Analysis of Solar Census Remote Solar Access Value Calculation Methodology

J. Nangle, J. Dean, and O. VanGeet
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Technical Report
NREL/TP-7A40-63098
March 2015

Contract No. DE-AC36-08GO28308

Analysis of Solar Census Remote Solar Access Value Calculation Methodology

J. Nangle, J. Dean, and O. VanGeet
National Renewable Energy Laboratory

Prepared under Task No. PV10.IN27

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-7A40-63098
March 2015

Contract No. DE-AC36-08GO28308

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at http://www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) photo by Pat Corkery, NREL 16416, photo from SunEdison, NREL 17423, photo by Pat Corkery, NREL 16560, photo by Dennis Schroeder, NREL 17613, photo by Dean Armstrong, NREL 17436, photo by Pat Corkery, NREL 17721.

NREL prints on paper that contains recycled content.

Acknowledgments

The authors would like to thank the team at Solar Census for providing their data for analysis. In addition, the authors appreciate the support of the U.S. Department of Energy SunShot Incubator Program for making funding available to complete this analysis.

List of Acronyms

CI	Confidence Interval
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
SAV	Solar Access Value

Executive Summary

The costs of photovoltaic (PV) system hardware (PV panels, inverters, racking, etc.) have fallen dramatically over the past few years. Nonhardware (soft) costs, however, have failed to keep pace with the decrease in hardware costs, and soft costs have become a major driver of U.S. PV system prices. Upfront or “sunken” customer acquisition costs make up a portion of an installation’s soft costs and can be addressed through software solutions that aim to streamline sales and system design aspects of customer acquisition. One of the key soft costs associated with sales and system design is collecting information on solar access for a particular site. Solar access, reported in solar access values (SAVs), is a measurement of the available clear sky over a site and is used to characterize the impacts of local shading objects. Historically, onsite shading studies have been required to characterize the SAV of the proposed array and determine the potential energy production of a photovoltaic system.

Solar Census has developed an innovative method of remotely calculating solar access for any location in the United States. Having this information readily available, requiring only a location address, has the potential to lower a major component of PV system soft costs, and overall system installation costs, making systems more affordable.

With support from the U.S. Department of Energy SunShot Incubator Program, Solar Census and the National Renewable Energy Laboratory have analyzed the accuracy of the Solar Census methodology using data from four houses in the Los Angeles, California area. This study focused on analyzing the stastical differences in the Solmetric SunEye shade tool readings and the remote Solar Census readings. A reading was taken at eleven different locations at each house. The Solar Census tool produced annual average and seasonal average SAVs at each location, as well as monthly average SAVs for each location.

The two one-sided test (TOST) method was used to evaluate the data for statistical and practical equivalence. The TOST method incorporates an equivalence interval as a test for practical equivalence. If the mean and confidence interval (CI) bounds of a data sample fall completely within the equivalence interval, then the differences in SunEye and Solar Census data can be considered statistically and practically equivalent. A more detailed analysis discussion with all numeric values is included in Section 2.2.

The data were analyzed on three temporal bases: annual, seasonal, and monthly. The data were analyzed across the entire data set and on a house-by-house basis. The house-by-house analysis used the monthly SAV data for each house, and the temporal analysis used the data for each time section (i.e., each month) over all the houses.

Solar Census conducted a survey of PV system installers to determine an acceptable equivalence interval. An interval of ±5 SAVs was determined from the survey, but an interval of ±3 SAVs was also tested. The analysis indicates that the Solar Census method is equivalent to the SunEye readings within a range of ±3 SAVs on an annual and seasonal (Table 1) basis.

Table 1: Annual and Seasonal Equivalence Tests

Equivalence Interval	Annual	Summer	Winter
±3 SAV	Yes	Yes	Yes
±5 SAV	Yes	Yes	Yes
±10 SAV	Yes	Yes	Yes

Table 2 also indicates a similar equivalence in the monthly analysis. This analysis used the data for each month from all of the houses. The mean difference and CI for each month fell within ±3 SAVs except February [mean = 2.40, CI = (0.03, 4.76)] and December [mean = 1.26, CI = (-1.53, 4.04)]. However, the mean difference in readings for all months fell within the ±5 SAV interval determined by the installer survey.

Table 2: Monthly Equivalence Tests

Equivalence Interval	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
±3 SAV	Yes	**No**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**No**
±5 SAV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
±10 SAV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Evaluating the data for the individual houses (Table 3) indicates that the measurements were again within ±3 SAVs with the exception of Houses 1 and 3, [mean = -3.92, CI = (-4.96, -2.89)] and [mean = 4.34, CI = (2.59, 6.09)], respectively.. The largest differences in the readings at this house occurred near domed structures on the roof (see Figure 4, labels C and E) and during the winter and fall months.

Table 3: House-by-House Analysis

Equivalence Interval	House 1	House 2	House 3	House 4
±3 SAV	**No**	Yes	**No**	Yes
±5 SAV	Yes	Yes	**No**	Yes
±10 SAV	Yes	Yes	Yes	Yes

This analysis indicates the potential of the Solar Census method to characterize the potential for PV installations at given locations. However, this analysis is based on a small sample size. To truly test the efficacy of the Solar Census method, a larger sample of measurements should be analyzed to test the method for consistency within the range of ±5 SAVs.

Table of Contents

List of Figures

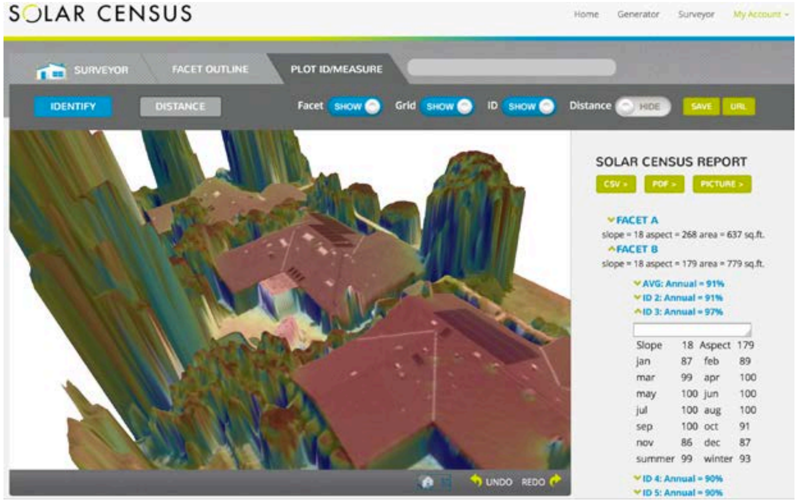
List of Tables

1 Introduction

Installed hardware costs for photovoltaic (PV) systems, i.e., for racking, panels, inverters, etc., have continued to drop over the last few years. However, the soft costs, i.e., of site surveys, system design, sales, marketing, and customer acquisition have not dropped at the same rate as the hardware costs. Upfront or “sunken” customer acquisition costs can be addressed through software solutions that aim to streamline sales and system design aspects of customer acquisition. One of the key soft costs associated with sales and system design is collecting information on solar access for a particular site. Solar access has historically been calculated as a part of the site survey. The survey is completed by measuring the degree of shading at different points on the roof or site location and is reported in terms of Solar Access Values (SAVs), which are the values of expected insolation for the site over a given time frame, relative to the same location with no shading. The completed survey analysis directly informs the system siting, location, design, and system economics, making the survey a critical component of the system design and installation.

The Solmetric SunEye shade tool is one of several potential devices available for taking SAV measurements. The device uses a wide-field camera to take an image of the sky at a given location. The device calculates the amount of the sky image that is obstructed by trees, utility poles, overhangs, etc., and reports the remaining clear sky as a percentage of the unobstructed image. The SunEye also takes into account the site latitude and longitude to calculate the trajectory of the sun over the course of a year. To take the readings, a technician must drive to the location and take multiple, direct readings, often from a rooftop location.

In contrast to SunEye readings, Solar Census Surveyor is an online tool that performs remote shading analysis and creates a fully articulated three-dimensional (3-D) model of the site. Surveyor uses state-of-the-art software and patented algorithms to provide a solar access value (SAV) for every 1-foot-by-1-foot section of the roof. The 3-D data, high-resolution imagery, and shade data are all preprocessed and stored in a database that can be instantly accessed by the solar community, given the address of the property.



SOLAR CENSUS REPORT

FACET A
slope = 18 aspect = 268 area = 637 sq.ft.
FACET B
slope = 18 aspect = 179 area = 779 sq.ft.
AVG: Annual = 91%
ID 2: Annual = 91%
ID 3: Annual = 97%

```
Slope    18  Aspect 179
jan      87  feb     89
mar      99  apr    100
may     100  jun    100
jul     100  aug    100
sep     100  oct     91
nov      86  dec     87
summer   99  winter  93
```

ID 4: Annual = 90%
ID 5: Annual = 90%

Figure 1: Example of Solar Census 3D data. Image courtesy of Solar Census.

To validate work completed by Solar Census as part of the U.S. Department of Energy (DOE) SunShot Incubator Program, DOE asked NREL to measure the relative accuracy of Surveyor compared with SunEye readings.

2 Analysis

The National Renewable Energy Laboratory (NREL), in partnership with Solar Census, and with support from the U.S. Department of Energy's SunShot Incubator Program, conducted onsite assessments at four residential homes to validate the accuracy of Solar Census' remote shading algorithms. Measurements were taken at 43 distinct points across four different homes in Northridge, California. Figure 2 illustrates the multiple measurement locations at each house location. Each letter represents a measurement location.

The sites in Northridge were selected because of their relative complexity compared to typical residential properties. The neighborhood features mature trees and complicated roof designs. Following identification of the exact measurement points on each roof, the annual, summer, winter, and monthly solar access values (SAVs) from two Solmetric SunEye devices were compared to the SAVs remotely generated by Solar Census. The shading of the four houses varied from heavily shaded to lightly shaded and included natural and manmade obstructions. NREL collected the SunEye SAVs independently. Solar Census calculated SAVs using Surveyor for identical points on the roof and provided the data to NREL. Solar Census had no knowledge of NREL's SunEye readings, enabling a blind study.

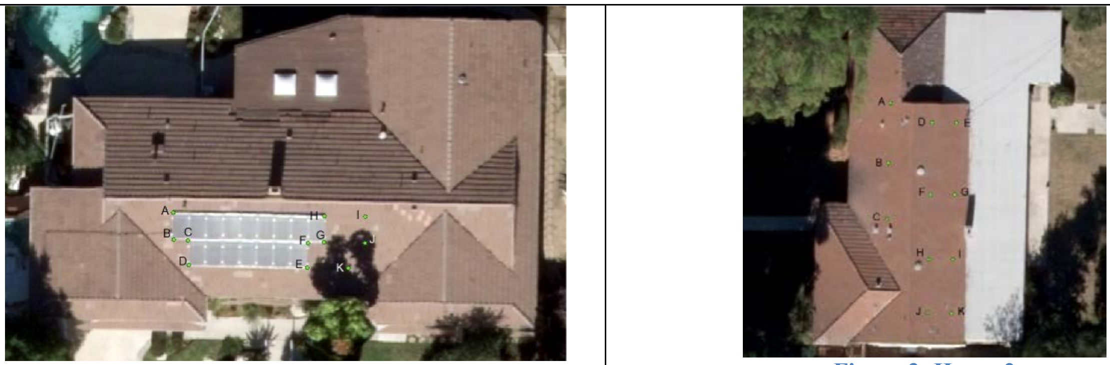


Figure 2: House 1

Figure 3: House 2

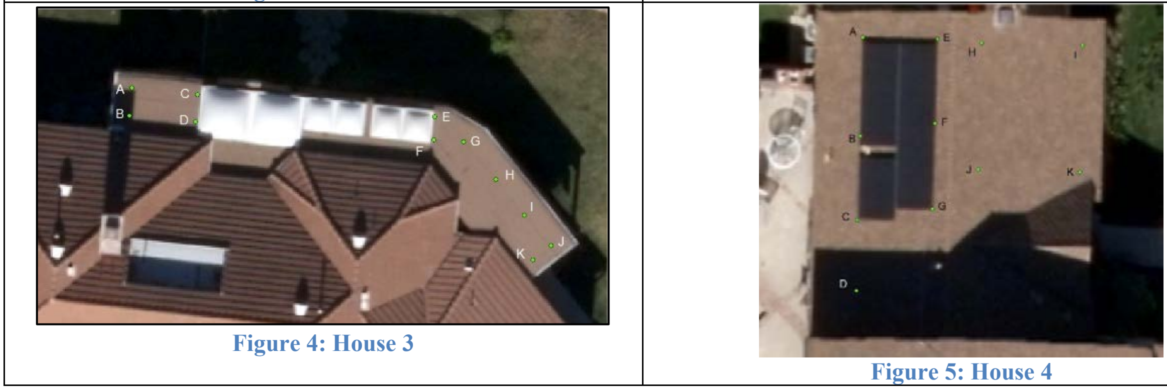


Figure 4: House 3

Figure 5: House 4

Figure 2-5: Example illustration of measurement locations. Images courtesy of Solar Census.

The data from the two SunEye devices was averaged to create a single SunEye value. The SunEye data were then subtracted from the Solar Census data for each of the measurement sites.

2.1 Method

The *t*-test is a standard method of making inferences on the mean value of a population of data, or the difference of means of paired data (Dunlop and Tamhane 2000). For the purposes of this discussion, the *t*-test is discussed in the context of inferring the population mean. The *t*-test proposes a null hypothesis of

$$H_0: \bar{x} = \mu$$

where μ is the population mean and $\bar{x}$ is the sample mean, with an alternative hypothesis of

$$H_1: \bar{x} \neq \mu$$

In this case, $\mu = 0$. The *t*-test is a straight-forward process involving calculating a test statistic, T, using

$$T = \frac{\bar{x} - \mu}{s/\sqrt{n}} \tag{1}$$

Where s is the sample standard deviation and n is the sample size. If $|T| \geq t$, where t is the critical value calculated from a Student's *t*-distribution, $t_{(\frac{\alpha}{2}, n-1)}$, then H_0 can be rejected at a 100(1-α)% confidence level and the sample mean is determined to be statistically different from the population mean.

A 100(1-α)% confidence interval, I, for the mean is calculated as:

$$I = \bar{x} \pm t_{\frac{\alpha}{2}, n-1} \frac{s}{\sqrt{n}} \tag{2}$$

Problems with this method can arise, though, if the sample sizes are small, or there is large variance in the data, leading to a smaller value for T. In the absence of any other evidence, it can be more difficult to determine if the samples are different. This situation can lead to mistakenly accepting H_0 and deciding that the sample means are equivalent. Another problem can arise when the sample standard deviations are small. In this case, the difference in the sample means can be statistically significant, but of little practical value. In other words, if the sample data have high precision, then a small difference in means may be statistically significant, but of no practical use (Limentani et al. 2005).

A different method, called the Two One-sided Test (TOST) method turns the analytical question around by proposing a null hypothesis of

$$H_0: \bar{x} \neq \mu \tag{3}$$

with an alternative hypothesis of

$$H_1 : \bar{x} = \mu \tag{4}$$

Now the default assumption is that of nonequivalence, and equivalence remains to be proven. The method also imposes a practical limit on the equivalence by specifying an *acceptance interval*, Θ. The acceptance interval allows for statistically significant differences in the means, but demonstrating equivalence on a practical scale.

A 100(1-2α)% confidence interval is then developed using α instead of $\alpha/2$. The reason for this change is that the TOST method is essentially using the upper tail of a *t*-distribution for the lower bound of the confidence interval, and the lower tail of another *t*-distribution for the upper bound.

$$I = \bar{x} \pm t_{2\alpha,n-1} \frac{s}{\sqrt{n}} \tag{5}$$

If $I \subset \Theta$, then the sample mean is *statistically* and *practically* equivalent to the population mean. Note that the confidence interval must be fully contained within the acceptance interval for equivalence to hold. The proposed hypotheses for the TOST method are then

$$H_0 : \ \bar{x} \leq \ \Theta_L \text{ or } \ \bar{x} \geq \Theta_U, \tag{6}$$

and an alternate hypothesis of

$$H_1 : \ \Theta_L < \ \bar{x} < \ \Theta_U \tag{7}$$

where θ_L and θ_U are the lower and upper bounds of the acceptance interval.

2.2 Results

The data set under analysis was the set of differences at each location between the Solar Census and SunEye measurements. The analysis was performed using the TOST method in aggregate, seasonal, monthly, and on a house-by-house basis to verify the efficacy of the Solar Census method. In determining the equivalence of the two measurement methods, an acceptance interval of ± 5 SAVs had been previously determined by Solar Census by surveying PV system installers. Out of 7 respondents, 4 found ±10 SAVs acceptable and 3 found ±5 SAVs acceptable. However, a ± 3 SAV level was also tested. A typical 95% confidence interval was calculated for the mean difference between Solar Census and SunEye data in each of the data sets. Table 1 lists the mean of the differences and the upper and lower confidence bounds for each data set.

Table 4: Seasonal Analysis

Seasonal Analysis			
	Annual	**Summer**	**Winter**
CI Upper Bound	-1.698	-1.256	-1.767
Mean	-0.691	-0.371	-0.661
CI Lower Bound	-2.705	-2.141	-2.874
Equivalence Tests			
±3 SAV	Yes	Yes	Yes
±5 SAV	Yes	Yes	Yes
±10 SAV	Yes	Yes	Yes

Each column in the table lists the mean difference and the upper and lower bounds of the confidence interval for each season. The columns under the equivalence tests indicate whether the Solar Census and SunEye methods are equivalent using the TOST method for different acceptance intervals. Because the mean differences fall within the 95% confidence intervals (CI Upper and Lower Bound rows), and the confidence intervals themselves fall completely within the tolerance interval of ± 5 SAVs, the Solar Census calculations are statistically and practically equivalent to the SunEye measurements. Moreover, the two datasets are equivalent with a tolerance interval of ± 3 SAVs, an even tighter interval than was originally deemed optimal for the analysis.

Because the Solar Census method is likely to be used to assess an individual location, a house-by-house analysis was also conducted. Table 2 contains the results of the house-by-house analysis. This analysis indicated a greater range of variability in the differences between the Solar Census calculations and the SunEye readings.

The data set for each house is the complete set of differences between SunEye measurements and Solar Census calculations for each roof location taken over the course of one year. Each data set had 132 points. The data for one roof location were removed from House 3 because of a satellite dish that had recently been added, leaving the data set with 120 data points. Figures 3-6 illustrate the distributions of the difference data for each house, along with the mean and standard deviation of each data set. All of the distributions appear to be approximately normally distributed with the exception of House 2 (Figure 4), which exhibits some left skewness, and House 3 (Figure 5), which exhibits some right skewness.

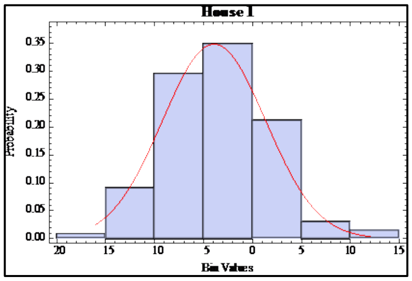


Figure 6: House 1 histogram and distribution ($\bar{x}$ = -3.924, σ = 5.268)

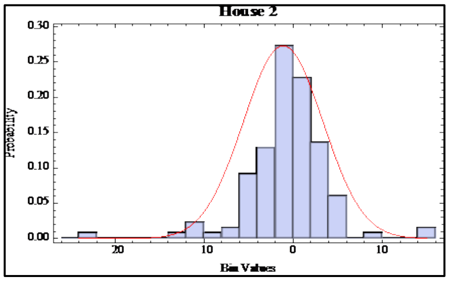


Figure 7: House 2 histogram and distribution ($\bar{x}$ = -1.114, σ = 4.466)

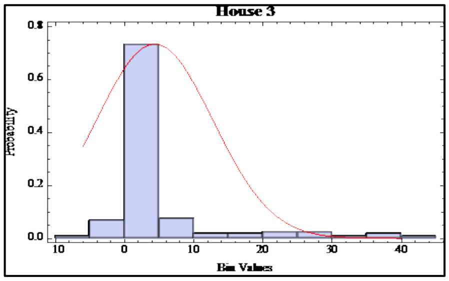


Figure 8: House 3 histogram and distribution ($\bar{x}$ = 4.342, σ = 8.450)

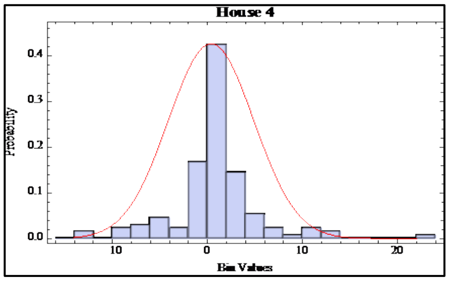


Figure 9: House 4 histogram and distribution ($\bar{x}$ = 0.386, σ = 4.494)

On an individual basis, the Solar Census method was still within the ± 5 SAV acceptance interval with the exception of House 3. The data for House 3 have a much wider dispersion than the other houses. The locations of the greatest discrepancies at House 3 are the edges of white domed structures on the roof. The discrepancies also peak in the winter and fall months, when the sun is closer to the horizon.

Table 5: House-by-House Analysis

House-by-House Analysis				
	House 1	**House 2**	**House 3**	**House 4**
CI Upper Bound	-2.89	-0.23	6.09	1.27
Mean	-3.92	-1.11	4.34	0.39
CI Lower Bound	-4.96	-2.00	2.59	-0.50
Equivalence Tests				
±3 SAV	No	Yes	No	Yes
±5 SAV	Yes	Yes	No	Yes
±10 SAV	Yes	Yes	Yes	Yes

Table 3 contains an analysis of monthly data taken over all of the houses. As with the annual, summer, and winter analysis, the monthly analysis shows that the Solar Census method is statistically and practically equivalent within ± 5 SAVs for all months. Only February and December indicated equivalence outside of ± 3 SAVs. Histogram and distribution plots are not included for the monthly analysis because the relatively small data sets (n = 43) did not yield informative plots.

Table 6: Monthly Analysis

Monthly Analysis												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
CI Upper Bound	2.79	4.76	1.39	0.77	0.78	0.32	0.28	-0.44	1.83	1.66	2.36	4.04
Mean	0.16	2.40	-0.70	-0.98	-0.02	-0.79	-0.84	-1.65	-0.44	-0.42	-0.14	1.26
CI Lower Bound	-2.47	0.03	-2.79	-2.72	-0.82	-1.90	-1.95	-2.86	-2.72	-2.49	-2.64	-1.53
Equivalence Tests												
±3 SAV	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
±5 SAV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
±10 SAV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

3 Potential for Reducing Soft Costs

Non-hardware (soft) costs have become a major driver of U.S. PV system prices, and aggressive soft-cost-reduction pathways must be developed to achieve the DOE SunShot Initiative's PV price targets. Upfront or "sunken" customer acquisition costs can be addressed through software solutions that aim to streamline sales and system design aspects of customer acquisition. Software solutions that automate portions of the sales and system design process can reduce overall customer acquisition costs. Through a previous study, NREL has estimated the soft cost reduction potential for solutions that address the sales-and-system-design part of the process. For software solutions, including remote site assessment and improved bid prep software, savings for a residential system (5 kW) are estimated to be \$.17/W at scale.[1] Although NREL has not independently certified the soft cost savings of the Solar Census Surveyor product, the estimated savings of this type of tool, deployed at market scale would be generally understood to impact soft costs to a similar degree. The automated CAD export capabilities of Surveyor will be investigated in an upcoming study. Additionally, there are likely several other applications for remotely and accurately generated SAVs that may have the potential to reduce soft costs in the area of consumer-targeting strategies.

Finally, while this analysis demonstrates the potential of the Solar Census Surveyor methodology, it is based on a small sample of data taken from houses in the same city. An analysis of a larger data set, composed of readings from multiple locations from around the country, is required to demonstrate the consistency of the Solar Census method within the defined acceptance levels.

---

[1] Non-Hardware ("Soft") Cost- Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013-2020, http://www.nrel.gov/docs/fy13osti/59155.pdf

References

Dunlop , Dorothy and Tamhane, Ajit. *Statistics and Data Analysis From Elementary to Intermediate*. 2000. Prentice Hall. Upper Saddle River, NJ.

Limentani, Giselle B., et al. "Beyond the t-test: Statistical Equivalence Testing." Analytical chemistry 77.11 (2005): 221-A.