Solar Site Evaluation

Tools & Techniques to Quantify & Optimize Production

By Mark Galli and Peter Hoberg

Improve system performance and energy harvest projections with a thorough site evaluation that includes shading analysis and insolation quantification.

There are multiple factors to consider when evaluating a site for a photovoltaic or solar thermal installation, and each may impact optimal energy production. In addition to latitude and longitude, which determine the sun path characteristics, panel or collector orientation—tilt and azimuth—defines the field of view that an array has of the sun. Shading from trees, hillsides, buildings or other obstructions can cause significant degradation in energy production. Additionally, local and regional weather patterns result in site-specific seasonal and daily fluctuations in solar insolation.

These factors combine and interact to determine the solar energy incident on an array and therefore impact both financial returns and customer satisfaction. Tools and techniques used in site evaluation emphasize shade analysis and optimizing solar access.

THE IMPORTANCE OF SITE EVALUATIONS

An early and thorough site evaluation can lead to better system designs that will result in the following benefits: increased energy production by selecting the best location for the solar array; improved accuracy in energy production estimates due to better quantification of shading and other site-specific issues; optimized financial incentives, such as state-specific rebates that adjust for panel orientation and shading; improved system installation and materials cost estimates; and increased customer satisfaction and confidence, which in turn can lead to repeat or referred business.

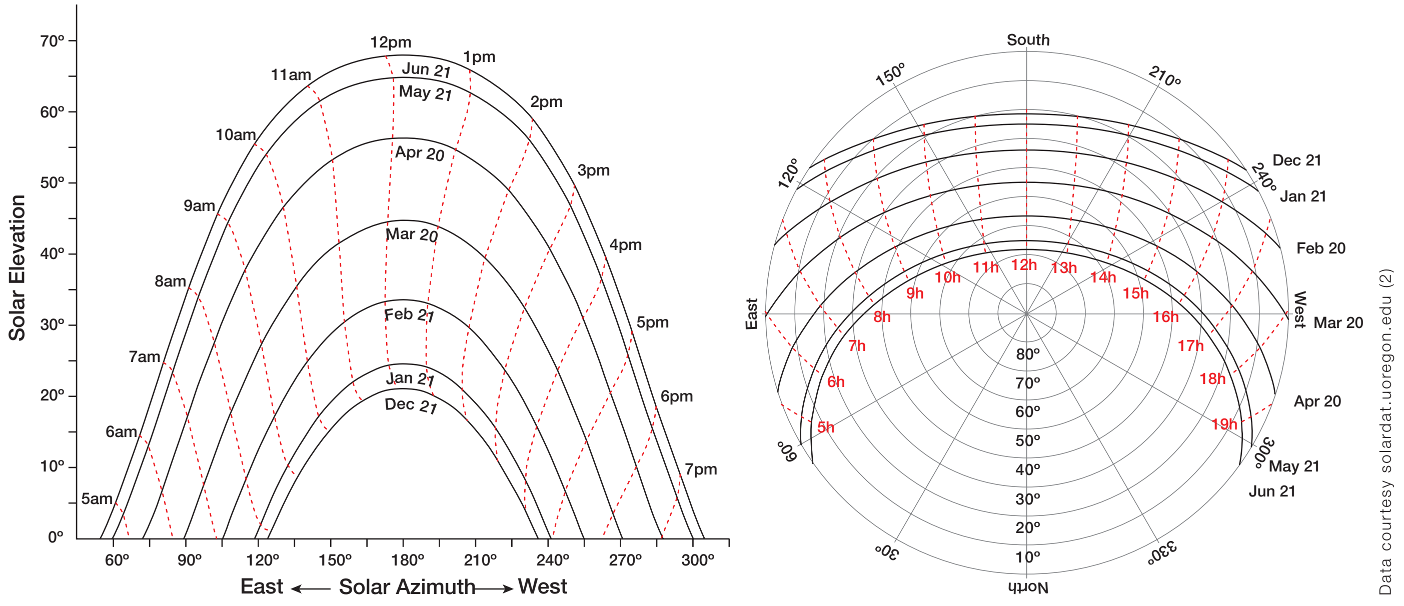
Leading solar system designers and installers invest significant efforts into on-site data collection and evaluation, especially during customer qualification, initial design and proposal preparation. The site information gathered includes:

- Measurement of location parameters, including available area for the array, roof pitch or site grade, and azimuth.
- Measurement of solar access and impact of shade-causing obstructions, as well as evaluation of shade-reduction strategies, such as tree trimming or removal.
- Identification of issues that could jeopardize the viability of a project or result in increased design and installation complexity and implementation cost, such as conductor and trench routing; proximity of array to inverter; roofing material integrity; rafter and beam spacing for engineering calculations; and safety concerns and access issues.
- Direct contact with the client to discuss additional issues, including possible aesthetic concerns and financing plan options.

SUN PATHS

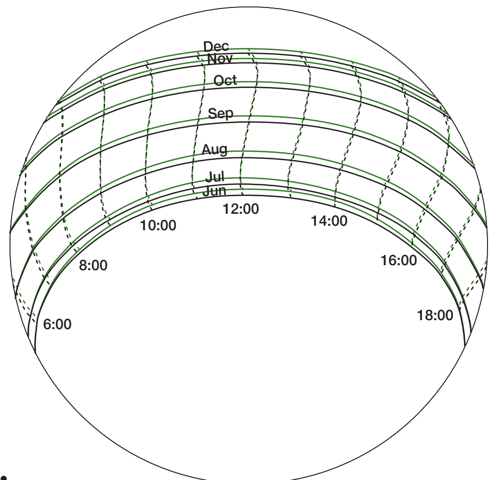
Solar access will depend on the sun's location, defined by elevation angle and azimuth direction, as it varies through each day and throughout the year. This path can be plotted for a given latitude and longitude. An example sun path chart is shown in both rectilinear and polar formats in Graphs 1a and 1b. Typically, sun charts are centered around south (180° azimuth) for sun path diagrams in the Northern Hemisphere, and around north for sun path diagrams in the Southern Hemisphere. Examples shown in this article are for the Northern Hemisphere with references to summer and winter from a Northern Hemisphere view.

The sun path is a function of latitude and longitude, and it shifts with changes in location. This effect is illustrated for two different locations in Graphs 2a and 2b (p. 56). Moving north toward higher latitudes, the annual sun path chart shifts, indicating that the sun is at lower elevations. Moving south, the chart shifts, indicating higher sun elevations.

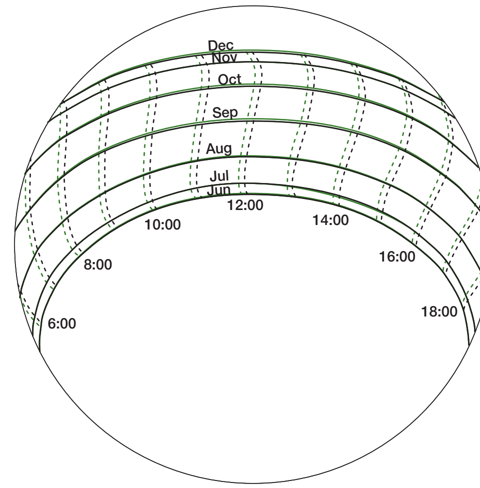


Graphs 1a & 1b A sun path chart for Portland, OR, in (a) rectilinear and (b) polar formats.

Graphs 2a & 2b The polar sun path chart in 2a shows Sacramento, CA (38.6N 121.5W, black lines), and a 2° shift in latitude to the north (green lines). Graph 2b shows a 2° shift in longitude to the west (green lines) of Sacramento.



Graph 2a



Graph 2b

Data courtesy solmetric.com (2)

Definitions: Terms Used in Solar Site Evaluation

INSOLATION. The incident solar radiation on the earth's surface in a given time window, typically expressed in kWh/m^2/day.

SOLAR ACCESS/SHADING. Solar access is the ratio of the insolation in a given location, including shade, to the insolation available at that location without shade. Solar access is typically expressed in percent for a given time period, such as a month, season, or year.

OPTIMUM TILT AND ORIENTATION. For any location, the optimum tilt and orientation is the specific fixed tilt and orientation for solar arrays that absorbs maximum solar energy over the course of one year.

TILT AND ORIENTATION FACTOR (TOF). TOF is the solar insolation at the *actual* tilt and orientation divided by the insolation at the *optimum* tilt and orientation, expressed in percent.

TOTAL SOLAR RESOURCE FRACTION (TSRF). TSRF is the ratio of insolation available accounting for both shading and TOF, compared to the total insolation available at a given location at the optimum tilt and orientation and with no shading. TSRF is also expressed as a percentage. TSRF = solar access x TOF

MAGNETIC DECLINATION. Magnetic declination is the azimuth offset between magnetic north and true north, expressed in degrees east or west.

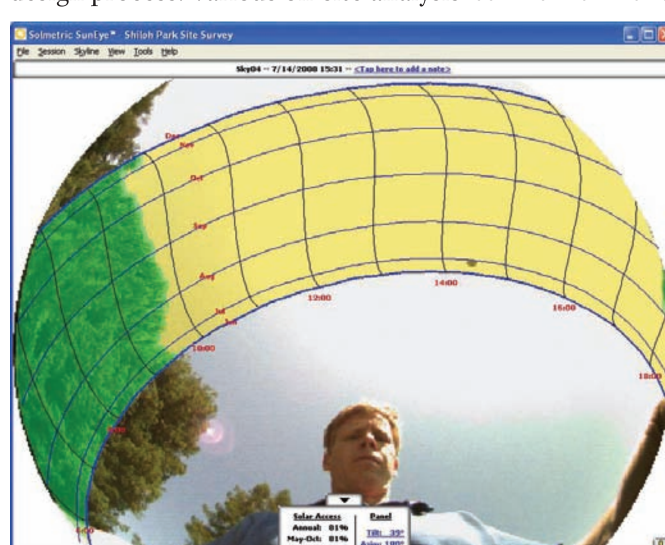
TYPICAL METEOROLOGICAL YEAR (TMY). TMY is a collection of weather information that includes data about insolation for every hour of a typical year computed using historical weather data.

Moving west toward greater longitude, the sun's path remains the same, but the time for each sun location is shifted toward later in the day.

Note that a latitude shift of 2° to the north (138 miles) shifts the noon elevation angle by less than 2°. A longitude shift of 2° (108 miles at 38.6° N) causes a time shift of about 10 minutes at noon. When making measurements at a site, using exact coordinates is ideal; but it is normally sufficient to use the sun paths for locations within 50 miles of the site being surveyed and in the same time zone.

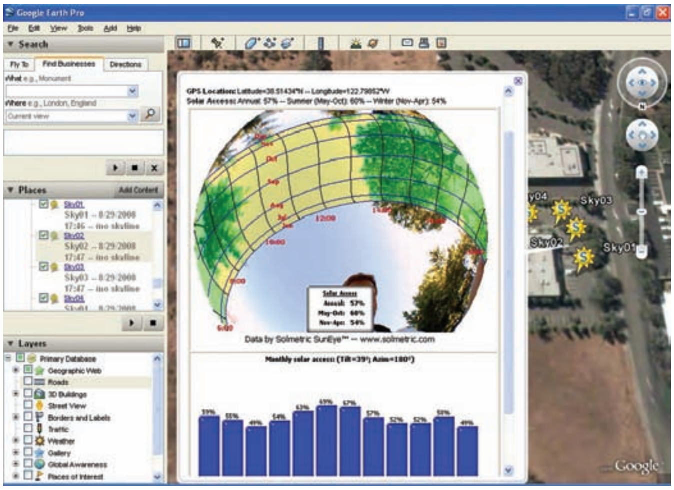
SHADING ANALYSIS

Shade can have a dramatic impact on solar production. Evaluating it is critical before getting too far into the system design process. Various on-site analysis CONTINUED ON PAGE 58



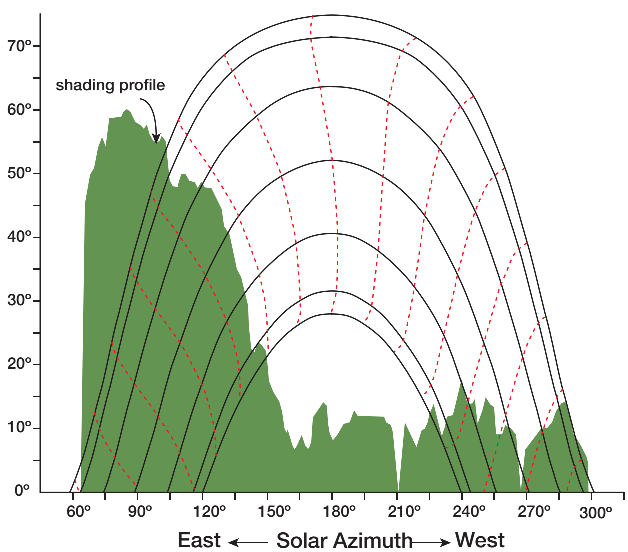
Courtesy solmetric.com

Image 1 Using a fish-eye lens, solar access measurements and computed results can be charted.



Courtesy solmetric.com

Image 2 A screen capture of a Google Earth image with an incorporated skyline plot map showing monthly shading data for Skyline Number 2 (Sky02).



Data courtesy solmetric.com

Graph 3 This graph represents a morning shade profile with sun paths superimposed.

Extending Point Measurements

This article focuses on ways of characterizing the solar access from point measurements, for example with the fish-eye lens. Specific modules in an array will experience shading at different times of day and year. Typically, to get a good estimate of a system's performance, multiple points should be measured in and around the array, such as at each corner of the array. Some techniques and trends for combining multiple point readings are listed below. The different techniques vary in accuracy and complexity.

➔ Average multiple point measurements. Average the monthly solar access values from each reading to generate 12 numbers that reflect the average monthly solar access for the entire array. The California Solar Initiative program requires that the measurements be taken at the four corners of the array and averaged in this manner. More points can improve accuracy but can be time consuming.

➔ Interpolation techniques. Use linear interpolation to estimate the solar access at locations in between measurement points. Precise measurements of the relative locations are necessary to enable accurate interpolation.

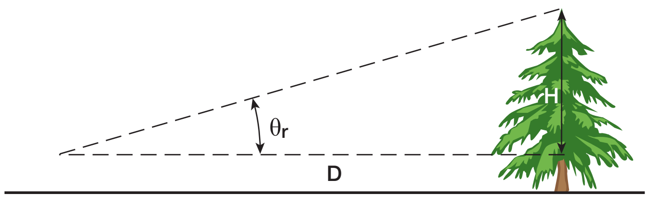
➔ 3-D modeling from on-site data. In this case, the height and elevation of each obstruction must be known. This can provide some measurement challenges. With few obstructions, this approach is practical, but the complexity increases with many obstructions.

➔ 3-D modeling from aerial/satellite imaging. GIS and mapping technologies are advancing rapidly. Tools like Google Earth, Microsoft Virtual Earth, and ArcGIS Explorer are extending our ability to view buildings and obstructions online. In the future, these technologies may provide the 3-D details necessary for initial estimates and may provide a useful complement to on-site evaluations.

tools and techniques can be used, including viewing reflections from a mirror dome (SolarPathfinder), multiple digital pictures (Wiley Electronics ASSET) or using a fish-eye lens and digital camera to capture the whole sky in a single image (Solmetric SunEye). The result is information about the shading obstacles' elevation versus azimuth. The sun path information described earlier can be overlaid directly onto these views, so that the impact of shading can be determined either graphically or numerically. An example of a polar chart taken with a fish-eye lens is shown in Image 1 (p. 56).

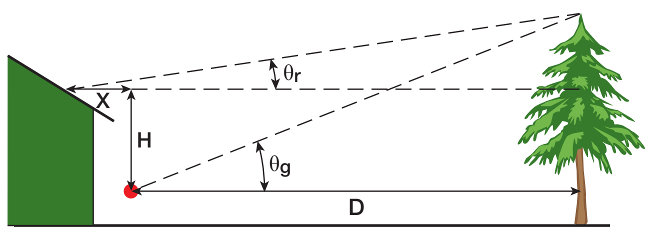
Even for small residential arrays, shading analysis typically requires taking multiple readings at various positions. These readings can then be averaged or processed in simulation programs to modify the energy production estimates for the entire array. For larger commercial and utility scale projects, readings from various locations can be tagged with their GPS coordinates and then compared on a map, like the Google Earth plot map shown in Image 2. Shading data can also be shown as elevation versus azimuth as depicted in Graph 3, using the same data as Image 1. Sun elevation and azimuth are also shown. CONTINUED ON PAGE 60

Data courtesy solmetric.com (3)



$$H/D = \tan(\theta_r)$$
$$\theta_r = \tan^{-1}(H/D)$$

Illustration 1 To quantify shading, determine the elevation angle (θ) as a function of the distance to the obstruction (D) and its height above the measurement plane (H).



$$\theta_r = \tan^{-1}(\,(D \times \tan(\mathrm{RADIANS}(\theta_g)\,) - H) / (D + X)\,)$$

Illustration 2 The necessary calculations for extrapolating ground level measurements to the roof, simplified for a single plane.

ELEVATION ANGLES AND EXTRAPOLATING MEASUREMENTS

Elevation angle is a very useful way to describe obstructions. However, the angle alone may be insufficient to describe the shape and direction of the shade on an array. For a more complete analysis, the distance to the obstruction and its height can be measured. Shading is sometimes quantified in this way. The relationship between elevation angle (θ), distance to the obstruction (D) and height above the measurement plane (H) is shown in Illustration 1.

The California Solar Initiative requires that the shading ratio (D:H) must be at least 2:1. This is equivalent to an elevation angle of less than 26.6°. If a site meets these requirements, it is deemed to have good solar access, and a detailed shade analysis is not required.

An alternative way to specify shading is to determine a site's shade-free hours, such as 10am–2pm or 9am–3pm. In this case, obstructions are allowed to cast shadows only before or after the specified time period.

The minimum D:H ratio can be specified for the shade-free time periods for a given location. Some example calculations are shown in Table 1. Note that this requirement is worst-case and applies only at the lowest sun elevation of the year within those time windows. This may be too conservative and restrictive for typical pitched roof applications, but it may be useful when considering row spacing in flat-roof or ground-mount system installations.

When collecting shading data, it is possible to take the data in one location and extrapolate it for another. This can allow an analysis using ground-level data by extrapolating up a distance H and over a distance X. This approach is useful and often necessary when taking measurements at a location where the building is not yet constructed or when it is not practical to get shading data from the true height of the proposed array. The calculations can be complex for the full 3-D analysis. For reference, a 2-D equation is shown in Illustration 2. For this equation to apply, the lines must all be coplanar.

ARRAY ORIENTATION

The tilt and azimuth of an array establish the field of view, and the sun paths as seen within that CONTINUED ON PAGE 62

Minimum Distance to Height Ratio

	Latitude °N	Longitude °W	10am–2pm EST	9am–3pm EST
New York	40.7°	74.0°	2.8:1	4.4:1
Atlanta	33.7°	84.4°	2.5:1	4.2:1
Miami	25.8°	80.2°	1.7:1	2.6:1

Table 1 The minimum D:H at several example locations guarantees shade-free status during the specified times.

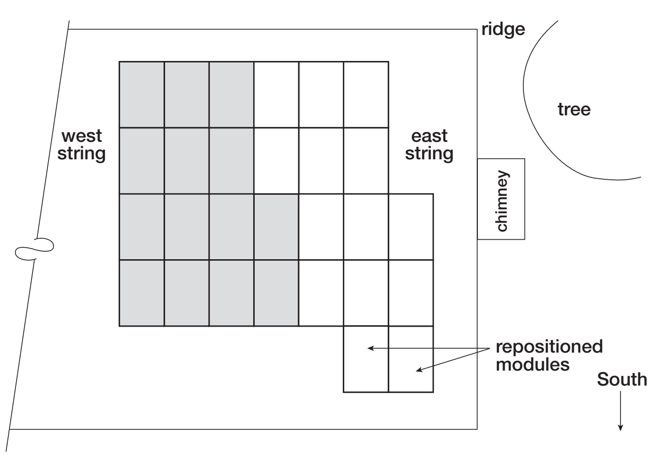


Illustration 3 Two modules in this array were repositioned to avoid the impact of shading from the tree and the chimney east of the array.

field of view will determine the solar insolation. Note that the field of view will also determine what shading obstacles will impact solar access. For example, if the field of view is toward the west, it will decrease the impact of shading obstacles on the eastern horizon and increase the impact of shading obstacles on the western horizon.

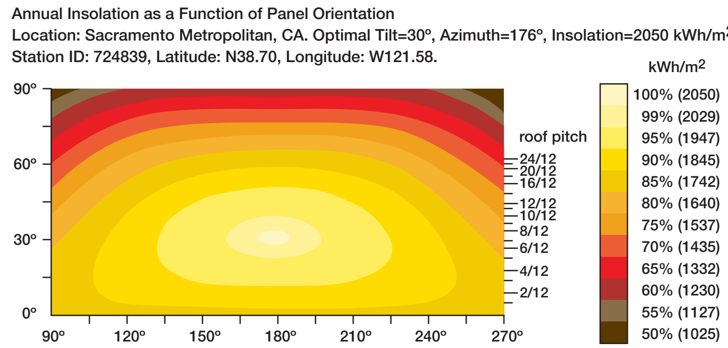
For rooftop solar installations, the roof parameters—pitch and azimuth—typically determine the array orientation and layout. Therefore the field of view can be adjusted only by picking the best section of the roof and the ideal location within that area. Rooftop obstacles, such as chimneys and vent pipes, can cause shading in locations that are otherwise desirable. In some cases, relocating modules that would be shaded can help significantly. Not only does this preserve the production of the affected modules, but, more importantly, it also can preserve the production of one or more series strings by minimizing shading and keeping string voltage within the inverter's maximum power point tracking window. Multiple-point shading analysis makes this kind of performance optimization possible. An example is shown in Illustration 3 (p. 60).

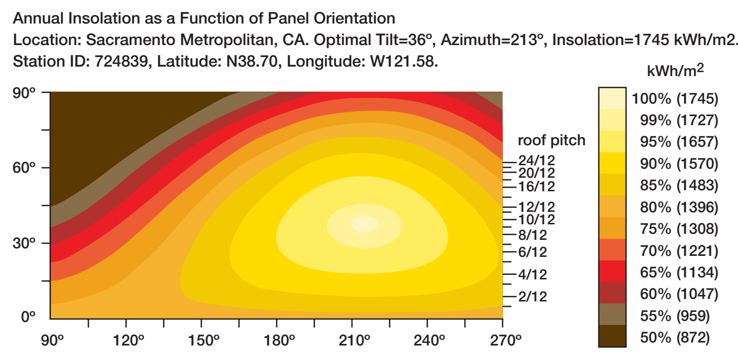
SITE SPECIFIC WEATHER PATTERN QUANTIFICATION

The insolation values for specific sites are heavily influenced by the weather patterns for that particular location. Various weather and insolation data is available for locations worldwide. The National Renewable Energy Laboratory recently released updated weather data for 1,020 locations in the US. The database, known as TMY3, records insolation during all hours of the year and can be very helpful in estimating weather-corrected insolation for a given site.

The effects of shading and weather can be observed using an annual insolation chart. Graph 4a shows a plot of annual insolation vs. tilt and azimuth values for Sacramento, California, without shading. Graph 4b incorporates significant shade to the east, as in the Skyline shown in Image 1. Notice that the optimum value shifts in azimuth and tilt, and the optimum available insolation is reduced. Sacramento's insolation chart is close to symmetrical around the southern direction, which indicates that morning and afternoon insolation is similar.

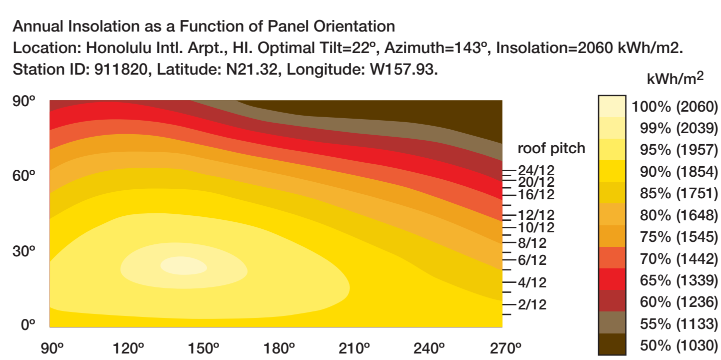
Honolulu, Hawaii, shown in Graph 5, reveals a significant eastward shift in the optimum values, indicating significantly less insolation in the afternoon than in the morning, most likely due to patterns of afternoon clouds and rain.





Data courtesy solmetric.com (3)

Graphs 4a & 4b Graph 4a plots the annual insolation versus tilt and azimuth for Sacramento, CA, with no shading. Graph 4b adds significant morning (eastern) shade and shows the resulting impact on insolation availability.



Graph 5 Annual insolation versus tilt and azimuth for Honolulu, HI, shows a significant eastward shift in the optimum annual values due to cloudy afternoon weather patterns.

The impact of climate change on insolation levels could be significant over an array's 30-year operational life. Although general trends may be clear, precise modeling is difficult, and results may be controversial. General trends, such as drier or wetter, could provide a qualitative indicator of either higher or lower solar production. CONTINUED ON PAGE 64

THE BOTTOM LINE

The financial plan for a photovoltaic or solar thermal project involves costs and benefits, and a detailed site evaluation can make or break a project's success. Contractors, investors and clients will all benefit from an open, honest review of the solar access data upfront to avoid unwanted surprises during or after project implementation.

The site assessment itself represents a project cost. Depending on the size of the array and complexity of the site, a thorough site assessment can add a few hundred to a few thousand dollars to the project. In the precontract phase, contractors are typically not getting paid for this work, so quick results with sufficient accuracy are critical. Often a preliminary site analysis is performed as part of the sales process with a more detailed analysis after a contract is signed.

Solar energy project success requires a good site assessment. Location, panel orientation, weather and shading all interact to influence solar access and therefore energy production potential. With the right tools and techniques, solar installers can dramatically improve the chances of their project's success.

CONTACT

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Resources:

California Solar Initiative / gosolarcalifornia.org/csi/index.html

National Renewable Energy Laboratory / nrel.gov/rredc/pvwatts (photovoltaic performance calculator)

National Renewable Energy Laboratory, TMY3 / rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3 (weather data)

University of Oregon Solar Radiation Monitoring Laboratory / solardat.uoregon.edu/SunChartProgram.html (sun path chart program)

University of Oregon Solar Radiation Monitoring Laboratory / solardat.uoregon.edu/PolarSunChartProgram.html (polar sun path chart program)

Shading analysis tool:

SolarPathfinder / solarpathfinder.com

Solmetric / solmetric.com

Wiley Electronics / we-llc.com