Residential Solar Site Measurements: New Developments

By Peter Hoberg

Courtesy Solmetric (2)

As the PV industry has matured, the expectations for accurate measurements have been ratcheting up. Increasingly, for the solar installer, competitive pressure to reduce cost of sales and BOS costs must be balanced with the financing companies' requirements to provide accurate up-front site measurements, design estimates and energy production guarantees. The industry's tools and best practices are evolving and maturing to keep pace. Here I describe recent developments and trends, including tools and best practices for measuring roof dimensions and shade, estimating system performance, and evaluating the impact of solar leasing options and performance guarantees on site measurement approaches. In addition, I address when, where and how the available technologies are most appropriately applied to help balance the needs of the different stakeholders associated with a PV system.

Stakeholder Perspectives on Site Measurement Accuracy

Throughout a typical residential PV system sales and installation life cycle (see Figure 1), the various stakeholders have different motivations and perspectives with regard to the accuracy of site measurements and the corresponding system performance estimates and guarantees.

Homeowner. Homeowners invest in solar energy because they want to reduce their energy costs and do so without adding new hassles and headaches. Their primary metric is their monthly electricity bill, before and after the installation, combined with any new financing payments. They may also want to view the system's instantaneous or historical performance with a simple web interface or smartphone app. The method the homeowners use to finance the system may also influence how they view the measurements and performance. If they own the system, they want optimum production and may be concerned about ongoing maintenance. If they have a solar lease with an energy production guarantee, they may want to compare energy production to the guarantee and may not be as concerned with optimizing production.

Installer. The company responsible for selling, installing and maintaining the system typically feels pressure to close a sale quickly, with moderate and predictable costs. The inside salesperson's goal is to close a sale over the phone. The outside salesperson attempts to close on the first site visit. Either way, sales representatives require accurate roof parameters and shade measurements so they can perform accurate system sizing and energy production estimates for the sales quote. After the sale, often an auditor or designer performs a more detailed on-site evaluation and makes any required adjustments to the initial design and system performance predictions. After installation, the installer wants assurance that the system performs to expectations within the warranty and/or performance guarantee period. Ultimately, the installer wants satisfied customers and minimal long-term risk to ensure repeat business and financial success.

State and local governments. In recent years, state programs have driven many of the industry's best practices for site measurements. Public accountability and political pressure to ensure that subsidized systems meet a minimum quality and performance standard have led to the development of required procedures for installers. For example, many of the leading states that support solar energy have solar access measurement requirements for their incentive programs. Some programs require that the proposed PV system meet a minimum solar access value, while others adjust the incentives in proportion to the available solar access.

State or utility programs that pay an up-front incentive based on system capacity often adjust the incentive to include shade values. In some programs, 10% shade means a 10% reduction in rebate value. The California Solar Incentive, for example, prorates the rebate based on the amount of shading. Frequently, the financial impact of shading is reflected in the actual energy production of the installed system to a greater degree than in the rebate payment.

Solar financing company. With the dramatic rise in third-party financing in the form of solar leases and power purchase agreements (PPAs), there has been a significant shift in the dynamics of residential site measurements. Financing companies and their investors want to optimize financial returns while controlling risk. Site measurements are supplied by the installer and are critical to determining the project's financial success. Increased measurement accuracy improves predictability and reduces guard bands built into the investment model to account for system performance variability, thus allowing for better all-around terms for the investor, the

Courtesy SolarTech

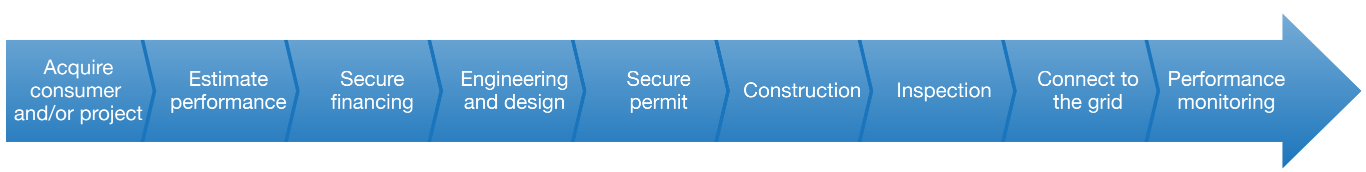


Figure 1 Solar project milestones are identified in this timeline developed by SolarTech. Site measurement accuracy impacts most of the stages of project development, from customer acquisition through measurements that verify performance over a system's operational lifetime.

installer and the customer. Better terms, such as lower interest rates, favorable performance guarantees and lower baseline energy rates, enable an attractive offering that helps win the deal by reducing the customer's payments and providing an assurance of energy production.

Figure 2 shows the typical scenario presented to customers for a residential lease or PPA. This scenario depends on the installation and operation of a high-performing PV system. If the system underperforms, then the utility bill is greater than expected, falling short of customer expectations and possibly the performance guarantee. Site measurement plays a key role during the sales process in determining the correct production estimate and performance guarantee values.

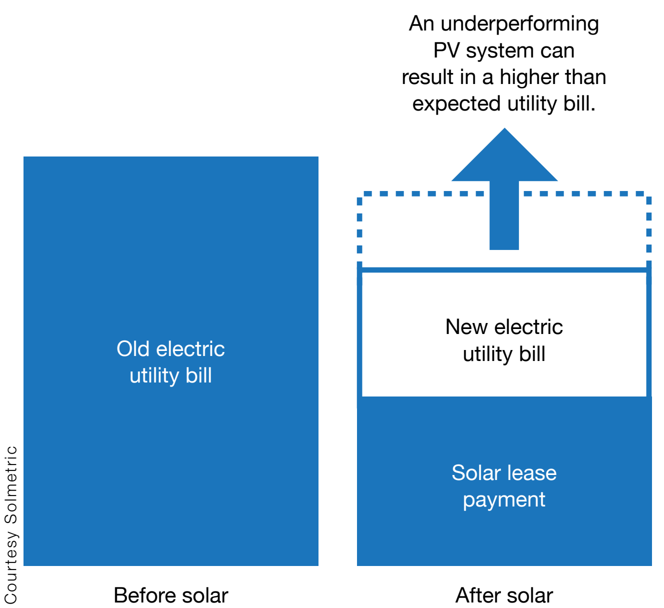


Figure 2 Accurate site measurements affect production estimates, performance guarantees and ultimately customer satisfaction. For residential projects with a solar lease or PPA, underperforming systems will result in higher than expected utility bills and possibly performance guarantee penalties.

Remote vs. On-Site Measurements

All stakeholders agree that accurately measuring a roof's pitch, orientation, dimensions and solar access is critical. The key question that remains is: When in the process should accuracy be maximized?

Consider solar access. Shading has a significant impact on the production of a PV system (see "Sun Paths and Shade Impacts," p. 78). Since financial return on the investment in a PV system is typically tied directly to energy production, shading clearly reduces the value of a solar asset. For example, in a net metered system, shading results in lower offset energy costs when on-site consumption is high, and less energy sold back to the grid when on-site consumption is low. Similarly, shading reduces the value of a PPA and production-based incentives such as solar renewable energy credits (SRECs) and feed-in tariffs (FITs) over the life of the system.

> "The need for accurate shade reports and production estimates has increased tremendously, since residential lease and PPA companies are guaranteeing a production estimate for the life of the contract. Shading can greatly affect the kWh/kW of a system's output, and needs to be accurately accounted for at the time of contract."—Kareem Dabbagh, SunRun

An estimate of the shading at a particular site can be obtained by looking at aerial photos on the web or by using an aerial photo mapping service. The cost can be less than it is for rolling a truck, climbing on the roof and making measurements on-site, but the trade-off is accuracy. Remote measurements can be useful in the presale stage, but verifying and correcting the initial estimates with actual on-site measurements is critical to make an accurate production estimate.

The challenge for installers and investors is to strike the right balance between minimizing the cost of sales and maximizing the accuracy of the production forecast. If integrators spend too much time up front collecting and recording site measurements, optimizing the system design and refining the performance estimates, they risk wasted efforts in the event that the sale does not close. If they do not spend enough time, there is an elevated risk that the proposal will not represent reality. If the proposal underpredicts production, money is potentially left on the table. If it overpredicts production, and this is discovered *before* installation, the contract may need to be revised, resulting in extra work and an unhappy or lost customer. If it overpredicts production and this is not discovered until *after* installation, the installer may end up paying production guarantee penalties. Somebody always loses when production is not accurately predicted. Measurement accuracy reduces risk for all stakeholders.

Kevin Myers, fleet manager of Clean Power Finance, a provider of software solutions that connect installation professionals with financing options, expresses the solar financing company's point of view: "Performance guarantees go hand in hand with leases and PPAs, and these CONTINUED ON PAGE 70

guarantees must be built upon data and accurate site and system parameter inputs in the production estimation phase of the project."

The relationship between site measurements and production estimates and guarantees is illustrated in Figure 3. Accurate on-site measurements can reduce the uncertainty inherent in estimates, guarantees and guard bands, increasing the sales bid's competitiveness and reducing the project's risk. The trade-off is increased time or measurement-tool cost and therefore increased sales costs.

There is no one formula that works in all cases to determine whether a sales proposal requires a presale on-site visit. Different installers have different business philosophies. Many installers always go on-site and make detailed measurements before generating a sales proposal so they know that they can actually build what the customer is signing up for. They also feel that the in-person customer contact makes closing the sale more likely, so the higher closing rate offsets the higher cost of obtaining the sale. Others try to win the sale without a site visit and then follow up with the detailed measurements later, accepting the risk that the site visit may uncover issues that force changes to the design. There are risk and reward trade-offs with either approach.

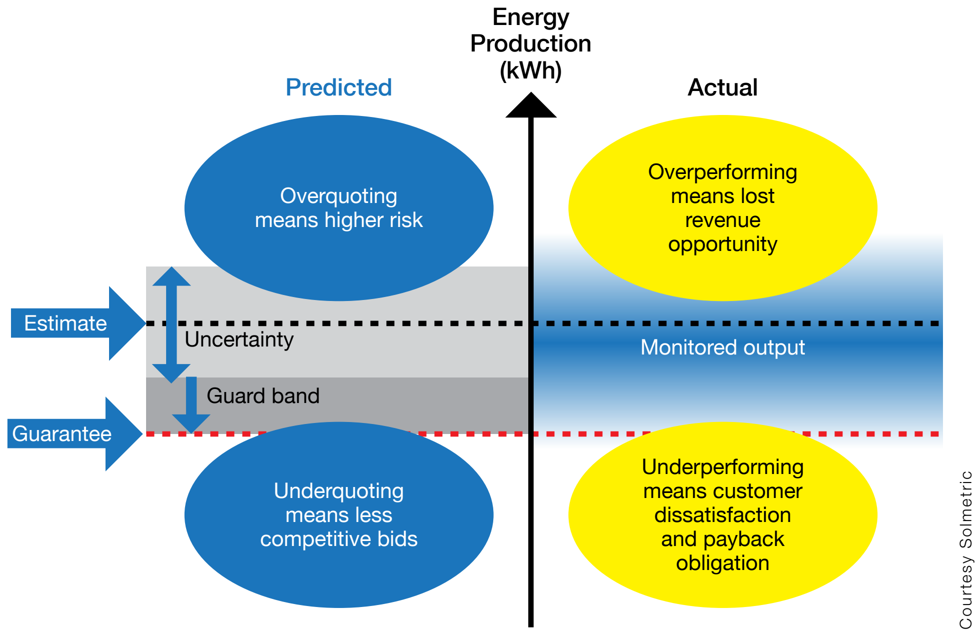


Figure 3 Inaccurate site measurements increase energy production estimation uncertainty. Overquoting production creates higher risk, while underquoting production results in less competitive bids and lost business opportunities.

"The use of Bing Maps, Google Earth and Pictometry has increased the efficiency of the sales process and has enabled solar sales firms like One Block Off the Grid to scale quickly into new markets. The use of aerial images does not impact the need for measurements on-site, however, because there still needs to be a verification process."

—Ryan Mazelli, One Block Off the Grid

"We are now able to sell or lease a system before visiting the house," comments Mateo Williford, a technologist at Sungevity, a solar lease provider. "Once a system is sold, we do a site visit. It is important that the on-site measurements are accurate so that we can confirm the system that we designed remotely." Jerry Shafer, CEO of Affinity Energy, a PV and solar heating integrator based in Windsor, California, advocates doing a site visit before selling the system. "There is no substitute for getting your feet on the site and looking for yourself," he says.

REMOTE EVALUATIONS VIA ONLINE IMAGERY

The widespread availability of aerial images from Google and Bing brings new tools to the solar sales process (see Resources). Integrators can use aerial images to determine approximate roof size and identify any showstoppers before visiting the site. In addition to aerial images, a variety of related services are available to help solar firms prospect, qualify and develop solar opportunities.

"It's typical for contractors to pull up imagery like Google Earth while on the phone with a client," states Brian Farhi, vice president of marketing and business development for SolarNexus, a supplier of software for solar business and operations management. "This provides a first pass at whether a roof is suitable," he continues, CONTINUED ON PAGE 72

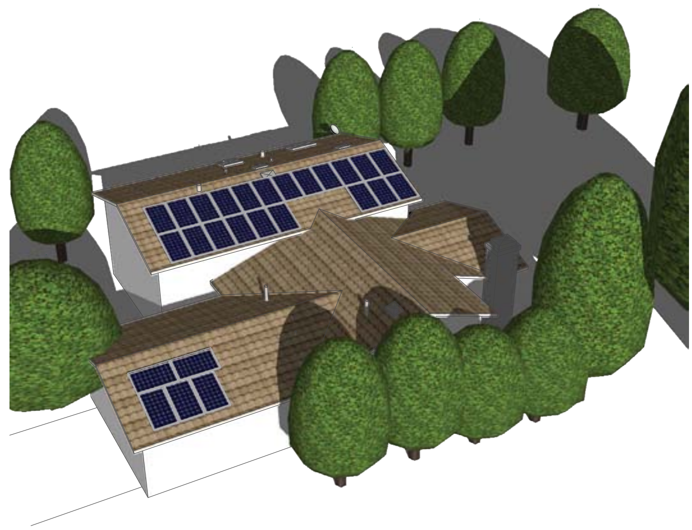
Online Tools for Roof Measurement and Layout

A variety of online tools can help users perform basic and advanced system sizing, array layout and in some cases energy production estimates. These tools give users the ability to make measurements on top of the aerial images.

Clean Power Finance (CPF). CPF Tools is an advanced solar proposal service with a roof measurement tool that characterizes roof shape, dimensions, tilt and azimuth. Additional features enable string sizing, array layout and financial modeling.

Google SketchUp. This online 3D drawing program provides a complete CAD environment, a rich library of images and advanced capabilities for shade visualization. Solar software suppliers have added a variety of capabilities by developing SketchUp plug-ins to enable drawing buildings and obstructions. Examples include Bright Harvest Solar and Skelion. In addition, Google Building Maker enables convenient drawing of a 3D building. (This is currently available in only some locations.)

In My Backyard (IMBY). Developed by the National Renewable Energy Laboratory, IMBY is a solar simulation tool that allows the definition of array area on an ortho image, and then enables basic PV system calculations including energy production modeling.



Courtesy Bright Harvest Solar

3D visualization Solar software providers like Bright Harvest Solar have developed free plug-ins that can be used for preliminary array layout within the Google SketchUp 3D drawing environment. Bright Harvest also offers more-detailed roof and array drawings and layout modeling for a fee.

"and allows the contractor to ask the customer some targeted questions to rule potential designs in or out. However, an onsite assessment is eventually necessary prior to finalizing any designs, since imagery can be out-of-date or can fail to show all the necessary details."

Common image perspectives. Online images are available in different forms and resolutions depending on a site's location. The following are the three most commonly used.

- **Orthophotos:** Often referred to as *ortho images* (see Figure 4, p. 74), orthophotos are projected onto a map to appear vertically overhead from all locations on the map. This imagery is available throughout the US, but image quality varies.
- **Oblique images:** These images are taken from off-vertical angles and from multiple directions, as shown in Figure 4. Currently, Bing Maps offers free oblique images from north, east, south and west perspectives for the entire US.
- **Street-view images:** As the name implies, street views are photos taken from public streets. These images have high resolution where imagery is available, but the views and visual access to some buildings may be limited. An example street view is shown in Figure 4.

Roof dimensions. An accurate measurement of roof dimensions is key to sizing a PV system and planning the installation. The most important parameters are the length, width, azimuth and tilt of the various roof surfaces. Length and width determine how many rows and columns of modules fit in the available space. Area is calculated from length and width and used to estimate maximum array capacity. Due to the limited resolution of most free aerial imagery, including ortho and oblique images, it is often difficult to resolve the exact locations of roof valleys and ridges. It can also be challenging to resolve vent pipes and utility service penetrations versus debris, discolored shingles or roof features. Due to these limitations, roof dimensions developed from aerial imagery typically have an accuracy of approximately ± 1 foot for a surface that is parallel to the ground.

When using ortho images to determine roof dimensions, measurements must be corrected CONTINUED ON PAGE 74

Courtesy Solmetric (4)

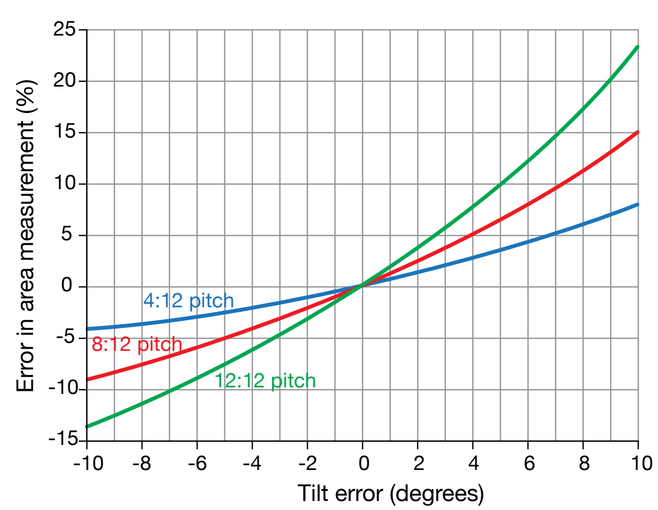
Figure 4 Common aerial image perspectives include orthophotos (top left), oblique (top right) and street view (bottom). Each perspective can assist sales and design teams and lower project acquisition costs via remote site evaluation.

according to the cosine of the tilt, since the area of a tilted roof is actually larger than it appears in an image taken from directly overhead. The accuracy of the roof dimensions therefore depends on the accuracy of the tilt used in the calculation. Figure 5 shows how error in the tilt creates errors in the area measurement, depending on the roof pitch. This error can dramatically impact system design in situations that have limited roof area, such as where a row of modules just barely fits—or in reality does not fit. Measuring tilt on-site with an inclinometer is more accurate than doing so from aerial images.

To get improved accuracy from aerial imagery, the roof can be analyzed using oblique views. With the right CAD software tools, an operator can measure the roof from multiple angles and create an accurate model. Using multiple images and incorporating calculations for specific roof types enables operators to overconstrain the geometry equations and improve the accuracy of the roof model.

Annual insolation. Tilt and azimuth are factors in determining the annual insolation for a fixed array in a given location, such as Sacramento, California, as illustrated in Figure 6 (p. 76). Note that insolation does not vary significantly with small changes in tilt, so approximate tilt numbers are usually acceptable for initial energy production estimates. The azimuth, sometimes referred to as the *heading* of the roof, also factors into the insolation and can be measured using online tools such as the Solmetric Roof Azimuth Tool (see Resources) as shown in Figure 7 (p. 77). Measuring roof azimuth via aerial images can often be more accurate and reliable than on-site measurement because nearby ferrous metals in building frames or rooftops can cause interference that results in errors in the compass reading. CONTINUED ON PAGE 76

Figure 5 When using ortho images to determine roof dimensions, errors in roof tilt can dramatically impact the accuracy of the calculated roof areas. This graph illustrates the effect that inaccurate tilt measurements have on area calculation accuracy.



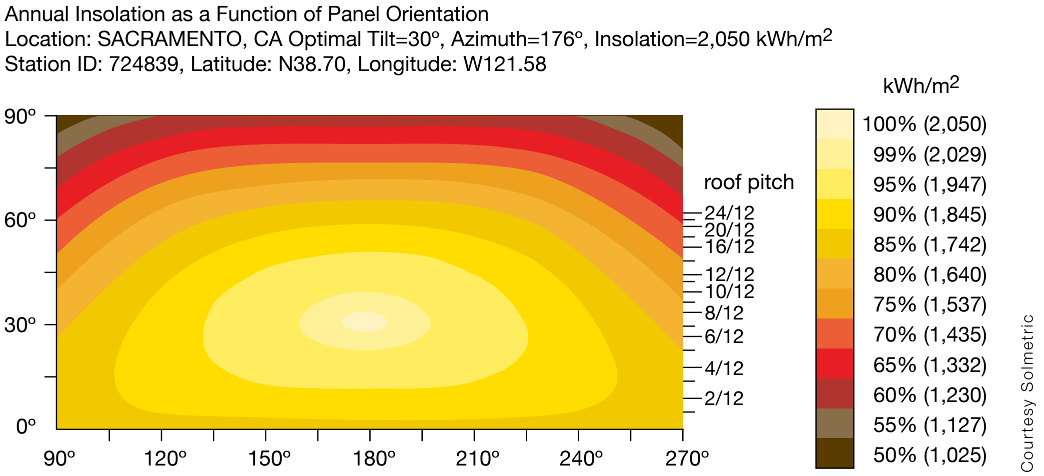
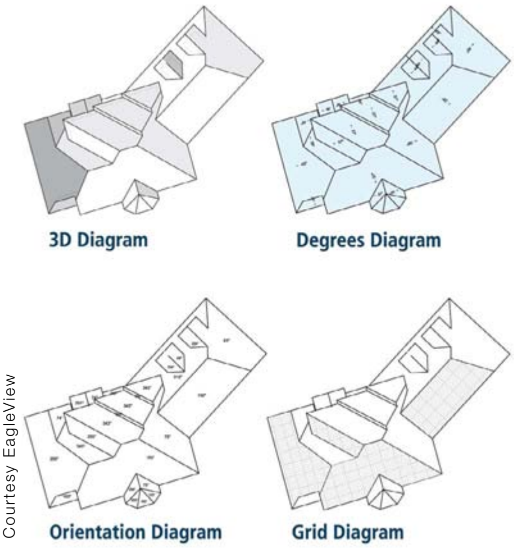


Figure 6 Tilt and azimuth are two variables used to determine annual insolation for a given site. This insolation map for Sacramento, CA, shows that insolation values do not vary significantly with small changes in tilt. While small errors in tilt measurements can have a significant impact on roof area calculations, they do not have a significant impact on energy production estimates.

Modeling approaches. CAD modeling requires a considerable investment in software tools, training and dedicated personnel. This may be a significant hurdle for many installers, who may instead opt to use a simpler tool in the presales phase (see "Online Tools for Roof Measurement and Layout," p. 72). Other installers may choose to use the services of an outside firm. Roof-modeling service providers often present analysis and reports with a 1- to 2-day turnaround and a per-building or per-site fee. Companies offering these services include Aerialogics, Bright Harvest Solar, EagleView Technologies, Pictometry and Precigeo (see Resources). Their reports include detailed roof dimensions and angles, as shown in Figure 8. Image resolution limitations make it difficult to identify gutters, vents and other small on-roof features, which remain a challenge to roof-mapping and analysis providers.

Courtesy Solmetric

Figure 7 Measuring roof azimuth via aerial images can be more accurate than on-site measurements. The latter can be affected by ferrous material in the building's roof or frame. The Solmetric Roof Azimuth Tool shown here is one option for determining roof azimuth remotely.



Courtesy EagleView

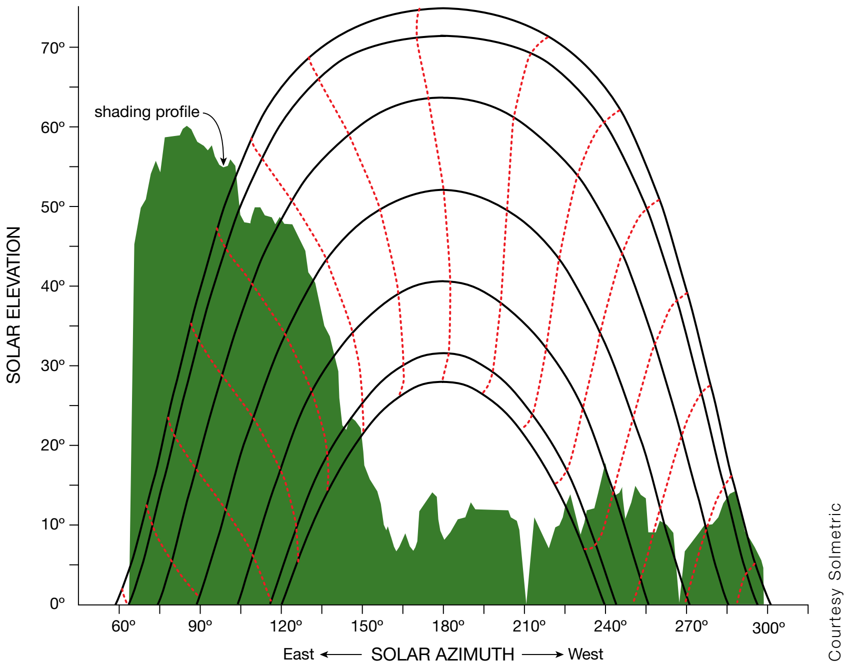
Figure 8 Roof modeling services provide cost-effective reports that contain an array of site specific information such as roof dimensions, azimuth and tilt values, 3D shadow maps and array layout diagrams.

In some cases, professional roofing reports include solar insolation analysis across the roof surface. Shade estimates and insolation charts prepared in this way often do a good job of characterizing the effects of adjacent roof surfaces or dormers, provided the modeling is done correctly. Some roof-modeling services attempt to model shade from nearby trees or buildings, although this has proved difficult in practice. Due to limited image resolution and the inability to overconstrain the CAD problem for a tree model, accuracy is poor for trees and other off-roof obstructions such as utility poles. In addition, images may be out of date and may not account for recent developments such as new construction and tree growth. Seasonal variations, such as those presented by deciduous trees, are difficult to model accurately with the available images because tree branches cannot be adequately resolved.

Sun Paths and Shade Impacts

The sun's azimuth and elevation angle relative to the horizon vary with the time of day and year. Obstructions that overlap with the sun's path cause shade during the time and month when that overlap occurs. Shading has a disproportionate impact on PV production, reducing a system's output power up to 30 times more than the relative size of the shadow on the array, according to Chris Deline, an engineer at the National Renewable Energy Laboratory (NREL). The lopsided nature of this dependency comes from the fact that cells are connected in series and that shading a substantial portion of just one cell is enough to trigger the associated bypass diode, temporarily eliminating the production of that module substring.

Optimizing string configurations relative to shading objects can mitigate their effects to some degree. Microinverters and dc power optimizers provide MPPT at the module level, which helps reduce shade impacts. However, a shaded module, regardless of whether it has per-module MPPT, produces less energy and therefore is a less valuable asset. Ryan Mazelli, senior solar advisor for One Block Off the Grid, a collective system purchasing provider, comments: "Requirements for shade measurements should not change if systems utilize microinverters, power optimizers or ac modules. What these products achieve is slightly better performance in partial shade conditions. Shade is shade, and a panel in complete shade is not going to produce any power." Installers and investors should not underestimate the importance of accurate shade measurements and mitigation approaches, regardless of the technology employed.



Shading profile Accurate shade measurements capture the sun's elevation angle and azimuth throughout the year and enable system designers to optimize array layout regardless of the power conversion technology used.

ON-SITE MEASUREMENTS AND EVALUATIONS

Although analysis using aerial imagery is increasingly useful in the early sales process, site visits provide critical information for solar installation companies. Being on-site enables sales representatives, auditors and designers to capture accurate dimensions and spot obstructions that may not have been apparent from aerial photos. Vent pipes, for example, are difficult to resolve in most aerial images and can significantly impact where modules can be placed.

Once on-site, you can verify roof dimensions and the location of obstructions such as skylights and vent pipes by using a tape measure, wheel or laser range finder. Tilt angles can be verified with an inclinometer with accuracies within 1 to 2 degrees. On rough roof surfaces, such as architectural shingles, tilt measurement accuracy can be improved by extending the footprint of the inclinometer: Place it on a length of wood or measure tilt on a rafter extending under the eave.

Shade measurements are always more accurate when made on-site using a tool such as the Solar Pathfinder or the Solmetric SunEye. These tools take into account everything within the array's field of view that can cause a shadow, from distant mountains to nearby trees to utility wires. They see what the array sees and correctly capture the current size of trees and other obstructions. They also enable the user to make measurements at the locations where the modules will be installed, such as 6 inches off the roof for a flush-mount system. (For a comprehensive review of CONTINUED ON PAGE 82

System Performance Measurements

Currently, solar lease and PPA financial vehicles are driving the residential market in many states. For example, according to Clean Power Finance, 55% of the residential systems installed in California in 2011 were financed. This number rose to a staggering 80% for the month of December 2011. System performance guarantees are a standard component in financed systems, and increased attention is being paid to system commissioning and ongoing performance measurements as a result.

The performance verification process can be separated into two phases. Phase one includes commissioning, when performance should be verified and documented to establish an initial benchmark for the system. Phase two covers the ongoing monitoring of the system over its lifetime, which is typically performed remotely. When systems are leased or financed, this phase is important to ensure that customer expectations and performance guarantees are met. "We can verify systems on-site through voltage, irradiance and temperature measurements," states Sungevity's Williford. "Through remote monitoring, we have diagnostic tools that allow us to determine if a system is performing as expected."

At the time of PV system installation, all stakeholders benefit from a comprehensive and well-documented system commissioning and performance verification procedure. (See "PV System Commissioning," October/November 2009, *SolarPro* magazine.) While commissioning residential systems is a straightforward process compared to commissioning commercial or utility-scale projects, its importance should not be undervalued. Proper commissioning is an essential aspect of limiting risk over the life of systems of any scale.

Jerry Shafer, CEO of Affinity Energy, confirms the importance of performance verification at the time of system commissioning. "We develop an as-built data sheet for the system to use as a starting point for the module and/or inverter output performance," he says. "It is a type of insurance policy for us and the investor to see the actual data. In the event of an output question, whether it is the result of dirt, shade, inverter operation or anything else that can affect performance, we know what we started with."

Industry best practices are evolving rapidly in the area of system commissioning and performance verification. Standard commissioning includes verifying system workmanship, operation, performance and acceptance documentation. Electrical testing including string open-circuit voltage, operating current and insulation resistance should be performed. Once the system is on line, system performance should be verified. A typical procedure for residential performance verification is to measure the module backsheet temperature and plane of array (POA) irradiance and simultaneously record the inverter power reading. Then a model is used to predict instantaneous power based on the irradiance, temperature, number of modules and other variables of the system. This number is compared to the inverter power that was recorded at the time of measurement. The ratio of actual power to expected power is often called the *power performance index.*

For systems using string or central inverters, more complete performance verification is possible through measurement of string I-V curves and comparisons with modeled performance (see "Field Applications for I-V Curve Tracers," August/September 2011, *SolarPro* magazine.) This approach is common for commercial and larger residential applications. An I-V curve tracer measures and quantifies how a string is performing compared with how it *should* be performing under current irradiance and temperature conditions. Confidence that a new system is performing optimally on day one is important to system owners, whether they are homeowners or finance providers.

> **"Accountability is a significant issue for this industry. By offering a performance guarantee for all our systems, we create our own accountability. I believe that this will become the standard within the industry."**
>
> **—Mateo Williford, Sungevity**

Beyond initial performance verification at the time of commissioning, ongoing performance monitoring is becoming more important industrywide, especially when residential leases and performance guarantees are in play. "Performance guarantees are becoming the norm, but they create a problem. In the past, a program would verify the performance expectation only one time after construction," states Kevin Wright, managing director of United Management and Consulting. "Under the new model with a PPA, performance is constantly evaluated," he adds. "In the end, this means system design and accurate site analysis are much more critical. Installation companies are married to the project for life." Clean Power Finance's Myers echoes Wright's comments: "Project underwriters are the new driver of best practices for financed systems and are accountable for maintaining prolonged system performance for the lifetime of the contract."

on-site shade measurements, see "Solar Site Evaluation," December/January 2009, *SolarPro* magazine.)

Leasing and PPA contracts typically guarantee a minimum level of performance. The contract may stipulate that the building owner is responsible for controlling shading. If a system begins to underperform after several years of operation, shading may be suspected. New on-site measurements may be required for comparison with the original measurements made when the system was installed. Accurate and repeatable solar access measurements can identify tree growth that may cause performance reductions.

To allow repetition of an on-site shade measurement years later, most likely by a different operator, it is critical to identify the precise physical location on the roof where each measurement was taken, since the solar access is different at different locations. Limitations of instrumentation accuracy and on-site measurement accuracy can both contribute to uncertainty in shade measurements. Dedicated shade measurement tools like the Solmetric SunEye are factory calibrated for precise operation of the camera and lens, as well as the compass and tilt sensors. The angle accuracy after calibration is typically less than 1° azimuth and 1° elevation. To facilitate accurate positioning of the shade profile skylines, the Solmetric SunEye measurement locations can be pinpointed on an aerial ortho image with the recent addition of a skyline-mapping feature, as illustrated in Figure 9. These measurements can be stored securely online and then used as a reference for future shade measurement comparisons.

Courtesy Solmetric

Figure 9 On-site shade measurements may need to be repeated at some point if a system is underperforming and shading from new vegetation growth is suspected. Solmetric's skyline mapping tool (shown here) allows the user to drag icons representing skyline locations to the exact location where they were taken and store the measurements and locations online. This allows the measurements to be repeated and compared to original measurements at a future date.

Other Trends to Watch

In addition to the tools and techniques I have discussed, other trends and developments are having an impact on the industry and will continue to do so in the coming years. Tablet computers and smartphones are becoming more capable and affordable, allowing users to automate and simplify many tasks on-site, including data gathering, proposals, audits, inspections and other functions. Data collected on-site, including shade measurements and performance verification data, will increasingly be securely stored online in the cloud, allowing streamlined access by the appropriate stakeholders. The solar industry will likely continue to benefit from business models and tools that have been developed in the more time-tested construction market.

Due in part to the increased availability and sophistication of financing options, the residential solar market is expanding rapidly. With this expansion comes more focus on system performance and on costs at every point in the system life cycle. Powerful web-based tools are enabling remote preliminary evaluations of solar sites and, coupled with accurate on-site measurement tools, are giving installers the ability to find the right balance between cost, time, risk and ROI. Whether on-site, online or both, measurement tools and techniques are evolving at a rapid pace to help meet the needs of a dynamic industry.

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