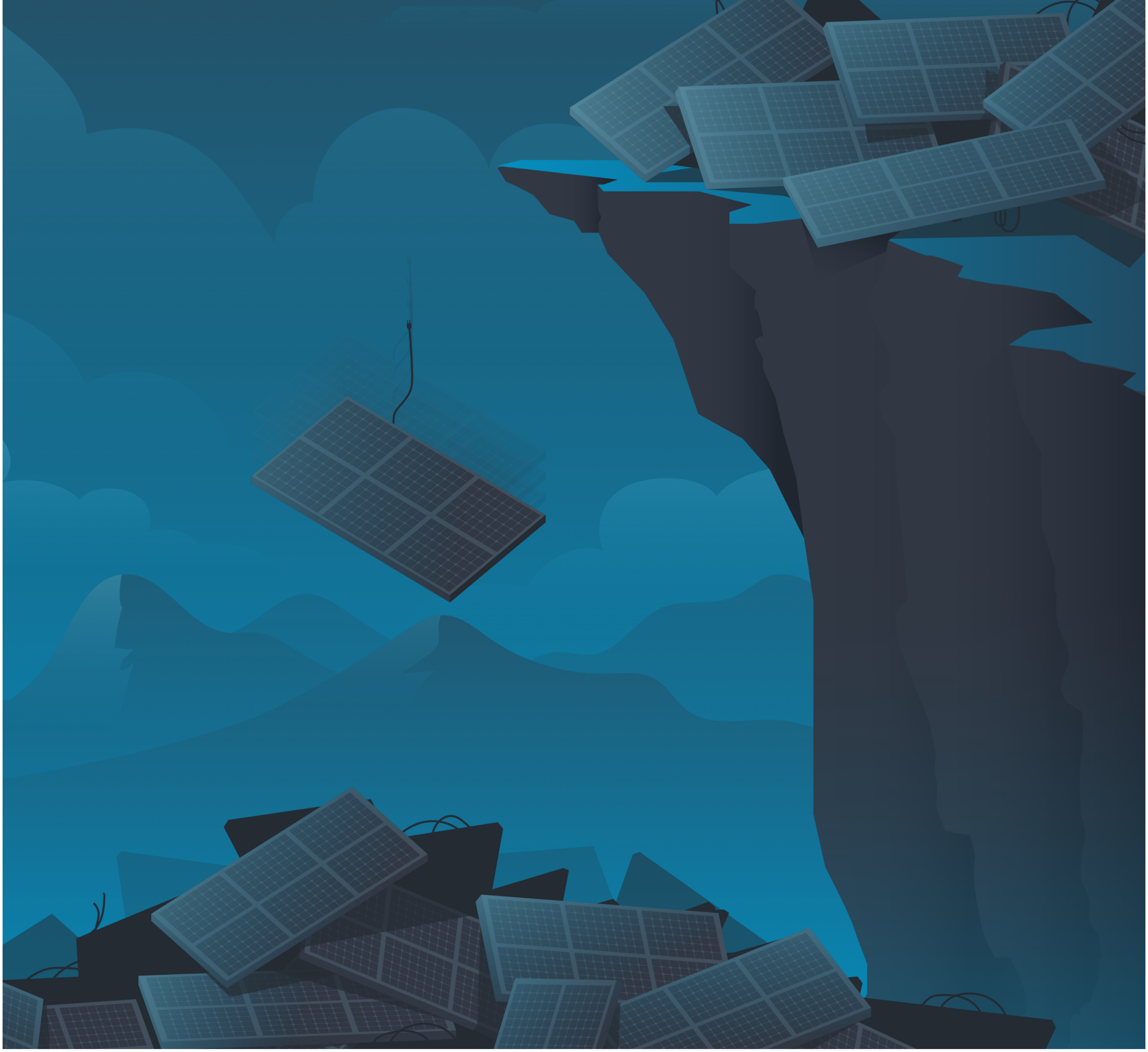
THE SOLAR VALUE CLIFF

The Diminishing Value of Solar Power

AUGUST 2017 | IER INSTITUTE FOR ENERGY RESEARCH



Executive Summary

Media headlines touting the falling costs of solar power do not tell the full story. While the manufacturing and installation costs of solar are in fact falling, solar's value to the electricity grid is also in decline. Solar power is reaching a steep drop-off point beyond which additional solar production contributes no additional capacity to the grid, and indeed begins to actively harm the grid's reliability and economics. This paper dubs the phenomenon the *solar value cliff*.

This paper seeks to refocus the discussion of solar where it should be: how solar production fits into the generation mix in a way that promotes the reliability and economical function of the grid. There is a common tendency among policymakers and the public to assume that more solar production is always good. But when it comes to discussing any investment in new generation sources, the pertinent question is how much this new generation will contribute to the grid's capacity to meet peak demand.

The findings of this paper show that solar photovoltaic (PV) energy contributes no additional capacity to the grid at a penetration level of 6 percent or beyond. Indeed, additional solar above the threshold is actively harmful to the ability of operators to maintain the capacity of the grid because it undermines the economics of those energy sources that must continue to provide the capacity to meet peak demand.

This paper finds:

- At low penetration levels, solar production can in fact reduce stress on the electrical grid, however, that does not hold true as penetration levels increase.
- Peak solar generation occurs early in the afternoon, while peak electricity demand typically occurs during early evening. This mismatch presents a scenario called the "duck curve," in which operators are forced to rapidly scale up other generation sources as solar generation ceases in order to seamlessly meet peak demand.
- By requiring operators to maintain backup capacity to address this duck curve, solar generation amounts to an imposed cost.
- When solar PV exceeds a 6-percent market share, the capacity value of additional solar PV falls to zero.

The policy implications of these findings include:

- At low penetration levels, new solar installations contribute positively to the capacity value of the grid and can reduce the need for new power plants. However, once the capacity value of new solar falls to zero, this effect is no longer valid.
- The federal Investment Tax Credit (ITC), as well as state and local incentives, should be phased out as solar power’s value to the grid diminishes as it approaches the capacity value cliff.
- In the absence of effective storage capability, any subsidies, mandates or incentives for solar penetration above a 5-percent threshold are actively harmful to the reliability and economics of the power grid.

Introduction

If someone were to ask you about the prospects for the solar photovoltaic (PV) industry, chances are, you'd say those prospects are strong. And with good reason—headlines about the industry's plummeting costs[1] abound even in popular media.[2] Solar advocates and some financial analysts[3] see the industry's falling costs[4] as an unstoppable trend sweeping the energy landscape and remaking the electricity sector as we know it.[5] Amidst this optimism, however, there is reason for concern.

While the cost of solar energy is indeed falling, so too is the value that additional increments of solar PV provide to the power grid, particularly during peak demand.

The fundamental reason for solar's falling value is its inherently intermittent nature. Solar generation is dependent on the weather, the time of day and the time of year. When the sun shines, solar energy is produced across a region almost all at once; when it doesn't shine, none is produced. If solar energy could be feasibly stored, the sun's intermittency would be a moot point, but storage is not yet economically viable. While some successful deployment of storage has occurred, it has been on a small scale at a few military installations and universities.

Because solar energy cannot be stored economically as the sun's rays intensify through the midday hours, solar energy must be immediately accommodated by grid operators; and the simultaneity of solar production means all of the available energy enters the electricity mix at the same time. When the sun sets, solar energy ceases to be a resource and other resources must be called upon.

Without storage or other grid-enhancing technology, as additional increments of new solar PV are added to the grid, they have decreasing value during peak demand periods. The opposite is true when new natural gas power plants, for example, are added to the power grid. Over the course of the day, as demand increases, more natural gas power plants can be brought online or ramped up to meet demand. If other plants go offline unexpectedly, the grid operator can bring more natural gas power plants online (or increase the output of plants already running, or both) to meet demand. Thus, while solar PV adds power to the grid, its contribution to meeting peak demand is limited. That is because as each incremental unit of solar PV is added, the peak is reduced which makes the "value" of the next unit of solar less valuable. As the peak is reduced, additional units of solar help the grid less and less until those units are costing more money than they are saving.

In countries that have high levels of solar PV penetration—namely, Spain and Italy—we have observed a quick drop-off in new solar PV investment.[6] This solar value cliff stems from the physical and economic problems of high amounts of solar PV power on the grid without storage or grid-enhancing technology. The development of advanced power controls could leverage solar PV's value from being simply an intermittent energy resource to providing ancillary services to the grid. However, currently, solar PV plants are not generally used by utilities or grid operators to provide grid-related services.

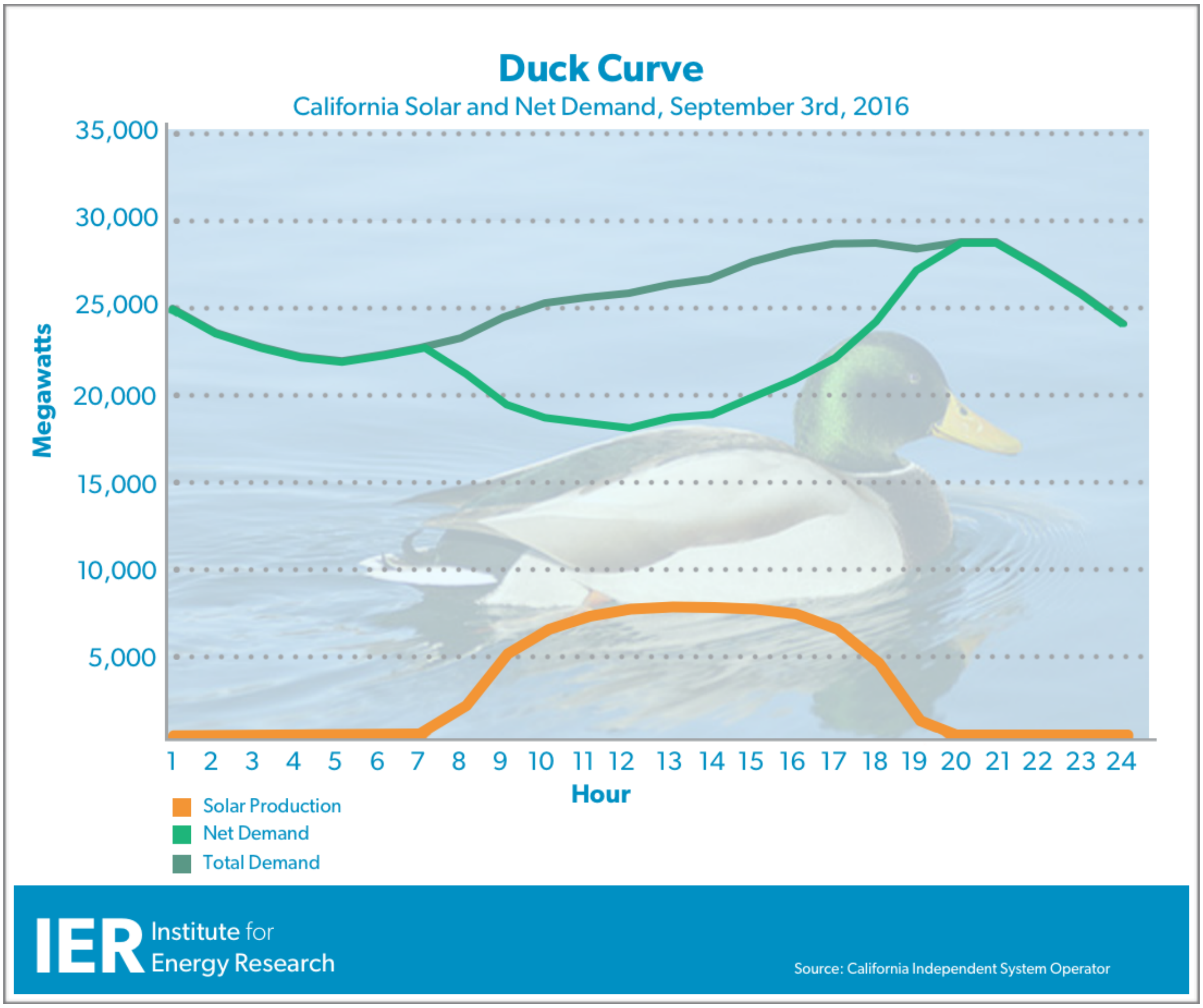
Solar's Role on the Grid

As we have begun to explain, solar energy is a unique resource on the power grid in that each additional incremental solar installation provides less value than the one before it. By its nature, energy from different solar photovoltaic installations comes on and off the grid at about the same time across the same region. That means solar is in direct competition with itself and operates under predictable timetables based on the season.

At very low penetration levels (the percentage of total demand that solar satisfies) solar PV generation is a useful resource that reduces the stress on the grid, but this is not the case at higher penetration levels. Counterintuitively, as solar penetration increases, the grid becomes more difficult to operate. This is because solar generation peaks in the early afternoon, while demand does not peak until early evening. When solar leaves the mix as the sun sets, other resources must be rapidly dispatched to make up the difference. This is especially problematic in the late summer and early fall when peak daily electricity demand often occurs in the late evening.

Below is a graph illustrating demand, solar output and net demand (demand minus solar) in California on September 3, 2016.[7] September 3 was a relatively low-demand day, but as a result, the penetration level was unusually high—a harbinger of what awaits as higher solar penetration becomes the norm.

In the graph below, the dark green line represents total demand while the orange line represents solar production. The lighter green line represents net demand—the difference between total demand and solar production. When late peak demand coincides with high solar penetration, as was the case on this selected date, the result is a system-taxing steep climb in net demand as solar production ceases with the setting of the sun.



In the graph, we can clearly see what is known as the "duck curve" in the industry.[8] The duck curve, named for its similarity to a duck's silhouette, shows the disruptive effect increased levels of solar penetration have on grid operation.

What Is Capacity Value?

To understand why solar's value is decreasing, it is important to understand the concept of capacity value. The National Renewable Energy Laboratory (NREL) defines the capacity value of generators as "their ability to reliably meet demand."[9] Capacity value is a crucial concept in helping grid operators make sure they have sufficient generation resources available to meet total customer demand under all realistic scenarios, particularly during times of highest demand.

For example, if the PJM interconnection—the regional grid that includes Washington, DC—expects an annual peak demand of 180,000 megawatts (MW) next year, it needs that much capacity value from generators in order to guarantee the lights stay on. On top of that, the Federal Energy Regulatory Commission (FERC) requires grid operators to procure about 15 percent more than what is required to meet peak demand in order to cover unforeseen contingencies, with the extra capacity called the "reserve margin."[10]

The capacity value of the generators within PJM would have to equal 180,000 MW to cover peak demand plus 27,000 MW in reserve margin, totaling 207,000 MW. Without applying the concept of capacity value, effective region-wide planning of generation resources—also called resource adequacy—would be impossible.

As NREL explains in a 2012 technical report[11]:

> Capacity value is the contribution that a plant makes toward the planning reserve margin…. The capacity value (or capacity credit) is measured either in terms of physical capacity (kW, MW, or GW) or the fraction of its nameplate capacity (%).

In this paper, we discuss the capacity value of solar power as a percentage of its nameplate capacity (maximum output). For example, if a solar array has a 100kW capacity, but can only contribute 20kW towards the planning reserve margin because the sun is low during times of peak electricity demand, then that facility has a capacity value of 20 percent.

But the capacity value of solar energy is not clear-cut, as it can be derived in several different ways. NREL adds, "[b]ecause variable energy sources [such as solar] are not as controllable as conventional power plants, analysis is needed to evaluate their capacity-related benefits, which are not always readily apparent," and "detailed analysis is needed to quantify solar capacity value."[12] The analysis we put forward here is a conservative and reliable way to estimate the capacity value of new solar facilities.

Why Solar's Capacity Value Matters

Capacity value is all about keeping the lights on—a goal everyone can get behind. It matters a great deal whether or not a regional grid like PJM or the California Independent System Operator (CAISO) has enough capacity to satisfy peak demand because, if it doesn't, the consequences are dire—rolling brownouts or full-blown blackouts and the immense hardship and economic loss that come with them.[13]

Historically, grid operators have done a stellar job of guaranteeing resource adequacy; however, the recent influx of intermittent generation presents them with new challenges. One key challenge is to determine how much solar PV installations can reduce peak demand. And one reason why rooftop panels and other distributed resources are treated by grid operators as negative demand (rather than supply) is because these resources tend to be outside the control of the grid operator.

Again, solar facilities are not "dispatchable." In a world in which solar panels could be called upon to produce electricity at 9pm if needed, solar's capacity value would not be an interesting or controversial subject. Alternatively, if a solar PV facility were "firmed up" by batteries or some other electricity storage device—which remain prohibitively expensive—the capacity value of such a facility could be quite high. But that is not the reality we are facing.

The Looming Capacity Value Cliff for Solar Power

Solar advocates are quick to argue that, even without storage, solar PV is a high-capacity resource that should be compensated accordingly. For example, an October 2016 report from Environment America said adding new solar capacity can reduce the amount of other capacity needed on the grid and avoid capacity investment[14]:

> Expanding the amount of electricity we generate from the sun can defer or eliminate the need for new grid capacity investments, particularly because demand for energy from the grid is currently often highest during the day when the sun is shining (although this may change with increasing deployments of rooftop solar). By reducing overall demand, expanding solar energy production helps ratepayers and utilities avoid the cost of investing in new power plants, transmission lines, reserve capacity and other forms of electricity infrastructure.

But the trade group for the solar industry, the Solar Energy Industries Association, seems to acknowledge the capacity value cliff facing solar energy[15]:

> As renewable technologies mature, recognizing and evaluating their economic value will become increasingly important for justifying their expanded use. In their report, Mills and Wiser used a unique investment and dispatch model to evaluate the changes in the long-run value of variable renewables with increasing penetration levels, based on a case study of California. They found that the value of solar is high at low penetration levels owing to the capacity and energy value of solar, even accounting for an increased need for ancillary services and imperfect forecastability. At higher penetration levels, the marginal value of additional PV and concentrating solar power (CSP) without thermal storage declines, largely due to a decrease in capacity value.

More academic approaches to solar PV's capacity value also acknowledge the falling capacity value of solar. The 2015 MIT study titled "The Future of Solar Energy" characterized the dynamic this way[16]:

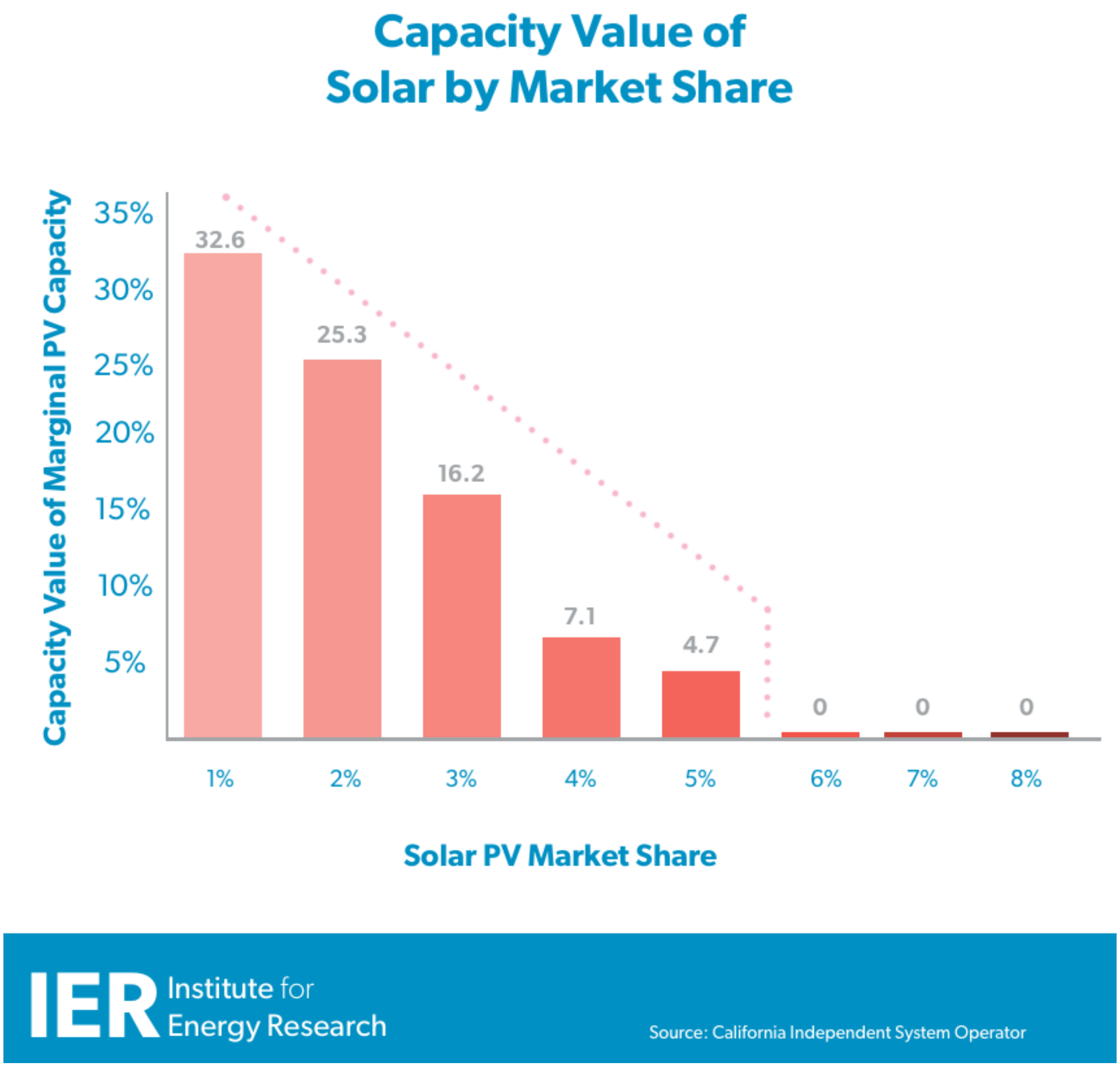
> The absolute net peak load, which is usually taken as a good proxy of the additional capacity needed on top of solar PV to supply system demand, can only be reduced when annual peak loads occur during the day. Even if this is the case, the reduction in absolute net peak load is very limited and does not continue to grow at higher levels of solar PV penetration.

Given the statements above, there appears to be an emerging consensus among solar energy experts that a capacity value cliff is looming for solar PV. As a logical next step, it seems like a worthwhile endeavor to use the best available data to get a better understanding of what happens to the capacity value of solar PV as penetration levels rise.

Empirical Evidence of Solar's Falling Capacity Value in California

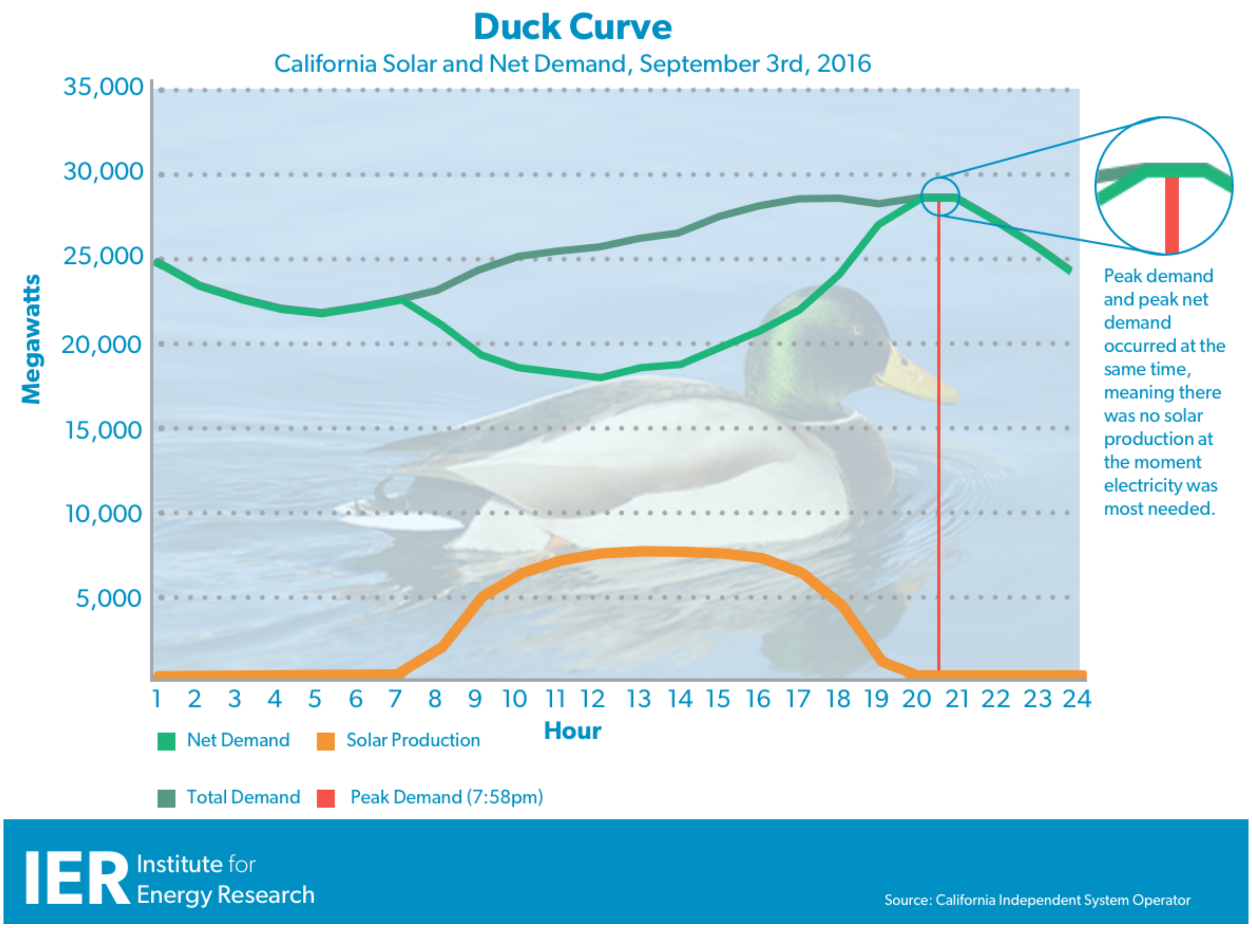
Solar energy's diminishing value problem is already empirically evident in the state of California, where solar energy enjoys by far its largest market share.

According to an IER analysis published last year, solar energy's capacity value falls sharply as we add more and more solar PV facilities to the grid.[17] In the July 2016 report titled "The Levelized Cost of Electricity from Existing Generation Resources," we analyzed supply and demand data from CAISO from calendar year 2014 and found that, for many of the highest-demand hours in 2014, solar power contributed little supply. Applying a conservative 75-percent confidence interval, we found that the capacity value of new solar power installations in CAISO has already fallen to zero. The graph representing solar's capacity value in CAISO as a function of solar's market share is below.



We found that additional solar capacity beyond a 5-percent market share no longer reliably satisfies peak net demand. CAISO explains, "Net demand is calculated by taking the actual demand and subtracting the electricity produced by variable generation resources, wind and solar, that are directly connected to the ISO grid."[18]

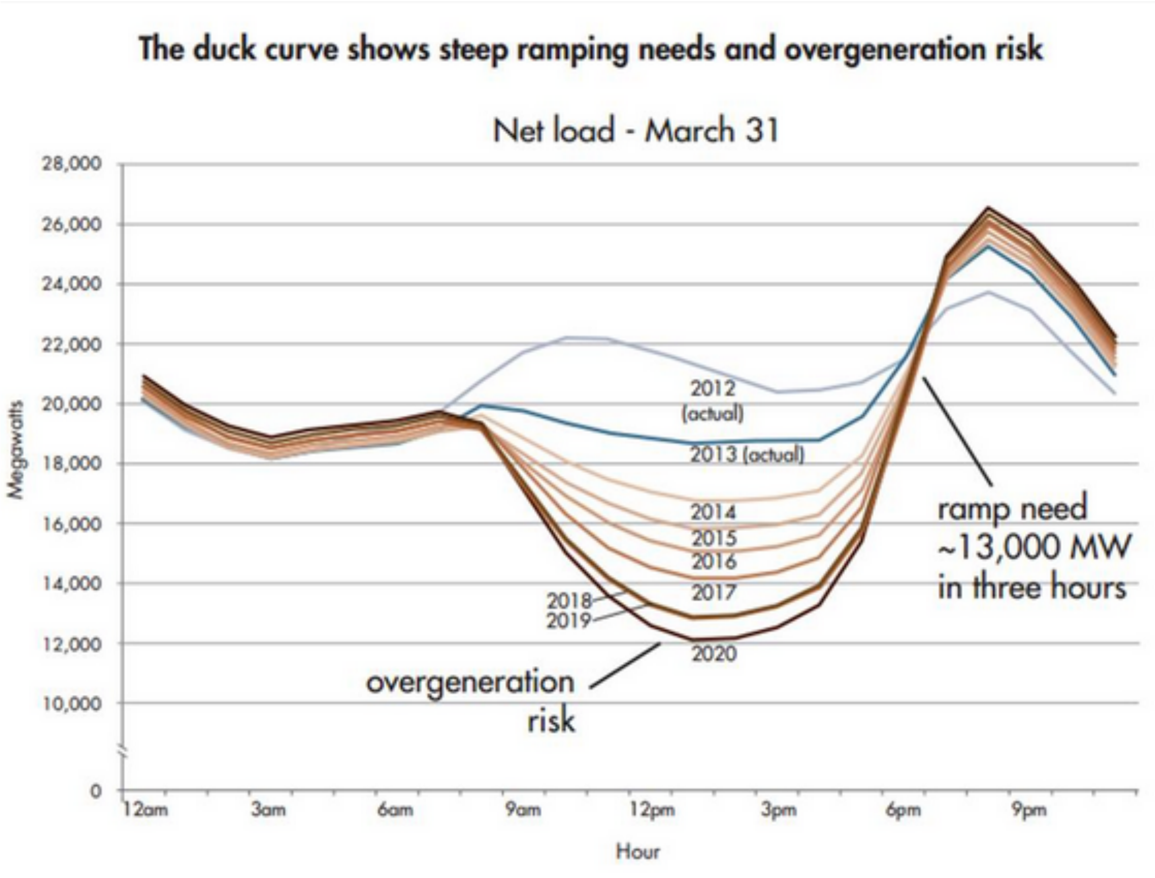
Solar production pulls down peak net demand at first, but fails to do so as the new, peak net demand occurs later and later in the day due to solar PV production. Eventually, peak net demand occurs in the evening, when the sun is no longer available as a resource. This is precisely what happened on the aforementioned September 3, 2016, when the sun set in Los Angeles at 7:16pm, but demand did not peak until 7:58pm. In the graph below, the red line shows that demand was highest after all solar production had stopped.



As we can see, peak demand and peak net demand occurred at the same time, meaning there was no solar production at the moment electricity was most needed. Because solar power already has more than a 5-percent share in CAISO, new solar installations in that region provide no additional capacity value and exacerbate the duck curve issue.

Capacity Value, Imposed Costs and CAISO's Duck Curve

Additional solar installations—shown by labeling solar growth projections each year through 2020—deepen the belly of the duck (mid-day net load) but do nothing to lower the head (peak net load in the evening). The height of the crown of duck's head represents peak net load, which can occur as late as 9pm, well after solar stops generating; this makes it clear that additional solar PV cannot help satisfy peak net load. This is the essence of the capacity value cliff for solar power—California is already experiencing it, especially on days in the shoulder seasons like the March 31 date CAISO chose to illustrate the effect of solar power on its grid.



[IER explained](#) solar energy's duck curve in 2014[19]:

> [P]hotovoltaic generation pulls down non-solar electricity demand to extremely low levels at midday when the sun is at its hottest and distributed photovoltaic generation is at a high. That is, the state's non-solar generating capacities must reduce their production to inefficient lows when the energy supply at the "belly" of the duck from solar distributed generation is at its highest.

A concept that ties together the duck curve and capacity value is that of "imposed costs," discussed at length in a previous [IER report](#).[20] By stripping dispatchable generators' run time during midday hours but not replacing their capacity value, solar PV actually imposes costs on the dispatchable resources on the grid.

A sports analogy may help drive this point home. Imagine you gave LeBron James a 3-year, $100 million contract but decided to take him out for the 2nd and 3rd quarters of every game so you could play someone from the bench. James would be no less amazing a player, but he wouldn't produce as many points for the team and his cost in terms of salary per minute of playing time would skyrocket.

In the report, we estimate that solar power imposes a cost on the rest of the grid of between $30 and $35 per megawatt-hour of solar production (pages 27-28 and Appendix B). Like James in the example above, reliable natural gas plants are forced to sit out midday production in order to accommodate solar output, but are still called upon to "close out games," i.e., ramp up and meet peak demand in the evening. That idle time in the middle of the day raises the levelized cost of dispatchable resources.

A case in point is the La Paloma combined cycle natural gas plant in Bakersfield, California. This 1,200 megawatt plant[21] filed for bankruptcy in December of 2016 because it cannot cover its costs due to the increase in solar power and other renewable energy in California as well as the state's unfriendly regulations. The plant is now operating at just 50 percent of its capacity[22] when it has typically operated at 78 percent of its capacity. At this lower operating level, the plant is losing money and would need a reliability contract or other support to remain in operation.

This is a case where the duck curve dipped net demand below the economic operating level of baseload natural gas resources, making the baseload resources uneconomical. Thus, when solar power reaches this level, it has a net negative effect on the overall system.

Our estimate of the imposed cost of solar power is conservative for at least two reasons. First, we modeled solar's interaction with natural gas plants, but we did not include a long-run analysis of the cost of closing existing nuclear plants in order to accommodate solar power, as is the case with the Diablo Canyon nuclear facility.[23] Second, we did not estimate increased ancillary service costs due to increased amounts of solar power on the grid, which is a different concern altogether.[24] Ancillary services are all the necessary support services that allow operators to keep the power grid running smoothly; they include important back-ups like spinning reserve and black start service,[25] as well as more complex features of the alternating current system such as reactive power.[26]

Solar in the Rest of the United States

For the rest of the U.S., the low penetration level of solar energy means that new solar installations currently help satisfy peak demand, at least on sunny summer days. So under current electricity grid conditions, solar advocates are correct to argue that the supply of solar energy overlaps somewhat with peak demand. However, the same analysis relating to CAISO holds at the national level: new solar installations beyond a very low market share simply will not contribute any capacity value.

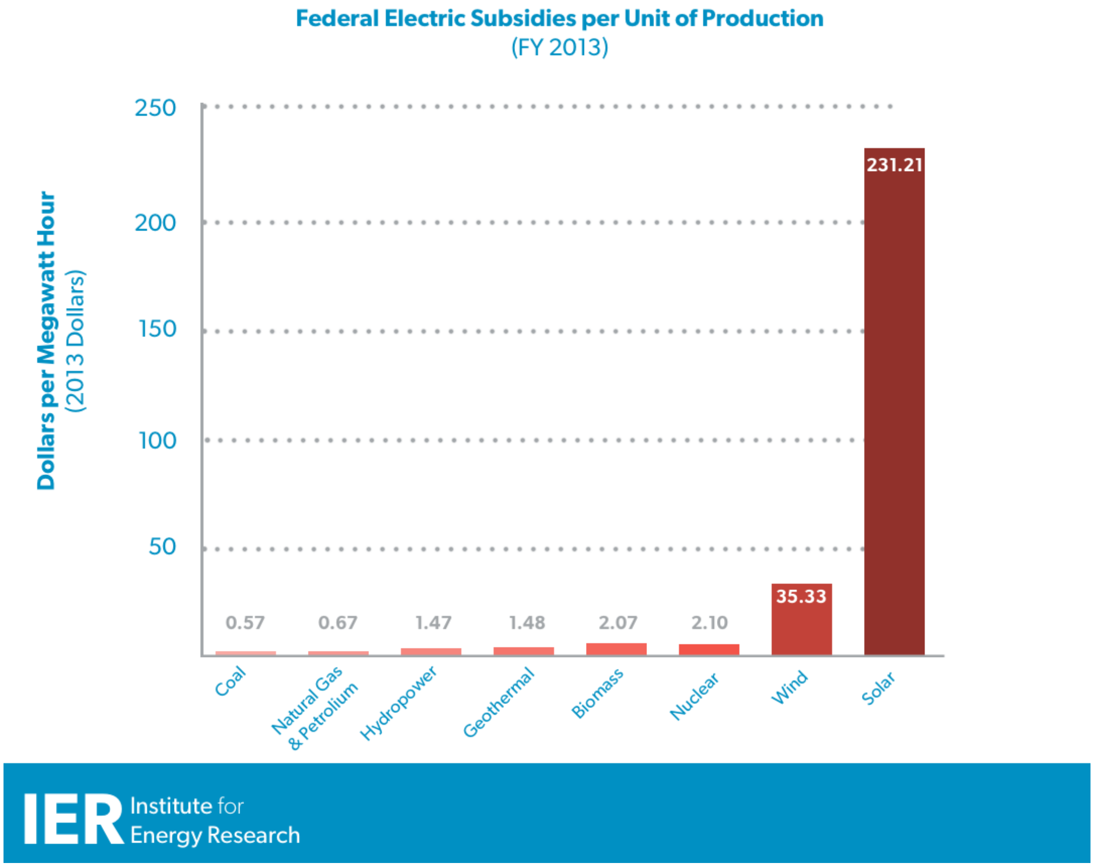
The key difference between CAISO and the rest of the country is that CAISO is already beyond the 5-percent threshold, whereas the U.S. as a whole has not reached this threshold and is currently at approximately 2 percent. If the rest of the U.S. follows the same demand and supply patterns as CAISO, then going from 2 to 3-percent market share for solar energy—the relevant marginal addition nation-wide—represents a drop in capacity value for those marginal units from 25.3 percent to 16.2 percent. This means that, during peak demand hours, the minimum consistent output of solar facilities will be only 16 percent of their nameplate capacity. From a 100kW facility, we would only be guaranteed (with a 75-percent confidence interval) to see 16kW during peak hours.

Policy Implications of Zero Capacity Value for Solar Power

One of the benefits of solar energy often touted by advocates is that new solar installations reduce the need to build power plants, or even that solar facilities can in fact replace existing power plants like the Diablo Canyon nuclear facility.[27] However, once the capacity value of new solar facilities falls to zero, those arguments are no longer valid.

Dispatchable sources of electricity—facilities that run on fuels controlled by people as opposed to the weather or time of day—will be needed to satisfy peak demand. Practically speaking, by the time some of the largest subsidies for solar energy are due to sunset in the next few years, new solar facilities will already be over the capacity value cliff. Further, because solar energy is by far the most heavily subsidized source of electricity in the U.S., it stands to reason that the solar industry is most sensitive to policy changes.[28]

Regarding net metering policy (by which rooftop solar producers are credited for the energy they produce) and distributed solar PV, many arguments put forward by groups in favor of keeping the full retail rate for net metered customers rely on the extremely limited fact that distributed solar PV lowers peak demand (and lowers overall grid costs by forestalling construction of other power plants). We have shown that is only true for low penetration levels of solar PV.



Many states that currently have net metering set caps at very low levels. Given our analysis of the falling capacity value of solar PV, states could in fact keep those caps in place in order to avoid overcompensating solar PV at higher penetration levels, where PV no longer contributes capacity value to the grid. If states that do not have net metering caps wish to avoid overcompensating solar PV, they should rush to implement net metering caps as soon as possible. In Nevada, an estimated cost shift of $36 million fueled changes to that state's net metering policies.[29] Effective January 1, 2016, Nevada instituted a tight net metering cap to protect its non-solar ratepayers from increased solar-related costs.[30] The decision sparked a political backlash, however, and the state has since developed a new policy.

The opposite is true for states that choose to remove or raise caps on retail net metering; those states may woefully overcompensate solar PV and exacerbate the cost shift. For example, Massachusetts raised its net metering cap from 4 percent of total demand to 7 percent for private projects and 8 percent for public projects.[31] Through this net metering scheme, Massachusetts ratepayers are at serious risk of overcompensating solar customers and further contributing to a serious, multi-million dollar cost shift from solar customers to non-solar customers.

The federal Investment Tax Credit (ITC) should be allowed to sunset as current law provides. The various incentives offered by states and local governments should also be allowed to sunset as planned. At the present pace of solar adoption, these provisions phase out just as solar power approaches the capacity value cliff in many regions, and therefore it is appropriate to dial down subsidies as solar's value to the grid diminishes.

Renewable energy mandates also impact solar penetration levels. According to the Database for State Incentives for Renewables and Efficiency, 22 states and the District of Columbia have mandates or goals providing for a minimum level of solar or distributed generation.[32] Even with the falling market value of solar and the expiration of the federal ITC, these solar energy mandates could push solar penetration to levels that would undermine the reliability and the economics of the power grid.

Conclusion

The takeaway is that the common argument that solar aids grid operation: 1) only applies in solar energy's infancy; 2) is at best limited to sunny days with early peak demand; and 3) is already outdated in areas of high solar penetration, such as California.

At a certain point—and California seems to have reached it already—new solar PV does nothing to satisfy new peak net demand. Other states should realize this when they are determining what capacity to add to their grid.

Lastly, because public policy factors so heavily in energy investment decisions, policymakers should take special note of solar energy's looming value cliff. Solar advocates will continue to push for more subsidies and mandates despite solar PV's diminishing value to meeting net peak demand. Policymakers should be wary of throwing good money after bad—of subsidizing a resource whose value is diminishing as additional capacity is added unless storage or some other advanced technology becomes economical.

[1] Mike Munsell, *Solar PV Prices Will Fall Below $1.00 per Watt by 2020*, GreenTech Media, June 1, 2016, https://www.greentechmedia.com/articles/read/solar-pv-prices-to-fall-below-1.00-per-watt-by-2020

[2] David Roberts, *The Falling Costs of US Solar Power, in 7 Charts*, Vox, August 24, 2016, http://www.vox.com/2016/8/24/12620920/us-solar-power-costs-falling

[3] Travis Hoium, *The Solar Energy Paradox: Why Solar Is Booming and Companies Are Going Out of Business*, The Motley Fool, October 7, 2016, https://www.fool.com/investing/2016/10/07/the-solar-energy-paradox-why-solar-is-booming-and.aspx

[4] Tim Buckley, *Cost Competitive Solar Is Coming Soon to a Grid Near You*, Clean Technica, October 13, 2016, https://cleantechnica.com/2016/10/13/cost-competitive-solar-coming-soon-grid-near/ competitive-solar-coming-soon-grid-near/

[5] Stephen Lacey, *Are Utilities Ready for the Coming Death Spiral?*, GreenTech Media, August 18, 2013, https://www.greentechmedia.com/articles/read/are-utilities-ready-for-the-coming-death-spiral

[6] Craig Morris, *Happy with 25 Percent Wind and Solar? The Case of Italy and Spain*, Energy Transition, September 9, 2015, https://energytransition.org/2015/09/happy-with-25-percent-wind-and-solar-the-case-of-italy-and-spain/

[7] California Independent System Operator, *Daily Renewables Watch*, September 3, 2016, http://content.caiso.com/green/renewrpt/20160903_DailyRenewablesWatch.txt

[8] California Independent System Operator, *Fast Facts*, https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

[9] National Renewable Energy Laboratory, *Solar Energy and Capacity Value*, http://www.nrel.gov/docs/fy13osti/57582.pdf

[10] PJM, *Markets and Operation*, http://www.pjm.com/markets-and-operations.aspx

[11] Seyed Hossein Madaeni, Ramteen Sioshansi, and Paul Denholm, *Comparison for Capacity Value Methods for Photovoltaics in the Western United States*, National Renewable Energy Laboratory, July 2012, http://www.nrel.gov/docs/fy12osti/54704.pdf

[12] *Ibid*, 9

[13] M.M. Adibi and Nelson Mar ns, Impact of Power System Blackouts, Ins tute of Electrical and Electronics Engineers, July 2015, http://www.ieee-pes.org/presenta ons/gm2015/PESGM2015P-001079.pdf

[14] Gideon Weissman and Bret Fanshaw, *Shining Reward: The Value of Rooftop Solar Power for Consumers and Society*, Environment America, October 2016, http://environmentamerica.org/sites/environment/files/reports/AME ShiningRewards Rpt Oct16 1.1.pdf

[15] Solar Energy Industries Association, Solar Valuation in Utility Planning Studies, http://www.seia.org/research-resources/solar-valua on-utility-planning-studies

[16] Richard Schmalensee and Vladimir Bulovic, *The Future of Solar Energy*, Massachusetts Institute of Technology Energy Initiative, 2015, http://energy.mit.edu/wp-content/uploads/2015/05/MITEI-The-Future-of-Solar-Energy.pdf

[17] Thomas F. Stacy and George S. Taylor, *The Levelized Cost of Electricity from Existing Generation Resources*, Institute for Energy Research, July 2016, http://instituteforenergyresearch.org/wp-content/uploads/2016/07/IER_LCOE_2016-2.pdf

[18] California Independent System Operator, *Net Demand*, http://www.caiso.com/outlook/outlook.html - Net Demand

[19] Institute for Energy Research, *Solar Energy's Duck Curve*, October 27, 2014, http://instituteforenergyresearch.org/solar-energys-duck-curve/

[20] *Ibid*, 17

[21] Richard Nemec, *Historic California Gas-Fired Merchant Plant Files Chapter11*, NGI's Daily Gas Price Index, December 8, 2016, http://www.naturalgasintel.com/articles/108667-historic-california-gas-fired-merchant-plant-files-chapter-11

[22] Ivan Penn, *A Central Valley Power Plant May Close as the State Pushes New Building at Customers' Expense*, Los Angeles Times, June 10, 2017, http://www.latimes.com/business/la-fi-la-paloma-capacity-20170609-story.html

[23] Institute for Energy Research, *Diablo Canyon Nuclear Units to Shutter: What Are the Consequences?*, July 12, 2016, http://instituteforenergyresearch.org/analysis/diablo-canyon-nuclear-units-shutter/

[24] Jeff St. John, *In California, Solar and Wind Boost the Price of Frequency Regulation*, GreenTech Media, July 5, 2016, https://www.greentechmedia.com/articles/read/In-California-Solar-and-Wind-Boosts-the-Price-for-Frequency-Regulation

[25] Rupert Darwall, Hillary Clinton's Blackout America, National Review, October 21, 2016, http://www.nationalreview.com/article/441302/hillary-clinton-clean-energy-dangerously-unrealistic

[26] R Street, *Electricity Glossary*, http://www.rstreet.org/r-street-electricity-glossary/ -reactivepower

[27] Jeff St. John, *PG&E to Replace Diablo Canyon Nuclear Plant with 100% Carbon-Free Resources*, GreenTech Media, June 21, 2016, https://www.greentechmedia.com/articles/read/pge-to-replace-diablo-canyon-nuclear-plant-with-100-carbon-free-resources

[28] Arduin, Laffer, and Moore Econometrics, *The High Cost of Rooftop Solar Subsidies: How Net Metering Programs Burden the American People*, Institute for Energy Research, October 2016, http://instituteforenergyresearch.org/wp-content/uploads/2016/10/The-High-Cost-of-Rooftop-Solar-Subsidies-Oct-16.pdf

[29] Sean Whaley, *Rooftop Solar Shifts $36M a Year to Nonsolar Ratepayers in Nevada, Study Says*, Las Vegas Review-Journal, August 18, 2016, https://www.reviewjournal.com/business/energy/rooftop-solar-shifts-36m-a-year-to-nonsolar-ratepayers-in-nevada-study-says/

[30] Dsire USA, *Net Metering*, http://programs.dsireusa.org/system/program/detail/372

[31] Krysti Shallenberger, *Massachusetts Gov. Baker Signs Bill Lifting Solar Cap, Lowering Net Metering Rates*, Utility Dive, April 11, 2016, http://www.utilitydive.com/news/massachusetts-gov-baker-signs-bill-lifting-solar-cap-lowering-net-meterin-1/417201/

[32] Dsire USA, *Renewable Portfolio Standards (RPS) with Solar or Distributed Generation Provisions*, August 2016, http://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2014/11/RPS_carveout_3.pdf