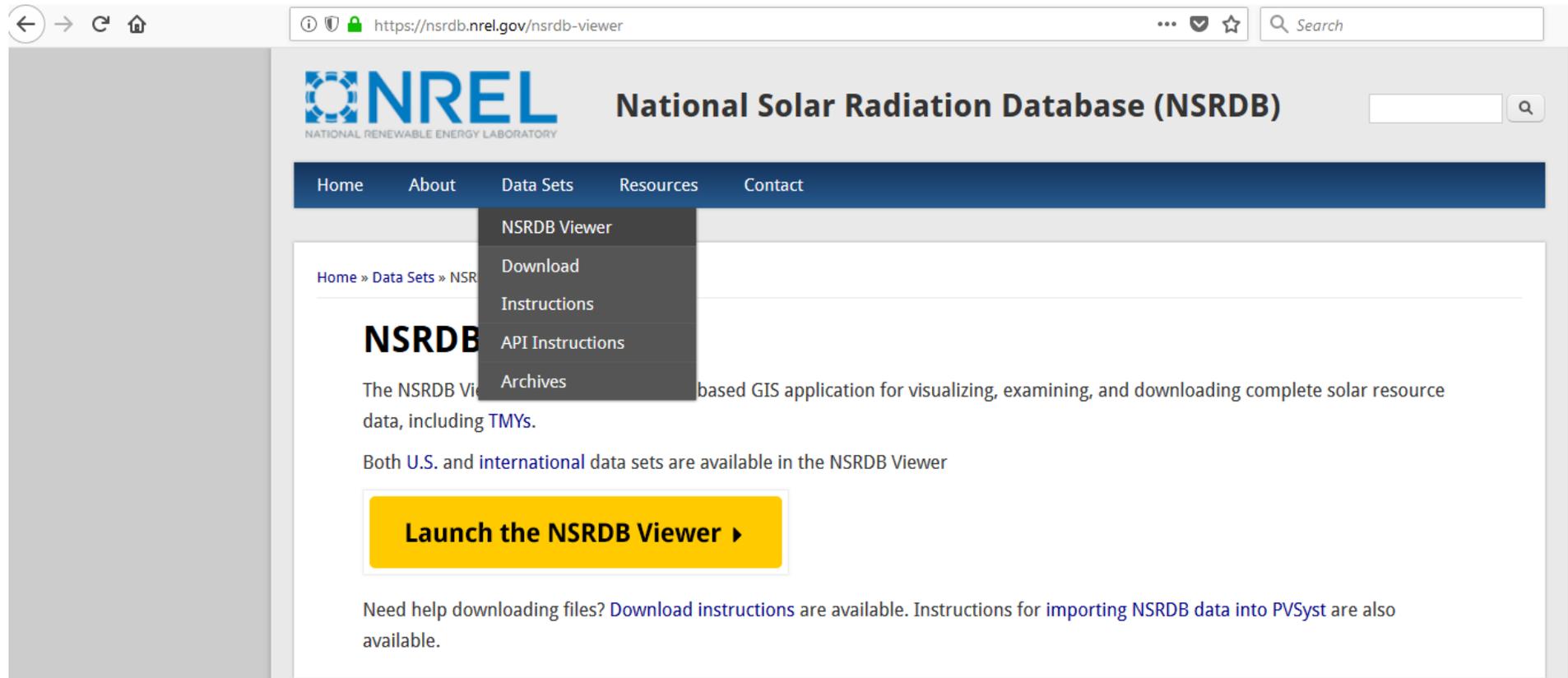
TDY: Typical direct normal irradiance year

TGY: Typical global horizontal irradiance year

NSRDB Viewer and Data Access

New NSRDB Viewer

<https://nsrdb.nrel.gov/nsrdb-viewer>



The screenshot shows the National Solar Radiation Database (NSRDB) website. The browser address bar displays <https://nsrdb.nrel.gov/nsrdb-viewer>. The website header features the NREL logo and the title "National Solar Radiation Database (NSRDB)". A navigation menu includes "Home", "About", "Data Sets", "Resources", and "Contact". A dropdown menu is open under "Data Sets", listing "NSRDB Viewer", "Download", "Instructions", "API Instructions", and "Archives". The main content area has a breadcrumb trail "Home » Data Sets » NSRDB Viewer" and a heading "NSRDB Viewer". Below the heading, it states: "The NSRDB Viewer is a web-based GIS application for visualizing, examining, and downloading complete solar resource data, including TMYs. Both U.S. and international data sets are available in the NSRDB Viewer". A prominent yellow button with the text "Launch the NSRDB Viewer ▶" is centered on the page. At the bottom, there is a note: "Need help downloading files? [Download instructions](#) are available. Instructions for [importing NSRDB data into PVSystem](#) are also available."

Direct link: <https://maps.nrel.gov/nsrdb-viewer>

New NSRDB Viewer

Select and Query Data **Download Data** **NREL NSRDB Data Viewer** Home Print Feedback

Data Layers Legend Query

- ▶ Environmental
- ▶ Infrastructure
- ▶ Land Ownership
- ▶ Power Plants
- ▶ Ground Measurement Sites
- ▶ NSRDB
- ▶ Solar Study Areas
- ▶ State/Local Borders

Google

Report a map error

Browse Data Layers

The screenshot displays the NSRDB Data Viewer interface. At the top, there are navigation tabs: 'Select and Query Data', 'Download Data', and the NREL logo. The main title is 'NSRDB Data Viewer'. On the right side, there are links for 'Home', 'Print', and 'Feedback'. Below the title bar, there are three tabs: 'Data Layers', 'Legend', and 'Query'. The 'Data Layers' tab is active, showing a list of categories with expandable arrows:

- ▶ Environmental
- ▶ Infrastructure
- ▶ Land Ownership
- ▶ Power Plants
- ▶ Ground Measurement Sites
- ▶ NSRDB
- ▶ Solar Study Areas
- ▶ State/Local Borders

A callout box with a blue border and white background points to the 'Data Layers' tab. It contains the text: 'Use the layer tree to find and display data layers'. The main area of the interface is a map of the United States and parts of Canada and Mexico, showing state and local boundaries. The map includes labels for major cities like Seattle, San Francisco, Los Angeles, San Diego, Las Vegas, Houston, Chicago, Toronto, and New York. The map also shows the Gulf of California and the Gulf of Mexico. In the bottom left corner, the Google logo is visible. In the bottom right corner, there is a link to 'Report a map error'.

Browse Data Layers

The screenshot shows the NSRDB Data Viewer interface. At the top, there are tabs for 'Select and Query Data', 'Download Data', and the NREL logo. The main title is 'NSRDB Data Viewer'. On the right, there are links for 'Home', 'Print', and 'Feedback'. Below the title bar, there are three tabs: 'Data Layers', 'Legend', and 'Query'. The 'Data Layers' tab is active, showing a list of categories with expandable arrows. The categories are: Environmental, Infrastructure, Land Ownership, Power Plants, Ground Measurement Sites, **NSRDB** (expanded), MTS1, MTS2, MTS3, **PSM Direct Normal Irradiance** (checked), PSM Global Horizontal Irradiance, Solar Study Areas, and State/Local Borders. The 'PSM Direct Normal Irradiance' layer is highlighted in blue. A callout box with a blue border and white background contains the text 'Use the layer tree to find and display data layers'. The map shows the United States and Mexico with a color scale from yellow to red, representing solar irradiance. Major cities like San Francisco, Los Angeles, San Diego, Las Vegas, Houston, and New York are labeled. The Gulf of California and Gulf of Mexico are also labeled. The Google logo is in the bottom left corner, and a 'Report a map error' link is in the bottom right corner.

Layer Metadata

The screenshot shows the NREL NSRDB Data Viewer interface. The top navigation bar includes 'Select and Query Data', 'Download Data', and the NREL logo. The main content area is divided into a left sidebar and a central map. The sidebar has tabs for 'Data Layers', 'Legend', and 'Query'. Under 'Data Layers', there are several categories: Environmental, Infrastructure, Land Ownership, Power Plants, Ground Measurement Sites, and NSRDB. The NSRDB section is expanded, showing a list of layers: MTS1, MTS2, MTS3, PSM Direct Normal Irradiance, and PSM Global Horizontal Irradiance. The 'PSM Direct Normal Irradiance' layer is selected and highlighted in blue. A callout box with a question mark icon is positioned over the metadata icon (a question mark inside a circle) next to this layer. The central map shows a yellow and orange color-coded solar resource grid over the United States, with numerous black dots representing measurement sites. A text box titled 'Average Annual DNI Grid' is overlaid on the map, providing a detailed description of the data. The text box contains the following text: 'This data provides monthly average and annual average daily total solar resource averaged over surface cells of 0.038 degrees in both latitude and longitude, or nominally 4 km in size. The solar radiation values represent the resource available to solar energy systems. The data was created using cloud properties which are generated using the AVHRR Pathfinder Atmospheres-Extended (PATMOS-x) algorithms. Fast all-'. The map also includes a 'Base Map' dropdown menu, zoom controls, and a 'Report a map error' link at the bottom right.

View metadata for each layer

Average Annual DNI Grid

This data provides monthly average and annual average daily total solar resource averaged over surface cells of 0.038 degrees in both latitude and longitude, or nominally 4 km in size. The solar radiation values represent the resource available to solar energy systems. The data was created using cloud properties which are generated using the AVHRR Pathfinder Atmospheres-Extended (PATMOS-x) algorithms. Fast all-

Layer Downloads

The screenshot displays the NSRDB Data Viewer interface. On the left, the 'Data Layers' panel is expanded to the 'NSRDB' section, where 'MTS3' is selected and highlighted. A blue circle highlights the download icon (a downward arrow) next to the 'MTS3' layer name. A white callout box with a blue border and the text 'Download layers' is positioned over the map area. A modal dialog box titled 'MTS3' is open in the center, containing the text 'Download map layer data in the following geospatial data formats:' and four buttons: 'CSV', 'Shapefile', 'KML', and 'GeoJSON'. The background map shows a solar irradiance map of the United States and Mexico with numerous black dots representing measurement sites. The interface includes navigation controls like 'Home', 'Print', and 'Feedback' in the top right, and a 'Report a map error' link in the bottom right.

Browse Data Layers

The screenshot displays the NSRDB Data Viewer interface. At the top, there are navigation tabs: "Select and Query Data", "Download Data", and "NSRDB Data Viewer". The "Legend" tab is selected, showing two data layers: "MTS3" and "PSM Direct Normal Irradiance (kWh/sq.m/day)". The "MTS3" layer is currently active, with a transparency slider set to 75%. The "PSM Direct Normal Irradiance" layer is visible in the background, showing a color-coded map of solar irradiance across North America. A callout box points to the "Legend" tab with the text: "Use the Legend tab to view legend and style layers".

Legend

MTS3

- MTS3

Transparency: 75%

PSM Direct Normal Irradiance (kWh/sq.m/day)

- < 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- 5.0 - 5.5
- 5.5 - 6.0
- 6.0 - 6.5
- 6.5 - 7.0
- 7.0 - 7.5
- 7.5 - 8.0
- 8.0 - 8.5
- > 8.5

Query Data Layers

The image shows a screenshot of the NSRDB Data Viewer web application. The interface includes a top navigation bar with 'Select and Query Data', 'Download Data', and the NREL logo. Below this is a secondary navigation bar with 'Data Layers', 'Legend', and 'Query' tabs. The 'Query' tab is highlighted with a blue callout box that contains the text: 'Use the Query tab to search within displayed layers'. On the left side, there are four query options: 'Point Query' (with a dot icon), 'Region Query' (with a square icon), 'Custom Shape Query' (with a shape icon), and 'Attribute Query' (with a magnifying glass icon). The main area is a map of North America showing a data layer with numerous black dots representing data points. The map also displays geographical features like the Gulf of California and the Gulf of Mexico, and labels for various cities and states. The Google logo is visible in the bottom left corner of the map area.

Interactive Tutorials

The screenshot displays the NSRDB Data Viewer interface. At the top, there are navigation tabs: 'Select and Query Data', 'Download Data', and 'Tutorials' (which is circled in red). The main content area is a map with a sidebar on the left containing a 'Data Layers' panel. The sidebar lists various data categories such as Environmental, Infrastructure, Land Ownership, Power Plants, Ground Measurement Sites, NSRDB (with sub-items Spectral TMY, MTS1, MTS2, MTS3), PSM v3.0.1 (with sub-items Multi Year PSM Direct Normal Irra..., Multi Year PSM Global Normal Irradian), Annual Means, PSM v2.0.1, India Summary Statistics, SUNY, Solar Study Areas, and State/Local Borders. The 'Tutorials' modal window is open in the center, featuring a title 'Interactive Tutorials' and two sections: 'GIS Functionality' and 'Attribute Query'. Each section includes a brief description and a 'Launch Tutorial' button. The background map shows a geographical area with a scale bar at the bottom right indicating 500 km and 500 mi.

Select and Query Data **Download Data** **NSREL** **NSRDB Data Viewer** About Home Print Feedback **Tutorials**

Data Layers Legend Query

- ▶ Environmental
- ▶ Infrastructure
- ▶ Land Ownership
- ▶ Power Plants
- ▶ Ground Measurement Sites
- ▲ **NSRDB**
 - Spectral TMY
 - MTS1
 - MTS2
 - MTS3
- ▲ **PSM v3.0.1**
 - Multi Year PSM Direct Normal Irra...
 - Multi Year PSM Global Normal Irradian
- ▶ Annual Means
- ▶ PSM v2.0.1
- ▶ India Summary Statistics
- ▶ SUNY
- ▶ Solar Study Areas
- ▶ State/Local Borders

Interactive Tutorials

GIS Functionality

This interactive tutorial will walk you through the GIS functionality of the application. The tutorial will cover the following features:

- Navigating the map
- Viewing spatial layers
- Downloading spatial data
- Querying spatial data

[Launch Tutorial](#)

Attribute Query

This tutorial will show you how to query for data filtered by certain values of the data's properties.

[Launch Tutorial](#)

Change Base Map

500 km
500 mi

NSRDB Data Downloads

NSRDB Data Download

The screenshot displays the NSRDB Data Viewer interface. At the top, there are two tabs: "Select and Query Data" and "Download Data". The "Download Data" tab is active. Below the tabs, there are two main options for data download:

- NSRDB Data Download (Point)**: Download resource data from the National Solar Radiation Database by point. This tool will return data for the station closest to the point drawn.
- NSRDB Data Download (Box)**: Download resource data from the National Solar Radiation Database by box. This tool will return data for all stations falling within the drawn region.

The interface also features a map of North America with a color-coded solar radiation scale. A blue callout box with the text "Download from NSRDB database" points to the "Download Data" tab. In the top right corner, there are navigation links: "About", "Home", "Print", "Feedback", and "Tutorials". A "Change Base Map" dropdown menu is also present. At the bottom right, there are scale bars for 500 km and 500 mi.

NSRDB Data Download

The screenshot displays the NSRDB Data Viewer interface. On the left, there are two main options under the 'Download Data' tab:

- NSRDB Data Download (Point)**: Download resource data from the National Solar Radiation Database by point. This tool will return data for the station closest to the point drawn.
- NSRDB Data Download (Box)**: Download resource data from the National Solar Radiation Database by box. This tool will return data for all stations falling within the drawn region.

The main area features a map of the United States with a color gradient representing solar radiation levels. A blue callout box with a white background and a blue border points to the 'Point' option, containing the text: "Download by Point or by Box (area)".

At the top right of the interface, there are navigation links: About, Home, Print, Feedback, and Tutorials. Below these, there is a 'Change Base Map' dropdown menu and a set of map navigation controls (search, zoom in, zoom out, and refresh). At the bottom right, there are scale bars for 500 km and 500 mi.

NSRDB Data Download

The screenshot displays the NSRDB Data Viewer interface. On the left, there are two options under the 'Download Data' tab: 'NSRDB Data Download (Point)' and 'NSRDB Data Download (Box)'. The 'Point' option is selected. The main area shows a map of the United States with a blue location pin in the western region. A tooltip above the pin says 'Click map to place marker.' A large blue callout box with a white background and a blue border points to the map, containing the text 'Select a location by point click or draw area'. The interface includes a top navigation bar with 'About', 'Home', 'Print', and 'Tutorials' links, and a map control panel with 'Change Base Map', zoom in (+), zoom out (-), and refresh icons. A scale bar at the bottom right shows 500 km and 500 mi.

Select and Query Data Download Data

NSRDB Data Download (Point)

Download resource data from the National Solar Radiation Database by point. This tool will return data for the station closest to the point drawn.

NSRDB Data Download (Box)

Download resource data from the National Solar Radiation Database by box. This tool will return data for all stations falling within the drawn region.

Change Base Map

Click map to place marker.

Select a location by point click or draw area

500 km
500 mi

NSRDB Data Download

Select and Query Data | Download Data | NREL NSRDB Data Viewer | About Home Print Tutorials

Change Base Map

NSRDB Data Download (Point)

Download resource data from the National Solar Radiation Database by point. This tool will return data for the station closest to the point drawn.

NSRDB Data Download (Box)

Download resource data from the National Solar Radiation Database by box. This tool will return data for all stations falling within the box drawn.

Data Download Information Form

Please fill out the following information in order to utilize the data download tool. This information helps us to justify improvements to the tool.

Note: All fields are required.

Full Name: Test User

Email: test@test.com

Organization/Affiliation: NREL

Planned Use: webinar

Please keep me informed of future releases and publications.

Continue

500 km
500 mi

Nicaragua, Costa Rica, Panama, Venezuela

Enter information (required for downloads)

NSRDB Data Download

NSRDB Data Viewer

Select and Query Data | Download Data | **NSRDB Data Viewer** | About | Home | Print | Tutorials

NSRDB Data Download (Point)
Download resource data from the National Solar Radiation Database by point. This returns data for the station closest to the point drawn.

NSRDB Data Download (Box)
Download resource data from the National Solar Radiation Database by box. This returns data for all stations falling within the region.

Data Download Wizard

Spectral TMY | Spectral TMY India | PSM v2 | **PSM v3** | SUNY | MTS2 | Spectral On-demand

Physical Solar Model (PSM3)

The National Solar Radiation Database (NSRDB) is a serially complete collection of hourly and half-hourly values of the three most common measurements of solar radiation—global horizontal, direct normal, and diffuse horizontal irradiance—and meteorological data. These data have been collected at a sufficient number of locations and temporal and spatial scales to accurately represent regional solar radiation climates.

Supported by the U.S. Department of Energy's SunShot Initiative, the NSRDB is a widely used and relied-upon resource. The database is managed and updated using the most current data available.

Select Years | Select All | Clear All

<input type="checkbox"/> 2004	<input type="checkbox"/> 2005	<input type="checkbox"/> 2006	<input type="checkbox"/> 2007	<input type="checkbox"/> 2008	<input type="checkbox"/> 2009
<input type="checkbox"/> 2010	<input type="checkbox"/> 2011	<input checked="" type="checkbox"/> 2012	<input checked="" type="checkbox"/> 2013	<input checked="" type="checkbox"/> 2014	<input checked="" type="checkbox"/> 2015
<input checked="" type="checkbox"/> 2016	<input type="checkbox"/> TMY				

Select Attributes | Select All | Clear All

The minimum required attributes for the SAM PV and CSP models have been selected by default.

<input checked="" type="checkbox"/> DHI	<input checked="" type="checkbox"/> DNI	<input checked="" type="checkbox"/> GHI
<input type="checkbox"/> Clearsky DHI	<input type="checkbox"/> Clearsky DNI	<input type="checkbox"/> Clearsky GHI
<input type="checkbox"/> Dew Point	<input checked="" type="checkbox"/> Solar Zenith Angle	<input type="checkbox"/> Wind Speed
<input checked="" type="checkbox"/> Surface Albedo		

Download Options | Select All | Clear All

<input type="checkbox"/> Convert UTC to Local Time	<input checked="" type="checkbox"/> Half Hour Intervals
--	---

Download Limit Indicator

[Edit User Info](#) | [Download Data](#)

500 km | 500 mi

Choose years to download

NSRDB Data Download

The screenshot shows the NREL NSRDB Data Viewer interface. The main panel is titled 'Download Data' and contains several sections for configuring the data download:

- Download Solar Resource Data By Point:** Select a location on the map by clicking once. You will then be presented with a variety of download choices.
- Download Solar Resource Data By Region:** Use the drawing tool to draw a rectangle around the desired region. You will then be presented with a variety of download choices.
- PSM:** MTS3, MTS2, MTS1
- Select Years:** Select All, Clear All. Years 1998-2014 are listed with checkboxes. 1998 is selected.
- Select Attributes:** Select All, Clear All. A note states: 'The minimum required attributes for the SAM PV and CSP models have been selected by default.' Attributes include: DHI, Clear Sky DHI, Cloud Type, Pressure, Total Precipitable Water, Wind Speed, DNI, Clear Sky DNI, Dew Point, Relative Humidity, Snow Depth, Fill Flag, GHI, Clear Sky GHI, Temperature, Solar Zenith Angle, and Wind Direction. DHI, DNI, Dew Point, Relative Humidity, and Temperature are selected.
- Select Download:** Include L, Convert UTC to Local Time, Half Hour Intervals. Half Hour Intervals is selected.
- Download Limit Indicator:** A progress bar showing the download status.

The interface also includes a map on the right side and a 'Change Base Map' dropdown menu.

Select attributes to download

NSRDB Data Download

The screenshot shows the NSRDB Data Viewer interface. The main window is titled "Data Download Wizard" and is divided into several sections:

- Model Selection:** Tabs for Spectral TMY, Spectral TMY India, PSM v2, PSM v3 (selected), SUNY, MTS2, and Spectral On-demand.
- Select Years:** A list of years from 2004 to 2016, with checkboxes for 2010, 2011, 2012, 2013, 2014, 2015, and 2016. A "TMY" option is also present.
- Select Attributes:** A list of attributes with checkboxes, including DHI, Clearsky DHI, Cloud Type, Fill Flag, DNI, Clearsky DNI, Dew Point, Surface Albedo, GHI, Clearsky GHI, Solar Zenith Angle, and Wind Speed.
- Select Download Options:** A list of options with checkboxes, including Include Day, Convert UTC to Local Time, and Half Hour Intervals.
- Download Limit Indicator:** A text input field at the bottom of the wizard.
- Buttons:** "Edit User Info" and "Download Data" buttons at the bottom right.

A callout box with a blue border and a pointer to the "Download Limit Indicator" field contains the text: "Observe download limit indicator to ensure valid download".

NSRDB Spectral Data Download

Data Download Wizard

Spectral TMY Spectral TMY India PSM v2 PSM v3 SUNY MTS2 **Spectral On-demand**

Spectral PSM

The National Solar Radiation Database (NSRDB) is a serially complete collection of hourly and half-hourly values of the three most common measurements of solar radiation—global horizontal, direct normal, and diffuse horizontal irradiance—and meteorological data. These data have been collected at a sufficient number of locations and temporal scales to accurately represent solar radiation climates.

Supported by the U.S. Department of Energy's SunShot Initiative, the database is widely used and relied upon. The database is managed using the latest methods.

[Documentation](#)

Dr. Manajit Sengupta
National Renewable Energy Lab
[Contact](#)

Fixed Tilt 40 Panel Tilt Angle

1 Axis Tracking

130 Panel Azimuth Angle

[Edit User Info](#) [Download Data](#)

NSRDB Spectral Data Download

Data Download Wizard

Spectral TMY Spectral TMY India PSM v2 PSM v3 SUNY MTS2 Spectral On-demand

Spectral PSM

The National Solar Radiation Database (NSRDB) is a serially complete collection of hourly and half-hourly values of the three most common measurements of solar radiation—global horizontal, direct normal, and diffuse horizontal irradiance—and meteorological data. These data have been collected at a sufficient number of locations and temporal and spatial scales to accurately represent regional solar radiation climates.

Supported by the U.S. Department of Energy's SunShot Initiative, the NSRDB is a widely used and relied-upon resource. The database is managed and updated using the latest methods of research by a

[Documentation](#)

Dr. Manajit Sengupta
National Renewable Energy Lab
[Contact](#)

Select Year

1998 1999 2000 2001 2002 2003
 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015
 2016

Select Attributes

All attributes will be included

Select Download Options

Fixed Tilt Panel Tilt Angle
 Panel Azimuth Angle

1 Axis Tracking

[Edit User Info](#) [Download Data](#)

Fixed Tilt systems require additional user input

NSRDB Spectral Data Download

Select and Query Data | **Download Data** | **NREL NSRDB Data Viewer** | About | Home | Print | Feedback | Tutorials

Data Download Wizard

Spectral TMY | **Spectral TMY India** | **PSM v2** | **PSM v3** | **SUNY** | **MTS2** | **Spectral On-demand**

Spectral PSM

The **National Solar Radiation Database (NSRDB)** is a serially complete collection of hourly and half-hourly values of the three most common measurements of solar radiation—global horizontal, direct normal, and diffuse horizontal irradiance—and meteorological data. These data have been collected at a sufficient number of locations and temporal and spatial scales to accurately represent regional solar radiation climates.

Supported by the U.S. Department of Energy's SunShot Initiative, the NSRDB is a widely used and relied-upon resource. The database is managed and updated using the latest methods of research by a

[Documentation](#)

Dr. Manajit Sengupta
National Renewable Energy Lab
Contact

Select Year

1998 1999 2000 2001 2002 2003
 2004 2005 2006 2007 2008 2009
 2010 2011 2016

Select Attributes

All attributes will be included

Select Download Options

Fixed Tilt
 1 Axis Tracking

[Edit User Info](#) | [Download Data](#)

1 Axis Tracking requires no additional input

NSRDB Data Download

The screenshot displays the NSRDB Data Viewer interface. On the left, there are instructions for downloading data by point and by region. The main area shows a 'Download Data' button and a 'Download Limit Indicator'. A 'Data Download Instructions' dialog box is open, containing the following text:

Data Download Instructions

You will receive an email at `sample.user@email.gov` with a link to download your data. Please note that generating download archives can take anywhere from a few minutes to several hours.

OK

Below the dialog box, there are checkboxes for 'Include Leap Day', 'Convert UTC to Local Time', and 'Half Hour Intervals'. The 'Half Hour Intervals' checkbox is checked.

Click Download Data button when ready

Instructions for obtaining download will be emailed

NSRDB Data Download



no-reply@nrel.gov
to me ▾



Your data is ready! Please click the link below to download your file. This link will remain valid for 24 hours.

https://maps-stage.nrel.gov/api/developer_proxy?site_url=solar/nsrdb_file_download&filename=bd73aab1d504c8a7889d6965b8aec79d.zip

Thank you for using [The NSRDB Data Viewer](https://maps.nrel.gov/nsrdb-viewer) at <https://maps.nrel.gov/nsrdb-viewer>

For downloads less than about 130 GB, a direct link to the zip file will be included in the email

NSRDB Data Download



Downloads greater than about 130GB use the Globus download service.

Your data is ready! The file is named **08bc894a316c0c489c9b6cdb55413933.zip**. This file will be available for 24 hours.

For full instructions on completing your download via Globus Connect, please view the page at: <https://nsrdb.nrel.gov/download-instructions>

Thank you for using [The NSRDB Data Viewer](https://maps.nrel.gov/nsrdb-viewer) at <https://maps.nrel.gov/nsrdb-viewer>

Data Format

Standard Time Series Data File Format

also known as **SAM CSV**

Header

Field	Units	Recognized Names
Latitude	degrees	<i>latitude,lat</i>
Longitude	degrees	<i>longitude,lon,long,lng</i>
Time zone	hours offset from GMT	<i>tz,timezone,time zone</i>
Site elevation	meters above sea level	<i>el,elev,elevation,site elevation</i>
Year	n/a	<i>year</i>
Location ID	n/a	<i>id,location,location id,station,station id,wban,wban#</i>
City	n/a	<i>city</i>
State	n/a	<i>state,province,region</i>
Country	n/a	<i>country</i>
Source	n/a	<i>source,src</i>
Description	n/a	<i>description,desc</i>
URL	n/a	<i>url</i>
Units flag	yes or no	<i>hasunits,units</i>
Interpolate flag	yes or no	<i>interpmet</i>

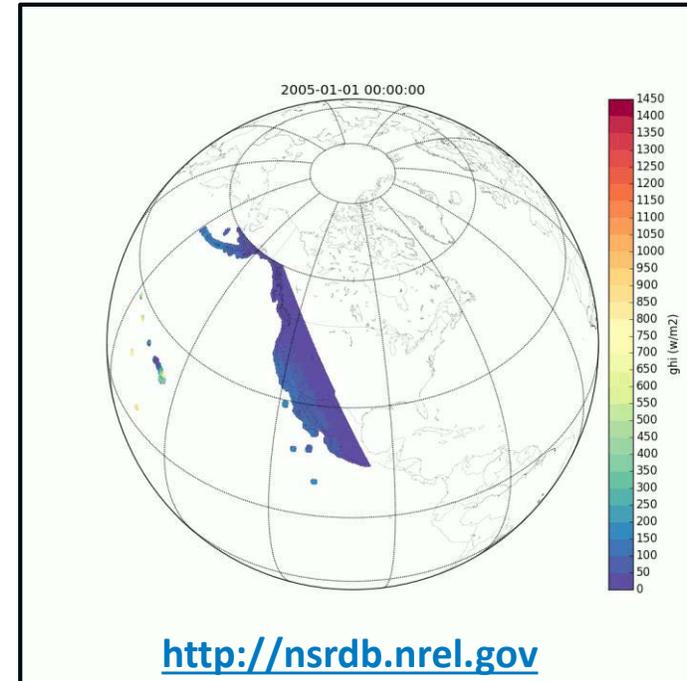
Data Format

Data Columns

Field	Units	Recognized names
Year	1950-2050	<i>year, yr</i>
Month	1-12	<i>month, mo</i>
Day	1-31	<i>day</i>
Hour	0-23	<i>hour, hr</i>
Minute	0-59	<i>min, minute</i>
Global horizontal irradiance	W/m ²	<i>gh, ghi, global, global horizontal, global horizontal irradiance</i>
Beam normal irradiance	W/m ²	<i>dn, dni, beam, direct normal, direct normal irradiance</i>
Diffuse horizontal irradiance	W/m ²	<i>df, dhi, diffuse, diffuse horizontal, diffuse horizontal irradiance</i>
Ambient dry bulb temperature	C	<i>tdry, dry bulb, dry bulb temp, temperature, ambient, ambient temp</i>
Wet bulb temperature	C	<i>twet, wet bulb, wet bulb temperature</i>
Dew point temperature	C	<i>tdew, dew point, dew point temperature</i>
Wind speed	m/s	<i>wspd, wind speed</i>
Wind direction	deg	<i>wdir, wind direction</i>
Relative humidity	%	<i>rh, rhum, relative humidity, humidity</i>
Atmospheric pressure	millibar	<i>pres, pressure</i>
Snow cover	cm	<i>snow, snow cover, snow depth</i>
Ground reflectance (albedo)	0..1	<i>albedo, alb</i>
Aerosol optical depth	0..1	<i>aod, aerosol, aerosol optical depth</i>

Future Work

- Improved identification and use of high albedo surfaces (sand and snow).
- Improved cloud retrievals from GOES-16.
- Aerosol retrieval from GOES-16.
- 5-min. data from GOES-16.

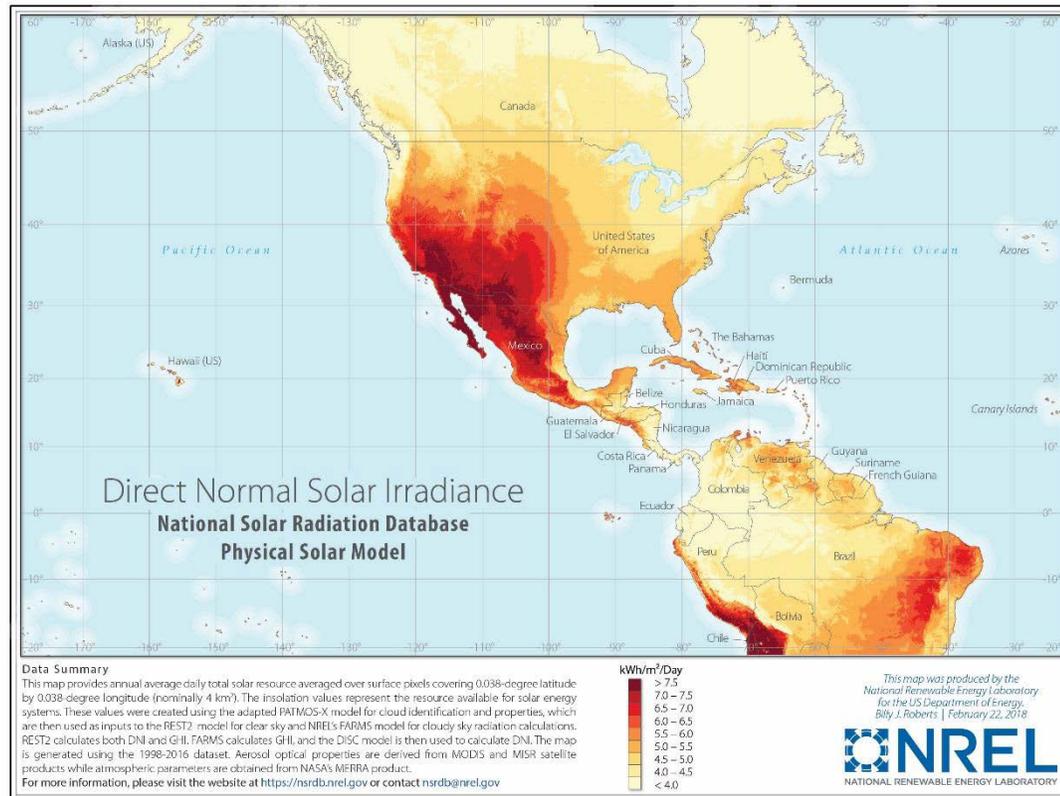


Thank You!

Email questions to: nsrdb@nrel.gov

<https://www.sciencedirect.com/journal/renewable-and-sustainable-energy-reviews/vol/89/suppl/C>

NSRDB: <http://nsrdb.nrel.gov>



The National Solar Radiation Data Base (NSRDB)
Review article
Pages 51-60
Manajit Sengupta, Yu Xie, Anthony Lopez, Aron Habte, ... James Shelby

Download PDF Article preview

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ORATORY



REopt Platform and Web Tool Overview for Solar Power International

Emma Elgqvist, NREL

September 24, 2018

History of REopt™

REopt evolved from an RE screening tool to a platform for energy systems integration and optimization

Key capabilities

- Renewable energy integration & optimization
- Portfolio planning
- Net zero analysis
- Mixed integer linear program
- Time series simulation
- Microgrid design
- Energy storage
- Operational energy
- EERE optimization
- Stochastic outage analysis
- Dispatching existing assets
- Web tool
- Macro-economic analysis
- Energy/water nexus



2007

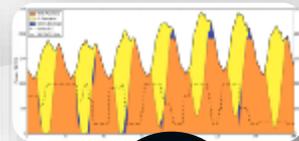
10 sites



2009

2011

100 sites



2013

10,000 sites



2015



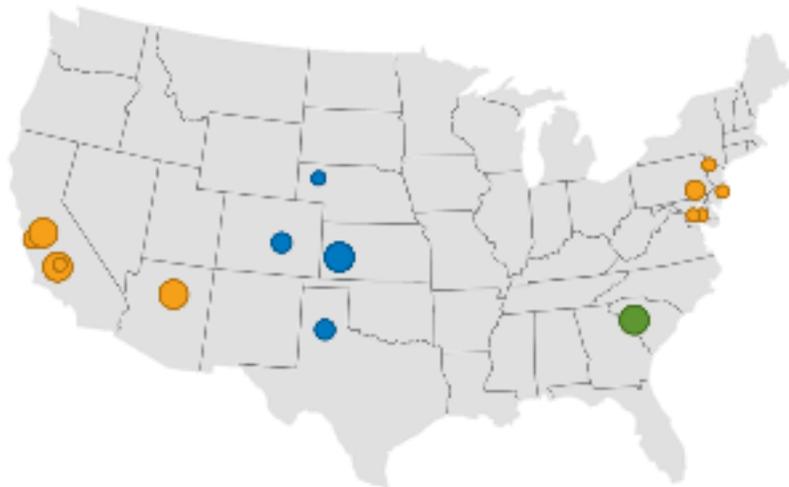
2017

100,000+ sites

Decision Support through Energy Planning Process

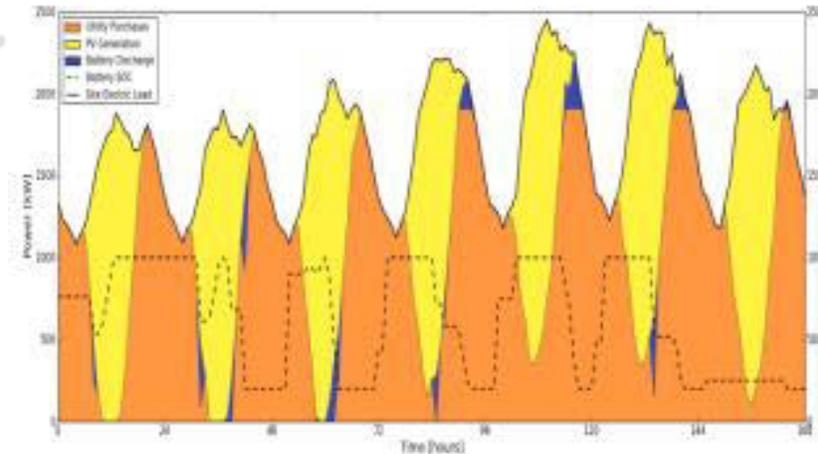
Optimization • Integration • Automation

- Portfolio prioritization
- Cost to meet goals



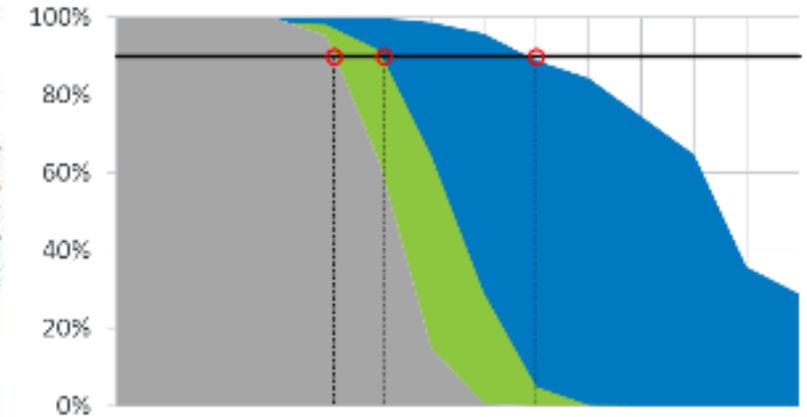
Cost-effective RE at Army bases

- RE and storage interaction
- Optimal operating strategies



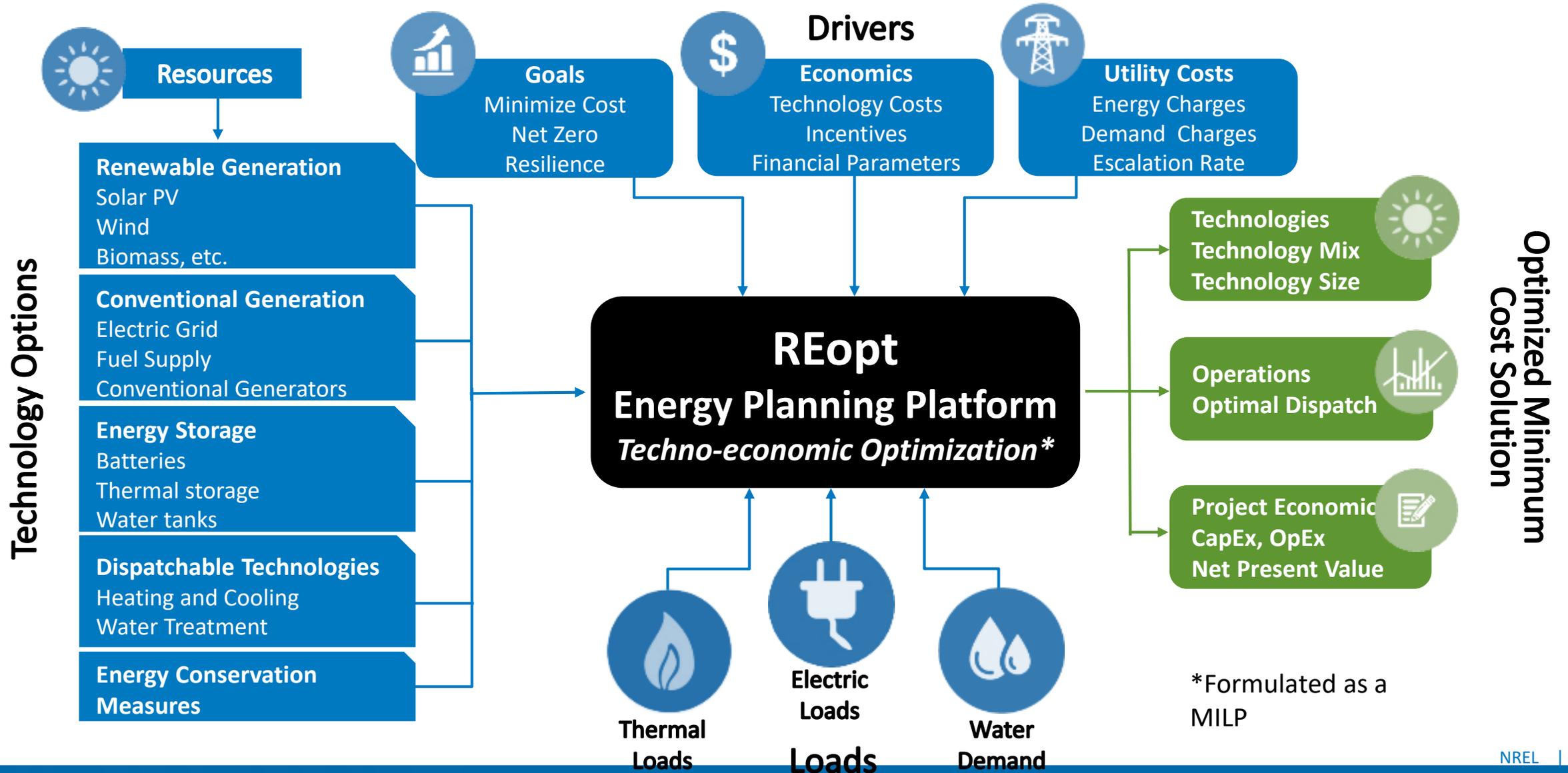
Cost-optimal Operating Strategy

- Microgrid dispatch
- Energy security evaluation



Extending Resiliency with RE

REopt Platform Inputs and Output



REopt Lite Web Tool

- The REopt Lite Web Tool offers a no-cost subset of NREL's more comprehensive REopt model
- Beta version of web tool launched September 2017; additional features added through 2018 and beyond
- **Financial mode** optimizes PV and battery system sizes and battery dispatch strategy to minimize life cycle cost of energy
- **Resilience mode** sizes PV+storage systems to sustain critical load during grid outages

Step 1: Choose Your Focus

Do you want to optimize for financial savings or energy resilience?

Financial Resilience



Step 2: Enter Your Data

Enter information about your site and adjust the default values as needed to see your results.

Site and Utility (required) ⊖

* Site location 📍 🔗 Use sample site

* Electricity rate ⚡ 📄 URDB Rate Details

Show more inputs 🔄 Reset to default values

Load Profile (required) ⊕

Financial ⊕

Step 3: Select Your Technology

Do you want to evaluate PV, battery, or both?

PV Battery Both

PV ⊕

Battery ⊕

[Reset to default values](#)

[Get Results](#) ➔

Required Site Specific Inputs (Financial Mode)

Site and Utility (required)

* Required field

* Site location [Use sample site](#)

* Electricity rate [URDB Rate Details](#)

[Show more inputs](#) [Reset to default values](#)

Load Profile (required)

* Required field

* Typical load Simulate Upload

How would you like to enter the typical energy load profile?

* Type of building

* Annual energy consumption (kWh)

[Download typical load profile](#) [Chart typical load data](#)

Financial

Step 1: Choose Your Focus

Do you want to optimize for financial savings or energy resilience?

Financial Resilience

Location and utility rate



Load profile – simulated or actual



Step 3: Select Your Technology

Do you want to evaluate PV, battery, or both?

PV Battery Both

Technologies to evaluate



PV Battery

Additional Inputs Can Be Edited, Or Left As Defaults

\$ Financial

Host real discount rate (%) 6.8%

Electricity escalation rate (%) 0.5%

[+ Show more inputs](#) [Reset to default values](#)

\$ Financial

Host real discount rate (%) 6.8%

Electricity escalation rate (%) 0.5%

[- Show fewer inputs](#)

Analysis period (years) 20

Host effective tax rate (%) 40%

Inflation rate (%) 2.5%

[Reset to default values](#)

Summary Results Include System Sizes and Savings

Results for Your Site

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.

[← Edit Inputs](#)



Your recommended solar installation size ?

781 kW
PV size

Measured in kilowatts (kW) of direct current, this recommended size minimizes the life cycle cost of energy at your site.



Your recommended battery power and capacity ?

131 kW
battery power

556 kWh
battery capacity

This system size minimizes the life cycle cost of energy at your site. The battery power and capacity are optimized for economic performance.



Your potential life cycle savings (20 years) ?

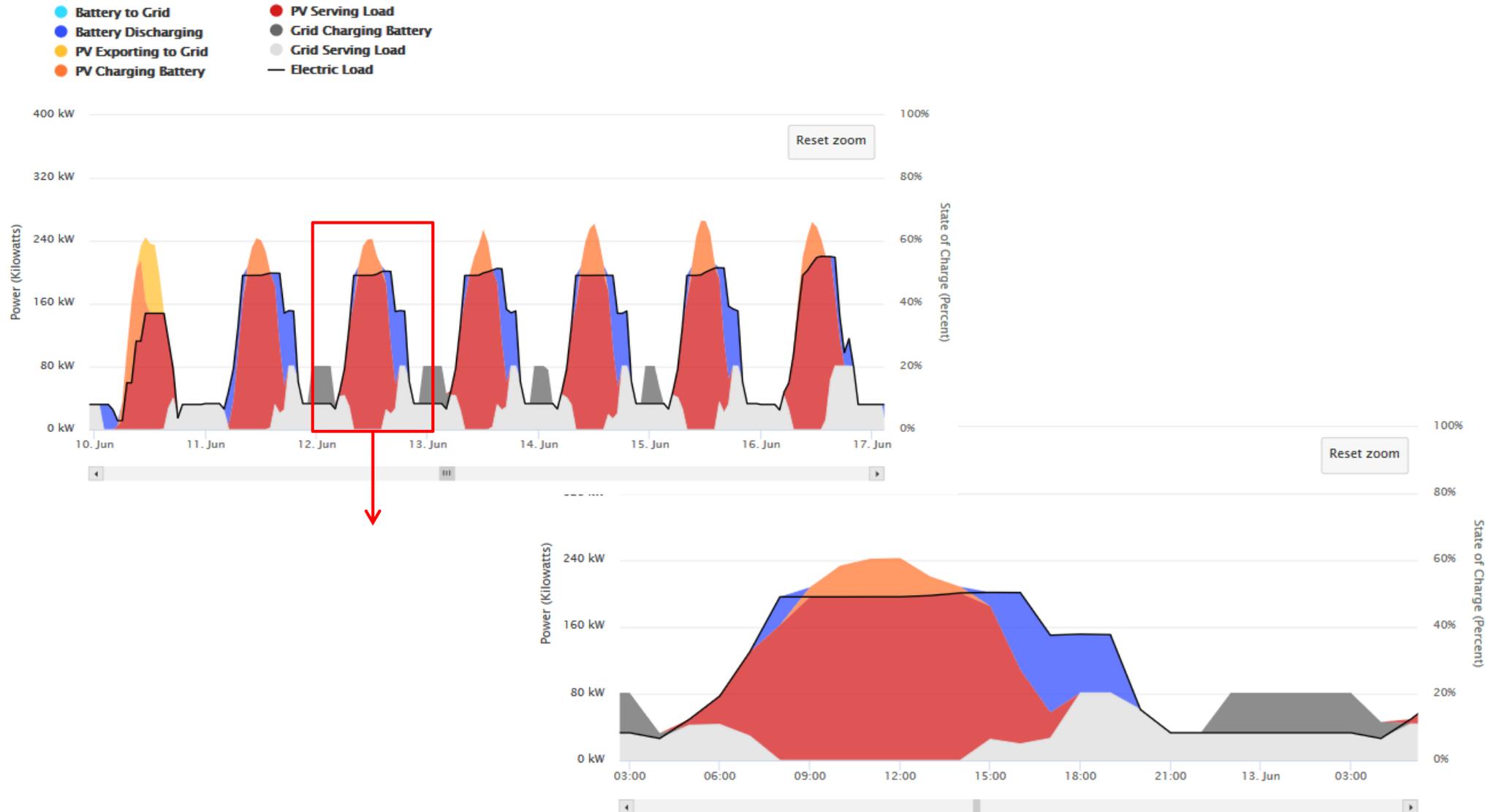
This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the life cycle energy cost of doing business as usual compared to the optimal case.

\$439,275

Additional Results Output: Economics Summary

	Business As Usual ⓘ	Optimal Case ⓘ	Difference ⓘ
System Size, Energy Production, and System Cost			
PV Size ⓘ	0 kW	392 kW	392 kW
Annualized PV Energy Production ⓘ	0 kWh	680,826 kWh	680,826 kWh
Battery Power ⓘ	0 kW	93 kW	93 kW
Battery Capacity ⓘ	0 kWh	342 kWh	342 kWh
DG System Cost (Net CAPEX + O&M) ⓘ	\$0	\$526,342	\$526,342
Energy Supplied From Grid in Year 1 ⓘ	1,000,000 kWh	358,623 kWh	641,377 kWh
Year 1 Utility Cost — Before Tax			
Utility Energy Cost ⓘ	\$118,263	\$34,216	\$84,047
Utility Demand Cost ⓘ	\$40,008	\$18,623	\$21,385
Utility Fixed Cost ⓘ	\$3,110	\$3,110	\$0
Utility Minimum Cost Adder ⓘ	\$0	\$0	\$0
Life Cycle Utility Cost — After Tax			
Utility Energy Cost ⓘ	\$857,868	\$248,200	\$609,668
Utility Demand Cost ⓘ	\$290,213	\$135,089	\$155,124
Utility Fixed Cost ⓘ	\$22,562	\$22,562	\$0
Utility Minimum Cost Adder ⓘ	\$0	\$0	\$0
Total System and Life Cycle Utility Cost — After Tax			
Life Cycle Energy Cost ⓘ	\$1,170,644	\$932,194	\$238,450
Net Present Value ⓘ	\$0	\$238,450	\$238,450

Additional Results Output: Hourly Dispatch Graph



Thank You!

Emma Elgqvist, NREL

Emma.Elqvist@nrel.gov

www.nrel.gov

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

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.



Fleet-scale photovoltaic system degradation analysis applied to hundreds of residential and non-residential PV systems

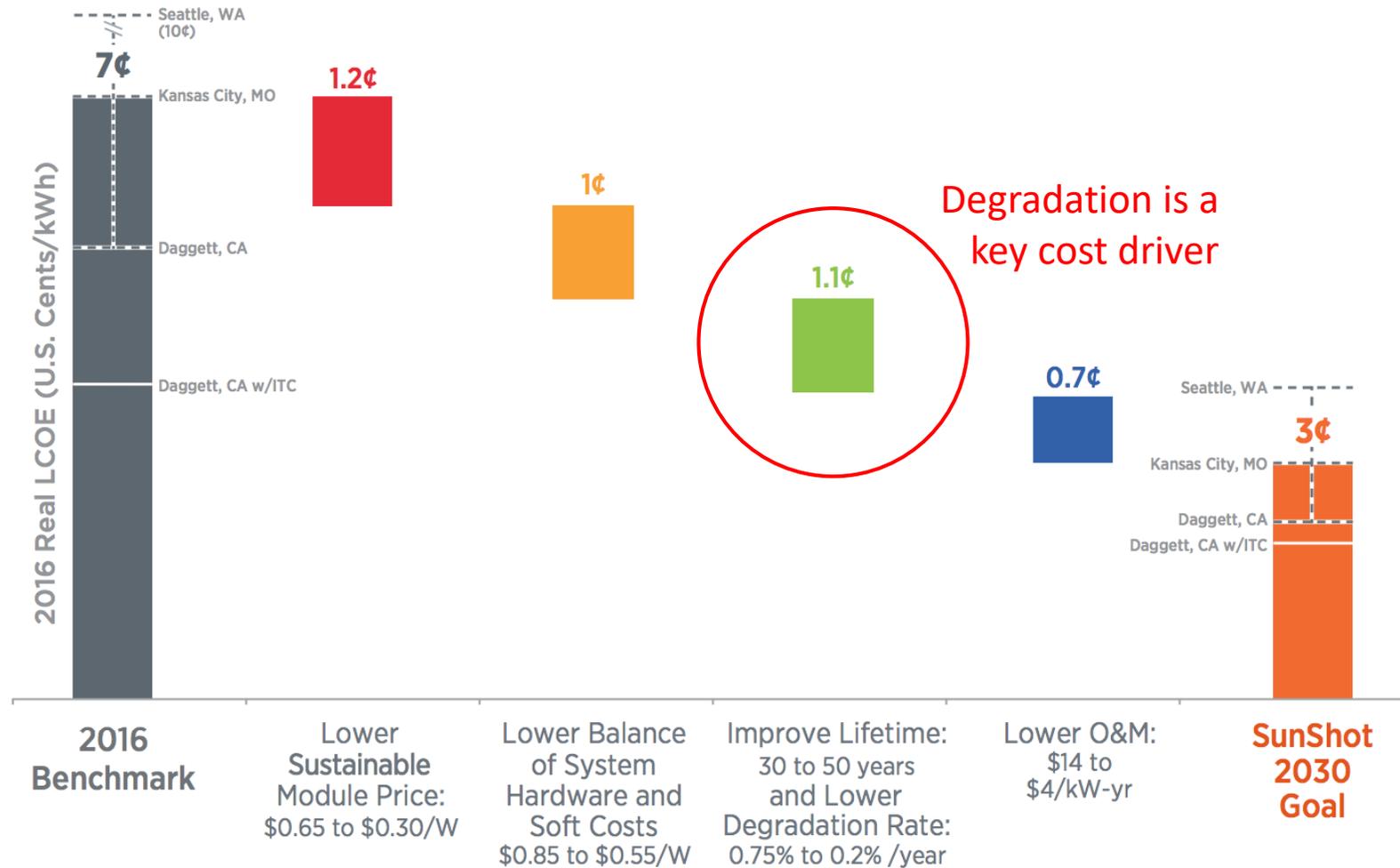
Michael G. Deceglie¹, Dirk C. Jordan¹, Ambarish Nag¹,
Adam Shinn², and Chris Deline¹

¹National Renewable Energy Laboratory

²kWh Analytics

Originally presented at WCPEC 2018

Importance of degradation rate



Comparative PV LCOE Calculator

NREL NATIONAL RENEWABLE ENERGY LABORATORY

HOME DOCUMENTATION

Inputs

Baseline PRESETS

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
2.32

Non-cell module cost (USD/m²)
18.00

Performance

Efficiency (%)
19.0

Energy yield (kWh/kW_{DC})
1475

Reliability

Degradation rate (%/year)
0.25

Service life (years)
25

Proposed COPY FROM BASELINE

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
2.32

Non-cell module cost (USD/m²)
18.00

Performance

Efficiency (%)
19.0

Energy yield (kWh/kW_{DC})
1475

Reliability

Degradation rate (%/year) ←

Service life (years)
25

Results

LCOE result

Baseline LCOE (USD/kWh)	0.0663
Proposed LCOE (USD/kWh)	0.0678

Please email [Timothy J Silverman](mailto:Timothy.J.Silverman@nrel.gov) with comments or questions.

Degradation rate is also important in modeling financials

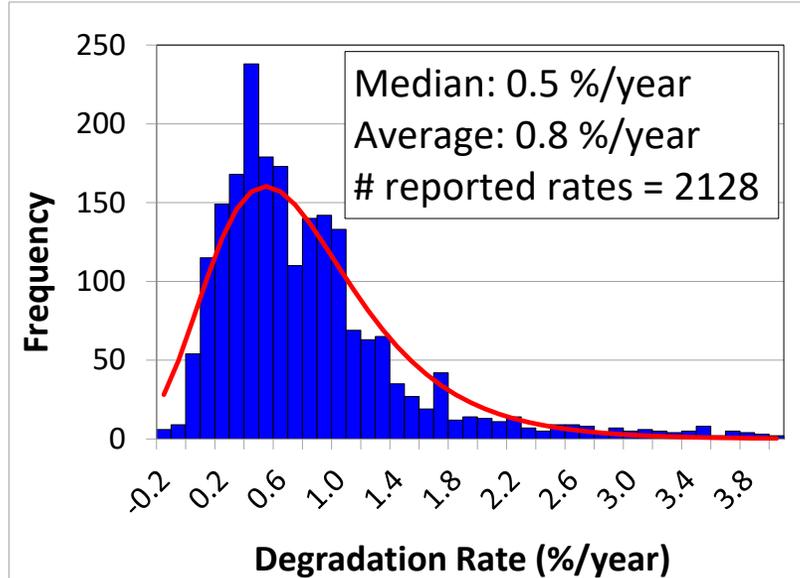
What degradation rate should I use?

pvloce.nrel.gov

Reported degradation rates

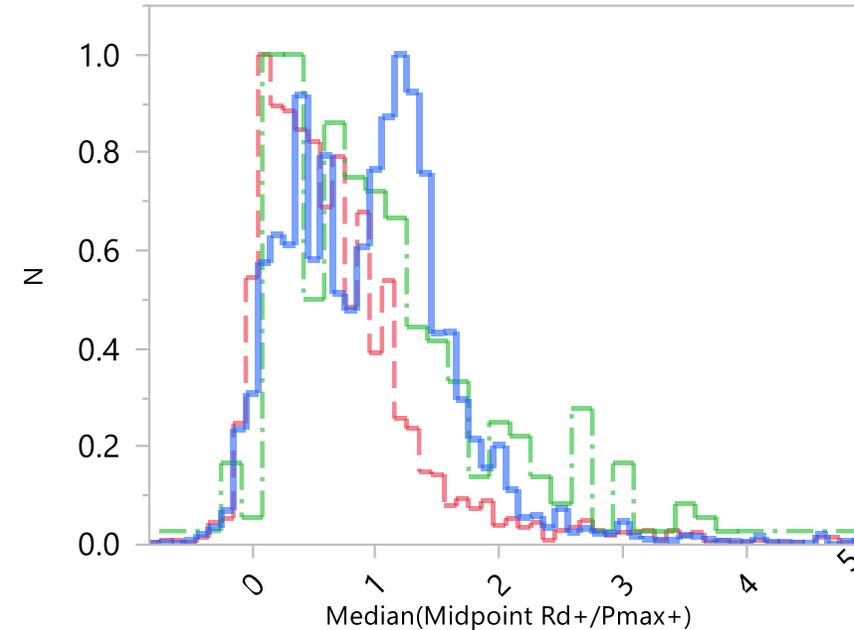
Literature survey

2011



Jordan et al., "Degradation Rates – An Analytical Review", Progress in PV, 2011

2016

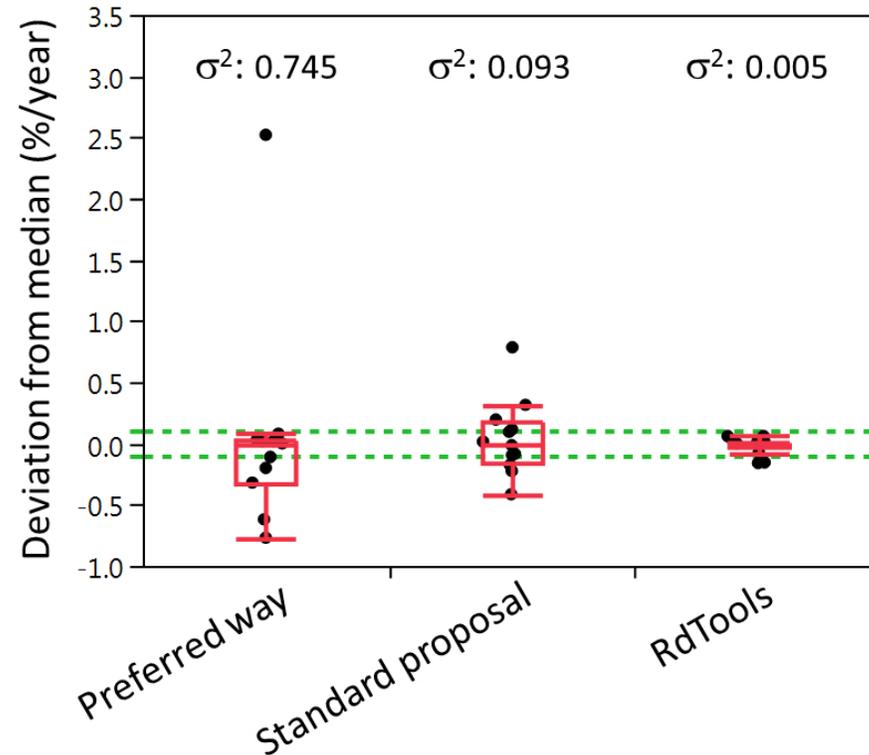


Jordan et al., "Compendium of photovoltaic degradation rates", Progress in PV, 2016

- The literature includes a variety of methods.
- Different methods can lead to bias.
- Large variation because of a lot of different factors such as method, technology, quality, climate, mounting etc. makes it difficult to draw large-scale conclusions.

Improving consistency

Different analysts analyzing the same data sets



With RdTools we can improve accuracy significantly over written procedures or analysts preferred way.

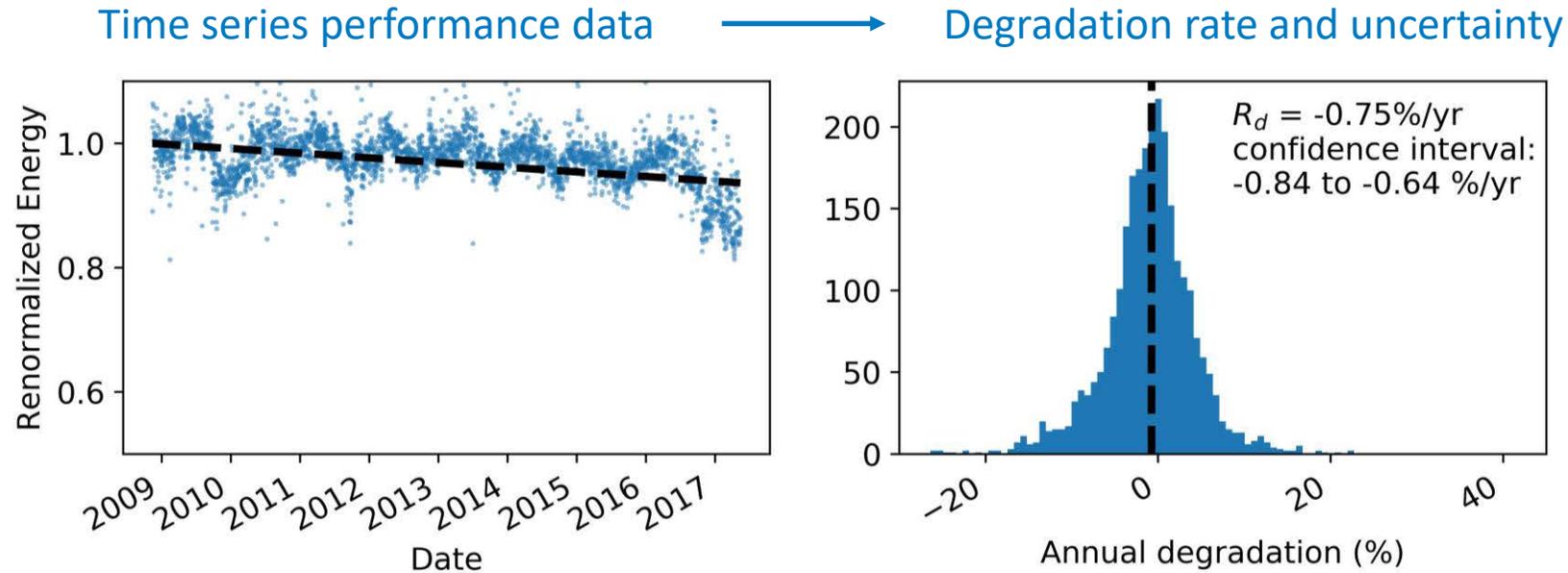
We an open source software library (RdTools) for retrospective analysis of PV system degradation.

more info: <https://www.nrel.gov/pv/rdtools.html>

Today's talk

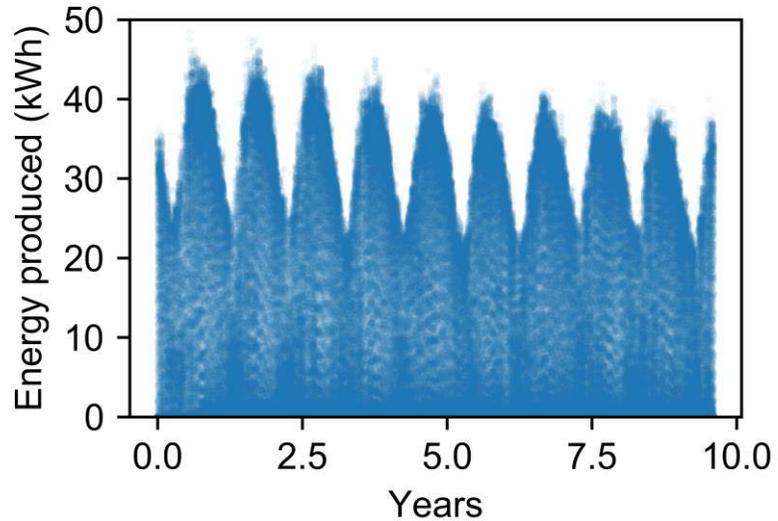
- Our methods and the open-source software we've developed to implement them
- Example fleet-scale analysis of 500+ PV systems
 - Differences in shade, technology, system age, and temperature

Our approach

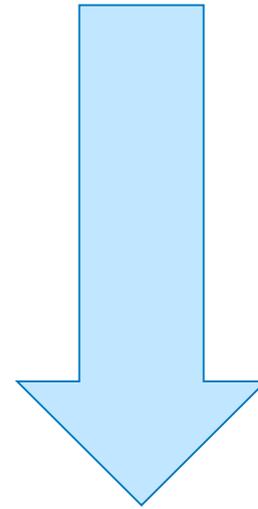


- Built with RdTools <https://www.nrel.gov/pv/rdtools.html>
 - Open-source python module for PV data analysis
 - API built around Pandas and PVLIB
- Steps:
 - Normalize
 - Filter
 - Aggregate
 - Analyze Rd

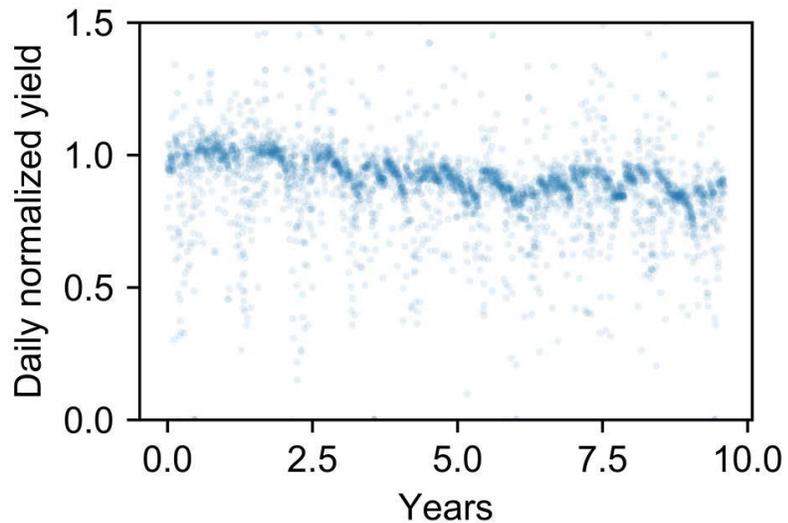
First three steps



Energy time series

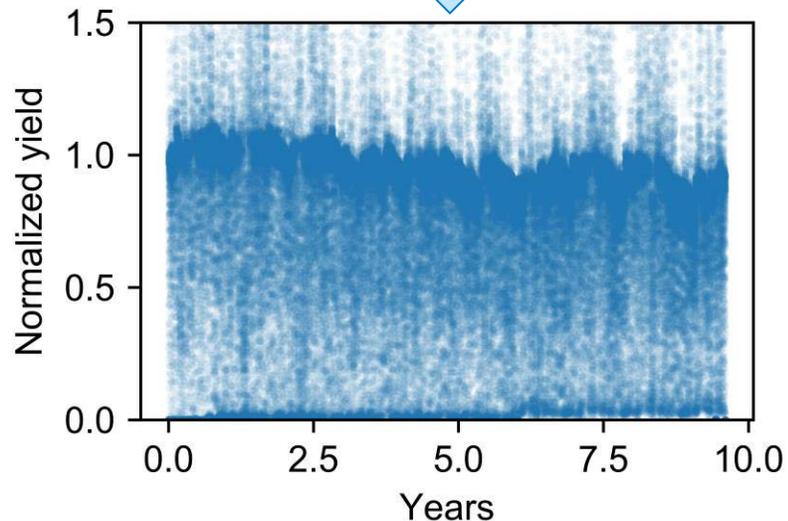
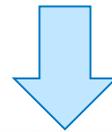
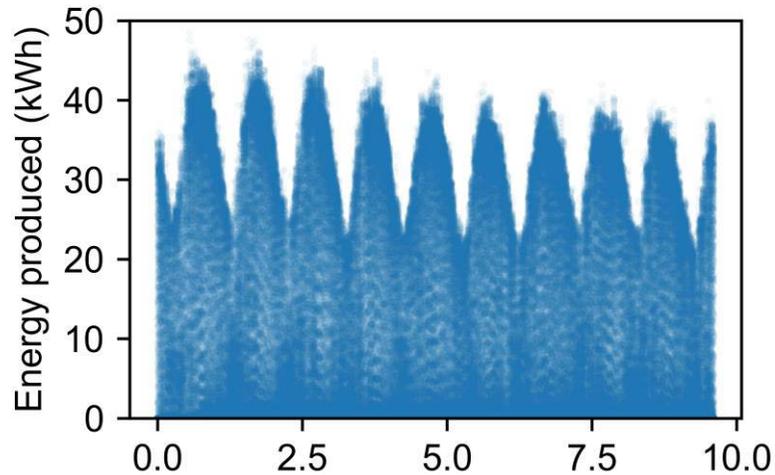


1. Normalize to model
2. Filter
3. Aggregate



Daily normalized energy yield

1. Normalize to a model



- Input: PV energy, Irradiance, cell temperature (modeled or measured)
- Use a simple irradiance and temperature model to calculate normalized high-frequency performance index

$$P = P_0 \frac{G_{POA}}{G_0} (1 + \gamma(T_{cell} - T_0))$$

- Frequency mismatch between weather and energy is automatically handled by RdTools

Weather data for model

- The normalization step requires modeled system performance based on weather/irradiance data
- Choices:

Site measured

pros:

- Can be high accuracy

cons:

- May not be available for smaller systems
- Irradiance sensors can drift over time, must be carefully maintained

Satellite based (e.g. NSRDB)

pros:

- Wide availability
- No instrumentation required

cons:

- Lower accuracy than carefully maintained met stations

Weather data for model

- The normalization step requires modeled system performance based on weather/irradiance data
- Choices:

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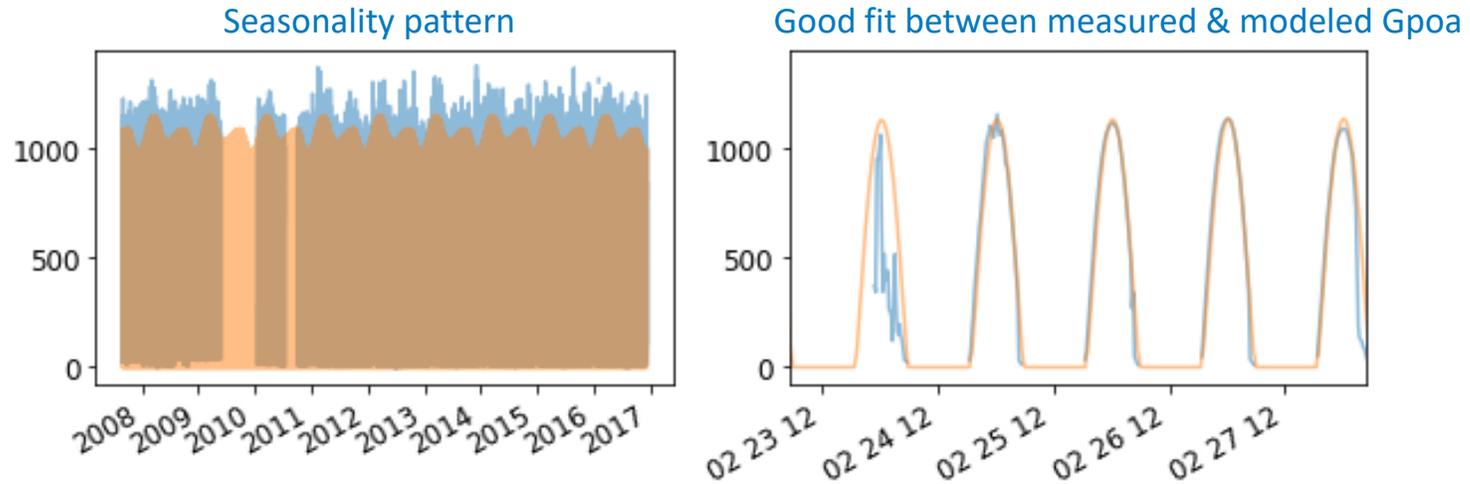
cons:

- Lower accuracy than carefully maintained met stations

Solution: Clear-sky workflow

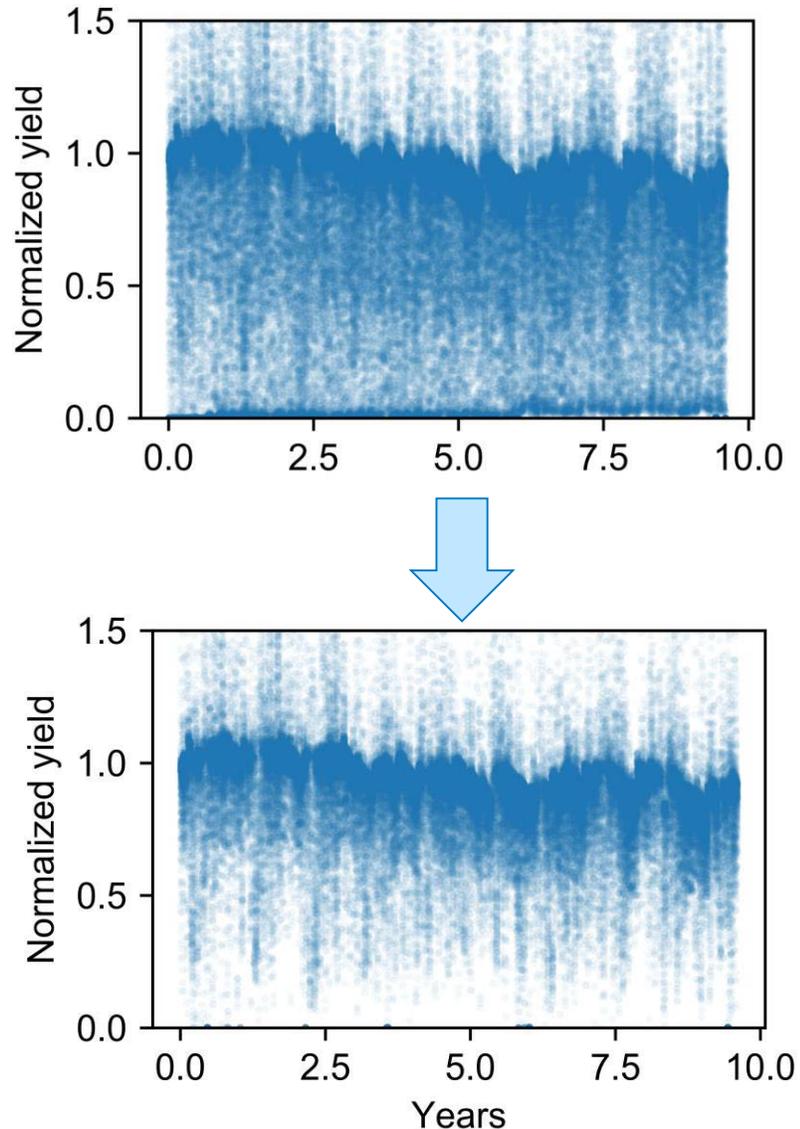


Clear sky workflow



- Alleviates bias due to long term drift in sensors when using site-measured weather data
- Steps
 - Model the irradiance using a relatively simple clear-sky model
 - Compare with measured irradiance to detect clear sky times
 - Use modeled clear-sky irradiance to normalize
 - Filter out non-clear-sky times
 - Example available in the RdTools docs

2. Filter



- Minimal filtering is more conservative
- Remove points:
 - ≤ 0
 - Irradiance < 200
 - Irradiance > 1200
 - $T_{\text{cell}} < -50^{\circ}\text{C}$
 - $T_{\text{cell}} > 110^{\circ}\text{C}$
 - Clearsky method only:
Clearness index
(measured/modeled G_{poa})
 < 0.85 and > 1.15
 - Optional: filter out inverter clipping
- Room for innovation:
 - Find outages and outliers without introducing bias

Note on filtering

Are you considering **system** or **module** degradation?



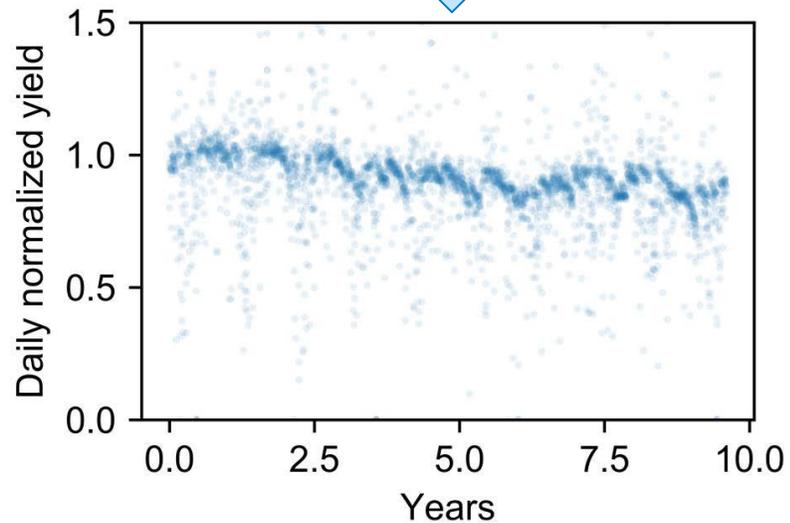
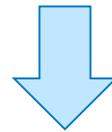
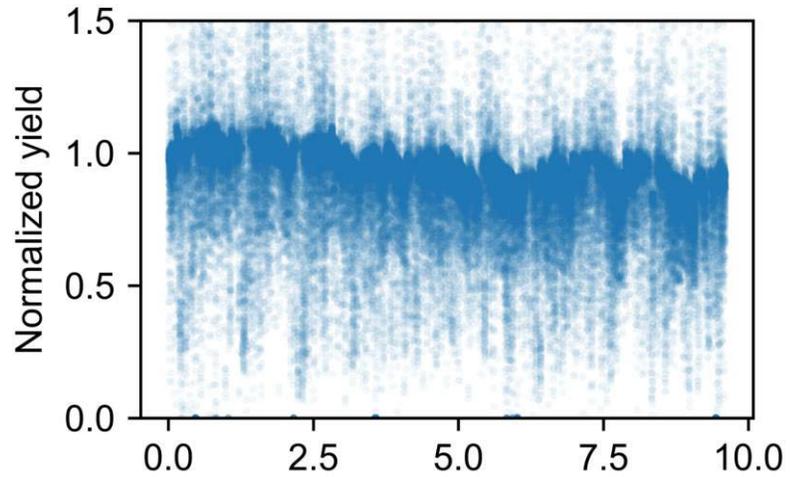
VS.



For modules → filter things like tracker downtime and clipping

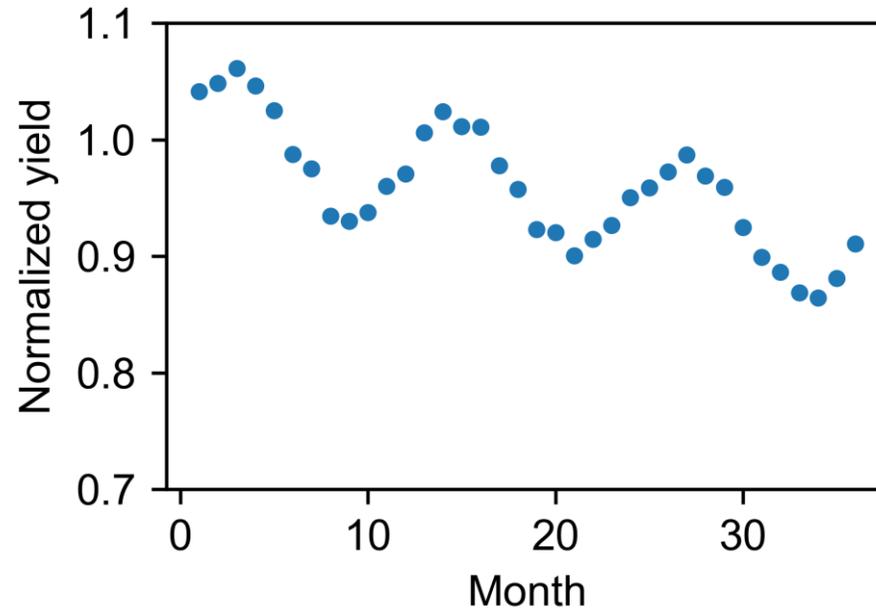
There are subtleties in filtering choices depending on the goals of the analysis

3. Aggregate



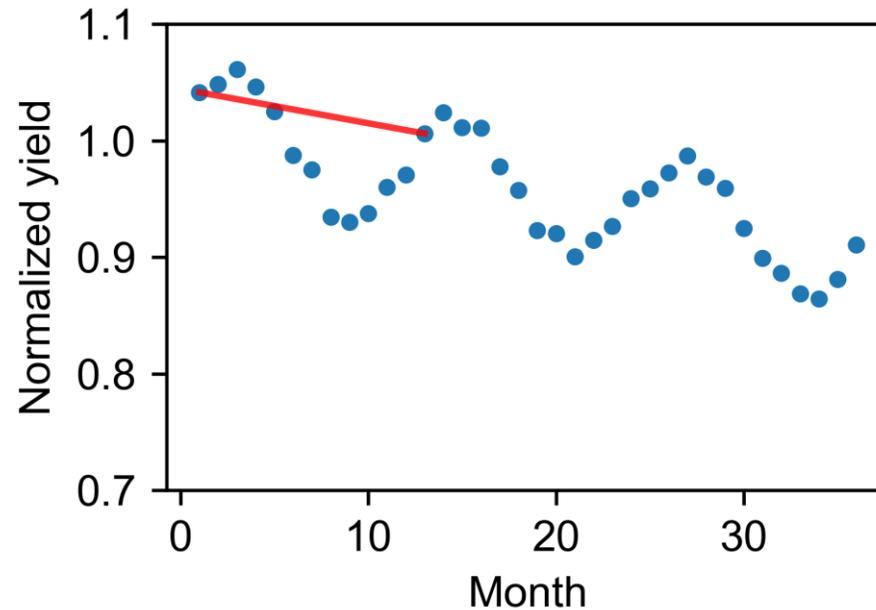
Calculate daily irradiance-weighted performance index

4. Rd Analysis: year-on-year



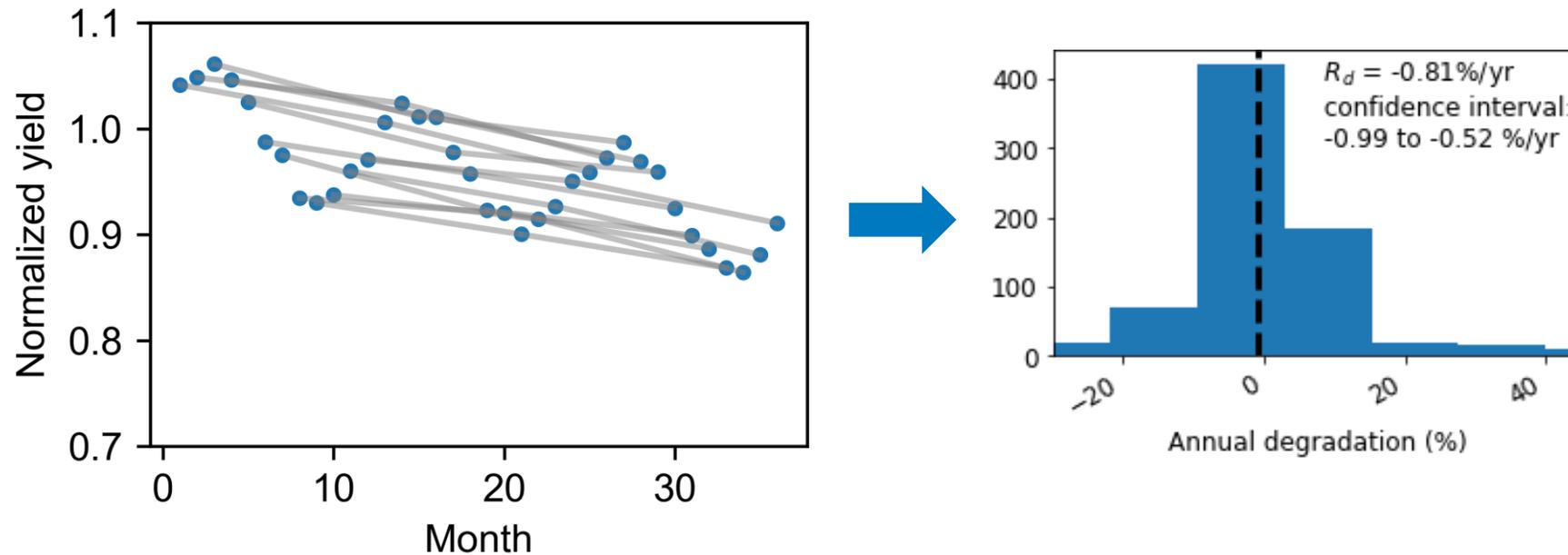
- Year-on-year is robust to seasonality and outliers
- Steps:
 - Compare each day (or week, month, etc.) to its corresponding day a year later
 - Calculate the median of all year-on-year slopes
- Pay attention to the confidence interval

4. Rd Analysis: year-on-year



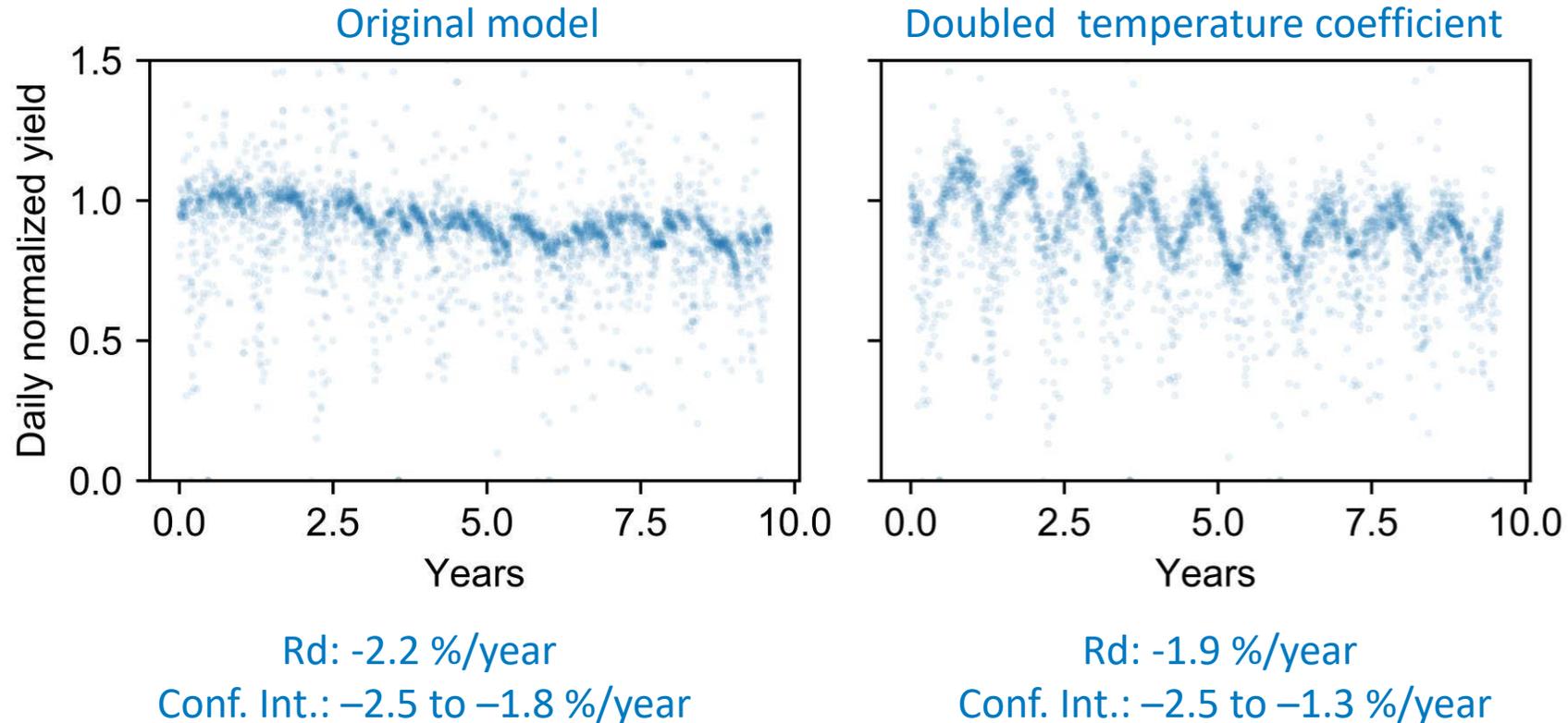
- Year-on-year is robust to seasonality and outliers
- Steps:
 - Compare each day (or week, month, etc.) to its corresponding day a year later
 - Calculate the median of all year-on-year slopes
- Pay attention to the confidence interval

4. Rd Analysis: year-on-year



- Year-on-year is robust to seasonality and outliers
- Steps:
 - Compare each day (or week, month, etc.) to its corresponding day a year later
 - Calculate the median of all year-on-year slopes
- Pay attention to the confidence interval

Year-on-year is robust



- Example: intentionally induced seasonality
- Results remain consistent
- Confidence interval appropriately expands
- **A very detailed performance model isn't needed**

All this is available in RdTools

The screenshot displays the GitHub interface for the repository `NREL / rdtools`. At the top, there are navigation links for Features, Business, Explore, Marketplace, and Pricing, along with a search bar and options to sign in or sign up. Below the repository name, there are statistics for Watch (16), Star (26), and Fork (20). The main content area shows the repository title "PV Degradation Analysis Tools in Python" and a list of recent commits. The commits are as follows:

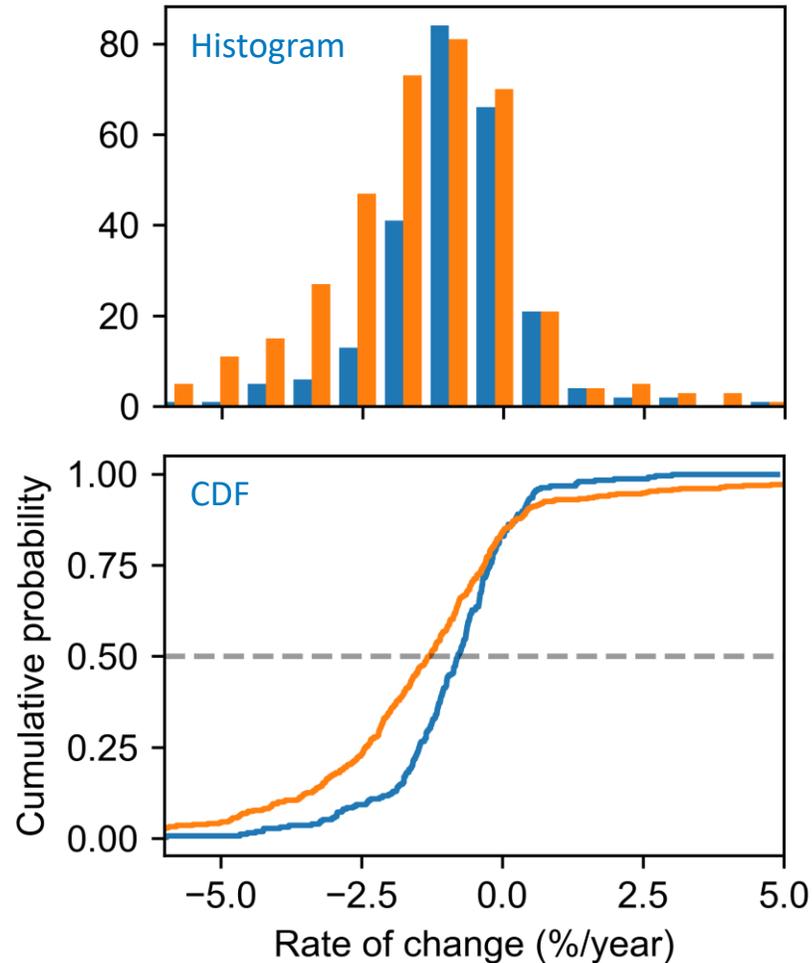
Commit	Description	Time Ago
<code>mdeceglie</code> Merge pull request #77 from nb137/patch-1	Latest commit 4348939 on Apr 13	
<code>docs</code>	use integer divide	3 months ago
<code>rdtools</code>	Merge remote-tracking branch 'upstream/development' into futurize	3 months ago
<code>screenshots</code>	screenshot images for Readme file	7 months ago
<code>tests</code>	Merge remote-tracking branch 'upstream/development' into futurize	3 months ago
<code>.gitattributes</code>	Add versioneer for compatibility.	2 years ago
<code>.gitignore</code>	ignore dist building files	7 months ago
<code>LICENSE</code>	Add NREL to copyright holders	11 months ago
<code>MANIFEST.in</code>	Add clearsky_tamb from clearsky_temperature branch	11 months ago
<code>README.md</code>	README typo correction	2 months ago
<code>setup.cfg</code>	add readme to setup.cfg	7 months ago
<code>setup.py</code>	Add python 3 to classifiers	2 months ago
<code>versioneer.py</code>	Add versioneer for compatibility.	2 years ago

- Read me and examples: <https://github.com/NREL/rdtools>
- install: `pip install rdtools`

Fleet-scale analysis

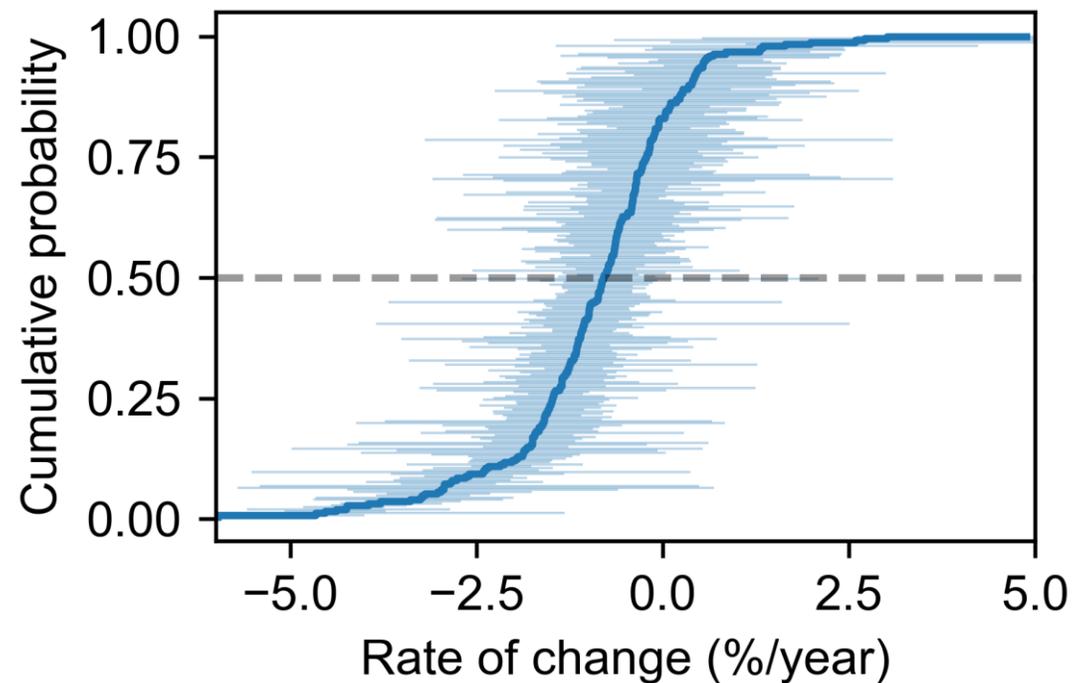
- Analyzed 634 subarrays from 503 PV systems in the United States
- 387 residential systems
- 116 larger, non-residential systems
- >3,400 system-years of time series data
- Used satellite weather data for consistency
- Study system energy-yield degradation

Cumulative distribution functions (CDFs)



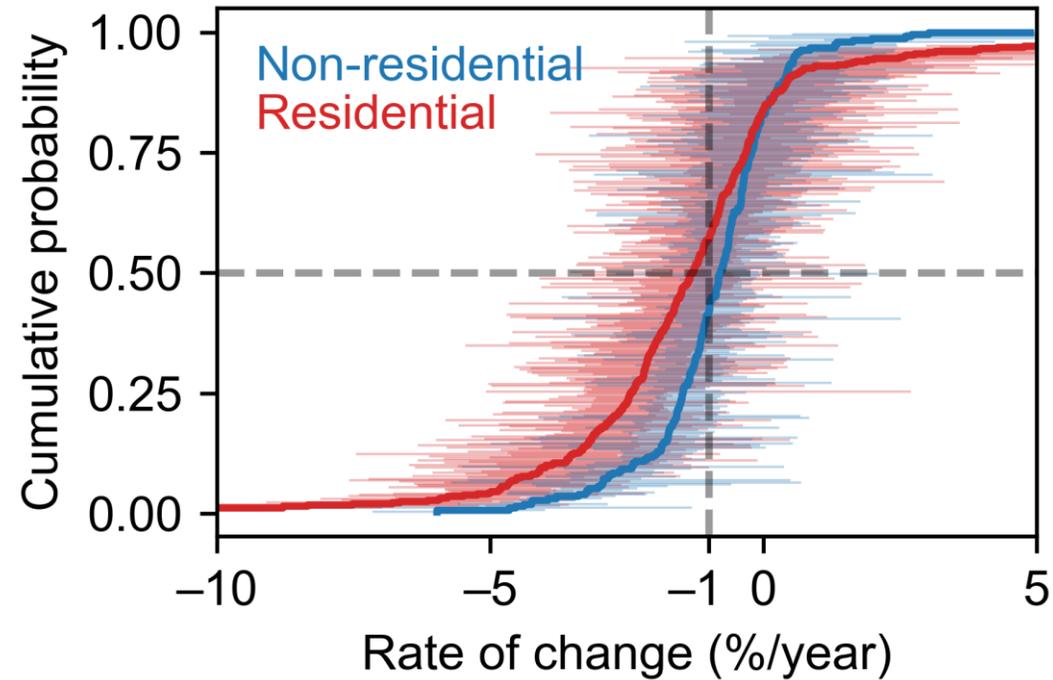
- CDFs provide a way to visualize distributions, independent of bin size
- CDFs make it easier to compare two samples

CDFs with individual confidence intervals



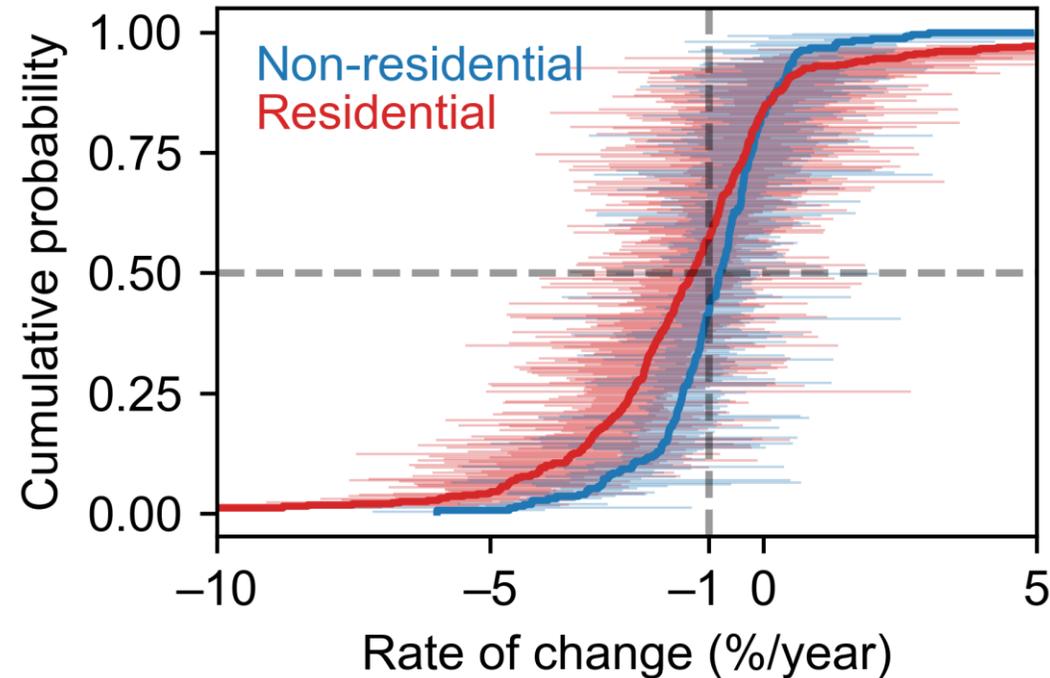
We can include each measurement's 95% confidence interval on the plot

Residential vs. Non-residential



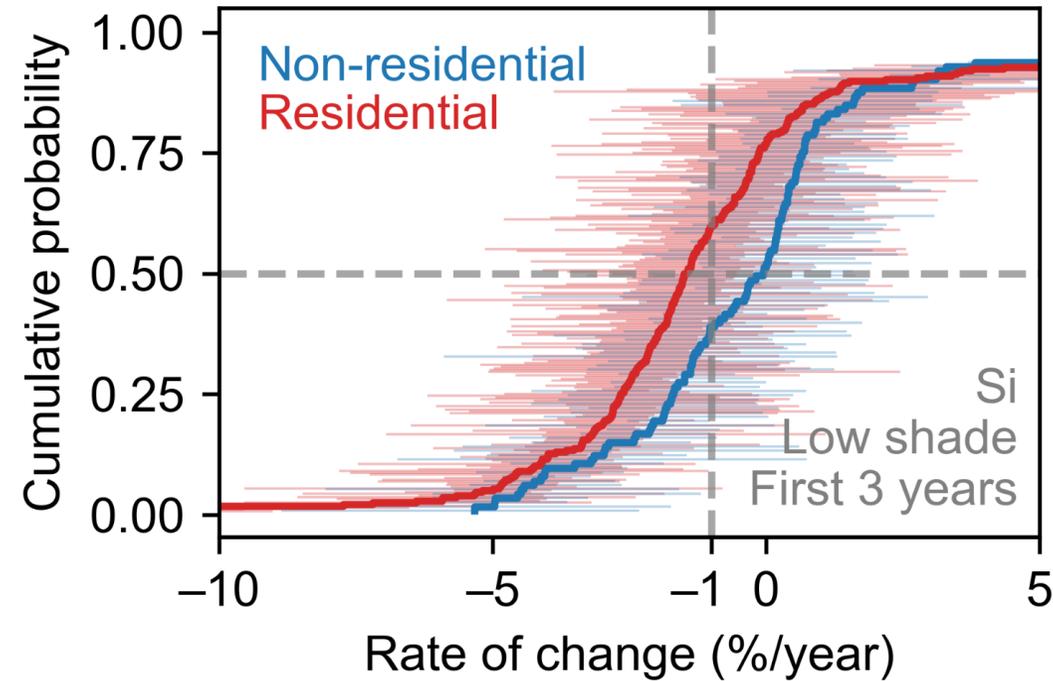
- Recall we are analyzing **system** yield degradation
- Negative rate of change = degradation (-1%/year indicated)

Residential vs. Non-residential



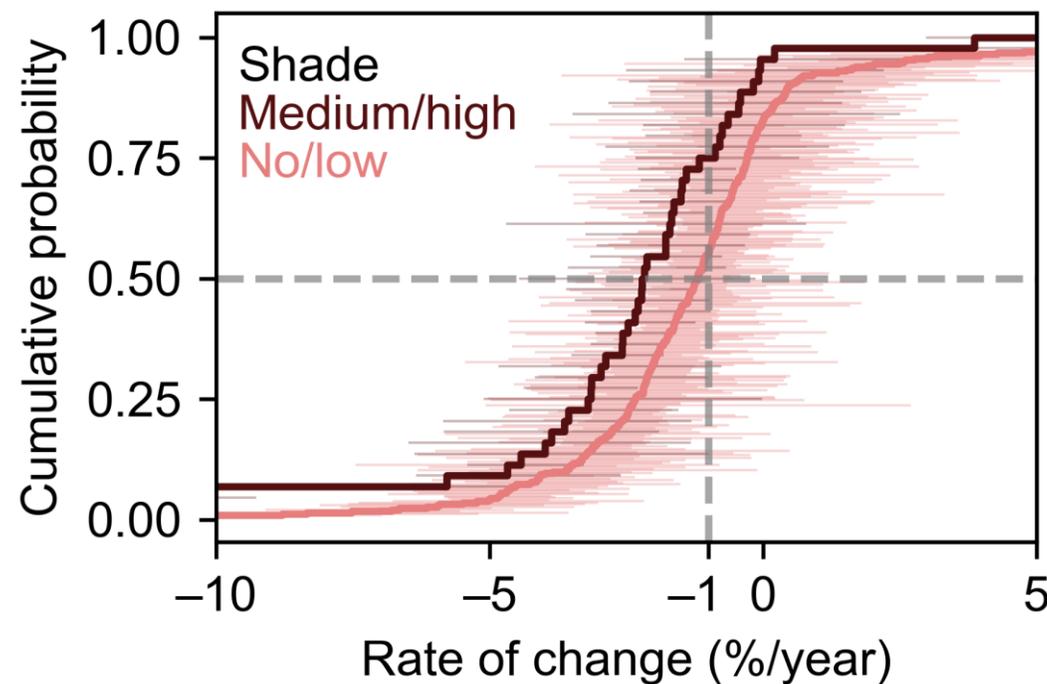
- Residential systems tended to degrade more rapidly
- 29% of residential and 38% of non-residential systems degraded slower than -0.5%/year
- What about differences in age, technology etc.?

Residential vs. non-residential



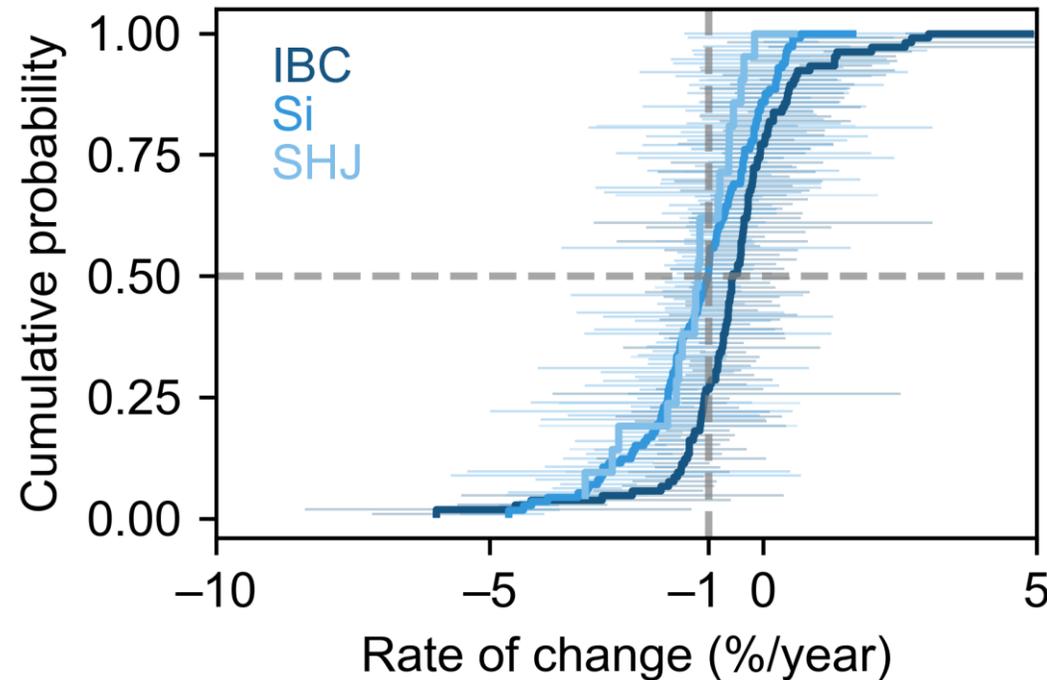
The difference persists with a more direct comparison

Shade in residential systems



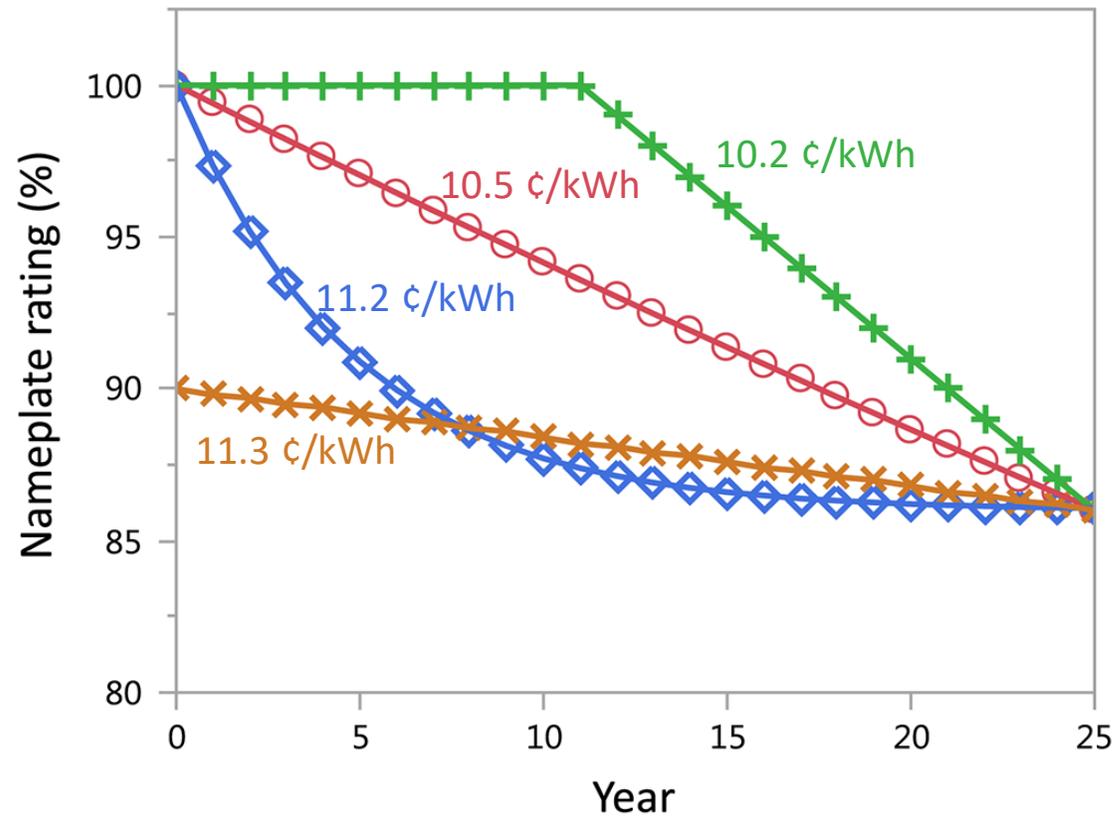
- Systems with higher shade tended to degrade more rapidly
- Possible causes:
 - Foliage growth
 - Hot spots

Cell technology in non-residential systems



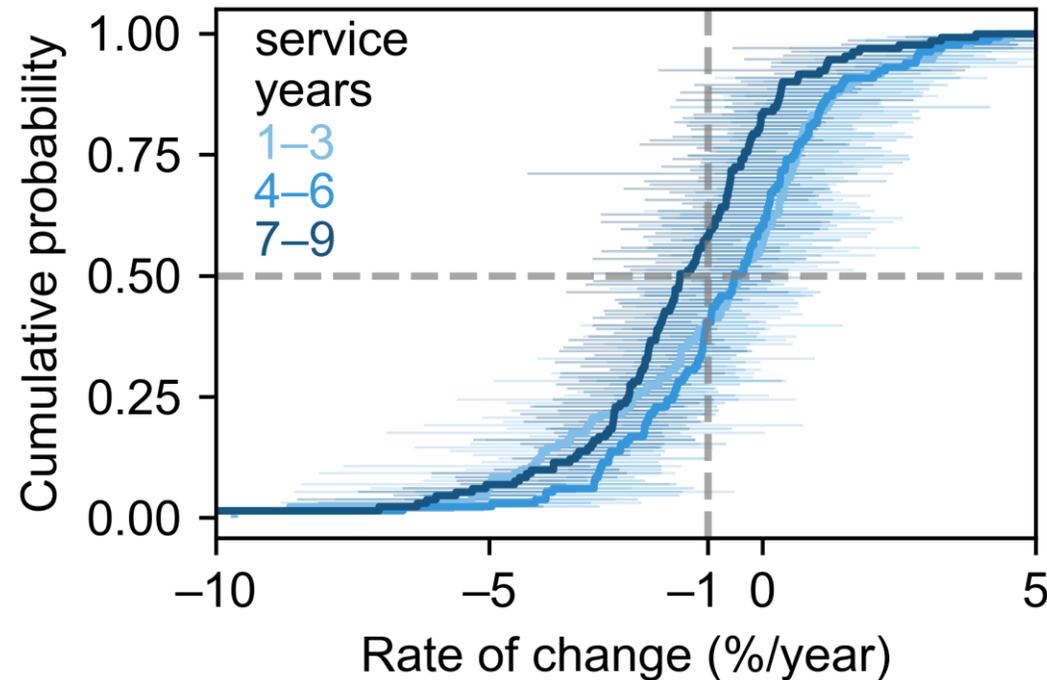
- Three cell technologies present in the non-residential dataset
 - Interdigitated back contact (IBC)
 - Conventional Si (Si)
 - Silicon heterojunction (SHJ) e.g. HIT
- IBC-based systems tended to degrade more slowly than other technologies
- Co correlated variables (manufacturer, module construction etc.)

Non-linear degradation



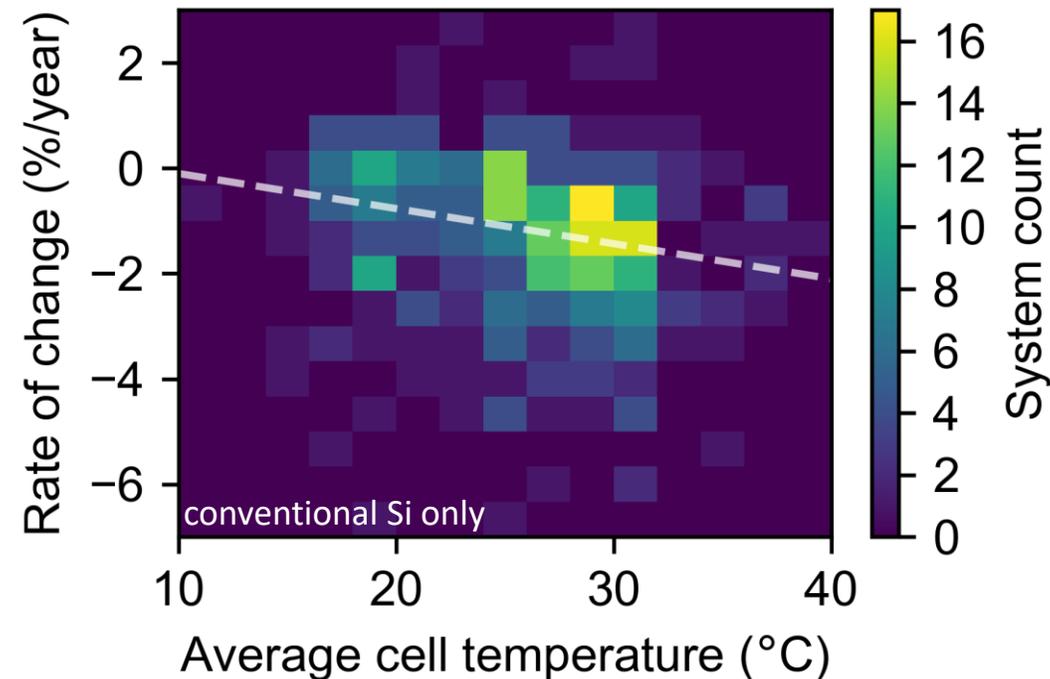
The shape of the degradation profile has financial implications

System age in non-residential systems



- The same 142 subarrays at 76 sites are considered over three different stages in system life
- Same systems in each CDF above
- Systems tended to show more rapid degradation later in life
- Should be careful about applying this generally

Temperature



- Systems with higher operating temperatures tended to degrade faster
- Possible explanation: thermally accelerated degradation modes
- Caution: confounding variables, e.g. UV and mounting

Example study summary

- Fleet-scale analysis elucidates system degradation trends
 - Residential vs. non-residential
 - More rapid degradation later in system life
 - More rapid degradation at higher temperature
 - Differences in module technology
 - More rapid reductions in energy in shaded residential systems

Conclusion

- What you need:
 - Time series energy output (preferably hourly or better)
 - Coincident irradiance and weather data (ground- or satellite-based)
- RdTools is open source and available:
github.com/NREL/rdtools
- Be clear about questions at the outset, build the analysis accordingly
- Pay attention to the resulting confidence intervals. Large confidence intervals indicate need for improved model or data
- RdTools is a library, build an application to suit your needs

Funding provided by Solar Energy Technology Office under agreement 30295. 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.





System Advisor Model

Solar Power International 2018

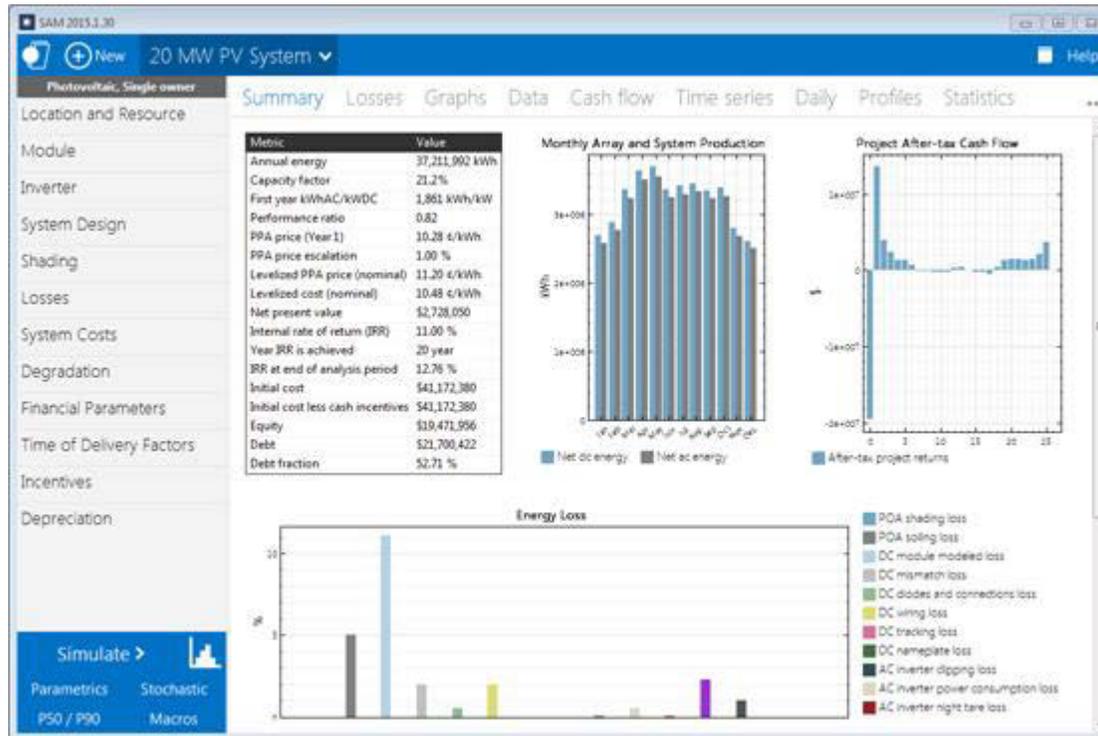
Nicholas DiOrio

September 24, 2018

System Advisor Model (SAM)

SAM is free software for modeling the performance and economics of renewable energy projects.

<http://sam.nrel.gov>
github.com/NREL/SAM



- Developed by NREL with funding from DOE
- Windows, OSX, and Linux
- One or two new versions per year
- Software Development Kit (SDK)
- Support

Download Beta version

https://sam.nrel.gov/sites/default/files/content/public_releases/sam-beta-windows-2018-9-10.exe



Technologies

Photovoltaics

- Detailed & PVWatts

- Battery Storage

Wind

- Concentrating solar power

- Geothermal

- Biomass

- Solar water heating

Financial Models

Behind-the-meter

- residential

- commercial

- third-party ownership

Power purchase agreements

- single owner

- equity flips

- sale-leaseback

Simple LCOE calculator

History

Developed by

- Department of Energy
- National Renewable Energy Laboratory
- Sandia National Laboratories



Original vision in 2004

- Allow DOE to make R&D choices based on analysis of the entire system including costs
- Model different renewable energy projects in a single platform
- Facilitate technology comparison by handling performance, costs and financing consistently across technologies

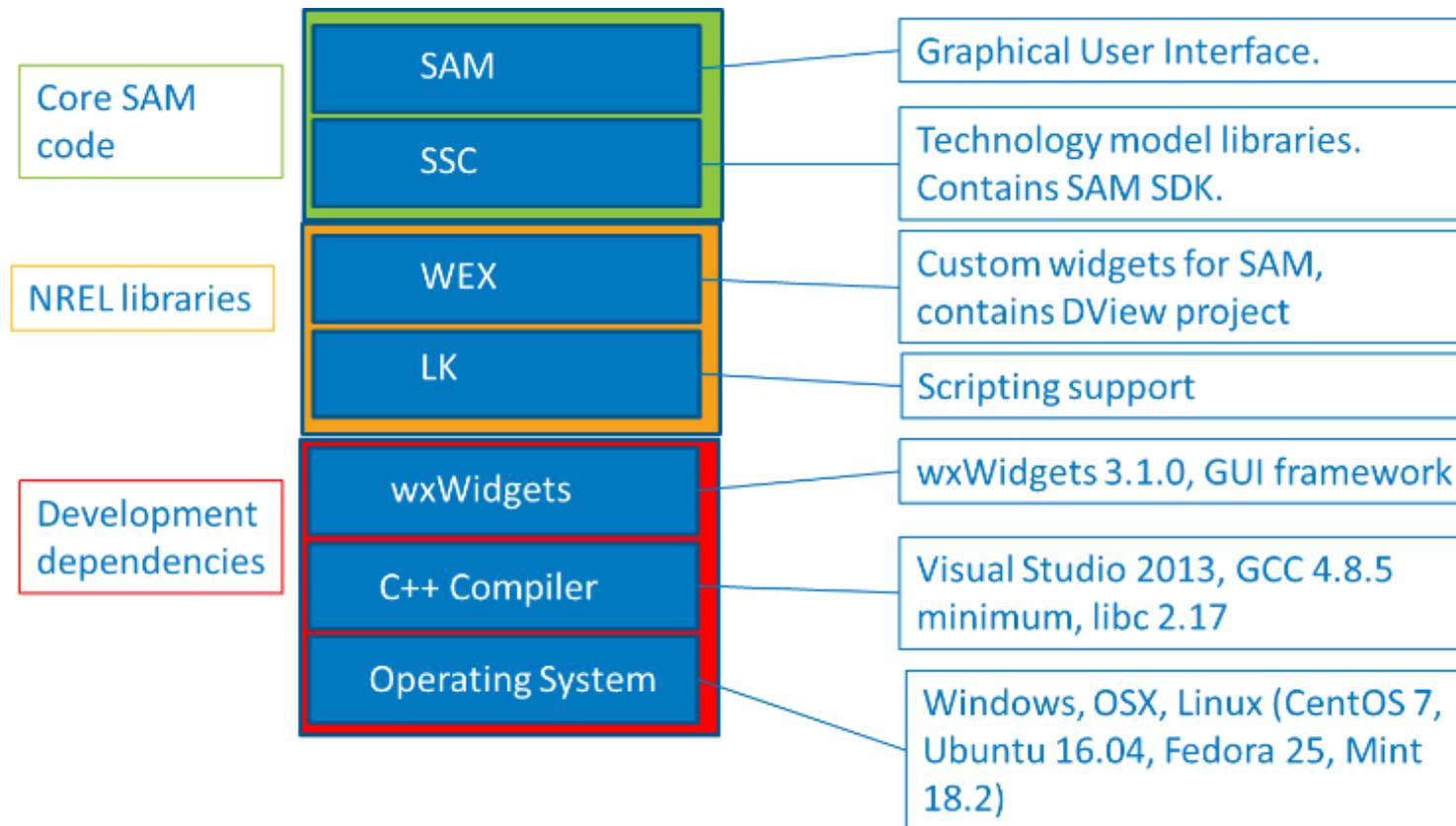
Some Applications

- Feasibility studies, benchmarking for other models, research projects, plant acceptance testing, evaluation of grant proposals

Outline of Topics

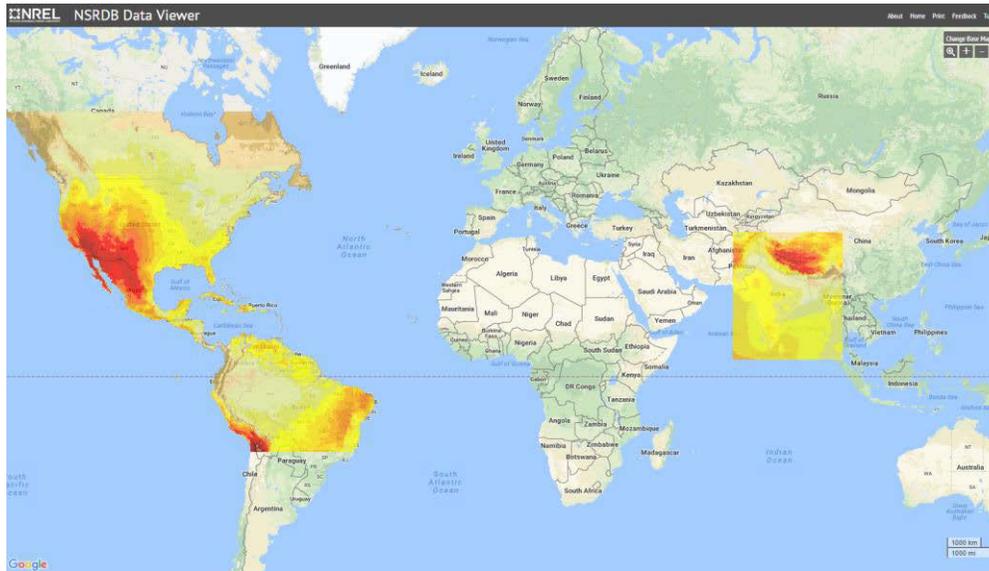
- **Open Source Code**
- **NSRDB Integration**
- **Photovoltaic Model**
- **Bifacial modeling**
- **Solar plus Storage modeling**
- **Tool comparison**

Open Source Code



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

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

File Add untitled

Photovoltaic, Commercial

Location and Resource

Module

Inverter

System Design

Shading and Snow

Losses

Lifetime

Battery Storage

System Costs

Financial Parameters

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 most long-term cash flow analyses, or choose files to download for single-year or P50/P90 analyses. See Help for details.

Download a weather file for your location... Choose files to download (advanced)... [Map on NSRDB website](#) [SAM weather data website](#)

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 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 address with the NSRDB, click Cancel now.

OK Cancel

Detailed photovoltaic 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

IEC61853 Single Diode Model

Module test data (according to IEC-61853)

Import...	Irr(W/m2)	Tc(K)	Pmp(W)	Vmp(V)	Voc(A)	Isc(A)
Export...	100	15	6.69435	63.8967	79.5398	0.1175
Copy	100	25	6.48283	61.6303	77.0356	0.118
Paste	100	50	5.9371	55.8834	70.7751	0.1191
	100	75	5.36686	50.0207	64.5146	0.1203
	200	15	13.889	66.2978	82.4388	0.2350
	200	25	13.5153	64.2559	80.0352	0.236
Rows:	200	50	12.5576	59.1117	74.0262	0.2383
	200	75	11.5662	53.9109	68.0172	0.2407
	400	15	28.1891	67.3057	85.3378	0.4701
	400	25	27.4968	65.39	83.0348	0.472
	400	50	25.7322	60.5878	77.2773	0.4767
	400	75	23.9194	55.7673	71.5198	0.4814

Additional information for parameter estimation

Number of cells in series: 116
Type: CdTe

Calculate parameters

STC parameters (from test data)

Power (Pmp): 67.83 W
Voltage (Vmp): 64.6 V
Current (Imp): 1.05 A
Open circuit voltage (Voc): 87 V
Short circuit current (Isc): 1.18 A
Efficiency: 9.42083 %

Installation and thermal behavior

Area: 0.72 m2
Nominal operating cell temp: 44.9 C
Standoff height: Ground or rack mounted
Approximate mounting height: One story building height or lower

Optical and spectral behavior

Module cover: Standard glass
Air mass modifiers: 0.9417, 0.06516, -0.02022, 0.00219, -9.1e-005

Calculated model parameters from IEC-61853 test data

STC parameters

Diode factor (n): 1.45071
Light current (Il): 1.18951 A
Saturation current (Io): 2.08522e-009 A
Bandgap voltage (Eg): 0.737668 eV

STC temp coeffs

alpha: 0.000472001 A/C
beta: -0.217 V/C
gamma: -0.258849 %/C

Rsh parameters

C1: 1930.15
C2: 474.64
C3: 1.48746

Rs parameters

D1: 13.5504
D2: -0.0769735
D3: 0.237327

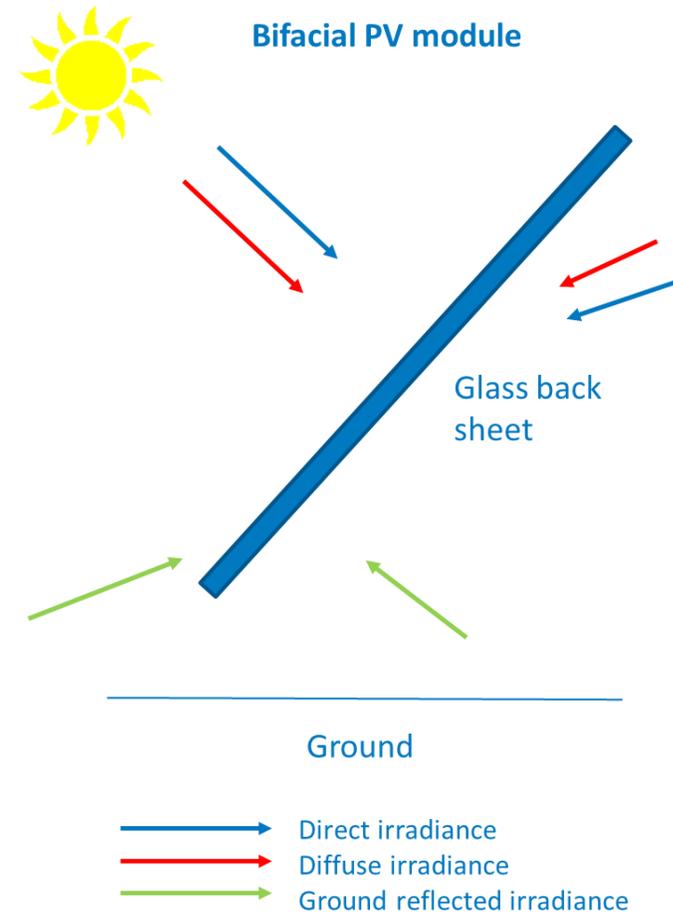
Update plot

IV curves

Could be calculated for real site data from RdTools analysis!

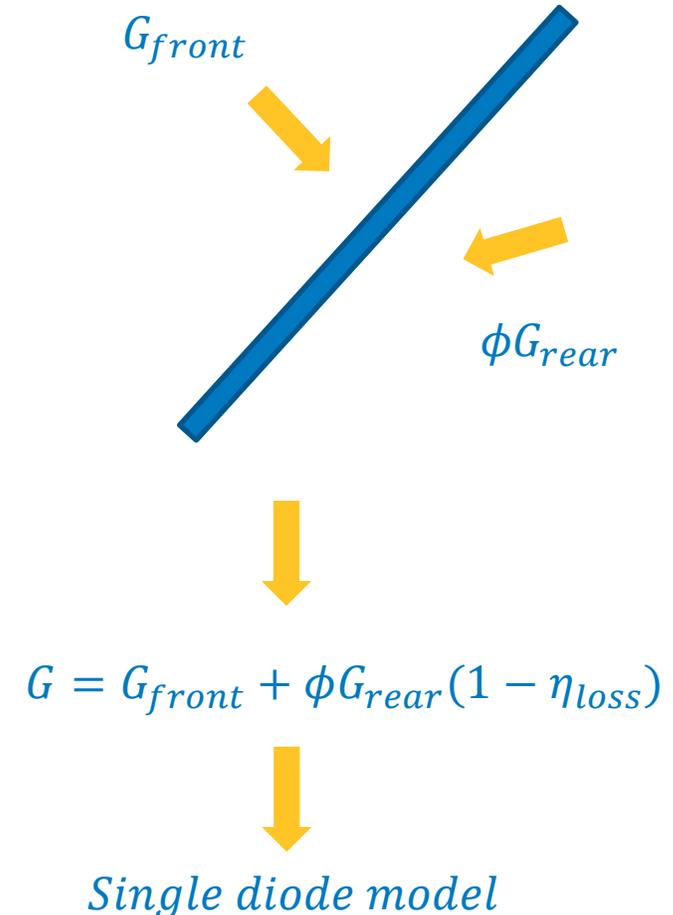
Bifacial Outline

- Overview of bifacial irradiance model
- Bifacial model implementation in SAM
- Example analysis
- Some quantitative results



Model assumptions

- Applicable for a row or multiple rows of PV modules, fixed tilt or 1-axis tracked.
- Calculation of configuration factors assumes isotropic radiation
- Bifacial modules are arranged in rows of infinite length (no irradiance variation along length)
- No rear mounting obstructions
- The POA rear-side irradiance (weighted by bifaciality) adds to the front-side irradiance.
- Combined irradiance is converted to DC power using single-diode model



Bifacial irradiance model



A Practical Irradiance Model for Bifacial PV Modules

Preprint

Bill Marion, Sara MacAlpine, and Chris Deline
National Renewable Energy Laboratory

Amir Asgharzadeh and Fatima Toor
University of Iowa

Daniel Riley, Joshua Stein, and Clifford Hansen
Sandia National Laboratories

*Presented at 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC)
Washington, DC
June 25–30, 2017*

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<https://www.nrel.gov/docs/fy17osti/67847.pdf>

SAM Implementation

<https://github.com/NREL/ssc>

The screenshot shows the GitHub repository page for 'NREL / bifacialvf'. At the top, it says 'NREL / bifacialvf' with 'Unwatch' and '7' stars. Below that are navigation links: 'Code', 'Issues 3', 'Pull requests 1', 'Projects 0', 'Wiki', and 'Insights'. The repository description is 'Bifacial PV View Factor model for system performance calculation'. It shows '51 commits', '4 branches', '6 releases', and '1 contributor'. There are buttons for 'Branch: master', 'New pull request', 'Create new file', 'Upload files', 'Find file', and 'Close'. A list of files is shown: 'cdeline Merge pull request #8 from NREL/development', 'bifacialvf update os.path.exists()', 'docs run the notebook and include output', '.gitignore v0.1.0 initial release', 'LICENSE Create LICENSE', 'README.md Roll back merge from github.com/cdeline', and 'setup.py Merge branch 'development' of https://github.com/NREL/bifacialvf into...'. Below the file list is the 'README.md' content, which includes the title 'bifacialvf - Bifacial PV View Factor model', a description 'python, configuration factor model', and credits: 'Original code by Bill Marion Python translation by Silvana Ayala Updates by Chris Deline'. It also references the publication: 'Based on the publication: "A Practical Irradiance Model for Bifacial PV Modules" B. Marion, S. MacAlpine, C. Deline, A. Asgharzadeh, F. Toor, D. Riley, J. Stein, C. Hansen 2017 IEEE Photovoltaic Specialists Conference, Washington DC, 2017' with the URL 'https://www.nrel.gov/docs/fy17osti/67847.pdf'. At the bottom of the screenshot is the repository URL: 'https://github.com/NREL/bifacialvf'.

Bifacial model in SAM

SAM 2018.8.13

File Add untitled

Photovoltaic, Residential

Location and Resource

Module

Inverter

System Design

Shading and Layout

Losses

Lifetime

Battery Storage

System Costs

Financial Parameters

Incentives

Electricity Rates

Electric Load

CEC Performance Model with Module Database

- Simple Efficiency Module Model
- CEC Performance Model with Module Database
- CEC Performance Model with User Entered Specifications
- Sandia PV Array Performance Model with Module Database
- IEC61853 Single Diode Model

	V _{mp_ref}	A _c	N _s	I _{sc_ref}	V _{oc_ref}	gam
SunPower SPR-X20-327-COM	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X20-445-COM	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X20-327-COM	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X20-445-COM	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X21-255	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X21-335	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X21-335-BLK	57.3	1.631	96	6.09	67.6	-0.3

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m², Cell temp = 25 C

SunPower SPR-X21-335-BLK

Parameter	Value	Units	Temperature Coefficient	Temperature Coefficient Units
Nominal efficiency	20.5521	%		
Maximum power (Pmp)	335.205	Wdc	-0.310	%/°C
Max power voltage (Vmp)	57.3	Vdc	-1.039	W/°C
Max power current (Imp)	5.8	Adc		
Open circuit voltage (Voc)	67.9	Vdc	-0.250	%/°C
Short circuit current (Isc)	6.2	Adc	0.040	%/°C
			0.002	A/°C

Bifacial Specifications

- Modules are bifacial
- Transmission Fraction: 0.013 (0-1)
- Bifaciality: 0.65 (0-1)
- Ground clearance height: 1 m

- Bifacial model available for module models which do not require test data

Bifacial system layout

Self Shading for Fixed Subarrays and One-axis Trackers
 Self shading is shading of modules in the array by modules in a neighboring row.

Self shading: Standard (Non-line) | None | None | None

Array Dimensions for Self Shading, Snow Losses, and Bifacial Modules
 The product of number of modules along side and bottom should be equal to the number of modules in subarray.

	Landscape	Portrait	Portrait	Portrait
Module orientation	Landscape	Portrait	Portrait	Portrait
Number of modules along side of row	1	2	2	2
Number of modules along bottom of row	7	9	9	9

- Calculated System Layout -

	Landscape	Portrait	Portrait	Portrait
Number of rows	100	0	0	0
Modules in subarray from System Design page	700	0	0	0
Length of side (m)	1.00031	3.261	3.261	3.261
GCR from System Design page	0.666667	0.3	0.3	0.3
Row spacing estimate (m)	1.50046	10.87	10.87	10.87

Module aspect ratio	1.63
Module length	1.6305 m
Module width	1.00031 m
Module area	1.631 m ²

row spacing = length of side + GCR

Shading and Layout – Important to turn on self-shading model and configure the geometry of the layout for correct calculation of front-side and rear-side irradiance!

Bifacial losses

Irradiance Losses
Soiling losses apply to the total solar irradiance incident on each subarray. SAM applies these losses in addition to any losses on the Shading and Snow page.

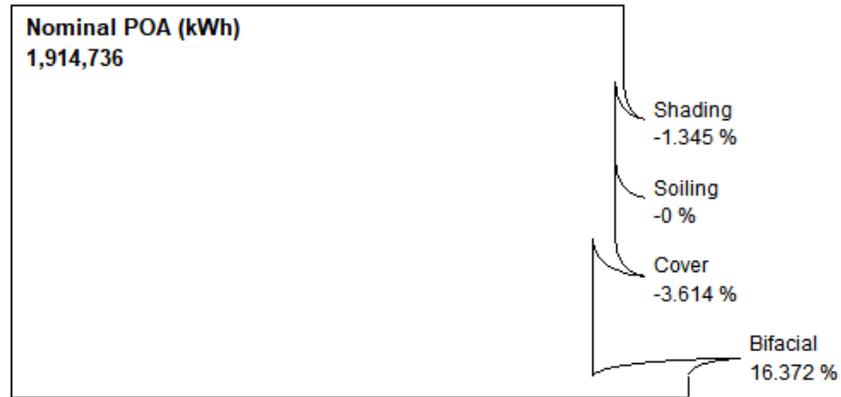
	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Monthly soiling loss	Edit values...	Edit values...	Edit values...	Edit values...
Average annual soiling loss	2	5	5	5
-Bifacial modules only-				
Average annual rear irradiance loss due to soiling, mismatch, or external shading (%)	2	0	0	0

Additional rear-side irradiance losses can input to approximate:

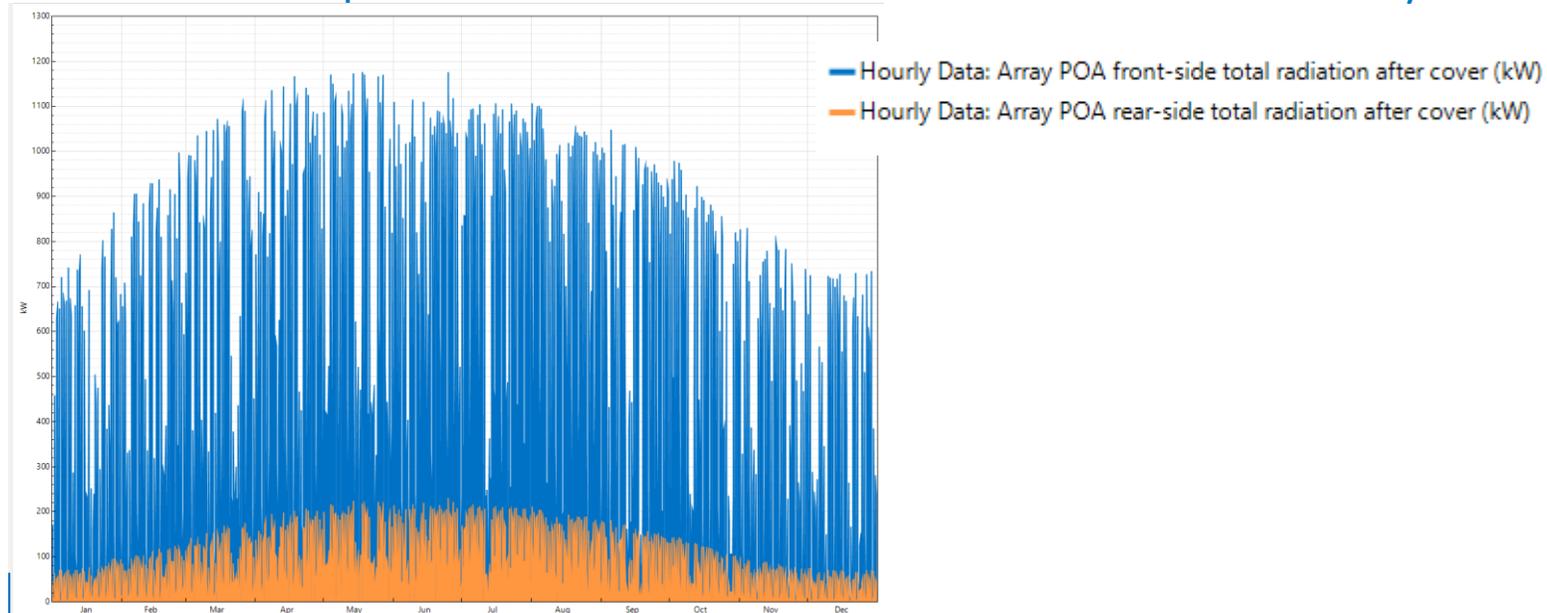
- Mismatch loss between front and rear-side
- Shading due to mounting structure or tracking system
- Soiling on the rear-side

Bifacial model outputs

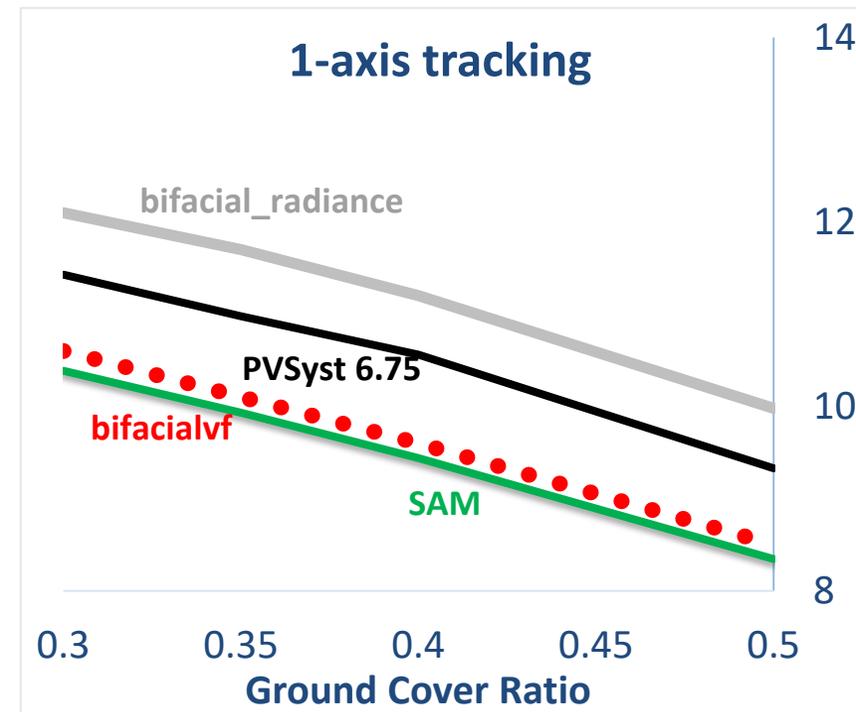
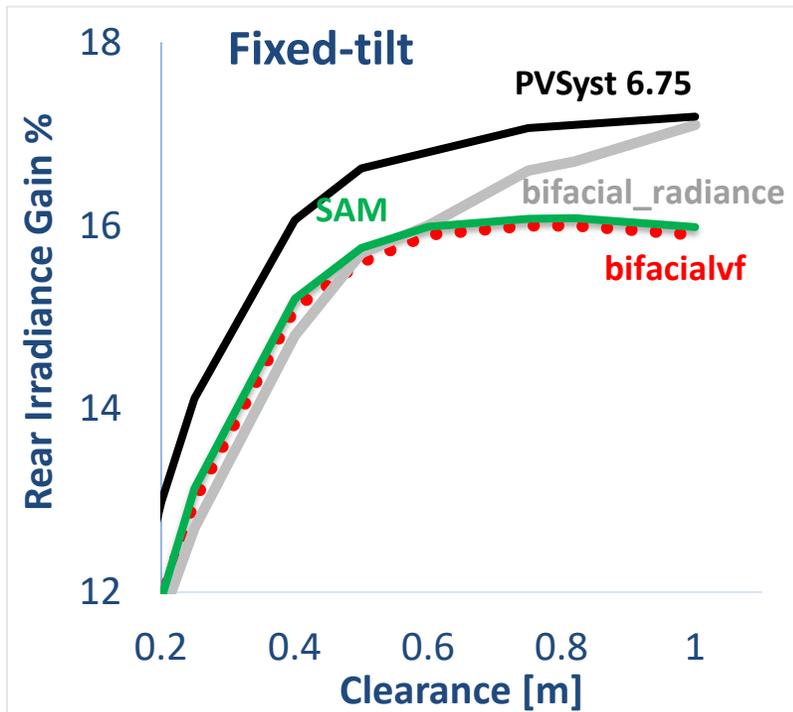
Updated loss diagram, showing bifacial irradiance gain



Time series outputs for front and rear-side irradiance for each subarray and total array



Model comparison

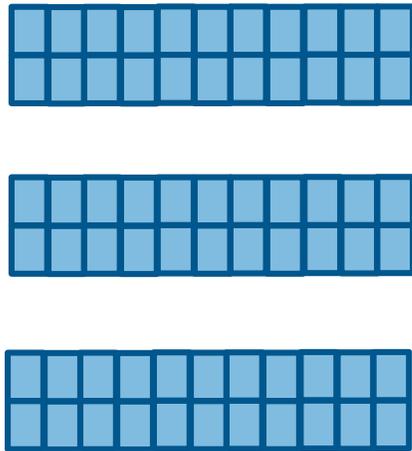


Preliminary results

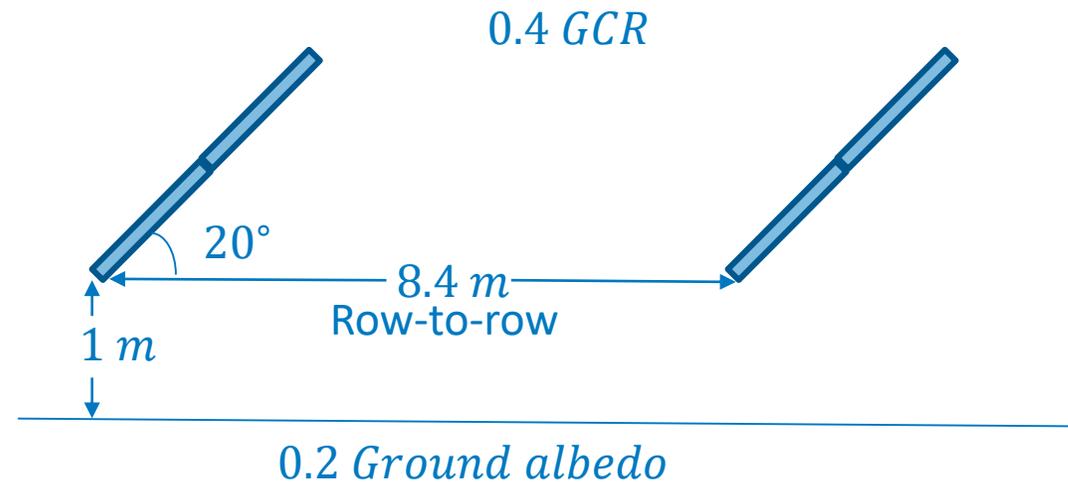
- SAM implementation closely tracks with bifacialvf prediction
- SAM tracks bifacial_radiance model at low ground clearances.
- SAM consistently predicts approximately 1-2% less rear-side irradiance than PVSyst
- For tracked systems bifacial_radiance predicts higher gain

Example analysis

- Evaluate the boost in energy production with bifacial modules compared to monofacial modules with and without tracking systems.



3 rows of 22 modules



Example results

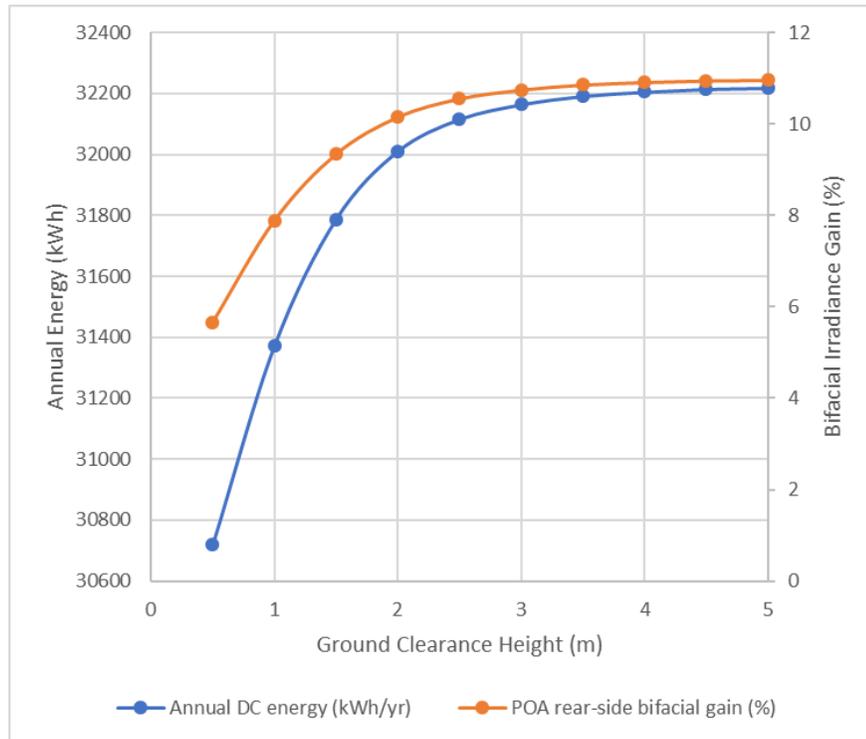
	Monofacial Fixed-tilt	Bifacial Fixed-tilt	Monofacial 1-axis track	Bifacial 1-axis track
POA Annual Irradiance (kWh)	190,961	206,030	254,943	265,187
Irradiance Gain	0%	7.9%	33.5%	38.9%
DC Annual Energy (kWh)	29,051	31,372	36,614	38,130
Energy Gain	0%	8.0 %	26.0%	31.3%

*Gains calculated relative to monofacial fixed-tilt system

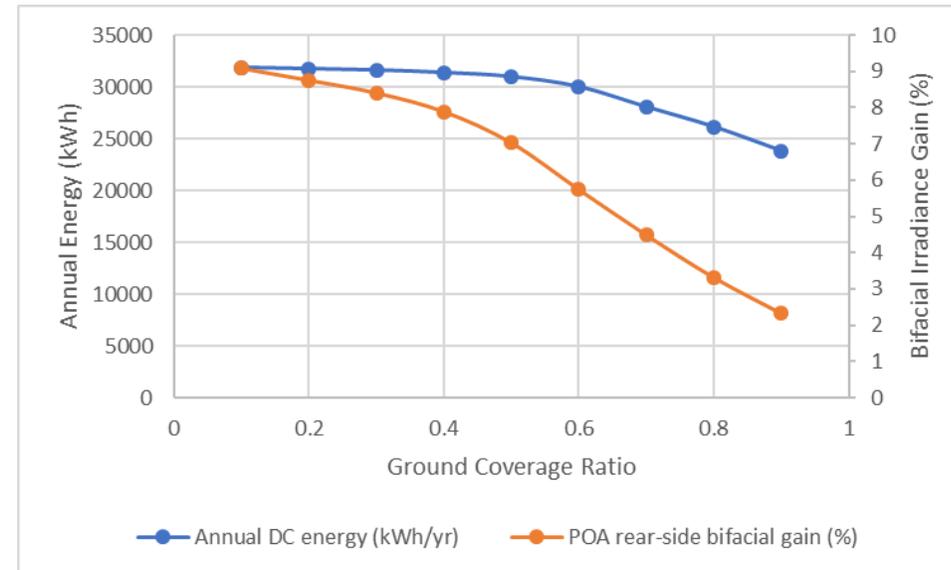
- DC energy gain is different from irradiance gain due to non-linear module response
- Installing 1-axis tracker on monofacial results in higher gain than installing bifacial (in this case).
- Installing bifacial modules with 1-axis trackers boosts annual DC energy by 31% over fixed monofacial system.

Sensitivity analysis of key variables

Ground Clearance Height



Ground Coverage Ratio



Key Variables:

- Ground Clearance Height
- Ground Coverage Ratio (row spacing)
- Albedo
- Tilt

Bifacial Summary and Future Work

Summary

- **Bifacial model added to SAM to calculate rear-side irradiance.**
- **Implementation tracks closely with other bifacial irradiance models**

Future Work

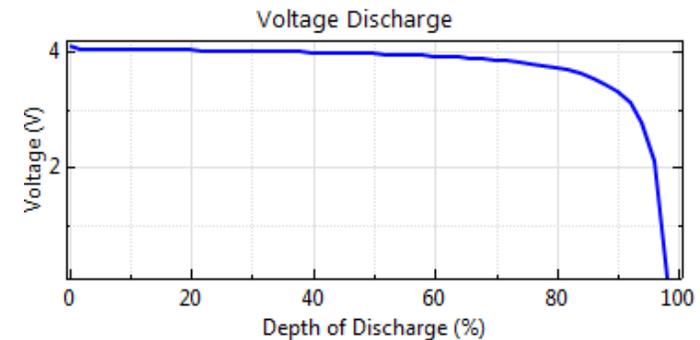
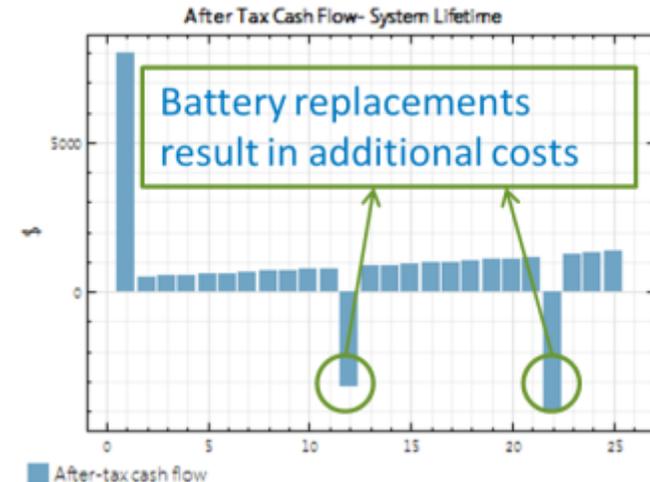
- **Model improvement and validation as part of upcoming NREL and Sandia projects:**
 - NREL installation of tracked bifacial PV
 - Impacts on bifacial PV shading from rack equipment
 - Research on mismatch from rear irradiance gradient.

SAM Battery Outline

- **Battery model introduction**
- **Dispatch**
- **Controlling charge source**

Model Overview

- **Techno-economic model for behind-the-meter and front-of-meter scenarios.**
 - Lead acid, lithium ion and flow battery chemistries
 - System lifetime analysis including battery replacement costs
 - Models for terminal voltage, capacity, temperature
 - Multiple dispatch controllers available



Detailed Battery Model

Photovoltaic (detailed)

SAM 2016.3.14

File Add Commercial Battery

Photovoltaic, Commercial **Enable Battery**

Location and Resource

Module

Inverter

System Design

Shading and Snow

Losses

Lifetime

Battery Storage

System Costs

Financial Parameters

Incentives

Electricity Rates

Electric Load

Battery Bank Sizing

Specify desired bank size Specify cells

Desired bank capacity: 3 kWh
Desired bank voltage: 12 V
Number of cells in series:
Number of strings in parallel:

Chemistry

Battery type: Lithium Ion: Nickel Manganese Cobalt Oxide (NMC)

Voltage Properties

Cell nominal voltage: 3.6 V
Internal resistance: 0.1 Ohm
C-rate of discharge curve: 0.2
Fully charged cell voltage: 4.1 V
Exponential zone cell voltage: 4.05 V
Nominal zone cell voltage: 3.4 V
Charge removed at exponential point: 1.78 %
Charge removed at nominal point: 88.9 %

Current and Capacity

Cell capacity: 2.25 Ah
Max C-rate of charge:
Max C-rate of discharge:

Computed Properties

Nominal bank capacity	3.0132 kWh	Maximum power	3.0
Nominal bank voltage	14.4 V	Time at maximum power	<input type="text"/>
Cells in series	4	Maximum charge current	20
Strings in parallel	93	Maximum discharge current	20

Power Converters

AC to DC conversion efficiency: 99 %

Ability to configure

- Battery size
- Battery voltage
- Cell properties
- Chemistry type
- Max charge, discharge rates
- Battery configuration
- Power electronics efficiencies
- Battery operational limits
- Battery dispatch
- Battery lifetime properties
- Battery replacement preferences
- Battery thermal properties

Battery Financials

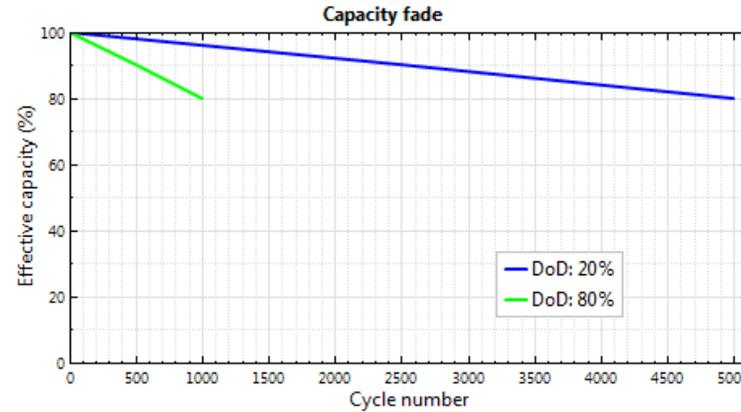
- Lifetime

PV simulation over analysis period ▾

PV Array Performance Degradation

Module degradation rate %/year

Applies to the array's hourly DC output.



Battery capacity fades with cycling, depends on depth-of-discharge

- System Costs

Direct Capital Costs

Module	<input type="text" value="928"/> units	<input type="text" value="0.2"/> kWdc/unit	<input type="text" value="199.8"/> kWdc	<input type="text" value="0.71"/> \$/Wdc	▾
Inverter	<input type="text" value="5"/> units	<input type="text" value="36.0"/> kWac/unit	<input type="text" value="180.0"/> kWac	<input type="text" value="0.21"/> \$/Wdc	▾
Battery bank	<input type="text" value="3.0"/> kWh dc	<input type="text" value="600.00"/> \$/kWh dc			

- Battery Bank Replacement (Battery Storage page)

Battery Bank Replacement

No replacements
 Replace at specified capacity
 Replace at specified schedule

Battery bank replacement threshold % capacity

Battery bank replacement schedule

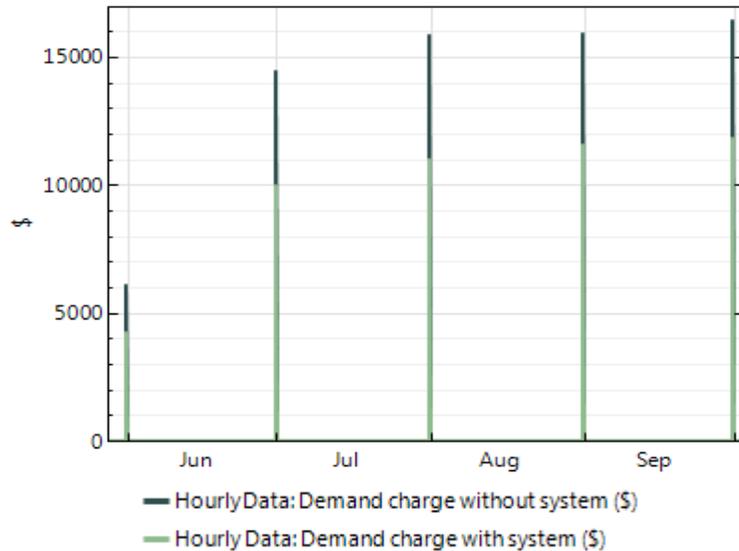
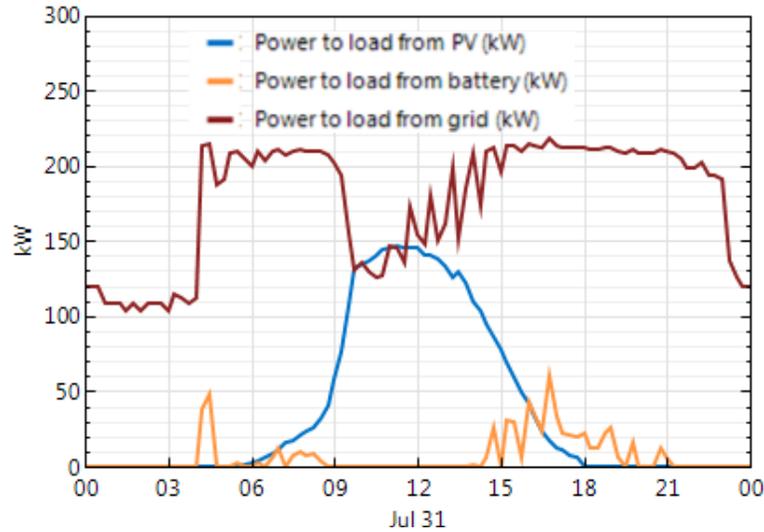
Battery bank replacement cost \$/kWh

Battery cost escalation above inflation %/year

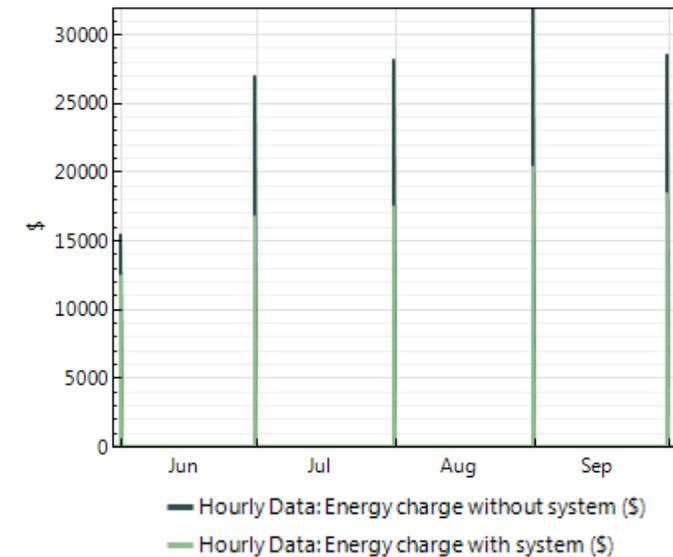
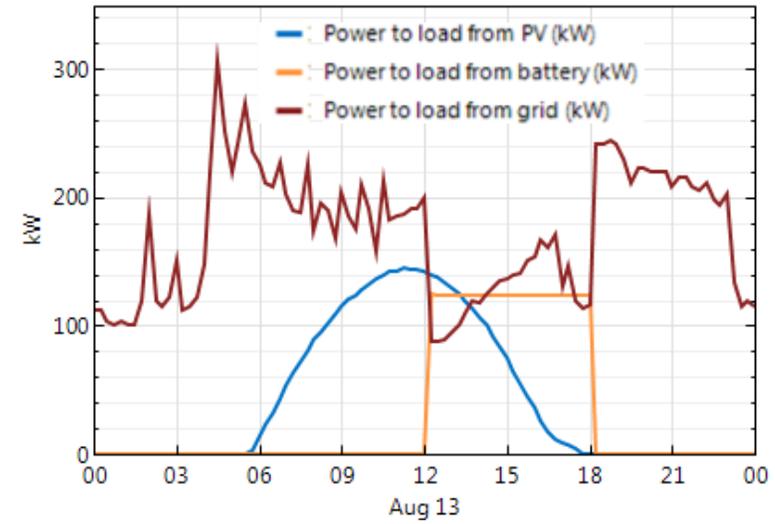
SAM applies both inflation and escalation to the first year cost to calculate out-year costs. See Help for details.

Dispatch Visualization

Peak shaving for demand charge reduction



Manual dispatch for energy arbitrage



Example Case Study

- Evaluate economics of installing PV-coupled battery system for demand-charge reduction:
 - Los Angeles, CA
 - 27,625 ft² building with 247 kW peak load
 - Southern California Edison TOU-GS-2 Option B

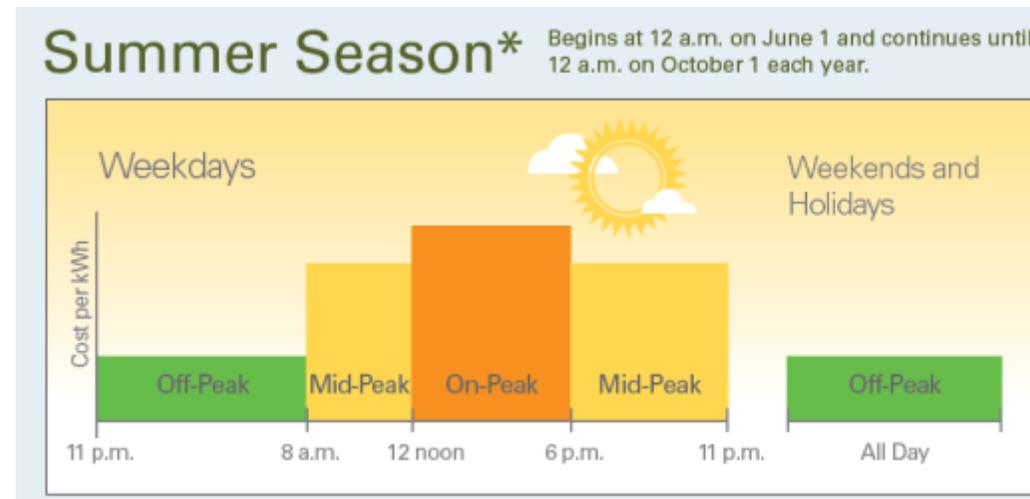


Image from SCE TOU-GS-2 Option B datasheet

Lithium Ion Battery System

- **Model battery similar to Tesla Powerwall**
 - Lithium-ion nickel manganese cobalt
 - Assumed can cycle full 7 kWh down to 30% of state-of-charge, for a full capacity of 10 kWh.
 - Price given as ~\$300/kWh before balance of system costs.
 - Assumed lifetime of 10-15 years before degrading to 70% of original capacity

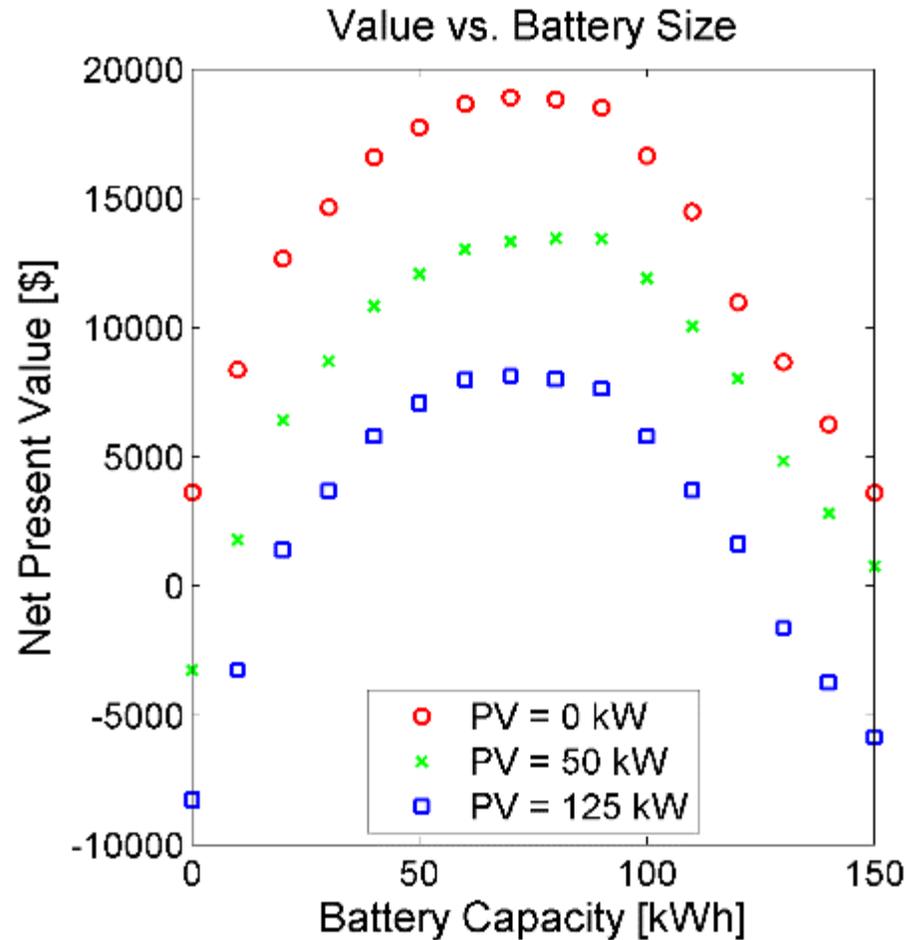
Table 3: Tesla Powerwall Specifications [13]

Property	Value
Price	\$3000
Capacity	7 kWh
Power	2.0 kW continuous, 3.3 kW peak
Efficiency	92%
Voltage	350 – 450 V
Current	5.8 A nominal, 8.6 A peak
Weight	100 kg
Dimensions	1300 mm x 860 mm x 180 mm



Image from teslamotors.com/powerwall

Parametric sizing results



- NPV maximized for no PV system, battery bank capacity of 70 kWh
- Illustrates simulation-based method to approximate 'optimal' sizing.

Modeling different system topologies

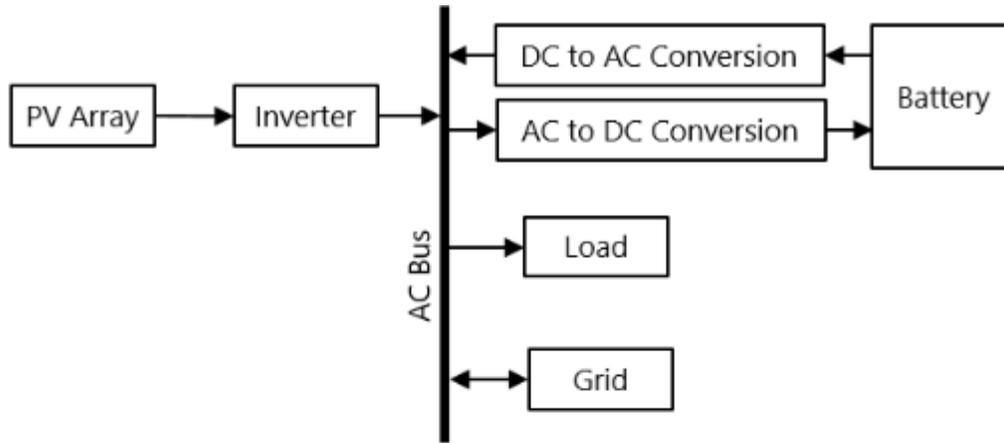


Diagram 1: Battery Connected to AC Side of Photovoltaic System

- AC-Coupled battery systems are solutions packaged with their own power electronics
- Can couple at common point of AC connection

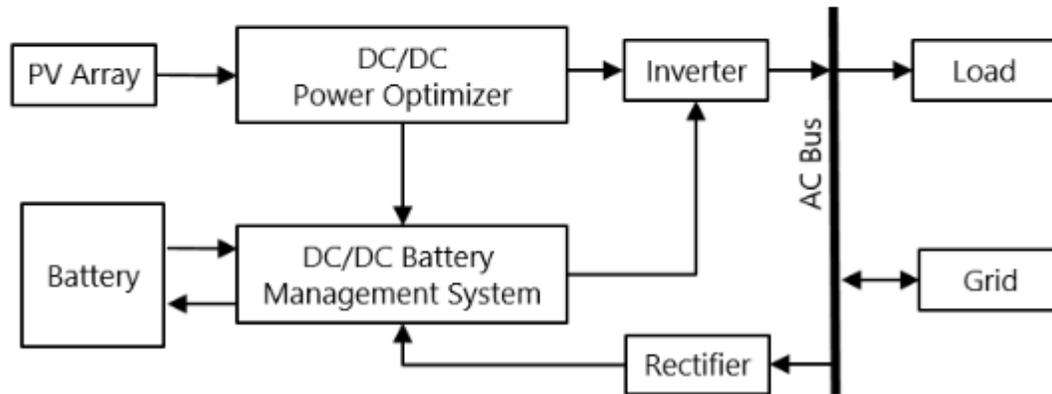
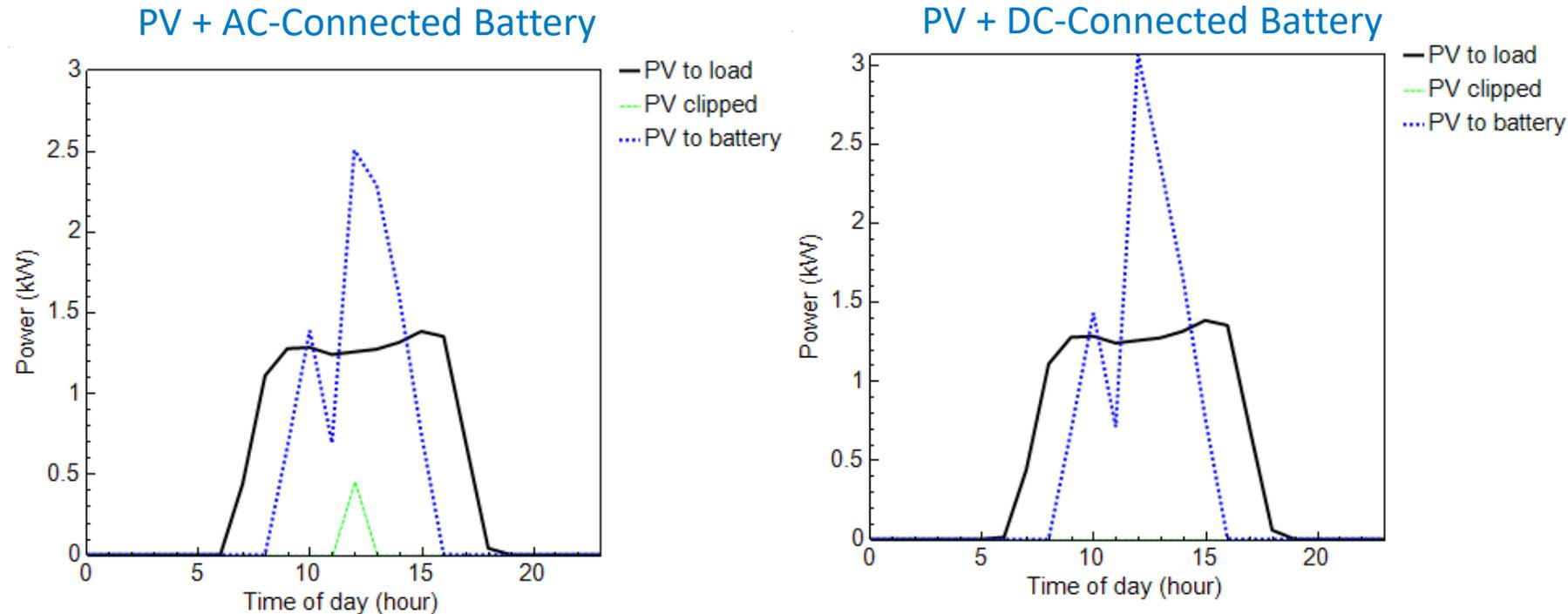


Diagram 2: Battery Connected to DC Side of Photovoltaic System

- DC-Coupled battery shares the PV inverter
- PV power can charge the battery without going through the inverter

DC-connected batteries to capture clipped power



- When the PV DC power output exceeds the inverter DC power input, excess power is clipped
- In an AC connected system, even if PV power is dumped to the battery, it doesn't reduce clipping, since PV power must still pass through the inverter before going to the battery
- In a DC connected system, PV power can be dumped to the battery before passing through the inverter

Battery Dispatch Front-of-meter

Storage Dispatch Controller

- Choose Dispatch Model

Auto DC-connected dispatch: 1-day look ahead
 Auto DC-connected dispatch: 1-day look behind
 Auto DC-connected dispatch: Input forecast
 Input battery dispatch
 Manual dispatch

For all non-manual dispatch options, select how the battery can be charged

- Battery charge options

Battery can charge from grid
 Battery can charge from system
 Battery can charge from clipped system power

Automated DC-connection options

- Choose Weather forecast file

Browse...

- Dispatch options

Frequency to update dispatch hours
Look-ahead period hours

- Battery cycle costs

When using the automated dispatch control, the model will cycle the battery only if the benefit is greater than the damage to the battery.

Battery cycle cost choice

Battery cycle costs \$/cycle-kWh

Input Battery Dispatch

Input a custom battery power dispatch (<0 for charging, >0 for discharging)

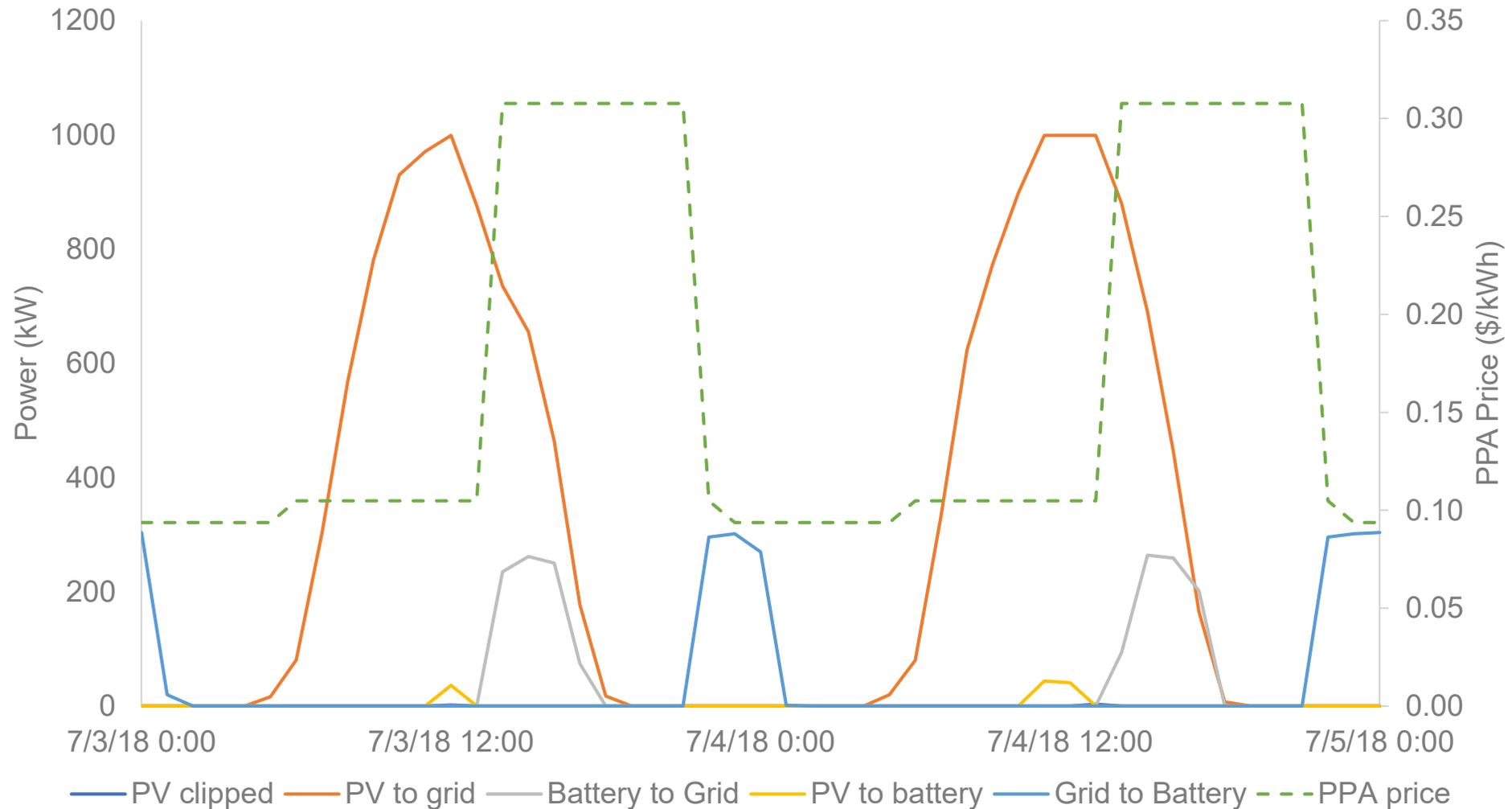
Input battery dispatch kWdc

- Recently added automated control strategies for large plants with DC-connected battery systems
- Optimize dispatch to charge from PV, capture clipping, and maximize value
- Will be released publicly in October.

Controller development

- **Develop a controller that at every time, looks ahead 18 hours and decides:**
 - Whether to charge from the grid
 - Whether to charge from PV
 - Whether to charge from PV power which would otherwise be clipped.
 - Whether to discharge
- **Factor in the PV production forecast, the PPA time-of-delivery factors, and estimated wear cost of the battery**

Example peak summer day operation



Battery charges from PV minimally during peak operation to reduce clipping, otherwise charges mostly from grid.

Example Results Summary

Variable	PV Only	DC-Connected Battery
Annual Energy (year 1)	1,912 MWh	1929 MWh
Year 1 Energy Clipped	44.0 MWh	11.2 MWh
Year 1 Battery Energy Charged	0 kWh	107 MWh
Year 1 Battery Energy Charged from PV	0 MWh	35 MWh
Year 1 Battery Energy Charged from Grid	0 MWh	72 MWh
Year 1 Battery Energy Discharged	0 kWh	92 MWh
Net Present Value	\$118,080	\$107,570

- PV is cost effective, and installing a battery slightly reduces this value
- DC-connected battery reduces clipping by 75%.
- In this case, the battery mostly charges from the grid to take advantage of the difference in buy rate vs. sell rate

Tools That You Can Use

PV analysis tools take into account the factors that impact project potential

Publicly available tools can be used to gauge initial potential, optimize system sizing & refine project economics

	Expertise and Effort needed	Required Inputs	Key Outputs
Distributed Generation Screening Maps	Low	<ul style="list-style-type: none"> • Location 	<ul style="list-style-type: none"> • Map interface with geospatial layers • High-level economics
PVWatts Calculator	Low	<ul style="list-style-type: none"> • Location • System configuration 	<ul style="list-style-type: none"> • PV energy generation (no economics)
REopt Lite Web Tool	Medium	<ul style="list-style-type: none"> • Location • Energy Consumption • Rate tariff 	<ul style="list-style-type: none"> • Optimized system size and dispatch • High-level economics
System Advisor Model (SAM)	High	<ul style="list-style-type: none"> • Energy Consumption • Rate tariff • Detailed system configuration • Financing inputs 	<ul style="list-style-type: none"> • Detailed technology performance • Detailed economic modeling

Thank you! Questions?

Janine Freeman - project lead, photovoltaic and wind models

Nick DiOrio - code architecture, battery storage models

Nate Blair - emeritus lead, financials, costs, systems

Steve Janzou - programming, utility rate structures (subcontractor)

Paul Gilman - user support and documentation (subcontractor)

Ty Neises - concentrating solar power models

Mike Wagner - concentrating solar power models

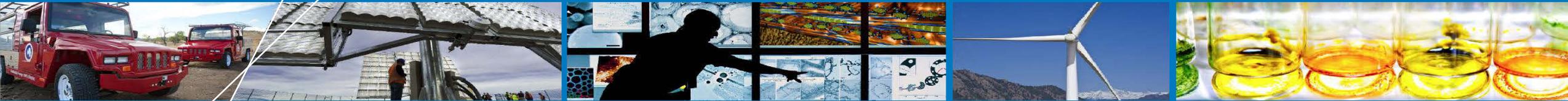
Matt Boyd- concentrating solar power models

www.nrel.gov

<http://sam.nrel.gov>



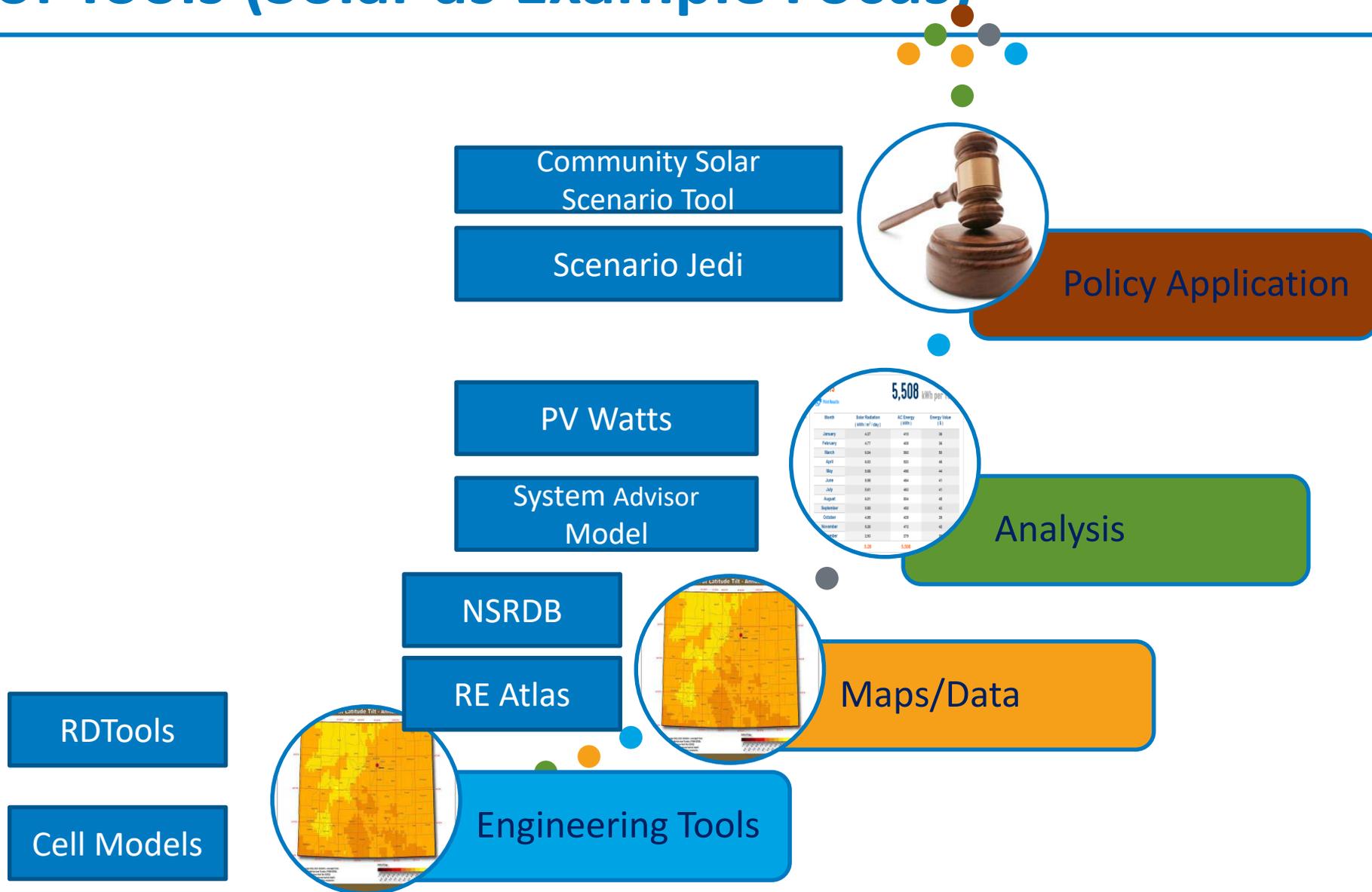
Additional Solar Tools



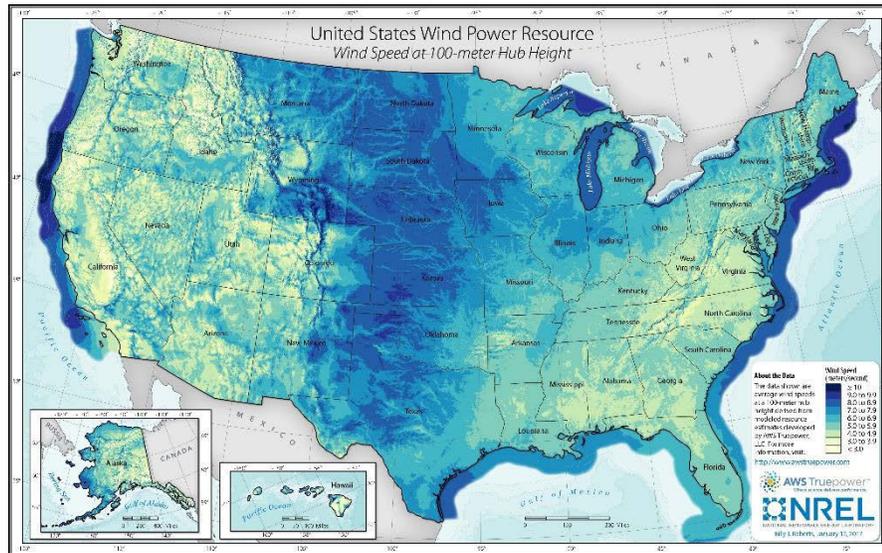
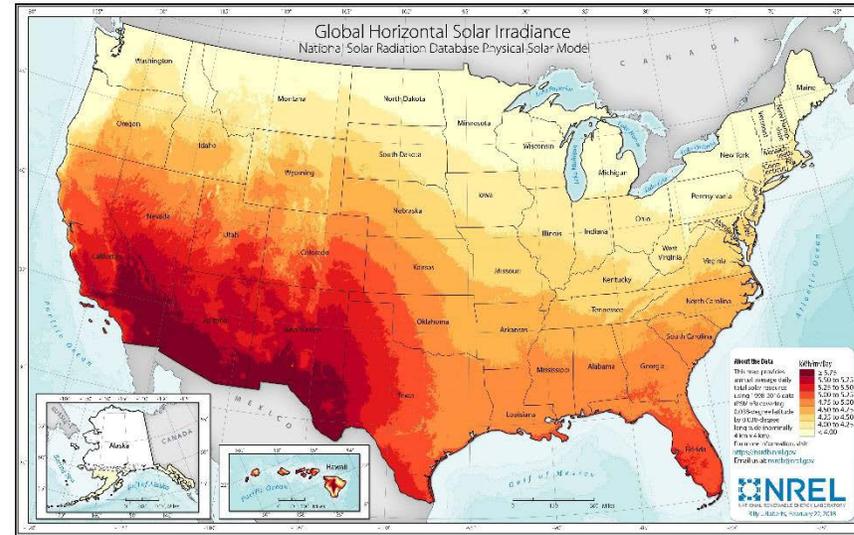
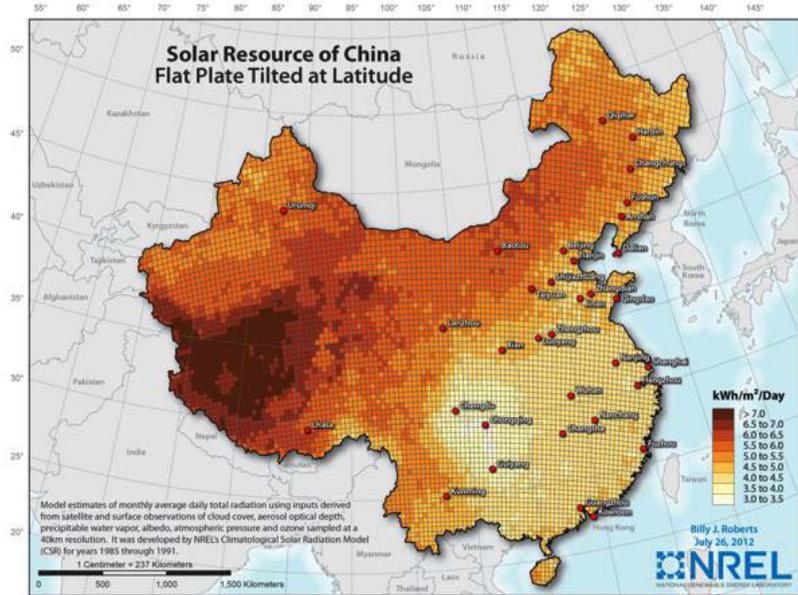
Nate Blair

Group Manager

Range of Tools (Solar as Example Focus)



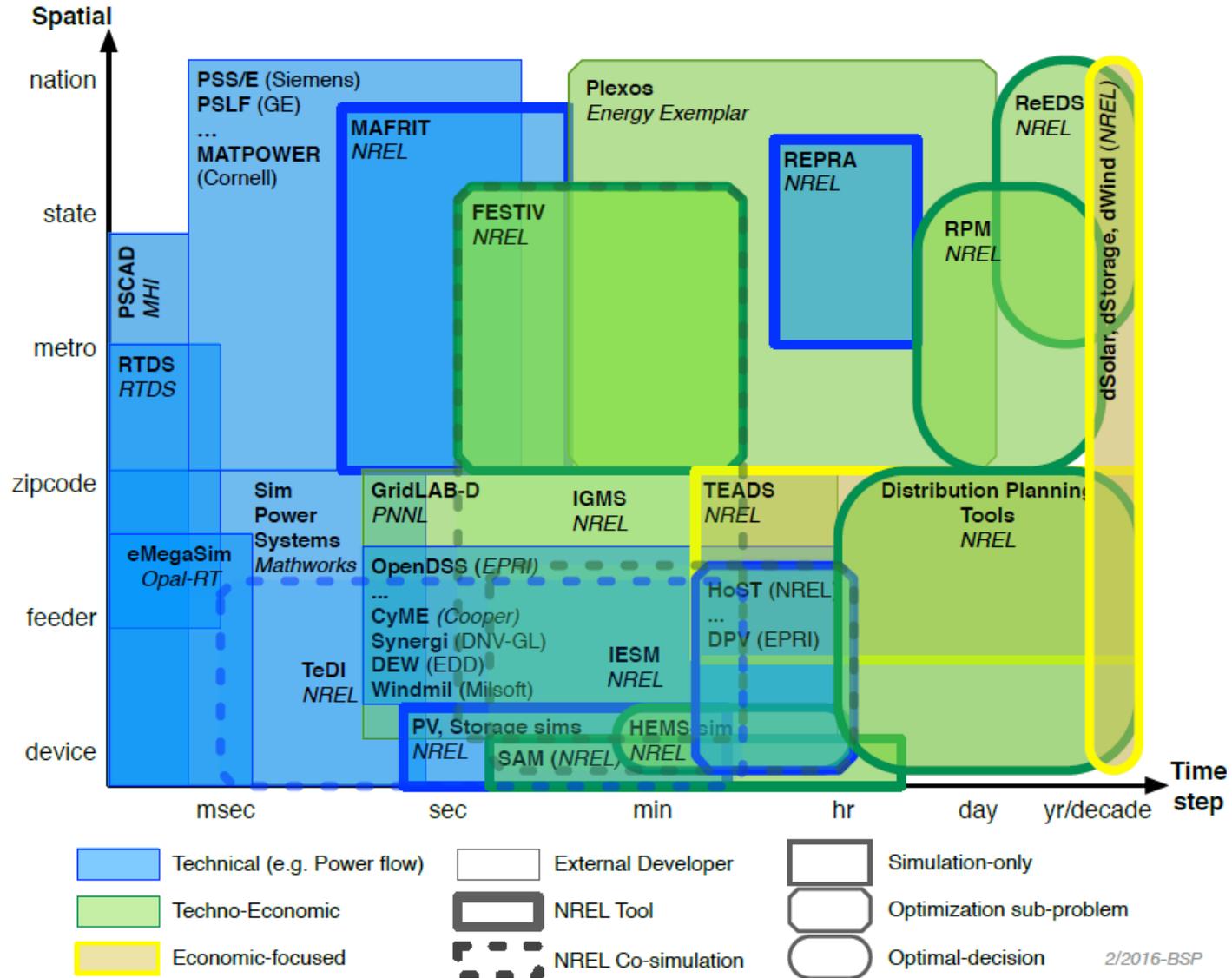
Clean Energy Models and Tools begin with high resolution, high quality Data



U.S. DEPARTMENT OF **ENERGY** Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

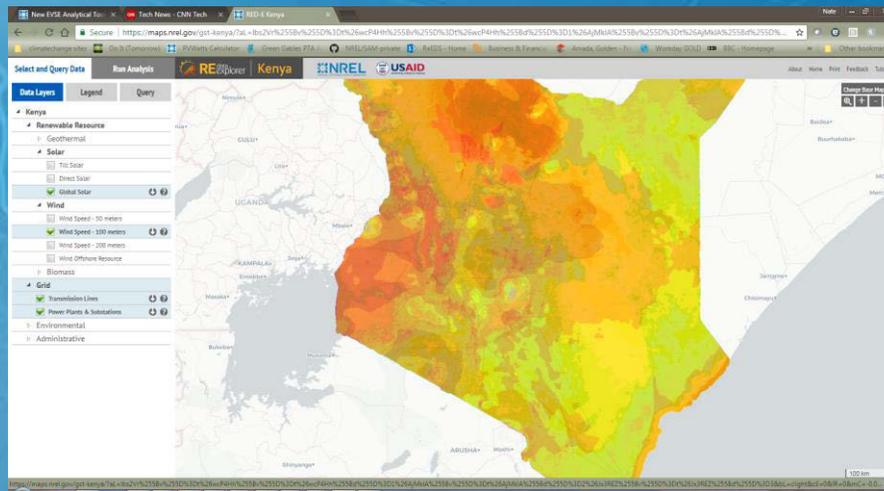
2016 Renewable Energy Data Book

Power System Model Map





Mexico, Ghana, Kenya, Kazakhstan, Afghanistan, Pakistan, India, Nepal, Bangladesh, the Lower Mekong region, Indonesia, and the Philippines



Types of questions the RE Data Explorer can help answer

- High-level prospecting and integrated resource planning questions
- Where are the most appropriate areas to site utility-scale solar and wind facilities based on:
 - Resource quality?
 - Proximity to load centers, transmission lines, and/or roads?
 - Site suitability? (e.g., terrain, protection status, current land use?)
- How does resource potential vary at the province level?
- Which sites may offer the best possibilities for investment in long-term measurement stations?



REexplorer
MAPPING OUR ENERGY FUTURE

www.re-explorer.org

State & Local Energy Data (SLED)

Share

Energy Market Overview for Denver, Colorado 80227

The State and Local Energy Data tool provides energy market data specific to your city and state. This section overviews the greenhouse gas emissions in your city and the national and state energy sources for electricity production. Use the buttons at the top to toggle between only city or only state and national data.

Annual Energy GHG Emissions for Denver, Colorado 80227 derived

Total GHG: 11,944,700 metric tons
GHG per capita: 20 metric tons/person
GHG per BTU: 0.11 metric tons/MMBTU

[Download Chart](#)

Category	residential	commercial	industrial	diesel	gasoline
Vehicles	0	0	0	~200k	~2,800k
Natural Gas	~1,000k	~500k	~500k	0	0
Electricity	~2,500k	~1,500k	~1,000k	0	0

Fuel Sources

Your state uses the following types of energy sources to generate electricity. National energy sources for electricity generation are shown for comparison

[Download Chart](#)

National Electricity Sources in 2015 Colorado Electricity Sources in 2015

Map Satellite

Denver, Colorado 80227

Filter By: All

New Search: Enter Zip Code or City, State [Start Over](#)

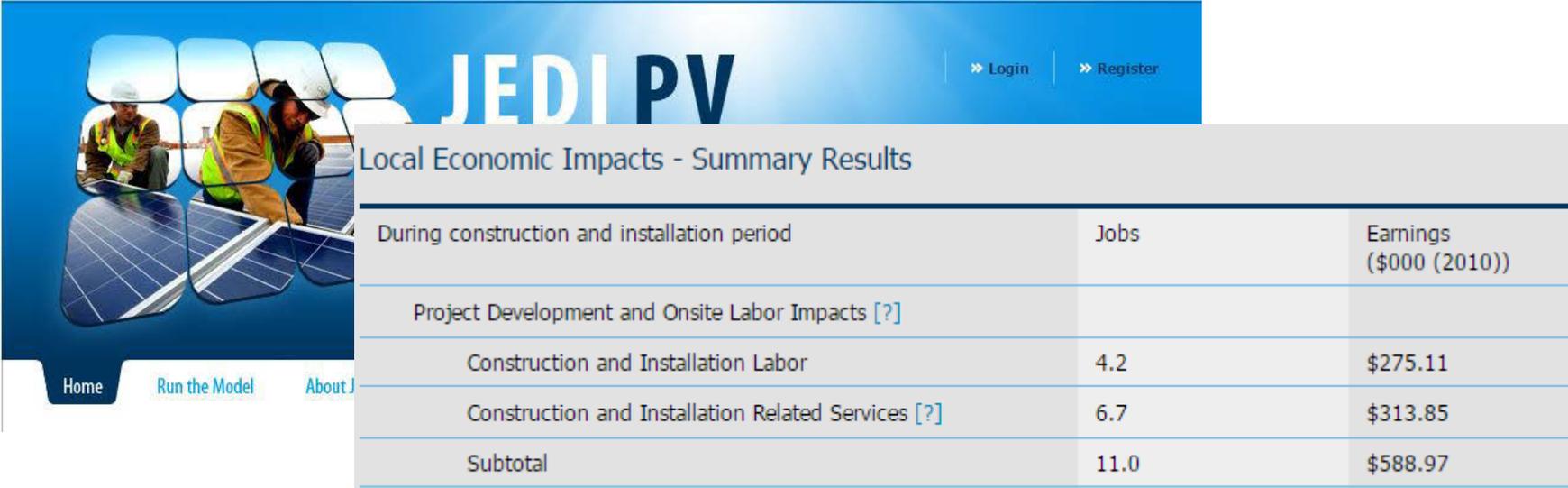
Home

- Electricity and Natural Gas
- Transportation
- Buildings and Industry
- Demographics
- Policies and Incentives
- Toolbox
- Data Sources
- Contact

<https://apps1.eere.energy.gov/sled>

JEDI PV – Jobs and Economic Development

- **NOTE:** JEDI models exist for wind, biofuels, Solar CSP, Coal, Hydropower, Geothermal, Marine Hydrokinetic, Petroleum, Transmission as well as PV
- **PURPOSE:** Estimate the economic impacts of constructing and operating photovoltaic power generation at the local and state levels.
- **TYPE:** Spreadsheet-based impact model (PV has a web version as well)
- **TAKEAWAY:** Economic impacts for one, or, a portfolio of projects
- **CONTACT:** JEDISupport@nrel.gov



The screenshot displays the JEDI PV web interface. On the left, there is a navigation menu with links for 'Home', 'Run the Model', and 'About'. The main content area features a header with the 'JEDI PV' logo and 'Login' and 'Register' buttons. Below the header, a table titled 'Local Economic Impacts - Summary Results' is shown. The table has three columns: 'During construction and installation period', 'Jobs', and 'Earnings (\$000 (2010))'. The table lists four rows of data: 'Project Development and Onsite Labor Impacts [?]', 'Construction and Installation Labor', 'Construction and Installation Related Services [?]', and 'Subtotal'.

During construction and installation period	Jobs	Earnings (\$000 (2010))
Project Development and Onsite Labor Impacts [?]		
Construction and Installation Labor	4.2	\$275.11
Construction and Installation Related Services [?]	6.7	\$313.85
Subtotal	11.0	\$588.97

<http://www.nrel.gov/analysis/jedi/download.html>

Community Solar Scenario Tool



- **PURPOSE:** Evaluate economics of a community solar project from a customer’s perspective as well as the sponsoring utility
- **TYPE:** Spreadsheet-based model
- **TAKEAWAY:** “First cut” analysis of different community solar options for utility, state and local advocates.
- **CONTACT:** john.nangle@nrel.gov

System Information	
Number of Shares	400
Project Lifetime [yrs]	25
Subscriber Discount Rate	0.00%
System Size [kW]	400
First Year Generation [kWh/kW]	1,418
Average Annual Generation [kWh]	533,290
Utility Perspective	
Costs per kWh	
Real LCOE or PPA Price [\$/kWh]	\$ 0.158
Administrative Costs [\$/kWh]	\$ -
TOTAL COSTS [\$/kWh]	\$ 0.158
Annual Costs	
Average Annual Cost of Production [\$]	\$ 84,315
Administrative Costs [\$]	\$ -
TOTAL COSTS [\$]	\$ 84,315
Cost per Share	
Average Annual Cost per Share [\$]	\$ 210.79
Average Monthly Cost per Share [\$]	\$ 17.57
Utility Charges per Share	
No Credit	
Average Annual Charge per Share [\$]	210.79
Monthly Average Charge per Share [\$]	17.57
Average Monthly Charge per Share [\$/kWh]	0.16
Average Monthly Bill Credit	
No Bill Credit	17.57
Bill Credit Rate [\$]	\$ 5.56
Average Energy Credit [kWh]	

www.nrel.gov/tech_deployment/tools_community_solar.html

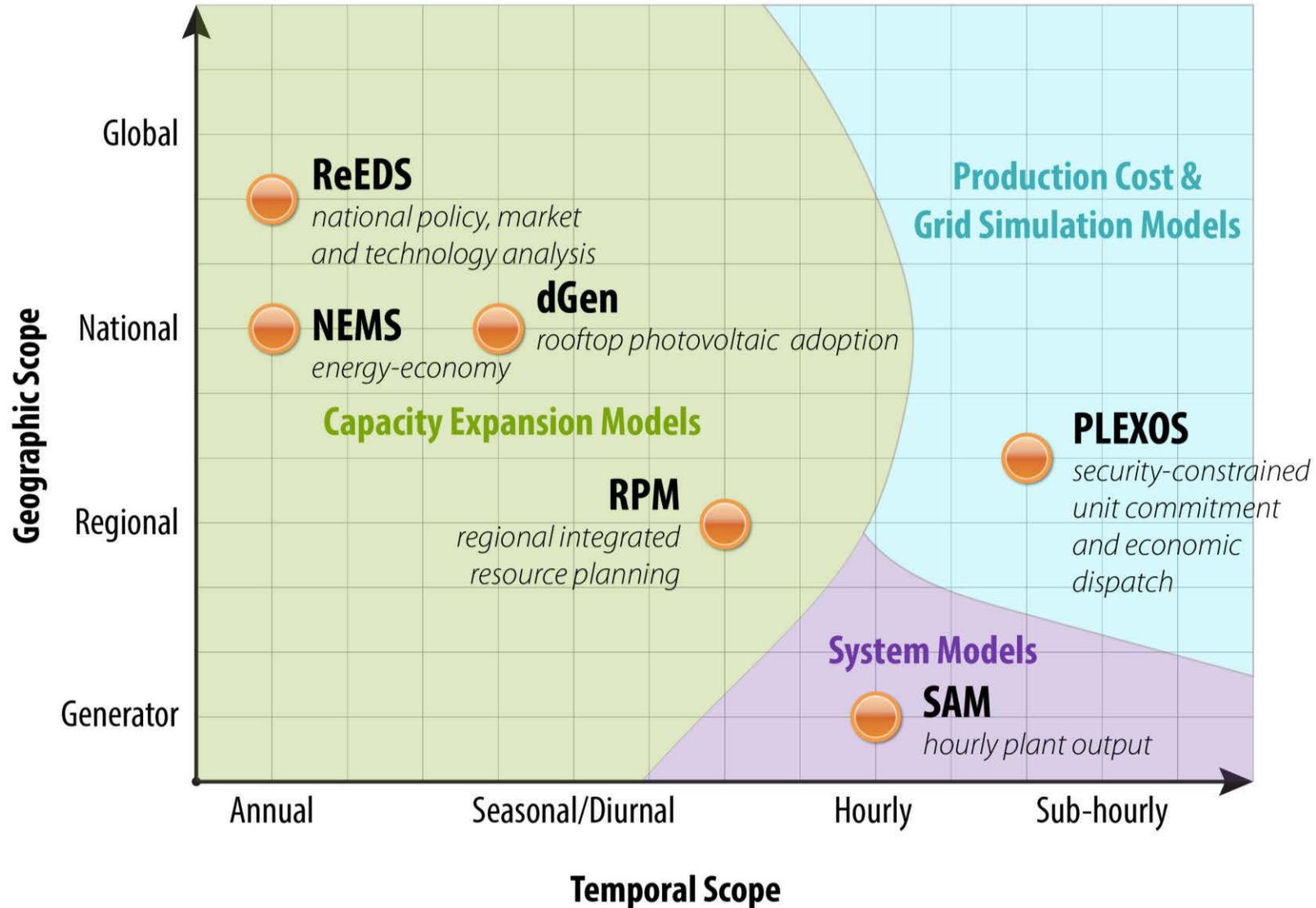
Making data and analysis tools available to developers via web services / APIs *including PVWatts API*

1. Public access to data/models/tools via Web Services
2. Increased access to real-time/dynamic data
3. Eliminates repeated downloads of data snapshots
4. Shifts NREL application development to platform development

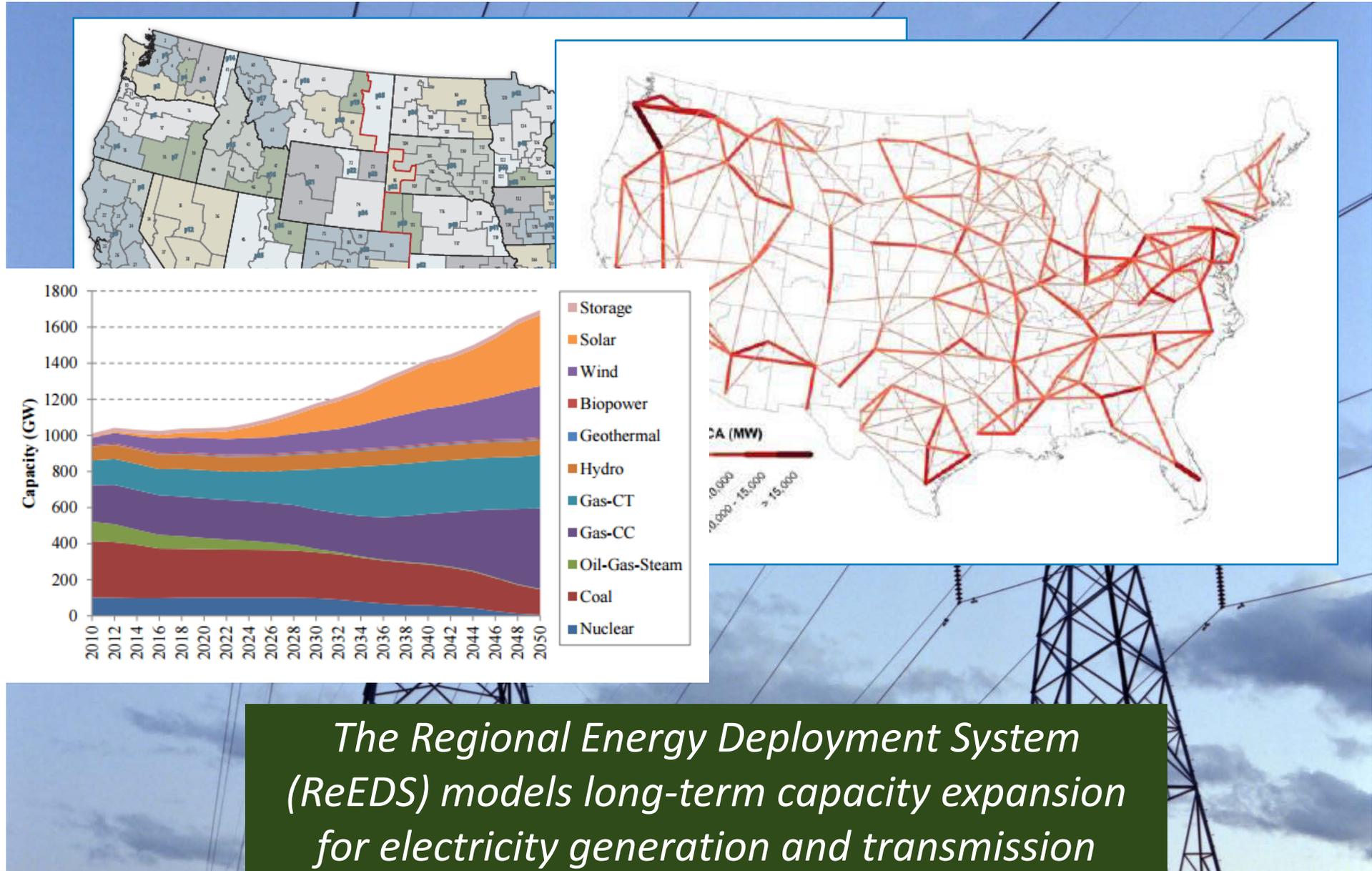


Connects data with those who will increase its visibility

Interoperability



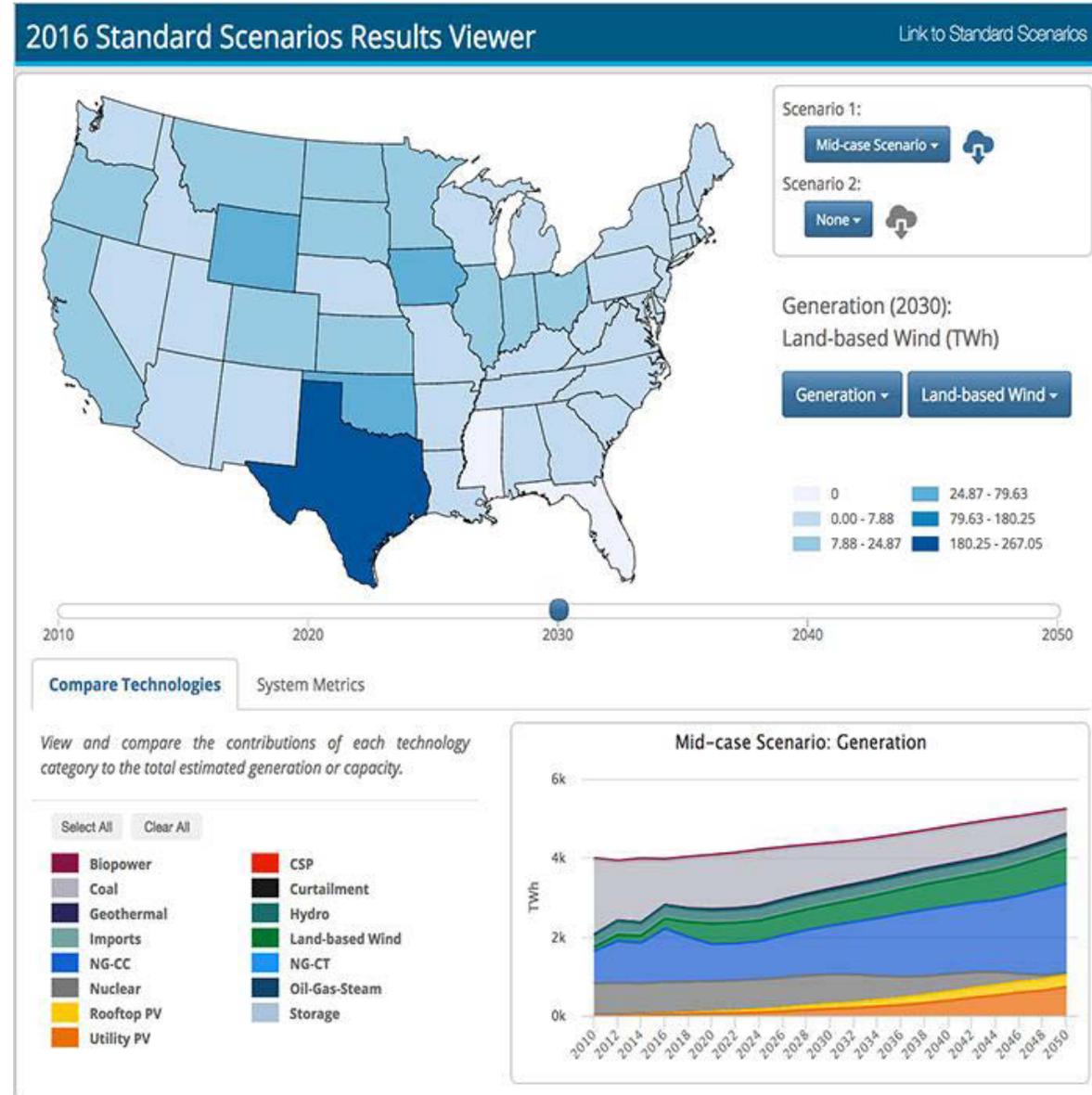
Tools: Modeling the Electric System



The Regional Energy Deployment System (ReEDS) models long-term capacity expansion for electricity generation and transmission

NREL Standard Scenarios Results Viewer

- 19 Scenarios Exploring Different future Electric Sector Scenarios
- Published annually for last 3 years
- Output of our ReEDS electric sector forecast model
- Results by state and year for each scenario
- Aggregate metrics including capacity, generation, emissions, electricity price, etc.
- <http://en.openei.org/apps/reeds/>
- Report at: <https://www.nrel.gov/analysis/data-tech-baseline.html>



Questions?

Tools you want us to build?

Thank you

Nate.blair@nrel.gov

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