MSCE in Energy Infrastructure

Brief on Wind and Solar Energy Software

MSCE Energy Infrastructure Brief on
Solar and Wind Energy Software

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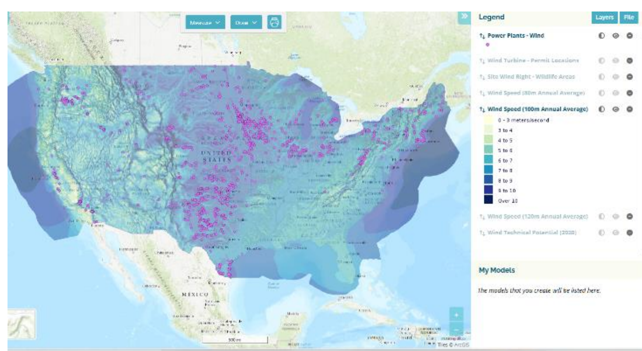
Introduction

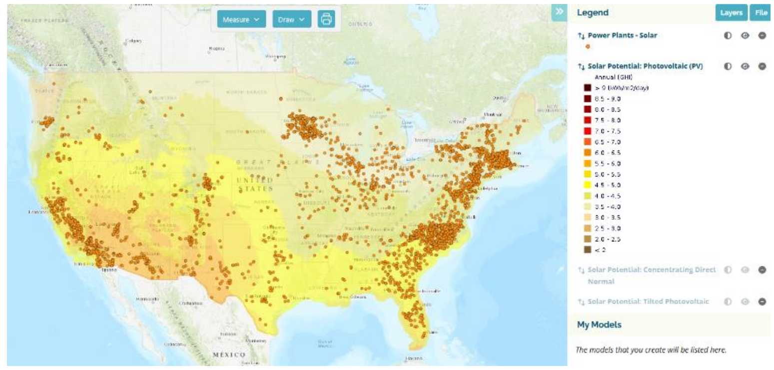
This brief will cover some basic software for assessing the feasibility of locating a new wind or solar farm in the continental U.S. The software presented here is used for preliminary assessments. We have limited our discussion to several widely available tools that are routinely updated and freely available from relevant federal government agencies. More detailed software is listed in the website links at the end of this brief.

U.S. Utility-scale Solar and Wind Energy Infrastructure



The Argonne National Laboratory maintains a website entitled *Geospatial Energy Mapper* (*[Geospatial Energy Mapper (GEM) (anl.gov)](https://gem.anl.gov)*). it is an online mapping tool useful for energy planning. It can help identify areas across the country that are suitable for wind, solar and other clean energy infrastructure projects". Shown in the map above are the locations of wind power plants in the U.S. overlaying a map of the annual average wind speed at 100-meter elevation. You can zoom in on a particular location or wind farm to see the location and nameplate capacity of the individual wind turbines at a given location. You can also view other infrastructure information, including a detailed map of the primary and secondary electrical transmission grid and restricted development areas.

Shown in the map on the right are the locations of solar power plants overlaying a map of the annual solar photovoltaic potential, i.e., the annual global horizontal irradiance in units of kWh/m^2/day. You can zoom in to obtain average monthly information at a location of your choosing. GEM also has a tool to identify suitable areas for future development, based on variables such as land slope (for PV), land cover, population density, wildlife habitat, protected land, energy output (1-Axis tracking flat plate collector), and distance to nearest electricity substation (220 to 345 kV).

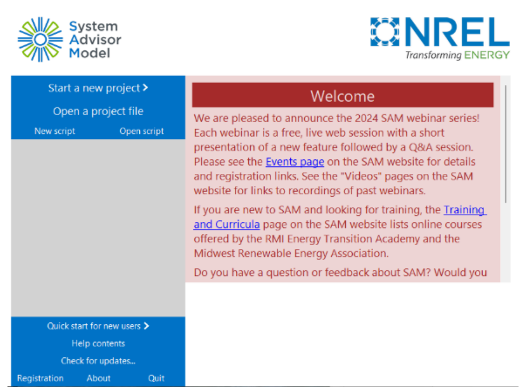


PV Watts Calculator

PV Watts is a simple, easy to use web-based application that estimates the electrical energy produced by a PV system. It is maintained by the National Renewable Energy Lab (PVWatts Calculator (nrel.gov)). However, it only estimates potential PV electrical energy output without providing any financial feasibility analysis. You can simply enter a U.S. address, DC system size (kW), module type (crystalline silicon or thin film), array type (fixed vs 1 or 2 axis tracking), tilt (default = 20 degrees), and system losses (default = 24%). Instead of using these default values, a simple calculator is provided if the user has additional input information. Advanced input parameters include DC to AC size ratio (default = 1.2), inverter efficiency (default = 96%), and ground coverage ratio (default = 0.4). The calculated output includes monthly averages of both solar radiation (kWh/m^2/day), AC electrical energy produced (kWh), and the overall DC capacity factor (%).

System Advisor Model (SAM): Overview

SAM is a free software package that provides both electrical energy output as well as financial analysis of a potential renewable energy project. It can be downloaded at Home - System Advisor Model - SAM. (nrel.gov). SAM is linked to NREL websites to provide detailed energy resource information and can run a detailed feasibility analysis for a given location anywhere within the continental U.S. In this brief we will focus on two technologies, solar PV and wind



energy. Other renewable energy technologies available in SAM include energy storage, concentrating solar power, geothermal energy, biomass combustion and marine energy. SAM also includes useful training courses and help content linked to all user inputs. NREL also provides more detailed software for follow-up analyses as listed in the links at the end of this brief.

In the next sub-section of this brief, we briefly discuss SAM's general financial model inputs. In the following two sub-sections, we discuss specific model inputs to describe selected details of both a proposed solar PV farm using SAM's Detailed PV Model and a proposed wind project using SAM's Wind Model. In both cases, we assume the finances are based on a single owner power purchase agreement. Other more complex financial arrangements are also available but not discussed here. SAM output examples for both a solar farm and a wind farm are discussed later in this brief. Also available in SAM are a Detailed PV-Battery Model that includes battery storage options and a Hybrid Detailed PV-Wind Model that combines the two technologies and includes battery storage options.

General Financial Model Inputs

SAM maintains default capital and operating costs for each technology option, updated with each new version of the software. Direct capital costs include balance of system equipment, installation labor, and installer margin and overhead. Indirect capital costs include land costs based on estimated land area, and optional inputs for permitting and environmental studies, engineering and developer overhead, and grid interconnection. Sales tax information is also input based on local information, resulting in an estimate of total installed project cost and cost per unit of electrical power. Operation and maintenance costs include input for either fixed annual cost ($/yr), fixed cost by capacity ($/kW-yr) or variable cost by generation ($/MWhac). Land leasing cost input is also available based on SAM's land area estimate.

Financing input options for each technology include the overall analysis period, the inflation rate and discount rates, state and federal income tax and both sales and property tax information. An optional project salvage value is also available. If a portion of the upfront costs is borrowed, project term debt options include a fixed percentage of the total installed cost or a debt service coverage ratio option based on cash available. An annual interest rate is also input here. Project revenue options include either specifying a power purchase agreement (PPA) price or a targeted internal rate of return (IRR) and breakeven target year. If the IRR target is specified, then the retail electricity rates can be found on the Electricity Purchase page using the Open EI Utility Rate Database link. When using either the IRR target or the PPA price, for a project to be financially feasible requires that the estimated levelized cost of electricity must be less than the PPA price and/or the local commercial and residential electricity rates. Financial incentive information includes either the investment tax credit or the production tax credit from both federal and state sources. Adding additional incentive information is also an option. Finally, six different depreciation calculation methods are available.

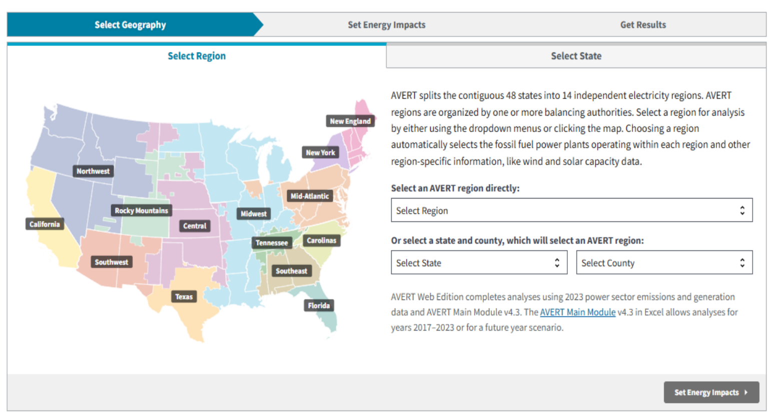
Additional Photovoltaic Project Details

Additional details include the solar resource at a chosen location, the commercially available PV modules and inverters to be installed, and the layout of the modules. To include information of the solar resource at a given location, you can download relevant weather files via SAM by entering a location name, street address or latitude/longitude in decimal degrees. The resulting file downloaded to SAM provides detailed hourly average information on relevant solar radiation at a given location. SAM also asks you to choose a commercially available set of PV panels and inverters from a large list of currently available products. The user can also specify additional details of the panel layout. For a given user-defined nameplate DC capacity, SAM then estimates total AC capacity, total inverter DC capacity, the number of required modules, the module layout, and the total module area. User inputs of system power losses are also provided (DC default = 4.4%; AC default = 1%) as well as module soiling losses (default = 5%).

Additional Wind Project Details

To include hourly information on the wind resource at a given location, you can download the relevant weather files for a given year via SAM by entering a location name or zip code, street address or latitude/longitude in decimal degrees. A specific wind turbine with a rated output, rotor diameter and hub height is then chosen by the user from a long list of commercially available turbines provided by SAM. Given the nameplate capacity of the chosen turbine and the required overall system nameplate capacity of the wind farm, the user can then specify the number of turbines required to reach system capacity. The turbines are then laid out in an array and a visual layout map is shown. The layout can be modified by the user.

AVERT Web-based Calculator: Averted Pollutant Emissions



EPA provides a simple web-based platform that estimates the air pollution emission reductions (including CO_2) associated with installing renewables to replace fossil-based electricity generation (AVERT Web Edition | US EPA). Installing renewable generation in one location can mean emission reductions somewhere else in the grid. EPA also provides a more detailed version of AVERT in a downloadable Excel-based format. The user can choose a location, enter the nameplate capacity of the wind or solar farm, and AVERT will estimate the fossil fuel emission reductions in the surrounding region, including nearby states.

SAM Example for a Wind Farm

This example involves a proposed 100 MW nameplate capacity wind farm with a single owner PPA. The proposed site is in the rolling hills of central Washington State. The wind turbines chosen for this site are manufactured by Vestas, model V-90, with a nameplate capacity of 2 megawatts per turbine at a hub height of 80 meters. There are 100 turbines at the farm with a layout of 5 rows with 10 turbines per row. Total losses are assumed to be 17 %. We used the capital and operating default costs for 2022 in this example. Financial assumptions used default values except for specifying that Washington State has no income tax. We also assumed a PPA electricity price of 8 cents per kilowatt-hour. A federal government production tax credit of 2.6 cents per kilowatt-hour was also assumed.

A summary table of the SAM estimates is shown in the accompanying figure. Given these set of assumptions, the large net present value (NPV) and internal rate of return (IRR) indicate that this is a financially viable project that would generate about 268,000 MWh per year of renewable electricity.

PPA set at $0.08/kWh

	Metric	Value
Performance metrics	Annual AC energy in Year 1	268,222,736 kWh
	Capacity	100,000 kW
	Capacity factor in Year 1	30.6%
Financial metrics	PPA price in Year 1	8.00 ¢/kWh
	PPA price escalation	1.00 %/year
	LPPA Levelized PPA price nominal	8.66 ¢/kWh
	LPPA Levelized PPA price real	6.88 ¢/kWh
	LCOE Levelized cost of energy nominal	5.54 ¢/kWh
	LCOE Levelized cost of energy real	4.40 ¢/kWh
	NPV Net present value	$81,916,288
	IRR Internal rate of return	57.01 %
	Year IRR is achieved	20
	IRR at end of project	57.02 %
	Net capital cost	$165,705,040
	Equity	$27,547,878
	Size of debt	$138,157,152
	Debt percent	83.38%

The annual emission changes estimated by AVERT are shown for Washington and for surrounding states for various air pollutants in the accompanying table. The largest reductions were from fossil-fueled power plants in Utah and Wyoming.

State		SO_2 (lb)	NO_X (lb)	CO_2 (tons)	$PM_{2.5}$ (lb)	VOCs (lb)	NH_3 (lb)
Idaho	From Fossil Generation	-60	-3,340	-6,860	-770	-240	-730
	From Vehicles	0	0	0	0	0	0
	Net Change	-60	-3,340	-6,860	-770	-240	-730
Montana	From Fossil Generation	-8,700	-13,620	-9,050	-2,000	-410	-90
	From Vehicles	0	0	0	0	0	0
	Net Change	-8,700	-13,620	-9,050	-2,000	-410	-90
Nevada	From Fossil Generation	-8,210	-15,200	-29,010	-5,010	-2,390	-1,670
	From Vehicles	0	0	0	0	0	0
	Net Change	-8,210	-15,200	-29,010	-5,010	-2,390	-1,670
Oregon	From Fossil Generation	-90	-1,830	-11,220	-790	-390	-790
	From Vehicles	0	0	0	0	0	0
	Net Change	-90	-1,830	-11,220	-790	-390	-790
Utah	From Fossil Generation	-31,800	-90,560	-46,690	-3,920	-1,310	-640
	From Vehicles	0	0	0	0	0	0
	Net Change	-31,800	-90,560	-46,690	-3,920	-1,310	-640
Washington	From Fossil Generation	-2,080	-17,570	-21,610	-1,900	-680	-520
	From Vehicles	0	0	0	0	0	0
	Net Change	-2,080	-17,570	-21,610	-1,900	-680	-520
Wyoming	From Fossil Generation	-67,500	-68,820	-51,330	-5,710	-1,630	-120
	From Vehicles	0	0	0	0	0	0
	Net Change	-67,500	-68,820	-51,330	-5,710	-1,630	-120

SAM Example for a Solar Farm

This example involves a proposed 20 MW nameplate capacity solar farm with a single owner PPA. The proposed site is in Phoenix, Arizona. The mono-crystalline PV panels chosen for this site are manufactured by SunPower with a 310 watt DC maximum power output. There are 64,488 fixed-tilt modules and 22 inverters at the farm. Total losses are assumed to be 17 %. We used the capital and operating default costs for 2022 in this example. Financial assumptions used default values except for specifying that Washington State has no income tax. We also assumed a PPA electricity price of 10 cents per kilowatt-hour. A federal government investment tax credit of 30% was also assumed.

Metric	Value
Annual AC energy in Year 1	37,449,416 kWh
DC capacity factor in Year 1	21.4%
Energy yield in Year 1	1,872 kWh/kW
Performance ratio in Year 1	0.77
PPA price in Year 1	10.00 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	10.81 ¢/kWh
LPPA Levelized PPA price real	8.63 ¢/kWh
LCOE Levelized cost of energy nominal	6.04 ¢/kWh
LCOE Levelized cost of energy real	4.82 ¢/kWh
NPV Net present value	$16,783,030
IRR Internal rate of return	45.43 %
Year IRR is achieved	20
IRR at end of project	45.45 %
Net capital cost	$23,234,276
Equity	$9,297,443
Size of debt	$13,936,832
Minimum DSCR	2.96

A summary table of the SAM estimates is shown in the accompanying figure. Given these set of assumptions, the large net present value (NPV) and internal rate of return (IRR) indicate that this is a financially viable project that would generate about 37 thousand megawatt-hours per year of renewable electricity.

The annual emission changes estimated by AVERT are shown for Washington and for surrounding states for various air pollutants in the figure below. The largest reductions were from fossil-fueled power plants in Zr Arizona and New Mexico.

State		SO_2 (lb)	NO_X (lb)	CO_2 (tons)	$PM_{2.5}$ (lb)	VOCs (lb)	NH_3 (lb)
Arizona	From Fossil Generation	-10,380	-18,010	-24,270	-2,270	-710	-1,050
	From Vehicles	0	0	0	0	0	0
	Net Change	-10,380	-18,010	-24,270	-2,270	-710	-1,050
California	From Fossil Generation	-10	-100	-810	-70	-20	-50
	From Vehicles	0	0	0	0	0	0
	Net Change	-10	-100	-810	-70	-20	-50
New Mexico	From Fossil Generation	-2,410	-6,280	-6,510	-1,240	-260	-300
	From Vehicles	0	0	0	0	0	0
	Net Change	-2,410	-6,280	-6,510	-1,240	-260	-300
Texas	From Fossil Generation	-10	-1,000	-1,430	-160	-120	-100
	From Vehicles	0	0	0	0	0	0
	Net Change	-10	-1,000	-1,430	-160	-120	-100

Useful Websites

- National Solar Radiation Database NSRDB (nrel.gov) complete collection of hourly and half-hourly values of meteorological data and the three most common measurements of solar radiation: global horizontal, direct normal and diffuse horizontal irradiance.
- Renewable Energy Integration and Optimization REopt Web Tool | REopt Energy Integration & Optimization | NREL Evaluates the economic viability of distributed PV, wind, battery storage, combined heat and power (CHP), geothermal heat pumps (GHP), and thermal energy storage and identify system sizes and dispatch strategies to minimize energy costs.
- Wind Resource Database WRDB (nrel.gov) A collection of modeled wind resource estimates for the United States and various countries around the globe of various lengths up to over 20 years. Most of the data are available in 5-minute (min.) intervals at 2-kilometer (km) spatial resolution. For the United States, uncertainty estimates are also provided.
- RE Explorer Home | Re-Explorer Explore Renewable Energy Potential Around the World
- UW MSCE Energy Infrastructure, https://www.energy-infrastructure.uw.edu/