Energy Trust of Oregon: Solar PV Evaluation Report

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Cadmus

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Executive Summary

Energy Trust of Oregon (Energy Trust) contracted with Cadmus to assess the true production of electricity from solar photovoltaic (PV) systems that received Energy Trust incentives between 2011 and 2015.

Objectives

The overall study goals and objectives are listed below:

- Estimate realization rates using customer-reported meter readings and third-party daily production data, including extrapolation to the full program population.
- Assess trends in realization rates by sector, system age, region, equipment type, and total solar resource fraction (TSRF).
- Provide information and evidence for updating Energy Trust's annual energy production calculation method, if applicable.

Methodology

In 2016, Cadmus administered an online survey to collect meter readings of customers' electricity production. The survey targeted customers with direct- and third party-owned residential systems and direct-owned commercial systems. Energy Trust also provided daily meter readings from third party-owned systems for the program's two largest solar installers. Cadmus calculated realization rates by comparing actual production with pre-installation estimates and normalizing the results for actual solar irradiance during the systems' performance periods. Cadmus summarized realization rates in many ways, including by sector (residential or commercial), ownership type, geographic location, installation year, equipment type, TSRF, and combinations of the aforementioned factors. Based on Cadmus' preliminary findings from the customer survey, Energy Trust conducted supplemental site visits at commercial PV installations as a means to clarify, or confirm, apparent meter reading anomalies reported in the initial online survey. The results of the commercial site visits were ultimately used in place of the survey readings.

Findings

Table 1 shows the final results of the 2011-2015 realization rate analysis. Commercial sites yielded 106% of expected production (from site visits), whereas the residential sites generally produced 117% to 124% of expected production, depending on the group.

Table 1. 2011-2015 Realization Rates

Evaluation Group	Data Collection Method	Count	Sum of Meter Reading kWh	Sum of Energy Trust Expected kWh	Realization Rate
Direct-Owned Commercial	Site Visits	38	4,624,447	4,349,925	106%
Direct-Owned Residential	Surveys	180	2,301,277	1,897,967	121%
Third-Party Residential	Surveys	144	1,914,839	1,550,442	124%
Third-Party Residential Production Data	Production Data	1,401	19,901,081	16,987,464	117%

The evaluated realization rates shown above (106% for commercial, 121% for direct-owned residential, and 117% for third-party residential[1]) were applied to the entire 2011-2015 program population, yielding an average realization rate of 112%. Overall, the systems incentivized by the program between 2011 and 2015 are producing nearly 64 million kWh on an annual basis, as shown in Table 2.

Table 2. 2011–2015 Evaluated Annual Program Savings

Sector	Quantity	Expected Savings (kWh per year)	Realization Rate	Evaluated Savings (kWh per year)
Commercial	407	31,981,092	106%	33,899,958
Direct-Owned Residential	2,570	11,681,789	121%	14,134,965
Third-Party Residential	2,753	13,602,688	117%	15,915,145
Total	**5,730**	**57,265,569**	**112%**	**63,950,068**

The following is a brief summary of key findings:

- PV systems incentivized by Energy Trust are generating more electricity than expected, even after accounting for the variability in the solar resource. Residential systems generate more electricity relative to program estimates than commercial installations.
- Production readings reported by third party-owned residential customers through an online survey resulted in a realization rate of 124%, while residential systems' production reported through trade ally automated systems resulted in a realization rate of 117%. While both values are in line with results from evaluations of similar programs elsewhere, the cause of the difference in realization rates between the two groups is not known.
- Systems with low estimated TSRF tend to have higher realization rates, particularly for third party-owned systems. This may indicate that the existing production estimation methods, which require using the worst case shading measurement for the site in estimating production, are overly conservative with respect to the impact of shading on PV system electricity production.

[1] The third-party owned residential systems yielded a realization rate of 117% from the production data, and 124% from the surveys. Due to the much greater sample size, and to be conservative, the 117% is applied to the population.

- Nearly 40% (15 out of 38) of commercial systems produced over 100,000 kWh since their installation and exhibited signs of meter registers rolling over and resetting to zero. This impacted some customers' self-reported meter readings and, as a result, Energy Trust had to collect supplemental information by conducting a series of site visits to obtain more accurate production histories from inverter logs.
- Six commercial site visits exhibited evidence of additional roll-over that was not being captured on the initial site visit reading. Roll-overs ranged from one to three times (at 99,999 kWh each). In several cases, the inverters were able to capture the full production without roll-over issues.
- Realization rates varied significantly between systems using string inverters and those using microinverters. Systems with string inverters achieved a realization rate of 112%, while those using microinverters achieved an average realization rate of 125%. Partial mitigation of the impacts due to shading has historically been a marketing claim made by microinverter manufacturers and these results suggest that there may be some performance improvements attributable to the use of microinverters, though further analysis would be required to draw a definitive conclusion about the impact of inverter technology on realization rate.

Recommendations

- **Consider less conservative input assumptions** to calculate estimated electricity production for residential systems. In particular, the use of a "worst case" value for TSRF from the most shaded roof area may be unnecessarily conservative. Other programs stipulate a shading measurement approach based on approximating the center point of the array, which will be slightly less conservative than using the most shaded portion of the array as the basis for estimating production for the entire system.
- For future evaluations, **do not ask commercial customers for meter readings, but instead, ask for inverter readings**. The most preferable method is to obtain ongoing system output from a data acquisition system,[2] if available.
- **Future evaluations can rely on meter (or inverter) readings from residential surveys** to obtain production data for use in calculating realization rates (all three residential realization rate estimates occur around 120%).
- **Incorporate TMY3, rather than TMY2, irradiance data** into future performance predictions to better reflect current weather conditions.
- **Consider additional analysis on inverter type** to determine if it would be appropriate to adjust production estimates and associated tools to account for additional productivity from some inverter types.

[2] A data acquisition system consists of sensors, measurement hardware, and a computer with programmable software.

MEMO

Date: January 26, 2017
To: Board of Directors
From: David McClelland, Program Manager – Solar
Sarah Castor, Evaluation Sr. Project Manager
Subject: Staff Response to the Solar PV Impact Evaluation

Energy Trust undertook an evaluation of the Solar PV program to assess the true production of systems installed between 2011 and 2015, and to determine if any changes were needed to methods used to estimate annual energy production.

Results of the evaluation show that PV systems incentivized by Energy Trust consistently produce more energy than claimed, by about 6% for commercial systems and close to 20% for residential systems. In particular, the evaluator noted that Energy Trust's practice of using the total solar resource fraction (TSRF) value from the most shaded portion of the array results in overly conservative generation estimates.

Going forward, the Solar program is allowing contractors to use approved remote shading analysis tools to measure shade and calculate the TSRF. Three tools – Bright Harvest, Aurora Solar and Helioscope – have been approved based on analysis of their accuracy relative to on-site shading measurements.

The program is also evaluating new models for estimating performance, which can be implemented during an upgrade to PowerClerk, the program's project application software. Energy Trust anticipates making this upgrade later in 2017.

Based on the actual generation results from this evaluation, Energy Trust plans to adjust claimed solar PV production for 2011-2015 projects during the next true-up of savings and generation, to occur in 2017. Moving forward, the program also will also incorporate the higher generation assumptions into its evaluations of solar above-market costs and adjust incentives as needed.

Further analysis of the data collected is planned within the following three focus areas:

1) Analysis of system production by inverter type to identify the increase, if any, in production for systems equipped with module- or string-level power electronics.
2) An update of system production capacity coefficients to provide solar trade ally contractors a standard method for quickly and accurately estimating system production.
3) Assessment of how closely solar production matches customer usage profiles in order to identify the impact of solar on customer loads.

Introduction

Energy Trust of Oregon (Energy Trust) is the primary organization in Oregon offering incentives to residential and commercial customers seeking to offset the upfront cost of installing a solar photovoltaic (PV) system. This report presents Cadmus' assessment of electricity generation from systems incentivized by Energy Trust's solar program between 2011 and 2015.

The purpose of this study was to compare electricity production data, obtained by acquiring meter readings directly from customers and by analyzing third-party records, to Energy Trust's annual production estimates.[3] This analysis entails a detailed examination of the components used in the energy generation estimation and produces realization rates that are informative aggregates of the accuracy of Energy Trust's estimates.

Annual energy production (AEP) for a given system can be estimated using many methods and tools, and the resulting performance is subject to the solar resource available each year. It is important to periodically compare the expected annual output to the actual electricity production achieved to verify the effectiveness of the estimation methods employed so that improvements can be made.

The overall study goals and objectives were to:

- Estimate realization rates using customer-reported meter readings and third-party data and extrapolate to the full program population.
- Assess trends in realization rates by sector, system age, region, equipment type, and total solar resource fraction (TSRF).
- Provide information and evidence for updating Energy Trust's annual energy production calculation method, if applicable.

About the Energy Trust Solar Program

Annual Energy Production

Energy Trust provided information on AEP reported within PowerClerk, the online incentive application and project tracking program used by Energy Trust's solar program. Energy Trust uses Equation 1 (below) and utilizes inputs collected from third parties to calculate annual energy production:

Equation 1: Annual Energy Production

$$AEP\ (kWh\ /\ year) = \ Local\ Production\ Capacity\ * Installed\ Calacity\ (DC\ Watts) * TSRF$$

3 Note that Energy Trust suspected these estimates to be on the conservative side by approximately 10%.

The local production capacity varies on a regionally defined basis throughout the state of Oregon.[4] These local production capacities depend on ideal tilt and ideal azimuth obtained through geographic location. Understanding the local production capacity at a given site is instrumental in forecasting potential electricity production. Forecasts of annual electricity production can then be verified through site visits/meter readings to yield an annualized or total realization rate. Realization rates for Energy Trust's solar program are presented in the following sections.

One important factor affecting the productivity of a PV system is the TSRF (of which the program requires a minimum of 0.75, with 1.0 representing a perfectly sited and oriented PV system). The TSRF, or Total Solar Resource Fraction, describes the ratio of the actual available solar irradiance of an array to the irradiance available to an ideally oriented and unshaded array. For the projects analyzed in this study, this value was typically measured on-site using a tool such as the Solmetric Suneye or Solar Pathfinder. For Energy Trust, the TSRF value reported by the installer, and used for AEP calculations, is reported from the lowest TSRF reading of the entire array. Typically, this represents a worst-case estimate of shading impacts.

Incentive Levels and Payment Structure

Energy Trust offers incentives for solar PV based on servicing utility (Portland General Electric [PGE] or Pacific Power), customer sector (residential or nonresidential), and ownership structure (direct-owned or third party-owned).[5] To be eligible for incentives, PV systems must be installed by a pre-approved Energy Trust solar trade ally, which can be located on Energy Trust's website.[6]

Metering for Solar PV System Electricity Production

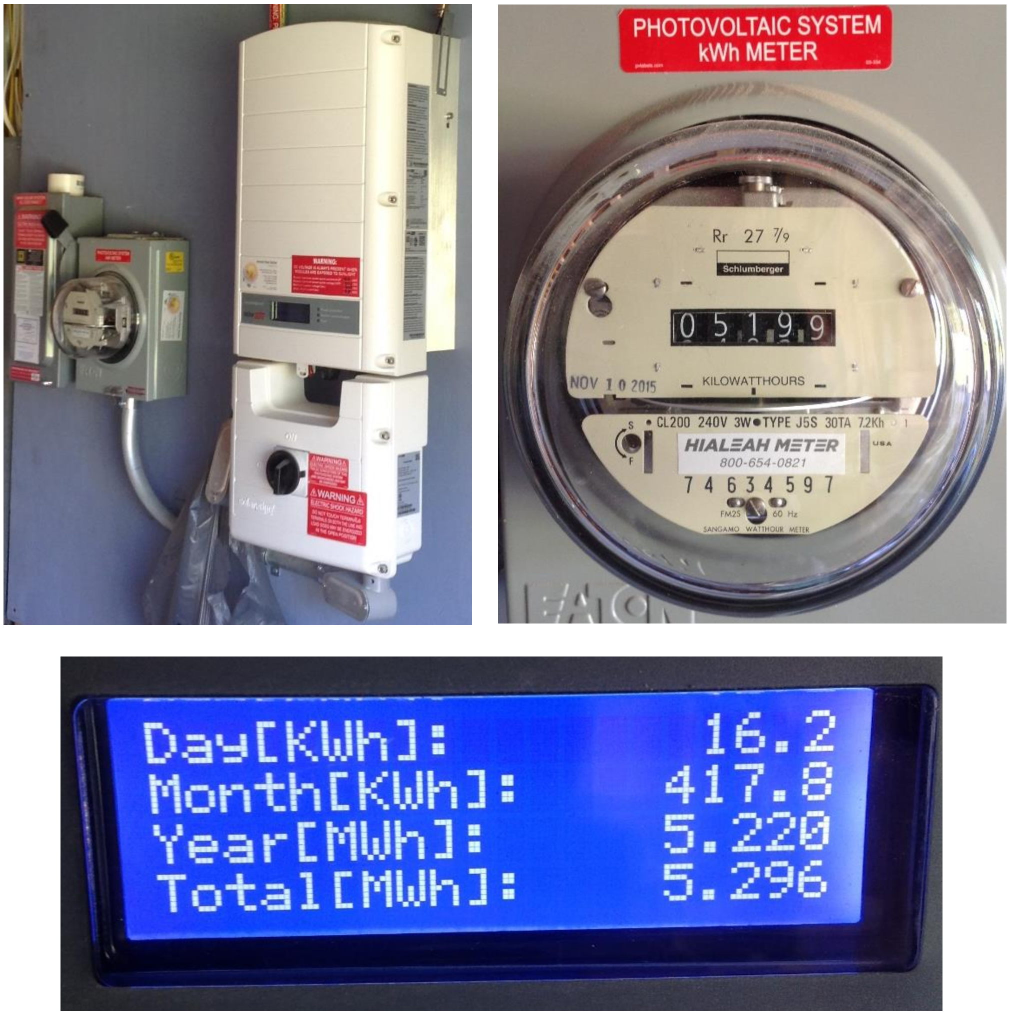
The amount of electricity generated by a solar PV system is recorded, per Energy Trust requirements, on a dedicated, revenue grade, production meter. In addition, inverters typically include built-in metering equipment (which may, or may not, be revenue grade) that records the amount of electricity generated. We have included readings from both production meters and inverters at various stages of this analysis, as described in the following sections. See Figure 1 for examples of meter and inverter readings. In the first picture to the left, the meter can be seen on the left side and the inverter is the larger white piece of equipment on the right. The right-most picture is a close up of the meter interface, and the lower picture is a close up of the inverter read out. The meter simply records the produced electricity, whereas the inverter converts DC power to AC power, as well as regulates voltage and frequency.

[4] Energy Trust of Oregon, *Ideal Tilt & Orientation & Local Production Capacities for Oregon Cities*. Available online: https://www.energytrust.org/library/forms/TiltOrient_OregonCities_V2.pdf

[5] Energy Trust of Oregon. *Solar Incentive Status Report.* July 8, 2016. Available online: https://energytrust.org/library/forms/Solar_Status_Report.pdf

[6] Energy Trust of Oregon. Accessed on July 19, 2016. Available online: http://energytrust.org/trade-ally/find-a-contractor/

Figure 1. Examples of Meter and Inverter Reading Interfaces



Methodology

Cadmus collected primary data via an online survey and/or site visit (commercial sites only; site visits were completed by Energy Trust solar program verifiers), and third-party production data from two of the program's largest installers, and then analyzed this production data to determine realization rates and identify any trends in the results across areas of interest. The study methods are explained in the following sections.

Data Types and Sources

Table 3 presents the data types and sources used in this evaluation.

Table 3. Data Sources and Their Applications

Data Type	Source	Purpose
Meter or Inverter Reading Data	Online Survey/Site Visit[7]	Electricity production data used to calculate realization rates
Participant Tracking Database	Energy Trust	Participant contact information, generation estimates, installation dates
PowerClerk System Data	Energy Trust	Key PV system attributes (tilt, azimuth, etc.)
Third-Party Production Data	Third-Party Providers	Daily third-party electricity production data used to calculate realization rates
Irradiance Data	Solar Data Warehouse	Used for normalizing electricity production year to year

Meter Reading Survey

Survey Sampling

A total of 5,730 solar PV systems were installed between January 1, 2011 and December 31, 2015 and were included in the dataset provided by Energy Trust. This total population was considered the starting sample set for the survey. Cadmus then removed those participants who had previously indicated to Energy Trust that they did not wish to be contacted or who owned or operated multiple properties. Participants who owned multiple properties were removed from the study to reduce ambiguity regarding which property's generation should be (or was being) reported. The project team also excluded third-party commercial customers due to a small population size (40 participants) and the relative difficulty of identifying individuals knowledgeable about the solar PV installation process at each of the participant facilities. Table 4 shows total installations, number of excluded participants, and the resulting sample set of 5,404 installations.

[7] Site visits were for commercial sites only.

Table 4. Sample Attrition

Step	Count
Total Solar PV Systems (2011–2015)	5,730
Do not contact	8
Multiple properties	220
Third-party commercial	40
2015 commercial sites*	58
Resulting Sample Size	**5,404**

*Commercial sites were excluded from the second round of surveys (2015 participants) because it was determined in the first round that site visits are more accurate.

Cadmus and Energy Trust created three sampling strata from which survey quotas were derived: direct-owned residential, direct-owned commercial, and third party-owned residential. Table 5 shows the three sampling strata and the population in each stratum, together with the target sample sizes and the individuals responding in each strata (survey completes). The team met, or exceeded, a target 90% confidence and 10% precision for both residential strata. For the survey analysis of the direct-owned commercial stratum, Cadmus met a 90/15 confidence interval because of population constraints—the population for direct-owned commercial sites was only 219 participants, of which 28 surveys were completed (13% response rate). This is a reasonable response rate for an online survey with commercial participants, based on industry experience.

Table 5. Targeted Survey Sampling Goals and Actuals

Strata	Population	Survey Sample	90/10 Goal	90/15 Goal	Survey Completes	Actual Precision (at 90% Confidence)	Response Rate
Direct-Owned Commercial	219	219	52	27	28	14.6%	13%
Direct-Owned Residential*	2,473	750	66	30	180	5.9%	24%
Third-Party Residential*	2,712	750	66	30	144	6.7%	19%
Combined Sampling Goal	**5,404**	**1,719**	**184**	**87**	**352**	**4.3%**	**N/A**

*The two residential strata had samples of 500 surveys distributed in the first round (2011–2014 systems) and 250 in the second round (2015 systems).

Survey Implementation

Cadmus programmed the survey questions using the online survey platform Qualtrics, with the primary goal of determining how much electricity the surveyed PV systems generated since coming online, as well as to collect relevant supporting data. The survey included questions on the following topics:

- Current meter reading (cumulative electricity generated since system startup)
- Inverter reading of cumulative electricity generated
- Meter reading date
- Warranty work performed (if any)

- Ownership change (if any)
- Whether the system was still present on property
- Whether the address on file was correct
- Open-ended additional feedback

Following Energy Trust's approval of the final survey instrument (see Appendix A) and recipient list, Cadmus conducted a pre-test by sending the survey, via email, to a limited number of customers to ensure the format of the survey and the meter reading instructions were clear and without technical issues, after which invitations were emailed to the rest of the sample. Cadmus e-mailed reminders when necessary to gain sufficient responses from survey participants. Cadmus monitored response rates as the survey was progressing to ensure it was achieving a reasonable qualitative distribution among factors such as TSRF and geographic region. During the survey, Cadmus provided customer service support by answering survey-related questions via phone and e-mail. Customers with meter reading questions were referred to Energy Trust's website guide to meter reading (see Appendix B).

The survey invitations were performed in two rounds. To control the survey cost, we did not invite the entire residential population to take the survey, as there is a small fee for each survey completed. In the first round, the two residential groups had an initial survey sample of 500 randomly selected sites each, whereas the entire commercial population of 219 received the survey invitation given the limited number of participants. Cadmus reviewed response rates with Energy Trust during the fielding process, and determined that a second round of survey reminders was not needed because there was significant residential participation and the commercial sample was exhausted. The first round survey was closed on February 4, 2016. The second round was performed in July 2016 for only 2015 participants from both residential groups, with sample sizes of 250 randomly selected sites each. Additional commercial sites that participated in 2015 were not surveyed, due to the site visits already performed.

Electricity Production Analysis Methodology

Cadmus compared Energy Trust's annual estimate of production with the reported actual production and calculated a realization rate for the sample. This reported production was derived from customer survey responses (direct-owned and third party residential PV systems) and from data acquisition system exports provided by Energy Trust's two largest solar installers (third party-owned systems). For the commercial systems, the reported production was derived from site visits conducted by Energy Trust. Cadmus subsequently applied the sample realization rate to the total expected production for the project population in each stratum to determine program-level production.

The team used Equation 2 (below) to calculate system-level realization rates:

Equation 2: System-level Realization Rate

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

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[8]

For example, Equation 3 (below) shows the realization rate for a system operating for 400 days with an average irradiance of 5 kWh/square meter/day in a region with a typical meteorological year (TMY) irradiance of 4 kWh/square meter/day, where the customer's meter reading was 5,000 kWh and Energy Trust's AEP was 4,500 kWh/year:

Equation 3: Example System-level Realization Rate

$$RR = \frac{5{,}000\ kWh}{4{,}500\ kWh/yr\left(\dfrac{400\ days * \frac{5kWh}{m2}/day}{365_{days/yr} * \frac{4kWh}{m2}/day}\right)} = 81\%$$

In this example, the system generated less than its expected level, with a realization rate of 81%. Because the system was operating for more than one year in a location with a higher solar resource than anticipated, the actual generation should have been more than 500 kWh higher than the typical annual value of 4,500 kWh; had the system been operating as assumed, it should have generated 6,164 kWh during this 400-day period.

Although conceptually simple, using this approach involved several simplifying assumptions:

- The impacts of temperature, humidity, and other weather factors were omitted. Colder temperatures can increase the efficiency of PV modules, which may produce an output somewhat higher than indicated by the irradiance alone. In Cadmus' experience, this effect is secondary compared to the impact of irradiance, but it is not always negligible and was not studied as part of this analysis.
- This approach assumes an even impact of shading/orientation losses across the operating period. In reality, shading and orientation losses are probably more pronounced when the sun is at a lower angle (i.e., during the winter); as a result, by using an annual TSRF value as part of

8 A Typical Meteorological Year, or TMY, is a data set of hourly values of solar radiation and meteorological elements for a 1-year period. The TMY2 data sets were derived from 239 locations within the National Solar Radiation Data Base, Version 1.1, which was completed in March 1994 by the National Renewable Energy Laboratory.

AEP, operating periods weighted toward this time of year may have underrepresented losses from shading that occurred during the period.

- This approach relied on average daily irradiance values, which may have led to rounding errors that decreased precision when the average irradiance values were multiplied by a large number of days.

To support Energy Trust's research objectives, Cadmus analyzed realization rates in several ways:

- **Overall Realization Rate.** The overall realization rate, and realized electricity production, for the sample of projects included in the analysis.
- **Realization Rate by Sector.** Separate realization rates for residential and commercial customers.
- **Realization Rate by Ownership Model.** The realization rates for direct-owned and third party-owned PV systems.
- **Realization Rate by TSRF Bin.** Realization rates for ranges of reported TSRF values from PowerClerk (reported collectively and by ownership model and system age).
- **Realization Rate by Installation Year.** Combined realization rates binned by installation year.

Findings and Results

The following findings and results are presented in several distinct sections. First, Cadmus presents the findings from the surveys and resulting realization rates, as well as the results from the commercial site visits and resulting realization rates. The residential survey results and the commercial site visit results are combined for various analyses by installation year, TSRF, and other parameters. Next, results for the third-party data acquisition systems are presented, followed by a short discussion of the solar resource, concluding with a synthesis of results by sector:

- Meter reading survey findings
- Commercial site visit findings
- Survey and site visit results analysis
- Third-party production data results
- Solar resource
- Synthesis of results by sector

Meter Reading Survey Results

Table 6 shows the residential survey population and realization rates by ownership type. The survey yielded valid results for 324 customers and obtained an overall realization rate of 122% when compared to annual electricity production estimates provided by Energy Trust.

Table 6. Residential Survey Data Results by Ownership Model

Owner/Sector	Count	Sum of Meter Reading kWh	Sum of Energy Trust Estimated kWh	Realization Rate
Direct-Owned Residential	180	2,301,277	1,897,967	121%
Third-Party Residential	144	1,914,839	1,550,442	124%
Grand Total	**324**	**4,216,116**	**3,448,410**	**122%**

Surveys were administered to 40 direct-owned commercial customers. Because of blank responses, or other obvious issues (e.g., sites that were producing 1% realization rates and indicated a possible MWh reading as opposed kWh), 12 sites were removed from the analysis. This attrition yielded 28 final direct-owned commercial sites in the surveyed population with a realization rate of 59%. As noted, this result is not used in the final analysis, but was an important step in the research that initiated the need for commercial site visits.

Commercial Site Visit Results

During discussions with Energy Trust, it became evident that there was an issue with the results for the direct-owned commercial sites. Either the customers were unable to provide accurate meter readings (because of things like meter register roll-over, the process by which a meter reaches a maximum reading and then resumes counting at zero) or there were technical issues impacting only commercial PV projects. Energy Trust elected to visit all commercial sites in the sample to obtain production readings from both the meter and inverter and to determine if the system had experienced equipment failures or other issues that would reduce productivity.

Table 7 shows the results of 38 viable[9] site visits yielding a realization rate of 106%. Commercial realization rates did not appear to correlate with system age or TSRF.

Table 7. Site Visit Results for Commercial Sites

Owner/Sector	Count	Sum of Meter Reading kWh	Sum of Energy Trust Estimated kWh	Realization Rate
Direct-Owned Commercial	38	4,624,447	4,349,925	106%

Of the 38 viable commercial site visits, nearly 40% (15 out of 38) produced over 100,000 kWh causing the meter to roll-over and falsely report low production values; thus, the survey meter reading did not accurately reflect the cumulative generation of the systems. Of these, there were six sites where the inverter reading exceeded the meter reading by a multiple of 100,000 kWh, indicating that the meter had rolled over once the maximum programmed meter value (99,999 kWh) had been reached. The other nine sites had inverters that recorded six-digit readings, averting the roll-over issue, and these site visit data were utilized. Two of these nine sites provided inverter readings only.

Survey and Site Visit Results Analysis

The following section summarizes the survey results for the direct-owned and third-party residential systems, as well as the site visit results for the commercial direct-owned systems. First, the team considered the impact of TSRF on realization rates. Table 8 shows the survey population realization rates when broken out by TSRF bin.

Table 8. Survey Data Results by TSRF (Residential Survey and Commercial Site Visits)

TSRF	Count	Sum of Meter Reading kWh	Sum of Energy Trust Estimated kWh	Realization Rate
0.75 - 0.79	71	1,162,849	891,167	130%
0.8 - 0.84	91	1,287,450	1,125,741	114%
0.85 - 0.89	53	1,885,343	1,771,429	106%
0.90 - 0.94	76	2,324,328	2,047,712	114%
0.95 - 1.00	71	2,180,593	1,962,286	111%
Grand Total	**362**	**8,840,563**	**7,798,335**	**113%**

9 Energy Trust visited 40 sites; however, two sites were not operational at the time, and no production data were provided. One site was under construction and the other was vacant and the PV system has been temporarily off-line pending the arrival of new building occupants.

Figure 2 shows cumulative realization rates by TSRF and sector. Note that even the highest values of TSRF exhibit realization rates around 110%, indicating that some variability is attributable to other factors.

Figure 2. Survey Data Realization Rates by TSRF and Sector (Residential Survey and Commercial Site Visits)

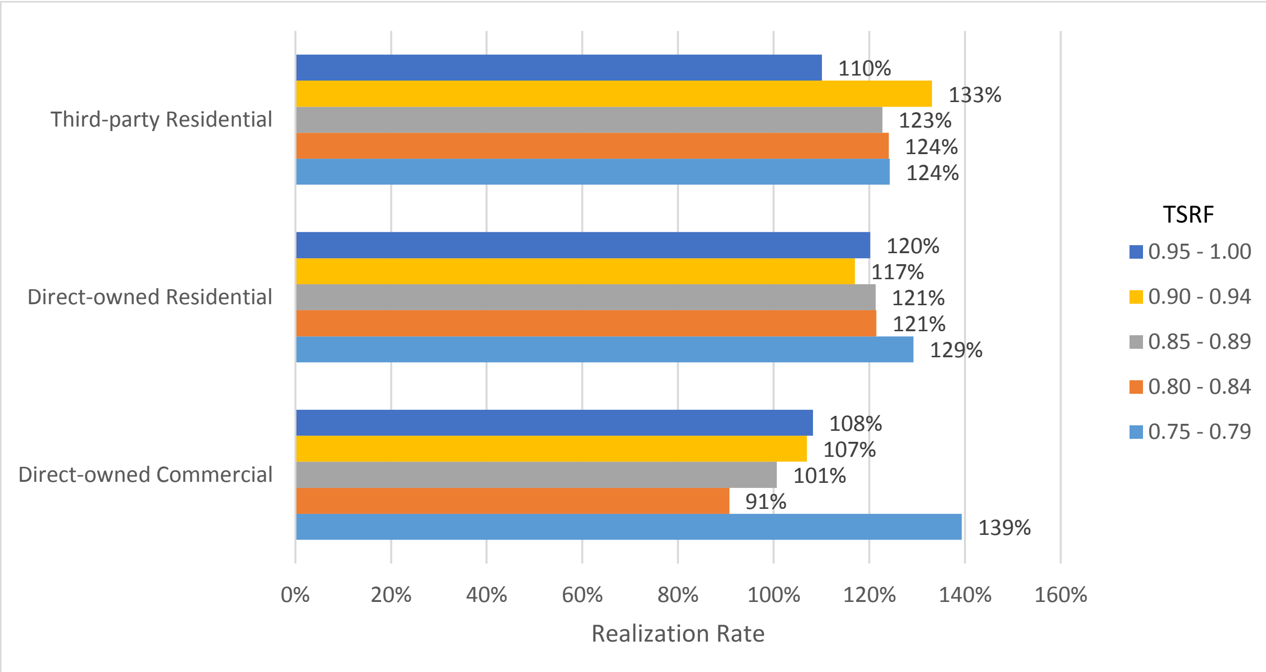


Table 9 details the counts and total cumulative capacity (kW) for direct-owned commercial systems by TSRF to provide additional context for Figure 2. Three systems had onsite readings lower than anticipated in TSRF bins 0.80 - 0.84, 0.90 - 0.94, and 0.95 - 1.00, respectively. These systems were evaluated by Energy Trust staff who indicated that the meters had rolled over (i.e., returned to 0 kWh once the meter had reached a value of 99,999 kWh). This caused the inverter readings in these instances to exceed meter readings by multiples of 100,000 kWh. The meter readings for these systems were corrected.

Table 9. Total Capacity of Direct-Owned Commercial Systems by TSRF

TSRF	Count	Cumulative Capacity (kW)	Average Capacity (kW)	Realization Rate
0.75–0.79	1	66	66	139%
0.80–0.84	7	116	17	91%
0.85–0.89	8	309	39	101%
0.90–0.94	11	276	25	107%
0.95–1.00	11	406	37	108%
Grand Total	**38**	**1,172**	**31**	**106%**

Solar resource varies spatiotemporally, with some portions of the state having generally more or less favorable solar resource and available solar energy. Table 10 provides realization rates by region, though it is important to note that not all regions contain statistically significant sample sizes.

Table 10. Results by Region (Residential Survey and Commercial Site Visits)

Region	Count	Sum of Meter Reading kWh	Sum of Energy Trust Total kWh	Realization Rate
Central Oregon	29	335,485	306,138	110%
Eastern Oregon	7	706,772	652,560	108%
North Coast	3	22,169	23,292	95%
Portland Metro & Hood River	226	4,073,059	3,539,458	114%
Southern Oregon	34	946,474	830,467	114%
Willamette Valley	63	2,756,604	2,446,419	114%
Grand Total	**362**	**8,840,563**	**7,798,335**	**113%**

Figure 3 shows realization rates by region and sector. The third party and direct-owned residential systems largely exhibit realization rates of 100% or greater. Note that over 60% of systems are located in the Portland Metro area.

Figure 3. Survey Data and Site Visit Realization Rates by Region and Sector (Residential Survey and Commercial Site Visits)

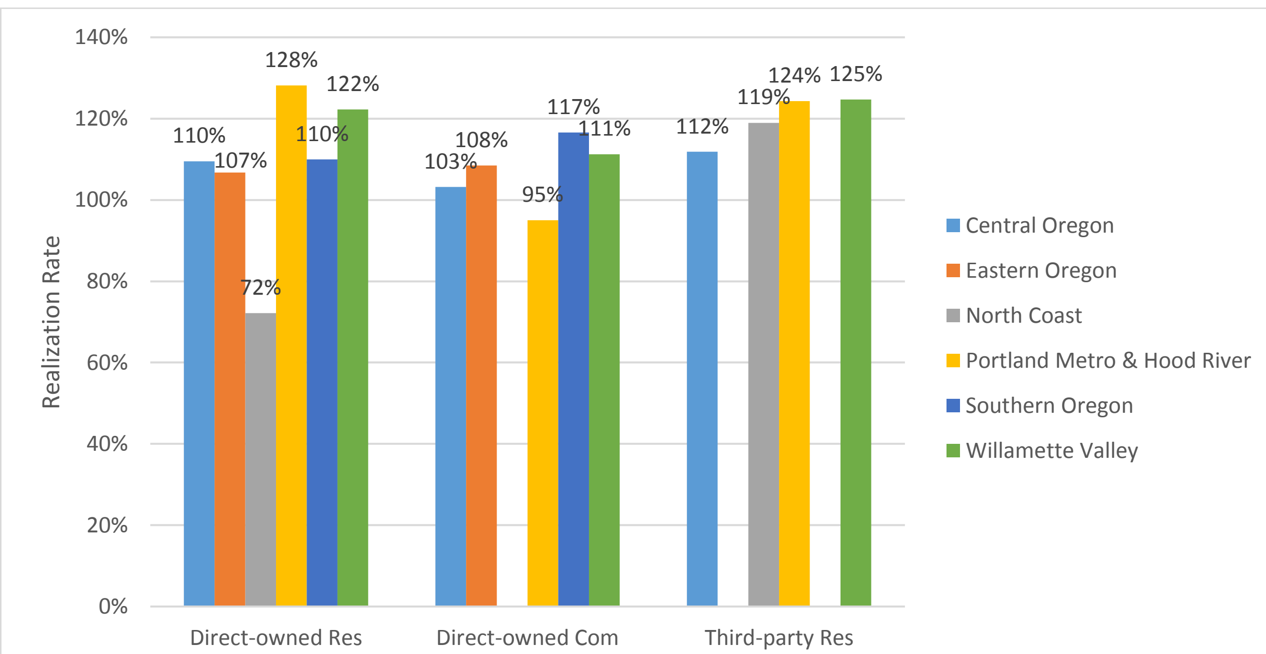


Table 11 presents realization rates by the year the system was installed. Examining realization rates by year may help in capturing broad trends in installation practices, equipment used, geographic spread of installations, and other factors. In this case, the realization rate for each installation year is greater than

100% but there is no clear upward or downward trend in realization rate based on the installation year for the PV systems.

Table 11. Realization Rates by Installation Year (Residential Surveys and Commercial Site Visits)

Year	Count	Sum of Meter Reading kWh	Sum of Energy Trust Total kWh	Realization Rate
2011	73	2,188,467	1,837,361	119%
2012	64	3,132,350	2,931,431	107%
2013	44	1,178,008	1,025,409	115%
2014	83	1,450,481	1,275,515	114%
2015	98	891,258	728,620	122%
Grand Total	**362**	**8,840,563**	**7,798,335**	**113%**

Figure 4 breaks out realization rates by year and sector. The two residential sectors show fairly consistent rates, but the commercial sector shows slightly more variability. Table 12 presents the number of direct-owned commercial sites by installation year indicating the relatively small sample sizes of the population.

Figure 4. Survey Data and Site Visit Realization Rates by Installation Year and Sector

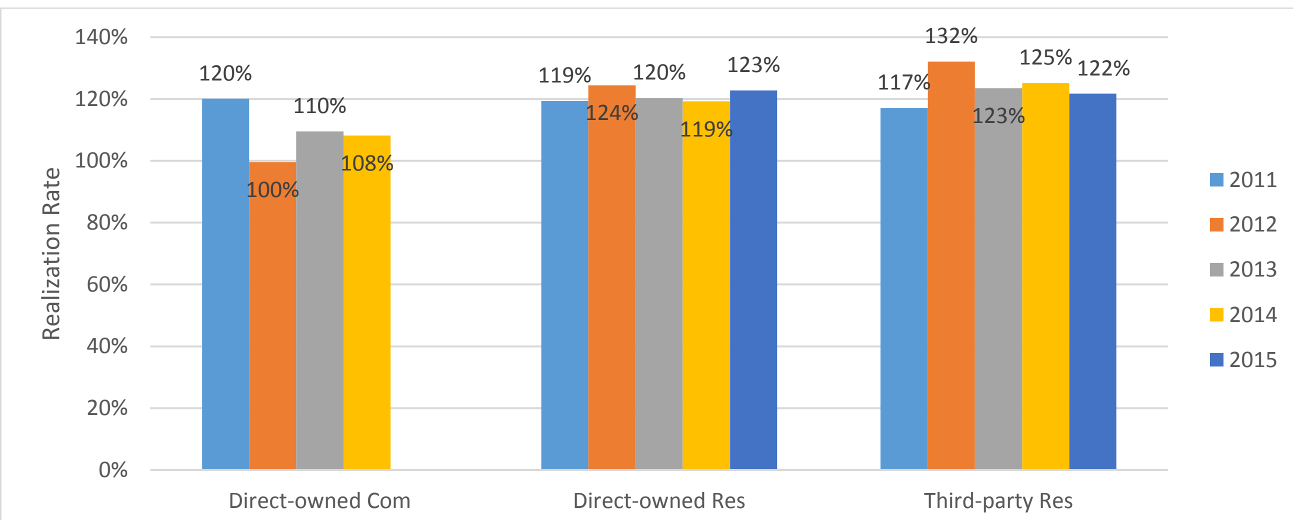


Table 12. Number of Direct-Owned Commercial Sites by Installation Year

Year	Count
2011	8
2012	12
2013	6
2014	12
2015	-
Grand Total	**38**

Another factor that may impact the realization rate for a PV system is the type of inverter used. For the purposes of this analysis, we have categorized inverters into two categories:

- **String inverters** convert the DC output of a group of PV modules connected in series (known as a string) to AC output that is synchronized with the utility grid. Most string inverters accept input from strings of 10-15 PV modules, which requires running high voltage DC conductors from the PV array to the input terminals of the inverter. This makes all of the inverter's controls and components easy to access but leaves strings vulnerable to shading or other factors that might reduce the output of one module and, as a result, reduce the effectiveness of the entire string.
- **Microinverters** are small inverters that are deployed on a single module (or a pair of modules). They perform all of the normal functions of an inverter, such as maximum power point tracking and synchronizing the AC output of the inverter to the utility grid, but they do so at the module level. This means that the performance of one module does not affect the performance of another module nearby, so microinverters can be more tolerant of factors such as shading.

Figure 4 breaks out realization rates by year and sector. Table 13 shows the significant difference in realization rates between microinverters (125%) and string inverters (112%). Each system for which we received data was categorized as using one of these types of inverters by the Energy Trust. While the overall realization rate for microinverters tends to be higher than for string inverters, a full comparison of the two technologies is beyond the scope of this study. In particular, DC optimizers such as products by Solar Edge were categorized as "string inverters" in the Energy Trust data, though these types of systems would benefit from many of the same productivity increases of microinverters.

Table 13. Realization Rates by Inverter Type (Residential Survey and Commercial Site Visits)

Inverter Type	Count	Sum of Meter Reading kWh	Sum of Energy Trust Estimated kWh	Realization Rate
Microinverter	73	1,189,419	948,572	125%
String inverter	289	7,651,144	6,849,763	112%
Grand Total	**362**	**8,840,563**	**7,798,335**	**113%**

Third-Party Production Data Results

In addition to the surveys and site visits to obtain production data, Energy Trust provided daily production data for residential projects from two third-party vendors that were equipped with data acquisition systems. Cadmus analyzed these data separately, as shown in the following section. The overall analysis yielded a realization rate of 117%, which is in line with the combined residential survey and commercial site visit realization rate of 113%, but somewhat lower than the residential survey population with a realization rate of 122%.

Table 14 shows the realization rate of the entire third-party population.

Table 14. Third-Party Production Data Realization Rates (Residential)

Count	Sum of Third-Party Meter Reading kWh	Sum of Energy Trust Total kWh	Realization Rate
1,401	19,901,081	16,987,464	117%

The realization rates by region and installation year are shown in Figure 5, with a discernable trend of lower realization rates for older systems for the Willamette Valley, Central Oregon, and Portland regions for systems in this sample. This increasing realization rate over time, while generally positive, may reflect one or more of the following factors:

- Increasing use of microinverters, which tend to operate more efficiently in lower TSRF regimes and are poorly represented in common PV system modeling tools and methods.
- Increasingly conservative estimates by installers seeking to avoid pushback from program staff and field verifiers.
- Reduced emphasis on ideal siting conditions, as financing mechanisms and tax credits began to play a more prevalent role in customer economics.
- Positive bias rating of PV modules (the tendency of module manufacturers to report nameplate power as a minimum output, with actual output several percent higher than rated output). As the module degrades each year, the impact of this factor would be reduced over time (i.e., be less prevalent for older systems).

Figure 5. Third-Party Production Data Realization Rates by Region and Year

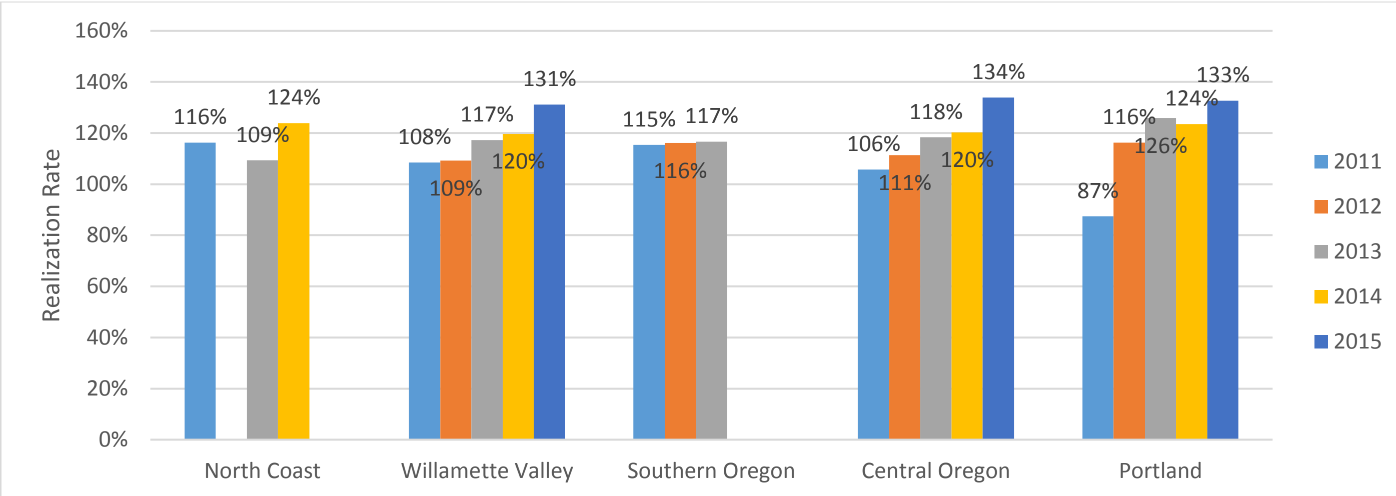


Figure 6 shows realization rates by region and TSRF value. There does not appear to be any discernable trend. While we do not have sufficient data to determine why this trend is different than what we observed for direct-owned PV systems, the more systematic TSRF measurement process employed by third-party ownership vendors may result in less variability in TSRF between sites (as the measurement practices and tools would likely be more consistent than projects chosen at random from the direct ownership sample).

Figure 6. Third-Party Production Data Realization Rates by Region and TSRF (Residential)

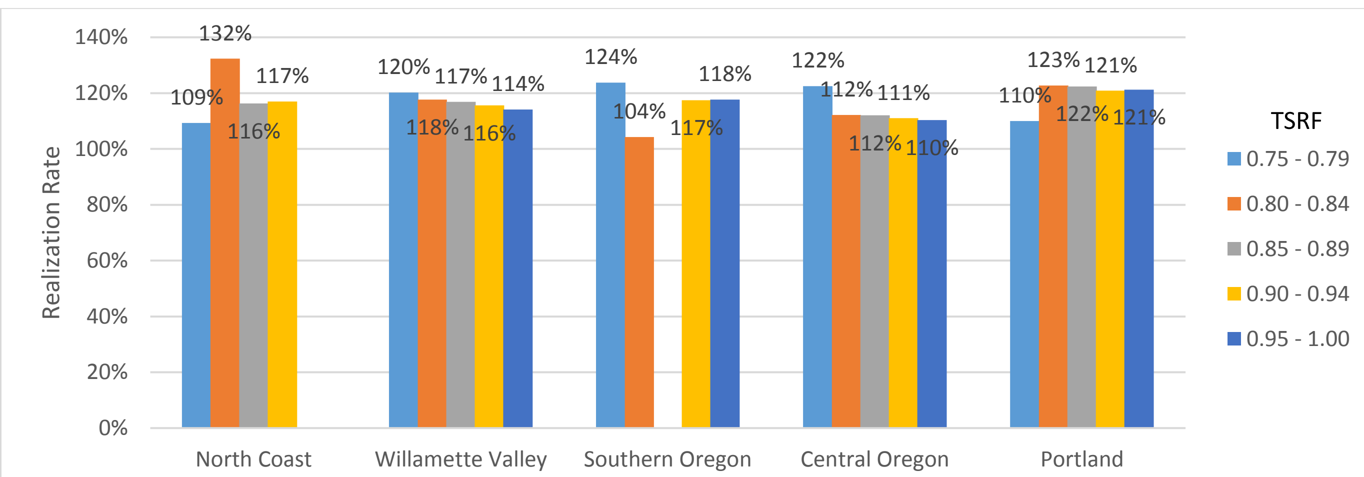


Table 15 shows realization rates by TSRF. For this sample, realization rates remain relatively constant across a range of TSRF values, suggesting that other aspects of the pre-installation AEP estimates may be overly conservative.

Table 15. Third-Party Production Data Realization Rates by TSRF (Residential)

TSRF Value	Count	Sum of Third-Party Meter Reading kWh	Sum of Energy Trust Total kWh	Realization Rate
0.75–0.79	358	4,879,252	4,343,874	112%
0.80–0.84	289	3,953,101	3,287,709	120%
0.85–0.89	264	3,715,878	3,111,168	119%
0.90–0.94	269	4,004,427	3,407,333	118%
0.95–1.00	221	3,348,423	2,837,380	118%
Grand Total	**1,401**	**19,901,081**	**16,987,464**	**117%**

Table 16 shows realization rates by region. There does not appear to be a discernable or obvious trend in realization rates by region.

Table 16. Third-Party Production Data Realization Rates by Region (Residential)

Region	Count	Sum of Third-Party Meter Reading kWh	Sum of Energy Trust Total kWh	Realization Rate
Astoria (North Coast)	4	46,927	40,214	117%
Eugene (Willamette Valley)	26	527,663	491,768	107%
Medford (Southern Oregon)	7	168,763	145,244	116%
North Bend (Central Oregon)	2	35,922	26,302	137%
Portland	1,010	13,200,728	11,168,780	118%
Redmond (Central Oregon)	170	2,834,795	2,510,794	113%
Salem (Willamette Valley)	182	3,086,282	2,604,362	119%
Grand Total	**1,401**	**19,901,081**	**16,987,464**	**117%**

Lastly, Table 17 shows realization rates by installation year where realization rates appear to be lower for older systems. This correlation may be directly caused by the age of the system itself or may be a combined effect of other variables. For example, perhaps better performing equipment are increasing realization rates (e.g., from the presence of more microinverters and DC optimizers).

Table 17. Third-Party Production Data Realization Rates by Installation Year (Residential)

Recognized Date	Count	Sum of Third-Party Meter Reading kWh	Sum of Energy Trust Total kWh	Realization
2011	172	2,937,646	3,052,341	96%
2012	245	3,667,445	3,213,585	114%
2013	354	6,078,142	4,940,274	123%
2014	458	5,463,422	4,455,282	123%
2015	172	1,754,427	1,325,982	132%
Grand Total	**1,401**	**19,901,081**	**16,987,464**	**117%**

Solar Resource

There are two predominant datasets used for estimating long term average solar irradiance (and other weather) conditions. Both the Typical Meteorological Year (TMY) 2 and 3 data sets are publicly available and widely used, though the TMY3 data set was released more recently and has more data locations available.[10] TMY 2 encompasses the weather from the years 1961 to 1990, and TMY 3 is based on data from 1976 to 2005. Because of rapidly changing weather patterns, it is advisable to utilize the newest dataset available.

Results Summary by Sector

Residential

The results of the customer-reported meter readings and analysis of third-party production data suggest that Energy Trust residential electricity production estimates are conservative by approximately 15% to 25%. The following are general findings for the residential sector:

- Realization rates decrease slightly with increased TSRF, suggesting electricity production estimates for systems based on lower TSRF values have been overly conservative.
- Realization rates are higher for newer PV systems. This may be due to a combination of technology (panels or inverters), module rating methods, available solar resource/shading, installer siting practices, or a combination of factors.
- The third-party customer survey produced a realization rate of 124% which is somewhat higher than the production data analysis that yielded a realization rate of 117%. The reason for this difference is unknown.

[10] For more information on the TMY2 and TMY3 data sets, please refer to the National Solar Radiation Database website here: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

Commercial

The initial commercial participant survey data were found to be inaccurate; based on verification and collection of data from sites with operational PV systems, the average realization rate was 106%. The following are general observations for the commercial sector:

- Because of roll-over issues with meters (an issue on approximately 40% of the systems in the site visit sample), it would be more accurate to collect inverter measurements rather than meter readings, or use other production data collection systems. This issue will only become more prevalent over time as cumulative production approaches the roll-over point for additional systems.
- Seven sites had evidence of roll-over that was not being captured in meter readings initially gathered in the site visit, but correct values were available from the inverter. Roll-over ranged from one to three times over the course of 2011 to 2014.

Conclusions and Recommendations

Table 18 shows the final results of the 2011-2015 realization rate analysis. Commercial sites yielded 106% of expected production (from site visits), whereas the residential sites generally produced 117% to 124% of expected production, depending on the sample examined.

Table 18. 2011-2015 Realization Rates

Evaluation Group	Data Collection Method	Count	Sum of Meter Reading kWh	Sum of Energy Trust Estimated kWh	Realization Rate
Direct-Owned Commercial	Site Visits	38	4,624,447	4,349,925	106%
Direct-Owned Residential	Surveys	180	2,301,277	1,897,068	121%
Third-Party Residential	Surveys	144	1,914,839	1,550,442	124%
Third-Party Residential Production Data	Production Data	1,401	19,901,081	16,987,464	117%

The evaluated realization rates above (106% for commercial, 121% for direct-owned residential, and 117% for third-party residential[11]) were applied to the entire 2011-2015 program population, yielding an average realization rate of 112%. Overall, the program is producing nearly 64 million kWh on an annual basis, as seen in Table 19.

Table 19. 2011–2015 Evaluated Annual Program Savings

Sector	Quantity	Expected Savings (kWh per year)	Realization Rate	Evaluated Savings (kWh per year)
Commercial	407	31,981,092	106%	33,899,958
Direct-Owned Residential	2,570	11,681,789	121%	14,134,965
Third-Party Residential	2,753	13,602,688	117%	15,915,145
Total	**5,730**	**57,265,569**	**112%**	**63,950,068**

This evaluation offers the following conclusions and recommendations.

Conclusion: The evaluation results show that residential systems are performing better than expected, by 17 to 24%. Contributing factors for this higher-than-expected electricity generation include conservative treatment of TSRF (particularly with microinverters).

Recommendation: In order to more accurately estimate energy savings attributable to the Energy Trust's PV program, we recommend the following actions:

11 The third-party owned residential systems yielded a realization rate of 117% from the production data, and 124% from the surveys. Due to the much greater sample size, and to be conservative, the 117% is applied to the population.

- Attempt to gather more representative site data on TSRF for the system overall. For this analysis, we have relied upon the reported TSRF values, which are based only on worst case measurements. With a better understanding of TSRF values from different locations on the array, and comparing it with the "worst case" estimate for the same site, Energy Trust can better consider a possible adjustment to the existing calculations.
- Modify program rules to require installers to provide a different TSRF measurement based on the above recommended analysis, rather than the worst case measurement currently used.
- Energy Trust should consider adopting an assumption that reflects the observed higher realization rates for microinverters.
- Update the current calculation method to use the most current solar irradiance data (i.e., TMY3).

Conclusion: The evaluation indicates that commercial systems are performing as expected (at 106% realized production); however, there is large variability in the ability of meters to capture accurate production values because of meters rolling over after surpassing five digits.

Recommendation: For future evaluations, do not ask commercial customers for meter readings, but instead, ask for inverter readings. The most preferable method is to obtain ongoing system output from production tracking software, if available at the site. Energy Trust may also wish to consider enforcing program requirements that metering equipment be configured to report up to ten years of expected output without register roll over.

Conclusion: Because of smaller system size and greater attentiveness to electricity bills, residential customers' meter readings were reliable estimates of production.

Recommendation: Future evaluations can benefit from residential surveys to obtain production data, if this analysis is desired again in the future.

Conclusion: Microinverters may offer more relative production than string inverters, compared with pre-installation estimates.

Recommendation: Consider conducting further analysis on AEP by inverter type, particularly as a function of TSRF, and determine if it would be appropriate to adjust production estimates and associated tools to account for additional productivity from some inverter types.

Appendix A: Online Survey Questions

Online Survey Email Invitation Language

Hi ${m://FirstName} ${m://LastName},

Energy Trust of Oregon is conducting a study to see how well the solar electric systems we've supported are performing. As a solar homeowner, we are hoping you can help us with this important study.

To help us, we need you to tell us how much electricity your system has produced since it was turned on by taking a lifetime meter reading from two locations: your system's solar meter and the inverter. This should take about 5 to 10 minutes. This research will help us determine how much solar energy is being generated across the state.

As a token of our appreciation, we will send a $100 gift card a customer chosen at random from those who provide their meter readings (we expect 100-200 responses).

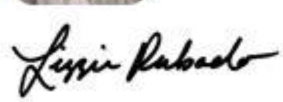
Share your meter readings from your computer or mobile device by clicking this link:

${l://SurveyLink?d=Submit your meter readings}

You can find detailed instructions on how to take the readings here. If you have any questions or need assistance, please contact Anthony Sharp at anthony.sharp@cadmusgroup.com .

Thank you in advance for your assistance. We sincerely appreciate your contribution to this study and your personal commitment to renewable energy.

With thanks,



Lizzie Rubado

Sr. Solar Project Manager

Online Survey Questions

Q1: Energy Trust is conducting a study to see how well the solar electric systems we've supported are performing. This important research relies on help from solar customers like you, so thank you for taking the time to help out. For this study, you will need to take a lifetime meter reading directly from your system's solar meter and inverter. If possible, please try to take the readings on the same day.

Q2 Solar Meter Reading: The solar meter looks like the one in the image below and is located near your electrical panel. If you don't see it, please check the outside of your house where the wiring from your solar panels enters your home or business. Just make sure you're not looking at your utility meter, which is a separate meter. More detailed instructions on how to take the reading can be found here.

Q3 Were you able to access and read your solar meter?

- ❍ Yes (1)
- ❍ No (2)

Answer If Were you able to access and read your solar meter? No Is Selected

Q4 Why were you not able to access and read your solar meter?

Answer If Were you able to access and read your solar meter? Yes Is Selected

Q5 Please provide your solar meter reading:

	Value	Unit	
		kWh (1)	MWh (2)
Meter reading (1)	(1)	❍	❍

Q6 Solar Inverter Reading: The solar inverter may look like one of the images below. It may be located near your electrical panel or the outside of your building where the wiring from your solar panels enters your home or business. To take a lifetime reading from your inverter, identify your inverter model and follow the instructions here.

Q7 Were you able to access and read your solar inverter?

❍ Yes (1)
❍ No (2)

Answer If Where you able to access and read your solar inverter? No Is Selected

Q8 Why were you unable to obtain an inverter reading?

Answer If Were you able to access and read your solar inverter? Yes Is Selected

Q9 Please provide your solar inverter reading:

	Value	Unit	
		kWh (1)	MWh (2)
Inverter reading (1)	(1)	❍	❍

Answer: If Were you able to access and read your solar meter? Yes Is Selected Or Were you able to access and read your solar inverter? Yes Is Selected

Q10 Please provide the date on which your reading(s) were taken:

Q11 Please check all the boxes that apply to you:

- ❑ I purchased this property with the system on it. (1)
- ❑ I have had warranty/repair work done. (2)
- ❑ There is no longer a solar electric system at this property. (3)

Answer If Please check all the boxes that apply to you: I have had warranty/repair work done. Is Selected

Q12 What warranty/repair work did you receive on the property and which contractor conducted this work?

Q13 Is this the address at which your solar system is installed?

- ❍ Yes (1)
- ❍ No (2)

Answer If Is this the address at which your solar system is installed? [PIPE IN ADDRESS FROM PANEL DATA] No Is Selected

Q14 What is the address at which your solar system is installed?

Address (1)
Address 2 (2)
City (3)
State (4)
Zip Code (5)

Q15 Please let us know if you have any additional feedback on your solar energy system.

Appendix B: Supplementary Instructions

How to Read your Solar Meters

Energy Trust is conducting a study to see how well the solar electric systems we've supported are performing. This important research depends on help from solar customers like you.

For this study, we need you to take a lifetime meter reading from two locations: your solar inverter and your solar meter. If you're not familiar with how to take these readings, this website will show you how.

Thank you for helping us with this important research.

1. Read your Solar Meter

What is a solar meter?

Your solar meter records all the electricity your solar electric system has produced since it was installed. It is different from your utility meter, which will be clearly labeled PORTLAND GENERAL ELECTRIC or PACIFICORP.

Where is it located?

Look for your solar meter near your electrical panel. If you don't see it, check the outside of your house where the wiring from your solar panels enters your home or business. Just make sure you're not looking at your utility meter.

How to take a reading from your meter

Your meter may cycle through several displays in addition to the lifetime generation of your system, such as the date and time. To take a lifetime reading from your solar meter, write down the number that is displayed when kWh is shown in the lower right-hand corner. This is the number of kilowatt hours (kWh) that your system has produced.

Enter this number, along with the reading from your inverter, into your online survey using the link embedded in the e-mail you received.

2. Read your Inverter

What is a solar inverter?

The inverter transforms the direct current (DC) electricity produced by your solar panels into alternating current (AC) electricity that can be used by your home or business. It also helps your system perform optimally and tracks the amount of energy produced by your systems over various time intervals.

Where is it located?

(1) Look for your inverter near your electrical panel. If you don't see it, check the outside of your house where the wiring from your solar panels enters your home or business.

(2) If you don't see an inverter, your system may have microinverters, which are tiny inverters attached to the underside of your solar panels and controlled by an online dashboard.

How to take a reading from your inverter

(1) Look up the manufacturer of your inverter in this document and follow the instructions.

(2) If your inverter isn't listed in this document or you're still having trouble, consult your owner's manual or search online for instructions on how to take a lifetime reading from your particular inverter.

3. Submit your Readings

You should have received an e-mail inviting you to participate in the study by completing a short survey. You will submit your meter readings as part of the survey. To complete the survey, use the link embedded in the e-mail. If you can't find the e-mail, contact Lolly Lim at 240.204.6226 or lolly.lim@cadmusgroup.com.

Get More Help

Contact Lolly Lim at 240.204.6226 or lolly.lim@cadmusgroup.com for help reading your meter or submitting your meter readings.

If your solar meter or inverter is displaying an error message of any kind, note the message and contact your installer. Please let us know about the problem by completing your survey. To complete the survey, use the link embedded in the email you received.