SOLAR CENSUS

Internal Statistical Report of 3rd Party Verification

Two One-Sided Test to determine equivalency between Solmetric SunEye and Solar Census Surveyor

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ABSTRACT

Solar Census and the National Renewable Energy Laboratory (NREL) with support from the U.S. Department of Energy's SunShot Incubator program petitioned a study to determine the equivalence of measuring solar access values (SAVs) using the Solmetric SunEye, a handheld shade-measurement tool, and Solar Census Surveyor, a software-only shade-measurement tool. Two SunEyes were used to measure forty-three points on four houses in Northridge, California. The annual, summer and winter SAVs for each of the points were compared to SAVs produced by Surveyor. The differences of the paired data were analyzed to determine equivalence. A two one-sided test (TOST) was used with a range of scientific indifference of (-5, 5). The range of scientific indifference was determined by sampling solar installers to determine the acceptable difference between the two methods. Using a significance level of 0.025, a 95% confidence interval was created. The confidence interval of (-2.70457, -0.69078) fell entirely within the range of scientific indifference. Therefore, we conclude that calculating SAVs physically using a Solmetric SunEye or remotely using Solar Census Surveyor can be declared equivalent.

INTRODUCTION

The solar industry continues to grow consistently at more than 40% per year. While the hard costs (panels, inverters, racking, etc.) of a solar system have plummeted, the soft costs have been slow to follow the same trend and now make up 60% of the cost of a system. Customer acquisition alone totals more than 10% of total system costs which is comprised of expenses for system design, sales, marketing and advertising. The survey process creates large hurdles in the sales cycle and is at the same time indispensable. The shade analysis determines the solar potential of the rooftop. Cost quotes, system design, permitting and financing are all ultimately dependent on the solar potential of each and every installation. The solar potential is determined by measuring the degree of shading expected on particular points on a 24/7/365 basis. These shade calculations are reported in terms of solar access values (SAVs), which are the percentage of the solar insolation a position gets during a period of time divided by the total potential insolation of the same point with no shading.

More than 95% of shade analyses are performed using a Solmetric SunEye. To calculate the values the solar technician must drive to the residence, climb onto the roof and take measurements at various positions that are most likely to represent the corners of the proposed array. The technician must then manually adjust any errors within the SunEye software to determine the SAV for the each sampled position.

Solar Census Surveyor is an online tool that enables a complete 3D and shading analysis by remote. Surveyor leverages state-of-the-art software and patented algorithms to provide a solar access value for every foot. The 3D data, high resolution imagery and shade data is all preprocessed and stored in a database that can be accessed by installers instantly given only the location of query.

Solar Census and the National Renewable Energy Laboratory (NREL) with support from the U.S. Department of Energy's SunShot Incubator program decided to petition a study to determine if the method of measuring SAVs physically with a SunEye or remotely with Surveyor produced equivalent results. To determine if the two shade-measurement tools could be used interchangeably, SAVs were gathered at forty-three unique locations on four roofs in Northridge, California. The annual, summer and winter values from two SunEyes were compared to the SAV outputs from Surveyor for the same unique locations.

There are several ways to test equivalence. Perhaps the first that jumps to mind is to perform a two sample paired t-test with the goal of accepting the null hypothesis that there is no difference between the means. However, this approach has been proven false and is no longer acceptable.[1]

The most widely accepted and simplest equivalency test is a two one-sided test (TOST).[2] The hypotheses are

$$H_0: \mu_d < \theta_L \ \ or \ \ \mu_d > \theta_U$$
And
$$H_1: \theta_L < \ \mu_d < \theta_U$$

Where μ_d is the mean difference between the two methods, and the range of scientific indifference is (θ_L, θ_U). The range of scientific indifference is where the difference in the measurements using the two methods is acceptable. If the mean difference is within the range of scientific indifference, then the two methods can be considered equivalent. If the mean difference is outside the interval, then the two methods cannot be considered equivalent.

The TOST is essentially two tests, one to determine if the mean difference is below the lower bound of the range of scientific indifference, and another to determine if it is above the upper bound. If both of those hypotheses are rejected, then the mean difference is within the range of scientific indifference.

Determining a range of scientific indifference is a very important aspect of the TOST,[3] and lends credibility to the study. A previous report authored by Solar Census and issued to the Department of Energy sampled multiple groups of installers and designers to determine the range of difference that would be acceptable. They were asked what range was necessary in order to use the SunEye and Solar Census data interchangeably. The report generated a median response of ±10 and a minimum response of ±5. In order to prove acceptable to all installers and system designers, a range of scientific indifference of (-5, 5) was chosen.

In performing the TOST, or nearly any other statistical test, the mean difference outlined in the hypothesis is unknown. The mean sample difference is used to provide a point estimate for the true mean difference. However, sample statistics vary from sample to sample, so it is necessary to consider the distribution of all possible sample mean differences. These are distributed normally around the true mean difference which is unknown. To account for the variations in the sample statistics, confidence intervals can be calculated to provide an interval within which we are confident the true parameter lies. There are two methods for reporting the TOST outcome, a confidence interval and p-values. A confidence interval is easier to visualize and understand. In our TOST, we will use the confidence interval approach.

A confidence interval is calculated for the mean difference between the two methods. This gives an interval in which we are confident the true mean difference lies. If any part of the interval lies outside the range of scientific indifference, we cannot be confident the true mean difference is within the interval and thus we cannot be confident that the methods are equivalent.[2] However, if the entire confidence interval is within the range of scientific indifference, then we are confident the true mean difference is within the range. Therefore, we are confident the two methods are in fact equivalent.

METHOD

Through extensive canvasing, permission was obtained by Solar Census for accessing four roofs in Northridge, CA on Wednesday, February 18, 2014. Eleven locations were chosen on each rooftop. Their locations were carefully measured and photographed and are reported in Figures 1 through 4 in the Appendix. Before SunEye measurements were taken on the rooftop, Solar Census provided NREL with SAVs for each location determined by Surveyor.

An independent solar installer was hired by NREL to take readings using a SunEye. The installer used two SunEyes to take readings at each location. Great care was taken to stay as close to the predetermined measurements as possible, because in partially shaded areas a difference of a few inches can have a notable impact on the SAV.

NREL procured SunEye1 and Solar Census procured SunEye2. The SunEye images were edited to remove nonexistent shadows and add shadows were the SunEye failed to consider them. Upon agreement between Solar Census and NREL one of the points was removed due to the presence of a satellite dish that was not visible in the aerial image. The annual SAVs for each location are presented in Figure 5 for each SunEye and the Solar Census data. The mean was calculated at each location for the two SunEye measurements. The differences were then calculated between the Solar Census and the mean SunEye measurements and are reported in Figure 5. Figure 6 shows the histogram of the differences to illustrate the distribution. The differences were used in performing the TOST to determine equivalence.

ANALYSIS

The hypotheses we tested were

$$H_0: \mu_d < -5 \ \ or \ \ \mu_d > 5$$
And
$$H_1: -5 < \ \mu_d < 5$$

The level of significance (α) for this test was 0.025. TOST requires a confidence interval of $(1 - 2\alpha)\times 100\%$ to determine equivalence.[3] Therefore a 95% confidence interval was calculated using the formula

$$\bar{d} \pm t_{2\propto,n-1} \frac{s}{\sqrt{n}}$$

Where $\bar{d}$ is the mean sample difference, s is the sample standard deviation, n is the sample size, and $t_{2\propto,n-1}$ is the students t test statistic with a level of significance of $\propto$ and $n - 1$ degrees of freedom. The statistics are reported in Figure 7.

Figure 6

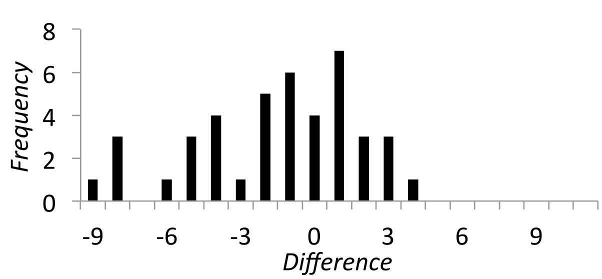
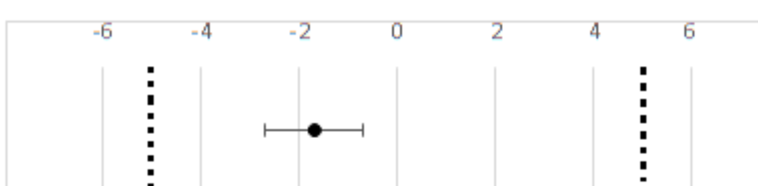


Figure 7

statistic	
$\bar{d}$	-1.69767
s	3.271703
$t_{2\propto,n-1}$	2.0181
n	43
95% CI	(-2.70457, -0.69078)

Figure 8



CONCLUSION

Figure 6 shows an approximately normal distribution of the differences between measurements. Using a significance level of 0.025, a 95% confidence interval was created. Figure 7 shows the 95% confidence interval was calculated to be (-2.70457, -0.69078). We can be 95% confident that the true mean difference between the two methods of calculating the SAV is within that interval. Figure 8 shows the interval in relation to the range of scientific indifference (-5,5) illustrated by dashes. The entire 95% confidence interval is within the range of scientific indifference. Therefore, we conclude that calculating SAVs physically using a Solmetric SunEye or remotely using Solar Census Surveyor can be declared equivalent.

Additional research should be done to compare SAVs on a wide range of rooftops and differing topological and geographical areas. Both the SunEye and Solar Census data adjust the sun's path and insolation based upon the region, but due diligence should be done to ensure the tools agree. When gathering the SAVs great care must be given to ensure precise location, as SAVs can vary dramatically in areas of shading gradient. Some issues arose in identifying the exact location because the distance measurements were taken from an aerial photograph where precision is difficult to obtain. Great care was taken to ensure the SunEye readings were accurate by manually adjusting the shade images, but this is a subjective process. Additionally, the SunEye method does not excel at measuring shade during leaf-off seasons of the year. This study was performed in February, it would be a benefit to reproduce this study in the summer when leaves are on the deciduous trees.

REFERENCES

(1) Hoenig, J.M. and Heisey, D.M. (2001) The abuse of power: the pervasive fallacy of power calculations for data analysis. The American Statistician. 55: 19–24

(2) Schuirmann, DJ (1987) A comparison of the two one-sided tests procedure and the power approach for assessing equivalence of average bioavailability. Journal of Pharmacokinetics and Biopharmaceutics. 15: 657-680

(3) Walker, E. and Nowacki, A.S. (2010) Understanding Equivalence and Noninferiority Testing. Journal of General Internal Medicine. 26(2): 192-196

APPENDIX

Figure 1

House 1	*location*	*description*
9814	A	Along roof edge, 2.5 ft down from edge corner
Lasaine Ave.	B	6.5 ft from apex, 16 ft from A
Los Angeles	C	6.5 ft from apex, 15 ft from B
CA 91325	D	4.75 ft from apex, 4.7 ft from north edge
	E	6.5 ft down from D
	F	4.75 ft from apex, 19.5 ft from D
	G	6.5 ft down from F
	H	4.75 ft from apex, 17.3 ft from F
	I	6.5 ft down from H
	J	4.75 ft from apex, 14.5 ft from H, 8.1 ft from south edge
	K	6.5 ft down from J

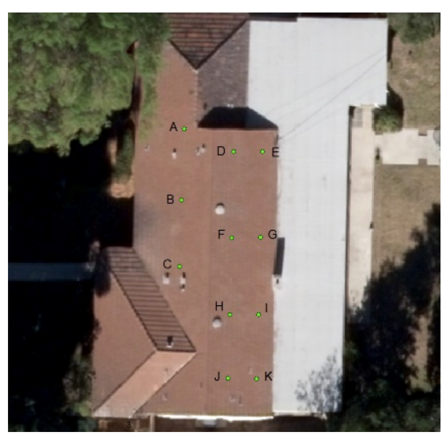


Figure 2

House 2	location	description
9815	A	NW corner of solar panels
Babbitt Ave.	B	12.75ft from A
Los Angeles	C	SW corner of solar panels
CA 91325	D	9ft from C, 5.75ft from west edge
	E	NE corner of solar panel
	F	11ft from E
	G	SE corner of solar panels
	H	4ft from north edge, 3.5ft from apex
	I	13ft down from H, 2.7ft from east edge
	J	3.5ft from apex, 16.25ft from H
	K	13ft down from J, 2.7ft from east edge

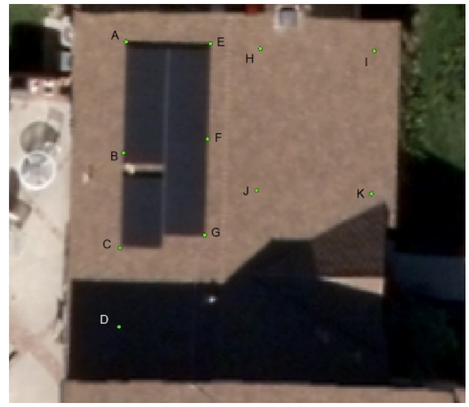


Figure 3

House 3	location	description
17123	A	2.25ft from North edge, 2.5ft from West edge
Labrador	B	2.25 ft from North edge
Los Angeles	C	3.75ft from C
CA 91325	D	2ft from edge
	E	3.25ft from E
	F	4.25ft from F, 3.75ft from edge
	G	3.75ft from edge, 7ft from G
	H	3.75 ft from edge, 6.5ft from H
	I	3.75 ft from West edge, 5.75 ft from I, 2ft from South edge
	J	3.25ft from J, 2ft from South edge

Figure 4

House 4	location	description
17339	A	NW corner of solar panels
Halsted	B	SW of top part of solar panels
Los Angeles	C	West concave vertex of solar panels
CA 91325	D	SW corner of solar panels
	E	SE corner of solar panels
	F	East concave vertex of solar panels
	G	SE of top part of solar panels
	H	NE corner of solar panels
	I	8ft from H
	J	8ft from G
	K	8ft from E

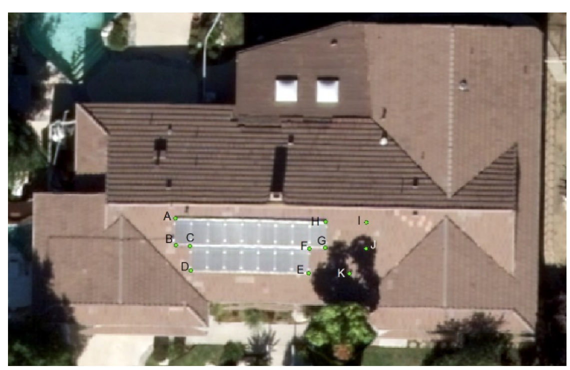


Figure 5

house	*loc*	*sc_ann*	*se1_ann*	*se2_ann*	*se_avg*	*sc-se*
9814 Lasaine Ave. CA 91325	A	69	72	72	72	-3
	B	76	85	84	84.5	-8.5
	C	74	83	81	82	-8
	D	68	72	72	72	-4
	E	66	70	70	70	-4
	F	73	78	78	78	-5
	G	71	76	76	76	-5
	H	71	78	77	77.5	-6.5
	I	70	75	75	75	-5
	J	72	76	76	76	-4
	K	70	71	72	71.5	-1.5
9815 Babbitt Ave. CA 91325	A	93	95	95	95	-2
	B	91	96	95	95.5	-4.5
	C	89	91	91	91	-2
	D	63	72	73	72.5	-9.5
	E	96	97	97	97	-1
	F	96	98	98	98	-2
	G	97	97	96	96.5	0.5
	H	97	95	94	94.5	2.5
	I	81	83	84	83.5	-2.5
	J	96	97	97	97	-1
	K	93	94	95	94.5	-1.5
17123 Labrador CA 91325	A	97	96	95	95.5	1.5
	~~B~~	~~92~~	~~79~~	~~82~~	~~80.5~~	~~11.5~~
	C	97	93	94	93.5	3.5
	D	95	92	92	92	3
	E	100	99	99	99	1
	F	99	97	96	96.5	2.5
	G	98	97	97	97	1
	H	98	97	97	97	1
	I	98	97	96	96.5	1.5
	J	98	98	96	97	1
	K	98	96		96	2
17339 Halsted CA 91325	A	99	98	98	98	1
	B	96	97	97	97	-1
	C	98	97	97	97	1
	D	96	96	96	96	0
	E	76	84	84	84	-8
	F	92	93	92	92.5	-0.5
	G	91	93	93	93	-2
	H	97	97	97	97	0
	I	96	96	96	96	0
	J	89	92	92	92	-3
	K	73	75	73	74	-1

