Solar Advisor Model

User Guide

Version 2009
Manual Release Date 10/12/2009

Solar Advisor Model Disclaimer

The Solar Advisor Model is provided by the National Renewable Energy Laboratory ("NREL"), which is operated by the Midwest Research Institute ("MRI") for the Department Of Energy ("DOE").
Access to and use of the Solar Advisor Model shall impose the following obligations on the user. The user is granted the right, without any fee or cost, to use the Solar Advisor Model for any purpose whatsoever, except commercial purposes or sales, but not to modify, alter, enhance or distribute. Further, the user agrees to credit DOE/NREL/MRI in any publications that result from the use of the Solar Advisor Model. The names DOE/NREL/MRI, however, may not be used in any advertising or publicity to endorse or promote any products or commercial entity unless specific written permission is obtained from DOE/NREL/MRI. The user also understands that DOE/NREL/MRI is not obligated to provide the user with any support, consulting, training or assistance of any kind whatsoever with regard to the use of the Solar Advisor Model or to provide the user with any updates, bug-fixes, revisions or new versions. The Solar Advisor Model is provided by DOE/NREL/MRI "as is" and any express or implied warranties, including but not limited to, the implied warranties of merchantability and fitness for a particular purpose are hereby disclaimed. In no event shall DOE/NREL/MRI be liable for any special, indirect or consequential damages or any damages whatsoever, including but not limited to claims associated with the loss of data or profits, which may result from an action in contract, negligence or other tortious claim that arises out of or in connection with the access, use or performance of the Solar Advisor Model.

Microsoft and Excel are registered trademarks of the Microsoft Corporation.

While every precaution has been taken in the preparation of this document, the publisher and the author assume no responsibility for errors or omissions, or for damages resulting from the use of information contained in this document or from the use of programs and source code that may accompany it. In no event shall the publisher and the author be liable for any loss of profit or any other commercial damage caused or alleged to have been caused directly or indirectly by this document.

Produced: October 2009

Table of Contents

1 About the Solar Advisor Model

The Solar Advisor Model Version SAM 2009 provides a consistent framework for analyzing and comparing power system costs and performance across the range of solar technologies and markets, from photovoltaic systems for residential and commercial markets to concentrating solar power and large photovoltaic systems for utility markets.

The Solar Advisor Model can be downloaded for free from the Solar Advisor website https://www.nrel.gov/analysis/sam/.

Solar Advisor is based on an hourly simulation engine that interacts with performance, cost, and finance models to calculate energy output, energy costs, and cash flows. The software can also account for the effect of incentives on project cash flows. Solar Advisor's spreadsheet interface allows for exchanging data with external models developed in Microsoft® Excel. The model provides options for parametric studies, sensitivity analysis, optimization, and statistical analyses to investigate impacts of variations and uncertainty in performance, cost, and financial parameters on model results.

Solar Advisor models system performance using the TRNSYS software developed at the University of Wisconsin combined with customized components. TRNSYS is a validated, time-series simulation program that can simulate the performance of photovoltaic, concentrating solar power, water heating systems, and other renewable energy systems using hourly resource data. TRNSYS is integrated into Solar Advisor so there is no need to install TRNSYS software or be familiar with its use to run Solar Advisor.

The Department of Energy's Solar Energy Technologies Program (SETP) initially developed Solar Advisor for analysis to support the implementation of the SETP Systems Driven Approach. The model also has applications for the solar industry for planning research and development programs, and developing project cost and performance estimates. Solar Advisor is being used as part of the solicitation and evaluation process for SETP funding programs.

The current version of the Solar Advisor Model models photovoltaic and concentrating solar power technologies for electric applications in several markets. Solar Advisor also includes a simple model of fuel-based electric generation that can be used to model baseline systems for comparison with the solar technologies. The current version of the Solar Advisor Model does not model solar heating and lighting technologies.

Photovoltaic Systems

Photovoltaic systems in Solar Advisor can be based on flat-plate system or concentrating photovoltaic modules. Solar Advisor offers several options for modeling flat-plate modules, and one option for concentrating photovoltaic modules.

Table 1. Current status of photovoltaic modeling

Technology	Module	Inverter	Storage and Loads
Flat-plate photovoltaic	• Simple efficiency • Sandia PV Array Performance Model • CEC Performance Model • PVWatts Solar Array	• Single-point efficiency • Sandia Performance Model for Grid-Connected PV Inverters	• A prototype model is available for testing with the PVWatts Solar Array model.
Concentrating photovoltaic	• Single-point efficiency	• Single-point efficiency • Sandia Performance Model for Grid-Connected PV Inverters	• Under development

The efficiency models are simplified representations of either modules or inverters based on rated capacities in Watts or kilowatts and efficiency values. The flat-plate PV simple efficiency model also includes a simple representation of module temperature effects. The Sandia and CEC models include parameter libraries for commercially available PV modules and inverters maintained by Sandia National Laboratories and the California Energy Commission (CEC), respectively. Modules and inverters only recently introduced to the market may not be available in the parameter libraries.

Concentrating Solar Power Systems

Solar Advisor models parabolic trough, power tower, and dish-Stirling concentrating solar power systems. The trough model is based on NREL's Excelergy model. The dish-Stirling and power tower models are based on research at the University of Wisconsin.

Table 2. Current status of Concentrating Solar Power modeling

Technology	Solar Field	Collector and Receiver	Power Block	Storage	Parasitics
Parabolic trough	• Layout as multiple of design point or specified area • List of heat transfer fluid options	• Library of collector types • Library of receiver types and condition	• Library of power cycle types	• Storage capacity defined in number of hours at full load • Thermocline • Two-tank storage	• Library of parameter sets for parasitic losses
Dish-stirling	• Field area defined by number of collectors and separation	• Mirror area reflectivity parameters • Conduction, convection, and radiation parameters	• Stirling engine part-to-full load efficiency curve • Engine operating parameters	• None	• Pump and fan motor loss parameters
Power tower	• Heliostat positions defined either in radial zones or individual x-y coordinates • Solar field optimization wizard	• Molten-salt external Receiver • Eight options for heat transfer fluid flow through the receiver	• Rankine steam cycle • Polynomial regression model using design electric output, cycle efficiency, inlet and outlet temperatures, and mass flow rate	• Storage capacity defined in number of hours at full load • Two-tank storage	• Library of parameter sets for parasitic losses

Generic (Fuel-based) Systems

The generic model is a simple, linear, efficiency-based representation of the performance of a fuel-based electricity generator coupled to Solar Advisor's cost model.

Table 3. Current status of Generic fuel-based electric generation modeling

Technology	Configuration
Generic	First year annual output calculated as a function of nameplate capacity, heat rate, capacity factor and other performance factors.

Financial and Incentive Models

Solar Advisor calculates economic metrics including the levelized cost of energy for a project based on the system's annual electric output and annual cash flow that captures installation and operating costs, taxes, incentives, and the cost of debt. The model includes a set of sample templates that contain default cost values that can be used as a starting point for analyses. The default cost values are representative of average U.S. costs at the time of the model's release, but of course do not capture the actual costs for any specific project. For more information about the financing options available in Solar Advisor, see Technology and Market.

2 Switching from Earlier Versions

Solar Advisor Model 2009 maintains the same capabilities as the version 3.0, but adds several new capabilities, has a new look and feel, and runs more efficiently.

One conceptual difference between the two versions is that in SAM 2009, the input variables on the input pages are separate from the simulation configurations. In SAM 3.0, you configure parametric analyses and set up linked spreadsheets directly from the input pages. In SAM 2009, all simulation configurations are handled in one place: The Configure Simulations page. The input pages only contain input variables, and each variable has a single "base case" value, or in the case of variables with annual schedules, a series of annual base case values.

Contents

New Look and Feel

SAM 2009 uses a redesigned user interface that preserves the general layout of SAM 3.0 and earlier versions, but runs more efficiently. In SAM 2009 you still aaccess input pages using the navigation menu just like in SAM 3.0, but the menu has been slightly reorganized.

- The navigation menu buttons in SAM 3.0 have been removed. In SAM 2009, you can click an item on the menu to open the input page.
- The Program page in SAM 3.0 where you define the project's technology and market has been replaced by the Technology and Market window.
- Right-clicking variables no longer displays the Input Type window. The Parametric Analysis and Excel Exchange (linked spreadsheets) features that were available by right-clicking variables in SAM 3.0 are now handled as simulation configuration options. Variables that can be entered as Annual Schedules display a button next to the label that you can click to edit the annual schedule.
- A new Annual Performance page displays annual degradation and availability variables, which are used consistently across all technologies to facilitate comparison.
- The Costs page in SAM 3.0 has been replaced with the system costs page for each technology, and its position on the navigation menu has been moved.

Working with Files from SAM 3.0

You can open a project file created in SAM 3.0 by saving it as a SCIF file and opening it in SAM 2009.

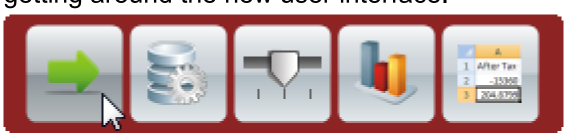
A SCIF file contains a complete set of input values for one or more cases in a project file. Note that SAM 2009 cannot save files in the SCIF format. Because the new *.zsam* project file format used by SAM 2009 is much more compact than the SAM 3.0's *.sam* format, the SCIF format has been deprecated in the new version.

> **Note.** SAM 2009 does not convert parametric variables or variables linked to spreadsheets from SCIF files. If your SAM 3.0 project files includes those features, you will need to set up the parametric analysis or Excel exchange in SAM 2009. See Parametric Analysis and Excel Exchange for details.

To convert a file from SAM 3.0 to SAM 2009:

1. Start both SAM 2009 and SAM 3.0. The two versions can run simultaneously on your computer without interfering with each other.
2. In SAM 3.0, on the File menu, click **Save As SCIF**.
3. In the Save As SCIF window, choose the cases from the file that you want to include in the SCIF file.
4. Click the Browse button ... to open the Save As window.
5. Navigate to the location on your computer where you want to save the file.
6. In **File name**, type the name of the file, *including the .scif extension*. For example, type the complete name "MySolarProject.scif"
7. Click **Save**. It may take several seconds to convert and save the file.
8. In SAM 2009, on the File menu, click **Open SCIF File**.
9. In the Choose a SCIF File window, browse to the folder containing the SCIF file.
10. In the Save Converted File As window, choose a location to save the SAM 2009 project file. You can save the file to any location on your computer or a network.
11. When SAM 2009 finishes converting the project to the *.zsam* format, click **Yes** to open the file.

    If the SCIF file uses a weather file that is not included in the SAM 2009 standard library, before going to the next step, you will need to add the file to the library of weather file locations on the Climate page. See Managing Weather Files for details.
12. Click Run all simulations to generate a set of SAM 2009 results. See Getting Started for help getting around the new user interface.

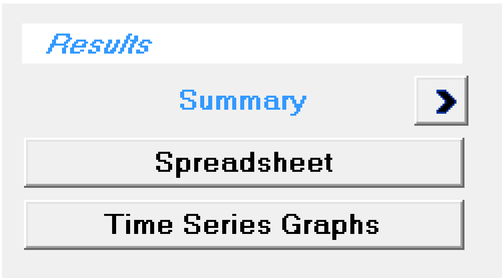
Results Graphs and Tables

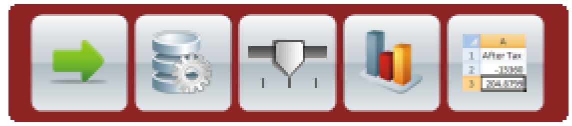
SAM 2009 displays tables and graphs of results on the Results page, whose appearance has significantly changed from SAM 3.0. See Reviewing Results for help getting started with the Results page, and see Results Page Reference for more details.

Some key differences include:

- The run and results buttons still appear on at the bottom of the navigation menu, but their appearance has changed. See Running Simulations and Reviewing Results for details.

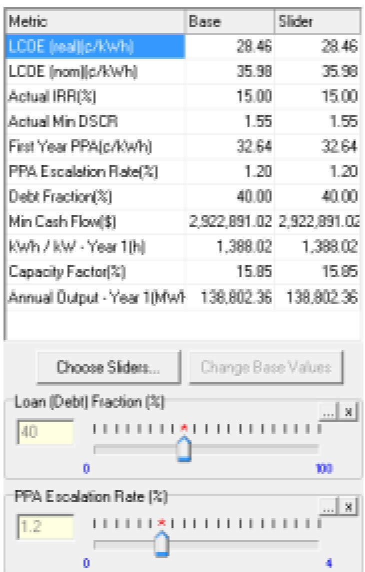
SAM 3.0 | **SAM 2009**



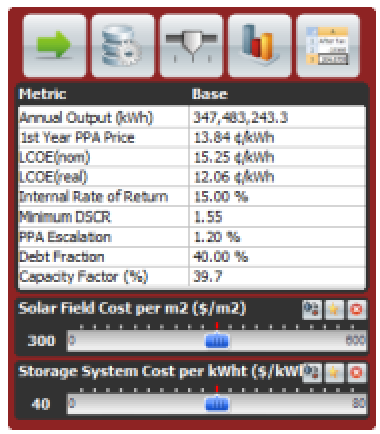


- The Metrics table and sliders appear under the navigation menu instead of on the Results page, freeing up space for graphs on the Results page.

SAM 3.0 | **SAM 2009**



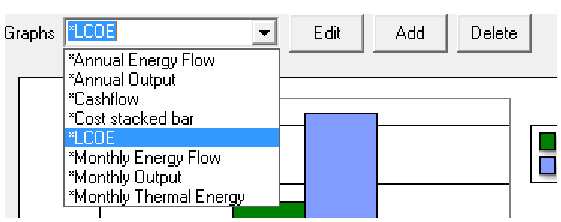
Metric	Base	Slider
LCOE (real)(c/kWh)	28.46	28.46
LCOE (nom)(c/kWh)	35.98	35.98
Actual IRR(%)	15.00	15.00
Actual Min DSCR	1.55	1.55
First Year PPA(c/kWh)	32.64	32.64
PPA Escalation Rate(%)	1.20	1.20
Debt Fraction(%)	40.00	40.00
Min Cash Flow($)	2,922,891.02	2,922,891.02
kWh / kW - Year 1(h)	1,388.02	1,388.02
Capacity Factor(%)	15.85	15.85
Annual Output - Year 1(MWh)	138,802.36	138,802.36

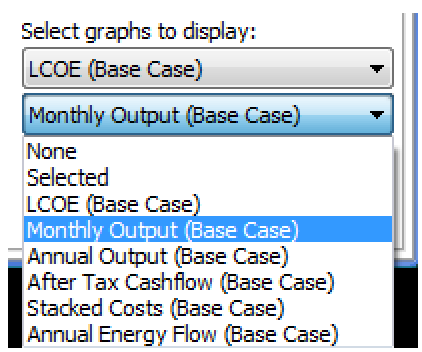


Metric	Base
Annual Output (kWh)	347,483,243.3
1st Year PPA Price	13.84 ¢/kWh
LCOE(nom)	15.25 ¢/kWh
LCOE(real)	12.06 ¢/kWh
Internal Rate of Return	15.00 %
Minimum DSCR	1.55
PPA Escalation	1.20 %
Debt Fraction	40.00 %
Capacity Factor (%)	39.7

- Choose graphs to display from the Graphing tab at the bottom of the Results page instead of from the list at the top.

SAM 3.0 | **SAM 2009**





General Model Improvements

SAM 2009 uses the same cost, financing, and performance models to simulate systems as SAM 3.0, with some improvements that may cause results from the two versions to differ:

- The photovoltaic single-point efficiency models for flat-plate and concentrating photovoltaic modules have been replaced by the simple efficiency models, which allow you to enter efficiency values for a range of standard incident radiation levels, and to define the reference radiation used to calculate the module's rated power.
- For CSP parabolic trough and power tower systems the storage dispatch logic has been improved.
- For CSP power tower systems, the input variables have been reorganized, and duplication of variables in the input pages and optimization wizard removed.
- For CSP trough and power tower systems, the backup boiler fuel cost is tracked and included in the cash flow and other economic metrics displayed on the Results page.
- The photovoltaic technology option includes a new implementation of NREL's PVWatts model, which includes preliminary test versions of battery storage and electric load models.
- Input variable libraries use the same format across all technologies and input variable types. The library format is text-based, and the library editor allows for data to be added to libraries without modifying the standard libraries. See Working with Libraries for details.
- For projects with utility financing, the financial variable optimization no longer requires excel.

Improvements to Parametric Analysis

SAM 2009's Parametric Analysis simulation configuration option makes setting up and managing parametric analyses much simpler than in SAM 3.0 and earlier versions:

- Parametric variables are defined on the Parametric Analysis Configuration page instead of by right-clicking variable names on the input pages.
- The new optimization option uses a search algorithm to find optimal values of variables. providing an automated alternative to the manual method using parametric analyses and graphs.
- The new Sensitivity Analysis option allows you to define ranges of variable values using upper and lower limits so that you can perform sensitivity studies without specifying individual values.
- Parametric simulation configurations can be enabled or disabled for each model run, allowing you to set up as many parametric analyses as you like and choose which ones to include in a simulation run to save time.

Improvements to Linked Spreadsheet Functionality

The Excel Exchange simulation option allows you to manage data exchange between SAM 2009 input variables and Excel worksheet cells. The new implementation provides several advantages over SAM 3.0:

- The Excel Exchange configuration page allows you to manage data sharing with Excel in a central location.
- Excel can run simultaneously with SAM without causing any interference. You can edit the Excel workbook while SAM is running. SAM exchanges values with the saved copy of the workbook.
- Excel workbooks can be stored in any location on your computer. They no longer have to be stored in the Worksheets folder.
- User-defined variables (UDVs) from SAM 3.0 have been replaced by user variables.

Weather Data Enhancements

By default, SAM 2009 project files do not include data from weather files to minimize file size and improve the model's efficiency. During simulations, SAM 2009 reads data from the weather files, rather than from a database stored within the project file. The new weather file location library helps you manage weather file locations.

- SAM 2009 reads the new TMY3 weather format, as well as the TMY2 and EPW formats recognized by SAM 3.0.
- An Excel tool is available for converting your own weather data to TMY3 format. Contact solar.advisor.

support@nrel.gov for a copy of the tool.

- If you are sharing a project file with another person and want to include weather data in the file rather than sharing the weather file separately, you can copy the weather data to the project.
- For SAM 3.0 or earlier projects with parametric variables or variables linked to Excel, you have to configure the simulations, see Configuring Simulations.

3 Getting Started

Welcome to the Solar Advisor Model Version SAM 2009! The Solar Advisor Model provides a consistent framework for analyzing and comparing power system costs and performance across the range of solar technologies and markets, from photovoltaic systems for residential and commercial markets to concentrating solar power and large photovoltaic systems for utility markets. For more general information about the model, see About the Solar Advisor Model.

Note. If you are using the current version of the Solar Advisor Model, the layout of the new model should look familiar, but expect to spend some time familiarizing yourself with new features. For an explanation of some differences between the old and new version, see Switching from Earlier Versions
.

The Welcome page provides three options for starting a project:

- **Start from a sample template** to create a project file by copying data from a template. When you open a template, Solar Advisor creates a project file that contains a complete set of inputs and results from the template. Each template demonstrates either a feature of the software or one of the technologies.
- **Start a new project** means creating a project file by selecting a technology and market for your analysis. When you start a new project in this way, all of the variables on the input pages are populated with default values, but no results are displayed on the Results page until you configure and run simulations.
- **Open a recent file** to choose from a list of project files. The list contains project files that were saved during previous Solar Advisor sessions.

When you install Solar Advisor, it creates the SAM Projects folder in your default documents folder and uses this as the default location for storing project files. You can change the default project file location by clicking **Preferences** in the File Menu.

Learning About the Model

The following help topics describe the basic features of the Solar Advisor Model:

- Projects and Cases: Manage your Solar Advisor analysis projects.
- Menus: Menu commands.
- Working with Notes: Store text notes using the notes feature.
- Entering Inputs: About input pages and conventions used to display input data.
- Running Simulations: Simulation options.
- Reviewing Results: About the Results page.
- File Formats: File formats used to store and transfer data.

Getting Help

The following resources are available for help using the model:

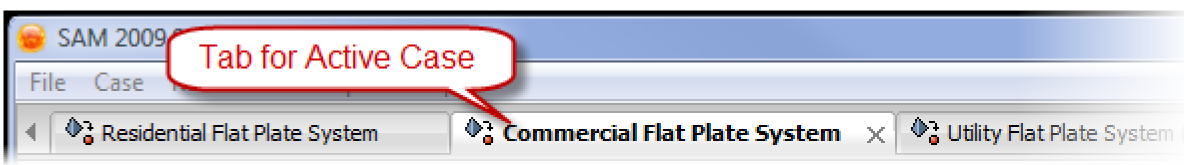
- For information about any page in the software, press the F1 key, click in the top right corner of the page, or choose **Help Contents** from the Help menu. In secondary windows, click the Help button for information about the window.
- The user guide is a version of this Help system in PDF format. It is available on the Help menu and the Solar Advisor Model website.
- For general information about the model, including a discussion of project costs, references to related publications and a list of frequently asked questions, and other information visit the Solar Advisor Model website: https://www.nrel.gov/analysis/sam/.
- To participate in the Solar Advisor Model discussion board, join Google Groups using your email address (a Gmail account is not required) at http://groups.google.com/group/sam-user-group.
- If you have questions comments about the software, please send an email to the support team at solar.advisor.support@nrel.gov. You can also use the User Support command on the Help menu to contact the support team.

3.1 Projects and Cases

A Solar Advisor project file contains one or more cases. Projects are stored in files with the extension *zsam*.

A case is a complete set of input data and results that represents a single system design. Solar Advisor uses tabs to display each case in the project, in a way similar to how Excel displays spreadsheets in a workbook.

> **Note.** The number of cases that a project file can contain depends on the storage and computing resources available on your computer. Solar Advisor displays a warning if you try to add more than six cases to your project. Your computer may be able to handle projects with more than six cases, but for the model to run efficiently, it is best to keep the number of cases to less than seven.



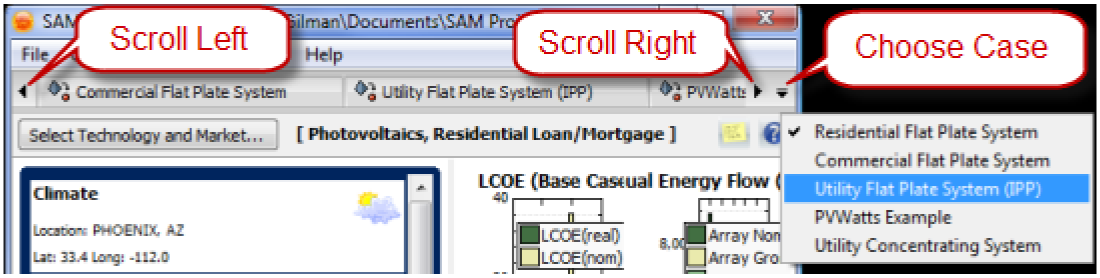
By creating more than one case in a file, you can easily compare the assumptions and results of different analysis scenarios. For example, you could use cases to compare the cost and performance of a residential photovoltaic system in several locations by defining a separate case for each location, or you could compare a utility-scale photovoltaic and concentrating solar power systems.

There are four commands on the Case menu that you can use to manage cases:

- **Create Case**: Adds a new case to the project file. Solar Advisor displays the Technology and Market window.
- **Rename Case**: Change the label identifying the case that appears on the case tab.
- **Duplicate Case**: Creates a copy of the active case, with a duplicate set of input parameters and results.

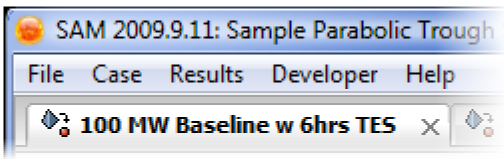
- **Delete Case**: Deletes the active case. You can also delete a case by clicking the 'x' on the case's tab.

For projects with more cases than can be displayed on tabs, the scroll and list controls allow you to access all of the cases in the project.



3.2 Menus

Solar Advisor's menu provide access to commands for managing projects, running simulations, exporting results, and getting more information about the model.



File

The File menu commands allow you to manage files, access component libraries, clear the simulation cache (advanced feature) and close Solar Advisor.

New Project

Start a new project using default input values. Solar Advisor creats a zsam file with no results.

Open

Open an existing project file.

Open Sample Template

Start a new project based on a sample template that contains a complete set of inputs and results. The Submenu lists the available sample templates.

Import SCIF File

Import a case from a SCIF file created in Version 3.0 or 2.5 of the model. See Switching from Earlier Versions for details.

Save

Save the project as a zsam file in its current location.

Save As

Save the project as a zsam file in a different location or with a new name.

Close

Close the project without exiting Solar Advisor.

Clear Cached Simulations

Clears stored results and other data from computer memory. Use this command if the program becomes sluggish after running a very large number of simulations, or if you are setting up very complex simulations and want to clear the cache before running them.

Libraries

Open the library editor to view or modify component libraries. See Working with Libraries for details.

Preferences

Open the Preferences window.

Recent Files

Open a file from the recent files list.

Quit

Closes the software.

Case

The Case menu commands apply to the current case, which indicated by the active case tab in the main window.

Create Case

Create a new case in the project. Solar Advisor opens the Technology and Market window where you choose options for the case. The new case will open with default input values and no results.

Rename Case

Change the name of the current case.

Duplicate Case

Create a copy of the current case.

Delete Case

Delete the current case. You can also delete a case by clicking the 'x' in the case's tab.

Run All Simulations

Runs all of the simulations configured in the current case. Equivalent to clicking the Run button. This option does not save hourly results.

Run All Saving Hourly Data

Runs all of the simulations configured in the current case. Creates a single set of hourly performance results based on the input values shown on the input pages.

Run Base Case Only

Runs a single simulation based on the input values shown on the input pages, ignoring any parametric, sensitivity, optimization or other configurations requiring multiple simulation runs, and does not save hourly results.

Run Base Case Saving Hourly Data

Runs a single simulation based on the input values shown on the input pages and saves hourly performance data. Ignores any parametric, sensitivity, optimization or other configurations requiring multiple simulation runs.

Reset to Tech/Market Default Inputs

Replaces all values on input pages with default values.

Clear Case Results

Clears results from the current case. Solar Advisor removes any graphs and sliders you may have created for the case.

Advanced

The advanced options create lines of code in Excel VBA, ANSI C, or for MATLAB that you can use in your own programs to call the Solar Advisor Model. If you would like to use these features, please contact Solar.Advisor.Support@nrel.gov.

Results

The Results menu commands allow you to export results for the current case to:

- The clipboard for pasting into documents.
- Comma-delimited text files.
- Excel files (PC computers running Windows only).
- The built-in DView data viewer for graphing hourly data (PC computers running Windows only).

Note. If the current case includes simulations that involve multiple input values, such as for parametric and sensitivity analyses, Solar Advisor only exports results for input values shown on the input pages, not for ranges of values defined in simulation configurations.

Graph Data

Exports data from the graphs currently displayed on the Results page.

Cashflows

Exports cash flow data for the current case.

Case Summary Data

Exports all performance and cash flow data for the current case.

View Hourly Time Series (DView)

Opens the DView data viewer and displays graphs of hourly data. See Time Series Graphs for details.

Developer

New SAMUL Script

Opens the script editor to create a program in the Solar Advisor Model User Language (SamUL) to automate Solar Advisor modeling tasks. See the Sam UL guide (on the Help menu) for more information, or contact Solar.Advisor.Support@nrel.gov.

Help

Help Contents

Opens the Solar Advisor Model help system.

User Guide

Opens the user guide, which is a version of the help system in PDF format.

SamUL Guide

Opens the instructions in PDF format for using the Solar Adviosr Model User Language, a scripting language that allows you to automate Solar Advisor modeling tasks.

Release Notes

Displays the Solar Advisor Model's version history.

Web Site

Opens the Solar Advisor Model website in your computer's default browser. (Requires an internet connection.)

User Group

Opens the Solar Advisor Model discussion board on the Google Groups website in your computer's default browser. (Requires an internet connection.)

User Support

Opens your computer's default email program to compose an email that you can send to the Solar Advisor Model support team at solar.advisor.support@nrel.gov. (Requires an internet connection.)

Check for updates

Checks for updates to the software, component libraries, and help system, and allows you to update your software when updates are available. (Requires an internet connection.)

About

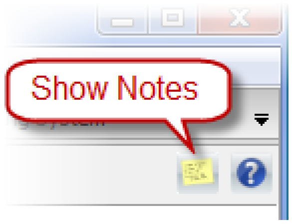
Displays the Solar Advisor Model legal disclaimer and information about the version of your copy of the software.

3.3 Working with Notes

The Notes feature allows you to store text associated with each input page and with the Results page.

To create notes:

1. From any input page or the Results page, click the Show Notes button at the top right of the window.



2. Type your text in the notes window.
3. Click the Notes window's close button to hide the window and save your notes.

   For input page notes, Solar Advisor displays a Notes icon in the navigation menu indicating that there are notes associated with the input page.

   For Results page notes, Solar Advisor opens the notes whenever you navigate to the page and after running simulations.

<u>To delete notes:</u>

1. Open the Notes window containing the notes you want to delete.
2. Select all text in the Notes window and press the Delete key.
3. Close the Notes window. Solar Advisor will remove the appropriate Notes icon from the navigation menu.

3.4 Entering Inputs

Solar Advisor's input pages provide access to the input variables, options, and libraries that define the assumptions of your analysis.

By default, the input variables contain values equivalent to those used in the sample templates. If you are in doubt about what value to use for an input variable, you can usually use the default value.

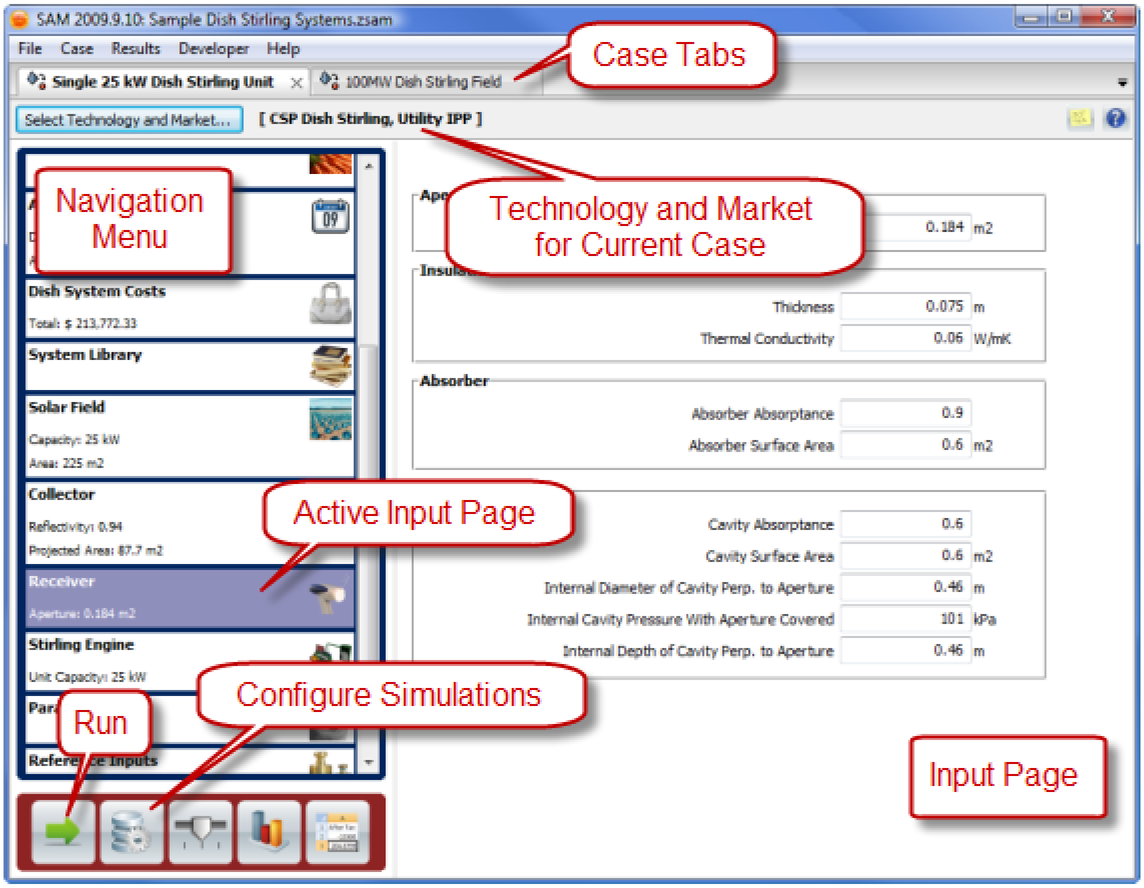
Refer to the Input Page Reference for detailed descriptions of the input variables on each page.

See Working with Libraries for information about the component libraries.

Input Page Overview

The input pages are where you view and edit input variables:

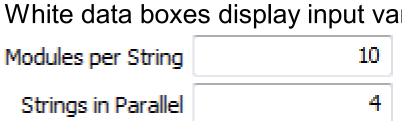
- The case tabs display different cases in the project. A project may consist of a single case, or may contain more than one case. Click a tab to display the case. Click the 'x' on a tab to delete the case.
- The navigation menu displays a list of input pages available for the technology and market of the current case. Click an item in the navigation menu to display an input page. The active input page is indicated on the menu in blue. When the menu is too long to fit in the window, use the vertical scroll bar to move through the menu, or resize the Main window to make the entire menu visible.
- The navigation menu also shows summaries of the data from the input pages. For example, the system costs item in the navigation menu shows the system's total installed cost.
- Click Configure Simulations to define the simulation parameters before running simulations.
- Click Run to run simulations and generate results.



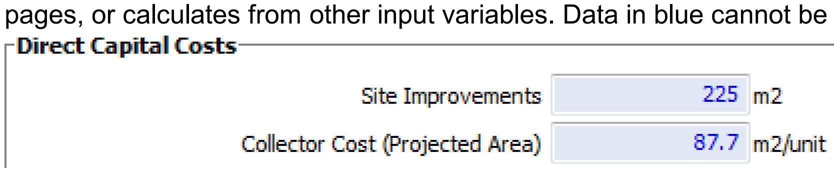
Input Page Color Conventions

The text and data box colors indicate the kind of information they contain:

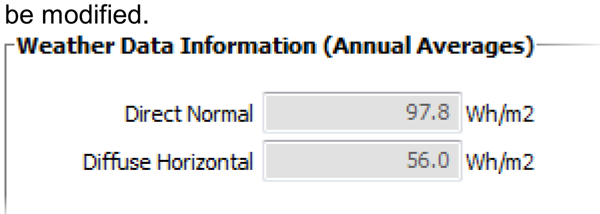
- White data boxes display input variables that you can modify.



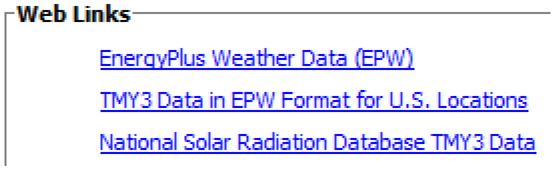
- Blue data boxes are for reference values that Solar Advisor either displays from other input pages, or calculates from other input variables. Data in blue cannot be modified.



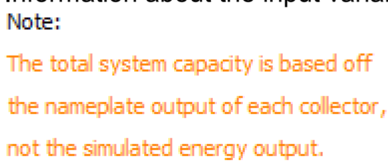
- Gray data boxes show values for your reference. For example, these weather data on the Climate page show annual averages calculated from data stored in the weather file. Data in gray cannot be modified.



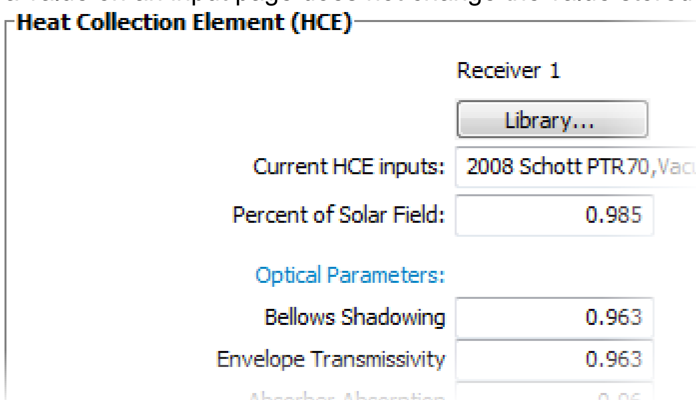
- Blue underlined text indicate links to websites with useful information related to the input page.



- Information about the input variables is displayed as orange text.



- Library buttons populate input variables with values from a library of stored parameters. Modifying a value on an input page does not change the value stored in the library.



3.5 Running Simulations

After you have set up your analysis on the input pages, click the Run all Simulations button to run simulations. Solar Advisor runs a simulation based on the values of input variables that appear on the input pages and reports those values as "base case" results. It also runs any simulations defined on the Configure Simulations pages.

Solar Advisor provides several options on the Case menu for running simulations:

Run All Simulations

Runs all of the simulations configured in the current case. Equivalent to clicking the Run button. This option does not save hourly results.

Run All Saving Hourly Data

Runs all of the simulations configured in the current case. Creates a single set of hourly performance results based on the input values shown on the input pages. See Viewing Hourly Performance Data for information about saving hourly results.

Run Base Case Only

Runs a single simulation based on the input values shown on the input pages, ignoring any parametric, sensitivity, optimization or other configurations requiring multiple simulation runs, and does not save hourly results.

Run Base Case Saving Hourly Data

Runs a single simulation based on the input values shown on the input pages and saves hourly performance data. Ignores any parametric, sensitivity, optimization or other configurations requiring multiple simulation runs. See Viewing Hourly Performance Data for information about saving hourly results.

3.6 Reviewing Results

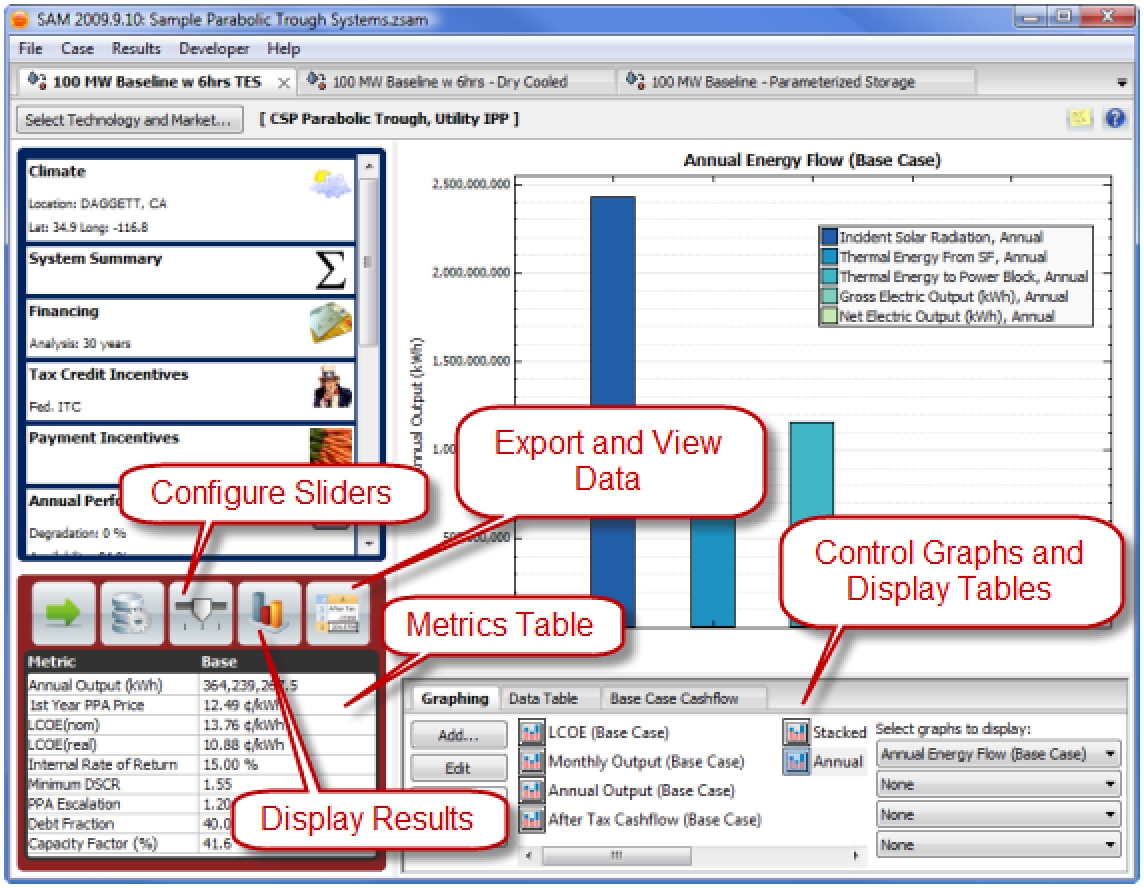
This section briefly describes the features on the Results page to help you get started using it. For detailed instructions on working with graphs and tables on the Results page, see Viewing Graphs and Results.

Note. In some cases, Solar Advisor displays graphs and tables for the "base case." In the context of displaying results, the "base case" is the set of results for the current case calculated from only values from the input pages and ignoring any results from additional simulations for parametric, sensitivity, or other simulation configurations that involve sets of multiple inputs.

Results Page Overview

After running simulations, Solar Advisor displays key metrics and a set of default graphs on the Results page:

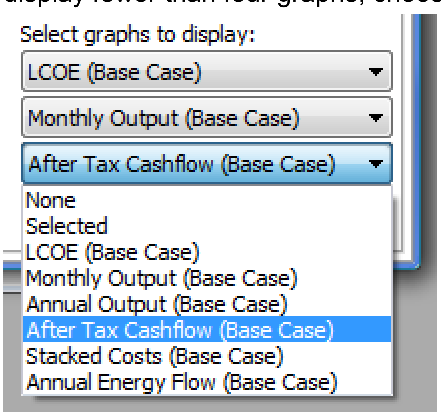
- Review economic and performance metrics in the Metrics table.
- Control the appearance of graphs and data tables using the tabs and buttons under the graph.
- Click Configure Sliders to set up and display sliders that allow you to dynamically change the value of an input variable and observe the effects on tables and graphs.
- Click Display Results to switch from viewing an input page to viewing results. Note that Solar Advisor will display results without running simulations whether or not any input values have changed since it last generated results.
- Click Export and View Data to export data in different formats and view hourly performance data.



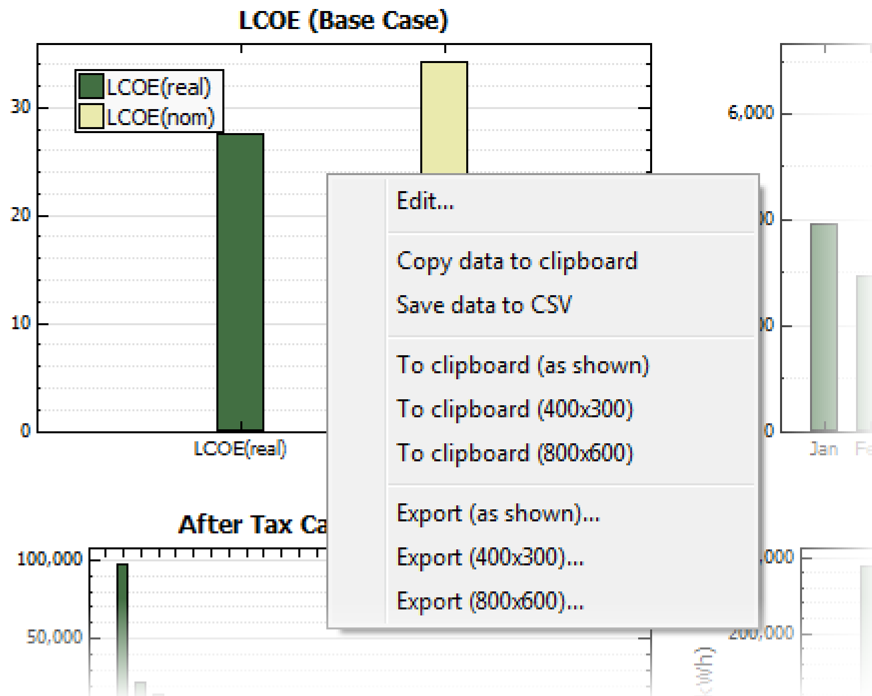
Results Page Quick Guide

The graph lists and results tabs allow you to determine how data are displayed on the Results page:

- By default, Solar Advisor displays a set of graphs on the Results page. Choose graphs in the four graph lists at the bottom right of the page to control which graphs appear on the Results page. To display fewer than four graphs, choose None for up to three graphs in the list.



- Right-click a graph to change its properties or export either an image of the graph or the graph data.



- Click the Data Table tab to display the data for all graphs visible on the Results page. Click and drag the border above the tabs to expand the table.

Graphing | **Data Table** | Base Case Cashflow

	A	B	C	D	E	F	G	H	I
1	X	LCOE(real)	LCOE(nom)		Month	AC Power Output (kWh), Monthly		Year	After Tax Cashflow
2	1	29.63	38.18		1	417.23		0	0
3					2	463.65		1	700.53
4					3	567.11		2	-1,303.45
5					4	643.8		3	-1,307.94
6					5	682.5		4	-1,312.99
7					6	629.61		5	-1,318.62
8					7	629.67		6	-1,324.88
9					8	609.77		7	-1,331.8
10					9	567.83		8	-1,339.42
11					10	541.7		9	-1,347.79
12					11	433.84		10	-4,196.95
13					12	394.2		11	-1,366.95
14								12	-1,377.85
15								13	-1,389.7
16								14	-1,402.55

- Click the Base Case Cashflow tab to display the cash flow for the current case.

Graphing | Data Table | **Base Case Cashflow**

	0	1	2	3
Federal ITC		64,131.7		
State ITC		0		
Sales Tax		10,544.06		
Tax Effect on Equity (State)				
State Depreciation	0	63,597.27	47,243.69	28,346.2
State Incentive Income Less Deductions	0	-66,063.63	-39,042.57	-20,011.1
State Taxable Income Less Deductions	0	-66,063.63	-39,042.57	-20,011.1
State Income Taxes	0	-5,285.09	-3,123.41	-1,600.8
State Tax Savings	0	5,285.09	3,123.41	1,600.8
Tax Effect on Equity (Federal)				
Federal Depreciation	0	63,597.27	47,243.69	28,346.2

3.7 File Formats

Solar Advisor uses the following types of files to store and transfer data. The file formats are listed below by file extension in alphabetical order.

Contact solar.advisor.support@nrel.gov for more information.

- BAS is a text file containing VBA code for use with Excel.
- BMP is a graphics file format used to export graph images.
- C is a text file containing ANSI C code for use in a C program.
- CSV is a text file containing a table comma-delimited columns that the model uses to export results data from graphs and tables.
- DVIEW is a file format used by Solar Advisor's time series data viewer, DView. See Times Series Graphs (DView) for more information.
- EPW is a weather file format that Solar Advisor can read directly. See Climate for more information on weather data.
- M is a text file containing MATLAB code.
- OUT is a text file format generated by Solar Advisor's simulation engine (TRNSYS) to store hourly performance data.
- SAMLIB is a text file used to store data for a Solar Advisor library. See Working with Libraries for more information.
- SCIF (SAM compressed inputs file) is an obsolete compressed file format used in Solar Advisor Model versions 2.5 through 3.0. The current version of Solar Advisor can open SCIF files created by older versions of the model.
- SUL is a text file containing SamUL script for automating Solar Advisor analyses. Refer to the SamUL Guide available on the Help menu for more information.

- TM2 and TM3 are a weather file formats that Solar Advisor can read directly. See Climate for more information on weather data.
- XLS are Excel files used to export data from Solar Advisor and to exchange data between the model and Excel. Note that Excel files must be in Excel 2003-2007 XLS format, and not in the newer XLSX format. See Excel Exchange for more information.
- ZSAM files store project data, which includes inputs and results for one or more cases.

4 Technology and Market

The Technology and Market window allows you to choose the technology and financing options for a new case, or to modify the options for the current case. The technology options determine whether the project is based on a photovoltaic, concentrating solar power, or generic fossil-fuel system. For each technology option, a different set of financing options is available, determining whether the project is a residential, commercial, or utility project. Solar Advisor displays a different set of input pages and variables based on the options defined on the Technology and Market window.

Contents

- Choosing options in the Technology and Market Window describes the steps for choosing options in the Technology and Market window.
- Overview of Technology Options explains the three technology groups and the models available for each.
- Overview of Financing Options explains the financial options available for residential, commercial, and utility market options.

Choosing Options in the Technology and Market Window

If you are starting a new project, you should open a sample template that most closely resembles the configuration you are modeling instead of changing options in the Technology and Market window. Starting from a sample template helps to ensure that the values of input variables are reasonable for a given combination of technology and market. This is important because, due to the large number of input variables in the model, most analyses will depend on using default values for at least some of the variables.

For some comparative analyses, it may be useful to change the technology or market options. For example:

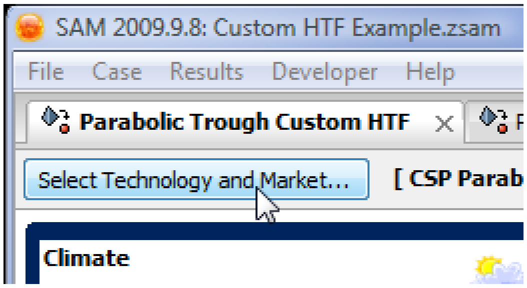
- To compare projects based on the same set of technology assumptions but using a different set of financing options. For example, to compare a 3 kW residential photovoltaic system with a 3 kW commercial photovoltaic system, you might start with the Residential Flat Plate System case from the Sample PV Systems template, modify input variables as needed to define a 3 kW system, and then create a copy of the case and change the market option to *Commercial - Standard Loan*. That would create two cases with the same set of technology assumptions, but with different financing options.
- To compare projects that use the same set of financial assumptions but use a different technology. For example, to compare a utility-scale photovoltaic system to a utility-scale parabolic trough system, you might start with a case from the Sample Parabolic Troughs template and change the technology option to a photovoltaic option to preserve the financial options from the trough template.

Whenever you make changes in the Technology and Market window, verify the variables on each input page to make sure that they are appropriate for your analysis.

To choose or modify technology and financing options:

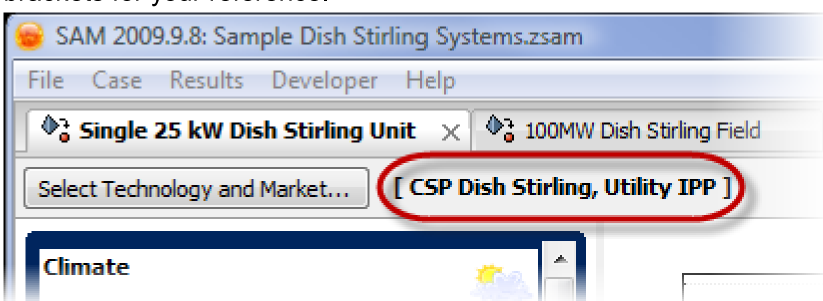
1. Open the Technology and Market window:

   If you are working in an existing file, click **Select Technology and Market**.

   If you are starting from a new file, click **New Project** on the File menu.
2. In the Technology and Market window, select a technology and financing option. See the tables below for descriptions of the options.
3. Check **Reset to Tech/Market-specific default inputs** to populate variables on the input pages with the default values used in sample templates. This will replace any values that may have been saved in previous model runs and is the default option.

   Clear **Reset to Tech/Market-specific default inputs** to use values stored from previous model runs. This is useful if you are switching between technologies and want to revert to input values that you saved in an earlier analysis.
4. Click **OK** to return to the main window. Solar Advisor displays the technology and market option in brackets for your reference.

Overview of Technology Options

The current version of Solar Advisor models photovoltaic, concentrating solar power, and fossil fuel-based electric power generation systems. The options are described in About the Solar Advisor Model, and summarized in the table below.

For photovoltaic systems, when you choose the component-based models option, the Module and Inverter pages each display a list of performance models to choose from. The module models are explained in the Module topic and include: Simple Efficiency Model, CEC Performance Model, Sandia PV Array Performance Model, and Concentrating PV model. The inverter models are explained in the Inverter topic and include: Single Point Efficiency Inverter, and Sandia Performance Model for Grid Connected PV Inverters. When you choose the PVWatts option, Solar Advisor models the entire system using parameters on the PVWatts Solar Array page and also includes experimental options for modeling a storage system and electric loads. (The storage and load models are currently under development, and may be available for the other photovoltaic model options in a future version of the software.)

Table 4. Summary of technology options in the Technology and Market window.

Technology	Description	Options
Photovoltaics	Systems that convert sunlight into electricity, based either on flat-plate photovoltaic modules or concentrating photovoltaic (CPV) modules.	• **Component-based Models** allows you to choose from four module performance models (including a CPV model) and two inverter performance models. • **PVWatts Performance Model** replicates NREL's web-based PVWatts model.
Concentrating Solar Power	Systems that convert concentrated solar radiation to thermal energy for use in a conventional steam generation plant.	• **Parabolic Trough System** models a field of parabolic trough collectors driving a power block with or without storage and fossil backup. • **Power Tower System** (central receiver systems) models a field of heliostats that focus light on a central, tower-mounted receiver and drive a power cycle with or without storage. • **Dish Stirling System** models a field of dish-shaped collectors, each equipped with a dish-Stirling engine that converts solar energy into electricity.
Generic Fossil	Systems that convert a fossil fuel into electricity.	This simple model allows you to compare the energy costs of a fossil fuel based system with those of solar technologies using a consistent set of financial assumptions.

Overview of Financing Options

The financing options determine the set of variables that Solar Advisor displays on the Financing page, and whether or not the Utility Rate page is available. See the table below for details.

Note. The electricity sales price is an input on the Utility Rate page for commercial projects with cash or loan financing. For utility and third-party ownership projects, the electricity sales price is a result reported as the first year PPA Price on the Results page. The Utility Rate page is not available for utility and third-party ownership projects.

Table 5. Summary of financing options in the Technology and Market window.

Financing Option	Description	Available for:
Residential Market	A small-scale project developed and owned by a residential homeowner with no depreciation tax deductions or investment return constraints. Residential projects sell electricity through a net metering agreement with an electric service provider at either a fixed rate or a rate based on a time-of-use pricing schedule defined on the Utility Rate page. The two residential financing options with parameters defined on the Financing page are: • **Cash**, where the total installation cost is incurred in year zero of the cash flow. • **Loan or Mortgage**, where a portion of the installation cost is incurred in year zero, and the rest is spread over the analysis period, with annual capital and interest payments. Residential projects may or may not benefit from tax credits or payment incentives	• Photovoltaic • Generic fossil
Commercial Market	A mid-scale project developed and owned by a commercial entity that qualifies for a depreciation deduction under U.S. federal tax code. Commercial projects sell electricity through a net metering agreement with an electric service provider at either a fixed rate or a rate based on a time-of-use pricing schedule defined on the Utility Rate page. The two commercial financing options with parameters defined on the Financing page are: • **Cash**, where the total installation cost is incurred in year zero of the cash flow. • **Loan**, where a portion of the installation cost is incurred in year zero, and the rest is spread over the analysis period, with annual capital and interest payments. The **Third-party Ownership** option is for a project that is installed, owned and operated by a party separate from the commercial entity that owns the property on which the project is installed. Third-party ownership projects sell electricity through a power purchase agreement with the property owner at a fixed price with optional annual escalation, are financed through a loan, and must meet a minimum internal rate of return target. The financing parameters and constraints are defined on the Financing page. The electricity sales price is reported as the first year PPA price in the Metrics table on the Results page. Commercial projects may or may not benefit from tax credits or payment incentives.	• Photovoltaic • Parabolic trough • Dish-Stirling • Generic fossil
Utility and IPP	A large-scale power generation project financed through a loan that sells electricity to an electricity off-taker through a power purchase agreement at a fixed price with optional annual escalation. Utility projects must meet minimum debt service coverage ratio and internal rate of return targets. Utility projects may or may not benefit from tax credits or payment incentives.	• All options
No Financials	This option is for analyses of system performance that do not involve cost or financial modeling.	• All options, except power tower

5 Input Page Reference

Solar Advisor's input pages display input variables and options. The navigation menu on the main window provides access to the input pages. For an introduction to input pages, see Entering Inputs.

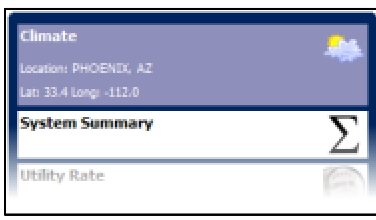
The following input pages are available in all Solar Advisor cases:

- Climate: Choose a weather file for the system's location.
- System Summary: Displays key characteristics of the system based on input variables on other pages.
- Financing: Define the project's debt structure and rate of return constraints as appropriate for the type of project.
- Tax Credit Incentives: Define incentives in the form of tax credits that apply to the project.
- Payment Incentives: Define incentives in the form of cash payments that apply to the project.
- Annual Performance: Define an annual degradation rate and availability factor to account for expected reductions in system output over time due to equipment aging or due to system down times.

The remaining input pages depend on the system's technology, and are described in the following sections:

- Photovoltaic Systems: Input pages for photovoltaic flat-plate and concentrating photovoltaic systems, and for systems modeled using the PVWatts array performance model.
- Parabolic Trough Systems: Input pages for CSP parabolic trough systems.
- Dish Stirling Systems: Input pages for CSP dish-Stirling systems.
- Power Tower Systems: Input pages for CSP power tower or central receiver systems.
- Generic Fossil Systems: Input pages for the simple fossil-fuel system model.

5.1 Climate



To view the Climate page, click **Climate** in the main window's navigation menu.

The Climate page allows you to choose the weather data file that Solar Advisor uses for all simulations in the current case. The Climate page displays a summary of the weather data, and also allows you to view all of the data in the hourly data viewer.

Contents

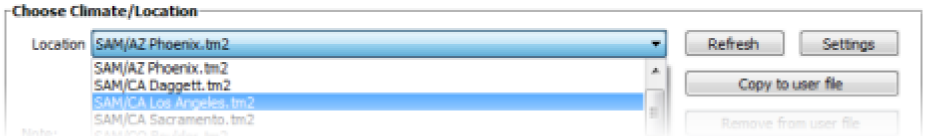
- Input Variable Reference describes the input variables on the Climate page.
- Managing Weather Files explains how to add weather files to the location list and how to include weather data in your project file.
- About Weather File Formats describes the TMY2 and EPW weather formats that Solar Advisor recognizes.
- Weather File Data Elements describes the weather data elements used by each

of the five technologies that Solar Advisor models.

- Downloading and Using EPW Weather Files explains how to download EPW files from the EnergyPlus website.

To choose a weather data file:

1. In the Location list, click the location name.



If the location you are modeling is not in the list, you can:

- Check to see whether data for your location is available in EPW format.
- If you have your own weather data file in either TMY2 or EPW format, add the file to the Location list.
- Purchase the Meteonorm database and software package, which contains climatological data for over 7,700 global weather stations and can convert the data into TMY2 format. Meteonorm can also import weather data in various formats and convert it to TMY2. The Metonorm website is http://www.meteonorm.com.

Input Variable Reference

Choose Climate/Location

Choose a location from the list of locations. If you plan to use a weather file that is not in the list and want to share your Solar Advisor project with another person who does not have a copy of the weather file, click **Copy to user file** to include the weather file in your project. (See below for more details on managing weather files.)

Variable	Description	Units
Location	The name of the weather file. A filename preceded by "SAM/" is a standard weather data file included with Solar Advisor and stored in the \exelib\climate_files folder. A filename preceded by "USER/" is a file stored with the SAM file.	--

Location Information

The location information variables display data from the weather file header that describes the location. An empty variable indicates that the information was not included in the header. The location information variables cannot be edited.

Variable	Description	Units
City	The name of the city.	--
State	The state abbreviation.	--

Timezone	The location's time zone, relative to Greenwich Mean Time (GMT). A negative number indicates the number of time zones west of GMT. A positive number indicates the number of time zones east of GMT.	--
Elevation	The location's elevation above sea level in meters.	m
Latitude	The location's latitude in degrees. A positive number indicates a location north of the equator.	degrees
Longitude	The location's longitude in degrees. A negative number indicates the number of degrees west of the Prime Meridian.	degrees

Weather Data Information (Annual Averages)

Solar Advisor calculates and displays the annual average of four of the hourly data columns from the weather file in the weather data information variables. Weather data information variables cannot be edited. You can view graphs and export data tables of the hourly data and statistical properties by clicking **View hourly data**.

Variable	Description	Units
Direct Normal	The annual average of the direct normal radiation data in the weather file, expressed in watt-hours per square meter.	Wh/m^2
Diffuse Horizontal	The annual average of the diffuse horizontal radiation data in the weather file, expressed in watt-hours per square meter. Note that the annual average global horizontal radiation is the sum of the direct normal and diffuse horizontal components.	Wh/m^2
Dry-bulb Temp	The annual average of the ambient temperature data in the weather file in degrees Celsius.	°C
Wind Speed	The location's elevation above sea level in meters.	m

Managing Weather Files

Solar Advisor comes with a collection of weather files that it displays in the Location list when you first install and run the software. You can add weather files to the list, as long as they are in one of the two formats that the software recognizes: TMY2 or EPW (see below for a description of the formats). The default location for the weather files is \exelib\climate_files, but Solar Advisor can read weather files stored in any location on your computer. When you add locations to the list, you are simply adding a search path that tells Solar Advisor where to look for the files, not making copies of the weather files.

To add weather files to the Location list:

1. On the Climate page, click **Settings**.
2. In the Library Settings window, click **Add**.
3. Navigate to the location on your computer where the weather file is stored.
   You can add as many file search paths as you wish.
4. Click **Close** to return to the Climate page.

Solar Advisor adds the search paths you added in the Location list.

To remove a search path from the list, click **Settings** to open the Library Settings window and then click **Remove**. Note that removing a search path does not delete any weather files.

When you want to share a Solar Advisor Model project with another person, and the project uses one or more weather files that the other person does not have, you can include a copy of the data from the weather files in the Solar Advisor Model file. Including weather data in a Solar Advisor Model file increases the size of the file, but also makes it more portable. For example, the size of the PV sample file with no weather files is 35 kB, with one weather file 274 kB, and with two weather files is 503 kB.

To copy data from a weather file to the project file:

1. On the Climate page, choose the weather file from the Location list.
2. Click **Copy to user file**.

   Solar Advisor adds the file to the location list with the "USER/" prefix, indicating that the data is included in the Solar Advisor project file. To remove a file from the list, select it, and click **Remove from user file**.

About Weather File Formats

Solar Advisor uses weather data files in two formats: Typical Meteorological Year format (TMY2) and EnergyPlus Weather format (EPW). Although Solar Advisor does not read files in the new TMY3 format, you can download them in EPW format from the EnergyPlus website. To learn more about the formats, visit the following websites:

- TMY2, http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/
- EPW, http://www.eere.energy.gov/buildings/energyplus/weatherdata_format_def.html
- TMY3, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

The TMY2 and TMY3 files are for U.S. locations only. You can download weather data for additional U.S. locations and locations in other countries in the EPW format as described below.

Solar Advisor weather files must meet the following criteria:

- A text file in TMY2 or EPW format.
- Filename extension tm2 or epw.

The data in TMY2, TMY3, and EPW files is typical year data, which is determined from long term measured data. Data for individual years (U.S. locations only) is available in the TMY2 file format from the following Beta test versions of NREL websites:

- Renewable Planning Model test website https://rpm.nrel.gov/rpmentry/
- Solar Prospector, http://mercator.nrel.gov/csp/

The time convention for Solar Advisor hourly simulations is determined by the convention used in the weather data. For example, TMY2 and TMY3 data both use local standard time, and the radiation data values represent energy received during the 60 minutes preceding the indicated hour. The global horizontal radiation shown for hour 1 represents the total radiation incident on a horizontal surface between midnight and 1:00 a.m. of the first hour of the year. Both data sets assume that there are 8,760 hours in one year and do not account for leap years.

Weather File Data Elements

Solar Advisor uses the data elements from the TMY2 file shown in the table below, depending on the technology being modeled. Note that the generic fossil model does not use data from the weather file.

Table 6. Weather data used for different technologies.

Data Element Name	Description	Units	PV Flat Plate	CPV	CSP Trough	CSP Dish	CSP Power Tower
Latitude	Degrees north or south of the equator of the project site.	degrees	x	x	x	x	x
Longitude	Site longitude.	degrees	x	x	x	x	x
Elevation	Height above sea level.	m	x				x
Local Standard Time	Day of year, month, hour of month, day of month, and hour of day. Used to calculate hour of year.	--	x	x	x	x	x
Direct Normal Radiation	Amount of solar radiation received in one hour within a limited field of view centered on the sun.	W/m^2	x	x	x	x	x
Diffuse Horizontal Radiation	Amount of solar radiation received in one hour from the sky, excluding the solar disk on a horizontal surface.	W/m^2	x				
Wind Velocity	Average velocity of the wind for the hour.	m/s	x		x	x	x
Dry Bulb Temperature	Average dry bulb temperature for the hour.	°C	x		x		x
Dew Point Temperature	Average dew point temperature for the hour.	°C			x		x

Data Element Name	Description	Units	PV Flat Plate	CPV	CSP Trough	CSP Dish	CSP Power Tower
Relative Humidity	Average relative humidity for the hour.	%			x		x
Snow Depth	Snow depth for the day.	cm	x				

Downloading and Using EPW Weather Files

You can download weather data in EPW format for locations around the world at no cost from the EnergyPlus weather data website at http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm.

<u>To use EPW weather data in Solar Advisor:</u>

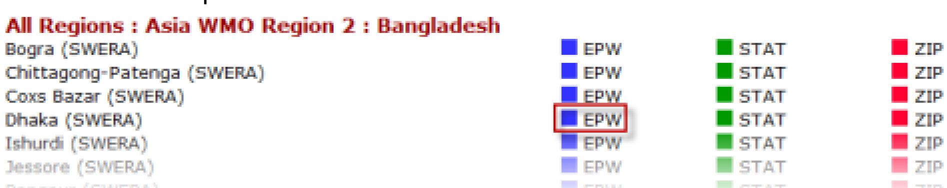
1. Go to the [EnergyPlus weather data website](http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm) and navigate to the region and location you want to model.
2. Download the EPW file for the location you are modeling.

   If there is not an EPW file for the location, download the ZIP file and extract the EPW file.
3. On Solar Advisor's Climate page, click **Settings**.
4. In the Library Settings window, click **Add** and navigate to the folder containing the EPW file to add the folder's path to the climate file search path list.

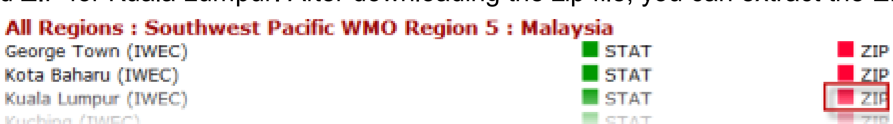
   You can remove the search path by selecting it and clicking **Remove**.
5. Click **Close** to return to the Climate page.

   The EPW file should now be visible in the Locations list.

For some regions, you can download an EPW file directly for a location. For example, for Bangladesh, you can download the data for Dhaka by right-clicking the blue square next to the word EPW for Dhaka. Be sure to save the file with the epw extension.



For other regions, you must first download a zip file containing the EPW file and then extract the EPW file. For example, for Malaysia, you can download the data for Kuala Lumpur by right-clicking the red square next to the word ZIP for Kuala Lumpur. After downloading the zip file, you can extract the EPW file.



5.2 System Summary

To view the System Summary page, click **System Summary** in the main window's navigation menu.

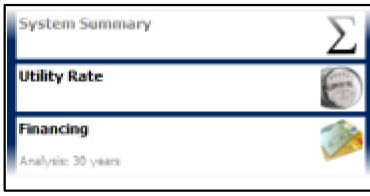
The System Summary page displays calculated variables that describe the system's capacity and capital costs. Solar Advisor displays the variables for reference so that you can quickly see some key properties of the system. The variables on the System Summary page are copies of variables from other input pages.

Solar Advisor displays the same set of summary variables for all of the technologies to facilitate quick comparisons of different cases using different technologies.

System Summary

Variable	Description	Units
System Nameplate Capacity	The system's rated or nominal capacity in kilowatts. For photovoltaic systems, the value is equivalent to the total array power calculated on the Array page. For concentrating solar power systems, the value is equivalent to the power block's rated capacity, which is an input on the Power Block, Power Cycle, or Stirling Engine page for trough, tower, or dish systems, respectively. The nameplate capacity is the value that Solar Advisor uses to calculate cost per kilowatt values displayed on the cost pages and used for economic modeling.	kW
Generic Heat Rate	The efficiency of a generic fossil system, or MMBTU of heat required to produce one MWh of electricity, an input on the Fossil Plant page. The generic heat rate is zero for photovoltaic and concentrating solar power systems.	MMBTUs/ MWh
Total Direct Cost	The total cost of installation equipment and services, calculated on the system cost page.	$
Total Installed Cost	The project's total capital cost, including direct and indirect costs, calculated on the system cost page.	$
Total Sales Tax	The sales tax paid on project installation costs, calculated on the system cost page.	$

5.3 Utility Rate



To view the Utilility Rate page, open a case with residential or commercial financing, and then click **Utility Rate** in the main window's navigation menu.

The utility rate page allows you to choose the rate structure for a distributed energy project

The utility rate is the price per kilowatt-hour available to distributed energy projects for electricity sold or purchased by the proejct. Solar Advisor displays electricity payments and revenue in the project cash flow, and accounts for them in the net present value reported in the Metrics table, but not in the levelized cost of energy (LCOE) calculations.

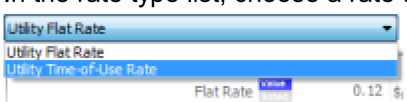
Note. The Utility Rate page is only available for distributed energy projects with residential or commercial financing. Those projects may both purchase electricity from and sell electricity to an electric service provider. Solar Advisor assumes that projects with utility financing sell all of the electricity they produce at a fixed or escalating rate negotiated through a power purchase agreement. For such projects, Solar Advisor calculates an electricity sales price as a result, and ensures that it covers project costs and meets financial constraints.

Contents

- Utility Flat Rate describes how to define the price of electricity for distributed energy projects that buy and sell electricity under a net metering agreement with the electric service provider.
- Entering the Flat Rate as an Annual Schedule describes how to manually assign a different electricity to each year in the analysis period.
- Utility Time-of-Use Rate describes how to define an electric rate schedule for projects that buy and sell electricity under a time-of-use pricing agreement with the electric service provider.

To choose the utility rate structure:

1. In the rate type list, choose a rate type.



Solar Advisor allows two options for modeling the utility rate: utility flat rate and utility time-of-use rate.

Utility Flat Rate

For the utility flat rate option, a single rate applies to every hour of the year. If you specify a non-zero escalation rate, Solar Advisor escalates the utility rate annually. The flat rate option assumes net-metering, where electricity is purchased and sold by the project at the same rate.

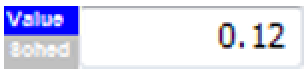
Variable	Description	Units
Flat Rate	The electricity price for sales and purchases of electricity under a net-metering agreement in dollars per kilowatt-hour.	$/kWh

Rate Escalation	The annual rate of increase of the electricity price above the inflation rate defined on the Financing page.	%/yr

Entering the Flat Rate as an Annual Schedule

In some cases, it may be useful to assign a different flat utility rate to each year in the analysis period. (The analysis period is defined on the Financing page.) For example, you could model a flat rate that increases every five years by assigning one value to years 1 through 5, a second one to years 6 through 10, and so on.

To enter the flat rate as an annual schedule:

1. Choose Utility Flat Rate for the rate type.
   The "Value" label is blue indicating that the single value mode is active for the variable.
   

2. Click the button with the "Sched" label to change the mode to schedule and activate the Edit button.
   

3. Click **Edit**.
4. In the Edit Schedule window, type values for each year in the analysis period. Use the horizontal scroll bar to move through the years.
   To delete a value, select it and press the Delete key on your keyboard.

Note. You must type a value for each year. If you delete a value, Solar Advisor will clear the cell, and you must type a number in the cell or Solar Advisor will consider the schedule to be invalid.

5. When you have finished editing the schedule, click **Accept**.

Utility Time-of-use

The utility time-of-use (TOU) option allows you to apply a TOU schedule in order to define electricity prices that vary with the time of day and month. Solar Advisor stores time-of-use schedules in a library, so you can either choose a schedule from the library, or create your own schedule.

Each TOU schedule can have up to nine periods, each with a different electricity price and annual escalation rate.

Variable	Description	Units
Period (1-9)	The period number and color corresponds to the number and color in the schedule matrix.	--
Name	The name of the time-of-use period. The name is a description of the period to help you identify the different periods. Solar Advisor does not use the name.	--
Rate	The electricity price in dollars per kilowatt for the time-of-use period.	$/kWh
Esc	The annual escalation rate that applies to the electricity price for the time-of-use period.	%/yr

Weekday Schedule	The time-of-day and month-of-year matrix that assigns the time-of-use periods to a given schedule that applies to the five working days of the week: Monday through Friday. Solar Advisor assumes that the year begins on Monday, January 1, in the hour ending at 1:00 a.m.	
Weekend Schedule	The time-of-day and month-of-year matrix that assigns the time-of-use periods to a given schedule that applies to the two weekend days of the week: Saturday and Sunday. Solar Advisor assumes that the year begins on Monday, January 1, in the hour ending at 1:00 a.m.	

To choose a schedule from the library

1. In the Schedule Library list, click a schedule name.

   Schedules with "SAM/" in the name are predefined schedules that you cannot modify. Schedules with "USER/" in the name are schedules that you can modify in the library manager. See Working with Libraries for details.
2. Click **Apply Schedule**.

   Solar Advisor displays the time-of-use schedule in the weekday and weekend schedule matrices, using colors and numbers that correspond to those in the list of Periods 1 through 9 in the time-of-use periods list.

You can modify values and times for the schedule. See the instructions for creating your own schedule below for details.

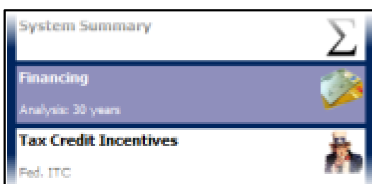
To create your own schedule

1. In the Schedule Library list, click a schedule name for a schedule similar to the one you want to create, if applicable.
2. In the time-of-use periods list, type a name, rate, and escalation rate for up to nine periods in the time-of-use schedule.

   See the descriptions in the table above for details about the variables.
3. In the weekday schedule matrix, use your mouse to select the blocks to which Period 1 applies, and type a '1' to populate the blocks.

   The block color changes to match the Period 1 color and the number 1 appears in the block.
4. Select the squares for the next period, type the period's number, and repeat until the schedule is complete.
5. Repeat Steps 3 and 4 in the weekend schedule matrix to define the weekend schedule.

5.4 Financing



To view the Financing page, click **Financing** in the main window's navigation menu.

The Financing page displays the variables that Solar Advisor uses to calculate the project cash flow and other related financial metrics that appear on the Results page. The variables that appear on the Financing page depend on the financing option specified in the Technology and Market window.

Note. If the Financing button does not appear in the main window's navigation menu, check that the No Financials option is not the active option on the Technology and Market window. The Financials page is available only for projects with an active financing option.

For more details on financing options, please refer to the list of publications under Project Economics and Financing in the References section. You can also download an Excel workbook for each financing type that includes formulas emulating Solar Advisor's financial calculations. The workbooks are available on the Solar Advisor website's support page, https://www.nrel.gov/analysis/sam/support.html.

Contents

Financing Options

The six financing options specified on the Technology and Market window represent the financing options typically available to projects in the residential, commercial and utility markets for renewable energy projects.

Solar Advisor assumes that residential and commercial projects are on the customer's side of an electric utility's meter, and that the electricity they produce offsets electricity purchased from the utility to meet the customer's electric load. Residential and commercial projects can buy and sell electricity at a flat rate (with or without annual escalation) or at rates determined by a time-of-use pricing schedule. For these projects, the electricity price is an input defined on the Utility Rate page.

Utility projects are revenue generating projects that sell electricity at a rate determined through a power purchase agreement. Utility projects sell electricity at a fixed rate with our without annual escalation. For utility projects, the electricity price is a result.

Table 7. Financing options for different project types. The financing options are also discussed in the Technology and Market topic.

Financing Option	Description
Residential Cash	The owner pays cash in the amount of the total installed cost in year zero of the project cash flow.
Residential Loan	The owner pays cash for the equity portion of the total installed cost in year zero of the cash flow, and makes an interest and principal payments in subsequent years.
Commercial Cash	The owner pays cash in the amount of the total installed cost in year zero of the project cash flow.
Commercial Loan	The owner pays cash for the equity portion of the total installed cost in year zero of the cash flow, and makes an interest and principal payment in subsequent years.
Commercial Third Party	The commercial project is owned by a third party that earns revenues through electricity sales at a fixed or escalating annual rate determined through a power purchase agreement to cover project costs. The owner pays cash for the equity portion of the total installed cost in year zero of the cash flow, and makes an interest and principal payment in subsequent years. Solar Advisor calculates a first year power purchase price that meets internal rate of return, minimum debt service coverage ratio and positive cash flow requirements.
Utility IPP	The project earns revenues through electricity sales at a fixed or escalating annual rate determined through a power purchase agreement to cover project costs. The owner pays cash for the equity portion of the total installed cost in year zero of the cash flow, and makes an interest and principal payment in subsequent years. Solar Advisor calculates a first year power purchase price that meets internal rate of return, minimum debt service coverage ratio and positive cash flow requirements.

The variable groups that appear on the Financing page depend on the financing option displayed in the Technology and Market window. For example, residential loan financing does not include the Depreciation group of variables, which is only available for the commercial and utility financing types. The variable groups are described in the input reference below.

Table 8. Financing variable groups for each type of financing. Variable groups are described in the input variable reference below.

Financing Option	Available Variable Groups
Residential Cash	General Taxes and Insurance
Residential Loan	General Taxes and Insurance Loan Type Residential Loan Parameters Weighted Average Cost of Capital
Commercial Cash	General Taxes and Insurance Federal Depreciation State Depreciation
Commercial Loan	General Taxes and Insurance Commercial Loan Parameters Federal Depreciation State Depreciation
Commercial Third Party	General Taxes and Insurance Third Party Ownership Financing Power Purchase Agreement Constraining Assumption Financial Optimization Federal Depreciation State Depreciation
Utility IPP	General Taxes and Insurance Utility IPP Financing Parameters Power Purchase Agreement Constraining Assumption Financial Optimization Federal Depreciation State Depreciation

Note. To model a utility project with cash financing when sufficient cash is available to fund the project with no debt, use the Commercial Cash financing option. Financing constraints do not apply to projects with cash financing.

Input Variable Reference

The groups of variables that appear on the Financing page depend on the financing option defined on the Technology and Market window.

General (applies to all financing options)

Variable Name	Description
Analysis Period	Number of years covered by the analysis. Typically equivalent to the project or investment life.
Inflation Rate	Annual rate of change of prices, typically based on a price index. Solar Advisor uses the inflation rate to calculate costs in the cash flows for years after year one.
Real Discount Rate	A measure of the time value of money expressed as an annual rate. Solar Advisor uses the real discount rate to calculate the present value (value in year one) of cash flows over the analysis period and to calculate annualized costs.

Taxes and Insurance (applies to all financing options)

Tax and insurance values are expressed as a percentage of the total installed costs shown on the system costs page. The Federal, state and property tax percentages apply applied in each year of the cash flow, and the sales tax and insurance is applied to year one of the cash flow.

Variable Name	Description
Federal Tax, State Tax	Federal and state income tax rate. Applies to annual income from incentives for all projects, and to revenues from electricity sales for utility projects.
Property Tax	Annual tax paid on project property, expressed as a percentage of total installed costs. Solar Advisor treats property tax as a tax-deductible operating expense for each year. In each year, the property tax expense is the property tax rate multiplied by the annualized installation cost.
Sales Tax	A one-time tax paid in year one on equipment purchases during installation, expressed as a percentage of the taxable portion of installed costs. Solar Advisor treats sales tax as a deductible expense. The taxable portion of installed costs is defined on the Costs page.
Insurance	An annual operating expense expressed as a percentage of total installed costs.

Loan Parameters (applies to all financing options except residential cash and commercial cash)

Variable Name	Description
Principal Amount	The amount of money borrowed to cover installation expenses. Solar Advisor calculates the loan amount based on the Loan (Debt) Fraction and the Total Installed Costs on the system costs page. See below for a description of the calculation.
Loan (Debt) Fraction, or Debt Fraction	Percentage of the total installed cost to be be borrowed. For projects with IPP Utility or Commercial Third Party Financing, when the financial optimization option is checked, the debt fraction is a result instead of an input variable.

Variable Name	Description
Loan Term	Number of years required to repay a loan. Can be more or less than the analysis period.
Loan Rate	Annual loan interest rate.
WACC	The weighted average cost of capital (WACC) is defined as the minimum return that the project must earn to cover financing costs. See below for a description of the calculation.

Loan Type (applies to residential loan or mortgage projects only)

Option Name	Description
Standard Loan	Loan interest payments are not tax deductible.
Mortgage	Loan interest payments are tax deductible.

Federal Depreciation and **State Depreciation** (applies to commercial and utility IPP projects only)

Variable Name	Description
No Depreciation	The project does not claim a depreciation tax deduction.
MACRS Mid-Quarter Convention	Modified Accelerated Cost Recovery System depreciation schedule offered by the Federal government and some states. This tax deduction, expressed as a percentage of the total installed cost, applies to the first years of the project life as follows: 35%, 26%, 15.6%, 11.01%, 11.01%, and 1.38%.
MACRS Half-Year Convention	Modified Accelerated Cost Recovery System depreciation schedule offered by the Federal government and some states. This tax deduction, expressed as a percentage of the total installed cost, applies to the first years of the project life as follows: 20%, 32%, 19.2%, 11.52%, 11.52%, and 5.76%.
Straight Line (specify years)	A depreciation schedule offered by the Federal government and some states. This tax deduction is 20% of the of total installed cost and applies to the number of years you specify, starting with year one of the project life.
Custom (specify percentages)	Allows you to assign a depreciation deduction as a percentage of the total installed cost for each year in the project life. Click Edit to assign the values, and see Editing Annual Schedules for details on entering the values.

Power Purchase Agreement (applies to utility IPP and commercial third party projects only)

Variable Name	Description
PPA Escalation Rate	An escalation rate applied (above inflation) to the first year PPA price to calculate the electricity sales price in years two and later in the project cash flow. When the financial optimization option is checked, the PPA escalation rate is a result instead of an input variable.

Constraining Assumptions (applies to utility IPP and commercial third party projects only)

The constraining assumptions only apply to systems with IPP and Utility financing. Solar Advisor calculates the actual IRR, actual minimum DSCR, first year PPA price and LCOE that meets the constraints and reports them in the Metrics table on the Results page.

Variable Name	Description
Minimum Required IRR	The lowest value of the internal rate of returned required for the project to be financially feasible. The internal rate of return is the discount rate that results in a project net present value of zero.
Require a minimum DSCR	A requirement that the debt-service coverage ratio not be allowed to fall below the specified level.
Minimum Required DSCR	The lowest value of the DSCR required for the project to be financially feasible. The DSCR is the ratio of operating income to expenses in a given year.
Require Positive Cashflow	A requirement that the annual project cash flow be positive throughout the project life.

Financial Optimization (applies to utility IPP and commercial third party projects only)

Option Name	Description
Automatically minimize LCOE with respect to Debt Fraction	Instead of entering a value for the debt fraction, allow Solar Advisor to find the debt fraction value that results in the lowest levelized cost of energy.
Automatically minimize LCOE with respect to PPA Escalation Rate	Instead of entering a value for the PPA Escalation Rate, allow Solar Advisor to find the debt fraction value that results in the lowest levelized cost of energy.

Calculated Values

Solar Advisor calculates two values displayed for reference on the Financials page. The calculated variables appear on the page in blue type with a blue background.

Principal Amount

The loan's principal amount is calculated as follows:

$$A_{\text{LoanAmount}} = C_{\text{TotalInstalled}} \cdot F_{\text{DebtFraction}}$$

Where,

$A_{LoanAmount}$ (\$) Principal Amount

$C_{TotalInstalled}$ ($)	Total Installed Costs (on the system costs page)
$F_{DebtFraction}$	Loan (Debt) Fraction, or Debt Fraction

WACC

The Weighted Average Cost of Capital (WACC) is defined as the minimum return that the project must earn to cover financing costs.

$$\text{WACC} = F_{\text{ReturnOnEquity}} \cdot (1 - F_{\text{DebtFraction}}) + (1 - F_{\text{EffectiveTaxRate}}) \cdot F_{\text{LoanRate}} \cdot F_{\text{DebtFraction}}$$

The effective tax rate is a single number that includes both the federal income tax rate and state income tax rate. Solar Advisor uses the effective tax rate for several calculations requiring a total income tax value.

The effective tax rate calculation is:

$$F_{\text{EffectiveTaxRate}} = F_{\text{FederalTaxRate}} \cdot (1 - F_{\text{StateTaxRate}}) + F_{\text{StateTaxRate}}$$

The federal and state tax rates are input variables on the Financing page.

For residential and commercial projects, the return on equity is equal to the discount rate, which is an input on the Financials page:

$$F_{\text{ReturnOnEquity}} = F_{\text{DiscountRate}}$$

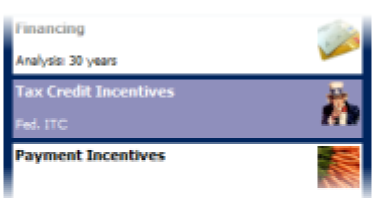
For utility and commercial third party projects, the return on equity is the required internal rate of return, also an input on the Financials page:

$$F_{\text{ReturnOnEquity}} = F_{\text{RequiredIRR}}$$

Where,

$F_{FederalTaxRate}$	Federal Tax
$F_{StateTaxRate}$	State Tax
$F_{DebtFraction}$	Loan (Debt) Fraction, or Debt Fraction
$F_{LoanRate}$	Loan Rate
$F_{DiscountRate}$	Real Discount Rate
$F_{RequiredIRR}$	Required Internal Rate of Return (IRR)

5.5 Tax Credit Incentives



To view the Tax Credit Incentives page, click **Tax Credit Incentives** in the main windows navigation menu.

The Tax Credit Incentives page allows you to define the parameters of investment tax credits (ITC) or production tax credits (PTC) provided by either the federal government, a state government, or both. For each tax credit that you define, you can specify whether the tax credit amounts are taxable, and how the tax credits affect the depreciation basis.

A tax credit is an amount that is deducted from the project's income tax. Solar Advisor displays tax credits and income tax payments in the project cash flow and in graphs and tables.

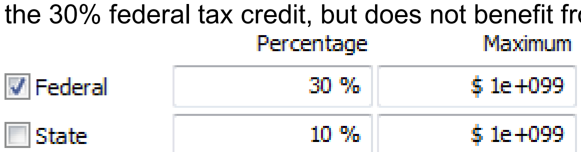
For a description of tax credits and incentives available to solar and other renewable energy projects in the United States, see the Database of State Incentives for Renewables and Efficiency at http://www.dsireusa.org.

Contents

To define a project's tax credits:

1. For each tax credit that applies to the project, check the federal and state options that apply.
2. For each checked tax credit, enter values for parameters describing the tax credit, including the amount, term, limits, and escalation rate as applicable.

   Solar Advisor only applies tax credits that are checked, regardless of the values assigned to each tax credit. For example, the image below shows tax credit options for a project that benefits from the 30% federal tax credit, but does not benefit from the 10% state tax credit.

3. Check the tax implication options that apply to each tax credit. If you are unsure of a credit's tax implication, use the default options from an appropriate project template.

Note. The tax credit variables and options are designed to be as flexible as possible to accommodate the wide variety of existing credit programs available to renewable energy projects in the U.S. and worldwide, and to allow for modeling of theoretical tax credit structures. It is possible to define combinations of tax credits and options that may be unrealistic, such as making a federal tax credit payment subject to federal income tax.

Input Variable Reference

Investment Tax Credit (ITC)

An investment tax credit reduces the project's annual tax liability in year one of the project cash flow. Solar Advisor allows the ITC to be expressed either as a fixed amount or as a percentage of the project's total installed cost with a maximum limit.

For each ITC that applies to the project, check an option and enter values to specify the credit amount and limit. If you specify a federal or state tax credit as both a fixed amount and a percentage of the total installed cost, Solar Advisor includes both amounts in the total tax credit amount.

Variable	Description	Units
Amount	The fixed dollar amount of the tax credit.	$

Percentage	The amount of the tax credit expressed as a percentage of the total installed cost displayed on the system costs page.	%
Maximum	The upper limit of the tax credit in dollars. For tax credits with no limits, type the value 1e+099.	$

Production Tax Credit

A production tax credit reduces the project's annual tax liability in year one of the cash flow and subsequent years up to and including the year specified in the term variable. The PTC is a dollar amount per kilowatt-hour of annual electric output. If you specify an escalation rate, Solar Advisor increases the annual tax credit amount in years 2 and later in the cash flow by a percentage of the previous year's payment.

Check an option for each production tax credit that applies to the project, and enter values to specify the credit amount, term, and annual escalation rate.

Variable	Description	Units
Amount	The amount of the production tax credit as a function of the system's total electrical output in the first year expressed in dollars per kilowatt-hour of AC output.	$/kWh
Term	The number of years, beginning with year 1 on the project cash flow, that the tax credit applies. For example, a credit with a 10-year term would apply to years 1 through 10 of the project cash flow.	years
Escalation	The annual escalation rate that applies to the tax credit. Solar Advisor applies the escalation rate to years 2 and later in the cash flow. For example, for a tax credit with a ten year term and two percent escalation rate, the tax credit in year 2 would be 2% greater than in year 1, and in year 3, 2% greater than in year 2, and so on.	%/year

Tax Implications

The tax implication options determine how Solar Advisor treats the income from tax credits. You can choose to make the payments taxable, reduce the basis used to calculate the investment tax credit, or reduce the basis used to calculate depreciation.

Check one or more options for each tax credit.

Option	Description
Taxable Incentive	Determines whether the tax credit is subject to federal or state income tax.

Reduces ITC Basis	Applies only to projects that benefit from an investment tax credit. Check an option if the basis used to calculate the investment tax credit from the federal or state government should be reduced by the amount of the tax credit payment.
Reduces Depreciation Basis	Applies only to commercial and utility projects with one of the depreciation options active on the Financing page. Check an option if the basis used to calculate federal depreciation, state depreciation, or both should be reduced by the tax credit payment amount.

Tax Credit Calculations

Solar Advisor provides three options for entering the tax credit amounts: As a fixed amount, percentage of the total installed cost shown on the system costs page for investment tax credits, or as a cost per unit of the system's electricity output calculated by the performance model for production tax credits.

The table below shows how Solar Advisor calculates the tax credit amount for each option, and the cash flow year to which the tax credit applies.

Table 9. Summary of tax credits.

tax Credit Name	Type	Tax Credit Calculation	Applies in year
Investment tax credit, ITC	Amount	Amount ($)	1
	Percentage	Total Installed Cost ($) × Percentage (%) Up to Maximum value	1
Production tax credit, PTC	Amount	Amount ($/kWh) × Annual Output in Year n (kWh) × [1 + Escalation (%)] ^ Year n	All, or Year 1 thru term

Impact of Tax Credit on Taxes

Tax credits may or may not be taxable by either the federal or state government. Solar Advisor allows you to control which tax credits, if any, are taxable.

Taxable Incentive: When you check a "Taxable Incentive" option for a tax credit, Solar Advisor applies a tax at either the the federal or state tax rate to each annual tax credit payment. Solar Advisor multiplies the applicable tax rate by the tax credit amount and adds it to the income tax amount the applicable years of the project cash flow. The state and federal tax rates are inputs on the Financing page.

Reduces ITC Basis: This option applies only to projects with one or more checked ITC options. When you check a "Reduces ITC Basis" option for a tax credit, Solar Advisor subtracts the amount of the tax credit payment from the total installed cost shown on the system costs page before calculating the ITC amount. The total installed costs is shown on the system costs page.

Reduces Depreciation Basis: This option applies only to projects with commercial or utility financing with one or more depreciation option selected on the financials page. When you check a "Reduces Depreciation Basis" option for a tax credit, Solar Advisor subtracts 50 percent of the tax credit amount from the depreciation basis in each applicable year of the project life.

Viewing Tax Credits in Results

The options you select on the Tax Credit Incentives page affect the financial metrics displayed in the results, including the levelized cost of energy, net present value, and payback.

You can see the tax credit amounts and their impact on income tax and depreciation in graphs and in the project cash flow.

<u>To display tax credit amounts in a graph:</u>

1. After running simulations, click the Graph button.
2. On the Graphing tab, click **Add**.
3. Choose the simulation for which you want to see tax credit amounts.
4. For **X Value**, choose **Single Value**.
5. For **Y1 Values**, check the name of each tax credit you want to display in the graph.
6. Clear the LCOE check boxes.

   Solar Advisor displays the graph as you choose graphing options. You can adjust the properties of the graph as needed.
7. Click **Accept** to return to return to the main window.

<u>To display tax credit amounts in the project cash flow:</u>

1. After running simulations, click the Graph button.
2. Click **Base Case Pro-Forma** to display the cash flow in a table.
3. Either drag the graph area border up or scroll down until the tax credits are visible in the table.

   You can also export the base case cash flow to a csv file or to Excel by clicking the Export button.

5.6 Payment Incentives

To view the Payment Incentives page, click **Payment Incentives** in the main windows navigation menu.

The Payment Incentives page allows you to define the parameters of investment based incentives (IBI), capacity based incentives (CBI), or production based incentives (PBI) provided by either the federal or state government, an electric utility, or other institution.

An incentive payment is an amount paid to the project that contribute's to the projects annual income in one or more years of the cash flow. Solar Advisor displays payment incentives in the project cash flow and in graphs.

For each payment incentive that you define, you can specify whether the incentive payments are taxable, and how the payments affect the depreciation basis.

For a description of incentives available to solar and other renewable energy projects in the United States, see the Database of State Incentives for Renewables and Efficiency at http://www.dsireusa.org.

Contents

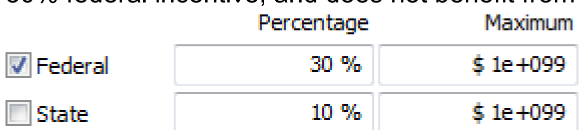
- Input Variable Reference describes the input variables on the Tax Credit Incentives page.
- Tax Credit Incentives Calculations describes how Solar Advisor uses the input variables to calculate the incentive amounts based on the input variables.
- Impact of Tax Credits on Income Tax describes the "Taxable Incentive," "Reduces ITC Basis," and "Reduces Depreciation Basis" options.

➢ Viewing Tax Credit Incentives in Results explains where to find results that show the effect of tax credits on the project metrics and cash flow.

To define a project's payment incentives:

1. For each incentive that applies to the project, check the federal, state, utility, or other option that applies.
2. For each checked incentive, enter values for parameters describing the incentive, including the amount, term, limits, and escalation rate as applicable.

   Solar Advisor only applies incentives that are checked, regardless of the values assigned to each incentive. For example, the image below shows incentive options for a project that benefits from a 30% federal incentive, and does not benefit from the 10% state incentive.

3. Check the tax implication options that apply to each incentive. If you are unsure of an incentive's tax implication, use you can the default options from an appropriate project template.

Note. The payment incentives variables and options are designed to be as flexible as possible to accommodate the wide variety of existing incentive programs available to renewable energy projects in the U.S. and worldwide, and to allow for modeling of theoretical incentive structures. It is possible to define combinations of incentives and options that may be unrealistic, such as making a federal payment incentive subject to federal income tax.

Input Variable Reference

Investment Based Incentive (IBI)

An investment-based incentive reduces the project's annual expenditures in year one of the project cash flow. Solar Advisor allows the IBI to be expressed either as a fixed amount or as a percentage of the project's total installed cost with a maximum limit.

For each IBI that applies to the project, check an option and enter values to specify the credit amount and limit. Note that if you specify two incentives from the same source (federal, state, utility, other) as both a fixed amount and a percentage of the total installed cost, Solar Advisor includes both amounts in the total incentive amount.

Variable	Description	Units
Amount	The fixed dollar amount of the incentive.	$
Percentage	The amount of the investment tax credit expressed as a percentage of the total installed cost displayed on the system costs page.	%
Maximum	The upper limit of the incentive in dollars. For incentives with no limits, type the value 1e+099.	$

Capacity Based Incentive (CBI)

A capacity-based incentive reduces the project's annual expenditures in year one of the project cash flow. Solar Advisor allows the CBI to be expressed as a function of the system's rated capacity in watts. The system's rated capacity depends on the technology:

- Photovoltaic systems: DC watts of array capacity.
- Concentrating solar power systems: AC watts of power block nameplate capacity.
- Generic fossil: AC watts of power block nameplate capacity.

Check an option for each capacity based incentive that applies to the project, and enter values to specify the credit amount, percentage, term, and annual escalation rate as applicable.

Variable	Description	Units
Amount	The amount of the incentive as a function of the system's nameplate electric capacity expressed in dollars per watt.	$/W
Maximum	The upper limit of the incentive in dollars. For incentives with no limits, type the value 1e+099.	$

Production Based Incentive (PBI)

A production-based incentive reduces the project's annual tax liability in year one of the cash flow and subsequent years up to and including the year specified in the term variable. The PBI is a dollar amount per kilowatt-hour of annual electric output. If you specify an escalation rate, Solar Advisor increases the annual incentive payment amount in years two and later in the cash flow by a percentage of the previous year's payment.

Check an option for each production based incentive that applies to the project, and enter values to specify the credit amount, term, and annual escalation rate.

Variable	Description	Units
Amount	The amount of the incentive as a function of the system's total electrical output in the first year expressed in dollars per kilowatt-hour of AC output.	$/kWh
Term	The number of years, beginning with year one of the project cash flow, that the incentive applies. For example, an incentive with a 10-year term would apply to years one through 10 of the project cash flow.	years
Escalation	The annual escalation rate that applies to the incentive. Solar Advisor applies the escalation rate to years two and later in the cash flow. For example, for an incentive with a ten year term and two percent escalation rate, the incentive in year two would be two percent greater than in year one, and in year three, two percent greater than in year two, and so on.	%/year

Tax Implications

The tax implication options determine how Solar Advisor treats the income from tax incentive payments. You can choose to make the payments taxable, reduce the basis used to calculate the investment tax credit, or reduce the basis used to calculate depreciation.

Check one or more options for each incentive.

Option	Description
Taxable Incentive	Determines whether the incentive payment is subject to federal or state income tax.
Reduces ITC Basis	Applies only to projects that benefit from an investment tax credit. Check an option if the basis used to calculate the investment tax credit from the federal or state government should be reduced by the amount of the incentive payment.
Reduces Depreciation Basis	Applies only to commercial and utility projects with one of the depreciation options active on the Financing page. Check an option if the basis used to calculate federal depreciation, state depreciation, or both should be reduced by the incentive payment amount.

Incentive Calculations

Solar Advisor provides three options for entering the incentive amounts: As a fixed amount, percentage of the total installed cost shown on the system costs page for investment-based incentives, cost per unit of installed capacity for capacity-based incentives, or as a cost per unit of the system's electricity output calculated by the performance model for production-based incentives.

The table below shows how Solar Advisor calculates the incentive amount for each option, and the cash flow year to which the incentive applies.

Table 10. Summary of incentive calculations.

Incentive Name	Type	Incentive Calculation	Applies in year
Investment-based incentive, IBI	Amount	Amount ($)	1
	Percentage	Total Installed Cost ($) × Percentage (%) Up to maximum value	1
Capacity-based incentive, CBI	Amount	System Rated Capacity (W) × Amount Up to maximum value	1
Production-based incentive (PBI)	Amount	Amount ($/kWh) × Annual Output in Year n (kWh) × [1 + Escalation (%)] ^ Year n	All, or Year 1 thru term

Note. The CBI is calculated based on the array's rated capacity in DC watts for phovoltaic systems, and on the power block's rated capacity in AC watts for concentrating solar power and generic fossil systems.

The PBI is calculated based on the system's annual output in AC kilowatt-hours.

Viewing Incentives in Results

The options you select on the Payment Incentives page affect the financial metrics displayed in the results, including the levelized cost of energy, net present value, and payback.

You can see the incentive amounts and their impact on income tax and depreciation in graphs and in the project cash flow.

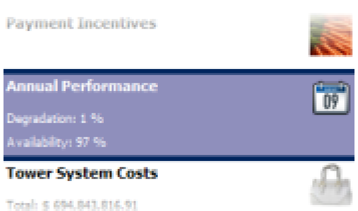
To display incentive amounts in a graph:

1. After running simulations, click the Graph button.
2. On the Graphing tab, click **Add**.
3. Choose the simulation for which you want to see investment amounts.
4. For **X Value**, choose **Single Value**.
5. For **Y1 Values**, check the name of each incentive you want to display in the graph.
6. Clear the LCOE check boxes.
   Solar Advisor displays the graph as you choose graphing options. You can adjust the properties of the graph as needed.
7. Click **Accept** to return to return to the main window.

To display incentive amounts in the project cash flow:

1. After running simulations, click the Graph button.
2. Click **Base Case Pro-Forma** to display the cash flow in a table.
3. Either drag the graph area border up or scroll down until the incentive payments are visible in the table.
   You can also export the base case cash flow to a csv file or to Excel by clicking the Export button.

5.7 Annual Performance



To view the Annual Performance page, click **Annual Performance** in the main windows navigation menu.

The Annual Performance page displays input variables that impact the system's total annual electric output.

Solar Advisor applies the annual performance factors to the total annual electric output calculated by the hourly simulation model.

The annual performance factors can be entered either as a single value, or as a series of values that apply to each year in the project life. See Editing Annual Schedules for details.

Annual System Performance

Variable	Description	Units
System Degradation	The system degradation rate can be used to account for annual reduction in electrical output due to aging system components. Solar Advisor applies the degradation rate to the electric output in year 2 and later. The default value of 1 % results in full output in year 1, 99% of the year 1 output in year 2, 99% of the year 2 output in year 3, and so on.	%

Availability	The availability factor accounts for downtimes due to forced and scheduled outages. Solar Advisor multiplies each hour's calculated electrical output by the system availability factor. The default value of 100 % results in no reduction in output.	%

5.8 Photovoltaic Systems

Solar advisor models grid-connected photovoltaic systems that consist of a photovoltaic array and inverter. The array can be made up of flat-plate or concentrating photovoltaic (CPV) modules with one-axis, two-axis, or no tracking.

The current version of Solar Advisor includes two options for modeling photovoltaic systems that you specify in the Technology and Market window: SAM Performance Models and PVWatts Performance Model.

For an example of photvoltaic systems, open the sample template *Sample PV Systems*: On the File menu, click **Open Sample Template** and select the template from the list. The template contains four cases demonstrating the model's use for projects based on residential, commercial, and utility financing assumptions, and using PVWatts and concentrating photovoltaic models.

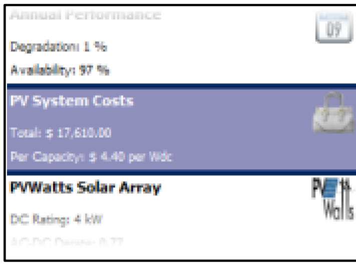
The SAM Performance Models option allows you to choose between the Sandia, CEC, and single-point efficiency models for photovoltaic modules, and between the Sandia and single-point efficiency models for inverters. The photovoltaic system input pages for this option described in this section are:

- PV System Costs: Define installation and other capital costs, and operation and maintenance costs.
- Array: Define the system's total capacity, number of inverters, array orientation, derating factors, and radiation model options.
- PV Array Shading: Assign shading factors to hours of the day for each month.
- Module: Choose the performance model and define characteristics of a single module.
- Inverter: Choose the performance model and define characteristics of a single inverter.

The PVWatts Performance Model option allows you to Solar Advisor's implementation of NREL's web-based PVWatts model. This implementation includes a preliminary test versions of models for loads and battery storage designed for investigations the potential benefits of including storage in a grid-connected project that benefits from time-of-use electricity pricing. (The storage and battery models are not available with the SAM Performance Models option.) The system input pages for the PVWatts option described in this section are:

- PV System Costs: Define installation and other capital costs, and operation and maintenance costs.
- PVWatts Solar Array: Enter parameter values for the PVWatts model.
- PV Loads: Import a text file of 8,760 hourly load values. (Preliminary model for testing.)
- PV Storage: Define a battery storage system. (Preliminary model for testing.)

5.8.1 PV System Costs



To view the PV System Costs page, select a photovoltaic technology, and click **PV System Costs** on the main window's navigation menu. Note that for the Array page to be available, the technology option in the Technology and Market window must be Photovoltaics - SAM Performance Models or Photovoltaics - PVWatts Performance Model.

Solar Advisor uses the variables on the PV System Costs page to calculate the project investment cost and annual operating costs reported in the project cash flow and used to calculate cost metrics.

Variable values in boxes with white backgrounds are values that you can edit. Boxes with blue backgrounds contain calculated values or values from other pages that Solar Advisor displays for your information.

The PV System Costs page is divided into four main categories. The first two, Direct Capital Costs and Indirect Capital Costs, are summed in the third category, Total Installed Costs. Because only the Total Installed Cost value affects the cash flow calculations, you can assign capital costs to the different cost categories in whatever way makes sense for your analysis. For example, you could assign the cost of designing the array to the module cost category or to the engineer-procure-construct category with equivalent results. The categories are provided to help you keep track of the different costs, but do not affect the economic calculations. After assigning costs to the categories, verify that the total installed costs value is what you expect. The fourth category of costs covers Operation and Maintenance.

Note: The cost values in the sample files are intended to illustrate Solar Advisor's use. The cost data are meant to be realistic, but not to represent actual costs for a specific project. Actual costs will, of course, vary. Because of price volatility in solar markets, the cost data in the sample files is likely to be out of date. For more information see the Solar Advisor Model website, https://www.nrel.gov/analysis/sam/cost_data.html.

Contents

- Input Variable Reference describes the input variables on the PV System Costs page.
- Entering Periodic Costs explains how to use annual schedules to assign operation and maintenance costs to particular years in the project cash flow.

Input Variable Reference

Direct Capital Costs

A direct capital cost represents an expense for a specific piece of equipment or installation service that applies in year zero of the cash flow.

Note: Because Solar Advisor uses only the Total Installed Cost value in cash flow calculations, how you distribute costs among the different direct capital cost categories does not affect the final results.

Variable	Description	Units
Module	For the SAM Performance model options, the cost is expressed per unit or per DC Watt. The total module cost is calculated as either: • Dollars per watt multiplied by Total Array Power on the Array page, or • Dollars per unit multiplied by Total Modules on the Array page. For the PVWatts Performance Model, the cost is expressed per unit or per DC Watt. the total module cost is calculated as either: • Dollars per watt multiplied by DC Rating on the PVWatts Solar Array page, or • Dollars per unit multiplied, where the number of modules is assumed to be one.	$/Wdc or $/Unit
Inverter	For the SAM Performance Model options, the cost of inverters in the system expressed in dollars per AC Watt or dollars per inverter. The total inverter cost is either: • Dollars per watt multiplied by Total Inverter Capacity on the Array page, or • Dollars per unit multiplied by Number of Inverters on the Array page. For the PVWatts Performance Model, the cost of an inverter in the system in dollars per watt or dollars per inverter. The total cost is calculated as either: • Dollars per watt multiplied by DC Rating on the PVWatts Solar Array page, or • Dollars per unit where the number of inverters is assumed to be one.	$/Wac or $/Unit
Battery	The cost of batteries in the system, expressed as the sum of a fixed cost and cost per kilowatt-hour of storage capacity. The total storage capacity is equal to Total Battery Capacity on the PV Storage page.	$ and $/kWh
Balance of System, Fixed	A fixed cost that can be used to account for costs not included in the module, inverter and battery cost categories, for example, the mounting racks, junction boxes, and wiring.	$
Installation, Fixed	A fixed cost that can be used to account for labor or other costs not included in the other cost categories.	$
Contingency	A percentage of the sum of the module, inverter, battery, balance of system, and installation costs to account for expected uncertainties in direct cost estimates.	%
Total Direct Cost	The sum of module, inverter, battery, balance of system, installation, and contingency costs.	$

Indirect Capital Costs

An indirect cost is typically one that cannot be identified with a specific piece of equipment or installation service, and may include all other costs that are built into the price of the system, such as profit, overhead, and shipping costs. Depending on the purpose of your analysis, you may decide to distribute profit among the direct cost categories or include them as a single value in an indirect category.

Note: Because Solar Advisor uses only the total installed cost value in cash flow calculations, how you distribute costs among the different indirect capital cost categories does not affect the final results.

Variable	Description	Units
Engineer, Procure, Construct	Costs associated with design and construction of the project, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Project, Land, Miscellaneous	Costs associated with profit, overhead (including marketing), permitting, or shipping, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Sales Tax	Percentage of direct costs to which sales tax applies, calculated by multiplying Total Direct Cost by the sales tax rate from the Financials page and the percentage that you specify.	%
Total Indirect Cost	The sum of Engineer-Procure-Construct costs, Project-Land-Miscellaneous costs, and sales tax.	$

Total Installed Cost

The total installed cost is the project's investment cost that applies in year zero of the project cash flow. Solar Advisor uses this value to calculate loan amounts and debt interest payments based on inputs on the Financing page, and to calculate tax credit and incentive payment amounts for incentive based tax credits and incentives defined on the Tax Credit Incentives page and Payment Incentives pages.

Variable	Description	Units
Total Installed Cost	The sum of total direct cost and total indirect cost.	$
Total Installed Cost per Capacity	Total installed cost divided by the total system capacity in Watts-DC of array capacity for PV systems and electric kilowatts of power block nameplate capacity for CSP systems. This value is provided for reference only and not used in cash flow calculations.	$/Wdc or $/kW

Operation and Maintenance Costs

Operation and Maintenance (O&M) costs represent annual expenditures on equipment and services that occur after the system is installed. Solar Advisor allows you to enter O&M costs in three ways: Fixed annual, fixed by capacity, and variable by generation. O&M costs are reported on the project cash flow.

For each O&M cost category, you can specify an annual escalation rate to represent an expected annual increase in O&M cost above the annual inflation rate specified on the Financing page. For an escalation rate of zero, the O&M cost in years two and later is the year one cost adjusted for inflation.

For a non-zero escalation rate, the O&M cost in years two and later is the year one cost adjusted for inflation plus escalation.

For expenses such as component replacements that occur in particular years, you can use an annual schedule to assign costs to individual years. See below for details.

O&M Cost Category	Description	Units
Fixed Annual Cost	A fixed annual cost applied to each year in the project cash flow.	$/yr
Fixed Cost by Capacity	A fixed annual cost proportional to the array capacity in DC kilowatts.	$/kWdc-yr
Variable Cost by Generation	A variable annual cost proportional to the system's total annual electrical output in AC megawatt-hours. The annual output depends on either the performance model's calculated first year value and the degradation rate specified on the Annual Performance page, or on an annual schedule of costs, depending on the option chosen.	$/MWh-yr
Fossil Fuel Cost	The cost per million British thermal units for fuel. Solar Advisor uses the conversion factor 1 MWh = 3.413 MMBtu. Applies only to the generic fossil, CSP trough, and CSP tower systems. The photovoltaic and CSP dish models ignore the fuel cost input variable. (When the fossil fill fraction variable on the Thermal Storage page for troughs or towers is greater than zero, the systems consume fuel for backup energy.)	$/MMBtu

Entering Periodic Costs

Solar Advisor allows you to specify any of the four operation and maintenance cost categories as an annual schedule of costs. An annual schedule makes it possible to assign a cost to particular years in the analysis period. Annual schedules can be used to account for inverter replacement costs and other periodic costs that do not recur on a regular annual basis. Note that you cannot have both a regularly occurring cost in addition to an annual schedule of costs. Solar Advisor will use whatever option is valid as indicated by a blue highlight on the “Value” button (regularly occurring) or “Sched” button (annual schedule) to determine which values are used in the model.

For example, to account for inverter replacement costs, you can specify the fixed annual cost category as an annual schedule, and assign the cost of replacing or rebuilding inverters to particular years. For a 30-year project using an inverter with a seven-year life, you would assign a replacement cost to years seven, 14, and 21. Or, to account for expected improvements in inverter reliability in the future, you could assign inverter replacement costs in years seven, 17, and 27. After running simulations, you will see the inverter replacement costs in the project cash flow, and they will be accounted for in the other economic metrics including the levelized cost of energy and net present value.

After running simulations, you will see the inverter replacement costs in the project cash flow, and they will be accounted for in the other economic metrics.

Note. Solar Advisor does not calculate any residual or salvage value remaining in inverters or other system components at the end of the analysis period.

To assign inverter replacement costs to particular years:

1. In the Fixed Annual Cost category, note that the "Value" label is blue indicating that the single value mode is active for the variable.

2. Click the button with the "Sched" label to change the mode to schedule and activate the Edit button.

3. Click **Edit**.
4. In the Edit Schedule window, use the horizontal scroll bar to find the first replacement year, and type the replacement cost in current or constant dollars for that year.

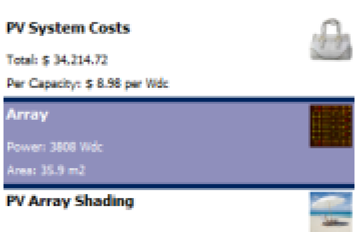
   To delete a value, select it and press the Delete key on your keyboard.

> **Note.** You must type a value for each year. If you delete a value, Solar Advisor will clear the cell, and you must type a number in the cell or Solar Advisor will consider the schedule to be invalid. Type a zero for years with no inverter replacement cost and no annual costs.

5. When you have finished editing the schedule, click **Accept**.

Because you must specify an O&M cost category as either an annual cost or annual schedule, to assign both a recurring annual fixed cost and periodic replacement cost, you must type the recurring cost in each year of the annual schedule, and for years with replacement costs, type the sum of the recurring and replacement costs. Note that dollar values in the annual schedule are in nominal or current dollars. Inflation and escalation rates do not apply to values in annual schedules.

5.8.2 Array



To view the Array page, click **Array** on the main window's navigation menu. Note that for the Array page to be available, the technology option in the Technology and Market window must be Photovoltaics - SAM Performance Models.

The Array page displays variables and options that describe the array layout, derating factors, array tracking and orientation, and allows you to choose from several radiation model options.

The variables on the Array page specify the properties of the photovoltaic array, number of inverters, and the model options for the solar radiation data processor. Solar Advisor uses the array properties to calculate the array's DC output and the system's AC output.

> **Note.** Before specifying the array, you should specify the module characteristics on the Module page, and the inverter characteristics on the Inverter page.

To specify the photovoltaic array:

1. Verify that the input variables on the Module and Inverter pages are correct.
2. Type a number of modules per string that results in a maximum power point voltage (Vmp) level close to the inverter's AC voltage level. Skip this step if you are using the inverter single-point efficiency model.
3. Type a number of strings in parallel that results in a total array power value close to the system's rated DC capacity.
4. Type a number of inverters that results in a total inverter capacity close to the total array power value. See Choosing Numbers of Modules and Inverters below for details.
5. Type values for the derate factors. To use the derate factor calculator, click **Edit Detailed Derates**. For help calculating a derate factor, click See About Derate Factors below for details.
6. Choose a tracking option: Fixed, one-axis tracking, or two-axis tracking.

   If you use a tracking system, be sure that the Balance of System cost category on the PV System Costs page includes the cost of installing the tracking system, and that the Operation and Maintenance cost includes the cost of maintaining the system.
7. Type a value for the array tilt angle in degrees from horizontal. Zero degrees is horizontal, 90 degrees is vertical.

   If you are unsure of a value, use the location's latitude (displayed in the navigation menu under Climate and on the Climate page).
8. If the array is oriented away from due south in the northern hemisphere (or oriented away from due north in the southern hemisphere), change the default azimuth angle to the desired value. An azimuth angle of 0 (facing the equator) normally maximizes energy production. For the northern hemisphere, increasing the azimuth angle favors afternoon energy production, and decreasing the azimuth angle favors morning energy production. The opposite is true for the southern hemisphere. In SAM, 90 degrees corresponds to west, and -90 degrees corresponds to east for both hemispheres.

9. Unless you have a reason to change the radiation model or tilt radiation type options, use the default options (Total and Beam, and Perez Model). See Input Variable Reference below for descriptions of the options.

Contents

- Input Variable Reference describes the input variables and options on the Array page.
- Choosing Numbers of Modules and Inverters describes how to choose values for the Modules per String, Strings in Parallel and Number of Inverters variables to avoid mismatching the array and inverter.
- About Derate Factors describes how Solar Advisor uses the derate factors in calculations, and provides guidelines for choosing appropriate values.

Input Variable Reference

Layout

Variable	Description	Units

Modules per String	The number of modules connected in series in a single string. Solar Advisor assumes that all strings in the array have the same number of modules connected in series. Press the Enter or Tab key after changing a value to update variables that depend on these values. **Note.** When the module type on the Module page is an array from the Sandia database (indicated by the word "array" in its name), the Modules per String variable represents the number of arrays rather than number of modules.	--
Strings in Parallel	The number of module strings connected in parallel. Press the Enter or Tab key after changing a value to update variables that depend on these values.	--
Total Modules	The number of modules in the array, equal to the product of the number of modules per string and the number of strings.	--
Total Area	The array's total area, not including space between modules, equal to the product of the module area and the number of modules	m^2
Total Array Power	The maximum DC power output of the array, equal to the product of the module's rated power on the Module page and the number of modules in the array.	Wdc
Voc (String)	The open circuit DC voltage of each string of modules, equal to the product of module's open circuit voltage displayed on the Module page and the number of modules per string. Solar Advisor displays an open circuit voltage of zero for the single-point efficiency module performance model because the model does not include voltage ratings.	Vdc
Vmp (String)	The maximum power point DC voltage of each string of modules, equal to the product of the module's maximum power point voltage displayed on the Module page and the number of modules per string. Solar Advisor displays a maximum power point voltage of zero for the single-point efficiency module performance model because the model does not include voltage ratings.	Vdc
Number of Inverters	The total number of inverters in the system. Press the Enter or Tab key to recalculate values that depend on the number of inverters.	--
Total Inverter Capacity	The total inverter capacity in AC Watts, equal to the product of the inverter's nominal AC power rating on the Inverter page and the number of inverters.	Wac

System Derates

Variable	Description	Units
Pre-Inverter Derate	Applies to the array DC power output in the hourly simulation. A derate factor of 100% is equivalent to no derating. A derate factor of 75% would reduce the calculated array DC output by 25%.	--

Post-Inverter Derate	Applies to the inverter AC power output in the hourly simulation. A derate factor of 100% is equivalent to no derating. A derate factor of 75% would reduce the calculated inverter AC output by 25%.	--
Total Derate Factor	The product of the pre- and post-inverter derate factors. This value is useful as a reference to compare to hand-calculated performance estimates, but is not used by Solar Advisor.	--

Tracking and Orientation

Variable or Option	Description	Units
Fixed	The array is fixed at the tilt and azimuth angles defined by the Tilt and Azimuth variables.	--
1 Axis	The array is fixed at the tilt angle defined by the Tilt variable and rotates from east in the morning to west in the evening to track the daily movement of the sun across the sky.	--
2 Axis	The array rotates from east in the morning to west in the evening to track the daily movement of the sun across the sky, and north-south to track the sun's seasonal movement throughout the year.	--
Tilt	Applies only to fixed arrays and arrays with one-axis tracking. The array's tilt angle in degrees from horizontal, where zero degrees is horizontal, and 90 degrees is vertical. As a rule of thumb, system designers often use the location's latitude (shown on the Climate page) as the optimal array tilt angle. The actual tilt angle will vary based on project requirements.	degrees
Azimuth	Applies only to fixed arrays with no tracking. The array's east-west orientation in degrees. An azimuth value of zero is facing the equator in both the northern and southern hemispheres. Positive 90 degrees is facing due west and negative 90 degrees is facing due east in both hemispheres. As a rule of thumb, system designers often use an array azimuth of zero, or facing the equator.	degrees
Ground Reflectance	The ground reflectance value for hours when the weather data indicate that there is no snow on the ground. A value of zero means that the ground is completely non-reflective, and a value of 1 means that it is completely reflective. A typical value for grassy ground is 0.2.	--
Ground Reflectance with Snow	The ground reflectance value for hours when the weather data indicate that there is snow on the ground. A value of zero means that the ground is completely non-reflective, and a value of 1 means that it is completely reflective. A typical value for snowy ground is 0.6.	--

Radiation Model

The data in the weather file includes data for global horizontal radiation, direct normal radiation, and diffuse horizontal radiation. The radiation model options determine which data Solar Advisor uses to calculate the solar radiation incident on the array.

Option	Description
Beam and Diffuse	This option tells Solar Advisor to use the direct normal radiation (beam) and diffuse horizontal radiation data, and to ignore the global horizontal radiation data. Solar Advisor calculates the global horizontal radiation as the sum of the direct normal and diffuse horizontal radiation.
Total and Beam	This option tells Solar Advisor to use the global horizontal radiation (total) and direct normal radiation (beam) data, and to ignore the diffuse horizontal radiation.

Tilt Radiation Type

Solar Advisor allows you to choose the method it uses to convert global horizontal solar radiation data to global solar radiation incident on the array. Each method uses information about the global horizontal solar radiation and either the direct normal or diffuse solar radiation, and about the sun's position and orientation of the array. The four methods differ in how they estimate the diffuse radiation incident on the array.

The isotropic sky model tends to under-predict the global radiation on a tilted surface, and is included as an option for analysis wanting to compare Solar Advisor results with those from other models using this approach. The remaining three methods provide comparable estimates of the incident global radiation.

Option	Description
Isotropic Sky Model	Assumes that diffuse radiation is uniformly distributed across the sky, called isotropic diffuse radiation.
Hay and Davies Model	Accounts for the increased intensity of diffuse radiation in the area around the sun, called circumsolar diffuse radiation, in addition to isotropic diffuse radiation.
Reindl Model	Accounts for the effect of horizon brightening, in addition to circumsolar diffuse radiation.
Perez Model	Accounts for horizon brightening, circumsolar and isotropic diffuse radiation using a more complex computational method than the Reindl and Hay and Davies methods.

Choosing Numbers of Modules and Inverters

For analyses using the single-point efficiency model options for photovoltaic modules and inverters, choose a number of modules and inverters that results in the array's rated power (Total Array Power) and inverter's capacity (Total Inverter Capacity) being as close as possible.

For analyses using the Sandia or CEC models, PV array and inverter capacities and voltages are displayed on the Array page for reference. Some recommendations for the array layout are:

- The PV array capacity (Total Array Power) and inverter total capacity (Total Inverter Capacity) should be as close as possible.
- The inverter nominal voltage (Vin,nom) shown on the Inverter page should be as close as possible to the array's maximum power point voltage (Vmp String).
- The PV array maximum power point voltage (Vmp String) should be between the minimum inverter voltage (Vin,min) and the maximum inverter voltage (Vin,max) shown on the Inverter page.

Solar Advisor assumes that multiple inverters are connected in parallel so that the inverter array voltages are equivalent to the single inverter voltages shown on the Inverter page.

If the inverter and array capacities or voltages are mismatched, Solar Advisor displays a warning message during simulations. The message appears under the following conditions:

- The total inverter capacity is less than the array power.
- The total inverter capacity is greater than 1.3 times the array power.
- The string maximum power point voltage (Vmp String) is less than the inverter minimum input voltage (Vin,min) or greater than the inverter maximum input voltage (Vin,max).
- The array open circuit voltage (Voc String) is greater than the inverter maximum voltage (Vin,max) shown on the Inverter page.

About Derate Factors

A photovoltaic system typically consists of a DC side that includes modules, diodes, and DC wiring and fuses, and an AC side that may include inverters, AC wiring and fuses, and transformers. Solar Advisor allows you to enter two derate factors, a pre-inverter derate factor to account for electrical losses on the DC side of the system, and post-inverter derate factor to account for losses on the AC side.

Solar Advisor uses the derate factors in the hourly simulation calculations to account for reductions in photovoltaic array and system performance that are not accounted for by either the module or inverter performance models.

Note. The total array power shown on the Array page is the array's rated power based on the module's power from the Module page and the number of modules shown on the Array page. Solar Advisor does not apply the derate factor to this rated capacity value.

Derate Factors in Performance Simulation Calculations

During the simulation, Solar Advisor multiplies the array's DC power output by the pre-inverter derate factor to calculate the inverter's DC input power for each hour of the simulation:

$$P_{DC,Inverter} = P_{DC,Array} \cdot F_{PreInverterDerate}$$

Similarly, to calculate the system's gross hourly output, it multiplies the inverter's output by the post-inverter derate factor:

$$P_{AC,SystemGross} = P_{AC,Inverter} \cdot F_{PostInverterDerate}$$

To calculate the system's net annual output, Solar Advisor adds up the 8,760 hourly gross system output values and adjusts this gross annual output value using the degradation and availability factors from the Annual Performance page.

Choosing Derate Factors

One source of information on derate factors is the website for NREL's PVWatts model, which includes a table of derate factor components for various sources of losses. Because Solar Advisor's performance model already accounts for some of the losses listed in the PVWatts table, it is not appropriate to use some of the PVWatts derate factor components in your Solar Advisor Model analysis.

Note. The PVWatts derate factors are described at http://www.nrel.gov/rredc/pvwatts/changing_parameters.html

If you are in doubt about the value to use for the derate factors, you can use the default values supplied with the Solar Advisor sample files. The following information is based on the information provided on the PVWatts website, and can be used as a reference for choosing values for the derate factors in Solar Advisor.

To calculate the pre-inverter derate factor to use in Solar Advisor, multiply the values of all of the pre-inverter derate factor components. Similarly, to calculate the post-inverter derate factor, multiply the values of all of the post-inverter derate factors.

The following derate factor components described on the PVWatts website are accounted for by Solar Advisor and should not be included in the pre- or post-inverter derate factors.

- PV module nameplate DC rating: The PV module nameplate DC rating is the manufacturers estimate of power production for a module under standard testing conditions. Solar Advisor's module performance models calculate the module output based on solar resource data from the weather file and the parameters defined on the Module page, and not based on a derate factor. (The performance model used to determine module output is defined on the Module page.)
- Inverter and Transformer: Solar Advisor's inverter performance models calculate the inverter output based on the output of the module (as determined by the performance model) and parameters defined on the Inverter page, and not based on a derate factor.
- System availability: The system availability is an input variable on the Annual Performance page, and should not be included as a derate factor.
- Shading: Solar Advisor accounts for shading based on the parameters specified on the PV Array Shading page.
- Age: Solar Advisor's degradation factor on the Annual Performance page accounts for performance losses over time due to aging of modules.

The following derate factor components described on the PVWatts website are not accounted for by Solar Advisor. The user may wish to include these factors in the pre- or post-inverter derate factors.

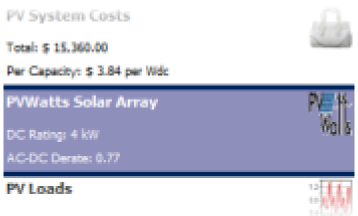
Table 11. Pre-inverter (DC) derate factors not accounted for by the module performance model.

Derate Factor Component	Cause of Loss	PVWatts Default Value	PVWatts Range
Mismatch	Slight differences in performance of different modules in the array.	98.0	97.0 - 99.5
Diodes and Connections	Voltage drops across blocking diodes and electrical connections.	99.5	99.0 - 99.7
DC Wiring	Resistive losses in wiring on the DC side of the system.	98.0	97.0 - 99.0
Soiling	Dirt, snow, or other matter on the module surface blocking solar radiation from reaching cells.	95.0	30.0 - 99.5
Sun Tracking	Inaccuracies in the tracking mechanisms ability to keep the array oriented toward the sun. Applies only to systems with one- or two-axis tracking arrays.	100.0	95.0 - 100.0

Table 12. Post-inverter (AC) derate factors not accounted for by the inverter performance model.

Derate Factor Component	Cause of Loss	PVWatts Default Value	PVWatts Range
AC wiring	Resistive losses in wiring on the AC side of the system.	99.0	98.0 - 99.3

5.8.3 PVWatts Solar Array



To view the PVWatts Solar Array page, click **PVWatts Solar Array** on the main window's navigation menu. Note that for the PVWatts Solar Array page to be available, the technology option in the Technology and Market window must be Photovoltaics - PVWatts Performance Model.

The PVWatts Solar Array page displays variables for Solar Advisor's implementation of NREL's PVWatts model.

Solar Advisor includes an implementation of NREL's PVWatts model to facilitate comparing results calculated by Solar Advisor's three other photovoltaic module performance models with PVWatts results, and to generate results based on the PVWatts performance model but using Solar Advisor's cost and financial model and assumptions.

Note. NREL's PVWatts model is a web-based simulation model for grid-connected photovoltaic systems. To use the model or find out more about it, visit the PVWatts website at http://www.nrel.gov/rredc/pvwatts/. The model is also described in Marion (2002).

Input Variable Reference

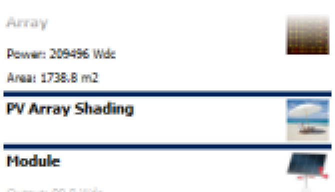
PVWatts System Inputs

The system inputs define the size of the system, derate factor, and the array orientation. For information about choosing values for the PVWatts input variables, see the PVWatts website at http://www.nrel.gov/rredc/pvwatts/changing_parameters.html.

Variable	Description	Units
DC Rating	The array's nameplate DC power rating in kilowatts under standard test conditions (STC). The DC rating is equal to a single module's DC power rating in watts at 25°C and 1,000 W/m^2 multiplied by the number of modules in the array divided by 1,000.	--
DC to AC Derate Factor	A factor accounting for conversion of the array's DC nameplate capacity to the system's AC power rating at STC. The default value is 0.77. For help calculating the derate factor, see the PVWatts derate factor calculator at http://rredc.nrel.gov/solar/calculators/PVWATTS/derate.cgi.	--
Array Tracking Mode	The three array tracking modes are: • A fixed array is fixed at the tilt and azimuth angles defined by the Tilt and Azimuth variables. • A one-axis tracking array is fixed at the tilt angle defined by the Tilt variable and rotates from east in the morning to west in the evening to track the daily movement of the sun across the sky.	--

	• A two-axis tracking array rotates from east in the morning to west in the evening to track the daily movement of the sun across the sky, and from north to south to track the sun's seasonal movement throughout the year.	
Tilt	Applies only to fixed arrays and arrays with one-axis tracking. The array's tilt angle in degrees from horizontal, where zero degrees is horizontal, and 90 degrees is vertical. As a rule of thumb, system designers often use the location's latitude as the optimal array tilt angle. The actual tilt angle will vary based on project requirements.	degrees
Azimuth	Applies only to fixed arrays with no tracking. The array's east-west orientation in degrees. An azimuth value of zero is facing the equator in both the northern and southern hemispheres. In the northern hemisphere, an azimuth of positive 90 degrees is facing due west, and negative 90 degrees is facing due east. As a rule of thumb, system designers often use an array azimuth of zero, or facing the equator.	degrees

5.8.4 PV Array Shading



To view the PV Array Shading page, click **PV Array Shading** on the main window's navigation menu. Note that for the PV Array Shading page to be available, the technology option in the Technology and Market window must be Photovoltaics - SAM Performance Models.

The PV Array Shading page allows you to enable and disable the shading model, displays the shading factors matrix, and allows for importing and exporting the matrix as a text file.

The photovoltaic array shading model simulates the effect of structures, vegetation, or objects surrounding the array that may block the sun at different times throughout the day and year. The shading model is not designed to represent inter-array (module-to-module) shading or strategies for avoiding it such as backtracking.

The shading model uses a 24-by-12 matrix to assign a shading factor to each hour of the day for each month of the year. Each shading factor is a value between zero and one that represents the fraction the direct normal solar radiation allowed to reach the array in a given hour. A shading factor of one represents no shading. A shading factor of zero represents complete blockage of direct normal radiation from the array.

Solar Advisor assumes that shading reduces the magnitude of the direct normal component of the global radiation incident on entire array over an hour. For example, a shading factor of 0.90 for an hour when the value of the direct normal incident radiation is 200 W/m^2 and the diffuse incident radiation is 10 W/m^2 would result in a global incident radiation value of 0.90 × 200 W/m^2 + 10 W/m^2 = 190 W/m^2 for that hour.

Note that for flat-plate photovoltaic arrays, solar advisor calculates the array output based on the value of the *global* incident radiation, which is equal to the sum of the normal and diffuse incident radiation components. For concentrating photovoltaic (CPV) arrays, on the other hand, the array output is calculated based only on the value of the direct normal incident radiation component.

Because Solar Advisor assumes that shading affects the entire array uniformly, it cannot model partial shading of the array or of individual modules within the array. The shading model does not consider factors such as string layout, location of blocking diodes, or cell layout in individual modules.

Contents

Enabling and Disabling Array Shading

Solar Advisor allows you to enable and disable array shading so that you can turn off array shading after defining a shading matrix without losing the values in the matrix.

Note. Shading factors must be enabled for Solar Advisor to use the data in the shading matrix.

- Check **Enable Shading Factors for Direct Radiation** to turn on array shading.
- Clear **Enable Shading Factors for Direct Radiation** to turn off array shading.

Defining the Shading Factor Matrix

To define the shading factor matrix, you assign a value to each cell in the matrix. The shading factor in a cell applies to a given hour for an entire month. For example, a shading factor of 0.90 in the 6 a.m. cell for May would mean that 90% of the direct normal radiation value in the weather file for each hour beginning at 6 a.m. and ending at 7 a.m. in May would be used to calculate the global solar radiation incident on the array.

Note. The time convention for the matrix is determined by the convention used in your weather file. For example, TMY2 and TMY3 data use local standard time.

As you work with the shading factor matrix, keep the following in mind:

- The first column in the matrix is for the hour beginning at 12:00 a.m. and ending at 1:00 a.m.
- A red cell indicates a value of zero, or full shading (direct normal radiation completely blocked).
- A white cell indicates a value of one, or no shading.
- A dark shade of red indicates more shading (more direct normal radiation) than a light shade of red.

<u>To define a shading factor for a single cell:</u>

- Click the cell and type the shading factor.
  To replace the value in a cell, click the cell and type a replacement value.
  To delete the value from a cell, double-click the cell and press the Delete key.

<u>To define a single shading factor for multiple cells:</u>

Select the cells to which you want to apply the shading factor.
Type a value between zero and one.

Press the Enter key or click **Apply to selected cells**.

Importing and Exporting Shading Factor Data

Solar Advisor allows you to import and export the shading factor matrix as a comma-delimited text file that contains 12 rows of 24 hourly shading factors separated by commas. The file should not have row or column headings.

- Each row contains the 12 shading factors for each hour of a day in that month separated by columns.

To export the shading matrix as a text file, click Export.

To import a data from a comma-delimited text file, click Import

5.8.5 Module

To view the Module page, click **Module** on the main window's navigation menu. Note that for the Module page to be available, the technology option in the Technology and Market window must be Photovoltaics - SAM Performance Models.

The Module page allows you to choose a module performance model from four options, choose or enter module parameters, and view module characteristics.

The photovoltaic module performance models calculate the hourly DC electrical output of a single module based on the hourly total incident solar radiation (plane-of-array irradiance) calculated by the Climate model. The photovoltaic array output depends on the number of modules and the pre-inverter derate factor specified on the Array page. Solar Advisor passes the array's hourly DC power output to the inverter model, whose characteristics are on the Inverter page.

Note. In addition to the number of modules and derate factors, the input variables on the Array page specify the array orientation and tracking, and the method used to calculate total incident radiation.

There are four options available for modeling PV modules:

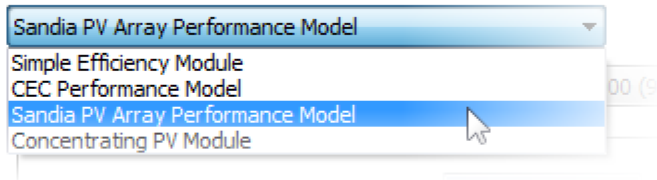
- Simple Efficiency Module
- CEC Performance Model
- Sandia PV Array Performance Model
- Concentrating PV Module

Each model uses a different algorithm to predict module performance. In general, if you are modeling a system that uses a particular brand and type of flat-plate PV module, you should first look for the module in the Sandia database, and then in the CEC database. If you do not find the module in either database, or are not modeling a particular brand of module, then use the single-point efficiency model.

For concentrating photovoltaic (CPV) modules, use the Concentrating PV Module model unless you are modeling the Entech 22x module, in which case you can choose the module from the database in the Sandia model.

To specify a photovoltaic module model:

1. Choose the model name from the list.



2. For the Sandia or CEC models, choose a module from the database of available models. For the Simple Efficiency Model and Concentrating PV Module, enter module characteristics.

Contents

- Choosing the Best Flat-plate Model for your Analysis describes in more detail when to use the different models.
- Modeling Thin Film Modules describes options for modeling amorphous silicon and other thin film modules.
- Modeling Concentrating Photovoltaic (CPV) Modules describes the two options for modeling CPV modules, and describes the input variables and algorithms for the single-point efficiency model for CPV modules.
- About the Sandia PV Array Performance Model describes the Sandia model in more detail, explains the model parameters, and suggests resources for learning more about the model.
- About the CEC Performance Model describes the CEC model in more detail, explains the model parameters, and suggests resources for learning more about the model.
- About the Simple Efficiency Model for Flat-plate Modules describes the input variables and algorithms for the single-point efficiency model for flat-plate modules.

Choosing the Best Flat-plate Model for your Analysis

This section briefly describes each model and provides guidelines for choosing the best model to meet the goals of your analysis. Each model is described in more detail in the "About" sections below.

There are three flat-plate PV performance models available in the current version of Solar Advisor:

- The Simple Efficiency Module model is a simple representation of module performance that requires you to provide the module area, conversion efficiency, structure, and a temperature coefficient.
- The Sandia PV Array Performance Model calculates hourly efficiency values based on field measurements of deployed systems using data from a database of commercially-available modules. The Sandia model tends to produce more accurate predictions of module performance than both the CEC model and Simple Efficiency model. However, because of the time and effort required to make the field measurements, the Sandia module database is less up-to-date than the CEC database.
- The California Energy Commission (CEC) Performance Model predicts module performance based on a database of module characteristics determined from module ratings. Like the Sandia model, the CEC model calculates hourly efficiency values, and allows you to select from a list of a commercially-available modules. Because the model coefficients can be generated quickly by the CEC using standard module specifications such as those provided by module manufacturers, the module database is more up-to-date than the Sandia database. The CEC model predictions are more accurate than the Simple Efficiency model, but less accurate than the Sandia model, particularly for thin-film modules.

Because the Sandia model is the most accurate of the three models, it should be your first choice when choosing between the models. If you are investigating a module that is not included in the Sandia database, you can either choose a different module in the database with similar characteristics, or see if the model is in the CEC database. If you do not find your module in either the Sandia or CEC databases, choose the single-point efficiency model. Some types of analyses that require sensitivity or parametric analyses are best performed with the single-point efficiency model.

Table 13. Summary of guidelines for choosing a photovoltaic module performance model.

Use this model...	...if your analysis involves...	Comments
Sandia *Model based on field test data.*	estimates of module performance for crystalline or thin-film modules, or to model the Entech 22x concentrating photovoltaic module.	If your module is in both the Sandia and CEC lists, use the Sandia model.
CEC *Model based on module ratings.*	estimates of module performance for crystalline-silicon modules or for new modules recently available on the market.	Use the CEC model when your analysis involves a particular module that is not available in the Sandia database.
Simple Efficiency Module *Simple constant efficiency model with temperature correction.*	sensitivity or parametric studies on module efficiency or temperature coefficients.	Use the Simple Efficiency model for modules not included in either the Sandia or CEC model database, or to model a system using a particular size of module where the make and model is not important.
Concentrating PV Module *Simple constant efficiency model.*	Modeling concentrating photovoltaic modules.	See Modeling Concentrating Photovoltaic (CPV) Modules for details.

Modeling Thin-film Modules

For modules based on thin-film cell technology, including amorphous silicon, copper indium diselenide (CIS), cadmium telluride (CdTe), and heterojunction with intrinsic thin layer (HIT), the CEC and single-point efficiency models do not adequately represent module performance at low-light levels. Because the Sandia model is based on field measurements, it provides a more reliable prediction of thin-film module performance, but its results for thin-film modules have only been validated at the module level, not at the system level.

For best results, if you are modeling a thin-film module, look for the module in the Sandia database. If the module is not available in the Sandia database, you may want to use a module from the database with similar characteristics to the one you are modeling. Use the table below to help identify the thin-film modules in the Sandia database.

Table 14. Thin-film module manufacturers and model numbers available in the Sandia module database.

Cell Type	Manufacturer	Model Series or Number
amorphous tandem junction (2-a-Si)	Solarex	MST
amorphous silicon triple junction (3-a-Si)	Uni-Solar	PVL, SHR, US, USF
cadmium telluride (CdTe)	BP Solar	BP980, BP990
	First Solar	FS
copper indium diselenide (CIS)	Shell Solar	ST
	Siemens Solar	ST
amorphous silicon heterojunction (HIT-Si)	Sanyo	HIP

Modeling Concentrating Photovoltaic (CPV) Modules

For CPV modules, other than the Entech 22X Concentrator module, use the Concentrating PV Module option. This model uses a simple algorithm that calculates the module's hourly DC output by multiplying the hourly direct normal component of the solar radiation data in the weather file by the module's area and efficiency as specified on the Module page.

If you are modeling the Entech 22X Concentrator (c-Si), you can use the Sandia PV Array Performance model instead of the Simple Efficiency model. The Entech module is modeled using a set of coefficients determined by analyzing field test measurements. To use the Entech module, choose the Sandia model option and select the Entech 22X Concentrator [1994] module from the list of available modules. The Entech module is a special case in the Sandia module database, and its coefficients have been selected to allow it to be modeled using global radiation data.

To use the single-point efficiency CPV model:

1. On the Module page, choose Concentrating PV Module.
2. Enter the module's total collector area in square meters.
3. In the Radiation Level and Efficiency Table, enter an efficiency value for each of up to five incident beam radiation reference values in increasing order. To enter fewer than five efficiency values, you must include five radiation values, but you can assign the same efficiency value to more than one radiation value. For example, to represent a module with 20% constant efficiency, you could assign the value 20.0 to each of the five radiation values 200, 400, 600, 850, 1000.

Concentrating PV Module Characteristics

Variable	Description	Units
Area	The module collector area in square meters.	m^2
Rated Power	The module's rated maximum DC power at the reference radiation value indicated in the efficiency table below. Solar Advisor uses this value to calculate the array cost shown on the PV System Costs page, but not in simulation calculations. The rated module power is the product of the reference radiation, reference efficiency and area.	W_{DC}

Radiation Level and Efficiency Table

Variable	Description	Units
Radiation	The incident beam radiation level at which the given efficiency value applies.	W/m^2
Efficiency	The module conversion efficiency at a given radiation level used in the hourly simulations to convert incident normal solar radiation to DC electrical output.	%
Reference	Indicates which value to use for the reference calculations.	

The module's hourly DC output is the product of the hour's direct normal solar radiation from the weather file as defined on the Climate page, collector area, and module efficiency from the Module page:

$$P_{mp,CPVModule} = E_{DirectNormal} \cdot A_{Collector} \cdot \eta_{Module}$$

Where,

$P_{mp,CPVModule}$ (WDC)	The module's average DC electric output for the hour.
$E_{DirectNormal}$ (W/m^2)	The direct normal solar radiation from weather processor.
$A_{Collector}$ (m^2)	The collector area in square meters.
η_{Module}	The module's conversion efficiency at the incident beam radiation for the current hour, extrapolated from the efficiency curve defined by the table on the Module page.

About the Sandia PV Array Performance Model

The Sandia PV Array Performance Model uses an algorithm and a database of commercially available modules developed at Sandia National Laboratory. To use the model, you simply select a module or array from the Module Name list.

The Sandia model is described in King et al, 2004. Photovoltaic Array Performance Model. Sandia National Laboratories. SAND2004-3535. http://www.osti.gov/bridge/product.biblio.jsp?query_id=0&page=0&osti_id=919131

To use the Sandia photovoltaic model:

1. On the Module page, choose **Sandia PV Array Performance Model**.
2. Choose a module from the list of available modules. Solar Advisor displays the module's characteristics and model coefficients for your reference.

   The first several items in the Sandia database are arrays instead of single modules. The arrays are indicated by the word "Array" in the name, which also includes the number of modules and the module type. When you use an array from the database, you should set the Pre-Inverter derate factor on the Array page to zero.

   If you are modeling a module not included in the database and want to use the Sandia model, you can try to find a module with similar characteristics to your module's specifications.

The Sandia model consists of a set of equations that provide values for five points on a module's I-V curve. The equations involve a set of coefficients that have been empirically determined based on field measurements taken from modules installed in real, operating photovoltaic systems. The Sandia database consists of a set of manufacturer specification and measured data for each module and array in the database.

Solar Advisor does not track voltage and current levels in the system and assumes that the array operates at its maximum power point.

The Sandia Module Library Parameters

When you select a module from the Sandia database on the Module page, Solar Advisor displays module's parameters for your reference. You can see the complete set of parameters in the Module library by using Solar Advisor's library editor.

The Sandia module library includes parameters for modules that have been tested by Sandia National Laboratory. Manufacturers wishing to add their modules to the Sandia database should contact Sandia National Laboratory directly. Because the parameters involve data from field measurements, it is not possible to generate parameters from manufacturer specifications.

The tables below describe the parameters in the Sandia module library, which are explained in more detail in the King 2004 reference cited above.

Module Characteristics

Parameter	Description	Units
Maximum Power (P_mp)	The module (or array's) rated power. Equal to the product of the maximum power voltage and maximum power current.	W_{DC}
Maximum Power Voltage (V_mp)	Maximum power voltage under reference conditions.	V
Maximum Power Current (I_mp)	Maximum power current under reference conditions. Defines the maximum power point on the module's I-V curve.	A
Open Circuit Voltage (V_oc)	Open circuit voltage under reference conditions. Defines the open circuit point on the module's I-V curve.	V
Short Circuit Current (I_sc)	Short circuit current under reference conditions. Defines the short circuit point on the module's I-V curve.	A
Cell Area (A_c)	The total cell area: Includes all cells in the module, but does not include space between cells. This value should be less than the module area. Equal to the area of a single cell multiplied by the number of cells	m^2
Material	Cell material	--
Number of Cells (N_c)	Number of cells per module, equal to the product of Series Cells and Parallel Cells under Additional Parameters (see below).	--

Additional Parameters

Parameter	Description	Units
Material	Cell material. Multi-crystalline silicon is mc-Si, single-crystal silicon is c-Si. See the table above for thin-film cell material abbreviations.	--
Series Cells	Number of cells in series per cell string.	--
Parallel Cells	Number of cell strings in parallel.	--
BVoco	Open circuit temperature coefficient	V/°C

MBVoc	Coefficient representing dependence of Bvoco on irradiance. Typically zero.	V/°C
Vintage	Year field measurement data were collected.	year
BVmpo	Temperature coefficient at module Vmp under reference conditions	V/°C
MBVmp	Coefficient representing dependence of Bvmpo on irradiance. Typically zero.	V/°C
AImp	Normalized maximum power temperature coefficient, calculated by dividing alpha by Isco.	1/°C
AIsc	Normalized short circuit temperature coefficient, calculated by dividing alpha by Isco	1/°C
N	Empirically determined factor, also called the "diode factor."	--
dTC	Temperature difference between the cell and module back surface under reference conditions.	°C
FD	Fraction of diffuse irradiance used by module. For flat-plate modules, FD=1; for CPV modules, FD=0; and for low-concentration modules, 0 < FD < 1.	--
Ixo	Current at module open circuit voltage of Voc / 2 under reference conditions. Defines one of the five points on the module's I-V curve.	--
Ixxo	Current at module open circuit voltage of (Voc + Vmp) / 2under reference conditions.Defines one of the five points on the module's I-V curve.	--

A, B, C Coefficients

Parameter	Description	Units
A0-4	Empirically determined coefficients used in polynomial representation of solar spectral effects of daily air mass variation on Isc.	--
B1-5	Empirically determined coefficients used in polynomial representation of optical effects of the angle of incidence (AOI) on Isc.	
C0-5	Empirically determined performance coefficients that relate Imp, Ix, and Ixx to effective irradiance.	--
a, b	Empirically-determined coefficients used in temperature correction calculations.	--

About the CEC Performance Model

The California Energy Commission (CEC) Performance Model uses the University of Wisconsin-Madison Solar Energy Laboratory's five-parameter model with a database of module parameters maintained by the California Energy Commission (CEC) for the California Solar Initiative. To use the model, you simply choose a module name from the CEC Module list.

The five-parameter model is described in brief in De Soto 2003, "Improvement and Validation of a Model for Photovoltaic Array Performance," Solar 2003 Conference Proceedings, American Solar Energy Society.

A more detailed description can be found in De Soto 2004, *Improvement and Validation of a Model for Photovoltaic Array Performance,* Master of Science Thesis, University of Wisconsin-Madison. http://sel.me.wisc.edu/theses/desoto04.zip.

For information about the CEC list of eligible photovoltaic modules, see http://www.gosolarcalifornia.org/equipment/pvmodule.html.

To use the CEC photovoltaic model:

1. On the Module page, choose CEC Performance Model.
2. Choose a module from the list of available modules. Solar Advisor displays the model's characteristics and model coefficients for your reference.

The modules in the list are from Solar Advisor's CEC module library, which is described in more detail below.

Note. To make sure that you have the latest CEC module library, on the Help menu, click **Check for updates**. Solar Advisor will connect to NREL servers on the Internet and, if a more recent version of the library is available, automatically update your current library. Updating the library only affects the standard CEC module library, and will not affect any modules you may have added to the library.

The five-parameter model calculates a module's current and voltage under a range of solar resource conditions (represented by an I-V curve) using an equivalent electrical circuit whose electrical properties can be determined from a set of five parameters. These five parameters, in turn, are determined from standard reference condition data provided by either the module manufacturer or an independent testing laboratory, such as the Arizona State University Photovoltaic Testing Laboratory.

Solar Advisor does not track voltage and current levels in the system and assumes that the array operates at its maximum power point.

The CEC Module Library Parameters

When you select a module from the CEC database on the Module page, Solar Advisor displays module's parameters for your reference. You can see the complete set of parameters in the Module library by using Solar Advisor's library editor.

The CEC module library contains a set of module parameters for modules included in the CEC's database of eligible photovoltaic modules. Manufacturers wishing to add their modules to the CEC database should contact the CEC directly.

If you would like to add a module to the CEC module library in your copy of Solar Advisor, please contact us at solar.advisor.support@nrel.gov. If you can provide us with a list of the module's specifications as shown on the Module page under Module Characteristics, we may be able to create a set of coefficients for you to use. We provide this service on a case-by-case basis, and cannot guarantee the quality of the coefficients we generate.

The parameters in the CEC module library include:

- A set of module characteristics at standard test conditions, which may be provided by either the module manufacturer or by an independent testing laboratory.
- A set of additional parameters used in the model's equivalent circuit to calculate the module's I-V curve.
- Reference inputs required to generate the calculated model parameters.

Module Characteristics

Parameter	Description	Units
Maximum Power (P_mp)	The module rated power. Equal to the product of the maximum power voltage and maximum power current.	W_{DC}
Maximum Power Voltage (V_mp)	Reference maximum power voltage at STC.	V
Maximum Power Current (I_mp)	Reference maximum power current at STC.	A
Open Circuit Voltage (V_oc_ref)	Reference open circuit voltage at STC.	V
Short Circuit Current (I_sc_ref)	Reference short circuit current at STC.	A
Cell Area (A_c)	Total cell area, equivalent to the product of the number of cells per module and the area of a single cell. The cell area should be less than the module area.	m^2
Number of Cells (N_s)	Total number of cells per module.	--
Short Circuit Temp. Coeff (Alpha_sc)	Maximum current temperature coefficient.	%/°C
Open Circuit Temp. Coeff. (Beta_oc)	Maximum voltage temperature coefficient.	%/°C
Max. Power Temp. Coeff. (Gamma_r)	Maximum power temperature coefficient from module specifications.	%/°C

Additional Parameters

Parameter	Description	Units
T_noct	NOCT temperature.	°C
A_ref	Modified ideality factor at reference conditions.	--
I_l_ref	Light current at reference conditions.	A
I_o_ref	Diode reverse saturation current.	A
R_s	Series resistance.	Ohm
R_sh_ref	Shunt resistance.	Ohm
Adjust	An adjustment factor used in the coefficient generator to verify that the calculated Gamma_r value is equal to the Gamma_r value in the module specifications.	
Gamma_r	Maximum power temperature coefficient calculated by the coefficient generator.	%/°C
Source	The source of manufacturer data used to generate the coefficients.	--

Reference Inputs

Parameter	Description	Units

T_amb_noct	NOCT ambient temperature. Default value is 25 °C.	°C
T_refC		%
FFV_wind	Wind speed adjustment factor to account for wind shear. Default value is 0.51 for arrays mounted at ground level or up to 22 feet (6.7 m) above the ground, and 0.61 for arrays mounted higher than 22 feet (6.7 m) above the ground.	--
I_noct	NOCT incident solar radiation. Default value is 800 W/m^2.	W/m^2
I_ref		W/m^2
tau_alpha		--
kL		--
eta_mppt	A derating factor to account for inverter losses at the array's maximum power point. The default value is one because inverter losses are handled separately by the inverter performance model.	--
e_g		eV

About the Simple Efficiency Model for Flat-plate Modules

The flat-plate photovoltaic single-point efficiency model calculates the module's hourly DC output assuming that the module efficiency is fixed, regardless of the amount of solar radiation incident on the module. The model makes an adjustment for cell temperature, assuming that it is mounted on an open rack that allows air to flow over the back of the module.

The model calculates the DC power output of a single module using the equations described below.

To use the single-point efficiency flat-plate model:

1. On the Module page, choose Simple Efficiency Module.
2. Enter a temperature coefficient.

   This is the number typically reported on manufacturer specification sheets as the maximum power coefficient. See the table below for sample values for different cell types.
3. Choose a module structure from the three available options (displayed as front material / cell / back material).

   Module manufacturers typically include a description of the front material, and frame or back material in a mechanical characteristics section of module specification sheets.
4. Enter the module's total cell area in square meters, equivalent to the product of the cell area and number of cells.
5. In the Radiation Level and Efficiency Table, enter an efficiency value for each of up to five incident beam radiation reference values in increasing order. To enter fewer than five efficiency values, you must include five radiation values, but you can assign the same efficiency value to more than one radiation value. For example, to represent a module with 13.5% constant efficiency, you could assign the value 13.5 to each of the five radiation values 200, 400, 600, 850, 1000.

Characteristics

The module characteristics define the module's capacity, efficiency, and thermal characteristics.

Variable	Description	Units
Power	The module's rated maximum DC power at the reference radiation indicated in the table below. Solar Advisor uses this value to calculate the array cost on the PV System Costs page, but not in simulation calculations. The module power is the product of the reference radiation, reference efficiency and area.	W_{DC}
Temperature Coefficient (Pmax)	The rated maximum-power temperature coefficient as specified in the module's technical specifications.	%/°C
Module Structure	The module's front and back materials (front material/cell/back material) used in the temperature correction algorithm. The model assumes that modules are mounted on an open rack that allows air to flow freely over the back of the module.	--
Area	The module collector area in square meters. To calculate the area for a given module power rating at a given reference radiation level, divide the power rating by the module efficiency and radiation level. For example, a 100 W module with 13.5% efficiency at 1000 W/m^2 requires an area of 100 W / (0.135 × 1000 W/m^2) = 0.74074 m^2.	m^2

Radiation Level and Efficiency Table

Variable	Description	Units
Radiation	The incident global (beam and diffuse) radiation level at which the given efficiency value applies.	W/m^2
Efficiency	The module conversion efficiency at a given radiation level used in the hourly simulations to convert incident normal solar radiation to DC electrical output.	%
Reference	Indicates which value to use for the reference calculations.	

Table 15. Sample temperature coefficient values for different cell types based on an informal survey of manufacturer module specifications.

Cell Type	Maximum Power Temperature Coefficient (%/°C)
Monocrystalline Silicon	-0.49
Polycrystalline Silicon	-0.49
Amorphous Silicon	-0.24
Amorphous Silicon Triple Junction	-0.21
Copper Indium Gallium DiSelenide (CIGS)	-0.45
Cadmium Telluride (CdTe)	-0.25

For each hour of the year, the flat-plate single-point efficiency model calculates the module DC output as the product of the total incident radiation, module area, and temperature correction factor:

$$P_{\text{mp\_Module}} = E_{\text{TotalIncident}} \cdot A_{\text{Module}} \cdot \eta_{\text{Module}} \cdot F_{\text{TempCorr}}$$

Where,

$E_{TotalIncident}$ (W/m^2)	Total incident radiation from the Climate model.
A_{Module} (m^2)	The module area in square meters.
$F_{TempCorr}$	Temperature correction factor, described below.

The temperature correction factor algorithm is the same one used for Solar Advisor's implementation of the Sandia model, and is described in detail in King et al, 2004. Photovoltaic Array Performance Model. Sandia National Laboratories. SAND2004-3535. http://www.osti.gov/bridge/product.biblio.jsp?query_id=0&page=0&osti_id=919131.

First, the model calculates the module back temperature T_{Back}:

$$T_{\text{Back}} = E_{\text{TotalIncident}} \cdot e^{a + b \cdot v_{\text{Wind}}} + T_{\text{Ambient}}$$

The cell temperature T_{cell} is:

$$T_{\text{Cell}} = T_{\text{Back}} + \frac{E_{\text{TotalIncident}}}{E_0} \cdot \Delta T_0$$

The temperature correction factor $F_{TempCorr}$ is:

$$F_{\text{TempCorr}} = 1 + \gamma \cdot (T_{\text{Cell}} - T_{\text{Ref}})$$

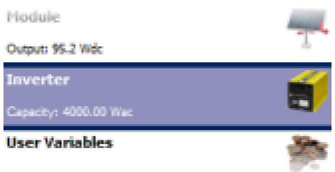
Where,

$E_{TotalIncident}$ (W/m^2)	The total incident solar radiation from weather processor.
E_0 (W/m^2)	The reference total incident radiation at STC
T_{ref} (25°C)	The reference temperature at STC
γ (%/°C)	The maximum power temperature coefficient from Module page
a, b	Empirically-determined coefficients for the T_{back} equation. Based on the temperature correction approach used for the Sandia model. determined by the Module Structure option on the Module page and the values in the table below.
ΔT_0 (3°C)	Temperature difference between the cell and module back surface at STC irradiance of 1000 W/m2. This value is for flat-plate modules in an open rack mount.
v_{Wind} (m/s)	Hourly wind speed from the weather file.
$T_{Ambient}$ (°C)	Hourly ambient temperature from weather file.

Table 16. Empirically-determined a and b coefficients for each of the three Module Structure options available on the Module page.

Module Structure (from Module page)	a	b
Glass/cell/polymer	-3.56	-0.0750
Glass/cell/glass	-3.47	-0.0594
Polymer/cell/steel	-3.58	-0.113

5.8.6 Inverter



To view the Inverter page, click **Inverter** on the main window's navigation menu. Note that for the Inverter page to be available, the technology option in the Technology and Market window must be Photovoltaics - SAM Performance Models.

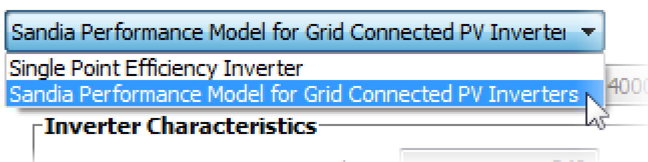
The Inverter page allows you to choose an inverter performance model from two options, and displays the characteristics of the of the inverter.

On the Inverter page, you specify the characteristics of a single inverter. To enter the number of inverters in the system, use the input variables on the Array page. Solar Advisor calculates the AC output of the total number of inverters in the system based on the DC output of the photovoltaic array calculated by the module performance model.

The current version of Solar Advisor includes two inverter performance models, the Sandia Performance Model for Grid-Connected PV Inverters model and the single-point efficiency model. The Sandia model allows you to choose an inverter from a list of commercially-available inverters. The single-point efficiency model allows you to model inverters that are not in the list.

To specify an inverter model:

1. Choose the model name from the list.



2. For the Sandia model, choose an inverter from the database of available models.
   For the Single Point Efficiency Model, enter inverter characteristics.

Contents

About the Sandia Inverter Performance Model

The Sandia Performance Model for Grid-Connected PV Inverters is an empirically-based performance model that uses parameters from a database of commercially available inverters maintained by Sandia National Laboratory. The parameters are based on manufacturer specifications and laboratory measurements for a range of inverter types.

The Sandia inverter model is described in King D et al, 2007. *Performance Model for Grid-Connected Photovoltaic Inverters*. Sandia National Laboratories. SAND2007-5036. http://www.prod.sandia.gov/cgi-bin/techlib/access-control.pl/2007/075036.pdf

To use the Sandia inverter model:

1. On the Inverter page, choose **Sandia Performance Model for Grid Connected PV Inverters**.
2. Choose an inverter from the list of available inverters. Solar Advisor displays the inverter's characteristics and model coefficients for your reference.
   If you are modeling an inverter not included in the database and want to use the Sandia model,

you can try to find an inverter with similar characteristics to your inverter's specifications.

The Sandia model consists of a set of equations that Solar Advisor uses to calculate the inverter's hourly AC output based on the DC input (equivalent to the derated output of the photovoltaic array) and a set of empirically-determined coefficients that describe the inverter's performance characteristics. The equations involve a set of coefficients that have been empirically determined based on data from manufacturer specification sheets and either field measurements from inverters installed in operating systems, or laboratory measurements using the California Energy Commission (CEC) test protocol.

The CEC inverter test protocol is described in Bower W et al, 2004. *Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems*. http://bewengineering.com/docs/index.htm

Because Solar Advisor does not track voltage levels in the system, it assumes that for each hour of the simulation, the inverter operates at the photovoltaic array's maximum power point voltage, given the solar resource data in the weather file for that hour.

The Sandia Inverter Library Parameters

When you select an inverter from the Sandia database on the Inverter page, Solar Advisor displays the inverter's parameters for your reference. You can see the complete set of parameters in the Inverter library by using Solar Advisor's library editor.

The Sandia inverter library includes parameters for modules that have been tested by Sandia National Laboratory. Manufacturers wishing to add their inverters to the Sandia database should contact Sandia National Laboratory directly. Because the parameters involve data from field and test measurements, it is not possible to generate parameters based only on manufacturer specifications.

The following table describes the parameters in the Sandia inverter library, which are explained in more detail in the King 2004 reference cited above.

Inverter Characteristics

Parameter	Description	Units
AC Voltage	Rated output AC voltage from manufacturer specifications.	V_{AC}
Power ACo	Maximum output AC power at reference or nominal operating conditions. Available from manufacturer specifications.	W_{AC}
Power DCo	Input DC power level at which the inverter's output is equal to the maximum AC power level. Available from manufacturer specifications.	W_{DC}
PowerSo	DC power required for the inverter to start converting DC electricity to AC. Also called the inverter's self-consumption power. Sometimes available from manufacturer specifications, and not to be confused with the nighttime AC power consumption.	W
PowerNTare	AC power consumed by the inverter at night to operate voltage sensing circuitry when the photovoltaic array is not generating power. Available from manufacturer specifications.	W
Vdcmax	The maximum DC voltage input, typically at or near the photovoltaic array's maximum power point voltage.	V
Idcmax	The maximum DC voltage input, typically at or near the photovoltaic array's maximum power point current.	A
Coefficient 0	Empirically-determined coefficient that defines the relationship between AC and DC power levels at the reference operating condition.	1/V
Coefficient 1	Empirically-determined coefficient that defines the value of the maximum DC power level.	1/V
Coefficient 2	Empirically-determined coefficient that defines the value of the self-consumption power level.	1/V
Coefficient 3	Empirically-determined coefficient that defines the value of Coefficient 0.	1/V
Vin,min	Manufacturer-specified minimum DC voltage, as described in CEC test protocol (see reference above).	V
Vin,nom	The average of Vin,min and Vin,max, as described in the CEC test protocol (see reference above).	V
Vin,max	Manufacturer-specified maximum DC voltage, as described in CEC test protocol (see reference above). The test protocol specifies that the inverter's maximum DC voltage should not exceed 80% of the array's maximum allowable open circuit voltage.	V

About the Single Point Efficiency Inverter Model

The inverter single-point efficiency model calculates the inverter's AC output by multiplying the DC input (equivalent to the array's derated DC output) by a fixed DC-to-AC conversion efficiency that you specify on the Inverter page. Unlike the Sandia inverter model, the single-point efficiency model assumes that the inverter's efficiency does not vary under different operating conditions.

To use the single-point efficiency inverter performance model:

On the Inverter page, choose **Single Point Efficiency Inverter**.

1. Enter the inverter's rated AC power output in Watts. This information is available on manufacturer specifications sheets.
2. Enter the inverter's conversion efficiency as a percentage.

Note that manufacturer specifications may include both a peak efficiency, which is the inverter's maximum efficiency; and a CEC weighted efficiency value, which is an average value that better represents the efficiency over a range of operating conditions.

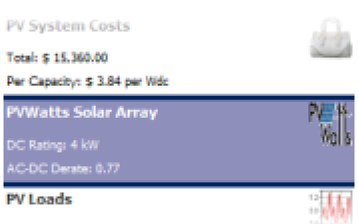
Solar Advisor calculates the inverter's rated DC power input using the following equation:

$$P_{\text{InverterDC}} = \frac{P_{\text{InverterAC}}}{\eta_{\text{Inverter}}}$$

Where,

$P_{InverterAC}$ (W_{AC})	Rated AC output power in Watts.
$P_{InverterDC}$ (W_{DC})	Rated DC output power in Watts, calculated based on Power (dc)
$\eta_{Inverter}$ (%)	Efficiency

5.8.7 PV Loads



To view the PV Loads page, click **PV Loads** on the main window's navigation menu. Note that for the PV Loads page to be available, the technology option in the Technology and Market window must be Photovoltaics - PVWatts Performance Model.

The PV Loads page allows you to specify a file that contains load data.

Note. Solar Advisor's load feature is currently under development. The simple implementation is intended for testing purposes. Feel free to experiment with the feature. If you have questions or feedback about modeling loads in Solar Advisor, please contact Solar.Advisor.Support@nrel.gov.

The following information will help you experiment with the loads feature:

- The feature is only available with the PVWatts Solar Array model. It does not work with the other SAM photovoltaic performance model options.
- Solar Advisor comes with a set of load data files for several cities in the United States. The files are located in the \samples\Residential Load Data folder.
- A load data file consists of a single column and 8,761 rows of data. The first row contains a name identifying the data, and the second through 8,761st row contain average hourly electric load values in kW.
- The PV load feature works in conjunction with the PV Storage model. Solar Advisor only uses load data when the total battery capacity on the PV Storage page is greater than zero.
- The load data appears in DView as "P_LOAD," and on the hourly tab of the results workbook as "Load Demand (kWh), Hourly."

5.8.8 PV Storage

To view the PV Storage page, click **PV Storage** on the main window's navigation menu. Note that for the PV Storage page to be available, the technology option in the Technology and Market window must be Photovoltaics - PVWatts Performance Model.

The PV Storage page allows you to specify the characteristics of the battery storage system.

Note. Solar Advisor's PV storage feature is currently under development. The current implementation is intended for testing purposes. Feel free to experiment with the feature. If you have questions or feedback about modeling battery storage in Solar Advisor, please contact Solar.Advisor.Support@nrel.gov.

The following information will help you experiment with the PV storage feature:

- The battery parameters determine the basic charging characteristics of the battery system.
- The battery's operation is determined by the timing control options and the schedule matrices.
- You can visually explore the results in DView to see how the model dispatches energy from the photovoltaic array, grid, and to and from battery.

Input Variable Reference

Battery Parameters

Variable	Description	Units
Total Battery Capacity	The total battery bank storage capacity in kWh. (kWh = Ah × V)	kWh
Roundtrip Efficiency	The battery's round-trip efficiency. Typically between 70% and 85% for batteries used in photovoltaic systems.	%
Initial Stored Energy	Battery state of charge at the beginning of the simulation. A fully charged battery would have an initial stored energy equal to the total battery capacity. A fully discharged battery would have an inital value of zero.	kWh
Min. Allowable State of Charge	The minimum battery capacity as a percentage of the total battery capacity.	%
Hours to Fully Charge/Discharge	The time to fully discharge the battery bank at the maximum discharge rate.	hours
Max. Charge/ Discharge Power	The maximum charge and discharge rate. Calculated by dividing the total battery capacity by the hours to fully charge/discharge.	kW

Solar Array Operation

Option	Description

Disable Solar Array Power Output	Choose this option to model a system with a load served by the grid and a battery, but no photovoltaic array. This option makes it possible to evaluate the cost of a battery storage system.

Battery Dispatch Timing Control

Option	Description
Force charging from the grid	Energy from the grid is used to charge the battery during hours when the battery capacity is at less than 100% of the total battery capacity.
Allow discharging of the battery?	Energy can be drawn from the battery bank.
Allow charge (from excess solar)?	Energy can be delivered to the battery bank from the solar array during hours when the solar array power exceeds the load requirement.

Battery Dispatch Control

The battery's operation is determined by the three timing control options and how they are assigned to the dispatch schedule matrices. The following tips will help you experiment with the dispatch controls:

- For each of the four periods, you can assign any combination of the three timing control options, which are defined above.
- The two matrices allow you to define a separate battery dispatch control schedule for weekdays and weekends.
- To assign a period to a month and hour of day, select cells in a matrix and type a period number. For example, to assign Period 3 to 6 am through 5 pm from June through July, select the cells in the June and July rows and 6 am through 5 pm columns and type the number 3.
- When you assign a period to a matrix, Solar Advisor applies the timing controls that you checked for the period to the times indicated in the matrix.

5.9 Parabolic Trough Systems

A parabolic trough system is a type of concentrating solar power (CSP) system that collects direct normal solar radiation and converts it to thermal energy that runs a power block to generate electricity. The components of a parabolic trough system are the solar field, power block, and in some cases thermal energy storage system. The solar field collects heat from the sun and consists of parabolic, trough-shaped solar collector assemblies (SCAs) that focus direct normal solar radiation onto tubular heat collection elements (HCEs) or receivers. Each collector assembly consists of mirrors and a structure that supports the mirrors and heat collection elements, allows it to track the sun, and can withstand wind-induced forces. Each heat collection element consists of a metal tube with a solar radiation absorbing surface in a vacuum inside a coated glass tube.

Note. Many of the input variables in the parabolic trough model are interrelated and should be changed together. For example, the storage capacity, which is expressed in hours of thermal storage, should not be changed without changing the tank heat loss value, which depends on the size of the storage system. Some of these relationships are described in this documentation, but not all. If you have questions about parabolic trough input variables, please contact Solar Advisor Support at solar.advisor.support@nrel.gov.

A heat transfer fluid (HTF) transports heat from the solar field to the power block and other components of the system. The power block is based on conventional power cycle technology, using a turbine to convert thermal energy from the solar field to electric energy. The parabolic trough systems may include a fossil-fuel backup system.

The concentrating solar power model in the current version of Solar Advisor is based on NREL's Excelergy software. For a more detailed description of the model, please download the CSP trough reference manual from the Solar Advisor website's support page: https://www.nrel.gov/analysis/sam/support.html.

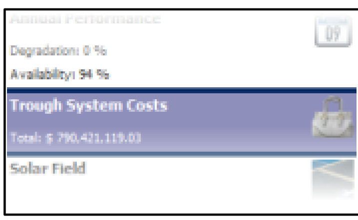
To use the model, the technology option on the Technology and Market window should be Concentrating Solar Power, Parabolic Trough System.

For an example of parabolic trough systems, open the sample template *Sample Parabolic Systems*: On the File menu, click **Open Sample Template** and select the template from the list. The template contains three cases. The first case represents a 100 MW baseline system with a medium temperature heat-transfer fluid and an indirect 2-tank thermal energy storage system. The second case represents a similar 100 MW system with dry cooling. The third case shows how to optimize the solar field thermal energy storage system size to minimize the system levelized cost of energy, and is described in Solar Multiple Optimization.

The parabolic trough input pages for this option described in this section are:

- Trough System Costs
- Solar Field
- SCA / HCE (solar collector assembly / heat collection element)
- Power Block
- Thermal Storage
- Parasitics
- User Variables

5.9.1 Trough System Costs



To view the Trough System Costs page, click **Trough System Costs** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Parabolic Trough System.

Solar Advisor uses the variables on the Trough System Costs page to calculate the project investment cost and annual operating costs reported in the project cash flow and used to calculate cost metrics reported in the Metrics table.

Because only the Total Installed Cost value affects the cash flow calculations, you can assign capital costs to the different cost categories in whatever way makes sense for your analysis. For example, you could assign the cost of designing the solar field to the solar field cost category or to the engineer-procure-construct category with equivalent results. The categories are provided to help you keep track of the different costs, but do not affect the economic calculations. After assigning costs to the categories, verify that the total installed costs value is what you expect.

Variable values in boxes with white backgrounds are values that you can edit. Boxes with blue backgrounds contain calculated values or values from other pages that Solar Advisor displays for your information.

Note: The cost values in the sample files are intended to illustrate Solar Advisor's use. The cost data are meant to be realistic, but not to represent actual costs for a specific project. Actual costs will vary depending on the market, technology and geographic location of a project. Because of price volatility in solar markets, the cost data in the sample files is likely to be out of date. For more information see the Solar Advisor Model website, https://www.nrel.gov/analysis/sam/cost_data.html.

Contents

- Input Variable Reference describes the input variables on the Trough System Costs page.
- Entering Periodic Operation and Maintenance Costs explains how to use annual schedules to assign operation and maintenance costs to particular years in the project cash flow.

Input Variable Reference

Direct Capital Costs

A direct capital cost represents an expense for a specific piece of equipment or installation service that applies in year zero of the cash flow.

Note: Because Solar Advisor uses only the Total Installed Cost value in cash flow calculations, how you distribute costs among the different direct capital cost categories does not affect the final results.

Variable	Description	Units
Site Improvements	A cost per square meter of solar field area to account for expenses related to site preparation and other equipment not included in the solar field cost category.	$/m^2
Solar Field	A cost per square meter of solar field area to account for expenses related to installation of the solar field, including labor and equipment.	$/m^2
HTF System	A cost per square meter of solar field area to account for expenses related to installation of the heat transfer fluid pumps and piping, including labor and equipment.	$/m^2
Storage	Cost per thermal megawatt-hour of storage capacity to account for expenses related to installation of the thermal storage system, including equipment and labor.	$/kWht

Fossil Backup	Cost per electric megawatt of power block nameplate capacity to account for the installation of a fossil backup system, including equipment and labor.	$/kWe
Power Plant	Cost per electric megawatt of power block nameplate capacity to account for the installation of the power block, including equipment and labor.	$/kWe
Contingency	A percentage of the sum of the site improvements, solar field, HTF system, storage, fossil backup, and power plant costs to account for expected uncertainties in direct cost estimates.	%
Total Direct Cost	The sum of improvements, solar field, HTF system, storage, fossil backup, power plant costs, and contingency costs.	$

Indirect Capital Costs

An indirect cost is typically one that cannot be identified with a specific piece of equipment or installation service, and may include all other costs that are built into the price of the system, such as profit, overhead, and shipping costs. Depending on the purpose of your analysis, you may decide to distribute profit among the direct cost categories or include them as a single value in an indirect category.

Note: Because Solar Advisor uses only the total installed cost value in cash flow calculations, how you distribute costs among the different indirect capital cost categories does not affect the final results.

Variable	Description	Units
Engineer, Procure, Construct	Costs associated with design and construction of the project, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Project, Land, Miscellaneous	Costs associated with profit, overhead (including marketing), permitting, or shipping, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Sales Tax	Percentage of direct costs to which sales tax applies, calculated by multiplying Total Direct Cost by the sales tax rate from the Financials page and the percentage that you specify.	%
Total Indirect Cost	The sum of Engineer-Procure-Construct costs, Project-Land-Miscellaneous costs, and sales tax.	$

Total Installed Cost

The total installed cost is the project's investment cost that applies in year zero of the project cash flow. Solar Advisor uses this value to calculate loan amounts and debt interest payments based on inputs on the Financing page, and to calculate tax credit and incentive payment amounts for incentive based tax credits and incentives defined on the Tax Credit Incentives page and Payment Incentives pages.

Variable	Description	Units
Total Installed Cost	The sum of total direct cost and total indirect cost.	$
Total Installed Cost per Capacity	Total installed cost divided by the total system capacity in Watts-DC of array capacity for PV systems and electric kilowatts of power block nameplate capacity for CSP systems. This value is provided for reference only and not used in cash flow calculations.	$/Wdc or $/kW

Operation and Maintenance Costs

Operation and Maintenance (O&M) costs represent annual expenditures on equipment and services that occur after the system is installed. Solar Advisor allows you to enter O&M costs in three ways: Fixed annual, fixed by capacity, and variable by generation. O&M costs are reported on the project cash flow.

For each O&M cost category, you can specify an annual escalation rate to represent an expected annual increase in O&M cost above the annual inflation rate specified on the Financing page. For an escalation rate of zero, the O&M cost in years two and later is the year one cost adjusted for inflation. For a non-zero escalation rate, the O&M cost in years two and later is the year one cost adjusted for inflation plus escalation.

For expenses such as component replacements that occur in particular years, you can use an annual schedule to assign costs to individual years. See below for details.

O&M Cost Category	Description	Units
Fixed Annual Cost	A fixed annual cost applied to each year in the project cash flow.	$/yr
Fixed Cost by Capacity	A fixed annual cost proportional to the array capacity in DC kilowatts.	$/kWdc-yr
Variable Cost by Generation	A variable annual cost proportional to the system's total annual electrical output in AC megawatt-hours. The annual output depends on either the performance model's calculated first year value and the degradation rate specified on the Annual Performance page, or on an annual schedule of costs, depending on the option chosen.	$/MWh-yr
Fossil Fuel Cost	The cost per million British thermal units for fuel. Solar Advisor uses the conversion factor 1 MWh = 3.413 MMBtu. Applies only to the generic fossil, CSP trough, and CSP tower systems. The photovoltaic and CSP dish models ignore the fuel cost input variable. (When the fossil fill fraction variable on the Thermal Storage page for troughs or towers is greater than zero, the systems consume fuel for backup energy.)	$/MMBtu

Note. For information on water consumption and other operation and maintenance costs and requirements for concentrating parabolic trough systems, see the Troughnet website: http://www.nrel.gov/csp/troughnet/power_plant_systems.html. For information on operation and maintenance costs for photovoltaic systems, see the California Energy Commission's online Distributed Energy Resource guide http://www.energy.ca.gov/distgen/economics/operation.html.

Entering Periodic Operation and Maintenance Costs

Solar Advisor allows you to specify any of the four operation and maintenance cost categories as an annual schedule. An annual schedule makes it possible to assign a cost to particular years in the analysis period. Annual schedules can be used to account for inverter replacement costs and other periodic costs that do not recur on a regular annual basis.

After running simulations, you will see the periodic costs in the project cash flow, and they will be accounted for in the other results displayed in the Metrics table.

Note. Solar Advisor does not calculate any residual or salvage value remaining in inverters or other system components at the end of the analysis period.

To assign costs to particular years:

1. In the Fixed Annual Cost category, note that the "Value" label is blue indicating that the single value mode is active for the variable.

2. Click the button with the "Sched" label to change the mode to schedule and activate the Edit button.

3. Click **Edit**.
4. In the Edit Schedule window, use the horizontal scroll bar to find the first year in which a cost occurs, and type the cost in current or constant dollars for that year.

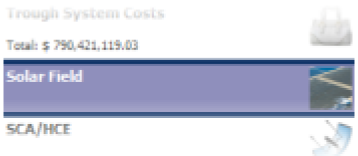
   To delete a value, select it and press the Delete key on your keyboard.

Note. You must type a value for each year. If you delete a value, Solar Advisor will clear the cell, and you must type a number in the cell or Solar Advisor will consider the schedule to be invalid. Type a zero for years with no inverter replacement cost.

5. When you have finished editing the schedule, click **Accept**.

Because you must specify an O&M cost category as either an annual cost or annual schedule, to assign both a recurring annual fixed cost and periodic replacement cost, you must type the recurring cost in each year of the annual schedule, and for years with replacement costs, type the sum of the recurring and replacement costs. Note that dollar values in the annual schedule are in nominal or current dollars. Inflation and escalation rates do not apply to values in annual schedules.

5.9.2 Solar Field



To view the Solar Field page, click **Solar Field** on the main window's navigation menu. Note that for the Solar Field page to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Parabolic Trough System.

The Solar Field page displays variables and options that describe the size and properties of the solar field, properties of the heat transfer fluid, reference design specifications of the solar field, and collector orientation.

For a more detailed description of the model, please download the CSP trough reference manual from the Solar Advisor website's support page: https://www.nrel.gov/analysis/sam/support.html.

Contents

Input Variable Reference

Field Layout

Name	Description	Units
Option 1: Solar Multiple, and Option 2: Solar Field Area	For option 1, (solar multiple mode), SAM calculates the solar field area and displays it in Solar Field Area (calc). For option 2 (solar field area mode), SAM calculates the solar multiple and displays it in Solar Multiple (calc). Note that SAM does not use the value that appears dimmed for the inactive option.	--
Distance Between SCAs in Row	The end-to-end distance in meters between SCAs (solar collection elements, or collectors) in a single row, assuming that SCAs are laid out uniformly in all rows of the solar field. SAM uses this value to calculate the end loss. This value is not part of the SCA library on the SCA / HCE page, and should be verified manually to ensure that it is appropriate for the SCA type that appears on the SCA / HCE page.	m

Name	Description	Units
Row spacing, center-to-center	The centerline-to-centerline distance in meters between rows of SCAs, assuming that rows are laid out uniformly throughout the solar field. SAM uses this value to calculate the row-to-row shadowing loss factor. This value is not part of the SCA library, and should be verified manually to ensure that it is appropriate for the SCA type that appears on the SCA / HCE page.	m
Number of SCAs per Row	The number of SCAs in each row, assuming that each row in the solar field has the same number of SCAs. SAM uses this value in the SCA end loss calculation.	--
Deploy Angle	The SCA angle during the hour of deployment. A deploy angle of zero for a northern latitude is vertical facing due east. SAM uses this value along with sun angle values to determine whether the current hour of simulation is the hour of deployment, which is the hour before the first hour of operation in the morning. SAM assumes that this angle applies to all SCAs in the solar field.	degrees
Stow Angle	The SCA angle during the hour of stow. A stow angle of zero for a northern latitude is vertical facing east, and 180 degrees is vertical facing west. SAM uses this value along with the sun angle values to determine whether the current hour of simulation is the hour of stow, which is the hour after the final hour of operation in the evening.	degrees

Heat Transfer Fluid

Name	Description	Units
Solar Field HTF Type	Name of the heat transfer fluid type. The Minimum HTF Temp value depends on the HTF type. The available fluid types are limited to those described in the HTF Properties section.	--
Property table for user-defined HTF	When the Solar Field HTF type is "User-defined," click **Edit** to enter properties of a custom HTF.	--
Solar Field Inlet Temp	Design temperature of the solar field inlet in degrees Celsius used to calculate design solar field average temperature, and design HTF enthalpy at the solar field inlet. SAM also limits the solar field inlet temperature to this value during operation and solar field warm up, and uses this value to calculate the actual inlet temperature when the solar field energy is insufficient for warm-up.	ºC
Solar Field Outlet Temp	Design temperature of the solar field outlet in degrees Celsius, used to calculate design solar field average temperature. It is also used to calculate the design HTF enthalpy at the solar field outlet, which SAM uses to determine whether solar field is operating or warming up. SAM also uses this value to calculate the actual inlet temperature when the solar field energy is insufficient for warm-up.	ºC
Solar Field Initial Temp	Initial solar field inlet temperature. The solar field inlet temperature is set to this value for hour one of the simulation.	ºC

Name	Description	Units
Piping Heat Losses @ Design Temp	Solar field piping heat loss in Watts per square meter of solar field area calculated based on design variables. Used in solar field heat loss calculation.	W/m^2
Piping Heat Loss Coeff (1-3)	These three values are used with the solar field piping heat loss at design temperature to calculate solar field piping heat loss.	-ºC-1, -ºC-2, -ºC-3
Solar Field Piping Heat Losses	Design solar field piping heat losses. This value is used only in the solar field size equations. This design value different from the hourly solar field pipe heat losses calculated during simulation.	W/m^2
Minimum HTF Temp	Minimum heat transfer fluid temperature in degrees Celsius. SAM automatically populates the value based on the properties of the solar field HTF type, i.e., changing the HTF type changes the minimum HTF temperature. The value determines when freeze protection energy is required, is used to calculate HTF enthalpies for the freeze protection energy calculation, and is the lower limit of the average solar field temperature.	ºC
HTF Gallons Per Area	Volume of HTF per square meter of solar field area, used to calculate the total mass of HTF in the solar field, which is used to calculate solar field temperatures and energies during hourly simulations. The volume includes fluid in the entire system including the power block and storage system if applicable. Example values are: SEGS VI: 115,000 gal VP-1 for a 188,000 m^2 solar field is 0.612 gal/m2, SEGS VIII 340,500 gal VP-1 and 464,340 m^2 solar field is 0.733 ga/m^2.	gal/m^2

Solar Multiple (Design Point)

Note. The ambient temperature, direct normal radiation, and wind velocity reference variables differ from the hourly weather data that Solar Advisor uses for system output calculations. Solar Advisor uses the reference ambient condition variables to size the solar field. Hourly data from the weather file shown on the Climate page determine the solar resource at the site.

Name	Description	Units
Solar Multiple (calc)	The solar field area expressed as a multiple of the exact area (see "Exact Area" below). SAM uses the calculated solar multiple value to calculate the design solar field thermal energy and the maximum thermal energy storage charge rate.	--
Solar Field Area (calc)	The solar field area expressed in square meters. SAM uses this value in the delivered thermal energy calculations. The solar field area is the total collection aperture area, which is less than the mirror area. The solar field area does not include space between collectors or the land required by the power block.	m^2
Ambient Temp	Reference ambient temperature in degrees Celsius. Used to calculate the design solar field pipe heat losses.	ºC

Name	Description	Units
Direct Normal Radiation	Reference direct normal radiation in Watts per square meter. Used to calculate the solar field area that would be required at this insolation level to generate enough thermal energy to drive the power block at the design turbine thermal input level. SAM also uses this value to calculate the design HCE heat losses displayed on the SCA / HCE page. The appropriate value depends on the system location. For example, 950 W/m^2 is an appropriate value for the Mohave Desert and typical locations under consideration for development in the U.S., and 800 W/m^2 is appropriate for southern Spain. See below for more information.	W/m^2
Wind Velocity	Reference wind velocity in meters per second. SAM uses this value to calculate the design HCE heat losses displayed on the SCA / HCE page.	m/s
Exact Area	The solar field area required to deliver sufficient solar energy to drive the power block at the design turbine gross output level under reference weather conditions. It is equivalent to a solar multiple of one, and used to calculate the solar field area when the Layout mode is Solar Multiple.	m^2
Exact Num. SCAs	The exact area divided by the SCA aperture area. SAM uses the nearest integer greater than or equal to this value in the solar field size equations to calculate value of the Solar Field Area (calc) variable described above. The exact number of SCAs represents the number of SCAs in a solar field for a solar multiple of one.	--
Aperture Area per SCA	SCA aperture area variable from SCA / HCE page. SAM uses this value in the solar field size equations to calculate the value of the Solar Field Area (calc) variable described above.	m^2
HCE Thermal Losses	Design HCE thermal losses based on the heat loss parameters on SCA / HCE page. SAM uses this value only in the solar field size equations. This design value is different from the hourly HCE thermal losses calculated during simulation.	W/m^2
Optical Efficiency	Weighted optical efficiency variable from SCA / HCE page. SAM uses this design value only in the solar field size equations. This design value is different from SCA efficiency factor calculated during simulations.	--
Design Turbine Thermal Input	Design turbine thermal input variable from Power Block page. Used to calculate the exact area described above.	MWt

Orientation

Name	Description	Units
Collector Tilt	The collector angle from horizontal, where zero degrees is horizontal. A positive value tilts up the end of the array closest to the equator (the array's south end in the northern hemisphere), a negative value tilts down the southern end. Used to calculate the solar incidence angle and SCA tracking angle. SAM assumes that the SCAs are fixed at the tilt angle.	degrees
Collector Azimuth	The azimuth angle of the collector, where zero degrees is pointing toward the equator, equivalent to a north-south axis. Used to calculate the solar incidence angle and the SCA tracking angle. SAM calculates the SCAs' tracking angle for each hour, assuming that the SCAs are oriented 90 degrees east of the azimuth angle in the morning and track the daily movement of the sun from east to west.	degrees

Choosing the Field Layout Mode

Solar Advisor provides two options for defining the size of the solar field: Solar Multiple (Option 1) and Solar Field Area (Option 2).

In Solar Multiple mode, Solar Advisor calculates the solar field area based on the solar multiple, the power block's rated thermal input capacity, reference weather conditions, and design heat loss parameters. For a solar multiple of one, Solar Advisor calculates the solar field area that, under reference weather conditions and accounting for heat losses from the field, generates a thermal energy amount equal to the design turbine thermal input value from the Power Block page.

In Solar Field Area mode, SAM uses the user-defined solar field area, and calculates the equivalent solar multiple.

The solar multiple mode is useful for determining the optimal solar field area for a given location. By varying the solar multiple, you can find the value that minimizes the levelized cost of energy for a given power block capacity. The levelized cost of energy metric captures the tradeoff between the benefit of higher annual electricity output and the cost of increased capital expenditures associated with increasing the solar field area.

Using the Solar Multiple mode is best for analyses involving a known or fixed power block capacity because Solar Advisor automatically calculates the solar field area based on the power block capacity. The Solar Field Area mode is best for analyses involving a known or fixed solar field area, but requires that the power block capacity be manually adjusted to match the solar field output.

The third case in the *Standard CSP Parabolic Trough Systems.zsam* sample file, "100 MW Baseline - Parameterized Storage," illustrates this approach, comparing levelized cost of energy for systems with different solar multiple values with and without storage. For a description of the case, see Solar Multiple Optimization.

About the Solar Multiple Reference Conditions

The three reference condition variables, ambient temperature, direct normal radiation, and wind velocity, are the ambient conditions at which the solar field thermal output is equal to the power block's design thermal input multiplied by the solar multiple. In other words, under reference conditions, the system operates at the system's design capacity. Note that these reference condition variables are system design parameters, and do not describe the weather conditions at the project site. Weather conditions are determined by the data in the weather file shown on the Climate page.

The reference ambient temperature and reference wind velocity variables are used to calculate the design heat losses, and do not have a significant effect on the solar field sizing calculations. Reasonable values for those two variables are the average annual measured ambient temperature and wind velocity at the project location.

The reference direct normal radiation value, on the other hand, does have a significant impact on the solar field size calculations. For example, a system with reference conditions of 25°C, 950 W/m^2, and 5 m/s (ambient temperature, direct normal radiation, and wind speed, respectively), a solar multiple of 2, and a 100 MWe power block, requires a solar field area of 871,940 m^2. The same system with reference direct normal radiation of 800 W/m^2 requires a solar field area of 1,055,350 m^2. Note that with a solar multiple of 2, both systems would produce two times the thermal energy required to drive the power block at its rated capacity during hours in which the direct normal radiation, temperature, and wind speed from the weather file are equal to the reference conditions.

For systems in the Mohave Desert of the United States, a value of 950 W/m^2 is reasonable, and for southern Spain, a value of 800 W/m^2 is reasonable.

Four factors affect the choice of a reference direct normal radiation value for a given system:

- Location defined on the Climate page.
- Storage capacity defined on the Thermal Storage page.
- Maximum storage charge rate defined on the Thermal Storage page.
- Variability of the solar resource over the year, determined by the weather data as defined on the Climate page.

Using too low of a reference direct normal radiation value results in excessive dumped energy: The actual direct normal radiation from the weather data is frequently greater than the reference value so that the solar field sized for the low reference radiation value often produces more energy than required by the power block, and excess thermal energy is either dumped or put into storage. On the other hand, using too high of a reference direct normal radiation value results in an undersized solar field that produces sufficient thermal energy to drive the power block at its design point only during the few hours when the actual direct normal radiation is at or greater than the reference value.

Method 1 for Choosing the Reference Direct Normal Radiation Value

The first approach to choosing a value for the reference direct normal radiaion value is to set the value to the direct normal radiation value in the weather data that has a cumulative annual frequency value of about 95%.

To display the cumulative distribution function for the direct normal radiation data:

1. On the Climate page, click **View hourly data**.
2. In the data viewer (DView), click the CDF tab and choose Direct Normal Radiation in the variable list to display the "CDF of Direct Normal Radiation" graph.

Method 2 for Choosing the Reference Direct Normal Radiation Value

Another approach to determine the reference direct normal radiation value for a given location is to find the value that minimizes the amount of thermal energy that the system dumps.

To minimize dumped thermal energy:

1. Use Option 1 (Solar Multiple) for the field layout option and set the value to one.
2. Enter an arbitrary value for the reference direct normal radiation, such as 950 W/m^2.
3. Run a simulation.
4. In the hourly results, examine the amount of dumped thermal energy QDump. You can view the variable's hourly values either in the time series data viewer or in Excel.

5. If the amount of dumped thermal energy is excessive, try a lower value for the reference direct normal radiation value and repeat the above steps.

To determine the reference solar radiation value based on dumped thermal energy:

1. On the Solar Field page use the Solar Multiple option under Layout and set its value to one.
2. Enter an arbitrary value for the reference solar radiation value.
3. Run a simulation.
4. In the hourly results, examine the amount of dumped thermal energy QDump. You can view the variable's hourly values by clicking either **Spreadsheet** or **Time Series Graph**.
5. If the amount of dumped thermal energy is excessive, try a lower value for the reference solar radiation and repeat the above steps.

Once you have chosen a value for the reference solar radiation, you can optimize the solar multiple and storage capacity to minimize the system's levelized cost of energy as illustrated in the third case of the *Parabolic Trough Systems.zsam* sample file, "100 MW Baseline - Parameterized Storage" case described in Solar Multiple Optimization.

About the Heat Transfer Fluid Properties

The solar field heat transfer fluid (HTF) absorbs heat as it circulates through the heat collection elements in the solar field and transports the heat to the power block where it is used to run a turbine. Several types of heat transfer fluid are used for trough systems, including hydrocarbon (mineral) oils, synthetic oils, silicone oils and nitrate salts.

When you choose a heat transfer fluid, Solar Advisor populates the minimum HTF temperature variable with that oil's minimum operating temperature value. Solar Advisor will not allow the system to operate at a temperature below the minimum HTF temperature. Electric heaters in the system maintain the fluid temperature. Solar Advisor accounts for the electric power requirement for heating on the Parasitics page.

The remaining heat transfer fluid parameters describe characteristics of the solar field that affect the performance of the heat transfer fluid. The two area-related parameters refer to square meters of solar field area. If you are unsure of what values to use for these parameters, refer to the Solar Field page for the case in *Sample Parabolic Trough Systems.zsam*.

Note. Solar field outlet temperature and solar field area data for U.S. parabolic trough power plants are available on the Troughnet website at http://www.nrel.gov/csp/troughnet/power_plant_data.html.

Table 17. Heat transfer fluids.

Name	Type	Min HTF Temp ºC	Max Operating Temp ºC	Freeze Point	Comments
Solar Salt	Salt	260	600	220	
Caloria	mineral hydrocarbon oil	-20	300	-40	used in first Luz trough plant, SEGS I
Hitec XL	Nitrate salt	150	500	120	New generation
Therminol VP-1	mixture of biphenyl and diphenyl oxide	50	400	12	Standard for current generation oil HTF systems
Hitec	Nitrate salt	175	500	140	For high-temperature systems
Dowtherm Q	Synthetic oil	-30	330	-50	New generation
Dowtherm RP	Synthetic oil	-20	350	-40	New generation

Equations for Calculated Values

Calcualted values appear on the Solar Field page in blue type with blue backgrounds.

Solar Multiple and Solar Field Area

When the Layout option is Solar Multiple (Option 1), Solar Advisor calculates the solar field area based on the value you enter for the solar multiple:

$$A_{SolarFieldCalculated} = F_{SolarMultiple} \cdot A_{ExactArea}$$

When the Layout option is Solar Field Area (Option 2), Solar Advisor calculates the solar multiple based on the value you enter for the solar field area:

$$F_{SolarMultipleCalculated} = \frac{A_{SolarField}}{A_{ExactArea}}$$

Where,

$A_{ExactArea}$ (m^2)	Exact Area
$A_{SolarField}$ (m^2)	Solar Field Area
$A_{SolarFieldCalculated}$ (m^2)	Solar Field Area (calc)
$F_{SolarMultiple}$	Solar Multiple
$F_{SolarMultipleCalculated}$	Solar Multiple (calc)

Exact Area and Exact Number of SCAs

The exact area is the solar field area for a solar multiple of one calculated as follows:

$$A_{ExactArea} = \frac{Q_{DesignTurbineThermalInput}}{Q_{DirectNormalRadiation} \cdot \eta_{OpticalEfficiency} - Q_{HCEThermalLosses} - Q_{SolarFieldPipingHeatLosses}}$$

The values used for these equations are displayed under Solar Multiple Reference Conditions and Values From Other Pages, except for the five F_{ET} factors, which are on the Power Block page.

Where,

$A_{ExactArea}$ (m^2)	Exact Area
$F_{ET0}...F_{ET4}$	Turb. Part Load Elec to Therm from the Power Block page
$\eta_{OpticalEfficiency}$	Optical Efficiency from the SCA / HCE page
$Q_{DesignTurbineThermalInput}$ (W)	Design Turbine Thermal Input from the Power Block page
$Q_{DirectNormalRadiation}$ (W/m^2)	Direct Normal Radiation
$Q_{HCEThermalLosses}$ (W/m^2)	HCE Thermal Losses from the SCA / HCE page
$Q_{SolarFieldPipingHeatLosses}$ (W/m^2)	Solar Field Piping Heat Losses

Note. Direct Normal Radiation does not represent weather conditions at the site, but is the reference radiation value used to calculate the solar field area when the solar multiple is one.

$$N_{ExactNumberOfSCAs} = \frac{A_{ExactArea}}{A_{ApertureAreaPerSCA}}$$

Where,

$A_{ApertureAreaPerSCA}$ (m^2)	Aperture Area per SCA, equivalent to SCA Aperature Area on SCA / HCE page
$A_{ExactArea}$ (m^2)	Exact Area
$N_{ExactNumberOfSCAs}$	Exact Number of SCAs

Solar Field Piping Heat Losses

The solar field piping heat losses are calculated using parameters of the heat transfer fluid and the reference ambient temperature:

$$Q_{SolarFieldPipeHeatLosses} = \left(F_{PHL3} \cdot \Delta T^3 + F_{PHL2} \cdot \Delta T^2 + F_{PHL1} \cdot \Delta T\right) \cdot Q_{SFPipeHLDesign}$$

$$\Delta T = T_{Average} - T_{Ambient}$$

$$T_{Average} = \frac{T_{SFinDesign} + T_{SFoutDesign}}{2}$$

Where,

F_{PHL1} ... F_{PHL3}	Piping Heat Loss Temp Coeff 1 through 3
$Q_{SFPipeHLDesign}$ (W/m^2)	Solar Field Piping Heat Losses @ Design T
$Q_{SolarFieldPipeHeatLosses}$ (W/m^2)	Solar Field Piping Heat Losses
$T_{Ambient}$ (°C)	Ambient Temperature
$T_{SFinDesign}$ (°C)	Solar Field Inlet Temperature
$T_{SFoutDesign}$ (°C)	Solar Field Outlet Temperature

5.9.3 Solar Multiple Optimization

This section describes the third case in the file *Sample Parabolic Trough Systems.zsam*, "100 MW Baseline - Parameterized Storage." The case demonstrates how to optimize the solar multiple for a parabolic trough system with storage to minimize the system's levelized cost of energy.

For a description of the variables used for this analysis, see the Solar Field page and Thermal Storage page descriptions. If you are not familiar with Solar Advisor's parametric variables, you may want to read Parametric Analysis, which explains how to configure a parametric analysis.

For a parabolic trough system with no storage, the optimal levelized cost of energy typically occurs at a solar multiple of between 1.4 and 1.5. Because a trough system only operates at its design point (solar multiple of one) for a very few hours of the year, over-sizing the system (solar multiple greater than one) allows it to operate closer to the design point for more hours of the year. The system with the oversized solar field produces more electricity, thereby reducing the system's levelized cost of energy. However, there is a trade-off between the increased installation cost of the larger system and the increased electric energy output: As the solar field size increases beyond a certain point, the higher cost outweighs the benefit of the higher output. Adding storage to the system introduces another level of complexity: Systems with storage can increase system output by storing energy from an even larger solar field for use during times when the solar field output is below the design point, but the thermal energy storage system's cost and thermal losses have a negative effect on the levelized cost of energy.

The analysis in this case investigates the levelized cost of energy (LCOE) turning point for systems with different solar field and thermal energy storage sizes.

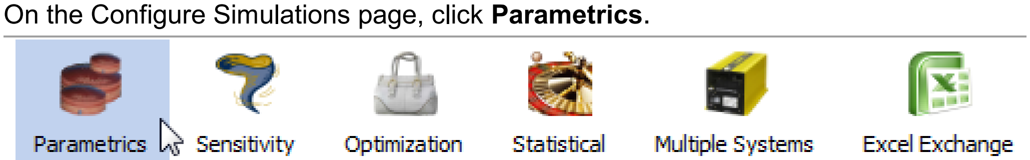
Note that the storage tank heat loss is an input on the Storage page and that its value depends on the storage tank size and type. Whenever you change the value of the Equivalent Full Load Hours of TES variable on the Thermal Storage page, you should also change the Tank Heat Losses value.

When the solar field is sized above its design point, the analysis should account for any energy that might be dumped during periods when the solar field produces more energy than the power block and storage system can handle. Typically, as long as the amount of dumped energy is less than about 10-15% of the new energy resulting from the oversized system, you can reduce the LCOE by increasing solar field size.

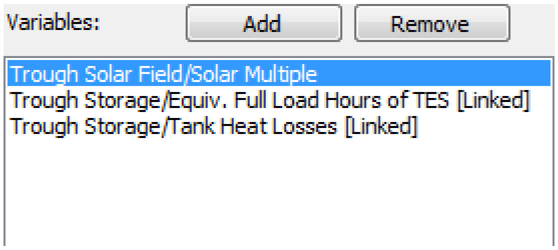
To review the parametric analysis on solar multiple and thermal energy storage:

1. On the file menu, choose **Open Sample Template**, **Sample Parabolic Trough Systems**.
2. Click the 100 MW Baseline - Parameterized Storage tab to display the case.
3. Click Configure Simulations.

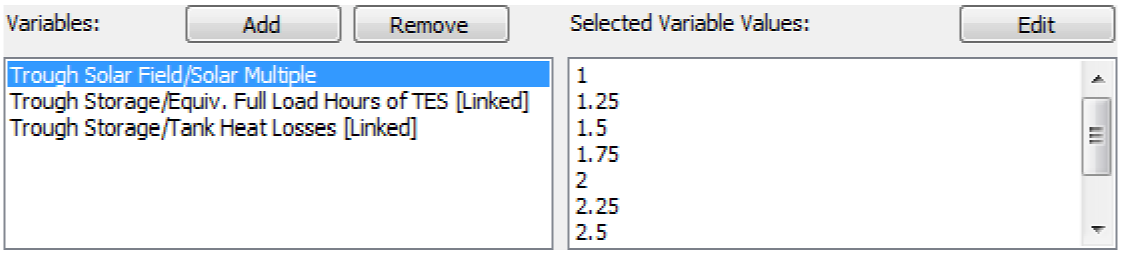
4. On the Configure Simulations page, click **Parametrics**.



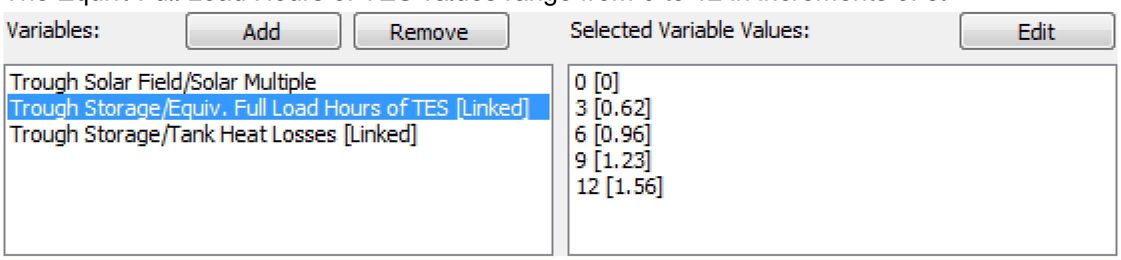
5. Note the three variables defined as parametric variables: Solar Multiple from the Solar Field page, and Equiv Full Load Hours of TES and Tank Heat Losses from the Storage page.



The Solar Multiple values range from 1 to 3.5 in increments of 0.25.



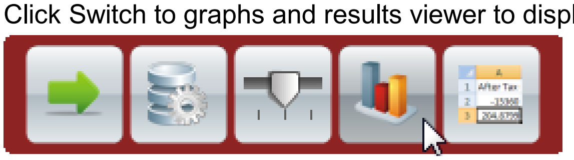
The Equiv. Full Load Hours of TES values range from 0 to 12 in increments of 3.



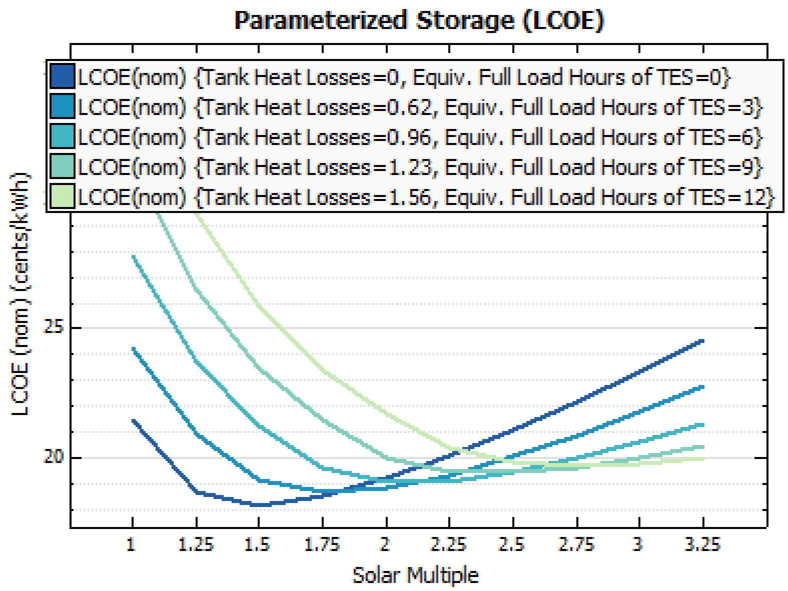
The Equiv Full Load Hours of TES and Tank Heat Loss variables are linked, because the tank heat losses depend on the size of the storage tanks. Solar Advisor will only simulate systems using values of each of the two variables that are in the same row. For example, for 0 hours of storage, Solar Advisor will use 0 for the tank heat loss. For 3 hours of storage, the tank heat loss will be 0.62, etc.

Solar Advisor must simulate one system for each combination of values for the two variables. In this case, 10 values for solar multiple × 5 values for hours of storage = 50 simulations.

6. Click Switch to graphs and results viewer to display the Results page without running simulations.



Solar Advisor displays the Parameterized Storage (LCOE) graph among others on the Results page.



Each line in the graph represents a number of hours of thermal energy storage from the list we saw in the list of parametric values for the Equivalent Full Load Hours of TES variable: 0, 3, 6, 9, and 12 hours of storage. Because the hours of storage variable is linked to the tank heat loss variable, each line also represents a tank heat loss value. We saw those values in the Edit Linked Group window: 0, 0.62, 0.96, 1.23, 1.56.

For the no storage case (the darkest line, zero hours of storage), the lowest levelized cost of energy occurs at a solar multiple of 1.5. For a given storage capacity, as the solar multiple increases, both the area-dependent installation costs electricity output increase. The interaction of these factors causes the levelized cost of energy to decrease as the solar multiple increases from 1, but at some point the cost increase overwhelms the benefit of the increased electric energy output, and the levelized cost of energy begins to increase with the solar multiple.

5.9.4 SCA / HCE

To view the SCA / HCE page, click **Solar Field** on the main window's navigation menu. Note that for the SCA / HCE page to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Parabolic Trough System.

The SCA / HCE page displays the characteristics of the solar collector assembly (SCA) and heat collection elements (HCE) in the solar field. Note that the SCA is often referred to as the collector. The HCE is often referred to as the receiver.

A solar collector assembly (SCA) is an individually tracking component of the solar field that includes mirrors, a supporting structure, and heat collection elements or receivers.

A heat collection element (HCE) is a metal pipe contained in a vacuum within glass tube that runs through the focal line of the trough-shaped parabolic collector. Seals and bellows ensure that a vacuum is maintained in each tube. Anti-reflective coatings on the glass tube maximize the amount of solar radiation that enters the tube. Solar-selective radiation absorbing coatings on the metal tube maximize the transfer of energy from the solar radiation to the pipe.

Note. See http://www.nrel.gov/csp/troughnet/solar_field.html for more information on solar collector assemblies and heat collection elements. Also see relevant articles in the list of publications on the Troughnet website.

For a more detailed description of the model, please download the CSP trough reference manual from the Solar Advisor website's support page: https://www.nrel.gov/analysis/sam/support.html.

Contents

- Input Variable Reference describes the input variables and options on the SCA / HCE page.
- About the SCA Parameters describes the physical charateristics of the four SCAs included in the default library.
- About the HCE Parameters describes the four HCE (receiver) types and five HCE conditions included in the default library.
- About the Mirror Reflectivity Value describes guidelines for choosing a mirror reflectivity value.
- Equations for Calculated Values describes the equations used to calculated the calculated values on the SCA / HCE page.

Input Variable Reference

Solar Collector Assembly (SCA)

The solar collector assembly (SCA) input variables describe the dimensions and optical characteristics of the SCA or collector.

Name	Description	Units
Current SCA inputs	The name of the collector in the SCA library	
SCA Length	Length of a single SCA. Used in SCA end loss calculation.	m
SCA Aperture	Mirror aperture of a single SCA. Used in the row-to-row shadowing loss factor and HCE thermal loss calculations.	m
SCA Aperture Area	Area of aperture of single SCA. Used in the solar field size calculations.	m^2
Average Focal Length	Average trough focal length. Used in end gain and end loss factor calculations.	m
Incident Angle Mod Coeff (1-3)	Incident angle modifier coefficients. Used to calculate the incident angle modifier factor, which is used to calculate the HCE absorbed energy and the solar field optical efficiency.	--
Tracking Error and Twist	Accounts for errors in the SCA's ability to track the sun. Sources of error may include poor alignment of sun sensor, tracking algorithm error, errors caused by the tracker drive update rate, and twisting of the SCA end at the sun sensor mounting location relative to the tracking unit end. A typical value is 0.985. Used to calculate SCA field error factor.	--

Name	Description	Units
Geometric Accuracy	Accounts for SCA optical errors caused by misaligned mirrors, mirror contour distortion caused by the support structure, mirror shape errors compared to an ideal parabola, and misaligned or distorted HCE. A typical range of values is between 0.97 and 0.98. Used to calculate SCA field error factor.	--
Mirror Reflectivity	The solar-weighted hemispherical reflectance of the mirrors. For 4-mm low iron, pristine, second surface tempered glass mirrors, a reasonable value would be 0.95. Used to calculate SCA field error factor.	--
Mirror Cleanliness Factor (avg)	Accounts for dirt and dust on the mirrors that reduce their effective reflectivity. Typically, mirrors are continuously cleaned, but a single mirror may be cleaned once each one or two weeks. The expected overall effect on the total solar field would be an average loss of between one and two percent. A typical value would be 0.985. Used to calculate SCA field error factor.	--
Dust on Envelope (avg)	Accounts for dust on the HCE envelope that affects light transmission. A typical value would be 0.99. Used to calculate HCE heat loss.	--
Concentrator Factor	A additional error factor to make it possible to adjust the SCE performance without modifying the other error factors. Useful for modeling an improved or degraded SCE. The default value is 1. Used to calculate SCA field error factor.	--
Solar Field Availability	Accounts for solar field down time for maintenance and repairs. Used to calculate absorbed energy.	--

Heat Collection Element (HCE)

The HCE variables describe the properties of up to four HCE types that can make up the solar field. This makes it possible to model a solar field with HCEs in different states. Each set of properties applies to one of the HCE types. The Fraction of Field variable determines what portion of the solar field is made up of a given HCE type.

Name	Description	Units
Current HCE inputs	The name of the receiver and its condition. Vacuum refers to an HCE in good condition, lost vacuum, broken glass, and hydrogen refer to different problem conditions. You can define up to four HCE (receiver) conditions.	--
Fraction of Field	Fraction of solar field using this HCE type and condition. Used to calculate HCE field error factor and HCE heat loss.	--
Bellows Shadowing	The portion of the HCE tube that does not absorb solar thermal radiation. Used to calculate HCE field error factor.	--
Envelope Transmissivity	Used to calculate HCE field error factor.	--
Absorber Absorption	Accounts for inefficiencies in the HCE black coating. Used to calculate HCE field error factor.	--

Unaccounted	Allows for adjustment of the HCE performance to explore effect of changes in performance of the HCE without changing the values of other correction factors. A typical value is 1. Used to calculate HCE field error factor.	--
Optical Efficiency (HCE)	The design optical efficiency of each of the four receiver type and condition options. SAM uses the values to calculate the design weighted optical efficiency.	--
Optical Efficiency (Weighted)	The design weighted optical efficiency, representing the average optical efficiency of all receivers in the field (see equations below). SAM uses the value to calculate the solar field area. Note that SAM also calculates a separate HCE optical efficiency value for each hour during simulation that counts for the loss factors on the SCA / HCE page that also accounts for the incident angle modifier factor, which depends on the time of day and collector orientation.	--
Heat Loss Coefficient A0...A6	Used to calculated the HCE heat loss. The default values are based on NREL modeling and test results. (See Forristall 2003 in References.)	--
Heat Loss Factor	The design heat loss factor that applies to the active HCE type and condition. Used to calculate design HCE heat loss that is part of the solar field area equation. The heat loss factor scales the heat loss equation and can be used to fine tune the results when measured heat loss data are available. The default value of 1.0 is valid for the current version of SAM using the default heat loss coefficients.	--
Min windspeed (m/s)	Used to calculated the HCE heat loss for hours when the wind speed from the weather file is lower than the minimum wind speed.	m/s
HCE Heat Losses (W/m) Thermal Losses (Weighted W/m) Thermal Losses (Weighted W/m2)	These values are provided for reference. SAM calculates the HCE heat loss for each hour during simulation based on the loss factor coefficients on the SCA / HCE page and other values from the weather data.	W/m, W/m^2

About the SCA Parameters

The default SCA library includes a set of parameters for four types of SCAs described in the table below. These SCA types are either installed in currently operating systems, or were used in past system designs. See Working with Libraries for information about managing libraries.

Table 18. Default collector types.

Name	Description	Location
Euro Trough ET150	Torque box, galvanized steel	SEGS V, Kramer Junction, California
Luz LS-2	Torque-tube, galvanized steel	SEGS I - VII, Kramer Junction, California

Luz LS-3	Bridge truss, galvanized steel	SEGS VII - IX, Kramer Junction, California
Solargenix SGX-1	Organic hubbing structure, extruded aluminum	Nevada Solar One, Boulder City, Nevada

The values of input variables on the SCA / HCE page are stored in libraries. See Working with Libraries for information about managing libraries.

About the HCE Parameters

The HCE library includes four HCE types, and for each HCE type, five HCE conditions. See Working with Libraries for information about managing libraries.

For each HCE type and condition, you can assign a Percent of Field value. For example, in the figure below, the receiver type is Schott PTR70, and 98.5% percent of the HCEs are in normal condition, 1.0% have lost vacuum, 0.5% have glass damage, and 0% have allowed hydrogen to enter the tube.

When you select a name from the Receiver Type and Condition list, Solar Advisor populates the optical and heat loss parameters using values stored in the library. When you change one or more of these values, Solar Advisor creates a copy of the parameter set and adds it to the library under the name "CUSTOM CUSTOM."

The four HCE types are described in the table below.

Table 19. Default HCE types.

HCE Type	Description
Luz Cermet	Original HCE design. Low reliability of seals.
Schott PTR70 Vacuum	Newer design with improved reliability.
Solel UVAC2	Newer design with improved reliability.
Solel UVAC3	The newest HCE available as of May 2008.

The performance of the HCE is highly dependent on the quality of the vacuum in the glass tube. Solar Advisor models the HCE under the five conditions described in the following table.

Table 20. HCE conditions.

HCE Condition	Description
Broken glass	Glass tube is damaged, increasing heat transfer between tube and atmosphere.
Fluorescent	Selective coating on metal tube is compromised, reducing absorption of solar radiation
Hydrogen	Hydrogen from hydrocarbon-based heat transfer fluid (e.g., mineral oil) has permeated through metal tube into the vacuum, increasing heat transfer between metal tube and glass.
Lost vacuum	Glass-to-metal seal is compromised
Vacuum	HCE is not damaged and is operating as designed.

About the Mirror Reflectivity Value

The following information is intended to help choose a value for the mirror reflectivity factor. The solar weighted hemispherical reflectance (SWV) of mirror glass depends on the iron content, thickness, and tempering of the glass, and the thickness of the reflective coating of the mirror:

- Glass transmittance and mirror reflectivity both depend on the iron (Fe_2O_3) content of the glass. The higher the iron content, the lower the transmittance and the higher the reflectivity of the mirror. Iron contents of more than 0.02% typically result in unacceptably low mirror reflectivity values.
- Mirror reflectivity increases as glass thickness decreases. The thinner glass requires faster pulling during manufacturing and is easier to break during shipping and handling than thicker glass. A glass thickness of one millimeter mounted with a substrate is a reasonable compromise to maximize mirror reflectivity and minimize the risk of mirror breakage. Five millimeter thick, non-tempered, low-iron, self-supporting glass mirrors are typically recommended for mirrors at the periphery of the parabolic trough field that are exposed to wind. Normally, five to ten percent of a solar field is equipped with 5 mm glass.
- Glass tempering generally raises mirror reflectivity.
- Mirror coating typically uses a silver thickness between 800 - 1200 Å or 0.8 -1.2 g/m2. Silver thicknesses less than 0.8 g/m2 result in unacceptably low mirror reflectivity values. Silver thicknesses greater than 1.2 g/m2 do not improve reflectivity, and have a tendency to delaminate.

Table 21. Suggested mirror reflectivity values for different types of commercially available glass solar mirrors using pristine second surface glass.

Glass Thickness (mm)	Iron Content	Mirror Reflectivity
4	low	0.93 ±0.002
1	low	0.96 ±0.002
4	low	0.948 ±0.003
4	very low	0.946 ±0.001
3	very low	0.956 ±0.001

Equations for Calculated Values

Optical Efficiency (HCE)

The design optical efficiency of each receiver type and condition option is a function of the efficiency and loss factors for each option.

$$F_{\text{OptEffD\_n}} = F_{\text{SCAFieldError\_n}} \cdot F_{\text{DustEnvelope\_n}} \cdot F_{\text{Bellows\_n}} \cdot F_{\text{Transmissivity\_n}} \cdot F_{\text{Absorbtion\_n}} \cdot F_{\text{Unaccounted\_n}}$$

Where,

$F_{OptEffD,n}$	Optical Efficiency (HCE) for each of the four receivers types.
$F_{SCAFieldError,n}$	The SCA field error factor, which is the product of Tracking Error and Twist, Geometric Accuracy, Mirror Reflectivity, Mirror Cleanliness Factor and Concentrator Factor. (Note that the Dust on Envelope factor is used for the HCE field error calculation above, not here.)
$F_{DustEnvelope,n}$	Dust on Envelope (avg) specified in the SCA parameters above. The same value applies to each of teh four receiver types.
$F_{Bellows,n}$	Bellows Shadowing for the receiver type n.
$F_{Transmissivity,n}$	Envelope Transmissivity for the receiver type n.
$F_{Absorption,n}$	Absorber Absorption for the receiver type n.
$F_{Unaccounted,n}$	Unaccounted for the receiver type n.
n	The receiver type number (1 through 4)

Optical Efficiency (Weighted)

The design weighted optical efficiency is a design value that Solar Advisor uses to calculate the solar field area. Note that the design optical efficiency equations differ from the optical efficiency factor equations used in the hourly simulation. It is a function of the four design optical efficiency factors and fraction of field values for each receiver type option:

$$F_{\mathrm{OptEffD}} = \sum_{n=1}^{4} F_{\mathrm{OptEffD},n} \cdot F_{\mathrm{PercentOfField},n}$$

Where,

$F_{OptEffD}$	Optical Efficiency (Weighted)
$F_{OptEffD,n}$	Optical Efficiency (HCE) for each of the four receivers
$F_{PercentOfField,n}$	Percent of Solar Field for each of the four receivers
n	Receiver number (1 through 4)

HCE Heat Losses (W/m)

The heat loss for each HCE type depends on the value of the six heat loss coefficients and heat loss factor for each HCE type, and on the solar field heat transfer fluid temperature design parameters:

$$Q_{\mathrm{HCELosses}} = F_{\mathrm{HeatLossFactor}} \cdot \frac{Q_{\mathrm{HL1}} + Q_{\mathrm{HL2}} + Q_{\mathrm{HL3}} + Q_{\mathrm{HL4}}}{T_{\mathrm{SFout}} - T_{\mathrm{SFin}}}$$

$$Q_{\mathrm{HL1}} = \left(F_{\mathrm{A0}} + F_{\mathrm{A5}} \cdot \sqrt{v_{\mathrm{Wind}}}\right) \cdot \left(T_{\mathrm{SFout}} - T_{\mathrm{SFin}}\right)$$

$$Q_{\mathrm{HL2}} = \left(F_{\mathrm{A1}} + F_{\mathrm{A6}} \cdot \sqrt{v_{\mathrm{Wind}}}\right) \cdot \frac{\left(T_{\mathrm{SFout}}^{2} - T_{\mathrm{SFin}}^{2}\right) - T_{\mathrm{Amb}} \cdot \left(T_{\mathrm{SFout}} - T_{\mathrm{SFin}}\right)}{2}$$

$$Q_{\mathrm{HL3}} = \left(F_{\mathrm{A2}} + F_{\mathrm{A4}} \cdot Q_{\mathrm{DNI}}\right) \cdot \frac{T_{\mathrm{SFout}}^{3} - T_{\mathrm{SFin}}^{3}}{3}$$

$$Q_{\mathrm{HL4}} = F_{\mathrm{A3}} \cdot \frac{T_{\mathrm{SFout}}^{4} - T_{\mathrm{SFin}}^{4}}{4}$$

Where,

$Q_{HCELosses}$ (W/m)	Receiver Heat Losses
$F_{HeatLossFactor}$	Heat Loss Factor
T_{SFout} (°C)	Solar Field Outlet Temperature from the Solar Field page
T_{SFin} (°C)	Solar Field Inlet Temperature from the Solar Field page
$F_{A0} \cdots F_{A6}$	A0 Heat Loss Coefficient through A6 Heat Loss Coefficient
v_{Wind} (m/s)	Reference wind velocity from the Solar Field page
T_{Amb} (°C)	Reference ambient temperature from the Solar Field page

Thermal Losses (Weighted W/m)

The total, or weighted HCE losses are expressed both in terms of the SCA aperture length:

$$Q_{HCELossesWeightedW/m} = \sum_{n=1}^{4} Q_{HCELosses,n} \cdot F_{PercentOfField,n}$$

Where,

$Q_{HCELossesWeightedW/m}$ (W/m)	Thermal Losses per SCA aperture length.
$Q_{HCELosses,n}$ (W/m)	Receiver Heat Losses for receiver number n
$F_{PercentOfField,n}$	Percent of Solar Field for each of the four receivers

Thermal Losses (Weighted W/m2)

And the SCA aperture area:

$$Q_{HCELossesWeightedW/m\text{^}2} = \frac{Q_{HCELossesWeightedW/m}}{A_{SCAAperture}}$$

Where,

$Q_{HCELossesWeightedW/m2}$ (W/m²)	Thermal Losses per SCA aperture area.
$Q_{HCELossesWeightedW/m}$ (W/m)	Thermal Losses per SCA aperture length
$A_{SCAAperture}$ (m²)	SCA Aperture Area

5.9.5 Power Block

To view the SCA / HCE page, click **Power Block** on the main window's navigation menu. Note that for the Power Block page to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Parabolic Trough System.

The Power Block parameters describe the equipment in the system that converts thermal energy from the solar field or thermal energy storage system into electricity. The power block is based on a steam turbine that runs on a conventional Rankine power cycle and may or may not include fossil fuel backup. Power block components include a turbine, heat exchangers to transfer heat from the solar field or thermal energy storage system to the turbine, and a cooling system to dissipate waste heat. Solar Advisor considers the thermal energy storage system to be a separate component, which is described on the Thermal Storage page.

The input variables on the Power Block page are divided into two groups. The turbine ratings group determines the capacity of the power block, and the power cycle group defines the performance parameters of the reference turbine.

For a more detailed description of the model, please download the CSP trough reference manual from the Solar Advisor website's support page: https://www.nrel.gov/analysis/sam/support.html.

Contents

- Input Variable Reference describes the input variables and options on the Power Block page.
- Power Cycle Library Options describes the reference steam turbines included in the default power block library.
- Equations for Calculated Values describes the equations used to calculated the calculated values on the Power Block page.

Input Variable Reference

Plant Characteristics

Name	Description	Units
Rated Turbine Net Capacity	Nameplate capacity of turbine. SAM does not use this variable in energy calculations, but does use it as the system capacity to calculate costs on the system costs page.	MWe
Design Turbine Gross Output	Gross electric output of turbine, typically 110% of rated turbine net capacity. Used to calculate the design turbine thermal input, which is displayed in the power cycle group with a blue background and described below. Also used to calculate the energy from the backup boiler.	MWe

Power Cycle

The variables in the power cycle group describe a reference steam turbine. SAM uses the reference turbine specifications to calculate the turbine output, and then scales the actual output based on the turbine rating variables. Each set of reference turbine specifications is stored in the reference turbine library.

Name	Description	Units
Current power block	Name of the reference turbine. Selecting a reference system determines the values of the other power cycle variables.	--
Design Turbine Thermal Input	The thermal energy required as input to the power block to generate the design turbine gross (electric) output. SAM uses the design turbine thermal input to calculate several power block capacity-related values, including the solar field size, power block design point gross output, and parasitic losses.	MWt
Design Turbine Gross Efficiency	Total thermal to electric efficiency of the reference turbine. Used to calculate the design turbine thermal input.	--
Max Over Design Operation	The turbine's maximum output expressed as a fraction of the design turbine thermal input. Used by the dispatch module to set the power block thermal input limits.	--
Minimum Load	The turbine's minimum load expressed as a fraction of the design turbine thermal input. Used by the dispatch module to set the power block thermal input limits.	--

Name	Description	Units
Turbine Start-up Energy	Fraction of the design turbine thermal input required to bring the system to operating temperature after a period of non-operation. Used by the dispatch module to calculate the required start-up energy.	--
Boiler LHV Efficiency	The back-up boiler's lower heating value efficiency. Used by the power block module to calculate the quantity of gas required by the back-up boiler.	--
Max Thermal Input	The maximum thermal energy that can be delivered to the power block by the solar field, thermal energy storage system or both.	MWt
Min Thermal Input	The minimum thermal energy that can be delivered to the power block by the solar field, thermal energy storage system or both.	MWt
Turb. Part Load Therm to Elec	Factors for the turbine thermal-to-electric efficiency polynomial equation. Used to calculate the design point gross output, which is the portion of the power block's electric output converted from solar energy before losses.	--
Turb. Part Load Elec to Therm	Factors for turbine's part load electric-to-thermal efficiency polynomial equation. Used to calculate the energy in kilowatt-hours of natural gas equivalent required by the backup boiler. SAM dispatches the backup boiler based on the fossil-fill fraction table in the thermal storage dispatch parameters on the Thermal Storage page.	--
Cooling Tower Correction	Cooling tower correction factor. Used to calculate the temperature correction factor that represents cooling tower losses. To model a system with no cooling tower, set F0 to 1, and F1 = F2 = F3 = F4 =0.	--
Temperature Correction Mode	In the dry bulb mode, SAM calculates a temperature correction factor to account for cooling tower losses based on the ambient temperature from the weather data set. In wet bulb mode, SAM calculates the wet bulb temperature from the ambient temperature and relative humidity from the weather data.	--

Power Cycle Library Options

The power cycle library includes six reference turbines. See Working with Libraries for information about managing libraries.

The reference turbines include five conventional Rankine-cycle steam turbines in a range of sizes, and one organic Rankine-cycle turbine. Conventional Rankine-cycle turbines are similar to those used in coal, nuclear, or natural gas power plants. A heat exchanger transfers energy from the solar field's heat transfer fluid to generate steam that drives the turbine. The organic Rankine-cycle turbine operates on the same principle as the conventional turbine, but uses an organic fluid, typically butane or pentane, to run the turbine instead of water.

Table 22. Power cycle reference systems.

Reference System	Approximate Solar Field Size Range m²	Approximate Operating Temperature ºC	Suggested Modeling Application
APS Ormat 1 MWe 300C	10,000	300	Organic Rankine-cycle power block
Nexant 450C HTF	-	450	High-temperature heat transfer fluid (molten salt)
Nexant 500C HTF	-	500	High-temperature heat transfer fluid (molten salt)
SEGS 30 MWe Turbine	180,000 - 230,000	300 - 400	Typical applications
SEGS 80 MWe Turbine	460,000 - 480,000	400	Typical applications
Siemens 400C HTF		400	High-temperature heat transfer fluid

When you choose a turbine from the reference system library, Solar Advisor changes the values of the Power Cycle variables. The following table of shows the power cycle parameters for the standard reference systems. Note that you can use any value for the Rated Turbine Net Capacity and Design Turbine Gross Output variables, Solar Advisor will use the reference system parameters with the rated and design turbine parameters.

Table 23. Reference system parameters.

Parameter Name	SEGS 30	SEGS 80	APS ORC	Nexant 450	Nexant 500	Siemens 400
Rated Turbine Net Capacity	30	80	1	100	100	50
Design Turbine Gross Output	35	89	1.160	110	110	55
Design Turbine Thermal Input	93.3	235.8	5.600	278.0	269.9	147.2
Design Turbine Gross Efficiency	0.3749	0.3774	0.2071	0.3957	0.4076	0.3736
Max Over Design Operation	1.15	1.15	1.15	1.15	1.15	1.15
Minimum Load	0.15	0.15	0.15	0.15	0.15	0.15
Turb. Part Load Therm to Elec F0	-0.0571910	-0.0377260	-0.1593790	-0.0240590	-0.0252994	-0.0298
Turb. Part Load Therm to Elec F1	1.0041000	1.0062000	0.9261810	1.0254800	1.0261900	0.7219
Turb. Part Load Therm to Elec F2	0.1255000	0.0763160	1.1349230	0.0000000	0.0000000	0.7158
Turb. Part Load Therm to Elec F3	-0.0724470	-0.0447750	-1.3605660	0.0000000	0.0000000	-0.5518
Turb. Part Load Therm to Elec F4	0.0000000	0.0000000	0.4588420	0.0000000	0.0000000	0.1430
Turb. Part Load Elec to Therm F0	0.0565200	0.0373700	0.1492050	0.0234837	0.0246620	0.044964
Turb. Part Load Elec to Therm F1	0.9822000	0.9882300	0.8521820	0.9751230	0.9744650	1.182900
Turb. Part Load Elec to Therm F2	-0.0982950	-0.0649910	-0.3247150	0.0000000	0.0000000	-0.563880
Turb. Part Load Elec to Therm F3	0.0595730	0.0393880	0.4486300	0.0000000	0.0000000	0.467190
Turb. Part Load Elec to Therm F4	0.0000000	0.0000000	-0.1256020	0.0000000	0.0000000	-0.130090

Equations for Calculated Values

Design Turbine Thermal Input

$$Q_{\text{DesignTurbineThermalInput}} = \frac{Q_{\text{DesignTurbineGross}}}{\eta_{\text{DesignTurbineGross}}}$$

Where,

$\eta_{DesignTurbineGross}$	Design Turbine Gross Efficiency
$Q_{DesignTurbineGross}$ (W)	Design Turbine Gross Output
$Q_{DesignTurbineThermalInput}$ (W)	Design Turbine Thermal Input

Max Thermal Input

$$Q_{\text{toPBMax}} = Q_{\text{PBDesign}} \cdot \left(F_{\text{ET4}} \cdot F_{\text{PBMax}}{}^{4} + F_{\text{ET3}} \cdot F_{\text{PBMax}}{}^{3} + F_{\text{ET2}} \cdot F_{\text{PBMax}}{}^{2} + F_{\text{ET1}} \cdot F_{\text{PBMax}} + F_{\text{ET0}}\right)$$

Where,

$Q_{toPBMax}$ (W)	Max Thermal Input
$Q_{PBDesign}$ (W)	Design Turbine Thermal Input
$F_{ET(0\text{-}4)}$	Turbine Part Load Elec To Therm coefficients
F_{PBMax}	Max Over Design Operation

Min Thermal Input

$$Q_{\text{toPBMin}} = Q_{\text{PBDesign}} \cdot \left(F_{\text{ET4}} \cdot F_{\text{PBMin}}{}^{4} + F_{\text{ET3}} \cdot F_{\text{PBMin}}{}^{3} + F_{\text{ET2}} \cdot F_{\text{PBMin}}{}^{2} + F_{\text{ET1}} \cdot F_{\text{PBMin}} + F_{\text{ET0}}\right)$$

Where,

$Q_{toPBMin}$ (W)	Min Thermal Input
$Q_{PBDesign}$ (W)	Design Turbine Thermal Input
$F_{ET(0\text{-}4)}$	Turbine Part Load Elec To Therm coefficients
F_{PBMax}	Minimum Load

5.9.6 Thermal Storage

To view the SCA / HCE page, click **Thermal Storage** on the main window's navigation menu. Note that for the Power Block page to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Parabolic Trough System.

A thermal energy storage system (TES) stores heat from the solar field in a liquid medium. Heat from the storage system can drive the power block turbine during periods of low or no sunlight. A TES is beneficial in many places where the peak demand for power occurs after the sun has set. Adding TES to a parabolic trough system allows the collection of solar energy to be separated from the operation of the power block. For example, a system might be able to collect energy in the morning and use it to generate electricity late into the evening.

In direct systems, the heat transfer fluid itself serves as the storage medium. In indirect systems, a separate fluid is the storage medium, and heat is transferred from the HTF to the storage medium through heat exchangers. The TES system consists of one or two tanks, pumps to circulate the liquids, and depending on the design, heat exchangers. A thermocline system stores both the hot and cold storage medium in one tank. The zone in the tank where hot and cold fluids meet is called a thermocline. The storage tank in a thermocline system contains low-cost filler materials such as sand and rock. A two-tank system consists of a hot tank to store heat from the solar field, and a cold tank to store the cooled storage medium after the power block has extracted its energy.

Note. For more information on thermal energy storage systems for parabolic trough systems, see http://www.nrel.gov/csp/troughnet/thermal_energy_storage.html.

The user inputs on the Storage page are divided into two groups. The thermal energy storage (TES) group defines the thermal energy storage capacity and type along with some efficiency parameters. The thermal storage dispatch controls group variables determine the the operation of the storage and fossil back up systems.

For a more detailed description of the model, please download the CSP trough reference manual from the Solar Advisor website's support page: https://www.nrel.gov/analysis/sam/support.html.

Contents

- Input Variable Reference describes the input variables and options on the Thermal Storage page.
- Estimating Tank Heat Loss Values describes how to choose values for the tank heat loss variable for different thermal energy storage capacities.
- Storage and Fossil Backup Dispatch Controls describes the dispatch controls that determine the timing of energy releases from the storage and fossil back up systems.
- Defining Dispatch Schedules explains how to assign dispatch periods to weekday and weekend schedules.
- Equations for Calculated Values describes the equations used to calculated the calculated values on the Thermal Storage page.

Input Variable Reference

Thermal Energy Storage (TES)

Name	Description	Units
Equiv Full Load Hours of TES	The thermal storage capacity expressed in hours. The physical capacity is the number of hours of storage multiplied by the power block design thermal input. Used to calculate the TES maximum storage capacity.	hours
Storage System Configuration	The current version of Solar Advisor models a two-tank TES consisting of a cold storage tank and hot storage tank.	--
Storage Fluid Type	The Storage fluid used in the TES. When the storage fluid and solar field heat transfer fluid (HTF) are different, the system is an indirect system with a heat exchanger. When the storage fluid and solar field HTF are the same, the system is a direct system that uses the solar field HTF as the storage medium. Used to calculate the heat exchanger duty.	--
Turbine TES Adj Efficiency	SAM applies the TES efficiency adjustment factor to the turbine efficiency for trough systems with storage to account for the lower steam temperature that results from imperfect heat exchange in the storage system. Used to calculate maximum TES discharge rate. Also used to calculate a TES correction factor.	--
Turbine TES Adj Gross Output	Efficiency adjustment factor. Used to calculate maximum TES discharge rate.	--
Initial Thermal Storage	The amount of energy in storage when the simulation starts, at midnight on January 1. The default value is zero.	MWht
Tank Heat Losses	Storage tank thermal losses. Solar Advisor subtracts value from the total energy in storage at the end of each simulation hour. See the table below for suggested values.	
Maximum Energy Storage	The maximum thermal energy storage capacity of the TES.	MWht
Design Turbine Thermal Input	The thermal input requirement of the power block to operate at its design point. Used to calculate the following dispatch parameters: power block input limits, power block load requirement, TES maximum storage capacity, and the start-up requirement	MWt
Max Power to Storage	Maximum TES charge rate. Used in the dispatch calculation when energy from the solar field exceeds the power block load requirement.	MWt
Max Power From Storage	Maximum TES discharge rate. Used in the dispatch calculation when energy from the solar field is less or equal to than the power block load requirement.	MWt
Heat Exchanger Duty	Applies only to indirect thermal storage systems that use a different storage fluid and solar field HTF. Used to calculate the maximum TES charge rate.	--

Thermal Storage Dispatch Control

The storage dispatch control variables each have six values, one for each of six possible dispatch periods. They determine how SAM calculates the energy flows between the solar field, thermal energy storage system, and power block. The fossil-fill fraction is used to calculate the energy from a backup boiler.

Name	Description
Storage Dispatch Fraction with Solar	The fraction of the TES maximum storage capacity (see table above) required for the system to start when the solar field energy is greater than zero. A value of zero will always dispatch the TES in any hour assigned to the given dispatch period; a value of one will never dispatch the TES. Used to calculate the storage dispatch levels.
Storage Dispatch Fraction without Solar	The fraction of the TES maximum storage capacity (see table above) required for the system to start when the solar field energy is equal to zero. A value of zero will always dispatch the TES in any hour assigned to the given dispatch period; a value of one will never dispatch the TES. Used to calculate the storage dispatch levels.
Turbine Output Fraction	A fraction of the design turbine thermal input adjusted by the turbine part load electric-to-thermal efficiency factors. Used to calculate the power block load requirement.
Fossil Fill Fraction	A fraction of the power block design turbine gross output from the Power Block page that can be met by the backup boiler. Used by the power block module to calculate the energy from the backup boiler.

Estimating Tank Heat Loss Values

An increase in the hours of thermal storage requires a both an increase in the solar field size to minimize the levelized cost of energy for the system, and an increase in the tank heat losses to account for the larger tank. The "100 MW Baseline - Parameterized Storage" case in *Sample Parabolic Trough Systems.zsam* illustrates these relationships. See Solar Multiple Optimization for a description of the case.

The following table shows suggested tank heat loss values for three sample systems over a range of thermal storage capacities. The relationship between tank heat losses and hours of thermal storage is linear, so you can extrapolate to estimate values for storage capacity values not on the table.

Table 24. Suggested Tank Heat Losses (MWt) values for different thermal storage capacities (hours).

	Hours of Thermal Storage					
System Description	**0**	**3**	**6**	**9**	**12**	**15**
100 MW Two Tank Indirect VP-1/Nitrate Salt	0	0.62	0.96	1.23	1.56	1.87
200 MW Two Tank Indirect VP-1/Nitrate Salt	0	1.0	1.61	2.21	2.81	3.56
200 MW Two Tank Direct Hitec Salt	0	0.34	0.64	0.93	1.24	1.52

Storage and Fossil Backup Dispatch Controls

The thermal storage dispatch controls determine the timing of releases of energy from the thermal energy storage and fossil backup systems to the power block. When the system includes thermal energy storage or fossil backup, Solar Advisor can use a different dispatch strategy for up to six different dispatch periods.

Storage Dispatch

Solar Advisor decides whether or not to operate the power block in each hour of the simulation based on how much energy is stored in the TES, how much energy is provided by the solar field, and the values of the thermal storage dispatch controls parameters. You can define when the power block operates for each of the six dispatch periods. For each hour in the simulation, if the power block is not already operating, Solar Advisor looks at the amount of energy that is in thermal energy storage at the beginning of the hour and decides whether it should start the power block. For each period, there are two targets for starting the power block: one for periods of sunshine (w/solar), and one for period of no sunshine (w/o solar).

The turbine output fraction for each dispatch period determines at what load level the power block runs using energy from storage during that period. The load level is a function of the turbine output fraction, design turbine thermal input, and the five turbine part load electric to thermal factors on the Power Block page.

For each dispatch period during periods of sunshine, thermal storage is dispatched to meet the power block load level for that period only when the thermal power from the solar field is insufficient and available storage is equal to or greater than the product of the storage dispatch fraction (with solar) and maximum energy in storage. Similarly, during periods of no sunshine when no thermal power is produced by the solar field, the power block will not run except when the energy available in storage is equal to or greater than the product of storage dispatch fraction (without solar) and maximum energy in storage.

By setting the thermal storage dispatch controls parameters, you can simulate the effect of a clear day when the operator may need to start the plant earlier in the day to make sure that the storage is not filled to capacity and solar energy is dumped, or of a cloudy day when the operator may want to store energy for later use in a higher value period.

Fossil Backup Dispatch

When the fossil fill fraction is greater than zero for any dispatch period, the system is considered to include fossil backup. The fossil fill fraction defines the solar output level at which the backup system runs during each hour of a specific dispatch period. For example, a fossil fill fraction of 1.0 would require that the fossil backup operate to fill in every hour during a specified period to 100% of design output. In that case, during periods when solar is providing 100% output, no fossil energy would be used. When solar is providing less than 100% output, the fossil backup operates to fill in the remaining energy so that the system achieves 100% output. For a fossil fill fraction of 0.5, the system would use energy from the fossil backup only when solar output drops below 50%.

The boiler LHV efficiency value on the Power Block page determines the quantity of fuel used by the fossil backup system. A value of 0.9 is reasonable for a natural gas-fired backup boiler. Solar Advisor includes the cost of fuel for the backup system in the levelized cost of energy and other metrics reported in the results, and reports the energy equivalent of the hourly fuel consumption in the hourly results. The cost of fuel for the backup system is defined on the Trough System Costs page.

Defining Dispatch Schedules

The storage dispatch schedules determine when each of the six periods apply during weekdays and weekends throughout the year. You can either choose an existing schedule from one of the schedules in the CSP trough TES dispatch library or define a custom schedule. For information about libraries, see Working with Libraries.

The TES dispatch library only assigns period numbers to the weekday and weekend schedule matrices. The dispatch fractions assigned to each of the six periods are not stored in the library.

To choose a schedule from the library:

1. Click **Dispatch schedule library**.
2. Choose a schedule from the list of four schedules. The schedules are based on time-of-use pricing schedules from four California utilities.
3. Click **OK**.

   You can modify a schedule using the steps described below. Modifying a schedule does not affect the schedule stored in the library.
4. For each of the up to six periods used in the schedule, enter values for the dispatch fractions described above. Use the period number and color to identify the times in the schedule that each period applies.

To define a dispatch schedule:

1. In the weekday schedule, select the times to which Period 1 applies.
2. Type the number 1.
3. Repeat Steps 1 and 2 for each of the up to six dispatch periods that you want to define, typing the period number to assign each period to times in the schedule.
4. Repeat Setps 1 through 3 for the weekend schedule.
5. For each of the up to six periods used in the schedule, enter values for the dispatch fractions described above. Use the period number and color to identify the times in the schedule that each period applies.

Equations for Calculated Values

Maximum Energy Storage

$$Q_{\text{MaximumStorage}} = N_{\text{HoursOfStorage}} \cdot Q_{\text{DesignTurbineInput}}$$

Where,

$Q_{MaximumStorage}$ (Wh)	Maximum Energy Storage
$Q_{DesignTurbineInput}$ (W)	Design Turbine Thermal Input
$N_{HoursOfStorage}$ (hours)	Equiv. Full Load Hours of TES

Design Turbine Thermal Input

The thermal energy required by the power block to operate at its rated capacity, described on the Power Block page.

Maximum Power To and From Storage

The maximum power to and from storage depends on whether the TES includes a heat exchanger. When the TES fluid is different from the solar field fluid, the TES includes a heat exchanger. When the fluids are the same, there is no heat exchanger.

For a TES with heat exchanger (TES fluid and solar field fluid are different):

$$P_{\text{MaximumToStorage}} = F_{\text{HeatExchangerDuty}} \cdot Q_{\text{DesignTurbineInput}}$$

$$P_{\text{MaximumFromStorage}} = P_{\text{MaximumToStorage}} \cdot \frac{F_{\text{TESAdjustOutput}}}{F_{\text{TESAdjustEfficiency}}}$$

For a TES with no heat exchanger (TES fluid and solar field fluid are the same):

$$P_{\text{MaximumToStorage}} = F_{\text{SolarMultiple}} \cdot F_{\text{TurbineMaximumOverDesign}} \cdot Q_{\text{DesignTurbineInput}}$$

$$P_{\text{MaximumFromStorage}} = Q_{\text{DesignTurbineInput}} \cdot F_{\text{TurbineMaximumOverDesign}} \cdot \frac{F_{\text{TESAdjustOutput}}}{F_{\text{TESAdjustEfficiency}}}$$

Where,

$F_{HeatExchangerDuty}$	Heat Exchanger Duty
$F_{SolarMultiple}$	Solar Multiple from Solar Field page
$F_{TESAdjustEfficiency}$	Turbine TES Adj. - Efficiency
$F_{TESAdjustOutput}$	Turbine TES Adjustment - Gross Output
$F_{TurbineMaximumOverDesign}$	Max Over Design Operation from Power Block page
$N_{HoursOfStorage}$	Equiv. Full Load Hours of TES
$P_{MaximumFromStorage}$ (W)	Maximum Power From Storage
$P_{MaximumToStorage}$ (W)	Maximum Power To Storage
$Q_{DesignTurbineInput}$ (W)	Design Turbine Thermal Input from Power Block page
$Q_{MaximumStorage}$ (W)	Maximum Energy Storage

Heat Exchanger Duty

The heat exchanger duty depends on the value of the solar multiple. When the solar multiple is greater than one:

$$F_{\text{HeatExchangerDuty}} = F_{\text{SolarMultiple}} - 1$$

When the solar multiple is equal to or less than one:

$$F_{\text{HeatExchangerDuty}} = 0$$

Where,

$F_{HeatExchangerDuty}$	Heat Exchanger Duty
$F_{SolarMultiple}$	Solar Multiple from Solar Field page

5.9.7 Parasitics

To view the SCA / HCE page, click **Parasitics** on the main window's navigation menu. Note that for the Power Block page to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Parabolic Trough System.

The Parasitics page displays parameters describing losses due to parasitic electrical loads, such as drive motors, electronic circuits, and pump motors. Solar Advisor includes a set of default parasitic parameters for a range of solar trough power systems. Choose a reference parasitic system option that is the same or similar to the system you are modeling. Solar Advisor will automatically adjust the total parasitic load to match the size of the solar field and power block in the system you are modeling.

The design point parasitic values are the maximum possible values for each parasitic loss category. Solar Advisor calculates the hourly parasitic loss value for each category during simulation based on the design point, the PF and F0-F2 coefficients, and the solar field thermal output and power block load in each hour, and reports them in the hourly results. The calculated parasitic loss values are never as high as the total design point parasitic losses.

For a more detailed description of the model, please download the CSP trough reference manual from the Solar Advisor website's support page: https://www.nrel.gov/analysis/sam/support.html.

Contents

- Input Variable Reference describes the input variables and options on the Parasitics page.
- Equations for Calculated Values describes the equations used to calculated the calculated values on the Parasitics page.

Input Variable Reference

The values of input variables on the Parasitics page are stored in a library of reference solar fields. You can change the parameter values without changing the values stored in the library. For information about libraries, See Working with Libraries.

Parasitic Electric Energy Use

Name	Description	Units
Current reference parasitic system	The reference system from the CSP trough parasticis library. SAM stores a set of parasitic parameters for reference systems.	--
Solar Field Area	The calculated solar field area from the Solar Field page. Used to calculate parasitic losses that are based on the solar field size with units of MWe/m^2.	m2
Gross Turbine Output	The design turbine gross output value from the Power Block page . Used to calculate parasitic losses that are based on the power block capacity with units of MWe/Mwe.	MWe
SCA Drives and Electronics	Electrical losses from electric or hydraulic SCA drives that position the collector to track the sun and from electronic SCA tracking controllers and alarm monitoring devices. Calculated as a function of the solar field area.	MWe

Solar Field HTF Pumps	Electrical losses from cold HTF pumping in the solar field. Calculated as a function of the solar field area. These losses are calculated only in hours when the solar field is operating, which is defined as when the solar field load is greater than zero.	
TES Pumps	Electrical losses from pumps in the TES system. Calculated as a function of the design turbine gross output.	
Antifreeze Pumping	Electrical losses from HTF pumps in the solar field. Calculated as a function of the solar field area. These losses are used only in hours when the solar field is not operating, which is defined as when the solar field load is zero.	MWe
Power Block Fixed	These fixed losses apply 24 hours per day, for all of the 8,760 hours of the year.	MWe
Balance of Plant	Electrical losses that apply in hours when the power block operates at part or full load.	MWe
Heater and Boiler	Losses that apply only when the back-up boiler is in operation.	MWe
Cooling Towers	The cooling tower parasitic losses are electrical losses that occur when the power block operates at part or full load. Calculated either as a function of power block load or at a fixed 50% or 100% of the design cooling tower parasitic losses.	MWe
Cooling Tower Operation Mode	Determines how cooling tower parasitic losses are calculated. For "Cooling Tower at 50% or 100%," parasitic losses are calculated as 50% of the design cooling tower parasitic losses when the power block load is 0.5 or less, and as or 100% of the design parasitic losses when the power block load is greater than 0.5. For "Cooling Tower parasitics a function of load," cooling tower parasitic losses are calculated as a function of power block load.	--
Total Design Parasitics	The sum of collector drives and electronics, solar field HTF pump, night circulation pumping, power block fixed, balance of plant, heater/boiler, and cooling towers design loss values. This value represents the maximum possible value if all parasitic losses were to occur simultaneously in a given hour, and is typically greater than the actual parasitic losses. Solar Advisor displays the value for reference only, and does not use it in simulation calculations.	MWe

Equations for Calculated Values

Each parasitic loss type has a set of parameters that includes a factor, PF and F0, F1, and F2 coefficient. The design point values are maximum values and are calculated using the factor and PF coefficient. Solar Advisor uses the F0-F2 coefficients in calculations for the hourly simulations, which are described in the reference manual.

Table . Design point parasitic loss equations for each parasitic loss category.

Source of Parasitic Loss	Equation
SCA Drives and Electronics	Factor x PF x Solar Field Area
Solar Field HTF Pumps	Factor x PF x Solar Field Area
TES Pumps	Factor x PF x Gross Turbine Output
Antifreeze Pumping	Factor x Solar Field HTF Pump losses
Power Block Fixed	Factor x Gross Turbine Output
Balance of Plant	Factor x PF x Gross Turbine Output
Heater and Boiler	Factor x PF x Gross Turbine Output
Cooling Towers	Factor x PF x Gross Turbine Output

The Total Design Point Parasitics is the sum of the the design point parastic loss categories:

- SCA Drives and Electronics
- Solar Field HTF Pumps
- TES Pumps
- Power Block Fixed
- Balance of Plant
- Heater and Boiler
- Cooling Towers

5.10 Dish Stirling Systems

A dish-Stirling system is a type of concentrating solar power (CSP) system that consists of a parabolic dish-shaped collector, receiver and Stirling engine. The collector focuses direct normal solar radiation on the receiver, which transfers heat to the engine's working fluid. The engine in turn drives an electric generator. A dish-Stirling power plant can consist of a single dish or a field of dishes.

Solar Advisor's dish-Stirling performance model uses the TRNSYS implementation of the energy prediction model described in the thesis *Stirling Dish System Performance Prediction Model (*Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB).

This user guide describes the dish-Stirling system input variables and some basic calculations in Solar Advisor, and is intended to be used with the Fraser publication, which describes dish-Stirling systems and the model algorithms in more detail.

This section describes the system input pages that are available when the technology option in the Technology and Market window is Concentrating Solar Power - Dish Stirling System.

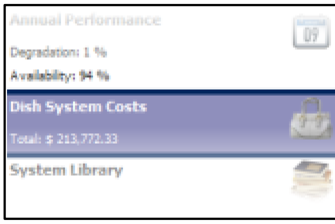
For an example of a dish-Stirling system, open the sample template *Sample Dish Stirling Systems*: On the File menu, click **Open Sample Template** and select the template from the list. The template contains two cases. The first case represents a 25 kW system consisting of a single collector-receiver-engine unit. The second case represents a 100 MW field of collector-receiver-engine units.

The dish-Stirling input pages are:

- Dish System Costs
- System Library

- Solar Field
- Collector
- Receiver
- Stirling Engine
- Parasitics
- Reference Inputs
- User Variables

5.10.1 Dish System Costs



To view the Trough System Costs page, click **Dish System Costs** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

Solar Advisor uses the variables on the Dish System Costs page to calculate the project investment cost and annual operating costs reported in the project cash flow and used to calculate cost metrics reported in the Metrics table.

Because only the Total Installed Cost value affects the cash flow calculations, you can assign capital costs to the different cost categories in whatever way makes sense for your analysis. For example, you could assign the cost of designing the solar field to the site improvements cost category or to the engineer-procure-construct category with equivalent results. The categories are provided to help you keep track of the different costs, but do not affect the economic calculations. After assigning costs to the categories, verify that the total installed costs value is what you expect.

Variable values in boxes with white backgrounds are values that you can edit. Boxes with blue backgrounds contain calculated values or values from other pages that Solar Advisor displays for your information.

Note: The cost values in the sample files are intended to illustrate Solar Advisor's use. The cost data are meant to be realistic, but not to represent actual costs for a specific project. Actual costs will vary depending on the market, technology and geographic location of a project. Because of price volatility in solar markets, the cost data in the sample files is likely to be out of date. For more information see the Solar Advisor Model website, https://www.nrel.gov/analysis/sam/cost_data.html.

Contents

- Input Variable Reference describes the input variables on the Trough System Costs page.
- Entering Periodic Operation and Maintenance Costs explains how to use annual schedules to assign operation and maintenance costs to particular years in the project cash flow.

Input Variable Reference

Direct Capital Costs

A direct capital cost represents an expense for a specific piece of equipment or installation service that applies in year zero of the cash flow.

Note: Because Solar Advisor uses only the Total Installed Cost value in cash flow calculations, how you distribute costs among the different direct capital cost categories does not affect the final results.

Variable	Description	Units
Site Improvements	A cost per square meter of solar field area to account for expenses related to site preparation and other equipment not included in the solar field cost category.	$\$/m^2$
Collector Cost (Projected Area)	A cost per square meter of projected mirror area from the Collector page to account for expenses related to installation of the collectors, including labor and equipment.	$\$/m^2$
Receiver Cost	A cost per kW of engine rated capacity from the Stirling Engine page to account for expenses related to installation of the receiver, including labor and equipment.	$/kW
Engine Cost	Cost per kW of engine rated capacity from the Stirling Engine page to account for expenses related to installation of the Stirling engine components, including labor and equipment.	$/kW
Contingency	A percentage of the sum of the site improvements, solar field, HTF system, storage, fossil backup, and power plant costs to account for expected uncertainties in direct cost estimates.	%
Total Direct Cost	The sum of site improvements, collector cost, receiver cost, engine cost, and contingency costs.	$

Indirect Capital Costs

An indirect cost is typically one that cannot be identified with a specific piece of equipment or installation service, and may include all other costs that are built into the price of the system, such as profit, overhead, and shipping costs. Depending on the purpose of your analysis, you may decide to distribute profit among the direct cost categories or include them as a single value in an indirect category.

Note: Because Solar Advisor uses only the total installed cost value in cash flow calculations, how you distribute costs among the different indirect capital cost categories does not affect the final results.

Variable	Description	Units
Engineer, Procure, Construct	Costs associated with design and construction of the project, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $

Project, Land, Miscellaneous	Costs associated with profit, overhead (including marketing), permitting, or shipping, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Sales Tax	Percentage of direct costs to which sales tax applies, calculated by multiplying Total Direct Cost by the sales tax rate from the Financials page and the percentage that you specify.	%
Total Indirect Cost	The sum of Engineer-Procure-Construct costs, Project-Land-Miscellaneous costs, and sales tax.	$

Total Installed Cost

The total installed cost is the project's investment cost that applies in year zero of the project cash flow. Solar Advisor uses this value to calculate loan amounts and debt interest payments based on inputs on the Financing page, and to calculate tax credit and incentive payment amounts for incentive based tax credits and incentives defined on the Tax Credit Incentives page and Payment Incentives pages.

Variable	Description	Units
Total Installed Cost	The sum of total direct cost and total indirect cost.	$
Total Installed Cost per Capacity	Total installed cost divided by the total system capacity in Watts-DC of array capacity for PV systems and electric kilowatts of power block nameplate capacity for CSP systems. This value is provided for reference only and not used in cash flow calculations.	$/Wdc or $/kW

Operation and Maintenance Costs

Operation and Maintenance (O&M) costs represent annual expenditures on equipment and services that occur after the system is installed. Solar Advisor allows you to enter O&M costs in three ways: Fixed annual, fixed by capacity, and variable by generation. O&M costs are reported on the project cash flow.

For each O&M cost category, you can specify an annual escalation rate to represent an expected annual increase in O&M cost above the annual inflation rate specified on the Financing page. For an escalation rate of zero, the O&M cost in years two and later is the year one cost adjusted for inflation. For a non-zero escalation rate, the O&M cost in years two and later is the year one cost adjusted for inflation plus escalation.

For expenses such as component replacements that occur in particular years, you can use an annual schedule to assign costs to individual years. See below for details.

O&M Cost Category	Description	Units
Fixed Annual Cost	A fixed annual cost applied to each year in the project cash flow.	$/yr
Fixed Cost by Capacity	A fixed annual cost proportional to the array capacity in DC kilowatts.	$/kWdc-yr

Variable Cost by Generation	A variable annual cost proportional to the system's total annual electrical output in AC megawatt-hours. The annual output depends on either the performance model's calculated first year value and the degradation rate specified on the Annual Performance page, or on an annual schedule of costs, depending on the option chosen.	$/MWh-yr
Fossil Fuel Cost	The cost per million British thermal units for fuel. Solar Advisor uses the conversion factor 1 MWh = 3.413 MMBtu. Applies only to the generic fossil, CSP trough, and CSP tower systems. The photovoltaic and CSP dish models ignore the fuel cost input variable. (When the fossil fill fraction variable on the Thermal Storage page for troughs or towers is greater than zero, the systems consume fuel for backup energy.)	$/MMBtu

Entering Periodic Operation and Maintenance Costs

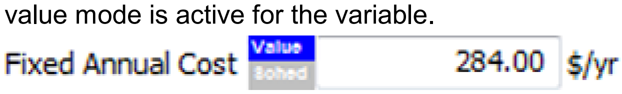
Solar Advisor allows you to specify any of the four operation and maintenance cost categories as an annual schedule. An annual schedule makes it possible to assign a cost to particular years in the analysis period. Annual schedules can be used to account for inverter replacement costs and other periodic costs that do not recur on a regular annual basis.

After running simulations, you will see the periodic costs in the project cash flow, and they will be accounted for in the other results displayed in the Metrics table.

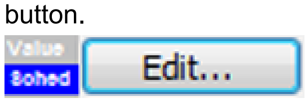
Note. Solar Advisor does not calculate any residual or salvage value remaining in inverters or other system components at the end of the analysis period.

To assign costs to particular years:

1. In the Fixed Annual Cost category, note that the "Value" label is blue indicating that the single value mode is active for the variable.



2. Click the button with the "Sched" label to change the mode to schedule and activate the Edit button.



3. Click **Edit**.
4. In the Edit Schedule window, use the horizontal scroll bar to find the first year in which a cost occurs, and type the cost in current or constant dollars for that year.

   To delete a value, select it and press the Delete key on your keyboard.

Note. You must type a value for each year. If you delete a value, Solar Advisor will clear the cell, and you must type a number in the cell or Solar Advisor will consider the schedule to be invalid. Type a zero for years with no inverter replacement cost.

5. When you have finished editing the schedule, click **Accept**.

Because you must specify an O&M cost category as either an annual cost or annual schedule, to assign both a recurring annual fixed cost and periodic replacement cost, you must type the recurring cost in each year of the annual schedule, and for years with replacement costs, type the sum of the recurring and replacement costs. Note that dollar values in the annual schedule are in nominal or current dollars. Inflation and escalation rates do not apply to values in annual schedules.

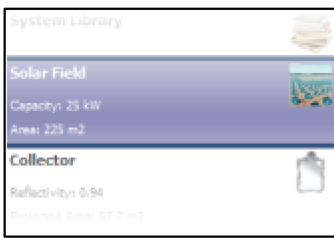
5.10.2 System Library

To view the Trough System Costs page, click **System Library** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

For dish-Stirling systems, a complete set of default values for the parameters on the system pages (except costs) are stored in the system library. There is a set of default input values for two systems: SES and WGA-ADDS. When you choose one of these systems, Solar Advisor populates the input pages with parameters appropriate for the system. You can modify variable values on the input pages without affecting the values stored in the library.

Note: These systems are discussed in the thesis *Stirling Dish System Performance Prediction Model* (Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB).

5.10.3 Solar Field



To view the Trough System Costs page, click **Dish Solar Field** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

The parameters on the Solar Field page define the size of the solar field and the layout of the dish network. To explore the impact of these parameters on the system's costs and performance, change the value of the parameter.

The relevant sections of the thesis *Stirling Dish System Performance Prediction Model* (Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB) are:

- 3.1 Parabolic Collector Model, p 63
- Appendix A: TRNSYS Parabolic Collector Model, p 152

Contents

- Input Variable Reference describes the input variables on the Trough System

Costs page.

- Entering Periodic Operation and Maintenance Costs explains how to use annual schedules to assign operation and maintenance costs to particular years in the project cash flow.

Input Variable Reference

Field Layout

The solar field is assumed to be a rectangular field with collectors oriented north-south and east-west.

Variable	Description	Units
Number of Collectors North-South	Number of collectors oriented along north-south lines. Used to calculate the total number of collectors.	-
Number of Collectors East-West	Number of collectors oriented along east-west lines. Used to calculate the total number of collectors.	-
Number of Collectors	Total number of collectors in the field. Used to calculate the predicted system output, the shading factor, and piping distance for pumping loss calculation.	-
Collector Separation North-South	Center-to-center distance between collectors along north-south lines. Used to calculate the solar field area, shading factor, and piping distance for pumping loss calculation.	m
Collector Separation East-West	Center-to-center distance between collectors along east-west lines. Used to calculate the solar field area, shading factor, and piping distance for pumping loss calculation.	m
Total Solar Field Area	The total ground area occupied by the collectors. Used in area-related cost calculations.	m^2

System Properties

Variable	Description	Units
Wind Stow Speed	When the wind velocity from the weather file for the current hour is greater than or equal to this value, the concentrator moves into stow position to prevent wind damage. The solar power intercepted by the receiver is zero during this hour.	m/s
Total Solar Field Capacity	Nominal electric output capacity of the solar field. Used in capacity-related cost calculations.	kWe

Array Shading Parameters

Solar Advisor uses the shading parameters to calculate the shading of the concentrator mirror by the dish components and by neighboring dish systems. Solar Advisor's approach to modeling shading is different from the Osborn approach described in the Fraser thesis.

Variable	Description	Units
Ground Slope, North-South	Slope of the ground in percent (rise over run) along a north-south line. A positive slope indicates that for two dishes aligned north-south, the dish to the south is lower than the dish to the north. Used to calculate shading factor.	%
Ground Slope,East-West	Slope of the ground in percent (rise over run) along a east-west line. A positive slope indicates that for two dishes aligned east-west, the dish to the east is lower than the dish to the west. Used to calculate shading factor.	%
Slot Gap Width	Average width of the slot in the mirror perpendicular to the vertical support post. Used to calculate shading factor.	m
Slot Gap Height	Average height of the slot in the mirror parallel to the vertical support post. Used to calculate shading factor.	m

Equations for Calculated Values

Number of Collectors

The total number of collectors is calculated based on the numbers of north-south and east-west oriented collectors.

$$N_{\mathrm{Coll}} = N_{\mathrm{Coll,N-S}} \cdot N_{\mathrm{Coll,E-W}}$$

Where,

N_{Coll} Number of Collectors

$N_{Coll,N\text{-}S}$ Number of Collectors North-South

$N_{Coll,E\text{-}W}$ Number of Collectors East-West

Total Solar Field Area

The total solar field area is the product of the north-south and east west dish collector separation distances and the number of collectors.

$$A_{\mathrm{SF}} = d_{\mathrm{CollSep,N-S}} \cdot d_{\mathrm{CollSep,E-W}} \cdot N_{\mathrm{Coll}}$$

Where,

A_{SF} (m^2) Total Solar Field Area

$d_{CollSep,N\text{-}S}$ (m) Collector Separation North-South

$d_{CollSep,E\text{-}W}$ (m) Collector Separation East-West

N_{Coll} Number of Collectors

Total Capacity

The total solar field capacity is the product of the number of collectors and the engine nameplate capacity on the Stirling Engine page.

$$P_{SF} = P_{Engine} \cdot N_{Coll}$$

Where,

P_{SF} (W) Total Capacity

P_{Engine} (W) Singe Unit Nameplate Capacity from the Stirling Engine page.

N_{Coll} Number of Collectors

5.10.4 Collector

To view the Trough System Costs page, click **Dish Collector** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

The collector consists of parabolic mirrors, a support structure, and two-axis tracking system. The mirrors focus direct normal solar radiation on the aperture of the receiver. The receiver aperture size is typically optimized to maximize the quantity of reflected solar radiation that enters the receiver and minimize convection and radiation losses out of the aperture.

The relevant sections of the thesis *Stirling Dish System Performance Prediction Model* (Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB) are:

- 2.1 Parabolic Concentrator, p 7
- 3.1 Parabolic Collector Model, p 63
- Appendix A: TRNSYS Parabolic Collector Model, p 150
- Appendix A: TRNSYS Parasitic Power Model, p 158

Input Variable Reference

The parameters on the Collector page are used to calculate the power output of the collector. The parameters are for a single dish collector, and are assumed to apply to each dish in the solar field.

Mirror Parameters

Variable	Description	Units
Projected Mirror Area	Area of one concentrator's mirror projected on the aperture plane. Used to calculated the solar power intercepted by the receiver, and the shading factor.	m^2
Total Mirror Area	Area of mirrored parabolic surface. Used to calculate collector diameter, which is used in the rim angle calculation and in the shading factor calculation.	m^2

Mirror Reflectivity	Fraction of total radiation incident upon the parabolic mirror surface that is reflected toward the receiver. Used to calculate the solar power intercepted by the receiver.	-

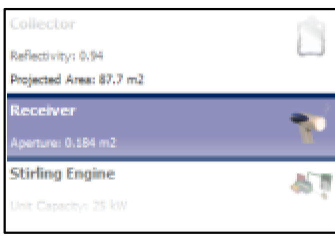
Performance

Variable	Description	Units
Insolation Cut In	Direct normal radiation value above which the cooling system fan operates. Used to calculated parasitic losses.	W/m^2

Table 25. Collector default parameter values.

Variable	SES	WGA	SBP	SAIC
Projected Mirror Area	87.7	41.2	56.7	113.5
Total Mirror Area	91.0	42.9	60	117.2
Insolation Cut In	200	275	250	375
Wind Stow Speed	16	16	16	16
Receiver Aperture Diameter for Reference Intercept Factor	0.184	0.14	0.15	0.38
Reference Intercept Factor	0.995	0.998	0.93	0.90
Reference Focal Length of Mirror	7.45	5.45	4.5	12.0

5.10.5 Receiver



To view the Trough System Costs page, click **Receiver** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

The receiver absorbs thermal energy from the parabolic concentrator and transfers the energy to the working fluid of the Stirling engine. The receiver consists of an aperture and absorber. The receiver aperture is located at the parabolic concentrator's focal point. The current version of Solar Advisor models one receiver type, direct illumination receivers, in which solar radiation is directly absorbed by absorber tubes containing the working fluid. Direct illumination receivers are the receiver type most commonly used for dish-Stirling systems.

The relevant sections of the thesis *Stirling Dish System Performance Prediction Model* (Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB) are:

- 2.2 Receiver, p 14
- 6.1 Modifying the Receiver Aperture Diameter, p 133
- 6.2 Receiver Cover versus no Cover, p 134

- Appendix A: TRNSYS Receiver Model, p 153

Solar Advisor uses the receiver parameters to calculate thermal losses from the receiver, which typically account for over 50% of the system's total losses. Other system losses include collector losses due to mirror reflectivity, receiver intercept losses, and Stirling engine losses. Receiver thermal losses are due to conduction, convection, and radiation:

- Conductive losses through the receiver housing.
- Natural convection from the cavity in the absence of wind.
- Forced convection in the presence of wind.
- Emission losses due to thermal radiation emitted from the receiver aperture.
- Radiation losses reflected off of the receiver cavity surfaces and out of the receiver through the aperture.

Input Variable Reference

Aperture

Variable	Description	Units
Receiver (note, not collector) Aperture Diameter	Diameter of the opening in the receiver that allows solar radiation to reach the absorber, and radiation and convection losses to escape the receiver cavity. Typical values range from 0.14 m to 0.20 m.	m

Insulation

Variable	Description	Units
Thickness	Thickness of the receiver housing insulation. Typically about 75 mm. Used to calculate conduction losses.	m
Thermal Conductivity	Thermal conductivity of the receiver cavity wall at 550 degrees Celsius. For high-temperature ceramic fiber, the value is 0.061 W/m€°K. Used to calculate conduction losses.	W/m-K

Absorber

The absorber is a component of the receiver that absorbs solar radiation and transfers thermal energy to the Stirling engine.

Variable	Description	Units
Absorber Absorptance	The ratio of energy absorbed by the receiver absorber to the solar radiation reaching the absorber. Used to calculate radiation losses.	-
Absorber Surface Area	Area of the absorber surface. Used to calculate the internal cavity area.	m^2

Cavity

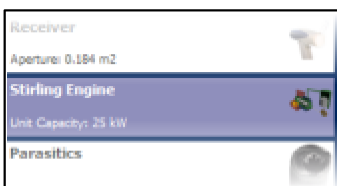
The cavity parameters determine the cavity's geometry. The internal cavity area is the sum of the cavity wall surface area and absorber area and is used to calculate radiation, conduction and convection losses.

Variable	Description	Units
Cavity Absorptance	The ratio of energy absorbed by the cavity wall to radiation reaching it. Used to calculated reflected radiation losses.	-
Cavity Surface Area	Area of the cavity wall surface. Used to calculate the internal cavity area.	m^2
Internal diameter of the Cavity Perp. to Aperture	Average diameter of the cavity perpendicular to the receiver aperture. Used to calculate the internal cavity area.	m
Internal Cavity Pressure with Aperture covered	Applies only to receivers with a cover. Used to calculate convection losses.	kPa
Internal Depth of the Cavity Perpendicular to the Aperture	Equivalent to the cavity's characteristic length, which is used to calculate convection losses.	m

Table 26. Receiver default parameter values.

Variable	SES	WGA	SBP	SAIC
Absorber Absorptance	0.90	0.90	0.90	0.90
Absorber Surface Area	0.6	0.15	0.15	0.8
Cavity Wall Absorptance	0.6	0.6	0.6	0.6
Cavity Wall Surface Area	0.6	0.15	0.15	0.8
Internal Diameter of the Cavity Perpendicular to the Receiver Aperture	0.46	0.35	0.37	0.5
Internal Depth of the Cavity Perpendicular to the Aperture	0.46	0.35	0.37	0.5
Receiver Insulation Thickness	0.075	0.075	0.075	0.075
Insulation Thermal Conductivity	0.06	0.06	0.06	0.06
Delta Temp. for DIR Receiver	90	70	70	90

5.10.6 Stirling Engine



To view the Trough System Costs page, click **Stirling Engine** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

The Stirling engine converts heat from the receiver's absorber to mechanical power that drives an electric generator.

The relevant sections of the thesis *Stirling Dish System Performance Prediction Model* (Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB) are:

- 2.3 Stirling Engine Design, p 29
- 2.4 Stirling Engine Analysis Methods, p 40
- 3.3 Stirling Engine/System Models, p 82
- 6 TRNSYS Model Performance Predictions, p 132
- Appendix A: TRNSYS Stirling Engine and Generator Model, p 156

The Stirling engine model is based on the Beale curve-fit equation with temperature correction described in Fraser (2008). The model calculates the average hourly engine power output in Watts as a function of the Beale curve-fit equation, pressure curve-fit equation, the engine displacement and operating speed, and expansion space (heater head) temperatures. The Beale curve-fit equation calculates the engine's gross output power as a function of the input power calculated by the collector and receiver models. Solar Advisor determines the compression space temperature from the ambient temperatures in the weather data file.

Input Variable Reference

Estimated Generation

Variable	Description	Units
Single Unit Nameplate Capacity	The nominal electrical power output of the engine-generator set for a single dish-Stirling unit. Used for capacity-related cost calculations.	kW

Engine Parameters

Variable	Description	Units
Heater Head Set Temperature	Expansion space temperature set point.	K
Heater Head Lowest Temperature	The expansion space temperature in an engine with multiple cylinders of the heater head with the lowest temperature. The heater head temperature is equivalent to the expansion space temperature.	K
Engine Operating Speed	The rotational speed of the engine drive shaft. Used to calculate the engine output power.	rpm
Displaced Engine Volume	The volume displaced by the pistons. Used to calculate the engine output power.	m^3

Beale Curve Fit Coefficients

The Beale numbers are a set of coefficients for the Beale curve-fit equation that describes the engine's power output as a function of its input power and the engine pressure.

Variable	Units
Beale Constant Coefficient	-
Beale First-order Coefficient	1/W
Beale Second-order Coefficient	1/W2

Beale Third-order Coefficient	1/W3
Beale Fourth-order Coefficient	1/W4

Pressure Curve Fit Coefficients

The pressure curve-fit equation expresses the engine pressure as a function of engine input power for a constant volume system.

Variable	Units
Pressure Constant Coefficient	MPa
Pressure First-order Coefficient	MPa/W

Engine parameters

Variable	Description	Units	Symbol
Single Engine Nameplate Capacity	The nominal electrical power output of the engine-generator set for a single dish-Stirling unit. Used for capacity-related cost calculations.	kW	P_{Engine}
Heater Head Set Temperature	Expansion space temperature set point.	K	$T_{Head,Set}$
Heater Head Lowest Temperature	The expansion space temperature in an engine with multiple cylinders of the heater head with the lowest temperature. The heater head temperature is equivalent to the expansion space temperature.	K	$T_{HeadnLow}$
Engine Operating Speed	The rotational speed of the engine drive shaft. Used to calculate the engine output power.	rpm	s_{Engine}
Displaced Engine Volume	The volume displaced by the pistons. Used to calculate the engine output power.	m^3	V_{Engine}

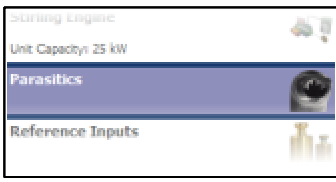
Table 27. Stirling engine default parameter values.

The following parameter values are based on values developed for the model. The SBP and SAIC engines are not included in the Solar Advisor standard library and require a different set of equations (see Fraser 35).

Variable	SES	WGA	SBP	SAIC
Heater Head Set Temperature	993	903	903	993

Heater Head Lowest Temperature	973	903	903	973
Engine Operating Speed	1800	1800	1800	2200
Displaced Engine Volume	3.80×10^{-4}	1.60×10^{-4}	1.60×10^{-4}	4.80×10^{-4}
Beale Constant Coefficient	4.247×10^{-2}	8.50686×10^{-2}	$-1{,}82451 \times 10^{-3}$	-1.6×10^{-2}
Beale First-order Coefficient	1.682×10^{-5}	1.94116×10^{-5}	2.60289×10^{-5}	1.5×10^{-5}
Beale Second-order Coefficient	-5.105×10^{-10}	-3.18449×10^{-10}	-4.68164×10^{-10}	-3.50×10^{-10}
Beale Third-order Coefficient	7.07260×10^{-15}	0	0	3.85×10^{-15}
Beale Fourth-order Coefficient	-3.586×10^{-20}	0	0	-1.6×10^{-20}
Pressure Constant Coefficient	6.58769×10^{-1}	-7.36342×10^{-1}	-2.00284×10^{-2}	3.47944×10^{-5}
Pressure First-order Coefficient	2.34963×10^{-4}	3.6416×10^{-4}	3.52522×10^{-4}	5.26329×10^{-9}

5.10.7 Parasitics



To view the Trough System Costs page, click **Parasitics** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

The input variables on the Parasitics page are used to calculate the compression space temperature and the electrical power consumption of pumps, cooling fans, and tracking controls.

The relevant sections of the thesis *Stirling Dish System Performance Prediction Model* (Fraser 2008) https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf (4.1 MB) are:

- 2.5 Cooling System, p 55
- 3.4 Cooling System Analysis for Total System Optimization, p 92
- Appendix A: TRNSYS Parasitic Power Model, p 158

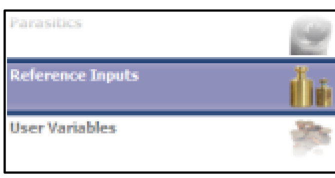
Input Variable Reference

Parasitic Parameters

Variable	Description	Units

Control System Parasitic Power, Avg.	Average power required by the tracking control system.	W
Cooling System Pump Speed	Cooling fluid pump operating speed. Used to calculated parasitic losses due to cooling fluid pumping.	rpm
Cooling System Fan Speed 1	Fan operating speed when the cooling fluid temperature is less than the fan speed 2 cut-in temperature below.	rpm
Cooling System Fan Speed 2	Fan operating speed when the cooling fluid temperature is greater than the fan speed 2 cut-in and less than fan speed 3 cut-in temperature below.	rpm
Cooling System Fan Speed 3	Fan operating speed when the cooling fluid temperature is greater than fan speed 3 cut-in temperature below.	rpm
Cooling Fluid Temp. for Fan Speed 2 Cut-In	Cooling fluid temperature set point. Used to determine fan operating speeds.	°C
Cooling Fluid Temp. for Fan Speed 3 Cut-In	Cooling fluid temperature set point. Used to determine fan operating speeds.	°C
Cooling Fluid Type	Fluid used in the cooling system. Options are water, 50% ethylene glycol (EG), 25% ethylene glycol, 40% propylene glycol (PG), and 40% propylene glycol. Percentages are by volume.	--
Cooler Effectiveness	Used to calculate working fluid temperatures in the cooling system as part of the compression space temperature calculation.	--
Radiator Effectiveness	Used to calculate cooling fluid temperature at the cooling system outlet as part of the compression space temperature calculation.	--
‘b_cooler’ Parameter		
‘b_radiator’ Parameter		

5.10.8 Reference Inputs



To view the Trough System Costs page, click **Reference Inputs** on the main window's navigation menu. Note that for the trough input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Dish Stirling System.

Solar Advisor uses the reference condition parameters in an iterative process to calculate the total collector error for a given set of values for the aperture diameter, focal length, and collector diameter. Once the collector error is calculated, that value can be used to calculate a new intercept factor for different aperture diameters (See Fraser, p 150-151).

Input Variable Reference

Collector Reference Condition Inputs

Variable	Description	Units
Intercept Factor	Fraction of energy reflected from the parabolic mirror that enters the receiver aperture. The intercept factor can be increased by increasing the concentration ratio or by increasing the size of the aperture. Intercept factors typically range between 0.94 and 0.99.	--
Focal Length of Mirror	Parabolic mirror focal length.	m

Receiver Reference Condition Inputs

Variable	Description	Units
Intercept Factor	Fraction of energy reflected from the parabolic mirror that enters the receiver aperture. The intercept factor can be increased by increasing the concentration ratio or by increasing the size of the aperture. Intercept factors typically range between 0.94 and 0.99.	--
Focal Length of Mirror	Parabolic mirror focal length.	m

Parasitic Variable Reference Conditions

The reference condition parameters given in the table below and as user inputs in Solar Advisor are used in the pump law calculations that are part of the parasitic loss equations.

Variable	SES	WGA	SBP	SAIC
Pump Parasitic Power	150	100	175	300
Pump Speed (rpm)	1800	1800	1800	1800
Cooling Fluid Type	50% EG	50% EG	water	50% EG
Cooling Fluid Temperature (K)	288	288	288	288
Cooling Fluid Volumetric Flow Rate (gal/min)	9	7.5	7.5	12
Cooling System Fan Test Power (W)	1000	410	510	2500
Cooling System Fan Test Speed (rpm)	890	890	890	850
Fan Air Density (kg/m3)	1.2	1.2	1.2	1.2
Fan Volumetric Flow Rate (CFM)	6000	4000	4500	10000

5.11 Power Tower Systems

A power tower system (also called a central receiver system) is a type of concentrating solar power (CSP) system that consists of a heliostat field, tower and receiver, power block, and optional storage system. The field of flat, sun-tracking mirrors called heliostats focus direct normal solar radiation onto a receiver at the top of the tower, where a heat-transfer fluid is heated and pumped to the power block. The power block generates steam that drives a conventional steam turbine and generator to convert the thermal energy to electricity.

Solar Advisor models power tower systems similar to the Solar Two system that use molten salt as the heat transfer fluid with external, cylindrical receivers. It models two-tank thermal energy storage systems.

Solar Advisor's power tower performance model uses TRNSYS components developed at the University of Wisconsin and described in *Simulation and Predictive Performance Modeling of Utility-Scale Central Receiver System Power Plants*, Wagner (2008) http://sel.me.wisc.edu/theses/wagner08.zip (32 MB).

The solar field optimization algorithm is based on the DELSOL3 model developed at Sandia National Laboratory, and described in *A User's Manual for DELSOL3: A Computer Code for Calculating the Optical Performance and Optimal System Design for Solar Thermal Central Receiver Plants*, Kistler (1986), (SAND86-8018) http://www.prod.sandia.gov/cgi-bin/techlib/access-control.pl/1986/868018.pdf (10 MB).

This user guide describes the power tower system input variables and some basic calculations in Solar Advisor, and is intended to be used with the two publications, which describes power tower systems and the model algorithms in more detail.

For an example of power tower systems, open the sample template *Sample Power Tower System*: On the File menu, click **Open Sample Template** and select the template from the list.The template three cases representing a 100 MW field of collector-receiver-engine units with and without thermal energy storage, and sample SamUL script for relative density calculation. For information about SamUL, on the Help menu, click **SamUL Guide**.

This section describes the system input pages that are available when the technology option in the Technology and Market window is Concentrating Solar Power - Power Tower System.

- Tower System Costs
- Heliostat Field
- Tower and Receiver
- Power Cycle
- Thermal Storage
- Parasitics
- User Variables

5.11.1 Tower System Costs

To view the Tower System Costs page, click **Tower System Costs** on the main window's navigation menu. Note that for the power tower input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Power Tower System.

Solar Advisor uses the variables on the Tower System Costs page to calculate the project investment cost and annual operating costs reported in the project cash flow and used to calculate cost metrics reported in the Metrics table.

Because only the Total Installed Cost value affects the cash flow calculations, you can assign capital costs to the different cost categories in whatever way makes sense for your analysis. For example, you could assign the cost of designing the solar field to the solar field cost category or to the engineer-procure-construct category with equivalent results. The categories are provided to help you keep track of the different costs, but do not affect the economic calculations. After assigning costs to the categories, verify that the total installed costs value is what you expect.

Variable values in boxes with white backgrounds are values that you can edit. Boxes with blue backgrounds contain calculated values or values from other pages that Solar Advisor displays for your information.

Note: The cost values in the sample files are intended to illustrate Solar Advisor's use. The cost data are meant to be realistic, but not to represent actual costs for a specific project. Actual costs will vary depending on the market, technology and geographic location of a project. Because of price volatility in solar markets, the cost data in the sample files is likely to be out of date. For more information see the Solar Advisor Model website, https://www.nrel.gov/analysis/sam/cost_data.html.

Contents

- Input Variable Reference describes the input variables on the Tower System Costs page.
- Entering Periodic Operation and Maintenance Costs explains how to use annual schedules to assign operation and maintenance costs to particular years in the project cash flow.

Input Variable Reference

Direct Capital Costs

A direct capital cost represents an expense for a specific piece of equipment or installation service that applies in year zero of the cash flow.

Note: Because Solar Advisor uses only the Total Installed Cost value in cash flow calculations, how you distribute costs among the different direct capital cost categories does not affect the final results.

Variable	Description	Units

Site Improvements	A cost per square meter of total reflective area from the Heliostat Field page to account for expenses related to site preparation and other equipment not included in the heliostat field cost category.	$/m^2$
Heliostat Field	A cost per square meter of total reflective area from the Heliostat Field page to account for expenses related to installation of the heliostats, including heliostat parts, field wiring, drives, labor, and equipment.	$/m^2$
Balance of Plant	A cost per electric kilowatt of power cycle nameplate capacity from the Power Cycle page expenses related to installation of the balance-of-plant components and controls, and construction of buildings, including labor and equipment.	$/kWe
Power Block	A cost per electric kilowatt of power cycle nameplate capacity from the Power Cycle page expenses related to installation of the power block components, including labor and equipment. The Power Block and Balance of Plant costs are rolled together into a single number for calculation purposes.	$/kWe
Storage System	Cost per thermal megawatt-hour of storage capacity from the Thermal Storage page to account for the installation of a thermal energy storage system, including equipment and labor.	$/kWht
Fixed Solar Field Cost	An additional fixed cost in dollars to include as a direct cost that is not accounted for by any of the above categories.	$
Fixed Tower Cost	A fixed cost to account for tower construction, materials and labor costs. The fixed tower cost serves as the multiplier in the tower cost scaling equation shown below.	$
Tower Cost Scaling Exponent	Solar Advisor uses the tower cost in the optimization calculations. The tower cost scaling exponent defines the nonlinear relationship between tower cost and tower height. See Total Tower Cost below.	--
Total Tower Cost	Total Tower Cost = Fixed Tower Costs x exp (Tower Height x Tower Cost Scaling Exponent)	$
Receiver Reference Cost	The cost per receiver reference area to account for receiver installation costs, including labor and equipment.	$
Receiver Reference Area	The receiver area on which the receiver reference cost is based.	m^2
Receiver Cost Scaling Exponent	Solar Advisor uses the receiver cost in the optimization calculations. The receiver cost scaling exponent defines the nonlinear relationship between receiver cost and receiver area based on the reference cost conditions provided.	--
Total Receiver Cost	Receiver Cost = Receiver Reference Cost x (Receiver Area / Receiver Reference Area) ^ Receiver Cost Scaling Exponent.	$
Contingency	A percentage of the sum of the site improvements, heliostat field, balance of plant, power block, storage system, fixed solar field, total tower, and total receiver costs to account for expected uncertainties in direct cost estimates.	%
Total Direct Cost	The sum of improvements, site improvements, heliostat field, balance of plant, power block, storage system, fixed solar field, total tower, total receiver, and contingency costs.	$

Indirect Capital Costs

An indirect cost is typically one that cannot be identified with a specific piece of equipment or installation service, and may include all other costs that are built into the price of the system, such as profit, overhead, and shipping costs. Depending on the purpose of your analysis, you may decide to distribute profit among the direct cost categories or include them as a single value in an indirect category.

Note: Because Solar Advisor uses only the total installed cost value in cash flow calculations, how you distribute costs among the different indirect capital cost categories does not affect the final results.

Variable	Description	Units
Engineer, Procure, Construct	Costs associated with design and construction of the project, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Project, Land, Miscellaneous	Costs associated with profit, overhead (including marketing), permitting, or shipping, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Sales Tax	Percentage of direct costs to which sales tax applies, calculated by multiplying Total Direct Cost by the sales tax rate from the Financials page and the percentage that you specify.	%
Total Indirect Cost	The sum of Engineer-Procure-Construct costs, Project-Land-Miscellaneous costs, and sales tax.	$

Total Installed Cost

The total installed cost is the project's investment cost that applies in year zero of the project cash flow. Solar Advisor uses this value to calculate loan amounts and debt interest payments based on inputs on the Financing page, and to calculate tax credit and incentive payment amounts for incentive based tax credits and incentives defined on the Tax Credit Incentives page and Payment Incentives pages.

Variable	Description	Units
Total Installed Cost	The sum of total direct cost and total indirect cost.	$
Total Installed Cost per Capacity	Total installed cost divided by the total system capacity in Watts-DC of array capacity for PV systems and electric kilowatts of power block nameplate capacity for CSP systems. This value is provided for reference only and not used in cash flow calculations.	$/Wdc or $/kW

Operation and Maintenance Costs

Operation and Maintenance (O&M) costs represent annual expenditures on equipment and services that occur after the system is installed. Solar Advisor allows you to enter O&M costs in three ways: Fixed annual, fixed by capacity, and variable by generation. O&M costs are reported on the project cash flow.

For each O&M cost category, you can specify an annual escalation rate to represent an expected annual increase in O&M cost above the annual inflation rate specified on the Financing page. For an escalation rate of zero, the O&M cost in years two and later is the year one cost adjusted for inflation. For a non-zero escalation rate, the O&M cost in years two and later is the year one cost adjusted for inflation plus escalation.

For expenses such as component replacements that occur in particular years, you can use an annual schedule to assign costs to individual years. See below for details.

O&M Cost Category	Description	Units
Fixed Annual Cost	A fixed annual cost applied to each year in the project cash flow.	$/yr
Fixed Cost by Capacity	A fixed annual cost proportional to the array capacity in DC kilowatts.	$/kWdc-yr
Variable Cost by Generation	A variable annual cost proportional to the system's total annual electrical output in AC megawatt-hours. The annual output depends on either the performance model's calculated first year value and the degradation rate specified on the Annual Performance page, or on an annual schedule of costs, depending on the option chosen.	$/MWh-yr
Fossil Fuel Cost	The cost per million British thermal units for fuel. Solar Advisor uses the conversion factor 1 MWh = 3.413 MMBtu. Applies only to the generic fossil, CSP trough, and CSP tower systems. The photovoltaic and CSP dish models ignore the fuel cost input variable. (When the fossil fill fraction variable on the Thermal Storage page for troughs or towers is greater than zero, the systems consume fuel for backup energy.)	$/MMBtu

Note. For information on water consumption and other operation and maintenance costs and requirements for concentrating parabolic trough systems, see the Troughnet website: http://www.nrel.gov/csp/troughnet/power_plant_systems.html. For information on operation and maintenance costs for photovoltaic systems, see the California Energy Commission's online Distributed Energy Resource guide http://www.energy.ca.gov/distgen/economics/operation.html.

Entering Periodic Operation and Maintenance Costs

Solar Advisor allows you to specify any of the four operation and maintenance cost categories as an annual schedule. An annual schedule makes it possible to assign a cost to particular years in the analysis period. Annual schedules can be used to account for inverter replacement costs and other periodic costs that do not recur on a regular annual basis.

After running simulations, you will see the periodic costs in the project cash flow, and they will be accounted for in the other results displayed in the Metrics table.

Note. Solar Advisor does not calculate any residual or salvage value remaining in inverters or other system components at the end of the analysis period.

To assign costs to particular years:

1. In the Fixed Annual Cost category, note that the "Value" label is blue indicating that the single value mode is active for the variable.

2. Click the button with the "Sched" label to change the mode to schedule and activate the Edit button.

3. Click **Edit**.
4. In the Edit Schedule window, use the horizontal scroll bar to find the first year in which a cost occurs, and type the cost in current or constant dollars for that year.

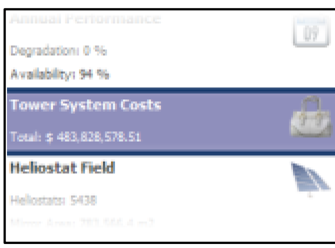
   To delete a value, select it and press the Delete key on your keyboard.

Note. You must type a value for each year. If you delete a value, Solar Advisor will clear the cell, and you must type a number in the cell or Solar Advisor will consider the schedule to be invalid. Type a zero for years with no inverter replacement cost.

5. When you have finished editing the schedule, click **Accept**.

Because you must specify an O&M cost category as either an annual cost or annual schedule, to assign both a recurring annual fixed cost and periodic replacement cost, you must type the recurring cost in each year of the annual schedule, and for years with replacement costs, type the sum of the recurring and replacement costs. Note that dollar values in the annual schedule are in nominal or current dollars. Inflation and escalation rates do not apply to values in annual schedules.

5.11.2 Heliostat Field



To view the Heliostat page, click **Heliostat Field** on the main window's navigation menu. Note that for the power tower input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Power Tower System.

The Heliostat Field page displays the variables that specify the position of the heliostats in the solar field along with the heliostat geometry and optical properties. Unlike parabolic trough and dish system designs, which can be based on modular designs of individual components, power tower system designs typically require optimization of the tower height, receiver geometry, and distribution of heliostats around the receiver as a complete system.

Page numbers relevant to this section from the Wagner (2008) and Kistler B (1986) references are:

- Wagner p 10, 23-42, 49
- Kistler p 25-37, 39-47, 74-75

You can define the heliostat field layout in two ways: If you have a field layout in mind, you can enter values by hand. Or, you can use Solar Advisor's optimization wizard to determine the optimal layout for you.

Contents

Input Variable Reference

Heliostat Properties

The heliostat properties define the area of a single heliostat mirrored surface, shape of the heliostat, and the boundaries of the solar field area. Note that Solar Advisor assumes that each heliostat employs a two-axis drive system with a pivot at the center of the mirrored surface.

Variable	Description	Units
Heliostat Width	The width of the heliostat surface in meters, including the mirrored surface, edge supports and any cutouts or slots.	m
Heliostat Height	The height of the heliostat surface in meters, including the mirrored surface, edge supports and any cutouts or slots.	m
Ratio of Reflective Area to Heliostat Profile	The fraction of the area defined by the heliostat width and height that actually reflects sunlight. This value determines the ratio of reflective area on each heliostat to the total projected area of the heliostat on a plane normal to the heliostat surface. The ratio accounts for non-reflective area on the heliostat that may cause shading of neighboring heliostats.	-
Mirror Reflectivity and Soiling	The fraction of sunlight incident on the mirror that is reflected toward the receiver. Solar Advisor assumes a constant value and does not account for reflectivity degradation between mirror washings.	-
Heliostat Availability	An adjustment factor that accounts for reduction in energy output due to downtime of some heliostats in the field for maintenance and repair. A value of 1 means that each heliostat in the field operates whenever sufficient solar energy is available. Solar Advisor multiplies the solar field output for each hour by the availability factor.	-
Use Round Heliostats (D=W)	Check the box to use round heliostats in place of the standard rectangular shape. For round heliostats, the heliostat diameter is equal to the value of the Heliostat Width variable.	-
Max Distance from Tower	The maximum allowable radial distance in meters between the center of the tower base and heliostats furthest from the tower. Under certain conditions, Solar Advisor uses this value to calculate the radial step size. (See radial step size variable description below.)	m

Min Distance from Tower	The minimum allowable radial distance in meters between the center of tower base and heliostats closest to the tower. Under certain conditions, Solar Advisor uses this value to calculate the radial step size. (See radial step size variable description below.)	m
Radial Step Size for Layout	The radial distance between centers of heliostat field zones. The zone centers are indicated by the symbol + in the zone layout sample diagram shown on the Heliostat Field page. • In the x-y coordinate mode, Solar Advisor disables the radial step size variable. • When you define the number of heliostats per zone by entering values in the field layout table by hand or by loading a file, the radial step size is the difference between the initial maximum distance from the tower and initial minimum distance from the tower divided by the number of radial zones. • When you use the optimization wizard to specify the field, Solar Advisor calculates the radial step size as a function of the initial minimum and maximum distances from the tower, which it in turn calculates as a function of the ratio of the optimized tower height to the minimum and maximum tower height specified on the Receiver/Tower Sizing tab of the optimization wizard.	m
Image Error	A measure of the deviation of the actual heliostat image on the receiver from the expected or ideal image that helps determine the overall shape and distribution of the reflected solar flux on the receiver. This value specifies the total conical error distribution for each heliostat at one standard deviation in radians. Solar Advisor applies the value to each heliostat in the field regardless of its distance from the tower. The image error accounts for all error sources, including tracking imprecision, foundation motion, mirror waviness, panel alignment problems, atmospheric refraction and tower sway.	radians
Heliostat Area	The area of the heliostat mirrored area. For rectangular heliostats, the area is the product of the heliostat width and height (or the product of the square of half the width and pi for round heliostats) and the ratio of reflective area to heliostat profile.	m^2

Circular Field Optimization Wizard

When the you are specifying the heliostat field using radial sections, Solar Advisor can find the optimal number of heliostats for each section automatically. See Optimization Wizard for more information.

Note. The optimization wizard will not work if you are specifying the solar field using x-y coordinates.

Field Parameters

Variable	Description	Units
Wind Stow Speed	Wind velocity from the weather file at which the heliostats defocus and go into stowed position to protect them from possible wind damage.	m/s
Heliostat Deploy Angle	Solar elevation angle below which the heliostat field will not operate.	degrees
Total Reflective Area	Total mirrored area of the heliostat field, equal to the heliostat reflective area multiplied by the number of heliostats. Solar Advisor uses the total field area to calculate the site improvements and heliostat costs on the Tower System Costs page.	m^2
Number of Heliostats	The total number of individual heliostats in the field. Solar Advisor displays the number of heliostats based either on the results of the optimization wizard, or based on the data in the heliostat layout file when the heliostat locations are loaded from a text file.	-

Field Geometry

The field geometry specifies the number of heliostats in the field. See Specifying the Field below for details.

Specifying the Field

Solar Advisor allows the heliostat locations in the field to be specified either by a set of rectangular coordinates (x-y) or as a number of heliostats per radial section of the field (number of radial and azimuthal zones).

Radial Zones

To specify the field as a number of heliostats per radial zone enter the number of radial zones and azimuthal zones to divide the heliostat field into radial zones shown in the field diagram. You can then specify the field manually or automatically. To specify the field manually, either type values in the Number of Heliostats Per Zone table or import the data as a text file. To specify the field automatically, use the optimization wizard to specify a set of optimization parameters and allow Solar Advisor to optimize the heliostat field design and calculate the optimal number of heliostats per zone, receiver tower height, receiver height and diameter, and other variables.

The solar field is divided into evenly distributed sections of a circle called zones, as shown in the sample diagram on the Heliostat Field page. The rows of the table specify the radial position if each zone relative to the tower located at the center of the field. The zone closest to the tower is assigned the number one, with each successively farther zone incrementing by one. The columns specify the position of the zone's center in degrees east of due north, where zero is north, 90 degrees is east, 180 degrees is south, and 270 degrees is west. The number of heliostats per zone can be a non-integer value because Solar Advisor converts the value to a mirror surface area for each zone that is equivalent to the total mirrored surface of all heliostats in the zone.

Rectangular (x-y) Coordinates

To specify the field as a set of rectangular coordinates, change the value of Azimuthal Zones to 2, and enter the number of heliostats for # of Heliostats. You can then either type the x-y coordinates of each heliostat in the field, or import a text file of x-y coordinates. Solar Advisor displays the location of each heliostat on the field diagram. It models the system based on the heliostat locations specified by the set of x-y locations, and based on the values you specify for the tower height, receiver height, receiver diameter, and other input values. This approach is appropriate for predicting the output of a system with a known design. The optimization wizard does not work in the x-y coordinate mode.

Each row specifies the position of an individual heliostat relative to the tower. The first column in the table specifies the x-coordinate along the east-west axis of the field, with negative values indicating positions west of the tower, and positive values indicating positions east of the tower. The second column specifies the y-coordinate along the north-south axis, with positive values indicating positions north of the tower, and negative values indicating positions south of the tower. The tower is assumed to be at 0,0. Note that this convention also applies to systems in the southern hemisphere. In the x-y coordinate mode, Solar Advisor requires that the field be symmetric about the north-south axis.

Working with Heliostat Field Files

Solar Advisor allows you to use text files to save and load field layout data when you specify the field layout by hand instead of relying on the optimization wizard to calculate the optimal layout.

For radial zone data, each row in the file represents a radial step (distance away from the center of the circle), and each column represents an azimuthal division (distance clockwise around the circle from the zero degree line pointing north), as shown on the sample layout diagram. The first row must contain data for the radial step closest to the center of the field, and subsequent rows should be in consecutive order away from the center. The first column of each row must contain data for the azimuthal division containing the north line at zero degrees, and the second column the next division moving counterclockwise from the first column, and so on. Zones with no heliostats should be indicated by a zero. Each column in the file should be separated by a space, and each row by a new line. For example, a text file with the following contents would describe a field with three radial steps and four azimuthal divisions:

```
9.0 10.0 9.0 10.0
15.5 15.5 15.5 15.5
22.5 18.0 18.5 22.5
```

For rectangular coordinate data, each row represents an individual heliostat position in the field, with the x coordinate in the first column and the y coordinate in the second column. A positive x value is east, and a positive y value is north of the tower. Use negative values for positions west and south of the tower. The heliostat coordinates do not have to be in a particular order in the file. Each column in the file should be separated by a space, and each row by a new line. A file with the following contents would describe a solar field with three heliostats at (x = 0.0, y = 75.0), (x = 7.5, y = 70.0), and (x = 15.0, y = 65.0):

```
0.0 75.0
7.5 70.0
15.0 65.0
```

5.11.3 Optimization Wizard

To start the power tower optimization wizard, first click **Heliostat Field** on the main window's navigation menu to view the Heliostat Field page, and then follow the instructions below. Note that for the power tower input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Power Tower System.

The power tower optimization wizard simplifies the task of choosing values for the relatively large number of input parameters required to specify the power tower solar field and receiver. Because the heliostat field is typically the most capital intensive part of a power tower project, often accounting for 30-40% of the total installation cost, optimizing the heliostat field size is a critical step in minimizing overall project cost.

The optimization wizard searches for a set optimal system parameter values, where the optimal system is defined as the one that results in the lowest levelized cost of energy. Note that the optimization process is separate from the simulation process. When you run the wizard, it populates some of the input variables in the Solar Advisor input pages (listed below) with optimal values. Before running simulations, you can choose to either keep the values generated by the wizard or modify them.

The wizard's underlying code is based on the DELSOL3 code from Sandia National Laboratory (Kistler 1986, see References), and is implemented in SAM through the PTGen program described in the thesis *Simulation and Predictive Performance Modeling of Utility-Scale Central Receiver System Power Plants* (Wagner 2008) http://sel.me.wisc.edu/theses/wagner08.zip (33 MB).

To use the optimization wizard:

1. On the Tower System Costs page, enter values for the capital costs.
2. On the Heliostat Field page, click **Start Wizard** to start the wizard.

   Solar Advisor initially populates the variables in the wizard with values from the Heliostat Field, Tower and Receiver, and Power Cycle pages. Solar Advisor assigns values to variables that don't appear elsewhere, such as Minimum Tower Height and Maximum Tower Height, using either default values or values based on the last time the wizard ran.
3. Enter values to define the parameters of the optimization.
4. Click **Optimize Solar Field**.
5. After the wizard finishes running, click **Close**.
6. Review the variables on the input pages. Modify any values as needed, and then configure and run simulations to simulate the system(s) and display annual production, levelized cost of energy, and other results on the Results page.

Contents

Input Variable Reference

Solar Field

Variable	Description	Units
Solar Multiple	The ratio of of the receiver's design thermal output to the power block's design thermal input.	--

Receiver and Tower

The receiver and tower optimization variables determine the optimization search range and step size for the receiver and tower dimensions.

Variable	Description	Units
Min Receiver Diameter	The minimum value for the range of receiver diameter values that the wizard will search for an optimal solution.	m
Max Receiver Diameter	The maximum value for the range of receiver diameter values that the wizard will search for an optimal solution.	m
Optimization Levels for Receiver Diameter	The number of receiver diameter values to evaluate in the search for an optimal solution. The maximum allowed number of optimization levels is 10.	--
Min Receiver Height / Diameter Ratio	The minimum receiver height to receiver diameter ratio for the range of values that the wizard will search for the optimal solution.	--
Max Receiver Height / Diameter Ratio	The maximum receiver height to receiver diameter ratio for the range of values that the wizard will search for the optimal solution.	--
Optimization Levels for Receiver H/D Ratio	The number of receiver height to diameter ratio values to evaluate in the search for an optimal solution.The maximum allowed number of optimization levels is 10.	--
Min Tower Height	The minimum value for the range of tower height values that the wizard will search for an optimal solution.	m
Max Tower Height	The maximum value for the range of tower height values that the wizard will search for an optimal solution.	m
Optimization Levels for Tower Height	The number of tower height values to evaluate in the search for an optimal solution. The maximum allowed number of optimization levels is 10.	

Overview of the Optimization Process

For each variable that is specified as a range in the optimization wizard, the wizard searches for the value within the range that meets the performance requirements at the lowest levelized cost of energy. The wizard searches discrete combinations of options based on the "optimization level" of each optimized variable. For example, if the minimum tower height is specified as 150 m and the maximum 250 m, and the tower height optimization level is 10, the wizard will simulate 10 systems with unique tower heights evenly incremented between 150 m and 250 m. Be sure to choose reasonable ranges and step sizes to minimize the number of calculations the wizard must perform.

The solar multiple is the ratio of of the receiver's design thermal output to the power block's design thermal input. The optimization wizard uses the solar multiple to calculate the receiver's thermal rating, which is equal to the solar multiple multiplied by the power cycle nameplate electric capacity divided by the rated cycle conversion efficiency, both of which are on the Power Cycle page.

The wizard holds the following variables constant as it searches for the optimal system:

- Solar Multiple on the Optimization Wizard window.
- Nameplate Capacity on the Power Cycle page.

- Heliostat Width on the Heliostat Field page.
- Heliostat Height on the Heliostat Field page.
- Maximum Receiver Flux on the Tower and Receiver page.

The wizard searches within the specified ranges to find optimal values of the following variables on the Tower and Receiver page.When the wizard finishes running, Solar Advisor populates the variables with the optimal values.

- Receiver Diameter
- Receiver Height (calculated as a function of the receiver height to the receiver diameter ratio)
- Tower Height

Solar Advisor also populates the following variables on the Heliostat Field page with values from the wizard:

- Radial Step Size for Layout
- Total Reflective Area
- Number of Heliostats
- Number of heliostats per radial zone in the field layout table

The optimization wizard uses the following values from the input pages, but does not change their values.

From the Heliostat Field page:

- Heliostat Width
- Heliostat Height
- Ratio of Reflective Area to Profile
- Mirror Reflectivity and Soiling
- Use Round Heliostats
- Max Distance from Tower
- Min Distance from tower
- Image Error
- Number of Radial Zones
- Number of Azimuthal Zones

From the Tower and Receiver page:

- Coating Absorptivity
- Max Receiver Flux

From the Power Cycle page:

- Nameplate Capacity
- Rated Cycle Conversion Efficiency

It is possible that the wizard will not find an optimal field layout given a set of values that you provide. Finding an optimal set of input parameters is often an iterative process that may require you to run the optimization wizard and adjust input value ranges several times until the wizard finds a reasonable field layout for your analysis. When the wizard cannot find an optimal layout, it displays a message with suggestions for adjustments. Typically, the suggestions include adjusting the upper or lower limits of optimization variables, and ensuring that the minimum and maximum heliostat distance from tower values are reasonable. Keep in mind that because the wizard uses capital costs from the Tower System Costs page in the optimization process, unreasonable cost values may also prevent the wizard from finding an optimal field layout. In some cases, wizard will fail to find an optimal design and exit without notice. When that happens, check to see if the values of optimized variables shown on the input pages are outside of the range specified for those variables in the wizard, and try adjusting the ranges you specified and rerunning the wizard.

Guidelines for Choosing Variable Ranges for Optimization

The optimization wizard does its best to find parameter values for an optimal system within the search ranges you specify on the wizard input tabs. Because the wizard searches a discrete number of values within the range for each parameter, defining too broad of a range increases the chances that the optimal value lies between the values included in the search. On the other hand, defining too narrow a range increases the chances that the optimal value lies outside of the search range.

The ability of the optimization wizard to find an optimal system is sensitive to the following variable ranges:

- Receiver diameter range, defined by Minimum Receiver Diameter and Maximum Receiver Diameter.
- Receiver height to diameter ratio range, defined by Minimum Receiver Height/Diameter Ratio and Maximum Receiver Height/Diameter Ratio.
- Tower height range, defined by Minimum Tower Height and Maximum Tower Height.
- Heliostat distance from tower range, defined by Maximum Distance from Tower and Minimum Distance from Tower values on the Heliostat Field page.

The following rules of thumb may be helpful in choosing search ranges for these variables, although they may not apply to some systems.

- *Tower height:* The tower height typically falls between 15 m for very small systems (5 MWe) and 300 m for very large systems (150 MWe). For example, a reasonable range for a 30 MWe system with a solar multiple of 1.0 would be between 40 m and 120 m.
- *Receiver diameter:* The optimization wizard searches for a receiver diameter value that maximizes absorbed radiation from the heliostat field within the flux limit defined by the maximum value on the Receiver/Tower page. Like the tower height, the receiver area typically scales with system's design thermal power. For very small systems, the optimal receiver diameter is typically between 1 m and 3 m, while very large systems may require a diameter of 25 m.
- *Receiver height to diameter ratio:* This ratio should generally fall between 0.5 and 2.0.
- *Heliostat distance from tower:* If the minimum distance is too small, the inner zones in the heliostat will contain no heliostats (the first rows in the field layout table on the Heliostat Field page contain zeros), which will cause the simulation to fail. If the maximum distance is too large, the outer zones will contain no heliostats. On the other hand, if the maximum distance is too small, all of the outer zones will contain heliostats. For very small systems, the maximum distance might be set to 300 m, and for very large systems, a distance of 2000 m might be appropriate.

5.11.4 Tower and Receiver

To view the Tower and Receiver page, click **Tower and Receiver** on the main window's navigation menu. Note that for the power tower input pages to be available, the technology option in the Technology and Market window must be Concentrating Solar Power - Power Tower System.

The Tower and Receiver page displays variables that specify the geometry of the heat collection system. The receiver model uses semi-empirical heat transfer and thermodynamic relationships to determine the thermal performance of the receiver. This allows the model to represent a wide array of geometries without deviating from a hypothetical reference system.

Page numbers relevant to this section from the Wagner (2008) and Kistler B (1986) references are:

- Wagner p 43-47, 68-71

The model makes several assumptions about the system geometry:

- The receiver consists of a discrete number of panels.
- Each panel in the receiver consists of a set of parallel tubes in thermal contact that share a common heat transfer fluid (HTF) header.
- The panel tubing is vertical and the heat transfer fluid flows through each sequential panel in a serpentine pattern (up one panel and down the adjacent panel).
- The number of tubes per panel is a function of the Number of Panels, Receiver Diameter, and Tube Outer Diameter variables.

The model varies the heat transfer fluid mass flow rate through the receiver to maintain the required outlet heat transfer fluid temperature. The model includes several practical safeguards to ensure realistic behavior in the receiver. For example, the mass flow rate through the receiver is limited to the value of the Max Flow Rate to Receiver variable, and the maximum receiver heat transfer fluid inlet temperature is kept at a value below the value of the Max Temp to Receiver variable.

Solar Advisor allows several options for the heat transfer fluid flow patterns through the receiver as indicated by the diagrams on the Receiver / Tower page. The Flow Pattern variable specifies the path taken by the fluid as it passes through the receiver. Options include a full circle around the receiver, a split path around the receiver, and a split pass with a single cross-over.

Input Variable Reference

Dimensions

For analyses involving the optimization wizard to optimize the heliostat field layout, Solar Advisor populates these variables with optimal values. You can change the values after running the optimization wizard, but results will no longer be for the optimal system.

Variable	Description	Units
Receiver Height	Height in meters of the receiver panels.	m
Receiver Diameter	Total diameter in meters of the receiver.The distance from center of the receiver to center of a receiver panel. The width of a single panel is the circumference of receiver divided by number of panels.	m
Tower Height	Height in meters of the tower structure from the ground, equal to the vertical distance between the heliostat pivot points and the vertical center of receiver.	m

Thermodynamic Characteristics

Variable	Description	Units
Number of Panels	Number of vertical panels in the receiver.	
Tube Outer Diameter	The outer diameter in millimeters of the tubing that carries the heat transfer fluid through the receiver panels. Typical values range from 25 mm to 50 mm.	mm

Tube Wall Thickness	The thickness in millimeters of the individual receiver panel tube walls.	mm
Required Outlet HTF Temp	The temperature set point in degrees Celsius for the heat transfer fluid at the receiver outlet.	°C
Max Temp to Receiver	The maximum allowable temperature of the heat transfer fluid at the receiver inlet.	°C
Coating Absorptivity	Absorptivity fraction of receiver tube coating. Typical values are 0.91 to 0.95.	--
Coating Emissivity	The emissivity of the receiver coating, assumed to be black-body emissivity constant over the range of wavelengths.	--
Heat Loss Factor	A receiver heat loss adjustment factor that can be used when the calculated heat loss value deviates from an expected value. The default value is 1, corresponding to no heat loss correction. The calculated receiver heat loss is the sum of convection and radiation losses from the receiver, reported in the hourly results as Rec_conv_loss and Rec_rad_loss, respectively.	--
Enable Night Recirculation through Receiver	With night circulation enabled, whenever the radiation incident on the receiver is zero, hot heat transfer fluid circulates through the receiver to prevent fluid in the receiver from freezing. For systems with storage, the system pumps heat transfer fluid from hot storage. For systems with no storage, or when there is insufficient energy in storage, the circulating fluid is heated with an electric heater.	--
Recirculation Heater Efficiency	With night circulation enabled, the electric-to-thermal conversion efficiency of the heater used to supply thermal energy for preventing the receiver heat transfer fluid from freezing. Solar Advisor calculates the heater electricity based on the required thermal recirculation energy and the heater efficiency, and reports the hourly electricity required by the heater as Par_recirc_htr in the hourly results.	--
Max HTF Velocity in Receiver	The maximum heat transfer fluid flow rate inside the receiver. If the fluid velocity through any single panel exceeds this value, the heliostat field is partially defocused until the fluid velocity constraint is met.	kg/hr
Max Flow Rate to Receiver	The maximum heat transfer fluid flow rate at the receiver inlet. Solar Advisor calculates this value as a function of the maximum heat transfer fluid velocity in the receiver.	kg/hr
Max Receiver Flux	The upper limit of solar radiation incident on the receiver allowed to be reflected from the heliostat field. Solar Advisor ensures that the optimal receiver size and heliostat positions do not result in a receiver flux that exceeds this value.	kW/m^2

Material Type	The material of the receiver panel tubes, typically a stainless-steel alloy.	--
Heat Transfer Fluid Type	One of two types of solar salt used for the heat transfer fluid, also called the working fluid.	--
Flow Pattern	One of eight heat available transfer fluid flow configurations shown in the diagram on the Receiver / Tower page. The views are from the top of the receiver, assuming that panels are arranged in a circle around the center of the receiver. Arrows show the direction of heat transfer fluid flow into, through, and out of the receiver.	--

Materials and Flow

Variable	Description
HTF Type	One of two types of solar salt used for the heat transfer fluid, also called the working fluid. You can also add a user defined HTF by choosing the user defined option and clicking the Edit button to open the HTF properties editor.
Property table for user-defined HTF	When the HTF type is "user defined," the Edit button provides access to the HTF properties editor.
Material Type	The material of the receiver panel tubes, typically a stainless-steel alloy. The current version of Solar Advisor allows only one material type.
Flow Pattern	One of eight heat available transfer fluid flow configurations shown in the diagram. The views are from the top of the receiver, assuming that panels are arranged in a circle around the center of the receiver. Arrows show the direction of heat transfer fluid flow into, through, and out of the receiver.

5.11.5 Power Cycle

The power cycle converts thermal energy to electric energy. The power cycle is assumed to consist of a Rankine-cycle steam engine, two open feed-water heaters, and a pre-heater, boiler and super-heater.

The parameters on the Power cycle page describe the steam turbine size and other properties.

Page numbers relevant to this section from the Wagner (2008) and Kistler B (1986) references are:

- Wagner 83, 86, 114, 164
- Kistler 224

The power cycle page displays variables that specify the design operating conditions for the steam Rankine cycle used to convert thermal energy to electricity.

Input Variable Reference

Power Block Parameters

Variable	Description	Units
Nameplate Capacity	The power block's full-load, continuous rating under design conditions in kilowatts of electricity, excluding parasitic electric loads.	MWe
Rated Cycle Conversion Efficiency	The Rankine cycle thermal-to-electric conversion efficiency at design conditions.	-
Design Thermal Power	The turbine's design thermal input. It is the thermal energy required at the power block inlet for it to operate at its design point, as defined by the value of the nameplate electric capacity and an estimate of the parasitic losses: Design thermal power = nameplate electric capacity + total parasitic loss estimate. (See Parasitics for a description of the total parasitic loss estimate.)	MWe
Design HTF Inlet Temp	The design temperature in degrees Celsius of the hot heat transfer fluid at the power block inlet. The design values are the operating conditions at which the power block operates at its nameplate capacity.	°C
Design HTF Outlet Temp	The design temperature in degrees Celsius of the cold heat transfer fluid at the power block outlet. The design values are the operating conditions at which the power block operates at its nameplate capacity.	°C
Boiler Steam Pressure	The saturation pressure of the steam as it is converted from liquid to vapor in the boiler or steam generator. Solar Advisor uses this value to determine the steam's saturation temperature and thus the superheating capability of the heat exchangers.	Bar
Min Temp to Load	The lowest heat transfer fluid temperature allowed at the power cycle inlet. Whenever the fluid temperature falls below this point, the power cycle shuts down.	°C
Low-Resource Standby Period	During periods of insufficient flow from the heat source due to low thermal resource, the power block may enter standby mode. In standby mode, the cycle can restart quickly without the startup period required by a cold start. The standby period is the maximum number of hours allowed for standby mode. This option is only available for systems with thermal storage.	hours
Standby Mode Thermal Fraction	The fraction of the turbine's design thermal input required from storage to keep the power cycle in standby mode. This thermal energy is not converted into electric power.	--
Turbine Startup Time	The time in hours that the system consumes energy at the startup fraction before it begins producing electricity. If the startup fraction is zero, the system will operate at the design capacity over the startup time.	hours
Turbine Startup Energy Fraction	The fraction of the turbine's design thermal input required by the system during startup. This thermal energy is not converted to electric power.	--

Ref Condenser Water dT	The temperature difference of the water at the inlet and outlet of the condenser at design conditions. Solar Advisor uses this value to size the condenser.	°C
Temperature Correction Mode	Determines whether Solar Advisor uses the wet bulb or dry bulb temperature data from the weather file as the condenser inlet water temperature.	--
Minimum Load Fraction	The fraction of the nameplate electric capacity below which the power block does not generate electricity. Whenever the power block output is below the minimum load and thermal energy is available from the solar field, the field is defocused. For systems with storage, solar field energy is delivered to storage until storage is full.The default value is 0.15.	--
Max Over Design Operation	The maximum allowable power block output as a fraction of the electric nameplate capacity. Whenever storage is not available and the solar resource exceeds the design value of 950 W/m2, some heliostats in the solar field are defocused to limit the power block output to the maximum load. The default value is 1.1.	--

5.11.6 Thermal Storage

The parameters on the Storage page describe the properties thermal energy storage system and the storage dispatch controls.

The variables on the Storage page are similar to the layout and control scheme implemented in the parabolic trough model, with the following differences:

- The power tower storage model uses storage tank geometry, which requires that the heat transfer fluid volume, tank loss coefficients, and tank temperatures be specified.
- Solar Advisor calculates the storage tank geometry to ensure that the storage system can supply energy to the power block at its design thermal input capacity for the number of hours specified by the Full Load TS Hours variable.

Note. Because the storage capacity is not tied to the solar multiple on the Heliostat Field page, be careful to choose a storage capacity that is reasonable given the system's thermal capacity. Mismatched storage and solar thermal capacities will result in high levelized cost of energy values.

Contents

Input Variable Reference

Storage System

Variable	Description	Units
Storage Type	Solar Advisor models only two-tank storage systems for power towers. A two-tank system consists of separate hot and cold storage tanks.	--
Full Load Thermal Storage Hours	The storage capacity expressed in hours at full load: The number of hours that the storage system can supply energy at the power block design turbine input capacity. Note that Solar Advisor displays the equivalent storage capacity in MWht on the Tower System Costs page.	hours
Storage HTF Volume	Solar Advisor calculates the total heat transfer fluid volume in storage based on the storage hours at full load and the power block design turbine thermal input capacity. The total heat transfer fluid volume is divided among the total number of tanks so that all hot tanks contain the same volume of fluid, and all cold tanks contain the same volume of fluid.	m^3
Tank Diameter	The diameter of the cylinder-shaped heat transfer fluid volume in each storage tank.	m
Tank Height	The height of the cylinder-shaped heat transfer fluid volume in each tank. Solar Advisor calculates the height based on the diameter and storage volume of a single tank.	m
Parallel Tank Pairs	The number of parallel hot-cold storage tank pairs. Increasing the number of tank-pairs also increases the volume of the heat transfer fluid exposed to the tank surface, which increases the total tank thermal losses. Solar Advisor divides the total heat transfer fluid volume among all of the tanks, and assumes that each hot tank contains an equal volume of fluid, and each cold tank contains and equal volume.	--
Min Fluid Volume	The minimum storage heat transfer fluid volume allowed in each storage tank. The usable fluid volume is equal to the total volume minus the minimum fluid volume. Calculated based on the minimum tank volume fraction, the total volume, and the number of parallel tank pairs.	m^3
Min Tank Volume Fraction	The minimum allowed fraction of the total storage heat-transfer fluid volume of each storage tank.	--
Max Fluid Volume	The maximum usable heat transfer fluid volume allowed in each storage tank. The maximum volume is less than the total volume when the minimum tank volume is greater than zero, or the number of parallel tank pairs is greater than 1.	m^3
Wetted Loss Coefficient	The thermal loss coefficient that applies to the portion of the storage tank holding the storage heat transfer fluid.	W/m^2-K
Dry Loss Coefficient	The thermal loss coefficient that applies to the portion of the storage tank that contains storage heat transfer fluid.	W/m^2-K
Initial Hot HTF Temp	The temperature of the storage heat transfer fluid in the hot storage tank at the beginning of the simulation.	°C

Initial Cold HTF Temp	The temperature of the storage heat transfer fluid in the cold storage tank at the beginning of the simulation.	°C
Initial Hot HTF Percent	The fraction of the storage heat transfer fluid in the hot storage tank at the beginning of the simulation.	%
Initial Hot HTF Volume	The volume of the storage heat transfer fluid in the hot storage tank at the beginning of the simulation.	m^3
Initial Cold HTF Volume	The volume of the storage heat transfer fluid in the cold storage tank at the beginning of the simulation.	m^3
Cold Tank Heater Temp Set-Point	The minimum allowed cold tank temperature. Whenever the heat transfer fluid temperature in storage drops below the set-point value, the system adds sufficient thermal energy from an electric heater to storage to reach the set-point.	°C
Cold Tank Heater Max Load	The maximum electric load of the cold tank electric heater.	MWe
Hot Tank Heater Temp Set-Point	The minimum allowed hot tank temperature. Whenever the heat transfer fluid temperature in storage drops below the set-point value, the system adds sufficient thermal energy from an electric heater to storage to reach the set-point.	°C
Hot Tank Heater Max Load	The maximum electric load of the hot tank electric heater.	MWe
Tank Heater Efficiency	The electric-to-thermal conversion efficiency of the hot- and cold-tank heaters.	--

Thermal Storage Dispatch Control

The storage dispatch control variables each have six values, one for each of six possible dispatch periods. They determine how SAM calculates the energy flows between the solar field, thermal energy storage system, and power block. The fossil-fill fraction is used to calculate the energy from a backup boiler.

Name	Description
Storage Dispatch Fraction with Solar	The fraction of the TES maximum storage capacity (see table above) required for the system to start when the solar field energy is greater than zero. A value of zero will always dispatch the TES in any hour assigned to the given dispatch period; a value of one will never dispatch the TES. Used to calculate the storage dispatch levels.
Storage Dispatch Fraction without Solar	The fraction of the TES maximum storage capacity (see table above) required for the system to start when the solar field energy is equal to zero. A value of zero will always dispatch the TES in any hour assigned to the given dispatch period; a value of one will never dispatch the TES. Used to calculate the storage dispatch levels.
Turbine Output Fraction	A fraction of the design turbine thermal input adjusted by the turbine part load electric-to-thermal efficiency factors. Used to calculate the power block load requirement.

Name	Description
Fossil Fill Fraction	A fraction of the power block design turbine gross output from the Power Block page that can be met by the backup boiler. Used by the power block module to calculate the energy from the backup boiler.

Storage and Fossil Backup Dispatch Controls

The thermal storage dispatch controls determine the timing of releases of energy from the thermal energy storage and fossil backup systems to the power block. When the system includes thermal energy storage or fossil backup, Solar Advisor can use a different dispatch strategy for up to six different dispatch periods.

Storage Dispatch

Solar Advisor decides whether or not to operate the power block in each hour of the simulation based on how much energy is stored in the TES, how much energy is provided by the solar field, and the values of the thermal storage dispatch controls parameters. You can define when the power block operates for each of the six dispatch periods. For each hour in the simulation, if the power block is not already operating, Solar Advisor looks at the amount of energy that is in thermal energy storage at the beginning of the hour and decides whether it should start the power block. For each period, there are two targets for starting the power block: one for periods of sunshine (w/solar), and one for period of no sunshine (w/o solar).

The turbine output fraction for each dispatch period determines at what load level the power block runs using energy from storage during that period. The load level is a function of the turbine output fraction, design turbine thermal input, and the five turbine part load electric to thermal factors on the Power Cycle page.

For each dispatch period during periods of sunshine, thermal storage is dispatched to meet the power block load level for that period only when the thermal power from the solar field is insufficient and available storage is equal to or greater than the product of the storage dispatch fraction (with solar) and maximum energy in storage. Similarly, during periods of no sunshine when no thermal power is produced by the solar field, the power block will not run except when the energy available in storage is equal to or greater than the product of storage dispatch fraction (without solar) and maximum energy in storage.

By setting the thermal storage dispatch controls parameters, you can simulate the effect of a clear day when the operator may need to start the plant earlier in the day to make sure that the storage is not filled to capacity and solar energy is dumped, or of a cloudy day when the operator may want to store energy for later use in a higher value period.

Fossil Backup Dispatch

When the fossil fill fraction is greater than zero for any dispatch period, the system is considered to include fossil backup. The fossil fill fraction defines the solar output level at which the backup system runs during each hour of a specific dispatch period. For example, a fossil fill fraction of 1.0 would require that the fossil backup operate to fill in every hour during a specified period to 100% of design output. In that case, during periods when solar is providing 100% output, no fossil energy would be used. When solar is providing less than 100% output, the fossil backup operates to fill in the remaining energy so that the system achieves 100% output. For a fossil fill fraction of 0.5, the system would use energy from the fossil backup only when solar output drops below 50%.

The tank heater efficiency determines the quantity of fuel used by the fossil backup system. Solar Advisor includes the cost of fuel for the backup system in the levelized cost of energy and other metrics reported in the results, and reports the energy equivalent of the hourly fuel consumption in the hourly results. The cost of fuel for the backup system is defined on the Tower System Costs page.

Defining Dispatch Schedules

The storage dispatch schedules determine when each of the six periods apply during weekdays and weekends throughout the year. You can either choose an existing schedule from one of the schedules in the CSP trough TES dispatch library or define a custom schedule. For information about libraries, see Working with Libraries.

The TES dispatch library only assigns period numbers to the weekday and weekend schedule matrices. The dispatch fractions assigned to each of the six periods are not stored in the library.

To choose a schedule from the library:

1. Click **Dispatch schedule library**.
2. Choose a schedule from the list of four schedules. The schedules are based on time-of-use pricing schedules from four California utilities.
3. Click **OK**.

   You can modify a schedule using the steps described below. Modifying a schedule does not affect the schedule stored in the library.
4. For each of the up to six periods used in the schedule, enter values for the dispatch fractions described above. Use the period number and color to identify the times in the schedule that each period applies.

To define a dispatch schedule:

1. In the weekday schedule, select the times to which Period 1 applies.
2. Type the number 1.
3. Repeat Steps 1 and 2 for each of the up to six dispatch periods that you want to define, typing the period number to assign each period to times in the schedule.
4. Repeat Setps 1 through 3 for the weekend schedule.
5. For each of the up to six periods used in the schedule, enter values for the dispatch fractions described above. Use the period number and color to identify the times in the schedule that each period applies.

5.11.7 Parasitics

The parameters on the Parasitics page describe parasitic electrical loads and other losses in the power tower system.

Page numbers relevant to this section from the Wagner (2008) and Kistler B (1986) references are:

- Kistler 224

The parasitic loss variables are factors that Solar Advisor uses to calculate the estimated total parasitic loss and hourly parasitic losses, which are described in more detail below.

Solar Advisor calculates two types parasitic loss values. The first is an estimate of the total parasitic losses used to calculate the power block design thermal input, and the second are the hourly values calculated during simulation of the system's performance.

> **Note.** Parasitic losses from components that do not exist in the system should be set to zero.

Input Variable Reference

Parasitic Energy Consumption

Variable	Description	Units
Startup Energy of a Single Heliostat	The electric energy in kilowatt-hours required to move each heliostat into position. Applies during hours when the heliostat is starting up.	kWe-hr
Tracking Power for a Single Heliostat	The electric power in kilowatts required by the tracking mechanism of each heliostat in the field during hours of operation.	kWe
Receiver HTF Pump Efficiency	The electro-mechanical efficiency of the receiver heat transfer fluid pump.	--
Storage Pump Power	The ratio of the electric power in kilowatts required by the storage pumps to the thermal power passing through the storage system.	MWe/MWt
Balance of Plant Power	Losses as a fraction of the power block nameplate capacity that apply in hours when the power block operates.	MWe/MWe
Cooling Tower Parasitic Power	The cooling tower parasitic losses as a fraction of power block nameplate capacity are electrical losses that occur when the power block operates at part or full load.	MWe/MWe
Piping Loss Coefficient	Thermal loss per meter of piping. Includes piping throughout the system.	Wt/m
Total Piping Length	Length of piping throughout the system: From the receiver to power block, power block to process heat, etc. The piping loss varies with output produced by turbine.	m

Estimated Total Parasitic Losses

The estimated total parasitic losses value used to calculate the power block design thermal input displayed on the Power Cycle page is based on the estimated total parasitic loss factor, which depends following variables and values:

The estimated total parasitic loss factor $total\_par$ in MWe of losses per MWe of power block nameplate capacity is given by:

$$total\_par = stor\_pump\_par \times stor\_hours \times 0.20 + 0.03 + bop\_par + cool\_par$$

Where,

- stor_pump_par = Storage Pump Parasitic Power
- stor_hours = Full Load Thermal Storage Hours (Thermal Storage page)
- 0.20 = estimate of the solar multiple where each solar multiple is assumed to require 5 hours of storage
- 0.03 = estimate of the tower pump parasitic loss fraction
- bop_par = Balance of Plant Parasitic Power
- cool_par = Cooling Tower Parasitic Power

The total estimated parasitic losses in MWe is then:

$$total\ parasitic\ loss\ estimate = total\_par \times Nameplate\ Capacity$$

Where Nameplate Capacity is the power cycle electric capacity from the Power Cycle page.

Hourly Parasitic Losses

Solar Advisor reports the hourly parasitic losses described in the tables below in the hourly results.

Table 28. Parasitic loss variable names used in hourly performance data.

Parasitic Loss Variable	Description
Par_store_pump	Storage pump parasitic losses
Par_plant_bal	Balance of plant parasitic losses
Par_cooling_tower	Cooling tower pumping parasitic losses
Par_pipe_loss	Piping thermal losses
Par_tank_htr	Storage tank heater electric parasitic losses
Par_recirc_htr	Recirculation pump parasitic losses
Par_total	Total parasitic losses
Hel_track_power	Electricity for heliostat tracking

The parasitic loss variables are calculated from the parasitic loss factors on the Parasitics page and variables from the hourly simulation.

Table 29. Equations used to calculate parasitic loss quantities in the hourly performance data.

Variable	Calculation
Par_store_pump	storage pump power × (flow rate from storage ÷ reference flow rate) × (Nameplate Electric Capacity ÷ Rated Cycle Conversion Efficiency)
Par_plant_bal	Balance of Plant Parasitic Power × Cycle_power
Par_cooling_tower	Cooling Tower Parasitic Power × Cycle_power
Par_pipe_loss	Piping Loss Coefficient × Total Piping Length × Cycle_eff × Cycle_power ÷ Rated Cycle Conversion Efficiency
Par_tank_htr	cold tank pump power + hot tank pump power
Par_recirc_htr	required recirculation energy ÷ Recirculation Heater Efficiency

The total parasitic load Par_total is the sum of the following parasitic losses:

- Storage pump
- Balance of plant
- Cooling tower
- Tower pump
- Heliostat tracking
- Piping loses
- Storage tank heaters
- Tower parasitic losses

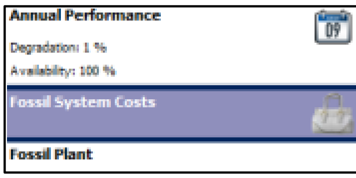
5.12 Generic Fossil Systems

The generic system model is a basic representation of a conventional fossil-fuel power plant. The Generic technology option makes it possible to compare analyses of photovoltaic and concentrating power systems to a base case conventional fossil fuel plant in the residential, commercial and central generation markets.

This section describes the system input pages that are available when the technology option in the Technology and Market window is Generic Fossil System:

- Fossil System Costs
- Fossil Plant
- User Variables

5.12.1 Fossil System Costs



To view the Fossil System Costs page, click **Fossil System Costs** on the main window's navigation menu. Note that for the generic fossil system input pages to be available, the technology option in the Technology and Market window must be Generic Fossil System.

Solar Advisor uses the variables on the Fossil System Costs page to calculate the project investment cost and annual operating costs reported in the project cash flow and used to calculate cost metrics reported in the Metrics table.

Because only the Total Installed Cost value affects the cash flow calculations, you can assign capital costs to the different cost categories in whatever way makes sense for your analysis. For example, you could assign the cost of designing the power plant to the direct plant cost category or to the engineer-procure-construct category with equivalent results. The categories are provided to help you keep track of the different costs, but do not affect the economic calculations. After assigning costs to the categories, verify that the total installed costs value is what you expect.

Variable values in boxes with white backgrounds are values that you can edit. Boxes with blue backgrounds contain calculated values or values from other pages that Solar Advisor displays for your information.

Note: The cost values in the sample files are intended to illustrate Solar Advisor's use. The cost data are meant to be realistic, but not to represent actual costs for a specific project. Actual costs will vary depending on the market, technology and geographic location of a project. Because of price volatility in solar markets, the cost data in the sample files is likely to be out of date. For more information see the Solar Advisor Model website, https://www.nrel.gov/analysis/sam/cost_data.html.

Contents

- Input Variable Reference describes the input variables on the Tower System Costs page.
- Entering Periodic Operation and Maintenance Costs explains how to use annual schedules to assign operation and maintenance costs to particular years in the project cash flow.

Input Variable Reference

Direct Capital Costs

A direct capital cost represents an expense for a specific piece of equipment or installation service that applies in year zero of the cash flow.

Note: Because Solar Advisor uses only the Total Installed Cost value in cash flow calculations, how you distribute costs among the different direct capital cost categories does not affect the final results.

Variable	Description	Units
Direct Plant Cost	The total cost of installing the generic fossil power plant, not including contingency.	$
Contingency	A percentage of the sum of the site improvements, heliostat field, balance of plant, power block, storage system, fixed solar field, total tower, and total receiver costs to account for expected uncertainties in direct cost estimates.	%
Total Direct Cost	The sum direct and contingency costs.	$

Indirect Capital Costs

An indirect cost is typically one that cannot be identified with a specific piece of equipment or installation service, and may include all other costs that are built into the price of the system, such as profit, overhead, and shipping costs. Depending on the purpose of your analysis, you may decide to distribute profit among the direct cost categories or include them as a single value in an indirect category.

Note: Because Solar Advisor uses only the total installed cost value in cash flow calculations, how you distribute costs among the different indirect capital cost categories does not affect the final results.

Variable	Description	Units
Engineer, Procure, Construct	Costs associated with design and construction of the project, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Project, Land, Miscellaneous	Costs associated with profit, overhead (including marketing), permitting, or shipping, calculated as the sum of a percentage of Total Direct Cost and a fixed cost.	% and $
Sales Tax	Percentage of direct costs to which sales tax applies, calculated by multiplying Total Direct Cost by the sales tax rate from the Financials page and the percentage that you specify.	%
Total Indirect Cost	The sum of Engineer-Procure-Construct costs, Project-Land-Miscellaneous costs, and sales tax.	$

Total Installed Cost

The total installed cost is the project's investment cost that applies in year zero of the project cash flow. Solar Advisor uses this value to calculate loan amounts and debt interest payments based on inputs on the Financing page, and to calculate tax credit and incentive payment amounts for incentive based tax credits and incentives defined on the Tax Credit Incentives page and Payment Incentives pages.

Variable	Description	Units
Total Installed Cost	The sum of total direct cost and total indirect cost.	$
Total Installed Cost per Capacity	Total installed cost divided by the total system capacity in Watts-DC of array capacity for PV systems and electric kilowatts of power block nameplate capacity for CSP systems. This value is provided for reference only and not used in cash flow calculations.	$/Wdc or $/kW

Operation and Maintenance Costs

Operation and Maintenance (O&M) costs represent annual expenditures on equipment and services that occur after the system is installed. Solar Advisor allows you to enter O&M costs in three ways: Fixed annual, fixed by capacity, and variable by generation. O&M costs are reported on the project cash flow.

For each O&M cost category, you can specify an annual escalation rate to represent an expected annual increase in O&M cost above the annual inflation rate specified on the Financing page. For an escalation rate of zero, the O&M cost in years two and later is the year one cost adjusted for inflation. For a non-zero escalation rate, the O&M cost in years two and later is the year one cost adjusted for inflation plus escalation.

For expenses such as component replacements that occur in particular years, you can use an annual schedule to assign costs to individual years. See below for details.

O&M Cost Category	Description	Units
Fixed Annual Cost	A fixed annual cost applied to each year in the project cash flow.	$/yr
Fixed Cost by Capacity	A fixed annual cost proportional to the array capacity in DC kilowatts.	$/kWdc-yr
Variable Cost by Generation	A variable annual cost proportional to the system's total annual electrical output in AC megawatt-hours. The annual output depends on either the performance model's calculated first year value and the degradation rate specified on the Annual Performance page, or on an annual schedule of costs, depending on the option chosen.	$/MWh-yr

Fossil Fuel Cost	The cost per million British thermal units for fuel. Solar Advisor uses the conversion factor 1 MWh = 3.413 MMBtu. Applies only to the generic fossil, CSP trough, and CSP tower systems. The photovoltaic and CSP dish models ignore the fuel cost input variable. (When the fossil fill fraction variable on the Thermal Storage page for troughs or towers is greater than zero, the systems consume fuel for backup energy.)	$/MMBtu

Entering Periodic Operation and Maintenance Costs

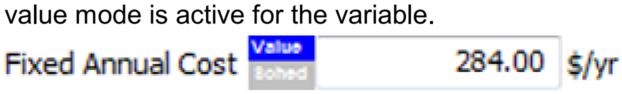
Solar Advisor allows you to specify any of the four operation and maintenance cost categories as an annual schedule. An annual schedule makes it possible to assign a cost to particular years in the analysis period. Annual schedules can be used to account for inverter replacement costs and other periodic costs that do not recur on a regular annual basis.

After running simulations, you will see the periodic costs in the project cash flow, and they will be accounted for in the other results displayed in the Metrics table.

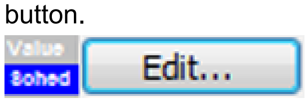
Note. Solar Advisor does not calculate any residual or salvage value remaining in inverters or other system components at the end of the analysis period.

To assign costs to particular years:

1. In the Fixed Annual Cost category, note that the "Value" label is blue indicating that the single value mode is active for the variable.



2. Click the button with the "Sched" label to change the mode to schedule and activate the Edit button.



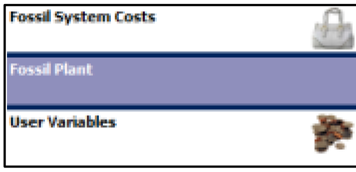
3. Click **Edit**.
4. In the Edit Schedule window, use the horizontal scroll bar to find the first year in which a cost occurs, and type the cost in current or constant dollars for that year.
   To delete a value, select it and press the Delete key on your keyboard.

Note. You must type a value for each year. If you delete a value, Solar Advisor will clear the cell, and you must type a number in the cell or Solar Advisor will consider the schedule to be invalid. Type a zero for years with no inverter replacement cost.

5. When you have finished editing the schedule, click **Accept**.

Because you must specify an O&M cost category as either an annual cost or annual schedule, to assign both a recurring annual fixed cost and periodic replacement cost, you must type the recurring cost in each year of the annual schedule, and for years with replacement costs, type the sum of the recurring and replacement costs. Note that dollar values in the annual schedule are in nominal or current dollars. Inflation and escalation rates do not apply to values in annual schedules.

5.12.2 Fossil Plant



To view the Fossil Plant page, click **Fossil Plant** on the main window's navigation menu. Note that for the generic fossil system input pages to be available, the technology option in the Technology and Market window must be Generic Fossil System.

The parameters for the generic fossil system are for a simple model of a fossil fuel power plant. Unlike the photovoltaic and concentrating solar power models, the generic model is not based on an hourly simulation engine. The first year annual output of the generic plant is based on a simple equation using the four System variables: Nameplate Capacity, Capacity Factor, Availability, and Derate.

The First Year Annual Output is calculated using the following equation:

$$E_{\mathrm{FirstYearOutput}} = E_{\mathrm{Nameplate}} \cdot F_{\mathrm{CapacityFactor}} \cdot F_{\mathrm{Availability}} \cdot (1 - F_{\mathrm{Derate}})$$

Where,

$E_{FirstYearOutput}$ (kW)	First Year Annual Generation: The generic system's total output in the first year, before annual degradation applies.
$E_{NamePlate}$ (%)	Nameplate Capacity: The rated capacity of the generic system.
$F_{CapacityFactor}$ (%)	Capacity Factor: The expected net generated electricity over one year (8760 hours) divided by the electricity that could have been generated at continuous full rated power over the year. Base load plants typically operate at capacity factors of about 90%, with capacity factors of less than 100% due to curtailed output. Load following plants and peaking plants will have lower capacity factors.
$F_{Availability}$ (%)	The Availability factor from the Annual Performance page: the number of hours per year that the generic system is able to produce electricity divided by the number of hours in one year (8760 hours). Availability factors of less than 100% are typically due to plant down time for maintenance and repair.
F_{Derate} (%)	A derating factor applied to the generic system rated capacity to account for output reductions caused by inefficiencies in the system from wiring losses or other causes.

Solar Advisor also applies the system degradation factor from the Annual Performance page to represent an annual reduction in system output due to equipment aging that applies to year two and subsequent years.

The heat rate determines the cost of fuel reported as **Fuel O&M Expense** in year one of the project cash flow, and accounted for in the output metrics reported on the Results page. Solar Advisor uses the heat rate to calculate the first year fuel cost as follows:

$$C_{\mathrm{FirstYearFuel}} = C_{\mathrm{CostOfFuel}} \cdot F_{\mathrm{HeatRate}} \cdot E_{\mathrm{FirstYearOutput}}$$

Where,

$C_{FirstYearFuel}$ ($/yr)	The total cost of fuel for year one of the project cash flow, shown as the *Fuel O&M Expense* reported for Year 1 in the project cash flow.
$C_{CostOfFuel}$ ($/MMBtu)	Cost of Fuel from the Fossil System Costs page.
$F_{HeatRate}$ (MMBtu/MWh)	The generic system's heat rate, or conversion efficiency, equivalent to the number of MMBtu of heat required to produce one MWh of electricity.
$E_{FirstYearOutput}$ ()	The generic system's total electricity output in the first year.

5.13 User Variables

To view the User Variables page, click **User Variables** on the main window's navigation menu. The user variable input page is available for all technologies.

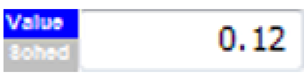
A user variable is a variable that you can create to store values in Solar Advisor for advanced analyses. Solar Advisor stores values of user variables but does not use them in any internal calculations. You can create up to six user variables.

One application of user variables is to enhance analyses that involve exchanging data with Excel. You can connect user variables, like other input variables, to cells in an Excel workbook. For example, you could use a user variable to convert units using a formula in Excel.

5.14 Editing Annual Schedules

Some input variables allow you to enter either a single value, or a series of values for each year in the analysis period defined on the Financing page. Examples of these variables are the System Degradation and Availability variables on the Annual Performance page, and the operation and maintenance costs on the system costs pages for each technology.

Variables with an annual schedule option have a small Value / Sched button next to the variable label. The variable's current mode is indicated in blue. In this case the variable's mode is Value, allowing you to define the variable's value as a single number:

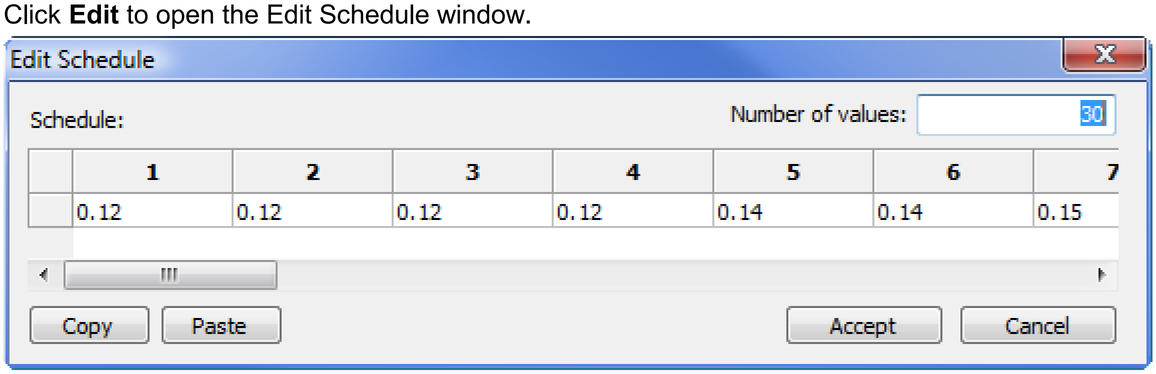


You can use an annual schedule to enter annual values either by hand, typing values or pasting values from a spreadsheet or text file. You can also exchange data from an annual schedule with an Excel worksheet, see Excel Exchange for details.

To enter year-by-year values by hand:

1. Click Sched to change the variable's mode from a single value to annual schedule mode. Solar Advisor displays the Edit button.

2. Click **Edit** to open the Edit Schedule window.



3. In Number of values, type the number of years for which you want to assign values. Typically, this

number should be equal to or less than the number of years in the Analysis Period defined on the Financing page.

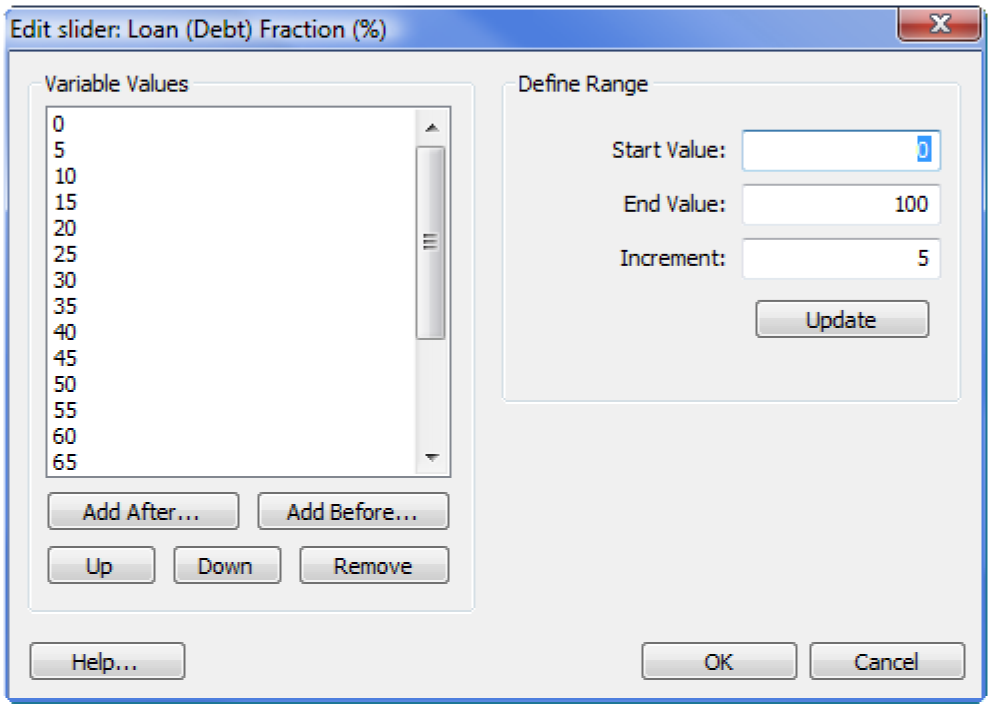
4. For each year in the schedule, type a value. The value should be in the same units as the variable's value.

   You can also copy a row of values from Excel, or a line of comma separated values from a text file and click **Paste** to enter a series of values.

5. Click **Accept** to return to the Costs page.

5.15 Working with Numeric Ranges

The numeric ranges window window allows you to assign one or more values to a parametric variable or to a slider.



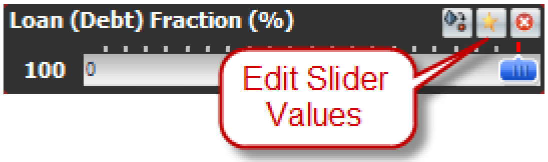
To open the numeric ranges window for parametric analyses:

1. On the Parametric Simulation Setup page, select a variable in the list.
2. Click **Edit**.

Note. Solar Advisor runs a complete hourly simulation for one year for each value that you assign to a variable. To avoid excessively long model runs, avoid assigning unnecessary values to parametric variables.

To open the numeric ranges window for sliders:

1. On the Results page, choose the sliders you want to display.
2. Click the Edit Slider Values button.



Define Range

	Description
Start Value	The range of variable values displayed in the Variable Values list begins with this value. The start value units and magnitude should be appropriate for the variable to which values are being assigned.
End Value	Range of variable values ends with this value. The start value units and magnitude should be appropriate for the variable to which values are being assigned.
Increment	Solar Advisor adds the increment value to each value in the list to calculate the next value. Increment values may be positive, negative, or decimal values.
Update	Calculates values based on the parameters defined above and displays them in the Variable Values list.

Variable Values

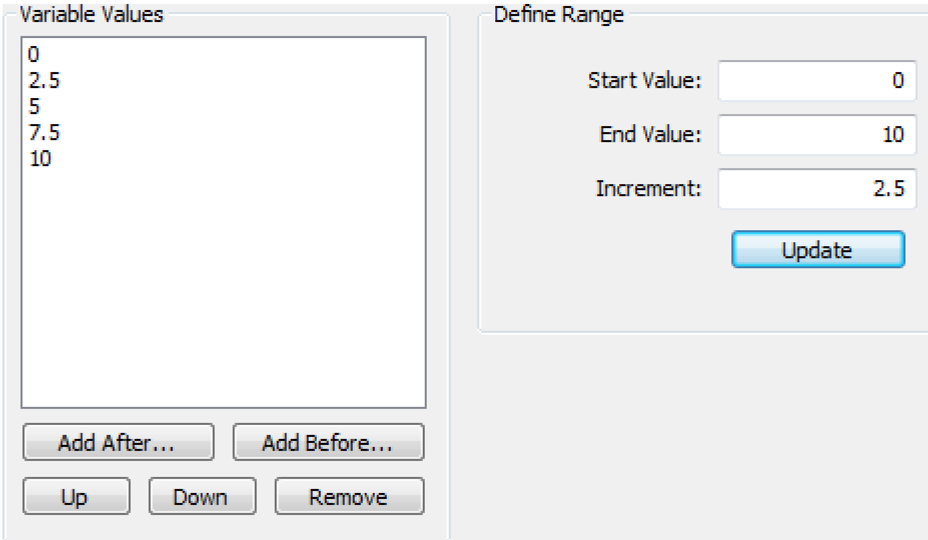
The Variable Values list shows the values that Solar Advisor will assign to the parametric variable or slider.

	Description
Add After	Add a value after the selected value in the Variable Values list.
Add Before	Add a value before the selected value in the list.
Up	Move the selected value one step up in the list.
Down	Move the selected value one step down in the list.
Remove	Remove the selected value from the list.

To assign values to a parametric variable or slider, you must define a range for the value. Values may or may not follow a regular pattern.

Regular pattern example: To assign the values 0, 2.5, 5, 7.5, 10 to a variable:

1. Type 0 for the start value.
2. Type 10 for the end value.
3. Type 2.5 for the increment.
4. Click **Update**.

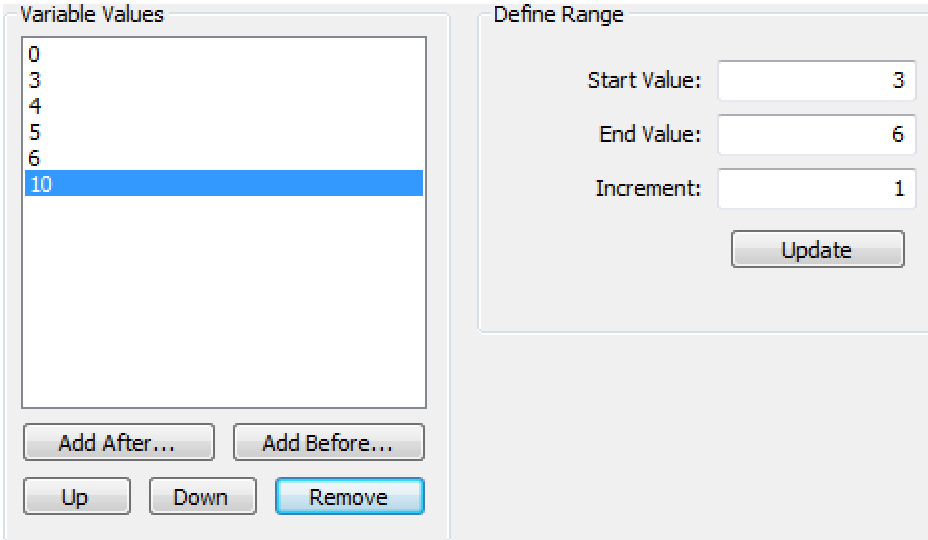


To assign values that do not follow a regular pattern, you can use the buttons under the Variable Values box to add values to the list.

Irregular range example: To assign the values 0, 3, 4, 5, 6, 10 to a variable:

1. Type 3 for the start value.
2. Type 6 for the end value.
3. Type 1 for the increment.
4. Click **Update**.
5. Select the number 3 in the Variable Values list.
6. Click **Add Before**.
7. Type 0 in the Add Before Selection window.
8. Click **OK**.
9. Select the number 6 in the Variable Values list.
10. Click **Add After**.
11. Type 10 in the Add After Selection window.
12. Click **OK**.

    Use the Up, Down, and Remove buttons to move through the list of variable values and to delete values.



6 Configuring Simulations

The Configure Simulations page allows you to set up simulations for a range of analyses options.

<u>To view the Configuring Simulations page:</u>

- Click the Configure Simulations button located under the navigation menu.

The available analysis options are:

- Parametrics: Assign multiple values to one or more input variables. Allows you to compare systems with different component sizes, locations, and financing assumptions, and to plot graphs of output metrics over a range of input variable values.
- Sensitivity: Examine how variation in one or more inputs affects the value of an output metric by assigning a range of variation to one or more input variables. Results are displayed in tornado graphs.
- Optimization: Find the value of one or more input variables that maximizes or minimizes an output metric.
- Statistical: Explore uncertainties in the inputs. Allows you to define a distribution for one or more input variables and runs multiple simulations using input values randomly picked according to the distribution.
- Multiple Systems: Model a system as a combination of subsystems. For example, model a photovoltaic system that consists of arrays with different orientations.

- Excel Exchange: Use Excel to store or calculate input variable values.

6.1 Parametric Analysis

A parametric analysis involves assigning multiple values to one or more input variables to explore the relationship between the input variables and results metrics. Examples of parametric analyses include:

- For photovoltaic systems, exploring the effect of array orientation on system electricity output by assigning multiple values to the array tilt and orientation variables.
- For CSP trough systems with thermal energy storage, exploring the effect of solar multiple and storage capacity on the levelized cost of energy.
- For any technology, exploring the effect of annual degradation rates on the system's annual output over the life of a project.

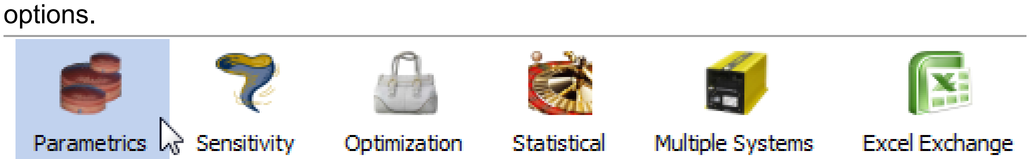
Configuring parametric variables makes it possible to plot graphs of performance or economic output metrics as a function of one or more input variables. For example, to plot a graph of the annual electric generation performance metric and the array tilt input variable, you would need to define the array tilt variable as a parametric variable. Parametric variables also appear on sliders, allowing you to dynamically change graphs and tables on the Results page.

> **Note.** Input variables that are not involved in the performance simulation calculations, such as those on the financing, tax credit and payment incentives, and utility rate pages, are available as sliders without being defined as parametric variables.

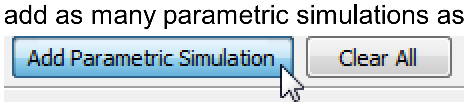
To display the parametric simulation setup options:

1. On the Main window, click **Configure Simulations** to view the Configure Simulation page.

2. On the Configure Simulations page, click **Parametrics** to display the Parametric simulation setup options.



3. Click **Add Parametric Simulation** to add a set of parametric simulation setup options. You can add as many parametric simulations as your analysis requires.



Click **Remove Simulation** to delete a simulation option.

Click **Clear All** to remove all simulation options from the case.

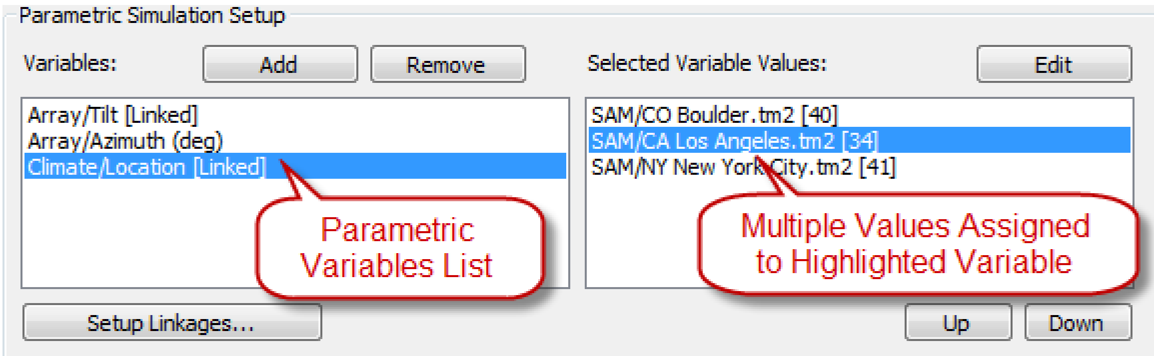
Contents

- Page Reference describes the parametric simulation setup options.

- Setting up a Parametric Analysis describes the steps for defining parametric variables.
- Working with Linkages explains how to set up a parametric analysis when parametric variables have a dependent relationship.
- Sample Parametric Results shows examples of the types of graphs that can be created using parametric analyses.

Page Reference

The Parametric Simulation Setup options allow you to add and remove variables from the list of parametric variables, assign values to and edit parametric variables, and to set up linkages between parametric variables that have interdependent values.



Parametric Simulation Setup

Add	Add an input variable to the parametric variables list. You must add a variable before you can assign it multiple values.
Remove	Remove a variable from the parametric variables list. When you remove a variable, Solar Advisor assigns the value from the variable's input page to the variable.
Setup Linkages	Create linkages between parametric variables when the values of one of the variables is dependent on those of the other.
Edit	Assign values to or edit values of the variable highlighted in the parametric variables list.
Up	Move the highlighted value in the variable values list up one row.
Down	Move the highlighted value in the variable values list down one row.
Remove Simulation	Remove the parametric simulation setup and delete all parametric values. You can also clear the Enable this simulation checkbox to keep the setup options but exclude the parametric analysis from simulations.
Enable this simulation	This box must be checked for the parametric simulation setup to be included in simulations when you run the model.

Setting up a Parametric Analysis

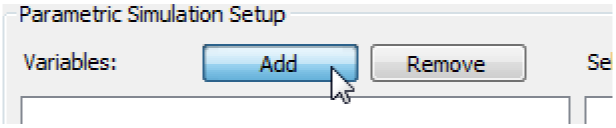
Once you have added a parametric simulation, you must add one or more parametric variables to the simulation, and assign multiple values to each variable.

After setting up the optimization, click the Run All Simulations button, or click **Run All Simulations** on the

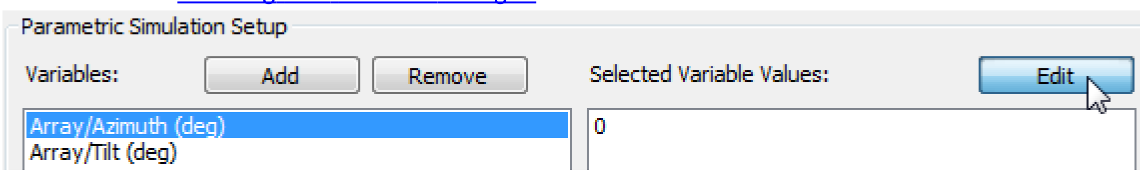
Case menu to run the optimization and any other enabled simulations.

<u>To set up a parametric analysis:</u>

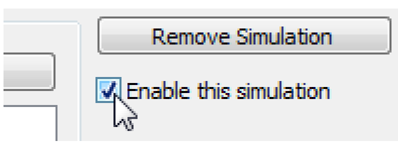
1. Display the parametric simulation setup options as described above.
2. Click **Add** to choose variables to which you want to assign multiple values from a list of available input variables. Solar Advisor adds the variables to the parametric variables list.



3. Highlight each variable in the parametric variables list and click **Edit** to assign values to the variables. See [Working with Numeric Ranges] for details.



4. Check **Enable this simulation** to include the parametric analysis in simulation runs. You can save the parametric simulation setup options and exclude the analysis from simulations by clearing the checkbox. Clearing the checkbox allows you to shorten simulation run times without losing the setup configuration.



Working with Linkages

In some analyses, parametric variables may be interdependent. For example:

- Tilt depends on location when an analysis assumes that the photovoltaic array or CSP collector tilt angle is equal to the location's latitude.
- Thermal storage capacity depends on the solar multiple for a CSP trough analysis that assumes that the storage system capacity scales with the solar field area.

For these analyses, linking the interdependent parametric variables prevents Solar Advisor from simulating combinations of parametric variable values that are not relevant to the analysis. For example, linking the array or collector tilt variable to the location variable ensures that Solar Advisor only simulates systems that use a location's latitude as the tilt angle. Without linkages, Solar Advisor would simulate all combinations of locations and tilt values.

<u>To setup a linkage between two parametric variables:</u>

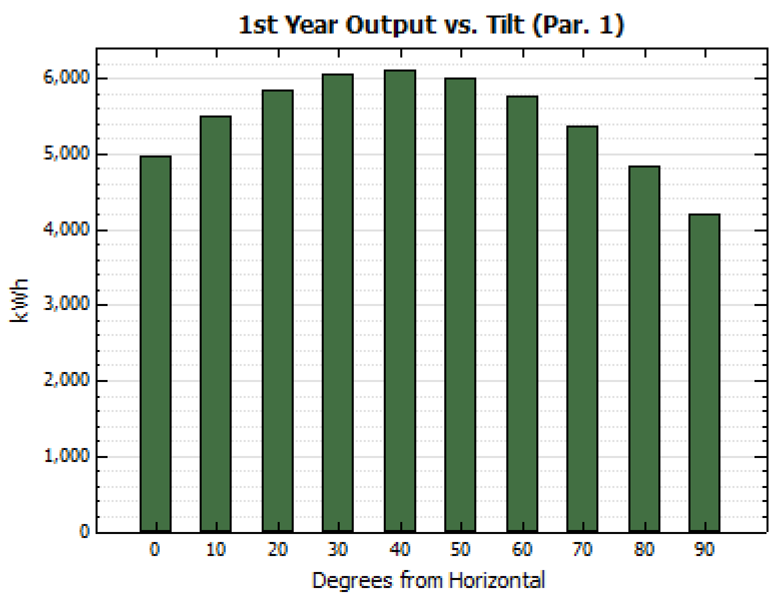
1. Add the two variables to the parametric variables list as described above. The parametric variables list may include other variables.
2. Click **Setup Linkages**.
3. In the Choose Linked Parametric Variables window, check the variable names for each of the two linked variables.
4. Click **OK**. Solar Advisor displays the word "Linked" in brackets next to the variable names in the parametric variables list indicating the linked variables
5. Click the first linked variable. Solar Advisor displays the variable's values in the variable values list, and shows the value of the other linked variable in brackets.

6. Click **Edit** to assign multiple values to the first linked variable. See Working with Numeric Ranges for details.
7. Click **OK**. Solar Advisor displays question marks in brackets next to the values of the second linked variable to which you have not yet assigned values.
8. In the parametric variables list, click the second linked variable.
9. Click **Edit** to assign multiple values to the variable. Note that you should assign the same number of values to this variable as you did to the first linked variable.
10. Click **OK**. Solar Advisor displays the values of both variables in the variable values list. Check the list to make sure that there are no question marks in brackets indicating a missing linked value and that the values are in correctly matched pairs.

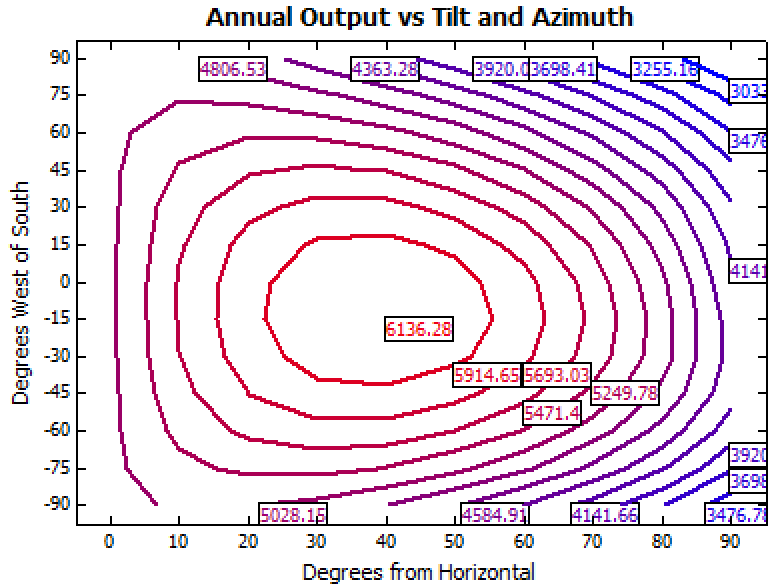
Sample Parametric Analysis Results

The following graphs were created by setting up parametric analyses. You can use these examples to better understand how to use parametric analysis to create useful graphs.

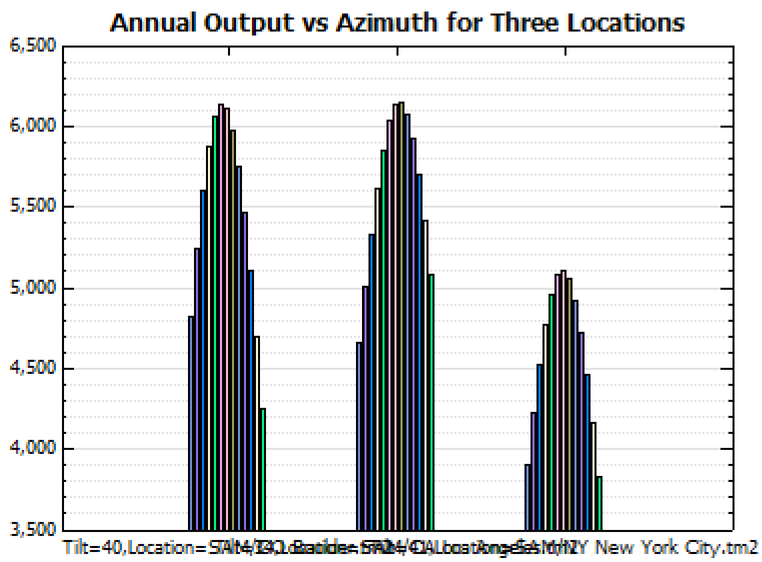
The following graph shows how a photovoltaic system's first year annual electric output depends on the array tilt. The tilt variable on the Climate page was defined as a parametric variable with ten values: 0, 10, 20, 30, 40, 50, 60, 70, 80, and 90 degrees from horizontal:



The next graph shows how the first year annual electric output depends on both the array tilt and azimuth. The tilt variable was assigned the same values as the previous graph, and the azimuth variable was assigned values between -90 and 90 degrees west of south in increments of 15 degrees:



The third graph shows the relationship between the first year annual electric output and array azimuth for three locations, assuming an array tilt equal to the location's latitude. The azimuth value was assigned ranges between -90 and 90 degrees as above, and the tilt and location variables were linked as follows: Location = Boulder : Tilt = 40 degrees, Location = Los Angeles : Tilt = 34 degrees, Location = New York City : Tilt = 41 degrees. Each cluster of bars in the graph shows the annual output for each azimuth value for Boulder, Los Angeles, and New York, respectively.



6.2 Sensitivity Analysis

The sensitivity analysis option allows you to specify a range of values as a percentage for one or more input variables to investigate how sensitive an output metric is to variations in the input variables' values. Examples of sensitivity analyses include:

- Determining the sensitivity of the levelized cost of energy to different capital cost components.
- Comparing the sensitivity of the levelized cost of energy to capital cost and financial assumptions.

Configuring sensitivity analyses makes it possible to plot tornado graphs showing the range of an output metric values for one or more sensitivity variables.

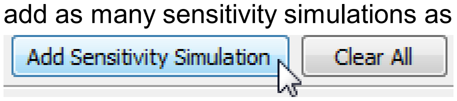
> **Note.** Solar Advisor calculates results for each sensitivity variable independently. In some analyses, this may cause misleading results. This is especially true when the sensitivity variable is a performance input variable rather than a cost or financial input variable. For example, for CSP trough systems with storage, varying the thermal storage capacity independently of the tank heat loss variable to examine how sensitive the system's electrical output is to storage capacity would not accurately account for the expected increase in heat loss for larger storage systems. Similarly, for photovoltaic systems, varying the number of modules per string independently of the inverter type or number of inverters might result in inaccurate system output calculations if the inverter is improperly sized for a number of modules within the range specified for the sensitivity analysis.

To display the sensitivity simulation setup options:

1. On the Main window, click **Configure Simulations** to view the Configure Simulation page.

2. On the Configure Simulations page, click **Sensitivity** to display the Parametric simulation setup options.

3. Click **Add Sensitivity Simulation** to add a set of sensitivity simulation setup options. You can add as many sensitivity simulations as your analysis requires.



Click **Remove Simulation** to delete a simulation option.

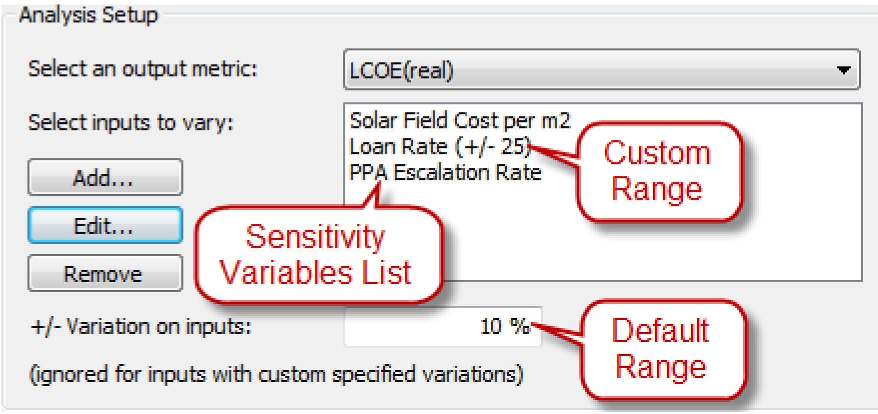
Click **Clear All** to remove all simulation options from the case.

Contents

created using sensitivity analyses.

Page Reference

The Analysis Setup options allow you to choose an output metric, add and remove variables from the list of sensitivity variables, assign values to and edit sensitivity variables, and assign ranges to each sensitivity variable.



Analysis Setup

Select an output metric	Choose an output metric for the sensitivity analysis. This metric will appear on tornado graphs in the results.
Add	Add an input variable to the sensitivity variables list.
Edit	Assign a "custom" variation range to the variable highlighted in the sensitivity variables list. Solar Advisor assigns the default range to all sensitivity variables that do not have a different custom range. Solar Advisor indicates the custom range in parentheses next to the variable's name in the sensitivity variable list.
Remove	Remove a variable from the sensitivity variables list.
+/- Variation on inputs	The default range applied to all sensitivity variables that do not have a different custom range. For a range value of 10 %, Solar Advisor would calculate the range of values of an input variable between 10 % below and 10 % above the variable's value on the input page.

Setting up a Sensitivity Analysis

Once you have added a sensitivity simulation, you must add one or more sensitivity variables to the simulation.

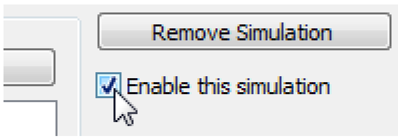
After setting up the optimization, click the Run All Simulations button, or click **Run All Simulations** on the Case menu to run the optimization and any other enabled simulations.

To set up a sensitivity analysis:

1. Display the sensitivity simulation setup options as described above.
2. Click **Add** to choose variables to which you want to assign a variation range from a list of available input variables. Solar Advisor adds the variables to the sensitivity variables list.
3. If you want to use a variation range value other than the default value displayed below the

sensitivity variables list, click **Edit** to assign a custom range value.

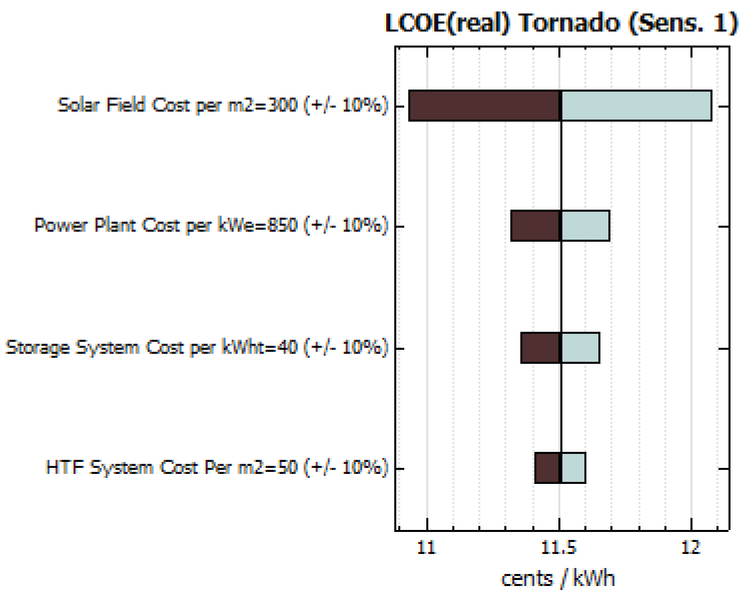
4. Check **Enable this simulation** to include the sensitivity analysis in simulation runs. You can save the sensitivity simulation setup options and exclude the analysis from simulations by clearing the checkbox. Clearing the checkbox allows you to shorten simulation run times without losing the setup configuration.



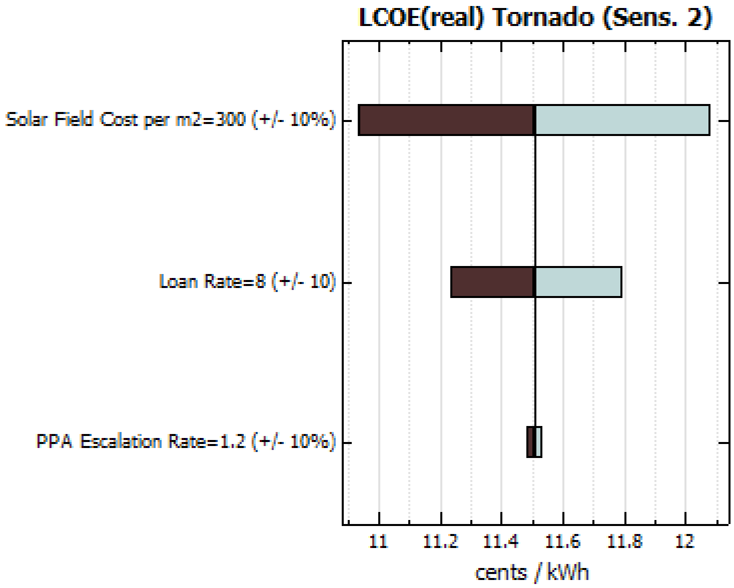
Sample Sensitivity Analysis Results

The following tornado graphs were created by setting up sensitivity analyses. You can use these examples to better understand how to use parametric analysis to create useful graphs.

The following graph shows how sensitive a CSP trough project's levelized cost of energy is to four capital cost categories. To create the graph, the following four variables were defined as sensitivity variables using the default variation range of 10 %: Power plant cost, solar field cost, HTF system cost, and storage system cost:



The next graph shows shows how sensitive the levelized cost of energy is to selected capital cost categories compared to selected financial assumptions for a CSP trough system. The solar field cost, loan rate, and PPA escalation rate were defined as sensitivity variables with a 10 % variation range. how the first year annual electric output depends on both the array tilt and azimuth. The tilt variable was assigned the same values as the previous graph, and the azimuth variable was assigned values between -90 and 90 degrees west of south in increments of 15 degrees:



6.3 Optimization

An optimization involves choosing an output metric that you would like to either maximize or minimize, and allowing Solar Advisor to find values of one or more input variables that result in the maximum or minimum output metric value. Examples of optimization include:

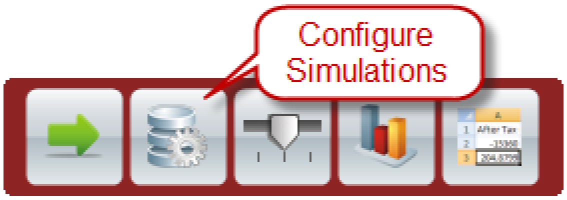
- For photovoltaic systems, finding the array tilt and azimuth values that result in the lowest levelized cost of energy to optimize the array orientation for lowest cost of energy.
- For a photovoltaic system modeled using the PVWatts performance model, optimize the storage capacity for minimum levelized cost of energy.
- For a CSP trough system, find the optimal collector deploy and stow angle to maximize solar field thermal output.

Note. When you optimize an input variable, be careful to choose one that is not interdependent on other variables. For example, for a CSP trough system with storage, optimizing the solar multiple independent of storage capacity to minimize the levelized cost of energy could give misleading results. Similarly, for photovoltaic systems, optimizing the number of modules per string independently of the inverter might result in a system with an improperly sized inverter. To find optimal values of interdependent variables, you can use parametric analysis.

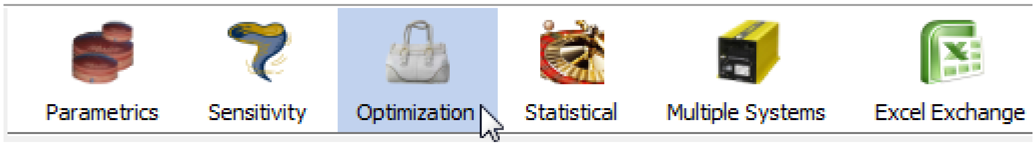
One application of Solar Advisor's optimization capability is to help you find values of input variables to use for your analysis. For example, for a photovoltaic system, you could use optimization to find the best array tilt and azimuth values to use on the Array page. Or, for a CSP trough system, you could use optimization to find the deploy and stow angle to use on the Solar Field page.

To display the optimization setup options:

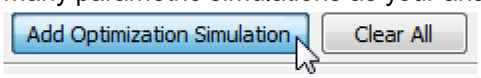
1. On the Main window, click **Configure Simulations** to view the Configure Simulation page.



2. On the Configure Simulations page, click **Optimization** to display the optimization simulation setup options.



3. Click **Add Optimization Simulation** to add a set of optimization setup options. You can add as many parametric simulations as your analysis requires.



Click **Remove Simulation** to delete a simulation option.

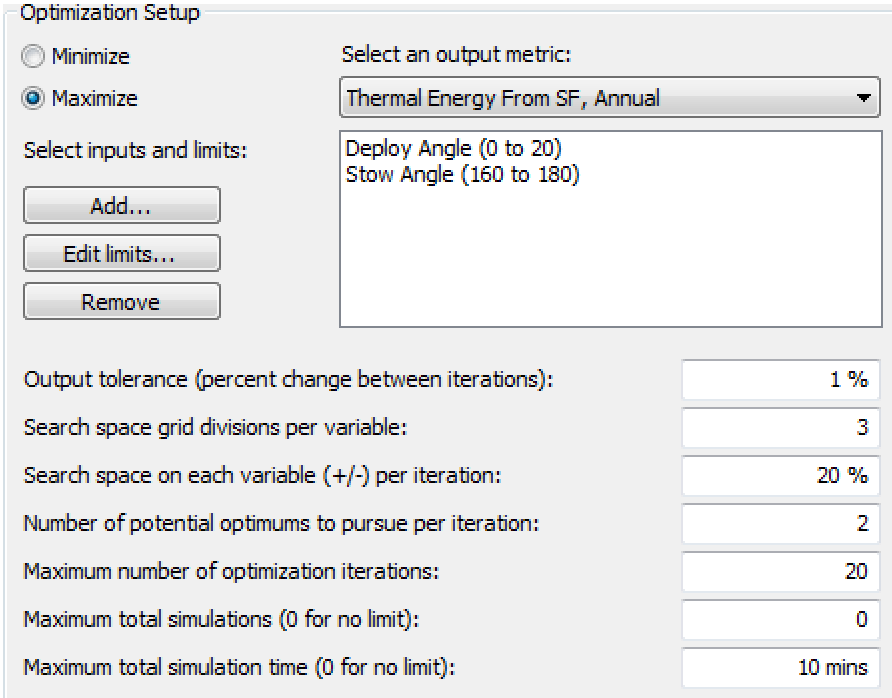
Click **Clear All** to remove all simulation options from the case.

Contents

- Page Reference describes the optimization simulation setup options.
- Setting up an Optimization describes the steps for defining optimization variables.
- Sample Optimization Results shows examples of results from an optimization analysis.

Page Reference

The Optimization Setup options allow you to select the output metric to maximize or minimize, add and remove variables from the list of optimization variables, and assign a range of values to optimization variables.



Optimization Setup

Minimize / Maximize	Choose whether to maximize or minimize the output metric.
Select an output metric	Choose the output metric to maximize or minimize.
Add	Choose one or more optimization variables from a list of available input variables.
Edit limits	Assign an upper and lower limit to the variable highlighted in the optimization variable list.
Remove	Remove the highlighted variable from the optimization variable list.
Advanced parameters	The advanced parameters affect the speed and resolution of the optimization. You can use the default values for most analyses, or experiment with the values for faster run times. You can also try adjusting the values if Solar Advisor does not find an optimal solution.

Setting up an Optimization

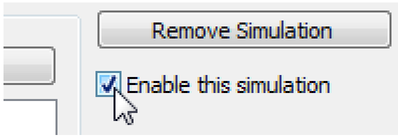
Once you have added an optimization simulation, you must choose an output metric to maximize or minimize, add one or more optimization variables to the simulation, and edit the limits of each variable.

After setting up the optimization, click the Run All Simulations button, or click **Run All Simulations** on the Case menu to run the optimization and any other enabled simulations.

To set up an optimization:

1. Display the parametric simulation setup options as described above.
2. Click **Add** to choose variables to which you want to assign multiple values from a list of available input variables. Solar Advisor adds the variables to the parametric variables list.

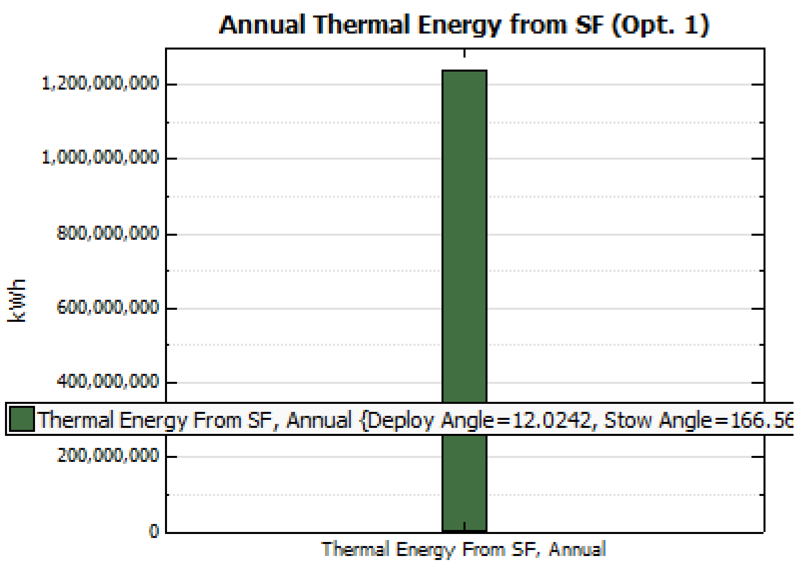
3. Highlight each variable in the parametric variables list and click **Edit** to assign an upper and lower limit to each variable.
4. Check **Enable this simulation** to include the optimization in simulation runs. You can save the optimization setup options and exclude the analysis from simulations by clearing the checkbox. Clearing the checkbox allows you to shorten simulation run times without losing the setup configuration.



Sample Optimization Results

The following example illustrates the use of optimization for Solar Advisor analyses.

This example is for a CSP trough system, and finds the optimal collector deploy and stow angles defined on the Solar Field page. Those angles determine the collector angle at which heat transfer fluid begins circulating in the morning, and stops circulating in the evening, respectively. The system starts tracking the movement of the sun at sunrise, but deploying collectors too early results in wasted energy from operating fluid pumps before there is sufficient energy to generate electricity. Similarly, continuing to operate the fluid pumps in the evening when the sun is below a certain point above the horizon wastes energy. Optimizing the deploy and stow angles for maximum thermal energy delivered by the solar field ensures that the system does not waste energy by deploying the collectors too late or stowing them too early. In this example for a system in Dagget, California, Solar Advisor found an optimal deploy angle of 12 degrees, and an optimal stow angle of 167 degrees. The optimization found the maximum value of the annual thermal energy from solar field output metric for deploy angle limits of 0 and 20 degrees, and stow angle limits of 160 to 180 degrees:



6.4 Statistical

A statistical analysis allows you to examine the effect of uncertainty in the value of one or more input variables on an output metric. For example, you could use statistical analysis to explore how the degree of uncertainty in the installation cost of one or more system components might affect the system's levelized cost of energy over the project life.

In a statistical analysis, Solar Advisor runs several simulations for a distribution of values assigned to one or more input variables, and displays a histogram showing the frequency distribution of different output metric values over each input variable's distribution of values.

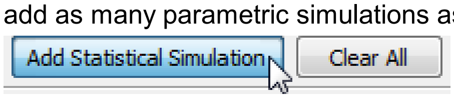
For an example of a Solar Advisor file with multiple systems, open the sample template *Statistical Analysis Sample*: On the File menu, click **Open Sample Template** and select the template from the list.

To display the statistical simulation setup options:

1. On the Main window, click **Configure Simulations** to view the Configure Simulation page.

2. On the Configure Simulations page, click **Statistical** to display the statistical simulation setup options.

3. Click **Add Parametric Simulation** to add a set of parametric simulation setup options. You can add as many parametric simulations as your analysis requires.



Click **Remove Simulation** to delete a simulation option.

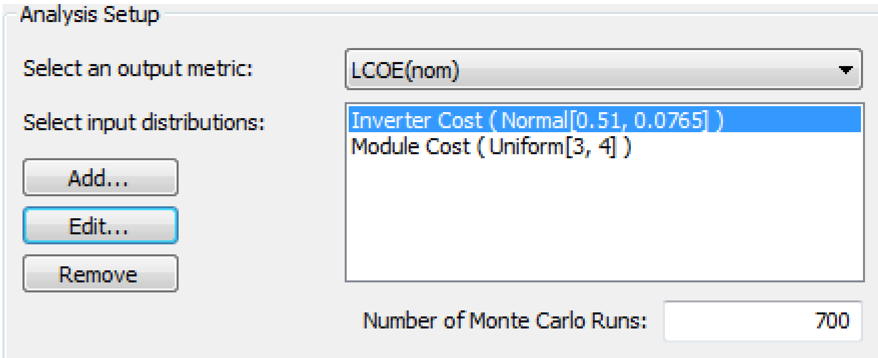
Click **Clear All** to remove all simulation options from the case.

Contents

- Page Reference describes the statistical simulation setup options.
- Input Distribution Options describes the distribution parameters that you specify for each statistical variable.
- Setting up a Statistical Analysis describes the steps for choosing an output metric, input variables, and distribution parameters for a statistical analysis.
- Displaying Histograms for Statistical Variables describes the graphing options on the Results page available for statistical analyses.

Page Reference

The statistical Analysis Setup options allow you to select the output metric, add and remove variables from the list of statistiacl variables, and assign distribution parameters to the statistical variables.

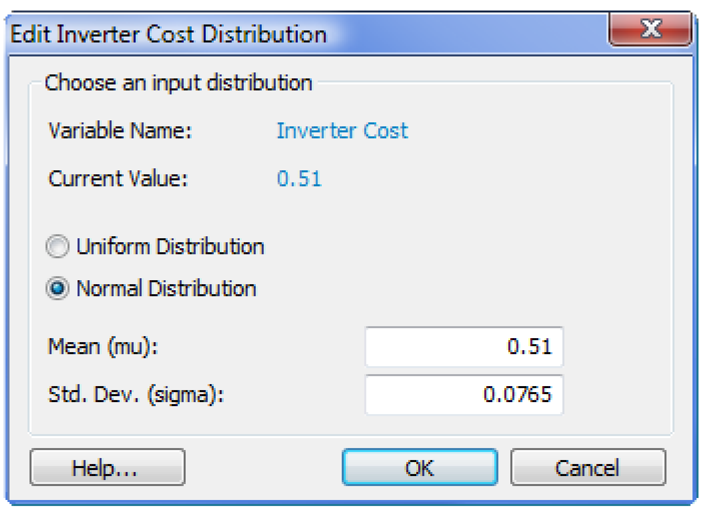


Analysis Setup

Select an output metric	Choose the output metric for the statistical analysis.
Add	Choose one or more statistical variables from a list of available input variables.
Edit	Assign an input distribution for the analysis. See below for details.
Remove	Remove the highlighted variable from the statistical variable list.
Number of Monte Carlo Runs	Enter a value for the number of simulations to run for the analysis. The default value is 400.

Input Distribution Options

The edit distribution window allows you to define the type of distribution to use for the statistical analysis and to assign values to the statistical analysis parameters.



Choose an input distribution

Variable name	The name of the statistical variable. This the variable that was

	highlighted in the statistical variable list when you clicked **Edit**.
Current Value	The value of the statistical variable on the variable's input page .
Uniform Distribution	Solar Advisor randomly selects a value for each simulation between the minimum and maximum values that you specify.
Minimum	The minimum value of the statistical variable for the uniform distribution option.
Maximum	The maximum value of the statistical variable for the uniform distribution option.
Normal Distribution	Solar Advisor chooses a value for each simulation according to a standard bell curve defined by the mean and standard deviation values that you specify.
Mean (mu)	The expected value (in statistical terms) of the statistical variable.
Std. Dev. (sigma)	The variability or dispersion of the variable's probability distribution, defining the apparent width of the bell curve.

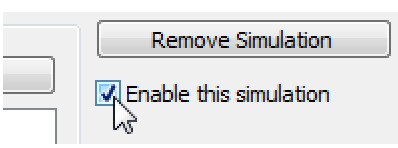
Setting up a Statistical Analysis

Once you have added a statistical simulation, you must choose an output metric for the analysis, add one or more statistical variables to the simulation, and edit the distribution parameters of each variable.

After setting up the optimization, click the Run All Simulations button, or click **Run All Simulations** on the Case menu to run the optimization and any other enabled simulations.

To set up a statistical analysis:

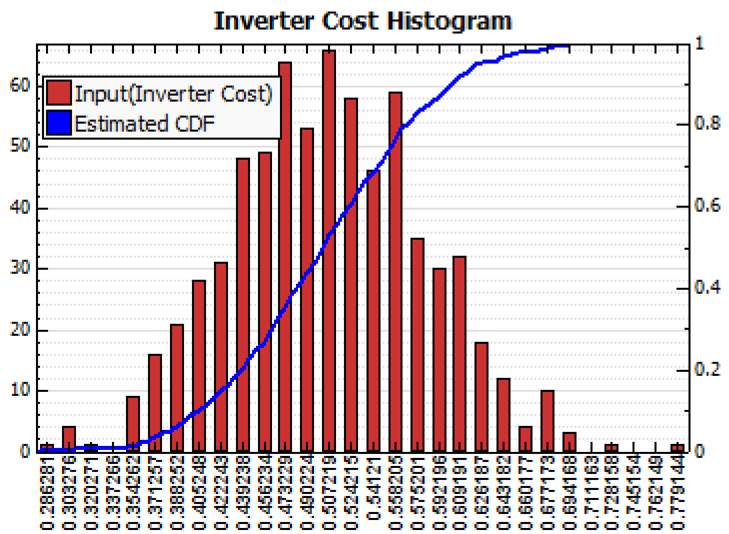
1. Display the statistical simulation setup options as described above.
2. Click **Add** to choose variables to which you want to assign a distribution from a list of available input variables. Solar Advisor adds the variables to the parametric variables list.
3. Highlight each variable in the parametric variables list and click **Edit** to assign the distribution parameters.
4. Enter a number of simulations for **Number of Monte Carlo Runs**. Solar Advisor will run this many simulations using variable values based on the distribution parameters you specify.
5. Check **Enable this simulation** to include the optimization in simulation runs. You can save the optimization setup options and exclude the analysis from simulations by clearing the checkbox. Clearing the checkbox allows you to shorten simulation run times without losing the setup configuration.



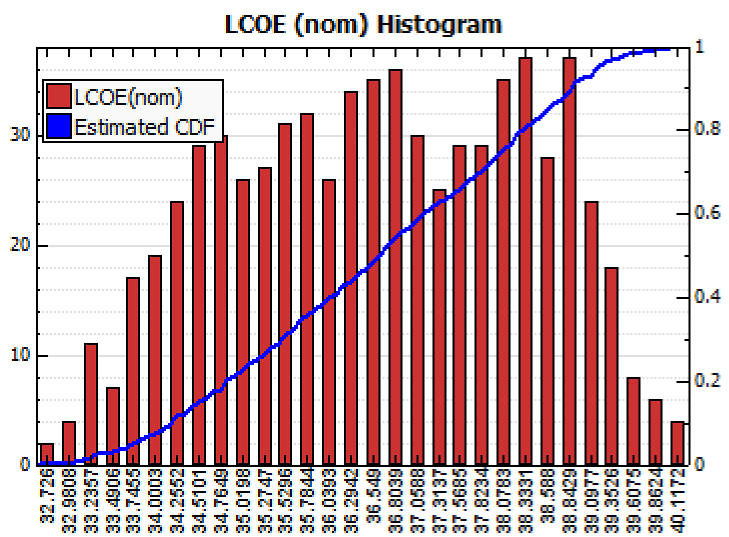
Displaying Histograms for Statistical Variables

After you run all simulations with one or more statistical simulations enabled, Solar Advisor allows you to view a histogram for each statistical variable on the Results page. To display a histogram, Solar Advisor sorts the values of the simulations into bins. The number of bins is specified in the graph setup.

For example, in the Statistical Analysis Sample file, the Inverter Cost histogram shows the number of occurrences of inverter cost that fall into each of the equally spaced bins, whose center values are shown along the x axis. The blue line is the estimated cumulative distribution function (CDF), labeled on the right axis from 0 to 1, and indicates the percentage of inverter cost values whose values fall below the corresponding x value.



The histogram graph can only plot a single variable. Instead of plotting the inverter cost values, you could plot the levelized cost of energy, showing histogram of the 700 calculated LCOE values that correspond to the random values chosen for the Inverter costs. This way, given different amounts of uncertainty in your chosen inputs, you can visualize the effect and uncertainty on any of the single-valued output metrics.



6.5 Multiple Systems

A multiple systems analysis allows you to model a power system as a combination of subsystems. This makes it possible to model a photovoltaic system consisting of separate subsystems with arrays oriented in different directions, or a CSP trough system consisting of two separate subsystems with different characteristics. Each subsystem is a complete electricity generating system, which means that for a CSP system for example, each subsystem would include a solar field, storage system, and power generating unit.

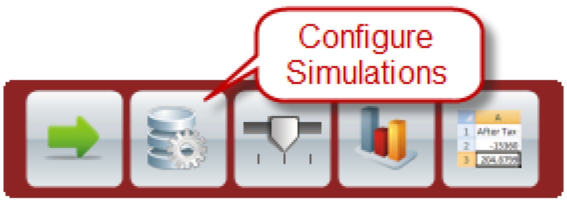
Solar Advisor applies a single set of financing, tax credit and payment incentives to a combined system, but applies separate performance and climate specifications to each subsystem.

The results such as levelized cost of energy and annual electric output displayed in graphs and tables on the Results page are for the combined system rather than for the individual subsystems.

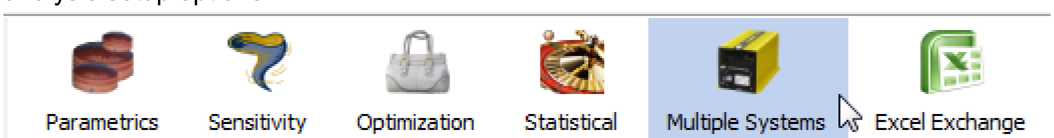
For an example of a Solar Advisor file with multiple systems, open the sample template *Combined Multiple PV Systems*: On the File menu, click **Open Sample Template** and select the template from the list.

To display the multiple system simulation setup options:

1. On the Main window, click **Configure Simulations** to view the Configure Simulation page.



2. On the Configure Simulations page, click **Multiple Systems** to display the multiple system analysis setup options.



Contents

- Page Reference describes the multiple system analysis setup options.
- Setting up a Multiple System Analysis describes the steps for combining subsystems into a combined system.

Page Reference

The multiple system setup options allow you to choose which cases in the project file to combine into a system, and display the capacity and cost values for the combined system.

Select Additional Performance Outputs

List of available cases	The list of available cases shows the cases in the project file that you can combine into a single system. You must create a case for each subsystem to be combined into a single system. Solar Advisor includes only checked cases in the combined system. The list of cases corresponds to the case tabs in the project file.
Enable this simulation	This box must be checked for the system to be modeled as a combined system.

Aggregate System Variables

The aggregate system variables display values for the combined system that Solar Advisor calculates by adding values from the individual subsystems.

Variable	Description	Units
Combined Nameplate Capacity	The sum of the subsystem nameplate capacities displayed on the System Summary page for each subsystem. For photovoltaic systems, the nameplate capacity is equivalent to the total array capacity in DC kW. For CSP systems, it is the nominal capacity of the power cycle in kW of electricity.	kW
Combined Heat Rate	This applies only to generic fossil systems and is the sum of each subsystem's heat rate from the Fossil Plant page.	MMBtu/MWh
Total Direct Cost	The sum of the total direct cost values displayed on each subsystem's costs page.	$
Total Installed Cost	The sum of the total installed cost values displayed on each subsystem's costs page.	$
Total Direct Sales Tax	The sum of the total sales tax values displayed on each subsystem's costs page.	$
O&M Annual Cost	The sum of the fixed annual operation and maintenance costs displayed on each subsystem's costs page.	$/yr
O&M Annual Capacity Cost	The sum of the fixed annual operation and maintenance costs displayed on each subsystem's costs page.	$/kW-yr
O&M Variable by Production	The sum of the fixed annual operation and maintenance costs displayed on each subsystem's costs page.	$/MWh

Setting up a Multiple System Analysis

Setting up a multiple system analysis involves creating a case for each subsystem to be combined, and then selecting the cases to be included in the multiple system analysis.

After setting up the analysis, click the Run All Simulations button, or click **Run All Simulations** on the Case menu to simulated the combined system..

To set up a multiple system analysis:

1. Create a case for each subsystem to be included in the combined system.
2. Display the case that you want to be the primary system.

   Solar Advisor will apply the input variables on the Utility Rate, Financing, Tax Credit Incentives, and Payment Incentives pages from the primary system to the combined system. It will ignore input values on those pages from the subsystems.
3. Display the multiple system analysis setup options as described above.
4. Under **Select Additional Performance Outputs**, check each case to include in the combined system, including the current (primary) case indicated by "This case is required" in parentheses next to the case name.

   Solar Advisor displays the combined system nameplate capacity and costs under **Aggregate System Variables**.
5. Check **Enable this simulation** to include the multiple system analysis in simulation runs. You can save the parametric simulation setup options and exclude the analysis from simulations by clearing the checkbox. Clearing the checkbox allows you to shorten simulation run times without losing the setup configuration.

6.6 Excel Exchange

This topic is under construction.

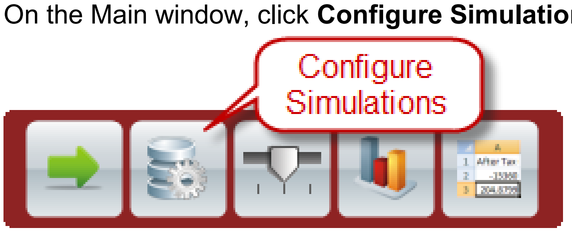
If you have questions about this topic, please contact user support: solar.advisor.support@nrel.gov.

Solar Advisor allows you to connect any input variable in Solar Advisor to a cell or range of cells in a Microsoft Excel workbook. This feature allows you to use external spreadsheet-based cost and performance models to generate values for Solar Advisor input variables. Because Solar Advisor can both import values from workbooks and export values to them, you can use the result of a spreadsheet calculation as the value of one input variable that depends on the value of other input variables. User variables are user-defined input variables that can also share values with external workbooks.

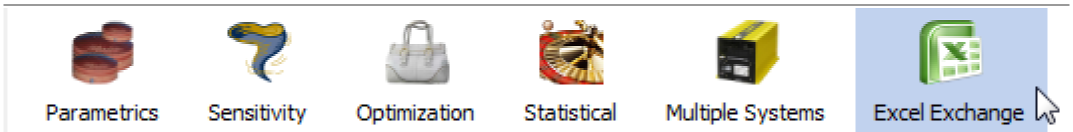
For an example of a Solar Advisor file with Excel Exchange, open the sample template *Excel Sample*: On the File menu, click **Open Sample Template** and select the template from the list.

To display the Excel data exchange setup options:

1. On the Main window, click **Configure Simulations** to view the Configure Simulation page.



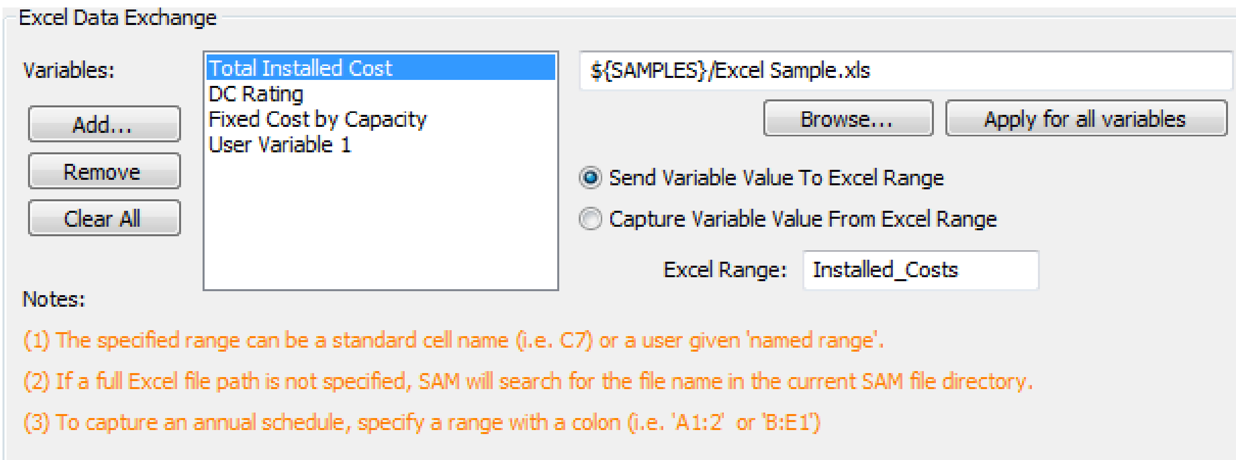
2. On the Configure Simulations page, click Excel Exchange to display the Excel data exchange options.



Contents

Page Reference

The Excel Data Exchange options allow you to add and remove Solar Advisor input variables to the list of variables to exchange data with Excel, specify the Excel workbook with which to exchange data, and for each input variable, define the relationship with a cell or range of cells in the workbook.



Parametric Simulation Setup

Add	Add one or more input variable from the input pages. You can configure each variable to either send a value to an Excel range, or "capture" a value from an Excel range.
Remove	Delete the highlighted variable from the list.
Clear All	Delete all variables from the list.
Browse	Browse your computer's folders to find the Excel workbook with which you want to exchange data. The workbook can be located in any folder on your computer.
Apply for all variables	
Send Variable Value to Excel Range	Configure the highlighted variable to send its value to the specified Excel range.

Capture Variable Value From Excel Range	Configure the highlighted variable to capture its value from the specified Excel range.
Excel Range	The range name or cell reference identifying the cell or range of cells in the Excel workbook with which the highlighted variable will exchange data.
Enable this simulation	This box must be checked for the analysis to exchange data with Excel.

Setting up Excel Exchange

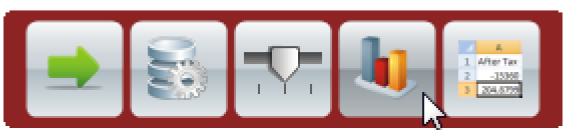
7 Results Page Reference

The Results page displays graphs and tables of output variables.

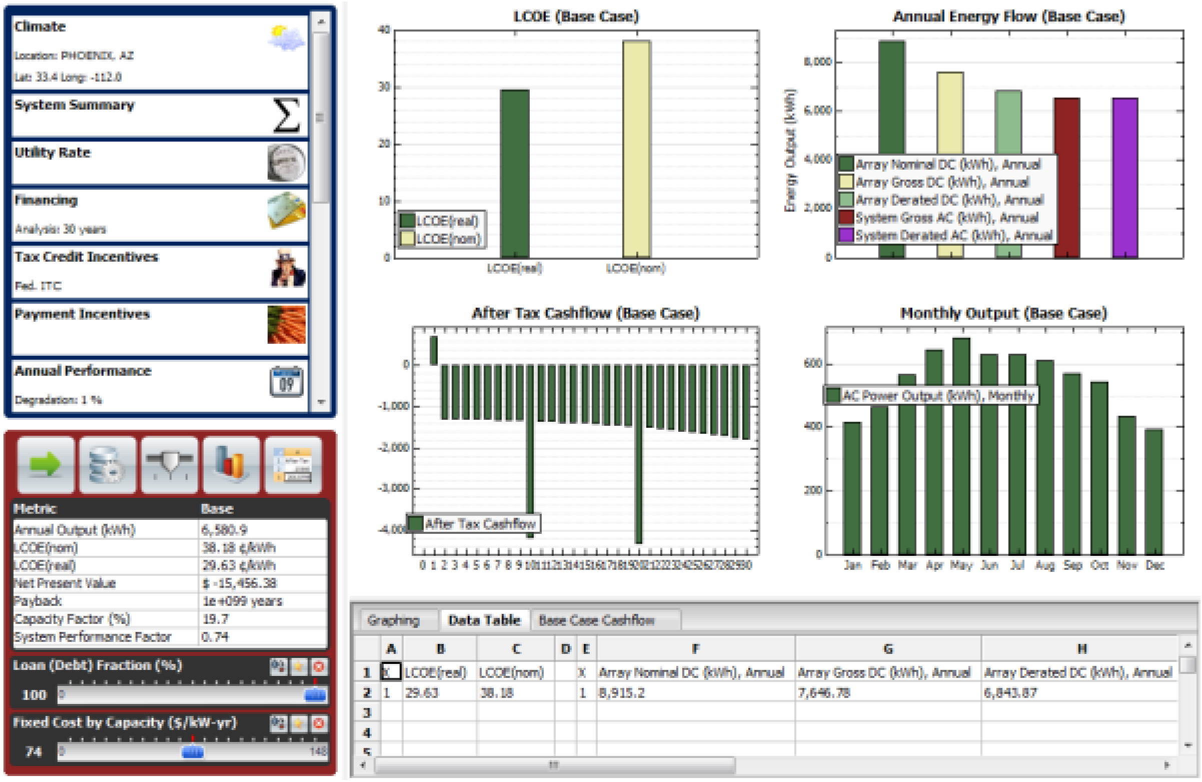
<u>To view the Results page:</u>

1. Click Run all simulations to recalculate output variables based on the current set of inputs, or

2. Click Switch to graph and results viewer to view graphs and tables without recalculating output variables.



Click on the following image of the Results page to jump to the topic describing the feature.



The following topics describe the Results page features:

- Metrics Table describing the function and contents of the Metrics table.
- Working with Graphs describing how to work with the functions on the Graphing tab.
- Configuring Sliders describing how to set up and manage sliders.
- Viewing Data Tables describing the Data Table and Base Case Cashflow tabs.

Related sections are:

- Output Variable Reference describing each the variables displayed on the Results page.
- Exporting Data and Graphs describing the options for exporting results data and graph images for use in reports and other applications.

7.1 Metrics Table

The Metrics table displays a set of output variables for each case in the project file. Solar Advisor displays the Metrics table under the navigation menu when results are available for a case. The output variables that appear in the Metrics table depend on the projects financing options, which are defined in the Technology and Market window.

Metric	Base
Annual Output (kWh)	6,580.9
LCOE(nom)	38.18 ¢/kWh
LCOE(real)	29.63 ¢/kWh
Net Present Value	$ -15,456.38
Payback	1e+099 years
Capacity Factor (%)	19.7
System Performance Factor	0.74

The output variables displayed in the metrics table are described in detail in Output Variables Reference.

The variables that appear in the Metrics table depend on the type of financing defined on the Financing page as shown in the table below.

Table 30. Output variables that appear in the Metrics table for different financing types.

Financing Option	Output Variables in Metrics Table
Residential - Cash Residential - Loan or Mortgage Commercial Cash Commercial - Standard Loan	Annual Output (kWh) LCOE(nom) LCOE(real) Net Present Value Payback Capacity Factor System Performance Factor (PV systems only)
Utility and IPP Commercial - Third-Party Ownership	Annual Output (kWh) 1st Year PPA Price LCOE(nom) LCOE(real) Internal Rate of Return Minimum DSCR PPA Escalation Debt Fraction Capacity Factor System Performance Factor (PV systems only)

For certain simulation configurations, Solar Advisor displays two columns of values for each output variable:

- For model runs involving the Multiple Systems simulation configuration, Solar Advisor displays output variables for the active case in the Base column of the Metrics table, and output variables for the combined system in the Combined column.
- For model runs involving the Statistical simulation configuration, the values of mu, sigma are displayed in the second column of the Metrics table.

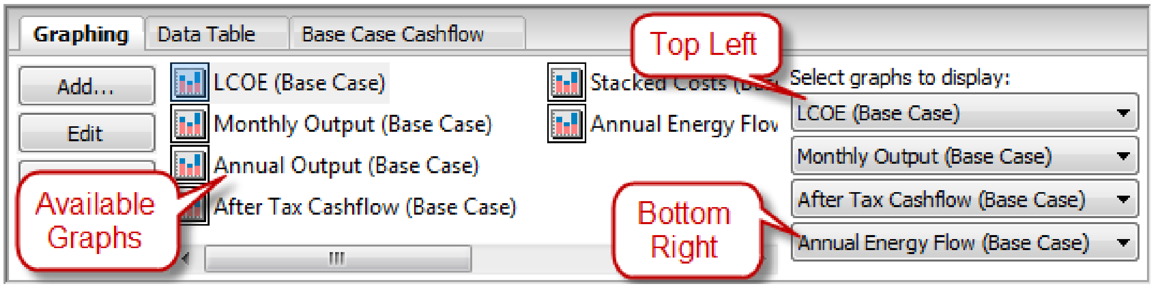
7.2 Working with Graphs

By default, Solar Advisor displays a set of default graphs on the Results page. The Results page can display up to four graphs at the same time.

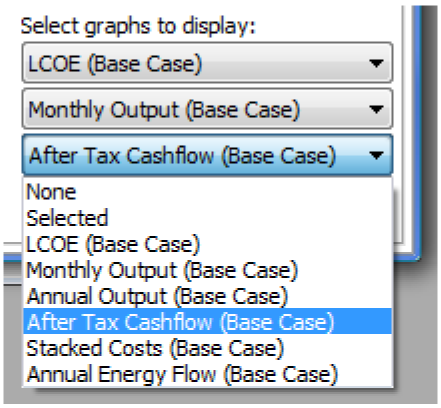
The best way to learn how to view graphs is to experiment with the functions on the Graphing tab. The following guidelines will help you understand how they work.

To select graphs to display:

- The Graphing tab displays the names of available graphs and lists of graphs to display in each of the four quadrants of the Results page:



  Select a graph from one of the lists to display the graph in a quadrant. For example, the following selection would display the After Tax Cashflow graph in the bottom left quadrant of the Results page.



  Choose **Selected** to display a graph by clicking its name in Available Graphs.

  Choose **None** to display no graph in the quadrant.

- To display a single graph on the Results page, Choose **Selected** or the name of a graph in one of the graph lists, and choose **None** in the remaining three graph lists.

To add or modify graphs:

1. To add a graph to the list of available graphs, click **Add**.

   To modify an existing graph, select the graph name in the available graphs and click **Edit**. You can also modify a visible graph by right-clicking it.
2. In the Edit Graph window, choose data to graph and other graph properties.

   Use the Properties options to assign graph labels, adjust line thickness, show and hide the legend, and change other properties.

Tips for working with graphs:

- Use sliders to see the effect of changing input variables on the graph without changing input variable values on the input pages.
- Right-click graphs to export graph images and data.
- View graph data tables on the Data Table tab. Click and drag the border above the tab to resize the table.

- Right-click a graph to hide the legend, change line thickness and colors, edit graph legends, and modify other graph properties.
- Click the Notes button above the top right corner of the Resulst page to display an editable text box to make notes about a graph.

The default graphs appear whenever you run a simulation and depend on the type of system being modeled.

Table 31. Descriptions of some default graphs.

Graph Name	Description
Annual Output	Total annual output versus project year. Shows the total energy produced by the system for each year of the project life.
Cashflow	After-tax cash flow for each year of the project life. Red indicates negative cash flow, green indicates positive cash flow.
LCOE	Real and nominal levelized cost of energy on a single graph.
Cost stacked bar	Cost of energy bar graph showing relative contribution of each project cost. The operation and maintenance (O&M) contribution is the value of all O&M cash flows discounted to year 1.
Monthly Output (Monthly Thermal Energy)	Monthly average values of system electric (thermal) output for each month of the year.
Monthly (Annual) Energy Flow	Monthly (annual) average incident radiation and electric output at various points in the system. For concentrating solar power systems, the graph shows intermediate thermal energy quantities.

The graph types available for a given analysis depend on the options defined on the Configure Simulations page. The Base Case simulation generates results based on the values of input variables visible on the input pages.

Table 32. Graph types available for different simulation configurations.

Graph Type	Description	Simulation Configuration
Bar Graph	Represents a y value for each x value as a vertical rectangular bar.	Base Case
Stacked Bar Graph	Similar to a bar graph, but rectangles within each bar represent categories of data.	Base Case
Line Plot	A line connects y values on a two-dimensional graph.	Base Case
Tornado Chart	Horizontal rectangular bars represent the variation in the value of an output variable with respect to one or more input variables.	Sensitivity
Contour Plot	A three-dimensional representation of the results of an output value over a range of values for two input variables.	Parametric
Histogram/CDF	Represents the frequency of occurrence of an output variable over a range of input variable values.	Statistical

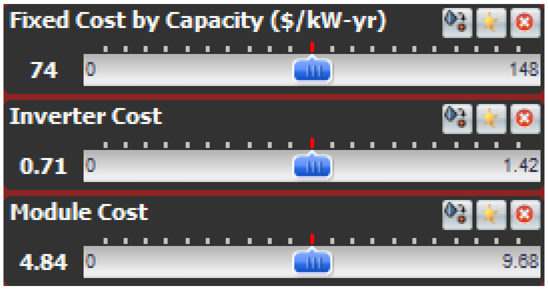
The graph axes available for graphs depend on the graph type.

Table 33. Graph axes available for different graph types.

Axis Name	Description	Graph Types
X Values	Horizontal axis of 2-D graphs and contour graphs. On 3-D surface plots, appears as horizontal axis perpendicular to the y-axis.	Bar, Stacked Bar, Line Plot, Histogram/ CDF, Tornado Chart
Y1 Values	Vertical axis of 2-D graphs and contour graphs. On 3-D surface plots, appears as horizontal axis perpendicular to the x-axis.	Bar, Stacked Bar, Line Plot, Tornado Chart
Y2 Values	Second vertical axis on 2-D graphs. Scale displayed on right side of graph.	Bar, Stacked Bar, Line Plot
Z Value	Vertical axis of 3-D surface plots. Colored lines on contour plot.	Contour Plot
X Parametric	Parametric variable to display on x-axis of 2-D graphs. Variable names only appear when one or more parametric variable is defined.	Contour Plot
Y Parametric	Second parametric variable to display on x-axis of 2-D graphs. Variable names only appear in list when two or more parametric variables are defined.	Contour Plot

7.3 Working with Sliders

A slider is a user interface element that allows you to dynamically change the value of an input variable and observe the effects on tables and graphs displayed on the Results Summary page. For example, the following group of three sliders would allow you to view the effect of changing operation and maintenance costs (Fixed Cost by Capacity), inverter cost and module cost on the levelized cost of energy and other graphs.

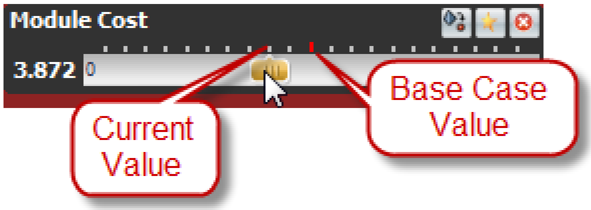


Note. Moving a slider only changes the graph. It does not change the stored inputs or results.

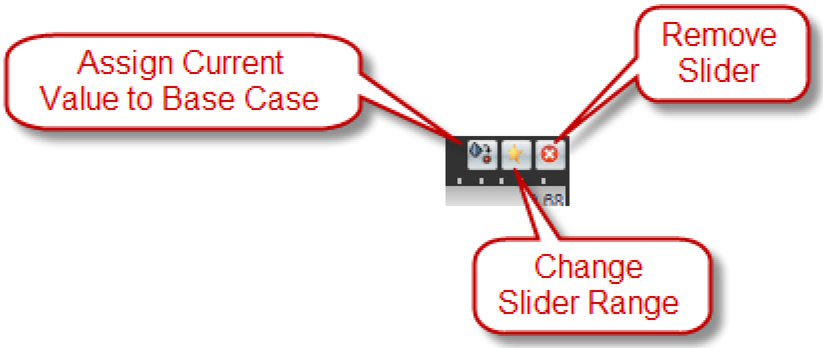
To use sliders:

- To add a slider, click Choose base case sliders:

- To change value of a slider, click and drag the blue slider button, which will turn yellow as you drag it. The button indicates the variable's current value, as does the number at the left end of the slider. The red line indicates the variable's base case value, which is the value from the variable's input page.



- The buttons on the top right corner of the slider allow you to assign the current value to the base case value, change the slider's range, and to remove the slider from the Results Summary page.



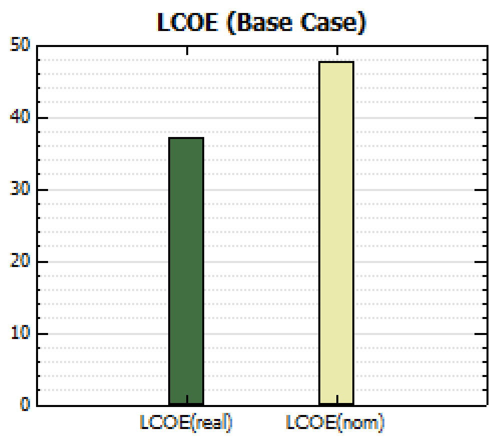
Note. Assigning a slider's current value to the base case changes the variable's value on the input page.

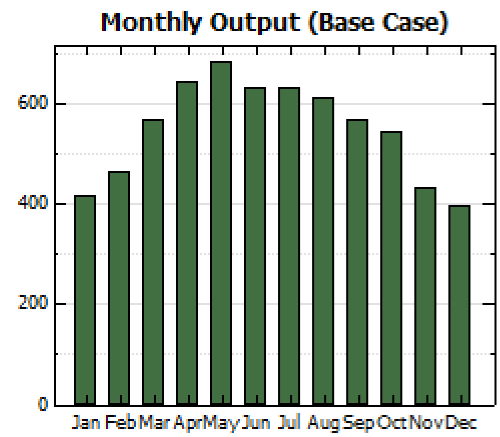
7.4 Viewing Data Tables

The data tables display graph data for graphs visible on the Results page and the cash flow for the analysis base case. The analysis base case results are based on the input variable values that are visible on the input pages. The base case results do not include results for parametric, sensitivity, optimization, or statistical analyses defined on the Configure Simulation page.

To view the data tables:

1. On the Results page, choose the graphs you want to view.
2. Click the Data Table tab.
3. Click and drag the border above the tabs to resize the table. You can also use the scrollbars to see hidden table data.





Graphing | **Data Table** | Base Case Cashflow

	A	B	C	D	E	F	G
1	X	LCOE(real)	LCOE(nom)		Month	AC Power Output (kWh), Monthly	
2	1	36.97	47.63		1	417.23	
3					2	463.65	
4					3	567.11	
5					4	643.8	
6					5	682.5	
7					6	629.61	
8					7	629.67	
9					8	609.77	
10					9	567.83	
11					10	541.7	
12					11	433.84	
13					12	394.2	

To view the base case cash flow:

1. On the Results page, click the Base Case Cashflow tab.
2. Drag the border above the tabs to resize the table. Use the scrollbars to view the entire cash flow table.

   See Cash Flow Reference for a description of the cash flow variables.

8 Output Variables Reference

Solar Advisor displays output variables in graphs and tables as described in Results Page Reference. This section describes each of the variables that appear in the Metrics table and in many graphs.

Hourly performance variables that appear on the Hourly tab of the Case Summary results spreadsheet and in the time series data viewer (DView) are described in Viewing Hourly Performance Data.

The variables described in this section are:

- Levelized Cost of Energy (LCOE)
- 1st Year PPA Price
- Annual Output
- Capacity Factor
- Debt Fraction
- Internal Rate of Return
- Minimum DSCR
- Net Present Value
- Payback
- PPA Escalation
- kWh/kW - Year 1
- System Performance Factor

8.1 Levelized Cost of Energy (LCOE)

The levelized cost of energy (LCOE) represents the value that a project must receive for each unit of electricity that it sells to cover capital and recurring costs over the project life. In Solar Advisor, commercial and residential projects sell electricity through a net metering agreement with or without time-of-use pricing. Utility and commercial third-party ownership projects sell electricity through a power purchase agreement at a fixed price with an optional annual escalation rate. For a description iof the available financing options, see Overview of Financing Options.

The LCOE is useful for comparing and ranking technology options because it accounts for the installation, financing, tax, and operating costs of a project over its life. The LCOE makes it possible to compare alternatives with different project lifetimes and performance characteristics. Analysts can use the LCOE to compare the option of installing a residential or commercial project to purchasing electricity from an electric service provider, or compare utility and third-party ownership projects with investments in energy efficiency, other renewable projects, or conventional fossil fuel projects. The LCOE captures the trade-off between typically higher-capital-cost, lower-operating-cost renewable energy projects, and lower-capital-cost, higher-operating-cost fossil-fuel based projects.

Solar Advisor calculates the LCOE for residential and commercial projects differently than it does for utility and commercial third-party ownership projects. For residential and commercial projects, the system is assumed to be on the electric consumer's side of a utility meter, and the project sells electricity to an electric service provider through a net metering agreement. For residential and commercial systems, the LCOE represents the cost of installing and operating the system per unit of energy it produces over the project life. Utility and commercial third-party projects are assumed to earn revenues through a power purchase agreement, and the LCOE represents the total project *revenue* per unit of energy the system produces over the project life.

The project's financing type (residential, commercial, utility) is defined in the Technology and Market window. The financing type is also displayed on the main window in the toolbar directly below the case tabs in the main window.

Note. The LCOE for the systems in the sample files includes the effects of incentives. To see what the LCOE would be with no incentives, set sliders for all incentives to zero, and read the LCOE value in Metrics table. See Working with Sliders for more information.

For more information about the levelized cost of energy and other economic metrics for renewable energy projects, see *Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies*. (Short 1995) http://www.nrel.gov/docs/legosti/old/5173.pdf.

Contents

- LCOE for Residential and Commercial Projects describes how Solar Advisor calculates the levelized cost of energy for systems with either Residential market or Commercial Market financing.
- LCOE for Commercial Third Party and Independent Power Producer Projects describes the calculation of the leveized required revenue for projects with either Commercial Market - Third-Party Ownership or Utiltity and IPP financing.

LCOE for Residential and Commercial Projects

For a project using one of the *Residential Market* or *Commercial Market* (except Third-Party Ownership) financing options defined in the Technology and Market window, the LCOE is the cost of installing and operating a system per unit of electricity it produces. Residential and commercial projects are assumed to be distributed energy projects on the retail customer side of the meter at the site of either a residential or commercial property, which means that a project's LCOE can be compared to the electricity rate that the residence or business would pay to an electric service provider if the project were not installed.

Solar Advisor uses the real discount rate and inflation rate on the Financing page in the LCOE calculation. The discount rate accounts for the time value of money, and is used to calculate the present worth of future costs. The inflation rate accounts for expected price increases over the project life, and is used to calculate future operating costs based on first year cost inputs on the system costs page.

Solar Advisor's LCOE calculation for residential and commercial projects assumes that the LCOE is the the cost per unit of energy, that, when multiplied by the total energy produced and discounted to a base analysis year, is equivalent to the present value of the total life-cycle cost of the project.

Solar Advisor reports both a real LCOE and a nominal LCOE value in the Metrics table. The form of the discount rate used in the denominator's total energy output term determines the form of the LCOE.

The choice of real or nominal LCOE depends on the analysis. Most long-term analyses are conducted in real (constant) dollars to adjust for many years of inflation, whereas most short term analyses use nominal (current) dollars. Regardless of the metric chosen, real or nominal LCOE, the lowest cost alternative will not change as long as all options are evaluated using the same form of the metric.

For the real LCOE, the real discount rate appears in the denominator's total energy output term:

$$\text{real LCOE} = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{real}})^n}}$$

Similarly, for the nominal LCOE, the nominal discount rate appears in the denominator's total energy output term:

$$\text{nominal LCOE} = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{nominal}})^n}}$$

Where,

Q_n (kWh)	Electricity generated by the project in year n, calculated by the performance model based on weather data and system performance parameters. The first year output is reported in the Metrics table and in the year one column of the project cash flow. Year two and subsequent output is the first year output reduced by the amount specified for the degradation rate on the Annual Performance page.
N	Project life in years as defined on the Financing page.
C_n ($)	Project net cost in year n, shown in Solar Advisor as the after tax cash flow in the cash flow tables.
d_{real}	The real discount rate defined on the Financing page.
$d_{nominal}$	The nominal discount rate, calculated as described below.

The summation in the numerator term starts at n = 0 to include project's capital costs incurred in year zero of the cash flow and shown as the Total Installed Cost on the system costs pages. The summation in the denominator term begins at n = 1, which is the first year that the project produces energy.

The nominal discount rate can be calculated based on the values of the real discount rate and the inflation rate on the Financing page:

$$d_{nominal} = (1 + d_{real})(1 + e) - 1$$

Where,

$d_{nominal}$	Nominal discount rate expressed as a fraction.
d_{real}	Real discount rate defined on the Financing page expressed as a fraction.
e	Inflation rate defined on the Financing page expressed as a fraction.

Note. You can verify the LCOE calculation in the cash flow table by exporting the table to Excel and using the NPV formula to calculate the present values in the numerator (NPV of *After Tax Cashflow*) and denominator (NPV of *Electric Output*. Be sure to use the correct forms of the discount rate in the Excel formulas. The value in Excel will be slightly different than the value reported by Solar Advisor because the model uses more significant digits than are displayed in the cash flow table.

LCOE for Commercial Third Party and Independent Power Producer Projects

For a project using either the *Utility and IPP* or *Commercial Market - Third-Party Ownership* financing option in the Technology and Market window, the LCOE is the value that the project must receive for each unit of electricity it sells to meet financial returns targets defined on the Financing page. Utility and Third-party ownership projects are assumed to be power generation projects that recover project costs through electricity sales to a customer through a power purchase agreement with a fixed annual electricity sales price and optional annual escalation rate.

Solar Advisor uses the real discount rate and inflation rate on the Financing page in the LCOE calculation. The discount rate accounts for the time value of money and the relative degree of risk for alternative investments, and is used to calculate the present worth of future costs. The inflation rate accounts for expected price increases over the project life, and is used to calculate future operating costs based on first year cost inputs on the system costs page.

Solar Advisor's LCOE calculation for utility and third-party ownership projects assumes that the LCOE is the the *revenue* per unit of energy, that, when multiplied by the total energy produced and discounted to a base analysis year, would be equivalent to the present value of the total life-cycle cost of the project.

Solar Advisor reports both a real LCOE and a nominal LCOE value in the Metrics table. The form of the discount rate used in the denominator's total energy output term determines the form of the LCOE.

The choice of real or nominal LCOE depends on the analysis. Most long-term analyses are conducted in real (constant) dollars to adjust for many years of inflation, whereas most short term analyses use nominal (current) dollars. The form of the LCOE should be chosen to be consistent with cost per unit of energy values used for alternative to the project.

For the real LCOE, the real discount rate appears in the total energy output term:

$$\text{real LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{real}})^n}}$$

Similarly, for the nominal LCOE, the nominal discount rate appears in the total energy output term:

$$\text{nominal LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{nominal}})^n}}$$

Where,

Q_n (kWh)	Electricity generated by the project in year n, calculated by the performance model based on weather data and system performance parameters. The first year output is reported in the Metrics table and in the year one column of the project cash flow. Year two and subsequent output is the first year output reduced by the amount specified for the degradation rate on the Annual Performance page.
N	Project life in years as defined on the Financing page.
R_n	Project revenue from electricity sales in year n , equal to the annual electric output multiplied by the annual electricity sales price. The required revenue in year one is equal to the first year PPA price reported in the results. The required revenue in subsequent years is equal to the first year PPA price escalated by the PPA Escalation Rate shown on the Metrics table.
d_{real}	Discount rate defined on the Financing page.
$d_{nominal}$	Nominal discount rate, calculated as described below.

The summation in the numerator and denominator both start at n = 1, the first year that the project generates electricity and earns revenue.

The nominal discount rate can be calculated based on the values of the real discount rate and the inflation rate on the Financing page:

$$d_{nominal} = (1 + d_{real})(1 + e) - 1$$

Where,

$d_{nominal}$	Nominal discount rate expressed as a fraction.

d_{real} Real discount rate defined on the Financing page expressed as a fraction.

e Inflation rate defined on the Financing page expressed as a fraction.

8.2 1st Year PPA Price

The first year PPA price is the electricity sales price for projects with *Utility and IPP* or *Commercial - Third-Party Ownership* financing as defined in the Technology and Market window. Solar Advisor assumes that such projects sell electricity through a power purchase agreement (PPA) at a fixed price over the life of the project with an optional annual escalation rate.

The first year PPA Price and annual escalation rate (PPA Escalation rate on the Financing page) determine the project's annual revenues. Solar Advisor calculates the annual revenues to meet the minimum requirements of the internal rate of return (IRR), debt service coverage ratio (DSCR), and positive cash flow, which are defined as constraining assumptions on the Financing page. Because of the way the first year PPA price, IRR, and minimum DSCR interact, Solar Advisor uses an iterative algorithm to determine the values of these variables.

For projects with *Utility and IPP* financing, the constraining assumptions defined on the Financing page are the Minimum Required IRR and the Minimum Required DSCR, and a positive cash flow requirement:

Find *First Year PPA* such that

IRR ≥ *Minimum Required IRR*, and

Min DSCR ≥ *Minimum Required DSCR*, and

Cash Flow in Year n > 0 (when the cash flow requirement is positive)

For projects with *Third-Party Ownership* financing, there is a single constraining assumption defined on the Financing page, the Minimum Required IRR:

Find *First Year PPA* such that

Actual IRR ≥ *Minimum Required IRR*

The following equations show the calculations used in the iterative algorithm to determine the IRR and minimum DSCR, which are both reported as results with the 1st Year PPA Price in the Metrics table.

The internal rate of return is the discount rate, IRR in the equation below, that corresponds to a project net present value, NPV, of zero:

$$NPV = \sum_{n=1}^{N} \frac{R_n - C_{AfterTax,n}}{(1+IRR)^n} + C_{AfterTax,0} = 0$$

Where,

NPV (\$) The net present value of the project over its life.

N The number of years in the project life, defined by the analysis period on the Financing page.

R_n (\$) The required revenue in year n, shown in the *Revenues* row of the cash flow. The revenue in year 1 ($R_{n=1}$) is equal to the first year PPA price. The revenue is subsequent years ($R_{1<n\leq N}$) is equal to the first year PPA price adjusted by the PPA escalation rate defined on the Financing page.

$C_{AfterTax,n}$ (\$) The after tax cash flow in year n, equal to *State Tax Savings* + *Federal Tax Savings* + *PBI Incentives* - *Operating Costs* - *Debt Total Payment* + *Revenues* in the project cash flow.

IRR Internal rate of return, calculated by systematically trying different values until the NPV is equal to zero.

The debt service coverage ratio in each analysis year ($DSCR_n$) is the ratio of operating income to expenses in that year:

$$DSCR_n = \frac{R_n - C_{Operating,n}}{C_{Interest,n} + C_{Principal,n}}$$

Where,

$DSCR_n$ Debt service coverage ratio in year n shown in the *PreTax Debt Service Coverage Ratio* row of the cash flow.

R_n (\$) The required revenue in year n, shown in the *Revenues* row of the cash flow. The revenue in year 1 ($R_{n=1}$) is equal to the first year PPA price. The revenue is subsequent years ($R_{1<n\leq N}$) is equal to the first year PPA price adjusted by the PPA escalation rate defined on the Financing page.

$C_{Operating,n}$ (\$) The total operating costs in year n, shown in the *Operating Costs* row of the cash flow.

$C_{Interest,n}$ (\$) The loan interest payment in year n, shown in the *Debt Interest Payment* row of the cash flow.

$C_{Principal,n}$ (\$) The loan principal payment in year n, shown in the *Debt Repayment* row of the cash flow.

The minimum DSCR is the lowest value of the project's debt-service coverage ratio that occurs in the life of the project:

$$\text{minimum} \quad DSCR = \min_{n\in[1,N]} DSCR_n$$

Where,

$minimum\ DSCR$ The minimum debt service coverage ratio, reported as a result in the Metrics table.

$DSCR_n$ Debt service coverage ratio in year n shown in the *PreTax Debt Service Coverage Ratio* row of the cash flow. (The symbol min represents the function that searches for the minimum value of the DSCR in the cash flow.)

8.3 Annual Output

The annual output reported in the Metric table is the total electric generation in kWh for the first year that the project operates, equivalent to Year one in the project cash flow. Note that output in subsequent years may be lower than in the first year depending on the value of the degradation rate on the Annual Performance page.

8.4 Capacity Factor

The capacity factor is the ratio of the system's predicted electrical output in the first year of operation to the output had the system operated at its nameplate capacity:

$$CF = \frac{E_{OutputYear1}}{P_{SystemCapacity} \cdot 8760}$$

Where,

CF	Capacity factor.
$E_{OutputYear1}$ (kWh)	The total annual electric generation in the first year of operation, equivalent to year one in the project cash flow.
$P_{SystemCapacity}$ (kW)	The system's rated capacity expressed in kilowatts (see table below).
8760 (hours)	Number of hours in a simulation year.

The system capacity depends on technology being modeled. Note that Solar Advisor converts the capacity value to kW before using it in the calculation.

Table 34. Rated system capacity values for each technology.

Technology	System Capacity	Input Page
PV SAM Performance Models	Total Array Power (Wdc)	Array
PV PVWatts	DC Rating (kW)	PVWatts Solar Array
CSP Parabolic Trough	Rated Turbine Net Capacity (MWe)	Power Block
CSP Power Tower	Nameplate Capacity (MWe)	Power Cycle
CSP Dish Stirling	Total Capacity (kW)	Solar Field
Generic Fossil	Nameplate Capacity (kWe)	Fossil Plant

8.5 Debt Fraction

The debt fraction is the percentage of the project total installed cost cost that is financed through a loan. The value is reported as a result only for projects with *Utility and IPP* or *Commercial - Third-Party Ownership* financing as defined in the Technology and Market window.

For these types of projects, depending on the financial optimization option on the Financing page, the debt fraction is either a user-defined input on the Financing page, or a value that Solar Advisor calculates. When the *Automatically minimize LCOE with respect to Debt Fraction* option is checked, Solar Advisor finds the debt fraction that results in the lowest levelized cost of energy.

Solar Advisor uses the debt fraction to calculate the principal and interest payments shown in the project cash flow, and used in the iterative search algorithm described in 1st Year PPA Price.

8.6 Internal Rate of Return

The internal rate of return is the discount rate that corresponds to a project net present value of zero for projects with *Utility and IPP* or *Commercial - Third-Party Ownership* financing as defined in the Technology and Market window.

$$NPV = \sum_{n=1}^{N} \frac{Revenues_n - AfterTaxCashFlow_n}{(1+IRR)^n} + AfterTaxCashFlow_0 = 0$$

Where *Revenues* and *After Tax Cash Flow* are rows in the project cash flow.

Solar Advisor calculates the internal rate of return using an iterative search algorithm described in 1st Year PPA Price.

8.7 kWh/kW - Year 1

The kilowatt-hour per kilowatt-year metric is the annual electric output in year one $E_{OutputYear1}$ divided by the system capacity $P_{SystemCapacity}$. For photovoltaic systems, the system capacity is the Array Power on the Array page. For concentrating solar power systems, the system capacity is the Rated Turbine Net Capacity on the Power Block page.

$$\text{kWh/kW Year 1} = \frac{E_{\text{OutputYear1}}}{P_{\text{SystemCapacity}}}$$

Where,

$E_{OutputYear1}$ (AC kWh/year)	The total annual electric generation in the first year of operation reported on the Metrics table, and in the year one column of the project cash flow.
$P_{SystemCapacity}$ (DC kW)	The system's rated capacity expressed in kilowatts (see table below).

The system capacity depends on technology being modeled. Note that Solar Advisor converts the capacity value to kW before using it in the calculation.

Table 35. Rated system capacity values for each technology.

Technology	System Capacity	Input Page
PV SAM Performance Models	Total Array Power (Wdc)	Array
PV PVWatts	DC Rating (kW)	PVWatts Solar Array
CSP Parabolic Trough	Rated Turbine Net Capacity (MWe)	Power Block
CSP Power Tower	Nameplate Capacity (MWe)	Power Cycle
CSP Dish Stirling	Total Capacity (kW)	Solar Field
Generic Fossil	Nameplate Capacity (kWe)	Fossil Plant

8.8 Minimum DSCR

The minimum DSCR is the minimum debt-service coverage ratio that Solar Advisor calculates for projects with *Utility and IPP* or *Commercial - Third-Party Ownership* financing as defined in the Technology and Market window.

The debt-service coverage ratio in each year n is the ratio of operating income to expenses in that year:

$$DSCR_n = \frac{R_n - C_{Operating,n}}{C_{Interest,n} + C_{Principal,n}}$$

Where,

$DSCR_n$	Debt service coverage ratio in year n shown in the *PreTax Debt Service Coverage Ratio* row of the cash flow.
R_n ($)	The required revenue in year n, shown in the *Revenues* row of the cash flow. The revenue in year 1 ($R_{n=1}$) is equal to the first year PPA price. The revenue is subsequent years ($R_{1<n\leq N}$) is equal to the first year PPA price adjusted by the PPA escalation rate defined on the Financing page.
$C_{Operating,n}$ ($)	The total operating costs in year n, shown in the *Operating Costs* row of the cash flow.
$C_{Interest,n}$ ($)	The loan interest payment in year n, shown in the *Debt Interest Payment* row of the cash flow.
$C_{Principal,n}$ ($)	The loan principal payment in year n, shown in the *Debt Repayment* row of the cash flow.

In Solar Advisor, the project's debt service coverage ratio (reported in results as the Minimum DSCR) is the lowest value of the $DSCR$ that occurs in the life of the project N, equivalent to the Analysis Period on the Financing page.

$$DSCR = \min_{n\in[1,N]} DSCR_n$$

Where,

minimum DSCR	The minimum debt service coverage ratio, reported as a result in the Metrics table.
$DSCR_n$	Debt service coverage ratio in year n shown in the *PreTax Debt Service Coverage Ratio* row of the cash flow. (The symbol *min* represents the function that searches for the minimum value of the DSCR in the cash flow.)

Solar Advisor calculates the minimum debt-service coverage ratio to be greater than or equal to the minimum required DSCR target defined on the Financing page. The iterative algorithm used for the calculation is described in 1st Year PPA Price.

8.9 Net Present Value

The net present value is the present value of the after-tax cash flow discounted to year one using the nominal discount rate, plus the after-tax cash flow in year zero:

$$NPV = \sum_{n=1}^{N} \frac{R_n - C_{AfterTax,n}}{(1 + d_{nominal})^n} + C_{AfterTax,0} = 0$$

Where,

NPV (\$)	The net present value of the project over its life.
N	The number of years in the project life, defined by the analysis period on the Financing page.
R_n (\$)	The required revenue in year n, shown in the *Revenues* row of the cash flow. The revenue in year 1 ($R_{n=1}$) is equal to the first year PPA price. The revenue is subsequent years ($R_{1<n\leq N}$) is equal to the first year PPA price adjusted by the PPA escalation rate defined on the Financing page.
$C_{AfterTax,n}$ (\$)	The after tax cash flow in year n, equal to *State Tax Savings* + *Federal Tax Savings* + *PBI Incentives* - *Operating Costs* - *Debt Total Payment* + *Revenues* in the project cash flow.
$d_{nominal}$	The nominal discount rate, calculated as shown below.

The nominal discount rate can be calculated based on the values of the real discount rate and the inflation rate on the Financing page:

$$d_{nominal} = (1 + d_{real})(1 + e) - 1$$

Where,

$d_{nominal}$	Nominal discount rate expressed as a fraction.
d_{real}	Real discount rate defined on the Financing page expressed as a fraction.
e	Inflation rate defined on the Financing page expressed as a fraction.

8.10 Payback

The simple payback is the time in years starting in year one of the project that it takes for the cumulative cash flow (expenses included) to switch from negative to positive.

The payback cash flows for each year n are shown in the project cash flow.

8.11 PPA Escalation

The PPA escalation rate is an annual escalation rate that Solar Advisor uses to calculate future electricity sales prices based on the first year PPA price. The value applies to projects with *Utility and IPP* or *Commercial - Third-Party Ownership* financing as defined in the Technology and Market window.

Depending on the financial optimization option on the Financing page, the PPA escalation rate is either a user-defined input on the Financing page, or a value that Solar Advisor calculates. When the *Automatically minimize LCOE with respect to PPA Escalation Rate* option is checked, Solar Advisor finds the PPA escalation rate that results in the lowest levelized cost of energy.

Solar Advisor uses the PPA escalation rate in the iterative search algorithm described in 1st Year PPA Price.

8.12 System Performance Factor

Solar Advisor calculates the system performance factor only for photovoltaic systems when the option in the Technology and Market window is *Photovoltaics - SAM Performance Models.* The system performance factor is a measure of the system's annual electric generation output in AC kWh compared to its nameplate rated capacity in DC kW, taking into account the solar resource at the system's location:

$$F_{SystemPerformance} = \frac{E_{OutputYear1}}{P_{SystemCapacity} \cdot N_{PeakSunHours}}$$

Where,

$F_{SystemPerformance}$	The system performance factor.
$E_{OutputYear1}$ (AC kWh/ year)	The total annual electric generation in the first year of operation reported on the Metrics table, and in the year one column of the project cash flow.
$P_{SystemCapacity}$ (DC kW)	The system's rated capacity expressed in kilowatts (see table below).
$N_{PeakSunHours}$ (hours)	The equivalent number of hours in a year that the array receives 1,000 W/m^2 of incident global solar radiation for flat-plate systems, and direct normal radiation for concentrating photovoltaic systems.

The system capacity depends on technology being modeled. Note that Solar Advisor converts the capacity value to kW before using it in the calculation.

Table 36. Rated system capacity values for each technology.

Technology	System Capacity	Input Page
PV SAM Performance Models	Total Array Power (Wdc)	Array
PV PVWatts	DC Rating (kW)	PVWatts Solar Array
CSP Parabolic Trough	Rated Turbine Net Capacity (MWe)	Power Block
CSP Power Tower	Nameplate Capacity (MWe)	Power Cycle
CSP Dish Stirling	Total Capacity (kW)	Solar Field
Generic Fossil	Nameplate Capacity (kWe)	Fossil Plant

9 Cash Flow Reference

Solar Advisor reports annual data in the cash flow table, including the system's annual electric output in kWh, electricity price in $/kWh, net-metering receipts or sales revenue, project expenses, taxes, and cost streams used to calculate the project payback.

The cash flow table only displays data from on the analysis base case, which is the set of results calculated from the input variable values that are visible on the input pages. The cash flow table does not include results from parametric, sensitivity, optimization, or statistical analyses defined on the Configure Simulations page.

The cash flow table is available in two places:

- On the Results page data tables by clicking the the Base Case Cashflow tab (drag the grey border above the tab to expand the table)
- By exporting to Excel by clicking the Export and view data button on the Results page, or clicking Cashflow on the Results menu.

An after-tax cash flow graph is also available as an option on the Results page Graphing tab.

Solar Advisor calculates the values for the cash flow and other economic metrics after completing the performance simulation calculations. The model uses the first year annual output value from the simulation results in the cash flow calculations. It also uses input variable values from the following input pages:

- Utility Rate (for commercial and residential projects only) for offset electricity payment calculations.
- Financing for electricity price, tax and insurance and debt-related calculations.
- Tax Credit Incentives for tax credit calculations.
- Payment Incentives for incentive payment calculations.
- Annual Performance for year two and later annual output calculations.

To calculate the project capital and operating costs, Solar Advisor uses input variables from the system costs page for the appropriate technology. In the explanations below, the term "system costs page" refers to one of the following input pages:

- PV System Costs
- Trough System Costs
- Dish System Costs
- Tower System Costs
- Fossil System Costs

> **Note.** You can learn more about the cash flow calculations by exploring the Excel formulas in the financial spreadsheets posted on the Solar Advisor website: https://www.nrel.gov/analysis/sam/download.html.

Electric Output

The electric output in year one is equal to the Annual Output value displayed in the Metrics table. The electric output value in year two and subsequent years is based on the year one value adjusted for the degradation rate on the Annual Performance page.

Electricity Purchase and Sales Price

For commercial and residential projects, the electricity purchase price is the annual average utility rate as defined on the Utility Rate page.

For utility and commercial third party projects, the electricity sales price is the 1st Year PPA price displayed in the Metrics table. For year two and later, the electricity sales price is the first year price adjusted by the PPA escalation rate also displayed on the Metrics table.

Offset Payments and Revenues

Residential and commercial projects may receive net-metering offset payments for electricity generated by the project. Commercial projects pay federal and state income tax on these payments as shown in the after tax cash flow explanation below.

Offset Payments = Electric Output x Electricity Purchase Price

For utility projects, annual revenues are determined in each year by the annual output and the electricity sales price for that year.

Revenues = Electric Output x Electricity Sales Price

Operating Expenses

The operating expenses include operation and maintenance costs, and insurance and property tax payments. The values in the Operating Costs row of the cash flow table is calculated as follows:

Operating Costs = Fixed O&M Annual + Fixed O&M + Variable O&M + Fuel O&M + Insurance + Property Taxes

The operation and maintenance (O&M) costs are defined on the system costs page and escalated in each year after year one using both the escalation rate for each O&M category on the system costs page and the inflation rate value on the Financials page. The insurance and property tax rates are also both on the Financials page, and apply to the total installed cost value on the system costs page.

CSP trough, CSP tower, and generic fossil systems also include an annual cost of fuel in the total operating expense. (When the fossil fill fraction variable on the Thermal Storage page for troughs or towers is greater than zero, the systems consume fuel for backup energy.) and For photovoltaic and CSP dish systems, the fuel cost is always zero.

Operating Income and Deductible Expenses

For residential and commercial projects, the deductible expenses are project costs that can be deducted from federal and state income taxes.

For residential projects, the deductible expense amount equals the property tax amount:

Deductible Expenses = - Property Taxes

For commercial projects, all operating costs are deductible:

Deductible Expenses = - Operating Costs

For utility projects, the operating income is the difference between revenues and operating costs:

Operating Income = Revenues - Operating Costs

Financing

The debt balance in year one is equal to the principal amount displayed on the Financing page. The debt balance in years two and later is equal to the previous year's debt balance less the previous year's debt repayment amount:

Debt Balance = - Debt Balance (previous year) - Debt Repayment (previous year)

The debt interest payment is the debt balance multiplied by the loan interest rate on the Financing page:

Debt Interest Payment = Debt Balance × Loan Rate

The debt repayment amount is the annual payment on principal amount assuming constant payments over the loan term defined on the Financials page and at the constant annual interest rate defined on the Financials page. Solar Advisor calculates the amount using a methodology equivalent to Excel's PPMT function.

The total debt payment is the sum of interest and principal payments:

Debt Total Payment = Debt Interest Payment + Debt Repayment

Income, Taxes and Incentives

All projects pay state and federal taxes on the total taxable income for each year when the state and federal annual tax rates on the Financing page are non-zero. Federal and state tax cash flows are displayed in two separate sections of the cash flow spreadsheet, under the rows labeled Tax Effect on Equity (State) and Tax Effect on Equity (Federal). The tax amount for each year appears in the Tax Savings row under each section.

Depreciation

For utility and commercial third party ownership projects with a depreciation option defined on the Financials page, Solar Advisor displays the depreciation amount in the State Depreciation and Federal Depreciation rows of the cash flow table. The depreciation amounts and applicable years are determined by the options on the Financials page.

Income Less Deductions

The cash flow table shows two income streams each for state and federal tax calculations:

- For residential and commercial projects, the incentive income less deductions is the sum of all incentive amounts less applicable deductions:

  Income Less Deductions = Deductible Expenses + IBI + CBI + PBI - Interest Payment

  For residential projects with the loan financing (not mortgage financing) option on the Financing page, the interest payment amount is not deducted.

  For utility and commercial third party projects, the incentive income less deductions is the operating income less applicable deductions:

  Income Less Deductions = Operating Income + IBI + CBI + PBI - Depreciation - Interest Payment

- The taxable income less deductions is the sum of all incentive amounts that are defined as taxable on the Payment Incentives page less applicable deductions:

  Taxable Income Less Deductions = Income Less Deductions - [IBI, CBI, PBI defined as taxable]

Income Taxes

The state and federal income tax amount is the taxable income multiplied by the tax rate on the Financing page for the applicable tax:

Income Taxes = Taxable Income Less Deductions × Tax Rate

Tax Savings

For both federal and state taxes, a positive value of Tax Savings indicates a tax savings or cash inflow. A negative value indicates a tax liability or cash outflow.

The tax savings amount is the income tax less PTC and ITC tax credit amounts:

Tax Savings = Income Taxes - PTC - ITC

The PTC and ITC are the production tax credit and investment tax credit, respectively:

- The PTC, if it applies, is calculated for each year by multiplying the tax credit percentage from the Tax

Credit Incentives page by the value electric output amount for that year.

- When an ITC applies, it is subtracted only in year one of the project; it is not subtracted in year two and subsequent years. The ITC is either equal to the fixed amount on the Payment Incentives page, or calculated by multiplying the ITC percentage on the Incentives page by the applicable basis.

A note about incentives. Some incentives have caps that limit their maximum value, while others have escalation rates that increase their value from year to year. Others have term limits that end payments after a given number of years. In some cases the incentive income is taxable at the federal or state level, and in other cases it is not. Finally, investment and capacity based incentives may or may not reduce the basis on which the investment tax credit (ITC) is calculated. All of these factors are defined on the Payment Incentives page.

After Tax Cash and Cost Flow

Year zero of the cash flow shows represents project capital cost. The capital cost is equal to the total installed cost displayed on the system costs page minus the loan principal amount from the Financing page.

Year one is the first year that the project generates electricity. The cash flow for year one and subsequent years accounts for project expenses, income from electricity sales, taxes, and incentive payments.

The after tax cash flow for year one and subsequent years is given by:

	After Tax Cashflow = After Tax Cost +
Residential	*Offset Electricity Payments*
Commercial	*Offset Electricity Payments - Offset Electricity Payments × Effective Tax Rate*
Utility	*Revenues*

The after tax cost in year one and subsequent years is:

After Tax Cost = State Tax Savings + Federal Tax Savings + PBI Incentives - Operating Costs - Debt Total Payment

Note. The cash flow table for utility projects does not include a row for the After Tax Cost flow.

The effective tax rate is a single number that includes both the federal income tax rate and state income tax rate. Solar Advisor uses the effective tax rate for several calculations requiring a total income tax value.

The effective tax rate calculation is:

$$F_{\text{EffectiveTaxRate}} = F_{\text{FederalTaxRate}} \cdot (1 - F_{\text{StateTaxRate}}) + F_{\text{StateTaxRate}}$$

The federal and state tax rates are input variables on the Financing page.

Payback Cash Flows

Solar Advisor displays payback cash flows for commercial and residential projects only. These cash flows are used to calculate the project payback displayed in the Metrics table and are explained in the payback description.

Payback expenses included = After Tax Cashflow + Debt Interest Payment × (1 - Effective Tax Rate) + Debt Repayment

Payback expenses excluded = Payback expenses included + Operating Costs + Deductible Expenses × Effective Tax Rate

The cumulative cash flow for each year is the sum of the current year's "payback amount" and the previous year's amount.

PreTax Debt Service Coverage Ratio (Utility and Third-party Ownership Only)

Solar Adviser displays the annual debt service coverage (DSCR) amounts for utility and commercial third party ownership projects only:

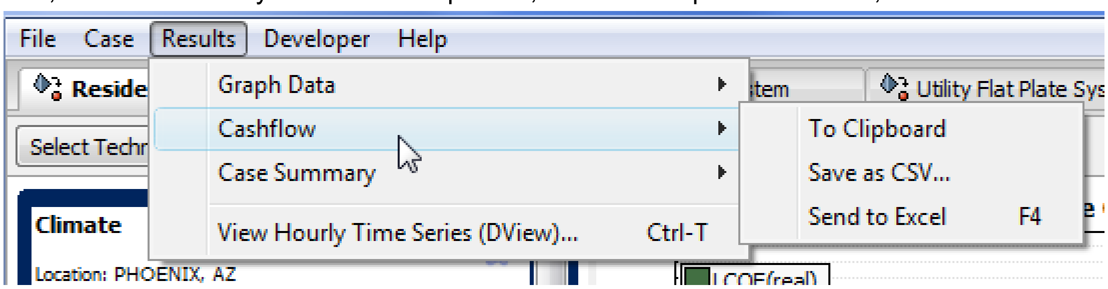
PreTax DSCR = Operating Income ÷ Total Debt Payment

10 Exporting Data and Graphs

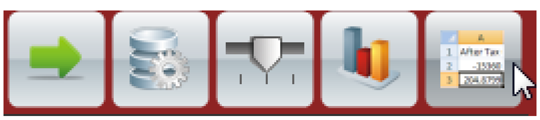
Solar Advisor provides a variety of options for exporting images of graphs and results data to other applications for further analysis or inclusion in reports and other documents.

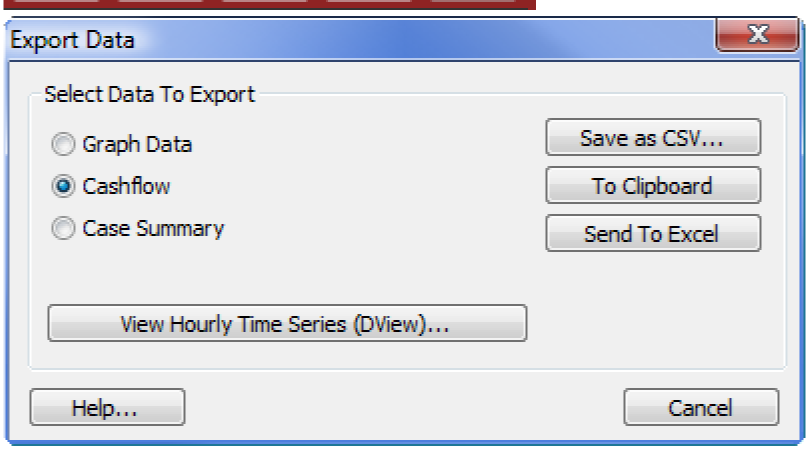
To export data from graphs and tables:

- Click an option on the Results menu to export data from the current graphs on the Results page, cash flow, or case summary to either the clipboard, a comma-separated text file, or to an Excel workbook.

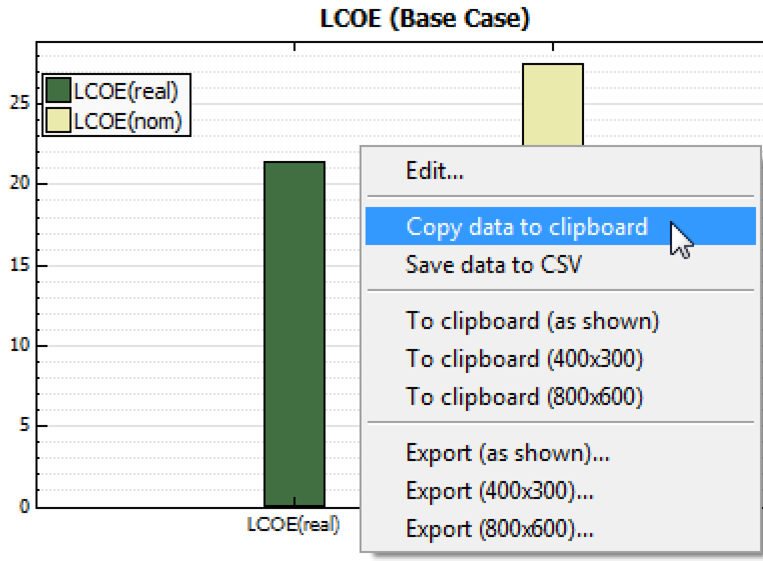


- Click the Export and view data button to display the same set of export options in the Export Data window:





- Right click a graph on the Results page and choose an export option:

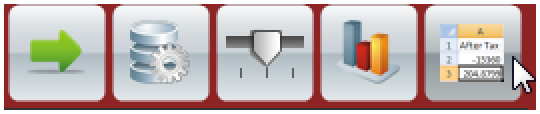


11 Viewing Hourly Performance Data

Solar Advisor generates a set of hourly performance data that you can view either in Excel or using the DView time series data viewer. The hourly data is for the "base case" input data, or based on values of input variables visible on the input pages. Hourly performance data for additional simulations for parametric or other analysis configurations that require multiple simulations are not included in these files.

To view hourly performance data in Excel:

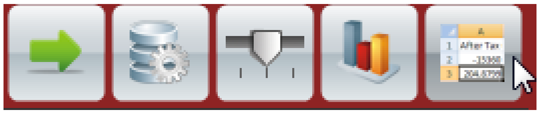
1. Click the Export and view data button to open the Export Data window.



2. In the Export Data window, click **Case Summary**.
3. Click **Send To Excel**. Solar Advisor opens an Excel workbook containing a complete set of results for the current case.
4. In the Excel workbook, click the Hourly Data tab.

To view hourly performance data in DView:

1. Click the Export and view data button to open the Export Data window.



2. In the Export Data window, click **View Hourly Time Series Data (DView)**. Solar Advisor opens

DView displaying hourly performance data for the current case.

See Time Series Data (DView) for more information about the data viewer.

Saving TRNSYS Simulation Data

The hourly performance data shown in Excel and DView is a subset of the complete set of hourly results generated by the TRNSYS simulation engine. Saving TRNSYS simulation data is an option for advanced users who are either familiar with TRNSYS, or want access to hourly data not provided in the standard hourly results files.

To save TRNSYS simulation output files:

1. On the File menu, click **Preferences**.
2. In the SAM Preferences window, check **Save TRNSYS hourly data, list, and log files**.
3. Click ... to specify for the folder where you want the files to be saved.
4. Click **Close**.
5. On the File menu, click **Clear Cached Simulations**.
6. On the Case menu, click one of the run simulation options.

   Solar Advisor saves the files in the folder you specified. The hourly data folder is named with the extension .out. The naming convention is *technology*.hourly.out. For example the CSP trough results are saved in a file named trough.hourly.out. You can view the hourly results files using a text editor, Excel, or DView.

11.1 Time Series Data (DView)

Solar Advisor displays hourly data for the current case in a built-in data viewer called DView. You can use the viewer to display graphs of hourly results as well as monthly and annual averages of the hourly data. You can also export the data to a tab-delimited text file, and to copy graph images for use in presentations and reports.

To display the graphs of time series data in DView:

1. On the Results menu, click **View Hourly Time Series (DView)** to display base case hourly results in the viewer, or

   on the Climate page, click **View hourly data** to view the weather file in the viewer.
2. Click the tab for the graph format you want to view. See the table below for a description of the different formats.
3. Select the variable or variables to view. Depending on the graph format, a list of available variables appears either in a drop-down box or as a list of check boxes.

For CSP systems, including trough, power tower, and dish-Stirling systems, when you view hourly results in DView, Solar Advisor displays a subset of the hourly results generated by the TRNSYS simulation engine. See Saving TRNSYS Simulation Data for details.

Tips for using the data viewer:

- For check box lists, checking a box in the leftmost column splits the graph into two and displays the checked variable in the upper graph. Checking a box in the rightmost column displays the graph in the lower graph, or in a single graph when no boxes are checked in the leftmost column.
- Right-click a graph to export an image of the graph or a table of the data in the graph.

- Change properties of a graph, such as the graph title and labels, line colors and style, and axis bounds by right-clicking a graph and choosing Properties.

Table 37. Data viewer graph formats.

Tab Name	Graph Format Description
DMap	8,760 point data map showing entire year of hourly data in a single graph
Hourly	Time series line graph, use scroll bars and zoom buttons to view entire data set
Daily	Daily average line graph
Monthly	Monthly average line graph
Boxplot	Monthly average with daily and monthly minima and maxima
Profile	Average daily profiles by month
PDF	Probability distribution function
CDF	Cumulative distribution function
DC	Duration curve

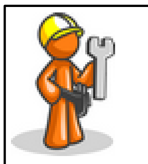
Table 38. Hourly data variable names and explanations for parabolic trough systems.

Variable name	Units	Description
E_dump	MW	solar electric generation in excess of power plant maximum output
E_gross	MW	gross total electric generation
E_min	MW	solar electric generation below minimum power plant output
E_net	MW	net electric energy production (gross parasitics)
E_parasit	MW	total parasitics for entire system
Epar_OffLine	MW	total offline parasitic losses
Epar_OnLine	MW	total online parasitic losses
Q_abs	W/m2	absorbed energy
Q_dni	MW	solar radiation incident on the collector
Q_dump	MW	the amount of energy dumped (in excess of turbine and storage)
Q_from_ts	MW	energy from thermal storage
Q_gas	MW	gas thermal energy Input
Q_hftFpHtr	MW	HTF freeze protection from auxiliary heater
Q_htfFPTES	MW	HTF freeze protection from thermal energy storage
Q_nip	W/m2	measured beam radiation
Q_SF(MW)	MW	solar field thermal output (availability factor not applied)
Q_to_PB	MW	energy to the power block
Q_to_ts	MW	energy to thermal storage
Q_ts_Full	MW	energy dumped because the thermal storage is full
Q_tur_SU	MW	the energy needed to startup the turbine
QSF_Abs	MW	absorbed energy for the solar field
QSF_HCE_HL	MW	receiver heat losses for the solar field
QSF_nipCosTh	MW	measured beam radiation cosine theta
QSF_Pipe_HL	MW	piping heat losses for the solar field
QTS_HL	MW	energy losses from thermal storage
TIME	none	hour of the year
TOUPeriod	none	time of use periods (1 through 6)

Table 39. Hourly data variable names and explanations for PV systems.

Variable Name	Units	Description
ACPower	kW	AC power at inverter output, not derated
AmbTemp	°C	ambient temperature
CellTemp	°C	cell temperature
DCPower	kW	DC power at array output, not derated
GlobHozRad	kW/m2	global horizontal radiation
IncBeamRad	kW/m2	incident beam radiation
IncDiffRad	kW/m2	incident diffuse radiation
IncTotRad	kW/m2	incident total radiation
InvEff	none	inverter efficiency by hour
InvPartLoad	none	inverter part load efficiency by hour
TIME	none	hour of the year
Windspd	m/s	wind speed

12 Working with Libraries



This topic is under construction.
If you have questions about this topic, please contact user support:
solar.advisor.support@nrel.gov.

A library is a collection of stored parameters for some performance model components.

Libraries Included with the Model

Solar Advisor uses libraries to store parameter sets for the following performance model components and displays them as lists on the relevant input pages:

- Photovoltaic CEC Module parameters on the Module page
- Photovoltaic Sandia Module parameters on the Module page
- Photovoltaic Sandia Inverter parameters on the Inverter page
- CSP parabolic trough parasitic losses on the Parasitics page
- CSP parabolic trough power cycles on the Power Block page
- CSP parabolic trough solar collector assemblies on the SCA / HCE page
- CSP parabolic trough thermal energy storage dispatch on the Thermal Storage page
- CSP power tower thermal energy storage dispatch on the Thermal Storage page

- CSP dish-Stirling systems on the System Library page

Opening the Library Editor

To open the library editor, click File, Libraries. You must open a project file before opening the library editor (the editor is not available from the Welcome page).

Default and User Libraries

There are two types of libraries, default libraries and user libraries:

- Default libraries are available to all project files on your computer and cannot be edited directly in the library editor. Default libraries are stored in the libraries folder. A set of default libraries is distributed with the Solar Advisor Model software. Default libraries are indicated in lists by the prefix "SAM/." You can add a library file to the default collection by putting it the libraries folder.
- User libraries are libraries stored in the project file. A user library must be added to a project file to be available in the file. User libraries are indicated in lists by the prefix "USER/." Unlike default libraries, user library parameters are stored in the project file and can increase the project file size. User libraries are useful when you are using custom parameter sets and sharing project files with other people. To make a user library available to another project, you can either export it as a library file and import it into the other project, or you can add the exported library file to the libraries folder to be included with the default libraries and made available to all projects on your computer.

Managing User Libraries

To add a new user library, open the library editor, and click New User Library. Type a name for the library (this is the name that will appear in library lists), and then choose a library type.

To add items to a user library, click the library's name in the Libraries list and click Add Entries. In the variables list, check one or more items that have similar characteristics to the item you want to add. Right-click each item's name and click Rename to change the item's name. You can then either change values manually by double-clicking each cell and typing a value, or you can paste a row of values from a text file with comma-separated columns or an Excel file by right clicking the item name and clicking Paste Values.

To edit parameter values in a user library, double-click cells in the parameter table. There is no error checking, so be sure to type valid values.

To modify values in a default library, copy the library from the libraries folder to another folder on your computer, and use the library editor to import it as a new user library.

To "convert" a user library to a default library, in the library editor, select the user library's name in the Libraries list, click Export, and save the file in the libraries folder. The library will now be displayed in the Libraries list with a "SAM/" prefix, and will be available to all project files on your computer.

Library File Types and Folders

Library files are text files with the extension .samlib. Library files contain sets of parameter values.

Library files can be stored anywhere on your computer, and must be imported into your project file as user libraries, unless they are stored in the libraries folder.

Default libraries are available to all project files on your computer, and must be stored in the libraries folder, which is c:\SAM\[*software version date*]\exelib\libraries by default.

Solar Advisor uses library type files to define the contents of library files. The library types are categories of parameter collections. For example, the TroughHCE library type stores parameters for trough heat collection elements. You cannot add or remove library types in the user library. Library types are stored as .samlibtype files in the libraries folder, and should not be modified for typical uses of the model.

13 References

Parabolic Trough Technology and Modeling

- McMahan A, 2006. Design & Optimization of Organic Rankine Cycle Solar-Thermal Power Plants. Master of Science Thesis. University of Wisconsin-Madison. http://sel.me.wisc.edu/theses/mcmahan06.zip
- Moens et al, 2005. Advanced Heat Transfer and Thermal Storage Fluids, National Renewable Energy Laboratory. NREL/CP-510-37083. http://www.nrel.gov/docs/fy05osti/37083.pdf
- NREL Troughnet Parabolic Trough Solar Power Network. http://www.nrel.gov/csp/troughnet
- Patnode A, 2006. Simulation and Performance Evaluation of Parabolic Trough Solar Power Plants. Master of Science Thesis. University of Wisconsin-Madison. http://sel.me.wisc.edu/theses/patnode06.zip
- Pilkington Solar International GmbH, 2000. Survey of Thermal Storage for Parabolic Trough Power Plants. National Renewable Energy Laboratory. NREL/SR-550-27925. http://www.nrel.gov/csp/troughnet/pdfs/27925.pdf
- Price H et al, 2006. Field Survey of Parabolic Trough Receiver Thermal Performance, National Renewable Energy Laboratory NREL/CP-550-39459. http://www.nrel.gov/docs/fy06osti/39459.pdf
- Stuetzle T, 2002. Automatic Control of the 30 MWe SEGS VI Parabolic Trough Plant. Master of Science Thesis. University of Wisconsin-Madison. http://sel.me.wisc.edu/theses/Stuetzle02.zip

Dish-Stirling Technology and Modeling

- Fraser P, 2008. Stirling Dish System Performance Prediction Model. Master of Science Thesis. University of Wisconsin-Madison. https://www.nrel.gov/analysis/sam/pdfs/thesis_fraser08.pdf
- International Energy Agency SolarPaces technology characterization Solar Dish Engine. http://www.solarpaces.org/CSP_Technology/docs/solar_dish.pdf

Power Tower Technology and Modeling

- International Energy Agency SolarPaces technology characterization Solar Power Tower. http://www.solarpaces.org/CSP_Technology/docs/solar_tower.pdf
- Kistler B, 1986. A User's Manual for DELSOL3: A Computer Code for Calculating the Optical Performance and Optimal System Design for Solar Thermal Central Receiver Plants. SAND86-8018. http://www.prod.sandia.gov/cgi-bin/techlib/access-control.pl/1986/868018.pdf
- NREL 2007 Solar Power Tower, Dish Stirling and Linear Fresnel Technologies Workshop presentations. http://www.nrel.gov/csp/troughnet/wkshp_power_2007.html
- U.S. Department of Energy Energy Efficiency and Renewable Energy. Concentrating Solar Power Technologies: Power Tower Systems. http://www1.eere.energy.gov/solar/power_towers.html
- Wagner M, 2008. Simulation and Predictive Performance Modeling of Utility-Scale Central Receiver System Power Plants. Master of Science Thesis. University of Wisconsin-Madison. http://sel.me.wisc.edu/theses/wagner08.zip

Photovoltaic Modeling

- Arizona State Photovoltaic Testing Laboratory. http://www.poly.asu.edu/ptl

- Bower W et al, 2004. *Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems*. http://bewengineering.com/docs/index.htm
- California Energy Commission, New Solar Homes Partnership Calculator: CECPV Calculator. The CEC calculator uses the same module performance model as Solar Advisor's CEC performance model; documentation included with the CECPV Calculator explains details of the model. http://www.gosolarcalifornia.ca.gov/nshpcalculator
- De Soto W, 2004. Improvement and Validation of a Model for Photovoltaic Array Performance. Master of Science Thesis. University of Wisconsin-Madison. http://sel.me.wisc.edu/theses/desoto04.zip
- De Soto W et al, 2003. "Improvement and Validation of a Model for Photovoltaic Array Performance." Solar 2003 Conference Procedings. American Solar Energy Society.
- King D et al, 2004. Photovoltaic Array Performance Model. Sandia National Laboratories. SAND2004-3535. http://www.osti.gov/bridge/product.biblio.jsp?query_id=0&page=0&osti_id=919131
- King D et al, 2007. Performance Model for Grid-Connected Photovoltaic Inverters. Sandia National Laboratories. SAND2007-5036. http://www.prod.sandia.gov/cgi-bin/techlib/access-control.pl/2007/075036.pdf
- Marion W et al, 2002. PVWatts Version 2: Enhanced Spatial Resolution for Calculated Grid-Connected PV Performance. http://rredc.nrel.gov/solar/codes_algs/PVWATTS/pvwatts2.pdf

Project Economics and Financing

- Short W et al, 1995. Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies. National Renewable Energy Laboratory. NREL/TP-462-5173. http://www.nrel.gov/docs/legosti/old/5173.pdf
- Wiser R, 1997. "Renewable energy finance and project ownership", Energy Policy Vol 25 No 1 pp 15-27.
- Wiser R et al, 1997. Financing Investments in Renewable Energy: The Role of Policy Design and Restructuring. Ernest Orlando Lawrence Berkeley National Laboratory. http://eetd.lbl.gov/ea/EMS/reports/39826.pdf

TRNSYS and Excelergy

- Klein S et al, 2004. TRNSYS 16 A Transient Simulation Program. Solar Energy Laboratory, University of Wisconsin-Madison. http://sel.me.wisc.edu/trnsys/
- Klein S et al, 2007. TRNSYS 16 A Transient Simulation Program, Volume 5 Mathematical Reference. Solar Energy Laboratory, University of Wisconsin-Madison.
- NREL has used Excelergy in analysis for the Department of Energy, Sargent and Lundy, and the Southwest Concentrating Solar Power 1000 MW Initiative. See http://www.nrel.gov/csp/modeling_analysis.html#systems

Weather Data

- Information about EnergyPlus weather data is available on the EnergyPlus website. http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm
- Typical Meteorological Year (TMY2 and TMY3) data and documentation is available on the Solar Radiation Resource Information website. http://rredc.nrel.gov/solar/old_data/nsrdb

Useful Web Sites

- Go Solar California: http://www.gosolarcalifornia.ca.gov
- International Energy Agency SolarPACES: http://www.solarpaces.org

- National Renewable Energy Laboratory: Energy Analysis, http://www.nrel.gov/analysis; National Center for Photovoltaics, http://www.nrel.gov/pv; Concentrating Solar Power Research, http://www.nrel.gov/csp
- Sandia National Laboratories: Photovoltaic Systems Research & Development, http://photovoltaics.sandia.gov; Concentrating Solar Power and SunLab, http://energylan.sandia.gov/sunlab
- U.S. Department of Energy Solar Energy Technologies Program: http://www1.eere.energy.gov/solar