# Is the "duck curve" eroding the value of energy efficiency?

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**ABSTRACT**

In recent years, utilities in the southwestern U.S. and California have experienced significant increases in the penetration of renewable resources – particularly solar PV. This has had a major effect on the operation and pricing of electricity in the wholesale markets in these regions. For example, the frequency of negative prices in the California ISO energy markets has increased in recent years, particularly during midday hours with low to moderate load (e.g. in April). This dynamic suggests a reduced energy savings value for efficiency measures during certain times of day. In response to these negative pricing events, several southwestern utilities have proposed major overhauls – including significant reductions – to their energy efficiency portfolios. Utility proposals have also included "reverse demand response" and other load building activities under the umbrella of demand-side management. Meanwhile, there is still a need to meet overall peak demand and evening ramps, which suggests continued value for efficiency measures.

In this paper we explore the impacts of recent changes and future projections of wholesale market prices on the value of energy efficiency. More specifically, we conduct a time-based analysis of wholesale market prices in conjunction with time-specific savings from efficiency measures to better understand how the energy value of efficiency is evolving as renewables reduce the marginal cost of generation. We find that while some measures are likely to become less cost-effective, there is still significant value in a diversified efficiency portfolio. As the resource mix evolves, it will be necessary to tailor energy efficiency portfolios accordingly. However, we do not find compelling evidence for major overhauls in efficiency portfolios based on current or near-future levels of renewable energy over the next decade.

## Solar PV and energy market trends in the Southwestern U.S.

Over the last decade, a significant amount of solar PV resources have been deployed in the Southwestern U.S. These are comprised of both large scale, utility-owned and contracted facilities, as well as smaller, distributed generation facilities that provide energy directly to customers “behind-the-meter” (e.g. rooftop solar). Figure 1 illustrates an example of this for the states of Arizona and California, which have some of the best solar resources in the U.S.

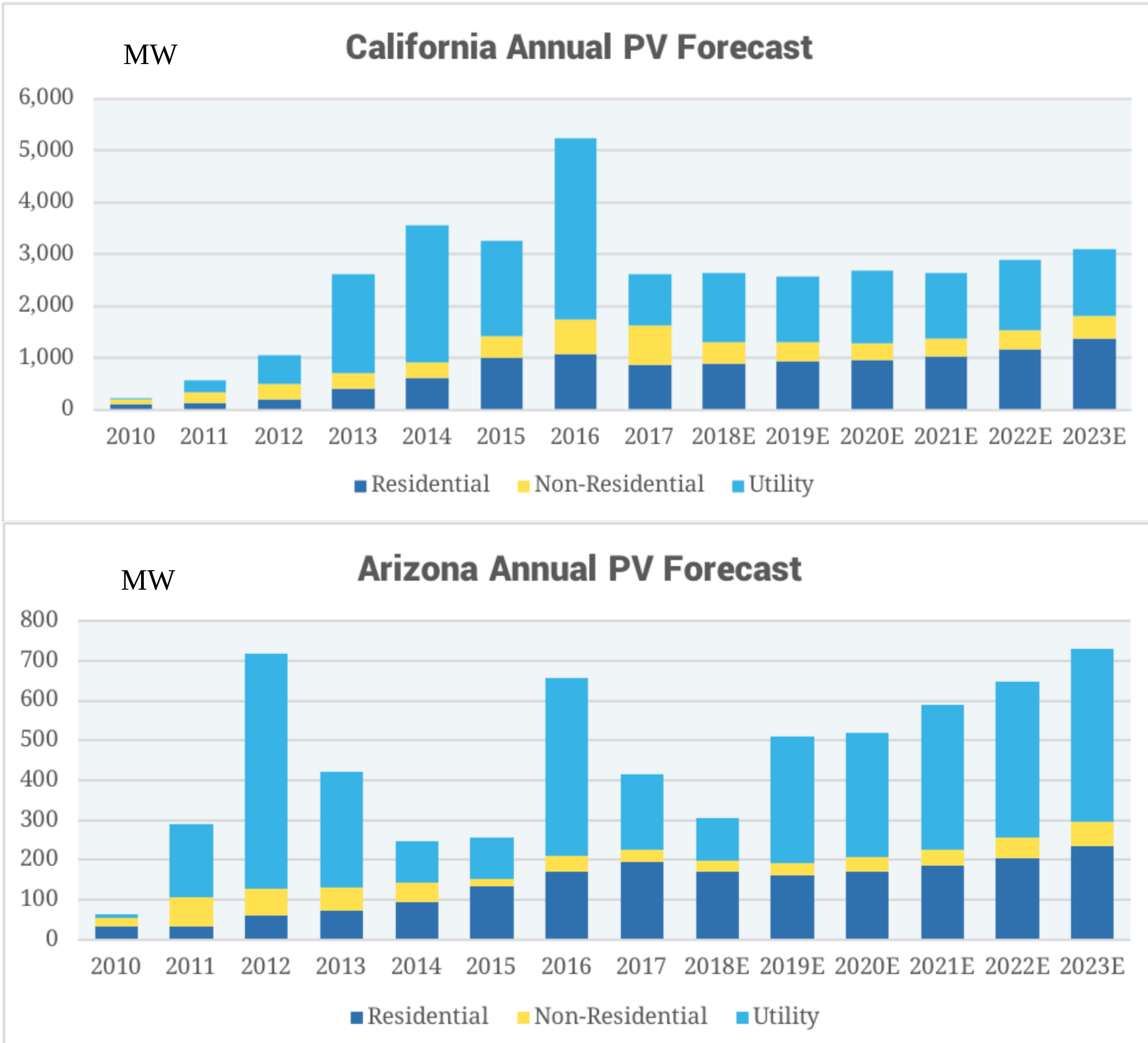


*Figure 1. Incremental MW of solar PV deployed in recent years and projected/estimated ("E") for future years in California and Arizona. Source: SEIA 2018.*

In the California ISO (CAISO), over 10,000 MW of large-scale solar resources and several thousand MW of distributed resources are already interconnected, versus an average system load of about 26,000 MW. Recently the CAISO reached an all-time maximum of serving 67.5% of its load with renewable resources during a brief interval, with about two thirds of these renewables coming from solar PV (CAISO 2018). These resource additions, combined with other market conditions (e.g. low natural gas commodity prices), have had a noticeable influence on wholesale market prices. In general, prices have been depressed – frequently even negative – particularly during mid-day in low or moderate load months in the spring (i.e., February-May). This phenomenon arises due to a combination of factors including low load conditions, abundance of hydro resources during spring runoff, and the need to keep certain thermal resources online at their minimum output levels for reliability reasons. The recent growth in solar generation has led to the potential for overgeneration conditions during these times (often referred to as the "belly of the duck curve")[1] which can lead to negative prices. Prices then tend to increase rapidly during evening hours when solar resources become unavailable and conventional generation must ramp up quickly in response.

While these dynamics have been known within California for some time, there is also increasing visibility into similar pricing trends for other parts of the Western Interconnection due to the expansion of the Western Energy Imbalance Market, operated by the CAISO. Below is an example of real-time prices (hourly averages) for recent months in the Arizona Public Service load area. The results show low or negative daytime prices during the months selected (March and September 2017).

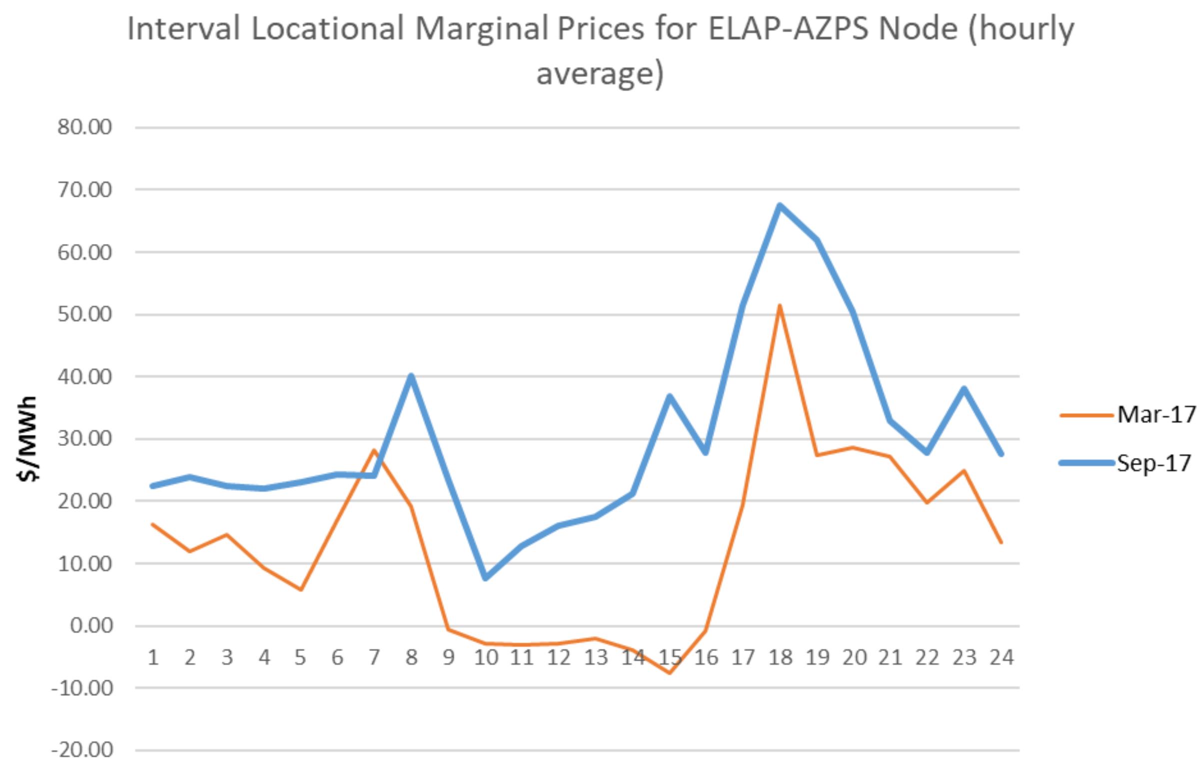


*Figure 2. Wholesale market prices for two months in 2017, for Arizona Public Service's load aggregation point. Source: CAISO 2018.*

Recent analysis on wholesale market pricing trends indicate that the frequency of negative pricing events in CAISO (and perhaps the broader Western region) may be somewhat unique to the region at present (see Figure 3). There are other drivers of these trends, particularly low natural gas prices. However, the frequency of low and negative pricing is likely at least in

[1] The "duck curve" refers to the graphical representation of system load, net of renewable energy, for a single day (typically a light load day in the spring), which has been described to resemble a duck. The curve illustrates the challenges of operating the system as solar PV penetration increases. During midday, overgeneration conditions can occur, sometimes referred to as the "belly of the duck." During early evening, solar PV becomes unavailable leading to increased ramping needs, sometimes referred to as the "neck" or "head" of the duck.

part due to renewable energy and may be increasing as renewable energy penetration increases.

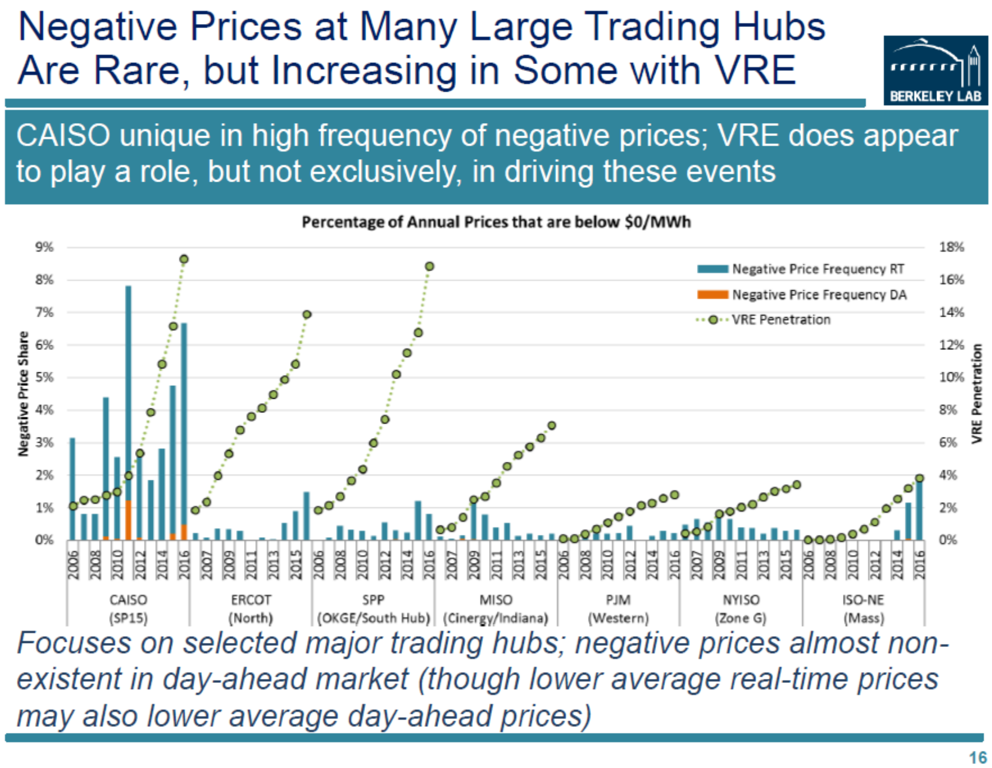


*Figure 3. Summary slide from a recent study conducted by Lawrence Berkeley National Lab titled, "Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs." As shown, the share of annual prices in CAISO that were negative was between 6-7% in 2016, while the percent of variable renewable energy (VRE) increased to approximately 9%. Source: Wiser 2017.*

## Examples of Utility DSM Program Changes

In response to these trends, some utilities in Arizona have proposed significant changes to their resource plans and their approach to demand-side management (DSM) programs. The notion presented in these utility proposals has been that the value of energy efficiency and demand management programs is diminished going forward – possibly even detrimental during some time periods – due to increasing penetration of solar PV and other renewables and their effect on wholesale market prices. As a result, these utilities have proposed to significantly reduce their planned amount of expenditures on cost-effective DSM programs and measures. For example, in its 2017 Integrated Resource Plan (IRP), Arizona Public Service (APS) proposed significant reductions to energy savings achieved through its DSM portfolio:

> While traditional EE programs provide customers a greater role in managing their energy use, the focus of DSM efforts needs to align with APS resource needs by emphasizing savings during high cost, high demand late afternoon and evening hours rather than midday hours when solar generation is abundant and wholesale energy market prices are lower (Source: APS 2017).

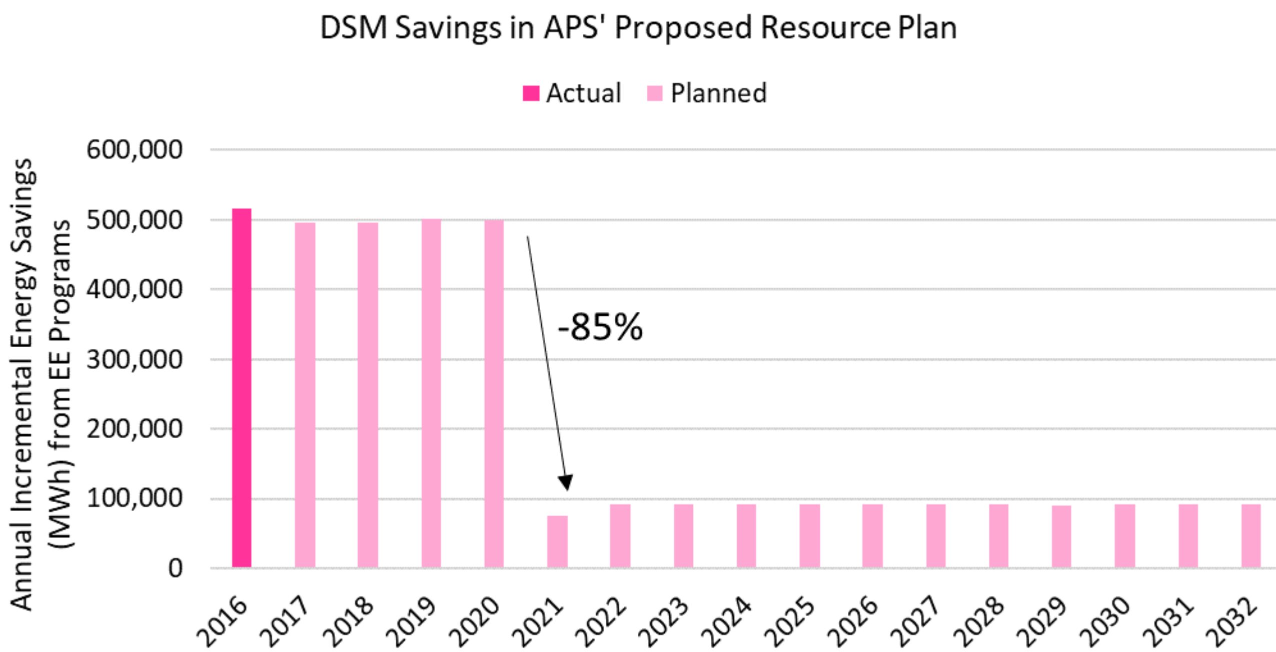


*Figure 4. Energy efficiency program energy savings (MWh) as projected in APS' 2017 IRP. Source: APS 2017 IRP, ATTACHMENT C.1(B) – ENERGY CONSUMPTION BY MONTH AND CUSTOMER CLASS, p 245-252. Source: APS 2017.*

Although APS provides the clearest example, reductions in DSM programs have also been proposed by Tucson Electric Power (TEP 2017a). TEP indicates in its resource plan that some DSM measures may be misaligned with system needs (TEP 2017b).

In addition to reducing overall investment in DSM programs, APS has also proposed to build load in midday periods to take advantage of negative pricing events. For example, in its proposed 2018 DSM Implementation Plan, APS includes the following statement and accompanying chart:

> "In addition, a new opportunity now exists within DSM to strategically build load in the middle of the day through load shifting, vehicle electrification, and reverse demand response. To illustrate the point, see Figure 3 below. The black line on the graph shows the real time hourly market prices for APS in April 2017, with hourly prices shown on the right-side Y-axis and hours of the day shown on the X-axis. It shows such persisting negative prices in real time that the hourly price during the highest solar production period is negative in many hours of the month, particularly during hours 10 through 15 (10am through 3pm). The opportunity for APS to take advantage of negative pricing is real today. The ability for customers to benefit from this is real, today. Also, from a regional perspective, given renewable targets in both California and Arizona (or, the region) and the likely continued deployment of solar resources, this opportunity is likely to increase. Thus, enhancing DSM to capture this value for customers is prudent. In addition, the bars on the graph show savings shapes for interior LED lighting measures in the APS non-residential programs, which show most savings occurring during times when prices are very low or negative. Continuing to promote EE savings during the middle of the day, when prices are shown as below, can actually harm customers by limiting the ability to take advantage of negative pricing." (Source: APS 2017b)

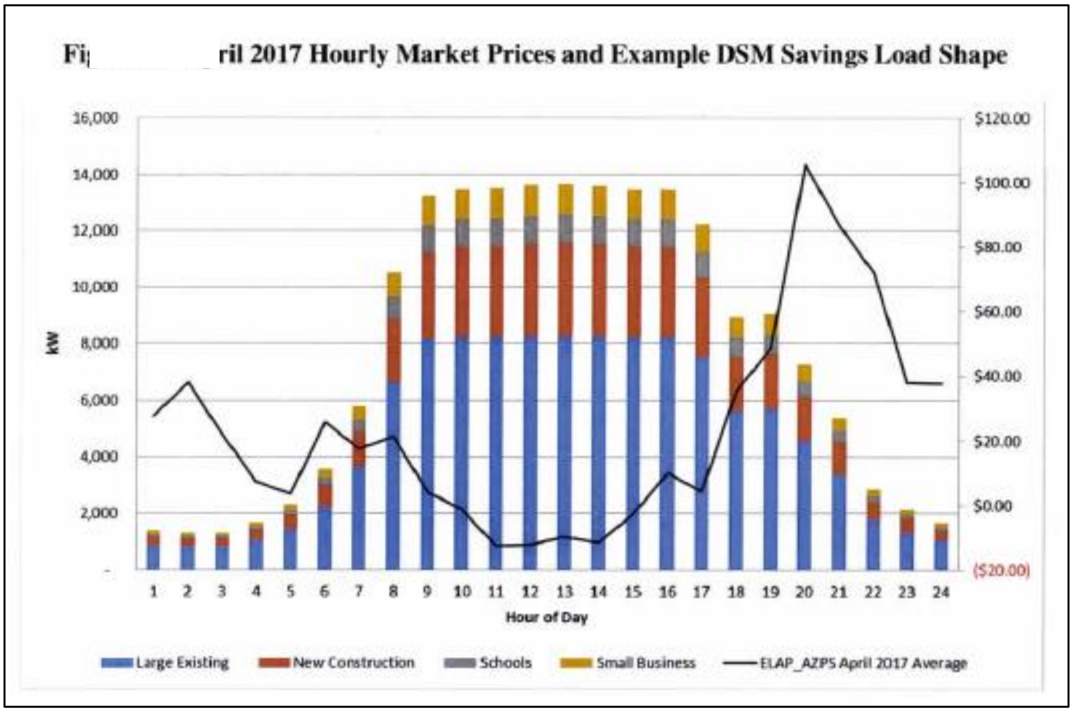


*Figure 5. Excerpt from APS' Proposed 2018 DSM Implementation Plan. The figure above illustrates just the savings achieved by a subset of APS DSM programs on a day in April and are not representative of the full DSM portfolio over the course of a year. Source: APS 2017b.*

While the effects of depressed or negative pricing are used in part to justify DSM program changes, APS also recognizes a continued and growing need to meet peak demand. As such, DSM measures that coincide with peak demand likely still have significant value in terms of reduced supply-side capacity investment needs. Additionally, it is clear that energy value persists during other hours of the day and in other months besides the solar PV production peak, and the energy value varies across the months and seasons. What is not clear from the analysis presented by APS is whether the energy savings occurring during low or negatively priced hours, and in other months, is sufficient to outweigh the value of savings during positively priced hours. In order to understand the relative impact these competing effects may have on the value of DSM, a more granular time-based analysis is necessary. This paper conducts such an analysis.

## Analytical approach

The energy value of DSM measures and portfolios are commonly evaluated using on-and off-peak and seasonal values in $/MWh based on wholesale prices or generation costs, or sometimes using annual average values in $/MWh. This approximation for value has generally not been a problem since load tends to correlate with energy prices and thus the energy value of a diverse portfolio of measures tends to be similar to average or seasonal wholesale prices. However, with the advent of higher penetrations of zero-marginal cost renewable resources, wholesale market prices are being affected in a new way that is independent of demand and conventional supply. As such, the impact of these trends on the energy value of DSM savings may need to be reevaluated, or at least should be analyzed in a more complete manner. For locations with high penetrations of solar PV, which has a predictable diurnal cycle, the time dimension of DSM savings becomes increasingly important.

To better understand the influence of changing wholesale market price trends on the value of DSM measures and programs, we sought to conduct a more granular time-specific analysis of wholesale market prices and their relationship to DSM program savings.

Several western utilities recently joined the CAISO-operated Western Energy Imbalance Market (EIM), including APS which began operating in the EIM in October 2016. As such, public wholesale price data is now available for all EIM participants on both an hourly Day Ahead basis and a 5-minute Real Time basis.[2] We examined the CAISO 5-minute real-time price data to develop 8760 hourly averages over a recent 12-month period for APS. The figure below summarizes the actual real-time prices for each month over the course of 2017. Note that there are several months that exhibit negative pricing on average during the middle of the day, however the vast majority of hours show positive prices.

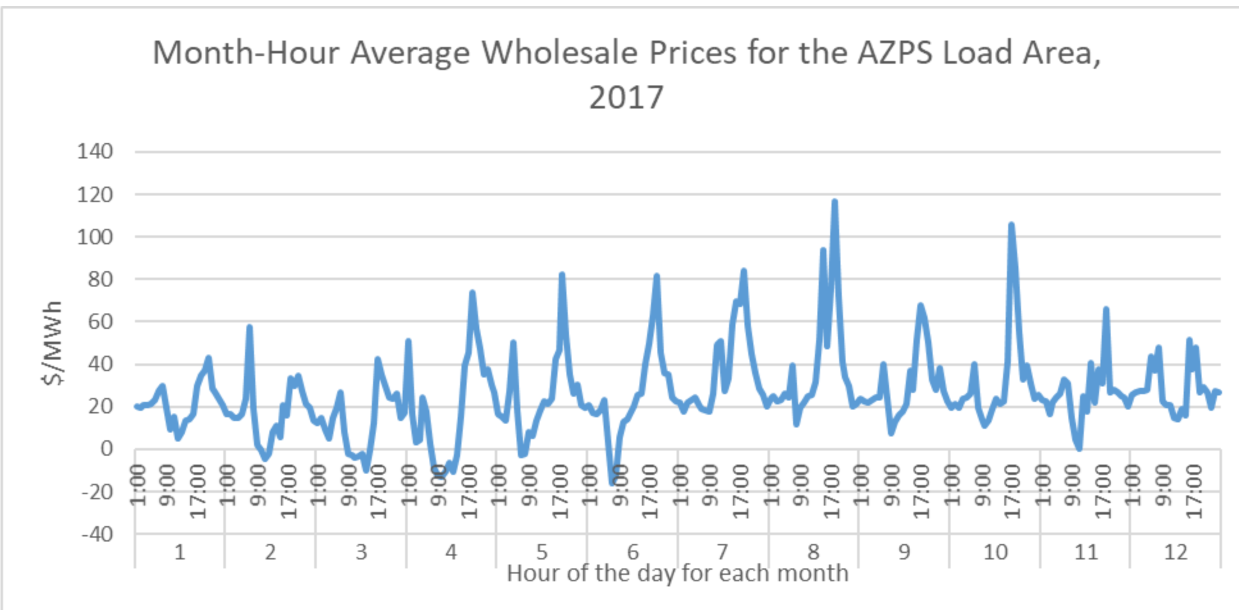


*Figure 6. 2017 month-hour averages of CAISO 5-minute interval, real-time market price data for the Arizona Public Service EIM Load Aggregation Point. Source: CAISO 2018b.*

The forecasted market price data was also presented in APS' 2017 IRP and reflects achievement of California's current 50% renewable portfolio standard, which includes significant additional investment in renewable resources. The forecasted prices show a similar pattern of negative prices during the middle of the day in March through May. The negative price values during these months are predicted to become even more extreme beyond 2025.

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[2] EIM-only participants do not participate directly in the CAISO Day Ahead market, but marginal Day Ahead prices are still reported through the CAISO OASIS system.

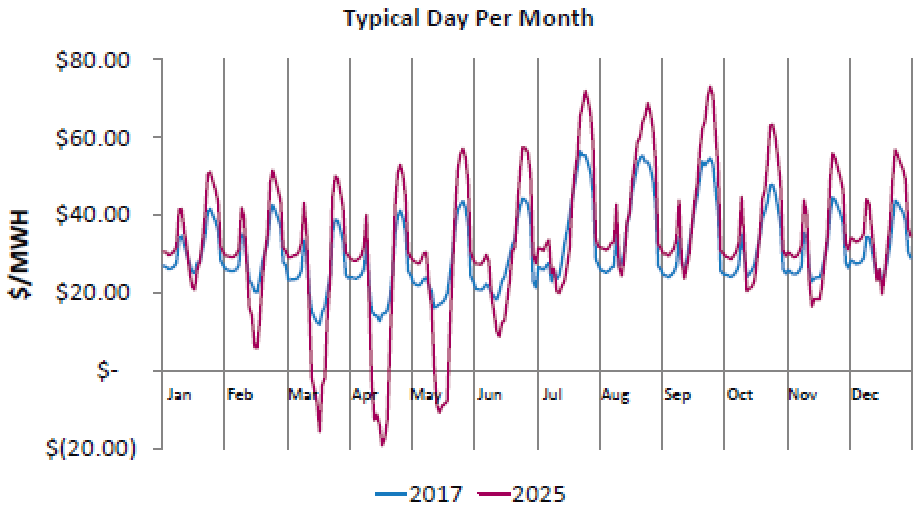


*Figure 7. APS Forecasted Day-Ahead Market Price Data for the Palo Verde hub. Source: APS 2017a.*

These actual and forecasted hourly price data were used to develop a time-weighted average energy savings value for a DSM portfolio, as well as for individual end uses that correspond to different types of DSM measures. We relied on the EPRI Load Shape Library to develop hourly load shapes for individual DSM measure types; Figure 7 illustrates the off-peak season DSM load shapes (EPRI 2018). For the overall DSM portfolio, we relied upon the hourly DSM load shape developed by APS as part of the "High DSM" case in its 2017 IRP.

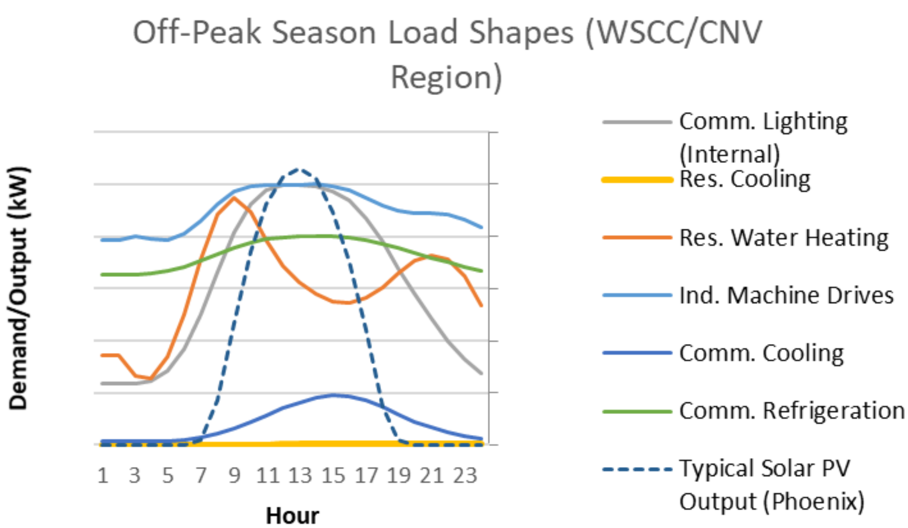


*Figure 8. Illustration of EPRI load shapes for selected end uses and comparison to typical solar PV system output. Off-peak season is displayed, which is when negative pricing events are most likely to occur. Scale is normalized to 5 kW of demand. Source: EPRI 2018, NREL 2018.*

## Analysis results

We calculated the dollar values of the energy savings for each hour based on the energy savings (MWh) achieved by the portfolio or measure and the actual or forecasted wholesale energy price ($/MWh) during that interval. The total dollars saved over the course of the year were then divided by the total energy savings to find the time-weighted average. Figure 9 below summarizes the results of this analysis for the APS DSM Portfolio and six DSM measure types. This reflects the single-year energy savings for each measure installed. For measures where avoided costs are low in later years (e.g. commercial lighting), more analysis may be needed to confirm cost-effectiveness. However, the higher avoided costs for all measures through 2027 suggests that measures installed today are likely still cost-effective over their lifetime.

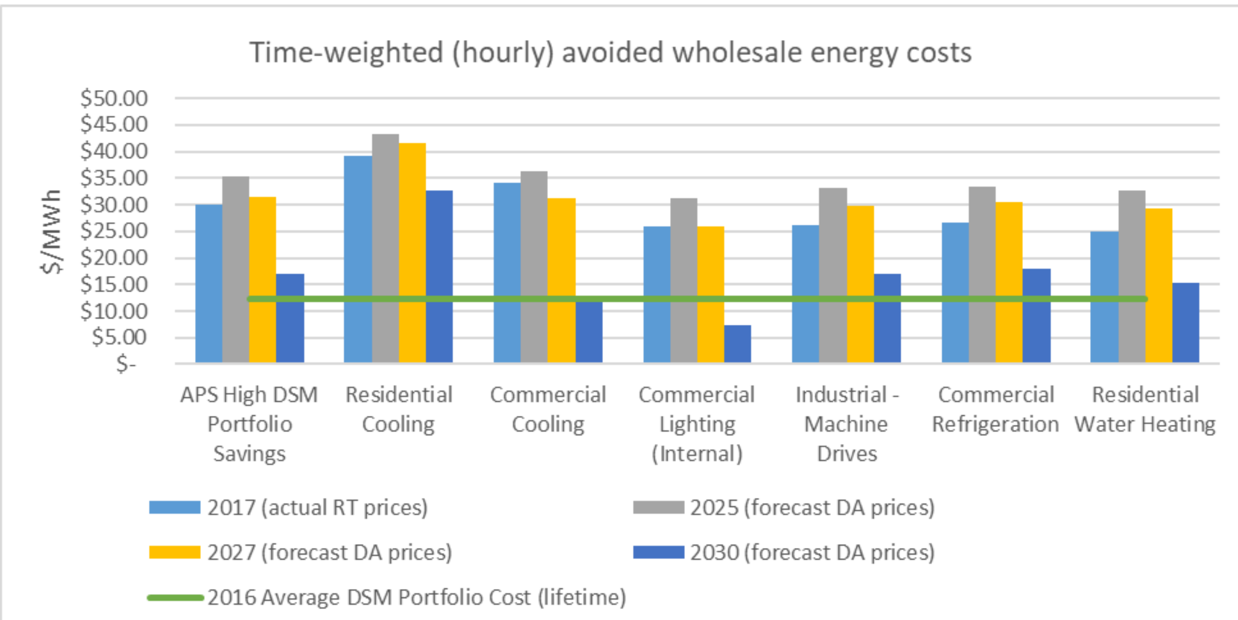


*Figure 9. Comparison of the actual and predicted future values of energy savings for a DSM portfolio and several DSM measures. Analysis was performed by calculating the time-weighted average wholesale prices that coincide with DSM savings. Actual 5-minute real-time ("RT") price data was used for 2017, while forecasted hourly price data (day ahead market, or "DA") was used for future years. For comparison, the actual DSM portfolio implementation cost is shown for a recent year (2016).*

The results show that the positive energy savings values of the DSM portfolio and each individual measure type significantly outweigh any value-reducing impacts from the effects of negative energy prices in the wholesale market over the next decade. In other words, deploying energy efficiency appears to be less costly for APS customers than purchasing energy from the wholesale market, even after accounting for future increases in the frequency of negative pricing events. Beyond the next decade the energy savings value of certain measures may start to decline as periods of negative pricing become more frequent. However, the time-weighted value remains positive overall for the measures analyzed even over the very long-term (2030). It is also important to note that this positive valuation for efficiency measures is solely based on avoided *energy* costs and does not take into account other energy system benefits such as avoided capacity costs from peak demand reduction which represents a significant additional source of value. In other words, in Figure 9 above the DSM measure types show positive economic value based solely on their energy value.

The long-term reduction in energy savings value due to negative energy prices is most pronounced for commercial lighting measures and much less pronounced for residential cooling measures. It is important to note that many factors may significantly alter projection this far out into the future including the exact type, size, and timing of renewable resource additions, natural gas prices, deployment of energy storage, vehicle electrification, and changes in transmission topology. However, DSM energy value still appears robust for the portfolio and the measure types analyzed here and exceeds recent APS costs of implementing the DSM portfolio.

***Caveats***

There are possible scenarios that include greater increase in the frequency of low and negative pricing events. Under such scenarios, energy efficiency measures may become much less cost effective than estimated here. Factors leading to such an outcome could include: accelerated adoption of renewable energy in the region, delayed retirement of inflexible thermal units, limited regional coordination of grid operations, and extremely low natural gas prices. Additionally, if measure costs increase substantially in the future, they could exceed the value of energy savings achieved.

## Discussion

Our analysis of actual recent wholesale market price data shows that (1) the number of hours with positive energy prices far outweighs the number of hours with negative prices, and (2) the instances of positive pricing far outweigh instances of negative pricing during times when DSM measures provide savings.

Analysis of forecasted future prices demonstrate that this is likely to remain true well into the foreseeable future, although there does appear to be some decline in the energy value for certain measure types that yield savings over a decade from now. The analysis presented here illustrates continued energy benefits of energy efficiency programs and DSM programs more broadly, even as negative pricing events become more common due to zero marginal cost renewable resources in periods with low to moderate load.

Negative pricing events represent a new dynamic that utility planners must contend with going forward. At this stage, however, the existence of hours with negative prices does not suggest that a departure from the current practice is warranted in the near-term or over the next decade. The near-term changes to DSM proposed by utilities to reduce investment in DSM and engage in load building activities do not appear to reflect a complete analysis of recent price trends or an understanding of future price projections over the next decade. In fact, the energy value of DSM alone, without factoring in capacity and other values of energy efficiency, appears to justify continued investment, despite the advent of negative pricing.[3] Additionally, the opportunity to take advantage of negative pricing events through load building labeled as negative demand response is currently limited to a very small number of hours over the course of the year. In our view and based on our analysis, such activities have a higher likelihood of being harmful than helpful to customers, as energy market prices continue to be higher than DSM costs in the majority of hours.

Over the very long term (beyond a decade), we anticipate that there could be more significant changes to the energy value of certain DSM measures that may warrant a gradual evolution in the utility DSM portfolio composition. For example, in 2030, under a budget constrained scenario, the energy value analysis suggests targeting incremental DSM program funds towards residential cooling measures rather than to interior commercial lighting. However, a full cost-effectiveness evaluation should be conducted at that time using then-current system and price data to determine not only the incremental energy value, but also the incremental costs and other potential benefits of the overall DSM portfolio. Such analysis should include factoring in the growing EV charging load and its load shape.

Going forward, cost-effectiveness tests should strive to include more temporal granularity to assess the effects of negative pricing events due to renewables, as well as to more accurately represent the variations in energy prices over time. Additionally, program implementers should closely monitor trends in renewable resource deployment and their effect on wholesale market prices. This should inform decisions about how to tailor DSM portfolios going forward to target measures that have a greater share of peak hour savings or savings in higher cost hours (whether on peak or not, based on market prices), and a lower share of off-peak savings or savings in lower cost hours that coincide with low or negative prices.

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[3] Notably, energy value expressed as energy avoided cost is a major component of all standard cost-effectiveness tests, including the Total Resource Cost test (TRC), Societal Cost Test (SCT), Utility Cost Test (UTC), etc.

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