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Technical Report
NREL/TP-6A20-61019
February 2014

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Executive Summary

This document describes the capabilities of the U.S. Department of Energy and National Renewable Energy Laboratory's System Advisor Model (SAM), Version 2014.1.14, released on January 14, 2014, for potential users or readers wanting to learn about the model's capabilities. SAM is a computer model that calculates performance and financial metrics of renewable energy systems. Project developers, policymakers, equipment manufacturers, and researchers use SAM results to evaluate financial, technology, and incentive options for renewable energy projects. SAM simulates the performance of photovoltaic, concentrating solar power, solar water heating, wind, geothermal, biomass, and conventional power systems. The financial model can represent financial structures for projects that either buy and sell electricity at retail rates (residential and commercial) or sell electricity at a price determined in a power purchase agreement (utility). SAM's advanced simulation options facilitate parametric and sensitivity analyses, and statistical analysis capabilities are available for Monte Carlo simulation and weather variability (P50/P90) studies. SAM can also read input variables from Microsoft Excel worksheets. For software developers, the SAM software development kit (SDK) makes it possible to use SAM simulation modules in their applications written in C/C++, C#, Java, Python, and MATLAB. NREL provides both SAM and the SDK as free downloads at http://sam.nrel.gov. Technical support and more information about the software are available on the website.

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SAM Overview

This document describes the U.S. Department of Energy and National Renewable Energy Laboratory's System Advisor Model (SAM), Version 2014.1.14, released on January 14, 2014. It is intended to both help potential users determine whether the model meets their modeling needs, and provide information for readers who do not plan to use the model but want to learn about its capabilities.

SAM is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry:

- Project managers and engineers
- Financial and policy analysts
- Technology developers
- Researchers.

SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. Projects can be either on the customer side of the utility meter, where they buy and sell electricity at retail rates, or on the utility side of the meter, where they sell electricity at a price negotiated through a power purchase agreement (PPA).

SAM is an electric power generation model and assumes that the renewable energy system delivers power either to an electric grid, or to a grid-connected building or facility to meet electric load. It does not model thermal energy systems that meet a thermal process load. SAM also does not model isolated or off-grid power systems, and does not model systems with electricity storage batteries.

Creating a SAM file involves choosing both a performance model and a financial model to represent your project. SAM automatically populates input variables with a set of default values based on your choices. After you create the file, you modify the inputs to provide information about the project's location, the type of equipment in the system, the cost of installing and operating the system, and financial and incentives assumptions. It is your responsibility as an analyst to review and modify all of the input data as appropriate for each analysis. Once you are satisfied with the input variable values, you run simulations, and then examine results. A typical analysis involves running simulations, examining results, revising inputs, and repeating that process until you understand and have confidence in the results.

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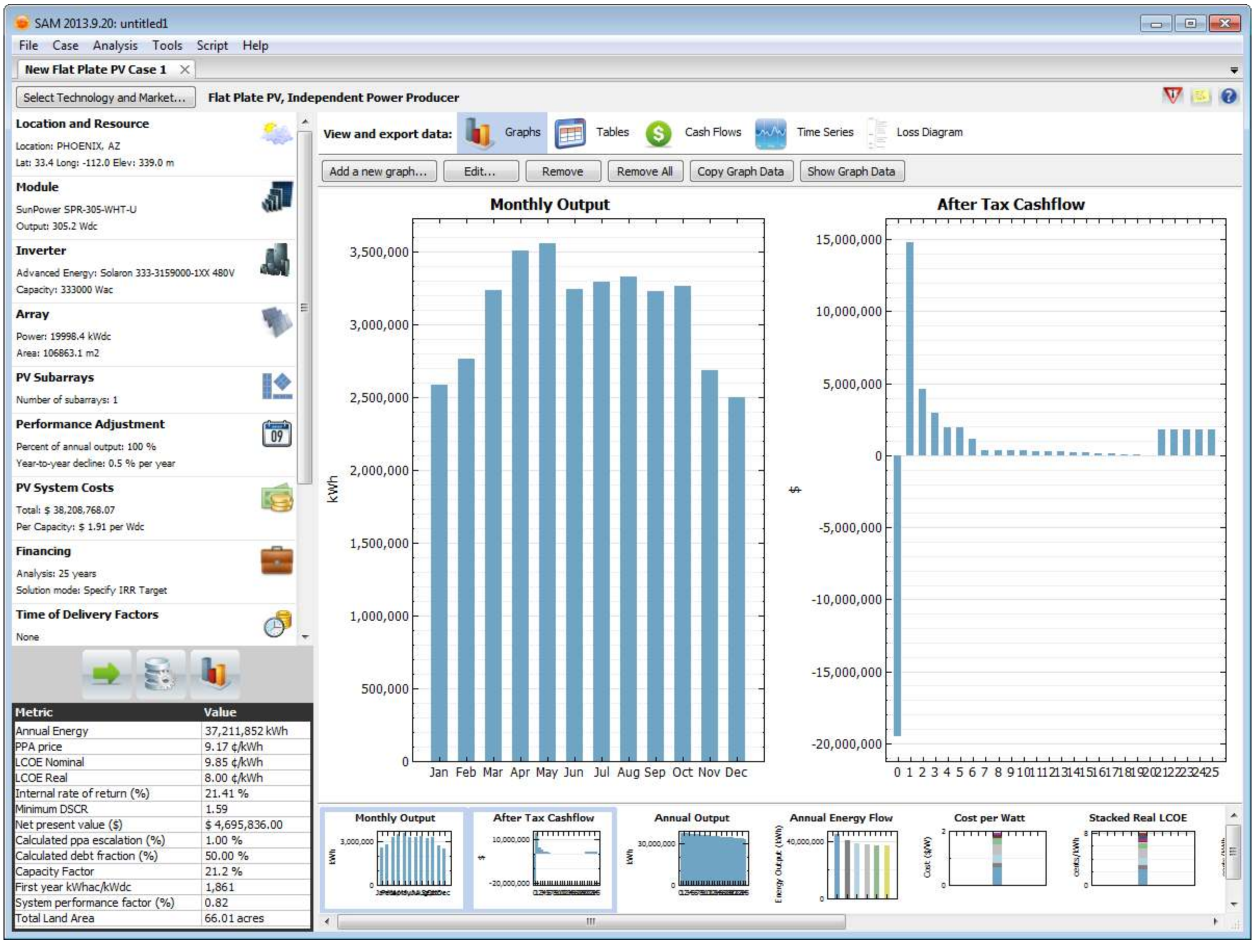

Figure 1. The SAM main window showing monthly electricity generation and the annual cash flow for a photovoltaic system

SAM is available as a desktop application for Windows and OS X. The National Renewable Energy Laboratory (NREL) distributes SAM for free at https://sam.nrel.gov. You may use SAM for any purpose, but you must acknowledge your use of SAM in any documentation of analysis involving the software, and credit NREL for developing the software, and the U.S. Department of Energy for supporting its development. Guidelines for citing SAM in publications are available at https://sam.nrel.gov/content/sam-publications.

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Model Structure

SAM consists of a user interface, calculation engine, and programming interface. The user interface is the part of SAM that you see. It provides access to input variables and simulation controls and displays tables and graphs of results.

The user interface performs three basic functions:

- Provide access to input variables, which are organized into input pages. The input variables describe the physical characteristics of a system, and the cost and financial assumptions for a project. SAM's input variables are populated with default values to help you get started with your analysis.
- Allow you to control how SAM runs simulations. You can run a basic simulation, or more advanced simulations for optimization and sensitivity studies.
- Provide access to output variables in tables and graphs on the Results page, and in files that you can open in a spreadsheet application or other software.

SAM's calculation engine, called the SAM Simulation Core (SSC), performs a time-step-by-time-step simulation of a power system's performance, and calculates project cash flow and financial metrics annually. The programming interface allows external programs to interact with SAM, and a public version is available in the SAM software development kit.

SAM Software Development Kit

The SAM Simulation Core (SSC) software development kit (SDK) is a package of tools for software developers for creating renewable energy system and project models using the SSC library. The SSC library is the collection of simulation and computation modules that SAM uses to simulate renewable energy projects: SAM is a desktop application that provides a user-friendly front end for the SSC library. The SDK allows you to use modules from the SSC library in Windows, OS X, or Linux applications that you write in C++, C#, Java, MATLAB, or Python.

NREL distributes the SAM Simulation Core SDK for free at https://sam.nrel.gov.

SAM Models and Databases

SAM represents the cost and performance of renewable energy projects using computer models developed at NREL, Sandia National Laboratories, the University of Wisconsin, and other organizations. Each performance model represents a part of the system, and each financial model represents a project's financial structure.

Source code for the SAM simulation and calculation modules is not available to the public. However, reference manuals describing the algorithms in each of the performance model modules are available for download from the SAM website.

The models require input data to describe the performance characteristics of physical equipment in the system, and project costs and financial assumptions. SAM's user interface makes it possible for people with no experience developing computer models to build a model of a renewable energy project, and to make cost and performance projections based on model results.

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To describe the renewable energy resource and weather conditions at a project location, SAM requires a weather data file. Depending on the kind of system you are modeling, you either choose a weather data file from a list, download one from the Internet, or create the file using your own data.

SAM includes several libraries of performance data and coefficients that describe the characteristics of system components such as photovoltaic modules and inverters, parabolic trough receivers and collectors, wind turbines, and biopower combustion systems. For those components, you simply choose an option from a list, and SAM applies values from the library to the input variables.

SAM can automatically download data and populate input variable values from the following online databases:

- DSIRE for U.S. incentives.
- OpenEI Utility Rate Database for retail electricity rate structures for U.S. utilities.
- NREL Solar Prospector for solar resource data and ambient weather conditions.
- NREL Wind Integration Datasets for wind resource data.
- NREL Biofuels Atlas and DOE Billion Ton Update for biomass resource data.
- NREL Geothermal Resource database for temperature and depth data.

For the remaining input variables, you either use the default value or change its value. Some examples of input variables are:

- Installation costs including equipment purchases, labor, engineering and other project costs, land costs, and operation and maintenance costs.
- Numbers of modules and inverters, tracking type, and derating factors for photovoltaic systems.
- Collector and receiver type, solar multiple, storage capacity, and power block capacity for parabolic trough systems.
- Analysis period, real discount rate, inflation rate, tax rates, internal rate of return target or power purchase price for utility financing models.
- Building load and time-of-use retail rates for commercial and residential financing models.
- Tax and cash incentive amounts and rates.

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Results: Tables, Graphs, and Reports

SAM displays modeling results in tables and graphs, ranging from the metrics table that displays levelized cost of energy, first year annual production, and other single-value metrics, to tables and graphs that show detailed annual cash flows and hourly performance data.

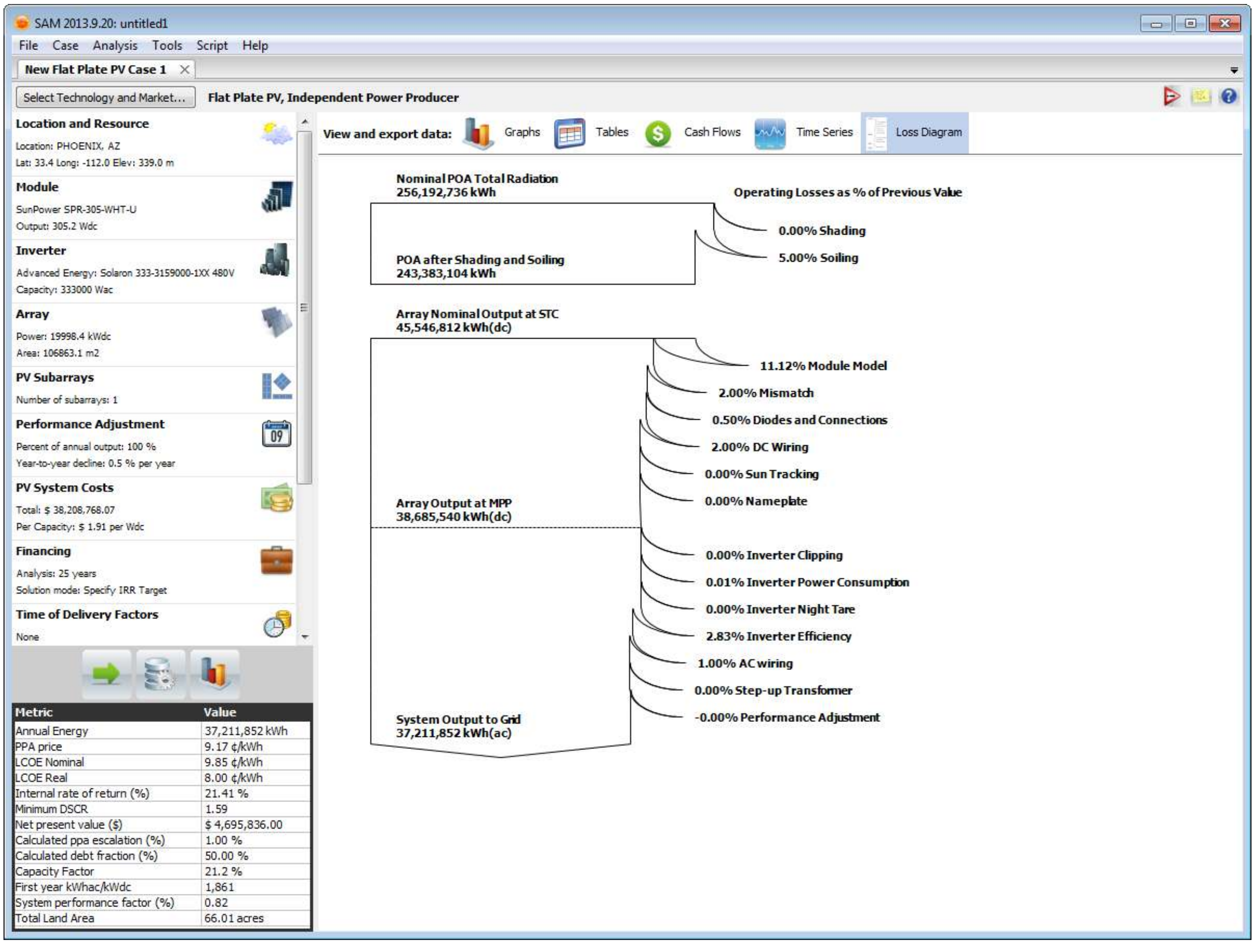

Figure 2. The Results page showing the energy loss diagram for a photovoltaic system

After you run simulations, SAM displays a set of default graphs. You can customize the graphs by changing titles, colors, and font sizes, or create new graphs that show different data. You can also export images of all graphs and the data they display to include in reports and presentations, or to analyze further with other software.

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Performance Models

SAM's performance models make hour-by-hour calculations of a power system's electric output, generating a set of 8,760 hourly values that represent the system's electricity production over a single year. You can explore the system's performance characteristics in detail by viewing tables and graphs of the hourly and monthly performance data, or use performance metrics such as the system's total annual output and capacity factor for more general performance evaluations.

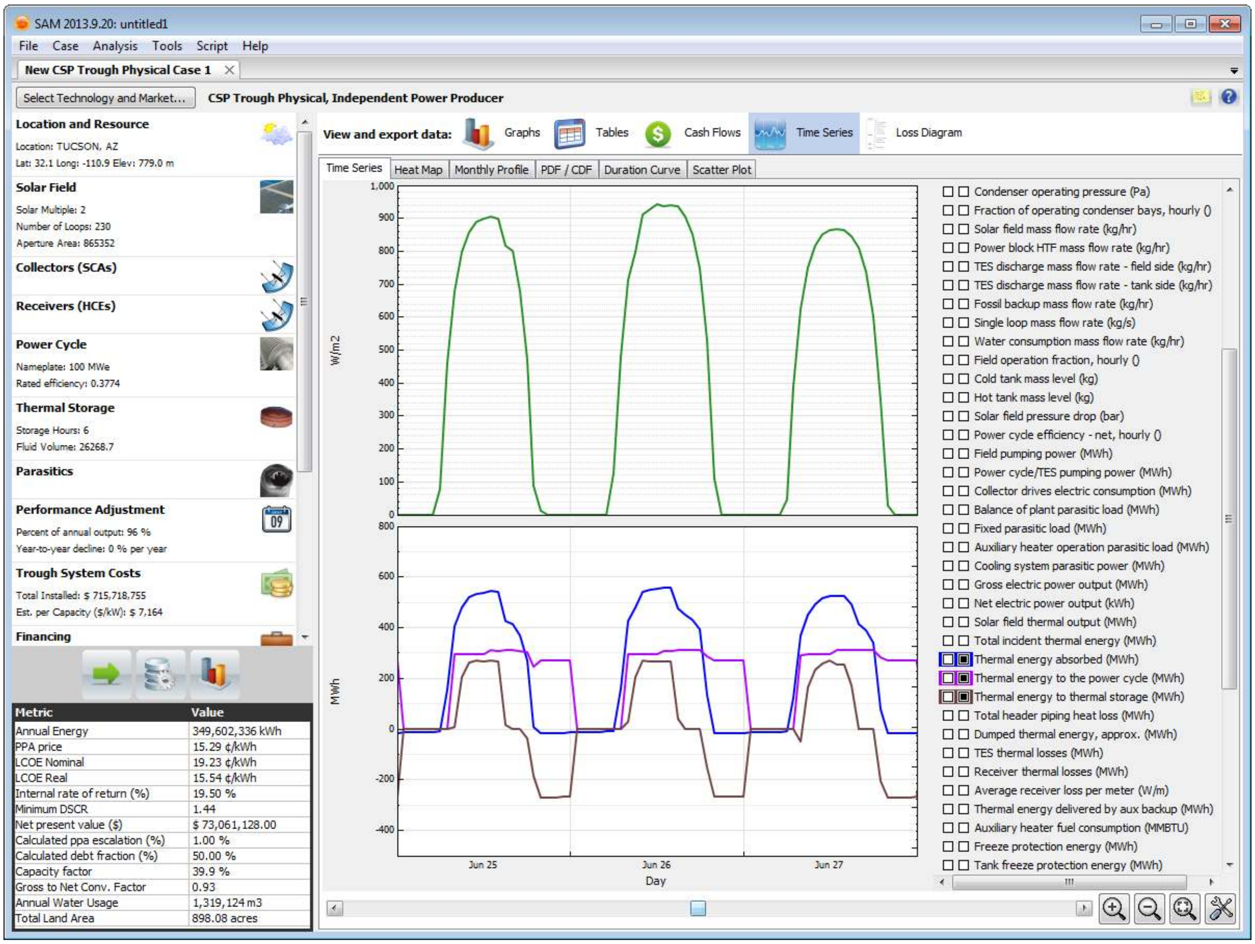

Figure 3. The Time Series graph on the Results page showing hourly electricity generation for a 100 MW parabolic trough system with 6 hours of storage

The current version of SAM includes performance models for the following technologies:

- Photovoltaic (PV) systems (flat-plate and concentrating photovoltaic)
- CSP parabolic trough
- CSP power tower (molten salt and direct steam)
- CSP linear Fresnel
- CSP dish-Stirling

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- Conventional thermal (a simple heat rate model)
- Solar water heating for residential or commercial buildings
- Large and small wind power
- Geothermal power and geothermal co-production
- Biomass power.

You can compare different kinds of projects by creating more than one case in a file. For example, you could compare the savings of a residential rooftop solar water heater to those of a photovoltaic system. Or, for a large utility-scale project, you could compare the power purchase price that would be required to make a wind, a photovoltaic, or a concentrating solar power project profitable at a given location. SAM does not model hybrid power systems. For example, you cannot model a single project that combines wind turbines and photovoltaic modules.

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Financial Models

SAM's financial models calculate financial metrics for various kinds of power projects based on a project's cash flows over an analysis period that you specify. The financial model uses the system's electrical output calculated by the performance model to calculate the series of annual cash flows.

SAM includes financial models for the following kinds of projects:

- Residential (retail electricity rates)
- Commercial (retail rates or power purchase agreement)
- Utility-scale (power purchase agreement):
    - Single owner
    - Leveraged partnership flip
    - All equity partnership flip
    - Sale leaseback.

Residential and Commercial Projects

Residential and commercial projects are financed through either a loan or cash payment, and recover investment costs through savings from reduced electricity purchases from the electricity service provider. For electricity pricing, SAM can model simple flat buy and sell rates, monthly net metering, or complex rate structures with tiered time-of-use pricing. For these projects, SAM reports the following metrics:

- Levelized cost of energy
- Electricity cost with and without renewable energy system
- Electricity savings
- After-tax net present value
- Payback period.

Power Purchase Agreement (PPA) Projects

Utility and commercial PPA projects are assumed to sell electricity through a power purchase agreement at a fixed price with optional annual escalation and time-of-delivery (TOD) factors. For these projects, SAM calculates:

- Levelized cost of energy
- PPA price (electricity sales price)
- Internal rate of return
- Net present value
- Debt fraction or debt service coverage ratio.

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SAM can either calculate the internal rate of return based on a power price you specify, or calculate the power price based on the rate of return you specify.

Levelized Cost of Energy and Cash Flow

For projects using retail electricity rates (residential and commercial), SAM calculates the levelized cost of energy (LCOE) from after-tax cash flows, so that the LCOE represents the cost of generating electricity over the project life, accounting for taxes and incentives. For projects selling electricity under a power purchase agreement (utility), SAM calculates the LCOE from the revenue cash flow, so that the LCOE also includes the developer's margin defined by the project's internal rate of return.

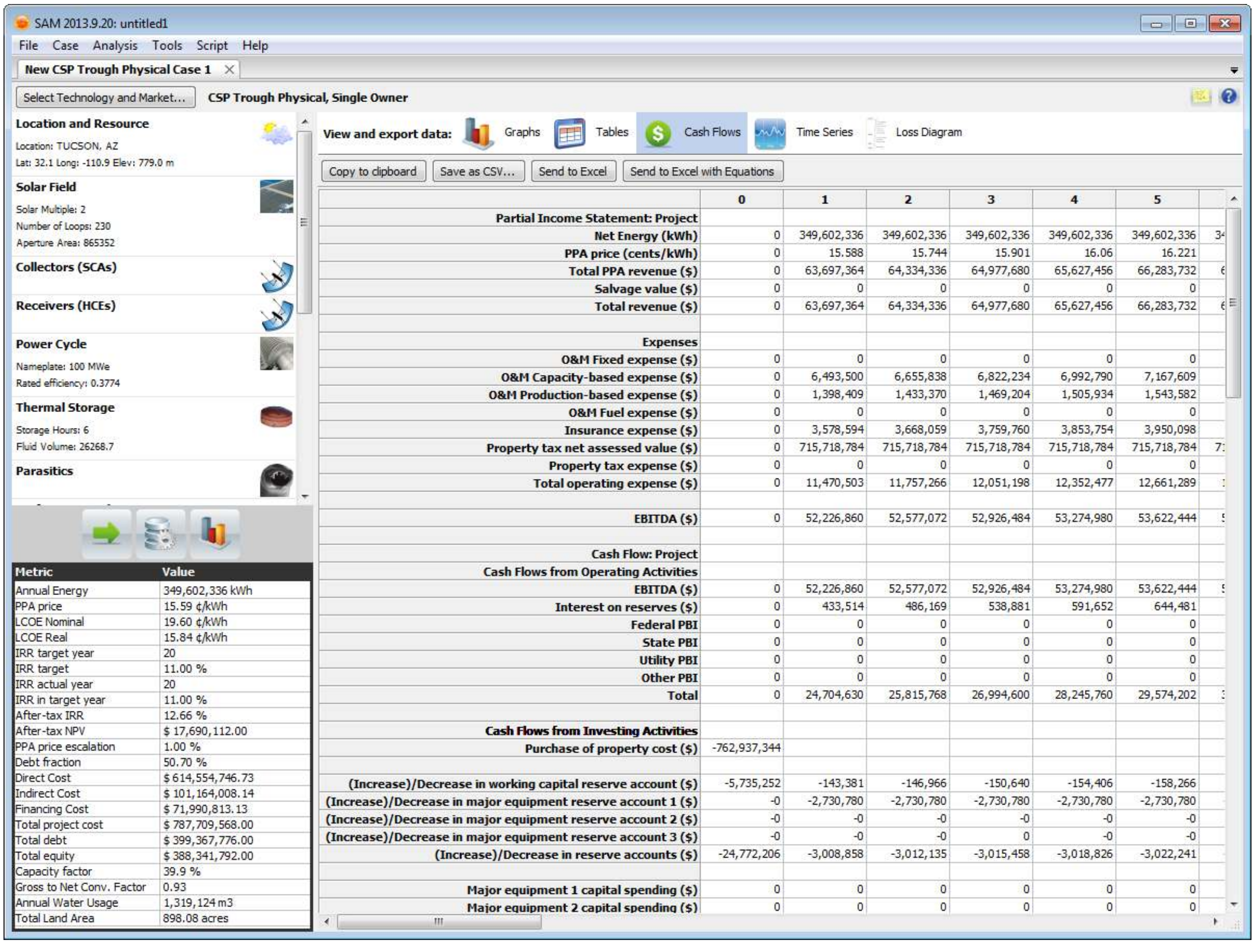

Figure 4. The first several rows of the cash flow table for a utility-scale project

The project annual cash flows include:

- Revenues from electricity sales and incentive payments
- Installation costs
- Operating, maintenance, and replacement costs

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- Loan principal and interest payments
- Tax benefits and liabilities (accounting for any tax credits for which the project is eligible)
- Incentive payments
- Project and partner's internal rate of return requirements (for PPA projects).

Incentives

The financial model can account for a wide range of incentive payments and tax credits:

- Investment based incentives
- Capacity-based incentives
- Production-based incentives
- Investment tax credits
- Production tax credits
- Depreciation (MACRS, Straight-line, custom, bonus, etc.).

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Analysis Options

In addition to simulating a system's performance over a single year and calculating a project cash flow over a multi-year period, SAM's analysis options make it possible to conduct studies involving multiple simulations, linking SAM inputs to a Microsoft Excel workbook, and working with custom simulation modules. The following options are for analyses that investigate the impacts on model results of variations and uncertainty in assumptions about weather, performance, cost, and financial parameters:

- Parametric Analysis: Assign multiple values to input variables to create graphs and tables showing the value of output metrics for each value of the input variable. Useful for optimization and exploring relationships between input variables and results.
- Sensitivity Analysis: Create tornado graphs by specifying a range of values for input variables as a percentage of a base value.
- Statistical Analysis: Create histograms showing the sensitivity of output metrics to variations in input values.
- Probability of Exceedance Analysis (P50/P90): For locations with weather data available for many years, calculate the probability that the system's total annual output will exceed a certain value.

SAM also makes it possible to work with external models developed in Excel or the TRNSYS simulation platform:

- Excel Exchange: Use Excel to calculate the value of input variables, and automatically pass values of input variables between SAM and Excel.
- Exchange Variables: Create your own input variables for use with Excel Exchange or a custom TRNSYS deck.
- Simulator Options: Change the simulation time step, or run SAM with your own simulation modules developed in the TRNSYS modeling platform.

Finally, SAM's scripting language SamUL allows you to write your own programs within the SAM user interface to control simulations, change values of input variables, and write data to text files.

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Software Development History and Users

SAM, originally called the "Solar Advisor Model," was first developed by the National Renewable Energy Laboratory in collaboration with Sandia National Laboratories in 2005 for internal use by the U.S. Department of Energy's Solar Energy Technologies Program in its systems-based analysis of solar technology improvement opportunities within the program. NREL released the first public version in August 2007 as Version 1, making it possible for solar energy professionals to analyze photovoltaic systems and concentrating solar power parabolic trough systems in the same modeling platform using consistent financial assumptions. Between 2007 and 2013, two new versions were released each year, adding new technologies and financing options. In 2010, the name changed to "System Advisor Model" to reflect the addition of non-solar technologies. Beginning in 2014, NREL will release one new version of the software each year, with periodic maintenance updates as needed.

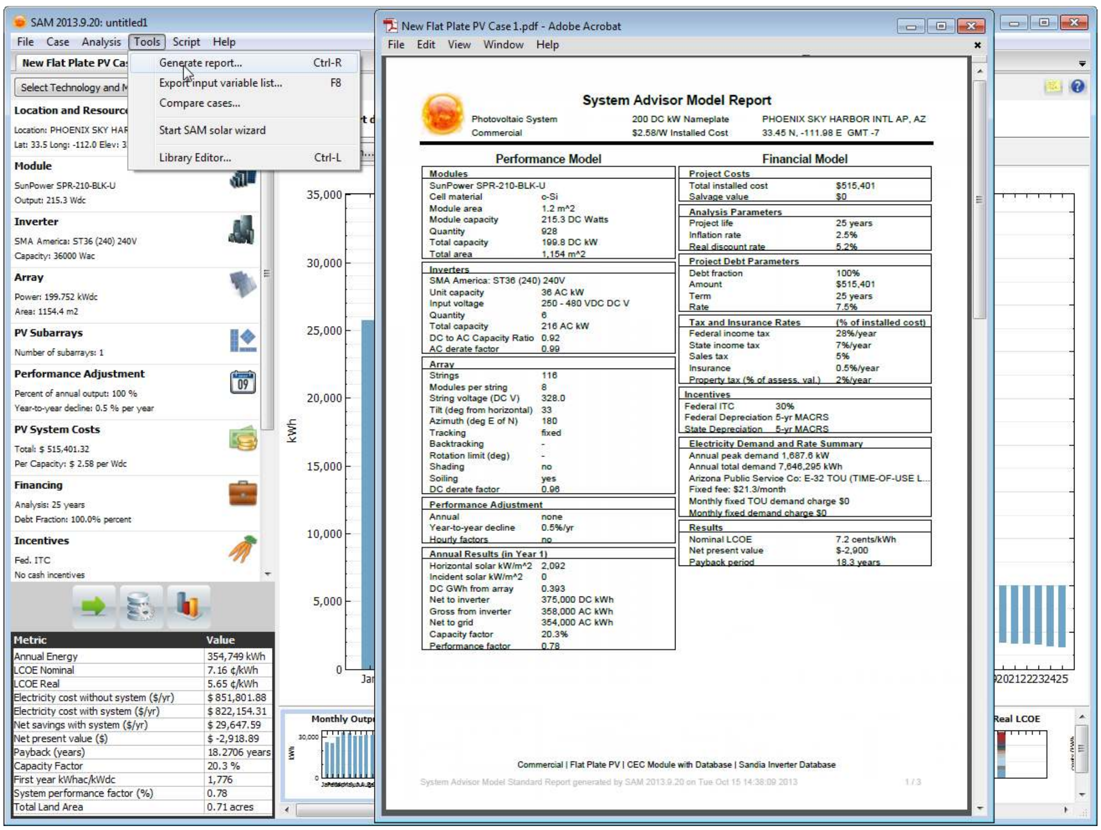

Figure 5. The report generator exports a PDF showing key assumptions and results from a SAM analysis case

The DOE and DOE laboratories continue to use the model for program planning and grant programs. Since the first public release, over 35,000 people have downloaded the software, representing manufacturers, project developers, academic researchers, and policymakers. Academic professionals use SAM for graduate-level classroom instruction and for research. Project developers use SAM to evaluate different system configurations to maximize earnings from electricity sales. Policymakers and designers use the model to experiment with different incentive structures.

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Downloading SAM and User Support

SAM runs on both Windows and OS X. It requires about 500 MB of storage space on your computer. SAM is available for free download. To download the software, you must register for an account on the website. After registering, you will receive an email with your account information. SAM's website includes software descriptions, links to publications about SAM and other resources.

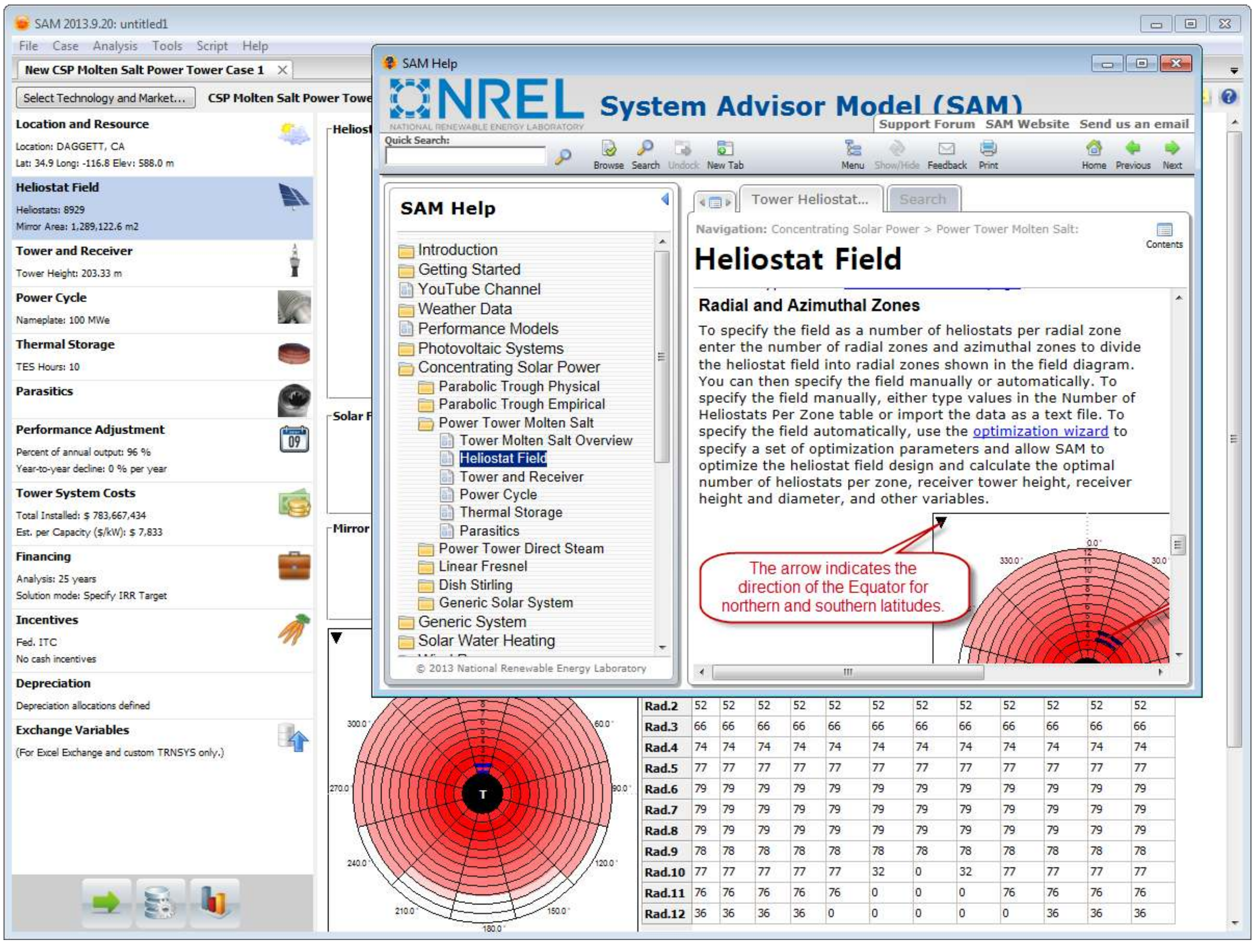

Figure 6. SAM's help system includes detailed descriptions of the user interface, modeling options, and results

The following resources are available for learning to use SAM and for getting help with your analyses:

- Help system: Press the F1 key in Windows or Command-? in Mac OS from any input or results page in SAM to view the Help topic for that page.
- User support forum.
- Documentation, videos, and training schedule on the SAM website Learning page.

You can contact the SAM support team by submitting a message on the Contact Us page.

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