Counting on Solar: An Impact Evaluation of Solar PV Systems

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ABSTRACT

Energy Trust of Oregon offers incentives to residential and commercial utility customers for installing solar photovoltaic (PV) systems on their homes and buildings. The systems can be direct-owned or owned by a third party. In 2016, Energy Trust undertook an impact evaluation of systems installed from 2011-2015 to assess actual electricity production and understand reasons for variation in system performance relative to expectations.

Methods for assessing energy production involved surveys of program participants to collect system meter readings. The commercial surveys were followed by site visits after analysis of survey data showed unusually low realization rates for commercial systems. In addition to survey data for residential systems, production data were obtained from two installation firms for a large number of third-party-owned residential systems, providing another check on actual generation.

Realization rates were analyzed by sector, ownership type, installation year, geographic region, total solar resource fraction (TSRF) and system inverter type. Overall, realization rates were high – 106% for commercial systems and 117-121% for residential systems. Realization rates were also consistently higher for systems with microinverters than for those with string inverters. An online survey was found to be a low-cost way to collect sufficient data from residential customers, but not from commercial customers, where site visits or access to online production system data provide more accurate information on electricity production.

Introduction

Energy Trust of Oregon is an independent nonprofit organization that provides more than 1.5 million utility customers in Oregon and southwest Washington with energy-efficiency and renewable energy information, services, cash incentives and referrals to qualified trade ally contractors. Since 2002, Energy Trust has incentivized the installation of 122 average megawatts (aMW) of small-scale renewable energy systems, including over 11,000 solar projects. Energy Trust of Oregon offers incentives to residential and commercial utility customers for installing grid-connected solar photovoltaic (PV) systems on their homes and buildings. The systems can be direct-owned or owned by a third party.

Commercial PV Systems

Since 2003, Energy Trust has provided incentives for over 1,000 commercial systems (Figure 1). The annual number of systems installed through the program peaked in 2011, and after a notable drop in 2013, has returned to levels seen between 2008 and 2012.[1] About 90% of commercial systems have been direct-owned. Third-party ownership has never represented a significant share of commercial sector solar PV systems.

[1] An Oregon state tax credit for commercial businesses installing renewable energy systems expired at the end of 2012, resulting in a sharp drop in installations in 2013 and 2014.

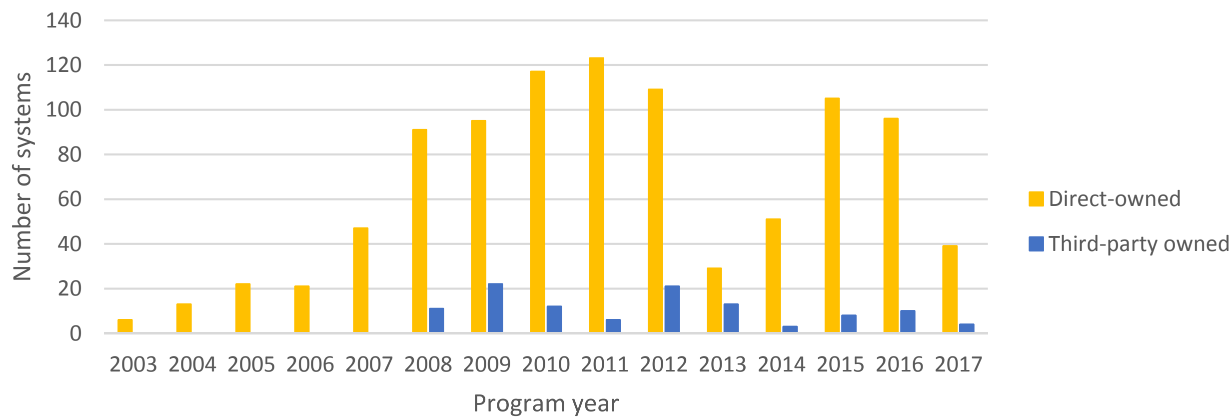

Figure 1. Energy Trust commercial PV systems by program year and ownership type, 2003-2017. Data for 2017 are through June 15.

Residential PV Systems

Energy Trust has also incentivized more than 6,000 direct-owned residential systems, and 3,000 third-party-owned residential systems (Figure 2). The vast majority of system installations have taken place since 2009. The third-party ownership model began to take off in 2011, peaked in 2015 and has since almost disappeared, due to the exit of players from the third-party market; but from 2012 through 2014, third-party-owned systems outnumbered direct-owned systems.

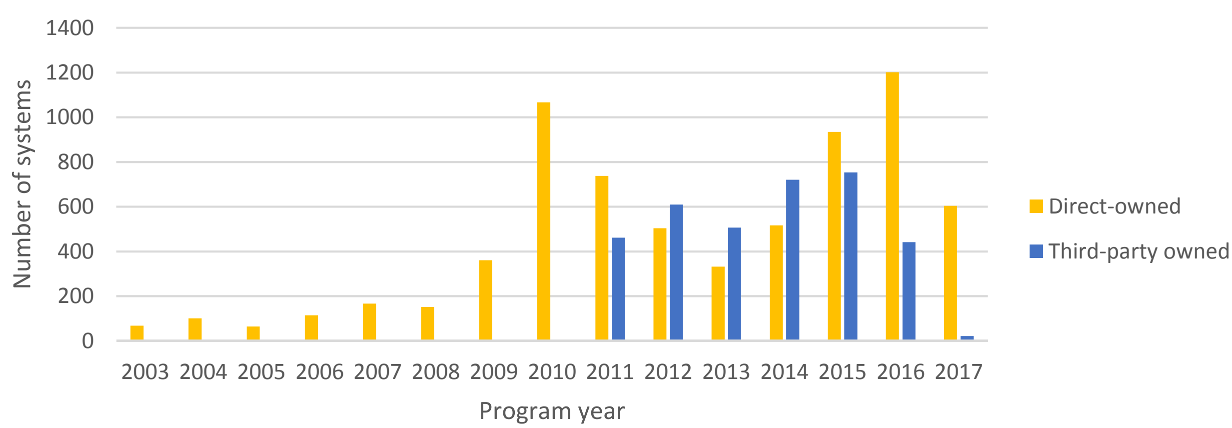

Figure 2. Energy Trust residential PV systems by program year and ownership type, 2003-2017. Data for 2017 are through June 15.

Decreasing PV System Costs

The dramatic increase in the number of systems over the last decade, especially residential systems, is closely related to the steady decrease in installed cost of solar, by about 50% from 2009 to 2015. If installed cost continues to decline at a similar rate, electricity generated by distributed solar PV may soon have no above-market cost, which is used to justify and set incentives levels in Oregon.[2]

As lower prices exert downward pressure on above-market cost, the precision of solar generation estimates becomes more important in the decision to continue offering financial incentives or concentrate

[2] Above-market costs are the difference between what the power produced by a project is worth at standard rates and what it actually costs to produce the power from the project.

program resources on other strategies to support the solar PV market. Despite the greater need for accurate information on system performance, it is not clear whether programs are attempting to validate the performance of systems or accepting ex ante estimates of generation at face value.

A (Very) Brief History of Solar PV Impact Evaluations

Published impact evaluations of solar PV systems are rare. Three studies generally confirm the reliability of solar PV generation. Weatherford, Merkt and Goodman (2013) presented two case studies of PV program impacts: one in California achieving a 98% realization rate, and a New York program with realization rates of 116% for residential systems and 120% for commercial. Connecticut Green Bank evaluated residential PV systems installed in 2012 and 2013. Systems were a mix of direct-owned and third-party-owned.[3] The overall realization rate for systems was 105% (Shaw et al. 2015). NYSERDA conducted an evaluation of residential and commercial PV projects installed between 2008 and 2011 and found realization rates of 112% and 110%, respectively (Cadmus 2013).

In an IEPEC paper on the NYSERDA study results, Shaw et al. (2013) cited best practices for evaluating solar PV projects. Key recommendations were to ensure evaluation of performance occurs at least a year after system installation to obtain performance across seasons, and to weather-normalize site generation using data from a weather station in close proximity to the site. The authors also noted causes of high realization rates that likely apply to systems installed via other programs throughout the U.S., including Oregon. The first cause noted was overly conservative treatment of shading in ex ante production estimates, whereby typical site analysis tools overestimate shading losses. The authors note that this is particularly significant for cloudy locations where diffuse solar radiation makes up a larger share of total radiation, a description that certainly fits Oregon's Portland Metro area, Willamette Valley and Coast regions. A second noted cause of high PV realization rates was overestimation of inverter losses, based on older inverter technology. A third cause of high realization rates, which would only apply well in Central and Eastern Oregon (not in the Portland Metro area), is the additional solar resource created by the reflection of sunlight off snow in the winter.

Another study looks at the difference in performance of string inverters and microinverters. String inverters accept input from a series of 10 to 15 PV modules, and while they are easy to wire and operate with high efficiency in unshaded conditions, one shaded module in a string may reduce the output of other modules attached to it. Microinverters are deployed on a single module or a pair of modules, and because each module is independent, arrays with partial shading can perform better than they would with a string inverter. While string inverters are more common and less costly, microinverters have seen increasing market share in the last several years. In a direct comparison of the two inverter types, Lee and Raichle (2012) found microinverters produced 20% more power compared to string inverters in arrays with no shade and 26% more power in arrays with partial shading.

Estimating Solar Generation

In 2016, Energy Trust undertook an impact evaluation of systems installed through the solar PV program between 2011 and 2015, to assess actual electricity production and understand reasons for variation in system performance relative to expectations (Kolp et al. 2017). A key objective of the evaluation was to determine if changes were needed to the methods Energy Trust uses to estimate annual energy production (AEP). Part of the impetus for this evaluation was evidence from production data for third-party systems that showed they were generally exceeding their generation expectations. Program staff also had similar anecdotal evidence from direct-owned systems. Additionally, program staff

[3] The paper does not note whether the systems evaluated in the California program were residential or commercial, or the ownership type or program years evaluated in either study.

recognized that their methods for estimating solar production had changed over time, in ways that were incrementally small and designed to maintain consistency from one version of methods to the next, but might add up to a large difference in production estimates over the long term.

The general equation used by Energy Trust to estimate AEP is:

*AEP (kWh/year) = Installed Capacity * Local Production Capacity * Total Solar Resource Fraction*

Energy Trust's original methodology for estimating local production capacity was taken from the University of Oregon Solar Radiation Monitoring Lab (SRML) and based on system performance data from 10 sites around Oregon. Meter readings from approximately 80 residential systems installed between 2003 and early 2006 showed a realization rate of 99% (Robison 2007), indicating the AEP estimation methodology was highly accurate.

Since 2010, Energy Trust has used PowerClerk software to estimate generation and process incentives.[4] During this time, PowerClerk developed the option to use TMY3 data on solar radiation in estimating local production capacity; however, Energy Trust has chosen to continue using TMY2 data to maintain consistency with older projects estimated using SRML.[5]

The other important factor affecting generation estimates is the total solar resource fraction (TSRF), which describes the ratio of the actual available solar irradiance of an array to the irradiance available to an ideally oriented and unshaded array. The program requires a minimum value of 0.75 to qualify for incentives, with 1.0 representing a perfectly sited and oriented PV system. For projects installed prior to 2017, shading was typically measured at the site and Energy Trust has required that, when using an on-site measurement tool, TSRF be taken from the most shaded portion of array. This represents a worst-case estimate of shading impacts and minimizes the chance that the system will generate less energy than expected.

As an additional measure of conservatism, since switching to PowerClerk, Energy Trust has applied a 5% derating factor to raw estimates of annual production to determine final claimed generation. This decision was based on internal analysis of differences between SRML and PowerClerk at the time of the switch, and intended to maintain historical consistency, given the 99% realization rate of projects estimated with SRML methods. All projects included in the 2011-2015 impact evaluation included this derating factor in their ex ante production estimate.

Energy Trust's generation estimation methods do not distinguish between inverter types, though differences in actual performance by inverter type have been suspected for some time.

Energy Trust Evaluation Methodology

The evaluation covered residential and commercial systems. Both direct-owned and third-party-owned residential systems were included in the evaluation, but third-party-owned commercial systems were excluded, due to the small number. Residential and commercial customers were contacted by email, asked to read their PV system meter and/or inverter, and enter the readings into an online survey.[6] Two rounds of invitations were sent to residential customers – one for 2011-2014 installations and another for

[4] PowerClerk was also used by Connecticut Green Bank and NYSERDA in the program years they evaluated.

[5] A Typical Meteorological Year, or TMY, is a data set of hourly values of solar radiation and meteorological elements for a 1-year period, produced by the National Renewable Energy Laboratory. The TMY2 dataset was derived from 239 locations within the National Solar Radiation Data Base, for the years 1961-1990. TMY3 has data for 1,020 locations based on the years 1976-2005.

[6] In addition to meter and inverter readings and read date, a few additional questions were asked to confirm that the system was appropriate to include in the evaluation: whether the respondent was the original system owner, whether warranty or repair work had been done on the system, and if so, what type.

2015 installations. Commercial customers with systems installed from 2011 through 2014 were only contacted in the first round, and no 2015 customers were contacted or included in the evaluation.

In all, 322 residential customers responded to the survey: 180 direct-owned customers and 142 third party-owned customers, which allowed the survey to exceed 90% confidence / 10% precision goals. Response was not as strong for commercial customers, with only 28 surveys completed. Table 1 presents the program population and survey response by strata (sector and ownership type).

Table 1. Survey sample and response by sector and ownership type

Strata	Population	Survey Sample	Survey Completes	Precision at 90% Confidence	Response Rate
Direct-Owned Commercial	219	219	28	15%	13%
Direct-Owned Residential	2,473	750	180	6%	24%
Third-Party Residential	2,712	750	142	7%	19%
Total	5,404	1,719	350	4%	-

The initial evaluation results from the survey of 28 commercial customers raised flags because of several cases of extremely low meter readings. Energy Trust opted to conduct site visits to 38 commercial sites to directly read PV system meters and inverters.[7] Total production from online tracking systems was also available for a subset of four sites, to confirm readings. Fifteen of the 38 systems, nearly 40%, produced over 100,000 kWh, causing the meter to roll over at least once and falsely report low production values. In these cases, inverter readings were used in place of meter readings, as the inverters recorded six digits, or Energy Trust was able to obtain customer permission to access online production data.

In addition to the survey data gathered from residential customers, two trade ally companies that installed and owned the majority of third-party systems provided Energy Trust with daily production data for a total of 1,401 systems, a sample large enough to achieve 1.5% precision at the 90% confidence level.

Table 2 shows the number of systems included in the evaluation by installation year; as previously noted, there were no commercial systems from 2015 included in the evaluation.

Table 2. Number of systems evaluated by sector, ownership type, data source and program year

	Survey / Site Visit Data			Production Data
Program Year	Commercial Direct-Owned	Residential Direct-Owned	Residential Third Party	Residential Third Party
2011	8	37	28	172
2012	12	27	25	245
2013	6	17	21	354
2014	12	40	31	458
2015	-	59	37	172
Total	38	180	142	1,401

[7] At 38, the site visit sample has a precision of 12% at 90% confidence.

To determine system realization rates, the following equation was used:

$$RR = \frac{E_{actual}}{AEP_{ETO}\left(\frac{OP_{days} * I_{act}}{365_{days/yr} * I_{TMY}}\right)}$$

Where:

E_{actual} = Reported production

AEP_{ETO} = Energy Trust's estimated annual electricity production

OP_{days} = Days of system operation

I_{act} = Actual irradiance

I_{TMY} = TMY2 irradiance

Actual energy production for individual systems was aggregated and compared to total estimated energy production to determine realization rates for each strata by program year, TSRF bin, geographic region and inverter type. In addition to the hypothesis that system performance would vary by inverter type, Energy Trust also suspected that there might be differences by region - due to weather patterns, installation contractors or other local factors – or by TSRF bin, given the subjective nature of estimating shading conditions at a site using a one-time measurement.

Evaluation Results

Results of the analysis indicate that Energy Trust has been underestimating generation from PV systems, by about 6% for commercial systems and close to 20% for residential systems (Table 3). While the confidence interval for commercial systems includes values less than 100% due to the relatively small number of site evaluated, the evidence for residential generation significantly exceeding expectations is strong.

Table 3. Realization rates by sector, ownership type and data source

	Survey / Site Visit Data			Production Data
	Commercial Direct-Owned	Residential Direct-Owned	Residential Third Party	Residential Third Party
Realization Rate	106%	121%	124%	117%
90% Confidence Interval	(93%, 119%)	(114%, 128%)	(115%, 132%)	(115%, 119%)

Commercial System Results

The overall realization rate of commercial PV systems was 106%. It is difficult to identify meaningful differences by year of installation or TSRF bin, due to the small number of systems evaluated. For example, yearly realization rates varied between 100% and 120% with no obvious upward or downward trend (Figure 3). The realization rate of 120% for 2011 systems is the only value outside of the 90% confidence interval, and as noted above, it is based on only eight systems.

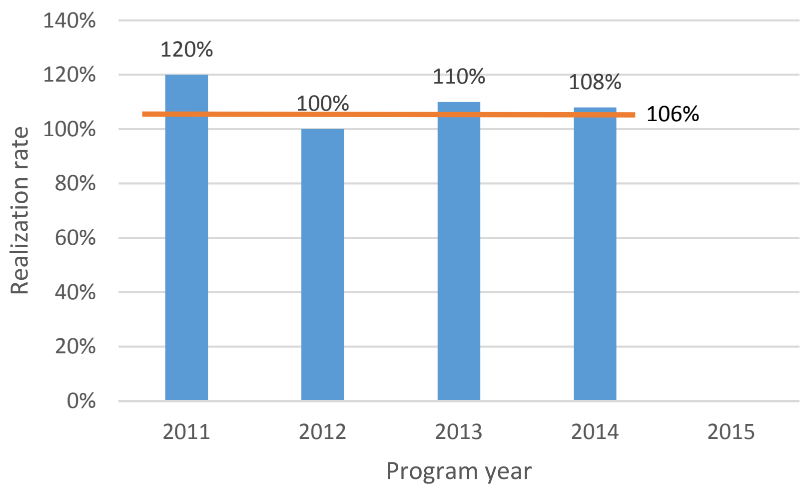

Figure 3. Commercial realization rate by program year. Note: no 2015 projects were included in the evaluation.

While the upper four bins of TSRF seems to appear to show a weak positive relationship between TSRF and realization rate, the lowest TSRF bin shows a realization rate of 139%, based on a single project (Figure 4). Results by geographic location were even less insightful. Ultimately, the small number of projects hinders a nuanced analysis of commercial system performance.

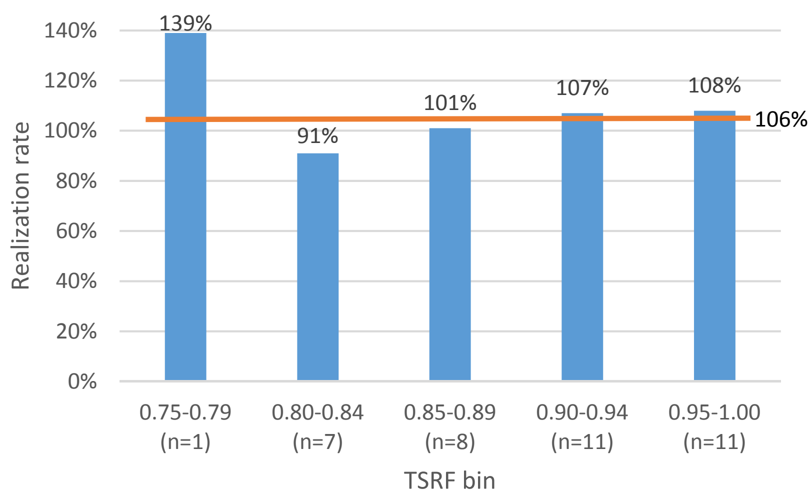

Figure4. Commercial realization rate by TSRF bin

Residential Direct-Owned System Results

Residential direct-owned systems significantly outperformed expectations, with a realization rate of 121%. As with commercial systems, there were no trends by year of system installation; realization rates by program year were very consistent, between 119% and 124% (Figure 5).

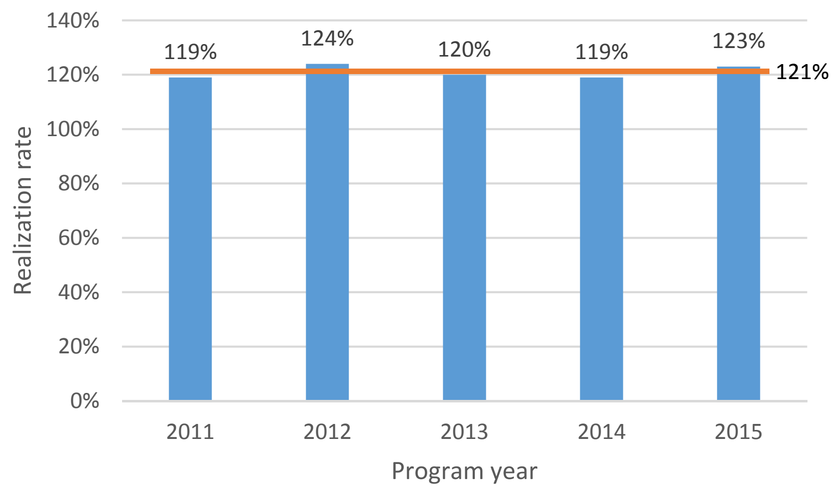

Figure 5. Residential direct-owned realization rate by program year

There was, however, the appearance of a slight trend of higher realization rates for lower TSRF bins, especially the lowest bin, 0.75-0.79 (Figure 6). This would not be unexpected; installers may understate the true TSRF – as long as it is at least 0.75 and the system qualifies for an incentive – in order to mitigate the risk of the system not delivering on generation expectations and diminishing customer satisfaction. However, the relationship is very weak, given that the realization rate for the lowest bin is just on the edge of the 90% confidence interval and all other bins are well within it.

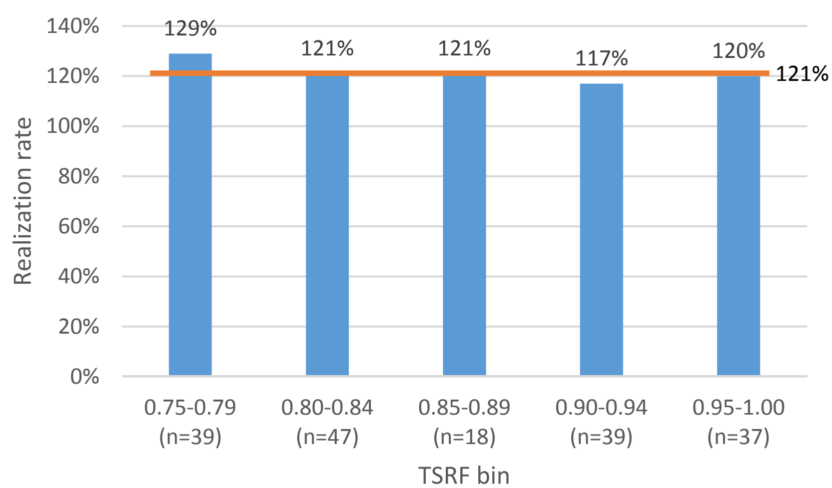

Figure 6. Residential direct-owned realization rate by TSRF bin

While there was some variation in system performance by geographic region, almost 60% of systems were located in the Portland Metro area, which had the highest realization rate of 128% (Table 4). Outside the Portland Metro area, realizations rates were lower, but generally still above 100%. Note that sample sizes for Central and Eastern Oregon, and the North Coast, were too small to draw reliable conclusions.

Table 4. Residential direct-owned realization rate by region

Region	Count	Realization rate
Portland Metro	102	128%
Willamette Valley	30	122%
Southern Oregon	29	110%
Central Oregon	13	109%
Eastern Oregon	5	107%
North Coast	1	72%

Residential Third-Party-Owned System Results

For third-party-owned residential systems, results from surveys and analysis of production data diverged somewhat. Given the substantially larger number of systems included in the production data analysis, those results should be considered more reliable; but the comparison of the results provides evidence that a smaller sample of data collected through a different medium may result in different conclusions – thus, methods matter.

Based on the survey data, the overall realization rate for third-party systems was 124%, while from production data analysis, the realization rate was 117%. Survey data indicated that the realization rate was relatively stable across program years; however, production data reveal that the realization rate increased over time, from 96% in 2011 to 132% by 2015 (Figure 7). The improvement in performance in more recent program years could be related to changes to installer practices in system siting or shading estimation over time, or bias in ratings of PV modules (manufacturers purposefully rate their modules so that they perform better than claimed for the first few years of operation, again to mitigate the chance of customer dissatisfaction). If the latter is true, this trend might have been evident for direct-owned systems if there were more sample points in the evaluation.

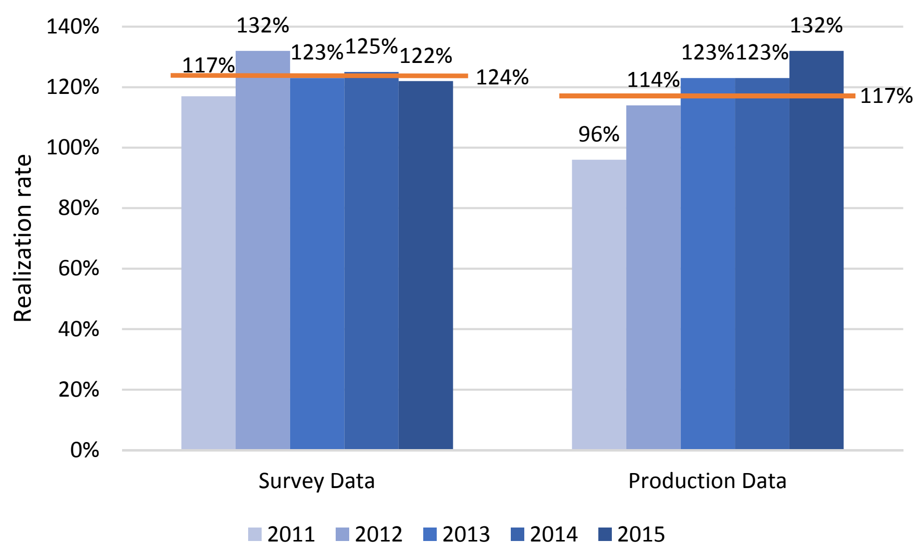

Figure 7. Residential third-party realization rate by program year and data source

Neither survey data nor production data suggest an inverse relationship between realization rate and TSRF bin, indicating that understatement of TSRF by installers is not really a factor, at least for third-party installers (Table 5).

Table 5. Residential third-party-owned realization rate by TSRF bin and data source

TSRF Bin	Survey Data		Production Data	
	Count	Realization rate	Count	Realization rate
0.75–0.79	30	124%	358	112%
0.80–0.84	36	124%	289	120%
0.85–0.89	27	123%	264	119%
0.90–0.94	26	133%	269	118%
0.95–1.00	23	110%	221	118%

As with direct-owned systems, survey data indicate that realization rates are highest in the Portland Metro and Willamette Valley regions, and lower in Central Oregon. While the same is true in the production data, the variance is much less pronounced than in the survey data (Table 6).

Table 6. Residential third-party-owned realization rate by region and data source

Region	Survey Data		Production Data	
	Count	Realization rate	Count	Realization rate
Portland Metro	109	124%	1,010	118%
Willamette Valley	22	125%	208	117%
Central Oregon	9	112%	170	113%
North Coast	2	119%	4	117%
Southern Oregon	0	-	9	119%
Eastern Oregon	0	-	0	-

Results by Inverter Type

Analysis by inverter type confirms that microinverters did result in about 10% more electricity generation than string inverters, regardless of sector and ownership type (Table 7).

Table 7. Realization rate by inverter type

Strata	Microinverter		String Inverter	
	Count	Realization rate	Count	Realization rate
Commercial Direct-Owned	9	116%	29	105%
Residential Direct-Owned	60	130%	120	118%
Residential Third-Party	4	141%	138	124%
Total	73	125%	287	112%

Note that while production data for third-party-owned systems was not analyzed by inverter type, the rarity of microinverter use in third-party survey data (only 3% of systems) is similar to the program population from 2011 to 2015, where 8% of third-party systems used microinverters. Additionally, most of those were installed in 2011 and 2012 projects; there was a steep drop-off in use of microinverters by third-party installers after 2012, despite increasing use in direct-owned systems during the same period.

Changes at Energy Trust

The evaluation results revealed that Energy Trust's generation estimation methodology is overly conservative, particularly for residential systems, but also for commercial systems. As a result, the program can easily justify eliminating the 5% derating factor. Energy Trust is also updating its version of PowerClerk in 2017, which will involve a switch to TMY3 data. While the difference in total annual solar irradiance between TMY2 and TMY3 is small and it is unclear whether the change will result in significantly more accurate estimates of annual generation, it seems reasonable to align weather data with other commonly used methodologies in order to focus on other aspects of methods that may affect estimates of generation. Future evaluations will be able to explore whether the use of TMY3 data results in more accurate AEP estimates.

In November 2016, Energy Trust began accepting shading measurements from three remote shade analysis tools, based on analysis done as part of the impact evaluation to cross-validate on-site and remote shading estimates for evaluated sites. These remote shading analysis tools use an average of shading across the array to estimate TSRF, which should be more accurate than using a single shading factor from the most shaded portion of the array (though that is still required for projects where an on-site measurement is used to estimate TSRF).

As noted, the largest third-party installers have exited the market in Oregon or converted their business model into installing direct-owned systems and offering financing to enable those installations. The effect of this change on the number of systems installed and generation claimed by the program remains to be seen, but it seems likely that access to production system data for systems installed after 2015, if available, may be more difficult to obtain.

While Energy Trust is not making any changes to estimation methods at this time to account for differences in system performance from inverter type, it plans to track the share of systems using microinverters to determine when methodology changes may be warranted. As microinverter prices come down and they become more common, underlying assumptions about average system production may need to be adjusted.

Energy Trust "trues up" its estimates of energy savings and generation based on evaluation results, and the findings from this evaluation will be used to adjust generation claimed for 2011-2015 systems. Going forward, higher generation estimates will result in lower incentives due to a reduction in above-market cost, though they should also improve estimated payback for customers. Given the continuing decreases in hardware and installation costs, solar PV remains a good investment, even with lower program incentives.

Conclusions and Areas for Future Research

While there may be a natural tendency on the part of programs and installers to under-promise on solar PV performance in order to hedge against customer disappointment, it is possible to be too conservative. The financial terms for solar are increasingly favorable, and as they approach parity with utility-provided electricity, it makes sense for programs to increase their focus on evaluating the accuracy of generation estimates in order to make more informed program decisions.

The evaluation results provide evidence that systems using microinverters generate more electricity than those with string inverters. Given the small number of systems included in this analysis, further research is warranted to confirm this finding and determine whether realization rates vary by amount of shading or TSRF.

The evaluation was able to obtain a sufficient number of meter readings by customers through an online survey to obtain better than 10% precision at the 90% confidence level for both direct-owned and third-party-owned residential customers, and proved to be a relatively inexpensive way to collect data about residential systems. In addition, most respondents with a string inverter were able to provide an inverter reading, as a check on the meter reading. However, the availability of production system data for a large number of third-party-owned residential systems provided a more precise view of the performance of those systems and led to slightly different conclusions than the survey data.

The online survey suffered from a low participation rate by commercial customers, as well as data quality issues due to PV system meter roll-over, which occurs sooner after installation and more frequently in large systems than in small, residential settings. Inverter readings, site visits to read meters, or access to online production data are better options for assessing performance of commercial systems than asking customers to report their meter reading in an online survey. The use of online production data presents the least-cost option for obtaining accurate performance of commercial systems, but availability or access may be limited. Site visits by evaluation staff to read commercial meters is likely the most expensive method, but may be the most practical option when online access to production systems is not available.

While Energy Trust was able to leverage the experience of a firm that had evaluated several other solar PV programs to design and implement its study, greater public availability of solar impact evaluations would help to identify best-practice methods and compare results across programs.

Finally, although this evaluation did not explore the demand (kW) aspects of solar systems, Energy Trust is beginning to explore the capacity benefits of its work, while other utilities are looking to manage the impacts to the grid of a growing number of distributed PV systems. Assessing the effects of solar PV systems on demand, as well as quantifying the total electricity production, will be important as this generation resource continues to grow.

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