Solar Savings in New England

From 2014 to 2019, small-scale solar in New England produced wholesale energy market benefits of $1.1 billion

December 2020

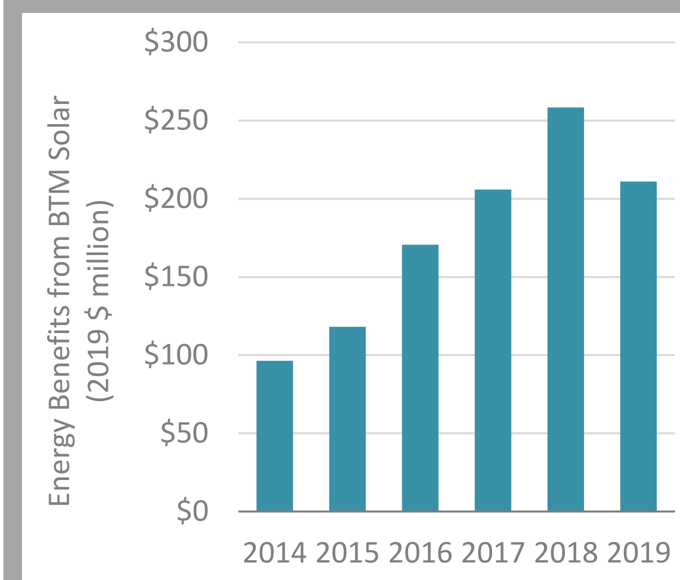
Between 2014 and 2019, behind-the-meter (BTM) solar produced more than 8,600 gigawatt-hours (GWh) of electricity in the six New England states. Electricity produced from BTM solar reduces the need to run other power plants, which reduces the amount of electricity that electric utilities need to buy and saves customers money. By avoiding the need to run the most expensive power plant, when BTM solar lowers the amount of electricity purchased, it also reduces the price that all utilities pay. Here, BTM solar is defined as small solar installations that do not participate in New England's energy markets (for more information see page 7).

Using hourly BTM solar data published in July 2020 by ISO New England, the nonprofit regional electric grid operator, Synapse estimated what demand and prices for electricity would have been without this resource.[1] We analyzed over 52,500 hourly datapoints from 2014 to 2019, and estimated that BTM solar reduced wholesale energy market costs in New England by $1.1 billion (see Figure 1). These include benefits that are shared by electricity customers throughout New England, not just the owners of the BTM solar facilities. Of this total, we estimate that benefits from price effects represent $743 million or 70 percent of the total. When the total benefits are divided by the quantity of electricity produced, we find the energy impact of BTM solar is 11.9 cents per kWh over this six-year period.

Hourly electricity benefits are just one benefit BTM solar can provide. Hourly analysis of this dataset using peer-reviewed tools published by the U.S. Environmental Protection Agency (U.S. EPA) shows that BTM solar avoided 4.6 million metric tons of climate-damaging carbon dioxide emissions in 2014 through 2019, and avoided millions of pounds of criteria pollutants proven to have negative impacts on human health. As a result, BTM solar contributed to $87 million in public health benefits in 2014 through 2019 (equal to 1.0 cents per kWh). Likewise, using a $112 per metric ton social cost of carbon, BTM solar provided $515 million dollars in climate benefits in 2014–2019 (equal to 6.0 cents per kWh).

BTM solar also provides other benefits, including reduced costs for generating capacity, transmission and distribution capacity, reliability, and retail margins. It also provides other economic benefits, such as job creation, local tax base support, and participant cost savings. All of these benefits should be considered when looking at a full societal value of BTM solar.

Figure 1. Energy benefits from BTM solar



Notes: 2018, a year with numerous heat waves and especially high summertime energy prices, has a particularly large amount of savings. Benefits described in this figure only include impacts related to the wholesale energy market. Other benefits (e.g., public health, climate, capacity, transmission and distribution, reliability, or retail margins) are not included.

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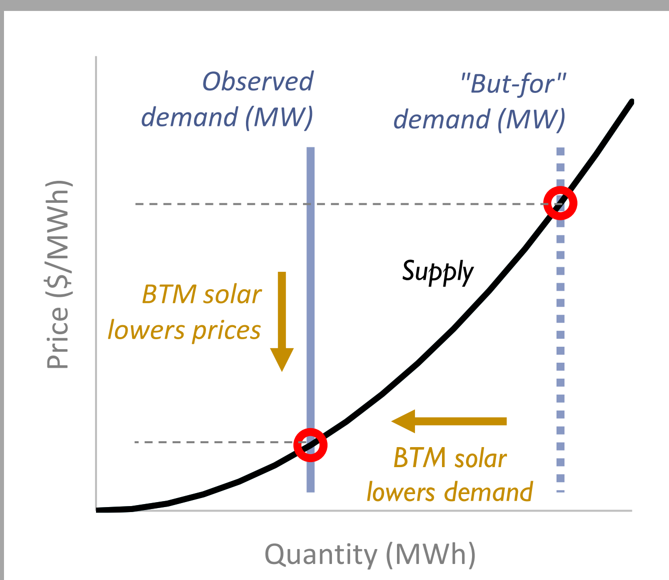
Methodology

When BTM solar produces electricity, electric utilities—and ultimately electric ratepayers—will purchase fewer kWh of electricity from other sources (e.g., fossil fuel-fired power plants). As BTM solar output increases, consumers pay less for electricity because the quantity of electricity purchased from other sources decreases. In addition, BTM solar has a second effect on electricity costs: because it reduces the demand for electricity to be purchased from other sources, it avoids the need to buy power from the most expensive power plant. This leads to a lower "market clearing price" that is paid to all electric generators on the grid (see Figure 2). As a result, more BTM solar not only decreases the quantity of electricity purchased, it also reduces the price paid for purchased electricity—which benefits all New England ratepayers .

Figure 2. Illustrative price and load impacts of BTM solar



In July 2020, for the first time, ISO New England published regionwide, hourly estimates of BTM solar generation for January 2014 through April 2020. This dataset is based on a sampling of hourly, actual solar output from individual facilities throughout New England, which are then upscaled to estimate aggregated solar production by state. After this data was posted on the ISO New England web site, Synapse deployed the "but-for" methodology (see call-out) for each week from 2014 through 2019.[2]

Predictive Equations: Step-by-Step

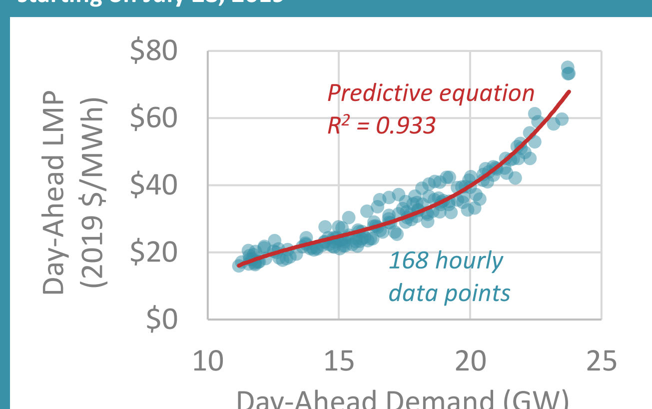
First, we assembled hourly, day-ahead price and demand data for 2014 through 2019.[3] We grouped hours into weeklong periods (Sunday through Saturday), and performed a regression for each individual week with demand as an independent variable and prices as a dependent variable. This regression provides a predictive equation of wholesale electricity price for any hourly demand in this week. For each hour, demand (measured in MW) and prices (measured in dollars per MWh) can be multiplied to calculate the total energy costs in that hour (measured in dollars).

Second, we assembled hourly BTM solar data. Each hourly datapoint was increased by 6 percent to reflect average transmission and distribution losses, then added to the demand in each hour. This provides an estimate of what demand would have been, if not for BTM solar.

Third, we used the predictive equations calculated in (1) to estimate what hourly prices would have been, if not for the BTM solar generation, all else being equal. As in (1), we can multiply the "but-for" demand by the resulting "but for" prices to estimate the total energy costs in each hour in the "but-for" hypothetical.

Fourth, we subtracted the total costs from the "but-for" costs to estimate the energy benefits resulting from BTM solar generation.

Figure 3. Illustrative predictive equation for week starting on July 28, 2019



Calculating energy benefits

For each week, we calculated the hourly total costs for each 24-hour period (24 hours x 313 weeks, producing costs for 7,512 hours) using week-specific predictive equations. Over the six-year period, the weekly predictive equations estimate total wholesale energy costs of $33.0 billion in 2019 dollars.

We then added the BTM solar output from ISO New England to each hour. Using each week-specific prediction equation, we calculated what energy costs would have been if not for BTM solar. Without BTM solar, we find that total wholesale market costs would have been $34.2 billion, suggesting that total benefits from solar are approximately 1.2 billion.

However, not all predictive equations are equally successful at estimating benefits. In some winter weeks, for example, energy market prices are more closely linked to fuel prices rather than demand for electricity. In these weeks, although BTM solar continues to reduce the demand for electricity produced from other sources, it is less able to reduce electricity costs.

To account for this, we examine two different time periods: summer weeks (any weeks in 2014 through 2019 that have at least one day in May, June, July, August, and September) and non-summer weeks (all other weeks). Summer weeks contain 43 percent of the total weeks analyzed, but 57 percent of the BTM solar produced. Predictive equations in summer weeks are generally very accurate. In 98 percent of summer weeks, estimated electricity prices are within 10 percent of the actual price. Meanwhile, non-summer weeks generally feature less successful predictive equations: only 83 percent of non-summer weeks estimate electricity prices within 10 percent of actuals.

For this analysis, we remove any weeks where the predictive equations are unable to accurately estimate prices within 10 percent, on average over the entire week. As a result, we estimate energy benefits of $1.1 billion, rather than $1.2 billion (a reduction of 10 percent). In reality, there is some non-zero quantity of energy benefits in these weeks because the BTM solar avoids the need for utilities to purchase energy from the wholesale markets. Thus, this is a conservative, lower-bound estimate as we only include those weeks with high predictive capabilities.

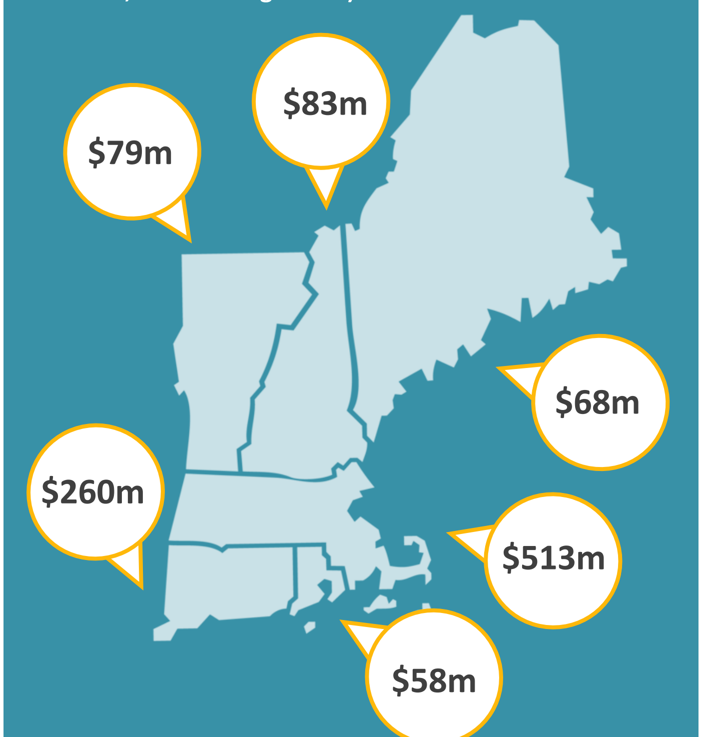
Load impacts and price impacts

The calculated energy benefits can be split into "load impacts" and "price impacts." Load impacts refer to the benefits associated with the reduction in the quantity of electricity purchased. "Price impacts" are due to the impact of reduced demand on the market-clearing price of electricity, as shown previously in Figure 2.

For each week, load impacts can be calculated by estimating energy benefits where demand is increased by the hourly BTM solar quantity but where prices are unchanged. The "price impact" can be estimated by subtracting the "load impact" from the total benefits. Over the six years analyzed, we find that load impacts provide about $317 million in benefits (30 percent of the total) while price impacts provide about $743 million in benefits (70 percent of the total). This only includes benefits for those weeks "screened into" our analysis.

To understand how each impact could be allocated to each state, we assume that load impacts are distributed across the six New England states based on each state's contribution to BTM solar production. In other words, states with more installed BTM solar accrue a greater share of the load impact.[4] Meanwhile, as shown in Figure 4's depiction of the total impacts for each state, we

Figure 4. Total energy savings from BTM solar accrued in each state, 2014 through 2019)



assume that the price impacts are distributed across the six New England states based on each state's contribution to observed day-ahead demand. In other words, states with larger electricity demand accrue a greater share of the price impact, and states with larger quantities of installed BTM solar accrue a greater share of the load impact.

Value per kWh

These energy benefits can be divided by the quantity of solar produced in each year to estimate the price impact value and the load impact value of BTM solar in cents-per-kWh terms. However, if each annual value is calculated using only the "screened-in" weeks, it will overestimate the cents-per-kWh benefits in weeks with poor predictive equations. In order to account for this, we multiply the cents-per-kWh value by the percentage of weeks that "screen in" for each year, thereby assuming the cents-per-kWh value in "screened out" weeks is 0 cents per kWh. We perform this operation separately for summer and non-summer weeks, which we then combine using an average weighted by the total number of all weeks in each seasonal period.

Figure 5 displays the resulting values for both load and price impacts in each year of the analysis. Because load impacts per kWh describe the benefits associated with reducing quantities, but not prices, they resemble average prices observed during the summer weeks. On average, over the six years analyzed, BTM solar provided a total value-per-kWh wholesale market benefit equal to 11.9 cents per kWh.

Figure 5. Energy benefits per kWh of BTM solar

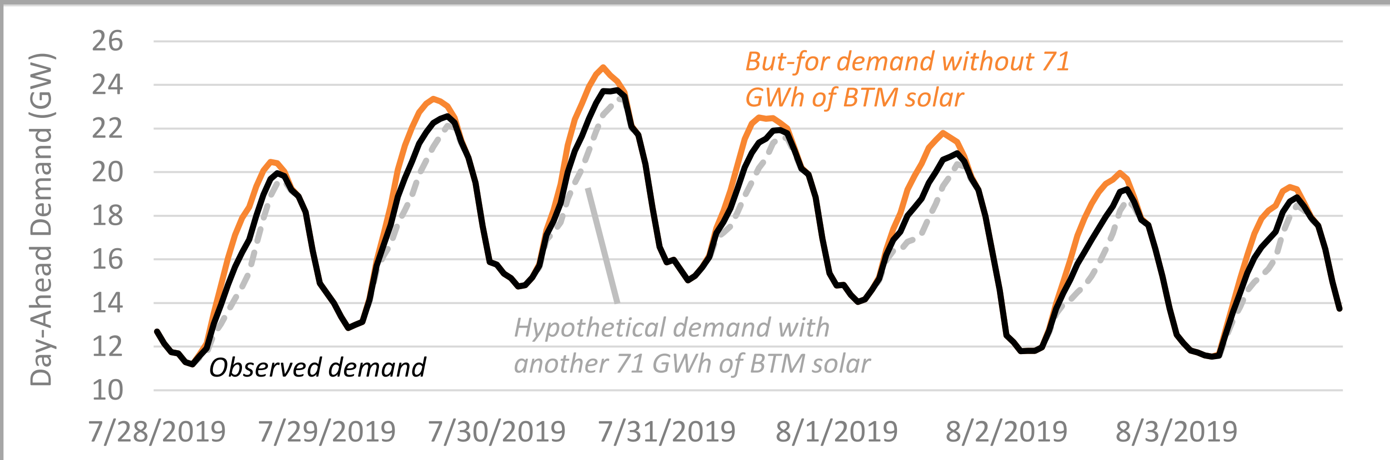
This value may vary week-to-week and year-to-year. For example, during hot years, total demand for electricity increases. This increase in demand often leads to increased prices, meaning that solar resources can avoid purchasing more energy at higher prices than in other years. 2018 in particular featured three separate heat waves, which contributed to a quantity of heating degree days that were 19 percent higher than the 2014-2019 average. This led to a year with summertime energy prices 11 percent higher than average.

Impact of increasing levels of BTM solar

Output from fixed solar facilities typically peaks around noon and decreases later in the day when demand for electricity remains high. This fact leads some to argue that as more BTM solar is installed, fewer energy benefits will accrue. Because energy prices are closely linked with demand in most summer weeks, as more solar comes online, it may increasingly reduce prices that are not necessarily the highest prices. Nonetheless, with the amount of BTM solar on the grid now, or expected in the next several years, prices at times of peak solar output are still likely to be high. Conversely, at times of high prices (e.g., later in the afternoon) systemwide BTM solar output may be reduced but not outright eliminated. As a result, additional BTM solar may provide fewer wholesale market cost benefits, but some benefits still remain.

To assess this issue, we examined one week in July 2019 with a total BTM solar output of 71 GWh. Figure 6 on the next page shows the observed hourly demand for this week in black, and the "but-for" demand in yellow. This figure also features a second hypothetical series in grey that posits what demand would have been with double the amount of BTM solar power. In our "but-for" analysis described above, the first 71 GWh of BTM solar provided $10.7 million in energy benefits. Doubling the amount of solar provides energy benefits of $19.1 million. In other words, doubling the quantity of solar would increase benefits by 80 percent.

Figure 6. Demand for illustrative week, with and without BTM solar



Note: Y-axis begins at 10 GW in order to highlight the difference between the three depicted scenarios.

This phenomenon often triggers discussions of conventional resources' capability to quickly ramp up or down to accommodate changes in solar output during the evening and morning hours, respectively. In this example week, the largest hourly change (a reduction of 2,082 MW) occurs between the hours of midnight and 1AM when solar is not operating in any circumstance. In hours when BTM solar is operating, additional BTM solar actually *reduces* the maximum hour-to-hour MW change, which occurs as demand is increasing between 7AM and 8AM (thereby likely making the morning ramp easier). Of all 112 hours in this week when BTM solar is operating, only 35 feature hourly changes that are greater after adding an additional 71 GWh of BTM solar . In these 35 hours, the maximum increase in hourly changes is 386 MW. This is equal to 2 percent of the day-ahead demand observed in that hour, or, about one-fifth the maximum hourly change observed (2,082 MW).

As discussed above, savings depend not only on how much BTM solar is installed, but also on other underlying system drivers. For example, temperatures were lower in 2019 than in 2018, leading to fewer periods of high summer prices. One way to examine these impacts is to model the 2019 quantity of solar on the weather and resulting energy prices that were observed in 2018. We find that total savings would have been $317 million, rather than $211 million, an increase of 50 percent.

Emissions and public health impacts

We used publicly available tools to evaluate the impact that BTM solar has on emissions and public health. First, we used the Avoided geneRation and Emissions Tool (AVERT) from the U.S. EPA. AVERT relies on actual, hourly, power plant-specific data published by U.S. EPA to statistically estimate the marginal emissions and generation avoided by renewable energy and energy efficiency.[5] According to AVERT, if the hourly output from BTM solar reported by ISO New England did not exist, 4.6 million metric tons of climate-damaging carbon dioxide would have been emitted from 2014 to 2019 (see Table 1). In addition, BTM solar avoided the release of hundreds of thousands of pounds of criteria pollutants proven to have negative impacts on human health. According to AVERT, in 2019, 94 percent of the generation avoided came from natural gas-fired power plants, while an additional 6 percent came from power plants fueled by oil, coal, or other resources.

Table 1. Estimated emissions avoided by BTM solar

Pollutant	Avoided emissions
Greenhouse gases (reported in million metric tons)	
Carbon dioxide (CO_2)	4.6
Criteria pollutants (reported in pounds)	
Sulfur dioxide (SO_2)	2,380,000
Nitrogen oxides (NO_X)	3,280,000
Particulate matter ($PM_{2.5}$)	340,000

Note: Avoided emissions for each pollutant are reported in the unit that is most commonly used for data reporting and other analysis. These emission benefits are calculated for all hours in 2014 through 2019, rather than only the weeks that met our screening criteria for energy benefits.

We then used these results in U.S. EPA's CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool. COBRA uses a reduced form air quality model to estimate how criteria pollutants like sulfur dioxide (SO2), nitrogen oxides (NOX), and particulate matter (PM2.5) are transported through the atmosphere. COBRA then relies on assembled data from the literature to estimate how these pollutants impact different populations on a county-by-county level, and it translates any decreases of these pollutants into monetized public health benefits.[6] According to COBRA, the BTM solar estimated by ISO New England in 2014 through 2019 contributed to $87 million in public health benefits (see Table 2). Dividing this cost by the solar produced in this time period yields a health benefit of 1.0 cents per kWh. We also examined the benefits of reducing greenhouse gas emissions across a range of social costs of carbon. Depending on the cost of carbon modeled in this analysis, benefits from 2014 to 2019 are as high as $1.9 billion dollars. This translates into 22.6 cents per kWh of BTM solar.[7]

Table 2. Monetized benefits from improved public health and social cost of carbon

Pollutant	2019 $ M	2019 cents / kWh
Climate benefits from reduced greenhouse gas emissions		
At $112/MT	$515	6.0 ¢
At 200/MT	$918	10.7 ¢
At $425/MT	$1,948	22.6 ¢
Public health benefits from reduced criteria pollutants		
SO_2, NO_X, and $PM_{2.5}$	$87	1.0 ¢

Note: A price of $112 per metric ton corresponds to the $100 per short ton price approved by the VT PUC in Case No. 19-0397-PET. Other prices illustrate the carbon benefits of solar at higher prices. These public health benefits are calculated for all hours in 2014 through 2019, rather than only the weeks that met our screening criteria for energy benefits. See footnote 6 for additional information.

Other avoided costs

In addition to the energy benefits and public health impacts described above, BTM solar can provide other benefits. Increased quantities of BTM solar reduce the demand for grid-level capacity that must be purchased through ISO New England's Forward Capacity Market (FCM). Lowering the demand for capacity reduces capacity costs, thus reducing the overall electricity costs paid by ratepayers throughout New England. For example, we estimate that the value of capacity for solar installed in 2019 was $1.75 per kilowatt-month, or about 1.6 cents per kWh.[8]

As with the energy market, costs and prices in the FCM are calculated through supply and demand curves. This means that, as in the energy market, there is the potential for BTM solar to not only reduce the quantity of capacity purchased, but to also decrease the clearing price paid for capacity. BTM solar can also reduce other costs such as transmission and distribution capacity, reliability, and retail margins (i.e., the markup on costs observed between retail and wholesale prices that in some cases may represent utility profit). Finally, BTM solar provides other benefits to states or individual customers, including job creation, local tax base support, and participant cost savings. All of these benefits would reasonably be considered when looking at a full societal value of BTM solar.

How do energy benefits get passed to ratepayers?

Energy and capacity benefits are passed to ratepayers by load-serving entities (LSE) such as distribution utilities that purchase electricity at the wholesale level. The benefits described in this analysis are calculated for the day-ahead energy market. However, most, if not all, LSEs use out-of-market contracts to hedge their purchase of energy from the day-ahead market, which effectively acts a spot market.[9]

Each LSE may sign many different contracts with different suppliers for different quantities. Contract terms may overlap and contract terms can last weeks or years. Because the day-ahead market represents what the market is willing to pay for electricity on a spot basis, the expectation of future day-ahead market prices can be viewed as a proxy for the price of electricity paid in bilateral contracts. As such, while any one entity may not garner the exact savings from BTM solar estimated in this analysis, lower costs for electricity purchased in the day-ahead market should translate into lower contract costs, and eventually, lower costs paid by ratepayers.

Other caveats

The energy benefits described in this document only cover the solar quantity that ISO New England describes as "BTM solar." BTM solar is defined as the output from small (i.e., less than 5 MW), distributed systems that do not participate in the energy markets.[10] The dataset of hourly BTM solar production provided by ISO New England does not include any output from facilities that have a commitment in the Forward Capacity Market (FCM) or facilities that may have load co-located behind the meter but participate in the energy market. The benefits described in this document would likely be higher were output from these power plants also included. The quantity of solar that is BTM solar versus other some other type is different in each state. In Vermont, ISO New England defines virtually all of the installed solar capacity as BTM solar, while in Rhode Island and parts of Massachusetts, BTM solar, as defined by ISO New England, represents just one-third to one-half of the total solar installed capacity.[11] Hourly dispatch from these plants is estimated by "upscaling" the output from a subset of solar facilities throughout New England; actual production from BTM solar facilities may differ from the hourly estimates provided by ISO New England.

This analysis does not take into consideration how the electric grid might have otherwise been different if not for solar.

Summary of impacts

Table 3 shows a summary of the solar benefits assessed in this study. These categories of benefits should be carefully weighed against costs of solar to estimate the full benefit-cost ratio of solar policies.

Table 3. Summary of historical BTM solar benefits (2019 cents per kWh)

Benefit category	High	Medium	Low
Energy	11.9 ¢	11.9 ¢	11.9 ¢
Capacity	1.6 ¢	1.6 ¢	1.6 ¢
Criteria pollutants (SO_2, NO_X, $PM_{2.5}$)	1.0 ¢	1.0 ¢	1.0 ¢
CO_2 @ $425/MT	22.6 ¢	-	-
CO_2 @ $200/MT	-	10.7 ¢	-
CO_2 @ $112/MT	-	-	6.0 ¢
Energy, capacity, and pollution reduction benefits of BTM solar	**37.1 ¢**	**25.2 ¢**	**20.5 ¢**

Additional benefits not calculated:

- Capacity price impacts
- Transmission and distribution capacity
- Local economic benefits
- Local tax support
- Reliability benefits
- Participant savings
- Retail margin

Endnotes and Sources

1. See hourly BTM solar data published by ISO New England on July 24, 2020 at www.iso-ne.com/static-assets/documents/2020/07/btm_pv_data.xlsx. Further documentation is available at https://www.iso-ne.com/static-assets/documents/2020/07/btm_pv_data_documentation.pdf.

2. Synapse explored a variety of other regression types and found that third-order polynomials remain the regressions that best explain the relationship between electricity demand and prices .

3. Hourly data on prices and loads is available at https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info. This analysis focuses on day-ahead demand and day-ahead locational marginal prices (LMP).

4. Load impacts from net-metered solar facilities are most appropriately allocated to their owners, while load impacts from standalone solar facilities can be allocated to the entire state.

5. See https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert for more information on AVERT.

6. See https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool for more information on COBRA.

7. A $112 per metric ton price (in 2019 dollars) corresponds to the $100 per short ton price (in 2018 dollars) approved by the Vermont Public Utility Commission in Case No. 19-0397-PET (order available at https://epsb.vermont.gov/?q=downloadfile/417666/138298). A $200 per metric ton value is in line with the value described in Hänsel, M.C., Drupp, M.A., Johansson, D.J.A. et al. Climate economics support for the UN climate targets. Nat. Clim. Chang. 10, 781–789 (2020). https://doi.org/10.1038/s41558-020-0833-x. A $425 per metric ton value is in line with the value described in Ricke, K., Drouet, L., Caldeira, K. et al. Country-level social cost of carbon. Nat. Clim. Chang. 8, 895–900 (2018). https://doi.org/10.1038/s41558-018-0282-y.

8. Calculated by adjusting the average avoided capacity price for FCA 9 and 10 (listed in AESC 2018, Table 39, available at https://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-Oct-ReRelease.pdf) to reflect peak line losses of 8 percent and a capacity credit of 19 percent (per slide 14 at https://www.iso-ne.com/static-assets/documents/2020/09/a6_a_iii_cea_mottmacdonald_presentation_cone_and_ortp.pptx) to derive $1.75 per kilowatt-month. This value was then multiplied by the peak BTM solar output in New England in 2019 (1.8 GW), then divided by the total BTM solar output reported by ISO New England (2.3 TWh). This estimation does not include the value of solar for future years (i.e., after December 2019), retail margin impacts, or capacity price suppression effects.

9. A separate real-time spot market exists to balance the differences between day-ahead demand (and supply commitments) with actual supply and demand requirements. Per ISO New England's September 2020 COO report (see https://www.iso-ne.com/static-assets/documents/2020/09/september-2020-coo-report.pdf, page 47), day-ahead demand represented 95 to 99 percent of actual, real-time demand between August 2019 and August 2020. The exact makeup of electricity power purchases (long-term contracts, day-ahead purchases, or real-time purchases) by New England LSEs is unavailable, as it represents a collection of private-party bilateral contracts and business practices. However, conversations between Synapse analysts and LSE representatives over the past two decades suggests that in general, roughly 60 percent of wholesale energy market purchases are hedged through bilateral agreements, with the remaining 40 percent purchased outright from the spot market (35 percent day-ahead, and 5 percent real-time). These rough percentages vary from LSE to LSE, and also vary over time.

10. Despite being called "BTM," this dataset does not necessarily exclude small, distributed systems that are physically installed in front of a meter.

11. See https://www.iso-ne.com/static-assets/documents/2020/07/btm_pv_data_documentation.pdf, page 8

About Synapse Energy Economics

Synapse Energy Economics, Inc. is a research and consulting firm specializing in energy, economic, and environmental topics. Since its inception in 1996, Synapse has grown to become a leader in providing rigorous analysis of the electric power sector for public interest and governmental clients.

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