Residential solar systems reduce summer peak demand by 58 percent in Texas research trial

West-facing solar PV generating more than south-facing PV among studied homes during summer months

Summer 2013

Of all emerging smart grid and distributed generation products, rooftop solar photovoltaic (PV) systems produce the most complex set of impacts for the electricity system.

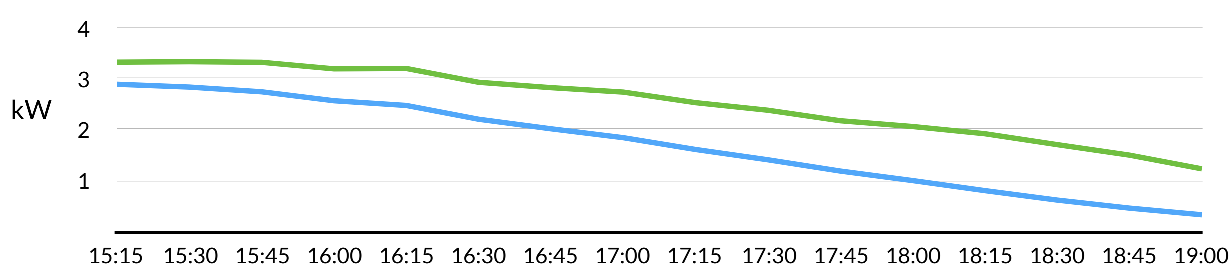
These systems potentially affect a range of key electricity system delivery and financial operations, including:

- voltage regulation on distribution systems
- revenue generation to cover system operations costs
- peak demand management

Drawing on original data from a research trial on solar PV performance and on how much of the rooftop generated energy was used inside the home (as opposed to sent back to the grid), this Pecan Street report analyzes a randomly selected subset of 50 homes participating in Pecan Street's consumer research trials. All homes in the sample are in Austin, TX.

This report calculates the actual generation and the amount of energy used inside each studied home to evaluate the impact of residential rooftop solar PV systems on utility operations and customer electricity use profiles. The analyzed period is June 1 - August 31, 2013.

Twenty four of the 50 homes have south-facing solar systems, 13 have west-facing systems, and the remaining 13 have rooftop systems with both south- and west-facing panels.



Peak hours only: Normalized daily generation (kW) for south- and west-facing residential rooftop solar PV. June 1 – August 31, 2013. For the west-facing systems, 84 percent of electricity generated during peak hours was used in the home. For the south-facing homes, 78 percent of generated electricity was consumed in the home. Source: *Pecan Street*

The median home size for the sample is 2,122 square feet. The median solar PV system size is 5,950 watts. Median daily electricity use was 47.5 kWh. Average daily use among participants ranged from 20 kWh to 70 kWh. (For some participants, average daily electricity use was reduced due to summer vacations.)

Electricity use averaged .022 kWh/square foot; for a 2,500 square foot home, this translates to 55 kWh per day and a $198 monthly electric bill (applying the EIA national average rate of $0.12 over a 30-day month).

In all studied homes, solar generation is measured separately at one-minute intervals using current transformer-based systems installed at the circuit panel. A subset of the homes also have electric cars; for purposes of this analysis, the electricity used to charge the car was subtracted from each measured interval of home electricity use. In other words, electricity use totals in this report exclude electric vehicle charging values.

Key Observations

Key findings from this analysis include:

- Counting only the electricity generated by a rooftop solar system that is actually used in the home (and therefore not counting electricity that was sent to the grid because it could not be used in the home), homes averaged a 58 percent peak demand reduction for electricity from the grid.
- West-facing solar PV systems produced a 65 percent peak demand reduction, on average. South-facing PV systems produced a 54 percent peak reduction. (This report uses ERCOT's most common definition of summer peak hours: 3-7 pm.)
- Normalized for a 5,500 watt system, west-facing PV systems generated 49 percent more electricity during peak demand hours than did south-facing systems.
- West-facing PV systems generated more electricity than south-facing systems over a full day, both on an actual and a normalized basis.
- Over a full day, counting only electricity actually used in the home, south-facing systems provided 35 percent of total daily electricity use. Homes with west-facing systems generated 37 percent of total daily electricity use.
- Eighty-four percent of electricity generated during peak demand hours by west-facing systems was used in the home. For homes with south-facing systems, uptake was 78 percent, and for homes with both south- and west-facing systems, uptake was 80 percent.

Key Takeaways

To the extent the measured patterns in the studied sample are confirmed by other research, these findings suggest the following:

- Rooftop solar systems, and particularly west-facing rooftop systems, may act as a fairly impactful peak demand reduction device.
- Utilities that offer residential rooftop solar rebates may want to extend rebate eligibility to west-facing systems and even offer higher rebate levels than is provided to south-facing systems.
- The highest value orientation for residential roof solar is significantly influenced by whether the residents work out of the home during the day.

Background

Accurately determining the impact for utilities and customers of rooftop solar PV requires evaluating variables such as —

- the amount of electricity used in homes with PV
- when this electricity is used
- how much energy the rooftop solar systems are producing
- when they are producing this electricity
- the price of the electricity at the time of generation
- whether net metering compensation structures are in place
- the density of PV adoption in the studied area

From the perspective of protecting electric reliability, it is better for energy generated by rooftop solar panels to be consumed on-site rather than be injected onto the utility distribution system.

Utilities typically design voltage regulation processes for distribution systems with the assumption that the only power source on the system is at the substation. When a grid-connected rooftop solar system generates more electricity than can be used in the home at that moment, the excess electricity is typically introduced back onto the distribution system.

At low solar PV penetration levels, utilities typically can use existing voltage regulation processes to manage intermittent dispatches of excess solar-generated electricity. However, the risk of distribution system instability increases when greater numbers of solar PV systems inject excess power onto distribution system assets.

Determining the adoption level at which solar PV systems trigger system instability is not straightforward. When the bulk of the electricity generated by a residential rooftop solar system is used inside the home, distribution systems can continue operating reliably at higher levels of solar PV adoption than is possible under scenarios where higher portions of each system's generated electricity is pushed back to the grid.

In addition to voltage regulation issues, excess electricity injected onto distribution systems leads to greater use of utility distribution assets such as transformers. The question is whether the benefits of higher generation uptake inside the home in the summer (and thus reduced use of the electric grid) outweigh the cost of the increased wear and tear created from excess generation in fall and spring months. (This issue is the subject of ongoing PSR research at the transformer level.)

While PV-generated energy used in the home reduces impacts on utility distribution assets, it also, of course, represents lost sales for utilities. This particularly impacts utility distribution operations, for which the cost of operating and maintaining poles and wires is typically recovered through distribution service charges based on the amount of electricity purchased from the grid.

Not all lost sales are financially disadvantageous (particularly for utilities that provide retail electric service). Electric utilities of all types are implementing or evaluating tools such as time-of-use pricing, thermostat cycling and demand response for a straightforward reason: providing peak demand electricity is costly and can be unprofitable. Thus, to the extent lost sales occur during summer afternoon peaks (for regions with high air conditioning loads) or winter morning peaks, utilities and customers alike could benefit.

Full Day Solar PV Production

During the June 1 – August 31, 2013 period, participants' rooftop solar PV systems generated, on average, 25.17 kWh over a full day. This average has a standard deviation of +/- 3.08 kWh.

The period of maximum production ran from noon to 3:30 pm. Normalized for a 5,500 watt system, generation averaged over 3 kW at all intervals over this period. Generation typically began (at low levels) between 6:30 and 6:45 am and ended between 8:00 and 8:15 pm.

Peak Hours Solar PV Production

Over the analyzed period, participants' rooftop solar PV systems generated, on average, 7.94 kWh during summer peak demand hours (3-7 pm) per day, accounting for 32 percent of total daily production.

South- vs. West-facing System Performance

The directional orientation and pitch angle at which solar panels are installed impacts the amount of sunlight that will reach the panels and when these panels generate electricity. For example, a solar panel oriented to the east would generate the bulk of its electricity in the morning hours, and production would drop off in mid to late afternoon. Conversely, panels oriented to the west will generate more of their electricity later in the afternoon. Additionally, solar panels on homes with a flat or nearly flat roof will capture more of the sun's rays than will solar panels on steep pitched roofs.

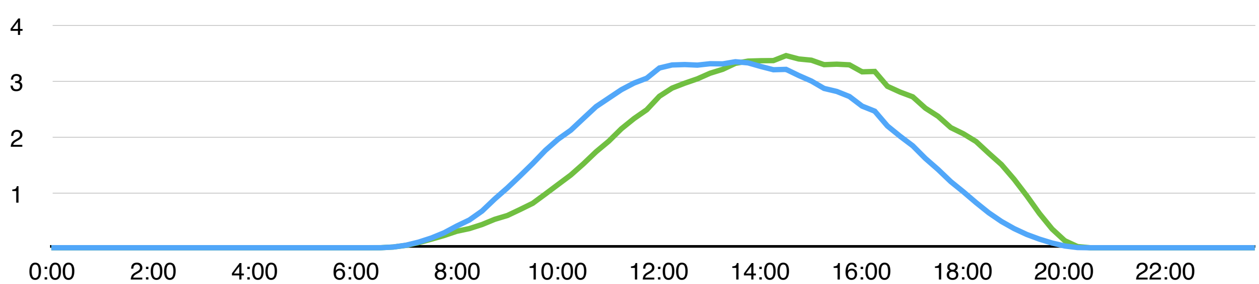
Most residential PV systems in the northern hemisphere are oriented to the south. Over the course of a full year, a south-facing orientation produces more total energy than other orientations. Most residential rooftop solar panels are installed at nearly the same pitch angle as the pitch angle of the roof, and most homes on which solar panels are installed have pitched roofs. The angle of pitch can vary considerably from home to home and between regions.

To the extent the value of rooftop solar panels is driven by how much of the electricity generated on the roof is consumed in the home, the optimal orientation would be that which maximizes the amount of generation used in the home.

A scenario where this would become salient would be where no net metering applied – i.e., customers receive no financial benefit for excess electricity generated by their panels that is sent back to the grid.

In areas with high summer air conditioning use, the value of solar panels could shift even more toward systems oriented to maximize the generation used in the home on summer afternoons – even if this resulted in less overall annual generation. This shift in highest value orientation would likely be accentuated even further for residential customers who pay a time-of-use electric rate and/or a critical peak price.

Likewise, utilities and grid operators could realize benefits from customer rooftop systems that are oriented to emphasize generation on summer afternoons that was used in the home. Many utilities and grid operators in areas with high air conditioning use already devote considerable resources to equipment (ranging from peak power plants to programmable thermostats) and customer programs (such as demand response and time-of-use pricing) that are employed on just a handful of hot summer afternoons each year.



Normalized daily solar PV generation (kW) for homes with south- and west-facing PV. Generation from west-facing systems peaks slightly later on a summer day than does generation from south-facing systems. Source: *Pecan Street*

To advance understanding of the comparative benefits from different orientations, PSR analyzed homes with south-facing systems, west-facing systems and systems with both south- and west-facing panels. (PSR paid a research stipend to some participants to incentivize installation of west-facing systems.)

During the studied period, west-facing PV systems generated more electricity than south-facing systems over a full day, both on actual and normalized bases.

Orientation	Avg. daily generation	Normalized
South	23	24.83
West	25	26.00
South + West	28.86	25.16

Daily average solar PV generation (kWh) and normalized average daily PV generation (normalizing all systems to 5,500 watts). Source: *Pecan Street*

On a normalized basis, west-facing systems generated four percent more electricity per day than comparably sized south-facing systems.

Peak demand generation from south- and west-facing systems

With production ramping up later in the day for west-facing systems, the difference in generation between the south- and west-facing systems was considerably more pronounced during peak demand hours.

Normalized for a 5,500 watt system, west-facing PV systems generated 49 percent more electricity during peak demand hours than south-facing systems generated.

Orientation	Avg. peak generation	Normalized
South	6.32	6.77
West	9.86	10.08
South + West	9.07	7.96

Peak demand hours only: Average solar PV generation (kWh) and normalized average peak PV generation. Source: *Pecan Street*

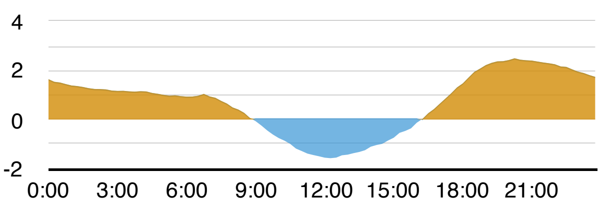
Full day solar PV uptake

The amount solar generation that is actually used in the home is a critical issue for utilities and grid operators that serve areas with increasing adoption of rooftop solar PV. It is also an important issue for owners of rooftop solar systems who do not receive a net metering financial benefit for generating excess energy.

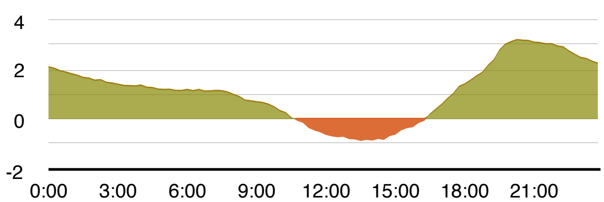
For homes with south-facing systems, 58 percent (13.43 kWh) of electricity generated from the rooftop system was used in the home, and 42 percent (9.57 kWh) was sent back to the utility grid. For homes with west-facing systems, 75 percent (18.78 kWh) of PV-generated electricity was used in the home, and 25 percent (6.72 kWh) was returned to the grid.

Among all homes in the sample, 64 percent (16.09 kWh) of daily electricity generated from rooftop solar systems was used in the home and 36 percent (9.09 kWH) was injected back onto the distribution system.

Counting only the electricity actually used in the home, rooftop solar systems provided 36 percent of average daily electricity use. For homes with south-facing systems, the rooftop solar provided 35 percent of average daily electricity use. For homes with west-facing systems, the average was 37 percent.



Daily net grid impact (kW) for homes with **south-facing** PV: draw from grid and PV generation sent to grid. Source: *Pecan Street*

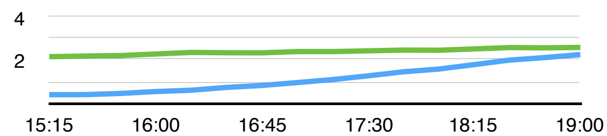


Daily net grid impact (kW) for homes with **west-facing** PV: draw from grid and PV generation sent to grid. Source: *Pecan Street*

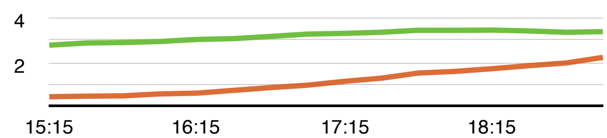
Peak demand reduction from rooftop solar PV

Applying the previous analysis to peak demand hours only, 80 percent (6.42 kWh) of electricity generated from rooftop solar systems was used in the home and 20 percent (1.53 kWH) was injected back onto the distribution system.

For homes with south-facing systems, 78 percent (4.96 kWh) of electricity generated by the rooftop system during peak was used in the home, and 22 percent (1.36 kWh) was sent back to the grid. For homes with west-facing systems, 84 percent (8.2 kWh) of PV-generated electricity was used in the home, and 16 percent (1.66 kWh) was returned to the grid.



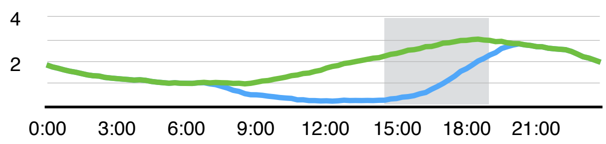
Peak hours only: Electricity drawn from grid (kW) for homes with no PV and south-facing PV. Source: *Pecan Street*



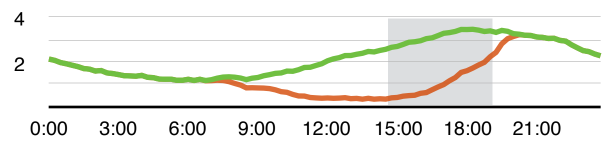
Peak hours only: Electricity drawn from grid (kW) for homes with no PV and west-facing PV. Source: *Pecan Street*

Sample representativeness

The 50 single-family homes in this sample are a randomly selected subset of the 175 homes with rooftop solar PV participating in Pecan Street's consumer research trials. All homes are located in Austin, Texas. For purposes of



Daily electricity drawn from grid (kWh) for homes with **south-facing** PV: use without PV and draw from grid with PV. The shaded area delineates peak demand hours. Source: *Pecan Street*



Daily electricity drawn from grid (kWh) for homes with **west-facing** PV: use without PV and draw from grid with PV. The shaded area delineates peak demand hours. Source: *Pecan Street*

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this analysis, the analyzed homes are a sample from the population of single family homeowners.

A core question in studying any sample from a larger population is how representative the sample is of the larger population. Future research will help in this regard by providing data on other regions and seasons.

This quarterly report focuses explicitly on a single period of the year: June 1 – August 31, 2013. The summer months have longer hours of daylight and higher levels of seasonal electricity use for air conditioning (in areas with such demands). Therefore, particularly for solar production and home energy use patterns, the summer months present a very different use and generation profile from other seasons.

Known questions that are the subject of current Pecan Street research and which will be included in future reports include:

- The impact of latitude on solar panel production. (Illinois, for example, has more daylight minutes than Texas during summer months and fewer daylight minutes during the winter.)
- The impact of seasonal variation on solar panel production. (Fall days are shorter than summer days, for instance, while solar PV efficiency has generally been found to be higher on temperate days than on very hot summer afternoons.)
- The impact of seasonal variation on solar uptake levels at homes. (In regions with high electric heating or cooling loads, homes use much less electricity during temperate periods, and solar panels produce less overall energy during fall and spring than during summer.)
- Incorporating azimuth and tilt values for rooftop systems at all studied homes
- Identifying the underlying drivers for differing performance among some solar panels.