Sacramento Municipal Utility District

September 2020

Value of Solar and Solar + Storage Study

Summary Report

Energy+Environmental Economics

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Contents

1. Executive Summary

The Sacramento Municipal Utility District (SMUD) has a long history of introducing solar technology and programs to its customer community. SMUD currently has over 25,000 customers participating in its net energy metering (NEM) program, through which on-site generation of electricity from "behind the meter" (BTM) solar systems is compensated through bill reductions at the retail rate. As the number of these systems grows, determining how to properly value their contributions to SMUD and all customers becomes increasingly important.

In March 2020 SMUD engaged Energy and Environmental Economics (E3) and GridSME (collectively, "the E3 Team") to conduct an independent analysis of the Value of Solar and Solar + Storage (VOS/S). This study focused specifically on distributed, behind the meter systems which are compensated through SMUD's net energy metering (NEM) program. This report provides a summary of the study and its key findings. For additional detail on the study, including in-depth methodological steps and additional results, please see the companion VOS/S Technical Report.[1]

Prior to engaging the E3 Team, SMUD convened a Technical Working Group (TWG) consisting of a broad range of stakeholders to inform the VOS/S analysis. The TWG identified 24 individual value components for customer solar and storage. E3 evaluated each of the 24 components either quantitatively or qualitatively. To capture the fact that not all value components flow to all parties equally, E3 used three different beneficiary perspectives:

- **SMUD Ratepayer Perspective:** the costs and benefits to all SMUD's customers, including non-solar customers;
- **Societal Perspective:** the costs and benefits to society, including ratepayer costs and benefits as well as additional benefits that accrue to society more broadly like reductions in air pollution, land, and water usage;
- **Solar Customer Perspective:** the costs and benefits to the customer with on-site solar and/or energy storage installations to lower their SMUD utility bills.

E3 considered three different system configurations recommended by the TWG:

- **Solar Only:** the value of customer solar installations not paired with battery storage
- **Solar + Storage, Customer Dispatch:** the value of paired solar and storage systems when operated by NEM customers to minimize their electricity bills
- **Solar + Storage, Utility Partnership:** the value of paired solar and storage systems when operated in partnership with SMUD to provide maximum value to all ratepayers

Value Scenarios: In order to assess a range of potential values, E3 also analyzed the customer installations under two different value scenarios, which can be thought of as bookends for how customer solar and solar + storage might benefit SMUD's ratepayers as a whole:

[1] Technical Report available at: http://www.smud.org/FairSolar.

- **Helps Meet Clean Energy Goals:** Customer solar installations are utilized to help SMUD achieve the clean energy goals specified by its Board of Directors, enabling SMUD to procure less utility-scale clean energy resources;
- **Incremental Clean Energy:** Customer solar installations provide clean energy *beyond* SMUD's goals, displacing natural gas generation at the margin.

The E3 team found that, from the Ratepayer perspective, the direct value of customer solar and solar + storage systems in 2020 is $0.03 - $0.07 per kWh of solar generated under the two bookend value scenarios. At the same time, under current SMUD tariff structures, the solar and solar + storage customers would receive average bill reductions of $0.12 per kWh of solar power generated. This results in a net cost of $0.05 - 0.09 per kWh. When considering all systems operating in 2020, the total compensation paid through NEM to customers with solar and solar + storage resources exceeds the value to SMUD ratepayers by $24 - 41 million. These estimates equate to annual bill increases of $26 - 45 for the average residential customer.

Figure 1 provides a summary of the Ratepayer costs and benefits from Solar Only systems in 2020 for the two different value scenarios (note that the tables below, alternatively, report combined results for the Solar Only and Solar + Storage system configurations)..

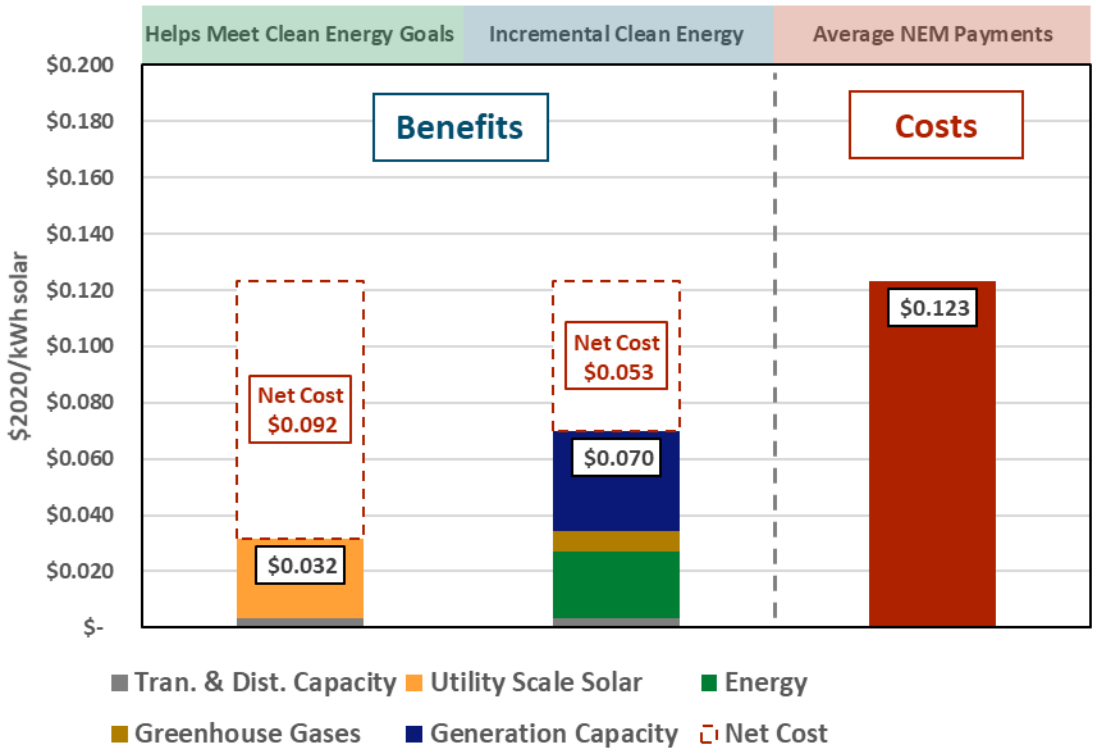

Figure 1. Value of Customer Solar, SMUD Ratepayer Perspective, 2020

Using SMUD projections of the growth in customer solar and solar + storage systems, E3 estimates that absent a change in SMUD's rate designs, by 2030 the net cost of customer solar and solar + storage will reach approximately $0.12 per kWh of solar, equivalent to a total of $90 million per year in bill increases

depending on the valuation scenario. For the average residential customer, this would mean $90 in annual bill increases by 2030.

Table 1 provides a summary of the estimated annual value and cost to ratepayers of the cumulative customer solar installations in SMUD's territory during the years of 2020, 2025, 2030 and 2040, along with levelized results (per kWh) and the net present value of these systems. This table reports combined results for customer solar and solar + storage systems under the *Incremental Clean Energy* scenario for the customer dispatch system configuration. This can be thought of as a conventional view on the value of customer systems which displace gas generation at the margin and over which the utility has no control.[2]

Table 1. Summary of Ratepayer Impacts: Incremental Clean Energy Scenario, Customer Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Cust. Dispatch)	*NPV*[3]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	**n/a**	**263**	**340**	**445**	**445**[4]
Benefits and Costs per kWh of Solar Output					
Value of Solar & Solar + Storage ($/kWh solar)	***0.049***	**0.070**	**0.057**	**0.039**	**0.045**
SMUD Revenue Reduction ($/kWh solar)	***0.184***	**0.123**	**0.134**	**0.163**	**0.232**
Net Cost Shift ($/kWh solar)	***0.135***	**0.053**	**0.077**	**0.124**	**0.187**
Total Change in SMUD Costs & Revenues					
Value of Solar and Solar + Storage	***$510 MM***	**$32 MM**	**$32 MM**	**$29 MM**	**$32 MM**
SMUD Revenue Change	***-$1,910 MM***	**-$56 MM**	**-$77 MM**	**-$120 MM**	**-$163 MM**
Net Cost Shift	***$1,399 MM***	**$24 MM**	**$44 MM**	**$91 MM**	**$131 MM**
Change in SMUD Average Rates (%)	***n/a***	**1.8%**	**2.9%**	**4.4%**	**4.5%**
Approximate Annual Bill Impact (non-solar residential customer @ 750 kWh/month)	***n/a***	**$26/yr.**	**$51/yr.**	**$90/yr.**	**$130/yr.**

Costs and benefits from the Societal and Participant perspective are described briefly in this report, and in further detail in the companion VOS/S Technical Report.

[2] Additional details on the alternative valuation scenario, as well as the system configuration where customers partner with SMUD to increase the value of their systems to all SMUD customers, can be found in the companion Technical Report.

[3] Net present value of customer solar and solar + storage systems over the period of 2020-2049. $/kWh solar figures in the NPV column are levelized over this period.

[4] The VOS/S study considers systems installed through 2030, holding the nameplate capacity beyond that year flat.

2. Introduction

The Sacramento Municipal Utility District (SMUD) provides electricity service to 635,000 customers in the Sacramento region, and has a peak demand of approximately 2,950 MW.[5] SMUD has a goal of reaching 90 percent carbon reductions by 2040, which informs its Integrated Resource Plan and related investment decisions. To reach this goal SMUD's supply-side portfolio of resources will see significant increases in solar, wind and battery storage.

At the same time, the electricity grid in the Western U.S. will also see significant investments in solar and wind due to clean energy policies led by individual states with goals to reduce their carbon emissions. As states increase the amount of renewable energy on their electric grids, the growing amount of solar production will lower wholesale energy prices during the daytime, especially during the spring and early summer months. Over time energy market prices will change dramatically.

Over 25,000 of SMUD's customers participate in the net energy metering (NEM) program, through which on-site generation of electricity from "behind the meter" (BTM) solar systems is compensated at the retail rate which customers pay to SMUD for energy from the electric grid.

Prior to 2020, there were approximately 215 MW of customer solar installed in SMUD's territory, from both residential and non-residential customers. As shown in Figure 2, SMUD anticipates that the cumulative nameplate capacity of customer solar will increase from to approximately 445 MW by 2030, with a growing share of these systems paired with battery storage.

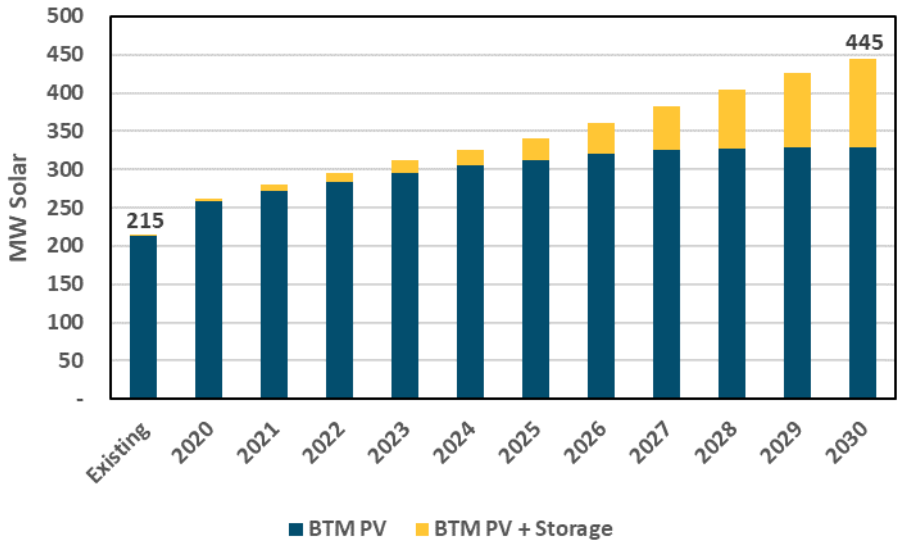

Figure 2. Cumulative Customer Solar and Solar + Storage Forecast

[5] 2018 SMUD Annual Report. Available at: https://www.smud.org/-/media/About-Us/Reports-and-Statements/2018-Annual-Report/2018-Annual-Report.ashx.

As the amount of customer solar system capacity grows, the question of how much value their generation provides to SMUD becomes increasingly important. This is especially true given the broad transition to renewable resources anticipated throughout the West, and the effects that transition will have on the value of solar generation. If the difference between the bill reductions customer solar system owners receive and the value these systems provide becomes greater, NEM will become a larger cost for SMUD ratepayers. This dynamic has led to discussions of the current NEM program and whether or not revisions may be necessary. This report is meant to further inform those discussions and deliberations.

Stakeholder Process

In October 2019, SMUD convened a group of stakeholders interested in NEM. This Technical Working Group (TWG) included 20+ stakeholders from the solar industry, energy storage associations, companies providing solar and storage products and services, environmental groups, low-income advocates, representatives of SMUD customers, members of academia and research organizations, and SMUD staff members. Over the course of six meetings the group discussed the values provided by customer solar installations, with the aim of ultimately informing SMUD's considerations of whether and how to change its current NEM program.

With the assistance of convenor Gridworks, the TWG produced a report released in February 2020 which provides recommendations as to the specific value components which an independent consultant should consider in conducting an analysis of the value of solar and solar + storage (VOS/S).[6] Through a competitive solicitation process, in March 2020 SMUD selected Energy and Environmental Economics (E3) and GridSME (collectively, "the E3 team") to conduct the VOS/S study.

The E3 team's scope of work was informed directly by the TWG report, which details the value components of interest summarized in Table 2 below. E3 analyzed these value components quantitatively where possible, and qualitatively where appropriate. Values marked as "societal" or "participant" do not accrue directly as monetary impacts to SMUD ratepayers yet remain relevant for society more broadly or for NEM customers, respectively.

[6] TWG report available at: https://gridworks.org/wp-content/uploads/2020/02/Report-SMUD-Technical-Working-Group-on-Value-of-SolarStorage-Final.pdf.

Table 2. TWG Value Components

Category	ID[7]	TWG Value Description (abbreviated)	E3 Value Component(s)	Ratepayer	Societal	Solar Customer
Energy	1	Avoided energy, including GHG / RPS requirements	Energy, GHG, Ancillary Services	✓	✓	
	2	Integration costs	Integration	✓	✓	
	3	Higher marginal cost of emissions (intermittency)	*Qualitative*	✓	✓	
Generation Capacity	4	Resource adequacy	Generation Capacity	✓	✓	
	5	Resource flexibility (increased need for flexibility)	Integration	✓	✓	
Financial Risk	6	Fuel price risk reduction	Fuel Price Risk	✓	✓	
	7	Increases in energy price volatility	Energy Price Volatility	✓	✓	
	8	Sunk cost of Emission Reduction Credits	*Qualitative*			
Variable Operating	9	Decreased thermal operations	Energy	✓	✓	
	10	Increased standby costs	Integration	✓	✓	
Criteria Emissions	11	Criteria emissions reductions	Criteria Pollutants		✓	
Carbon Emissions	12	Carbon reductions beyond SMUD compliance requirements	Carbon Emission Reductions		✓	
Land & Water Use	13	Reduced land and water usage	Land use; water use		✓	
Equity	14	Reduced energy burden for low income customers	*Qualitative*		✓	✓
Resilience	15	Customer ability to meet critical needs	Resilience			✓
Reliability	16	Restoring service or preventing outages in an emergency	Reliability	✓	✓	
Emotional / Political	17	Engaging customers through NEM, changing their relationship w/ energy	*Qualitative*		✓	✓
Local Economy	18	Jobs and local economic growth resulting from rooftop solar	*Qualitative*		✓	
Transmission	19	Transmission capacity	Transmission Capacity	✓	✓	
	20	Transmission line losses	Line Losses	✓	✓	
Distribution	21	Distribution capacity	Distribution Capacity	✓	✓	
	22	Distribution line losses	Line Losses	✓	✓	
	23	Grid modernization	*Qualitative*	✓	✓	
	24	Voltage / power quality	Voltage / power quality	✓	✓	

Climate Emergency Declaration

In July 2020, the SMUD Board of Directors adopted a Climate Emergency Declaration, committing to achieving carbon neutrality by 2030. This is an important step for the utility in continuing its climate leadership and will require significant effort to achieve the new and ambitious goals on an accelerated timeline relative to the previous goal of achieving net zero emissions by 2040.

The Climate Emergency Declaration is an important new commitment for SMUD. While this Value of Solar and Solar + Storage study was developed and largely completed prior to the July resolution adopting the new climate goals, E3 is cognizant of the fact that SMUD plans to continue its leadership in clean energy deployment and has designed this study explicitly to consider the scenario where customer solar is one component of a SMUD portfolio that is made up entirely of clean energy resources. Specifically, E3 has developed the *Helps Meet Clean Energy Goals* value scenario uniquely for this study. Under this scenario, customer solar is assumed to displace other forms of clean energy that SMUD would otherwise have to invest in to meet the Board's goal of carbon neutrality.

Indeed, while detailed plans have not been made on how SMUD will achieve carbon neutrality by 2030, one plausible scenario is that SMUD has no more gas generation to displace by 2030. It would not be possible for customer solar to go beyond SMUD's clean energy goals if SMUD is already achieving a 100% carbon free grid. Under this resource portfolio, the *Incremental Clean Energy* value scenario, which assumes customer resources displace natural gas generation at the margin, would simply no longer be relevant.

In summary, E3 anticipated for this study a potential future under which SMUD would have no more fossil generation, and designed a value scenario that would be appropriate under this future. For this reason, E3 believes that the Climate Emergency Declaration in no way invalidates the study; rather, it reaffirms the importance of E3's choice to evaluate customer solar under both the *Incremental Clean Energy* and the *Helps Meet Clean Energy Goals* scenarios.

3. Methodology

Overview

The E3 Team estimated the value of solar and solar + storage in this study using four primary steps, as depicted in Figure 3 below. First, E3 estimated SMUD's costs of supplying electricity over the study period, consistent with the SMUD integrated resource plan. Second, E3 modeled the detailed operation of solar and solar + storage systems, using anonymized SMUD NEM customer solar generation and energy usage data to represent different NEM customers (e.g., customers on different retail rates and with different system sizes). Third, E3 estimated the value of the customer solar installations based on the hourly operation of the customer solar installations and the associated hourly costs SMUD would have otherwise incurred to supply electricity. Finally, E3 calculated the benefits of reduction in SMUD costs to the foregone revenue from not supplying these customers to calculate the shortfall that must be covered by SMUD's other non-solar customers. In this analysis E3 estimated the value of *all* generation from customer systems,

[7] Note, the numbers in this table do not correspond precisely to the original numbers used in the TWG report.

treating solar energy consumed by customers equivalently to solar energy exported to the electric grid. Customer retail rates are therefore used to reflect the cost SMUD pays for all customer generation.

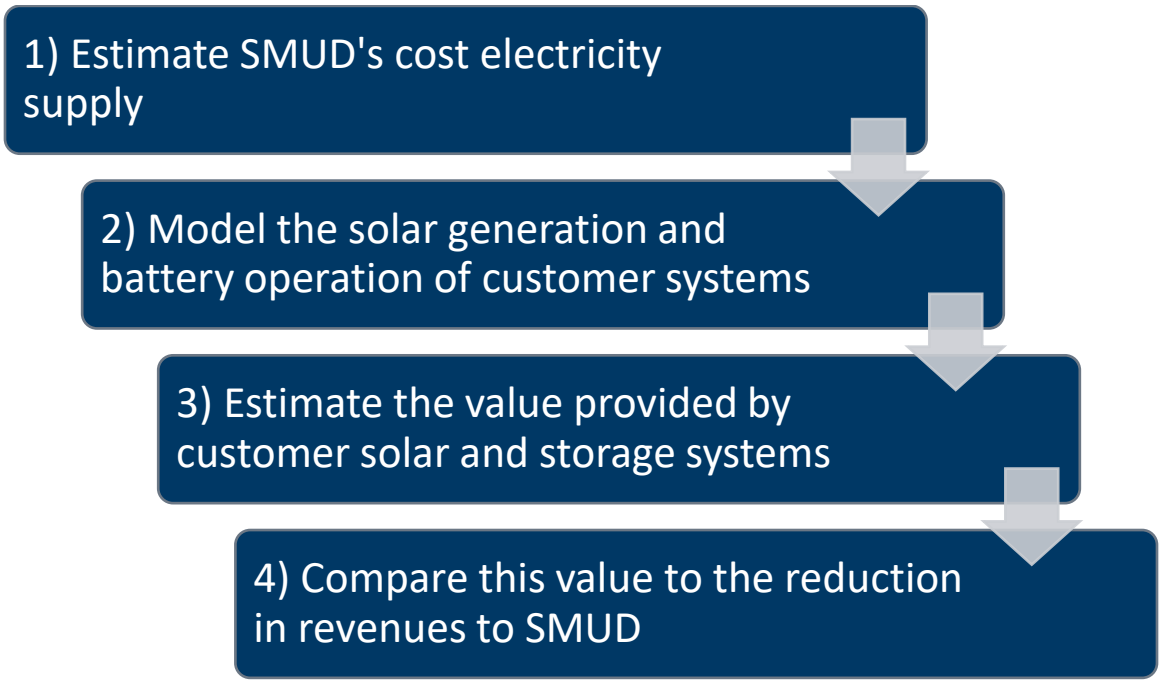

Figure 3. Primary Methodological Steps

Benefits

Ratepayer Benefits

E3 estimated the direct economic benefits provided to SMUD customers from reductions in usage of electricity from the grid. Ratepayer benefits are the reduced SMUD capital and operating costs realized from lower net customer loads from customer solar. These benefits include avoiding energy generation or purchases, including the monetized value of carbon dioxide embedded in electricity prices, as well as avoiding investments in generation, transmission, and distribution capacity. Additionally, local generation by customer solar installations reduces the losses of electricity which occur during transmission and distribution from power plants to end users.

Societal and Participant Benefits

Other categories of benefits which do not accrue financially to SMUD customers – yet still convey true value to society as a whole – include environmental benefits such as reductions in air pollution, water use, carbon emissions and fugitive methane emissions due to reduced thermal power plant operation. The societal benefits that customer solar installations provide depend on what energy these systems are assumed to displace. In the event that solar customer system generation results in less procurement of utility scale renewables (rather than less procurement of thermal resources), there would be no reduction in air pollution, water usage, carbon emissions, or fugitive methane emissions, but there would be a reduction in

land use. Other societal values include the potential to increase customer engagement with their energy usage through NEM or the local economic growth which may result from rooftop solar installations.

Customers adopting solar + storage systems receive several benefits. The largest benefit comes from the reduction in electricity bills provided by participating in NEM. Additional benefits include the state and federal incentives which reduce the cost of purchasing a solar system. Solar + storage systems configured to provide backup power during an outage also provide the benefit of this added resilience.

Costs

Ratepayer Costs

The primary cost which non-solar SMUD customers face due to the adoption of customer solar installations is the reduction in revenues collected. As NEM customers are compensated for their solar generation at the retail rate, this is the cost that SMUD ratepayers incur for that generation. If the value provided by the customer solar installations is less than the reduction in revenues SMUD collects due to lower sales, electricity rates will increase to make up the difference.

Additional ratepayer costs come in the form of increased expenditures by SMUD to integrate larger amounts of customer-owned renewable energy onto the electric grid. These can include upgrades to modernize the distribution grid in order to accommodate more electricity generation at the local level, as well as increased costs to have other generators readily available to account for the intermittent nature of renewable resources, including those that are behind the meter.

Societal and Participant Costs

Societal costs include any increased expense required to integrate larger amounts of renewable energy onto the electric grid, as well as the cost of installing and maintaining the customer solar system. The primary participant cost is the expenditure on the solar or solar + storage system.

4. Results

The E3 team conducted the VOS/S study for three distinct system configurations, as requested by SMUD and the TWG.

- **Solar Only:** the value of customer solar systems not paired with battery storage
- **Solar + Storage, Customer Dispatch:** the value of paired solar and storage systems when operated by NEM customers to minimize their electricity bills
- **Solar + Storage, Utility Partnership:** the value of paired solar and storage systems when operated in partnership with SMUD to provide maximum value to all ratepayers

Results in this section are shown for the solar only and customer dispatch configurations; please see the VOS/S Technical Report for additional detail and scenarios.[8]

[8] Technical Report available at: http://www.smud.org/FairSolar.

E3 also considered two "bookend" scenarios for the VOS/S, which differ in their assumption as to how the clean energy contributions of these systems are treated.

- **Helps Meet Clean Energy Goals:** Customer solar installations are utilized to help SMUD achieve the clean energy goals specified by its Board of Directors, enabling SMUD to procure less utility-scale clean energy resources;
- **Incremental Clean Energy:** Customer solar installations provide clean energy *beyond* SMUD's goals

Ratepayer Perspective

The E3 team found that from the Ratepayer perspective the customer solar and solar + storage systems today reduce SMUD's procurement, operating, and capital-related costs by approximately $0.032 per kWh of solar generated under the *Helps Meet Clean Energy Goals* scenario, and by $0.070 per kWh under the *Incremental Clean Energy* scenario. In return for the customer system energy generation, SMUD's NEM tariffs are providing the solar and storage customers with bill reductions averaging approximately $0.123 per kWh of solar. This results in a revenue gap that puts an upward pressure on rates of approximately $0.092 per kWh of solar generated (*Helps Meet Clean*) or $0.053 per kWh (*Incremental Clean*), equivalent to an annual cost of approximately $41 million or $24 million, respectively. These estimates equate to annual bill increases of $45 or $26 per year for the average non-solar residential customer. Figure 4 provides a summary of the ratepayer costs and benefits for solar only systems in 2020.

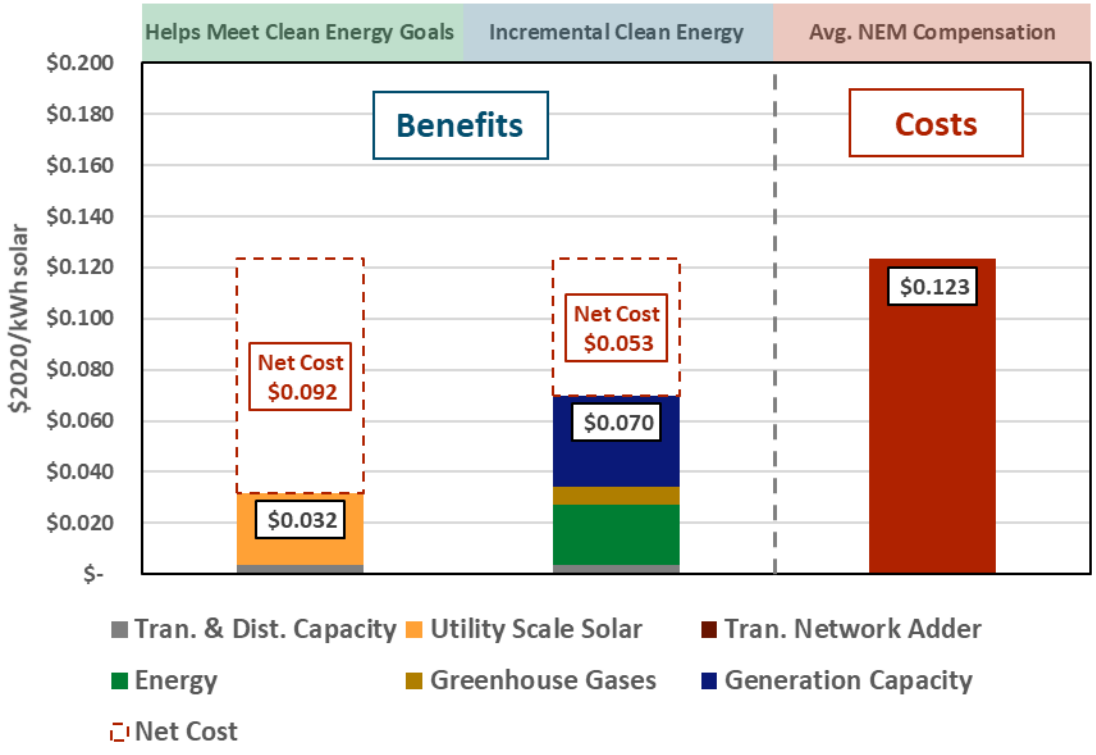

Figure 4. Value of Customer Solar Only, SMUD Ratepayer Perspective, 2020

E3 estimates that by 2030 the value of solar and solar + storage across the population of customer systems will increase in nominal terms to approximately $0.040 per kWh of solar generated in the *Helps Meet Clean Energy Goals* scenario, while decreasing to $0.039 per kWh in the *Incremental Clean Energy* scenario. This inversion in the VOS/S between the two scenarios is due to the significant decrease in the generation capacity value provided by solar and solar + storage systems over time, which in turn is due to the saturation of Western U.S. energy markets with solar as states progress towards their clean energy goals.

By 2030 the bill reductions under NEM will grow to $0.163 per kWh of solar generated, based on approved retail rates and an assumption of a 3.5 percent annual rate increase. The resulting net cost will therefore increase to approximately $0.124 per kWh of solar in both scenarios. The estimated annual net cost to SMUD customers is $90 million based on projections of the growth in customer solar and solar + storage systems. This is equivalent to an increase in non-solar residential customer bills between the two scenarios of approximately $90 per year.

Figure 5 provides the benefits and costs of Solar Only systems in 2030 (note that the figures in the preceding paragraphs are for the combined population of solar and solar + storage systems, while the chart below instead depicts the costs and benefits for Solar Only systems).

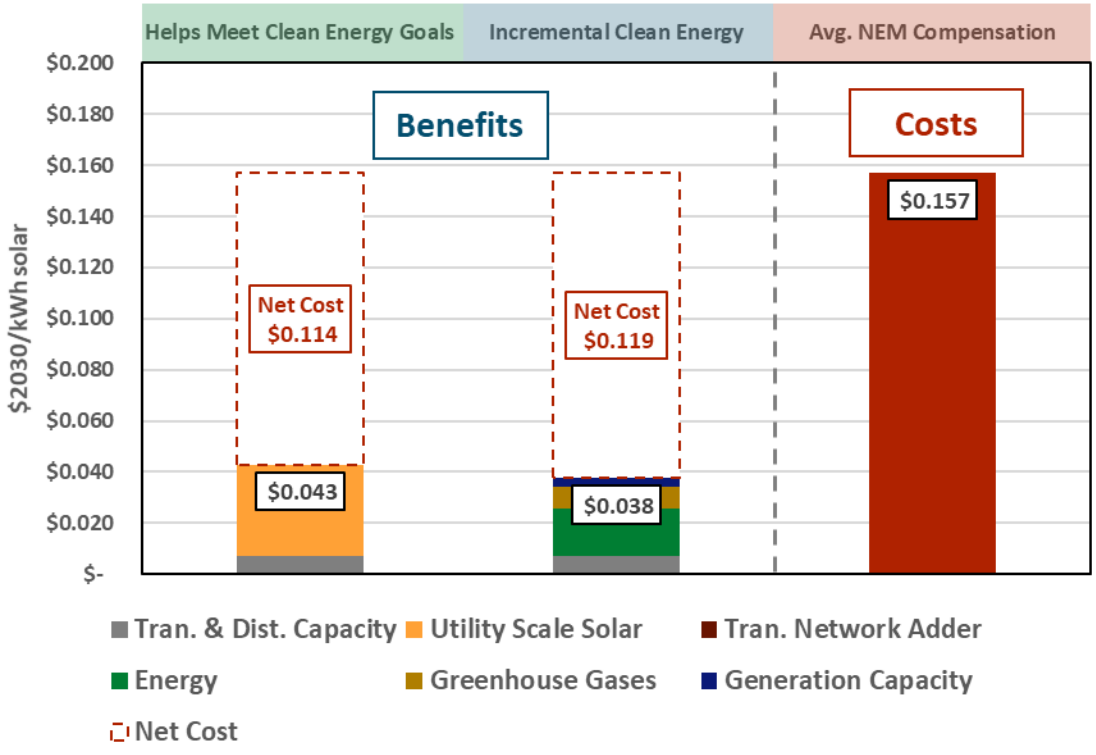

Figure 5. Value of Customer Solar Only, SMUD Ratepayer Perspective, 2030

Table 3 provides a summary of the range of estimated annual values and costs to ratepayers from the cumulative customer solar and solar + storage installations in SMUD's territory, under the *Incremental Clean Energy* scenario and the customer dispatch system configuration.

Table 3. Summary of Ratepayer Impacts: Incremental Clean Energy Scenario, Customer Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Cust. Dispatch)	NPV[9]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	**n/a**	**263**	**340**	**445**	**445[10]**
Benefits and Costs per kWh of Solar Output					
Value of Solar & Solar + Storage ($/kWh solar)	***0.049***	**0.070**	**0.057**	**0.039**	**0.045**
SMUD Revenue Reduction ($/kWh solar)	***0.184***	**0.123**	**0.134**	**0.163**	**0.232**
Net Cost Shift ($/kWh solar)	***0.135***	**0.053**	**0.077**	**0.124**	**0.187**
Total Change in SMUD Costs & Revenues					
Value of Solar and Solar + Storage	***$510 MM***	**$32 MM**	**$32 MM**	**$29 MM**	**$32 MM**
SMUD Revenue Change	***-$1,910 MM***	**-$56 MM**	**-$77 MM**	**-$120 MM**	**-$163 MM**
Net Cost Shift	***$1,399 MM***	**$24 MM**	**$44 MM**	**$91 MM**	**$131 MM**
Change in SMUD Average Rates (%)	***n/a***	**1.8%**	**2.9%**	**4.4%**	**4.5%**
Approximate Annual Bill Impact (non-solar residential customer @ 750 kWh/month)	***n/a***	**$26/yr.**	**$51/yr.**	**$90/yr.**	**$130/yr.**

Under the alternative utility partnership system configuration, where solar customers with battery storage dispatch their systems in order to provide the maximum value to all SMUD ratepayers, the value of solar + storage increases significantly in the *Incremental Clean Energy* scenario due largely to the additional generation capacity these systems are able to provide when dispatched against maximum value to SMUD ratepayers rather than retail rates. However, even in this configuration the compensation paid to NEM customers considerably exceeds the value provided by the systems. Figure 6 and Figure 7, below, depict this comparison between the two configurations for 2030.

[9] Net present value of customer solar and solar + storage systems over the period of 2020-2049. $/kWh solar figures in the NPV column are levelized over this period.

[10] The VOS/S study considers systems installed through 2030, holding the nameplate capacity beyond that year flat.

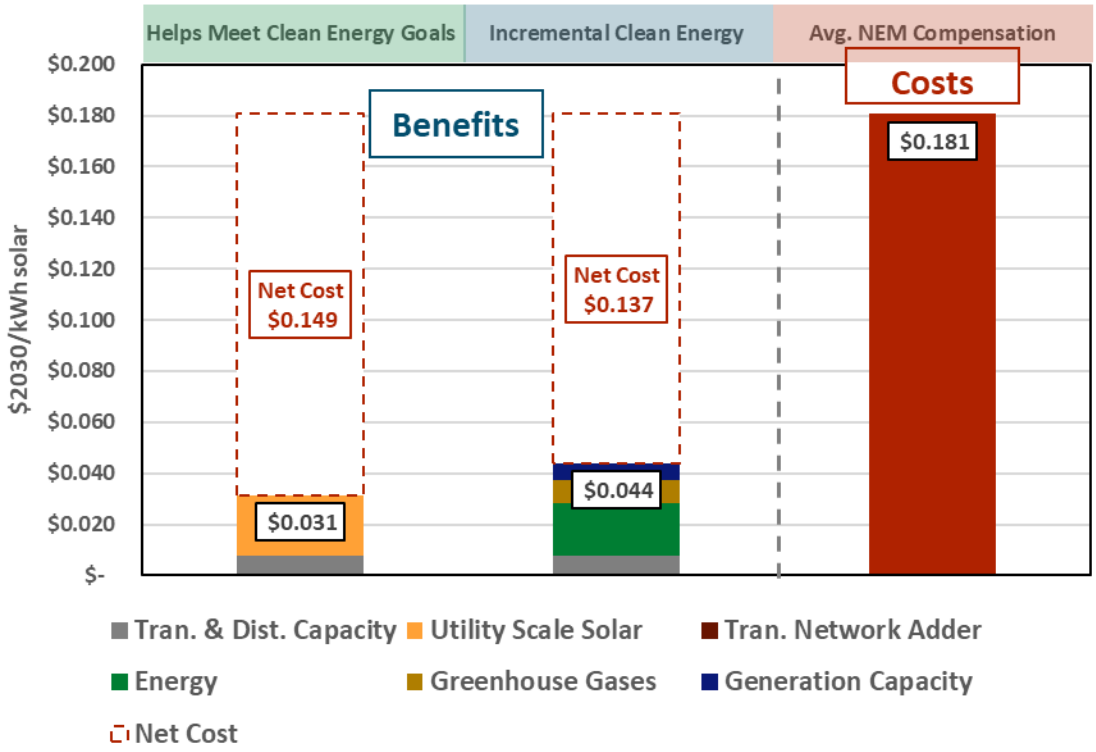

Figure 6. Value of Solar + Storage, Customer Dispatch System Configuration, 2030

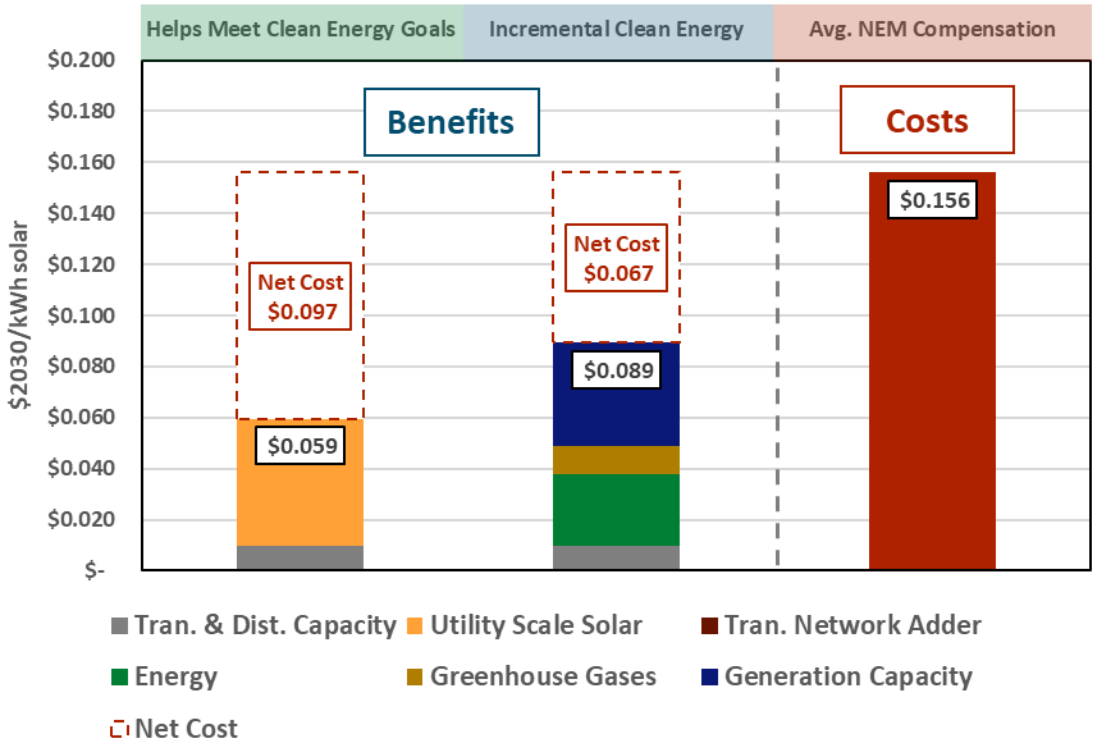

Figure 7. Value of Solar + Storage, Utility Partnership Configuration, 2030

Societal Perspective

E3 also estimated the societal value provided by customer solar installations in SMUD's service territory for several of the environmental value components. Given the difficulty in establishing the value of environmental components and the resulting wide range of estimates, as well as the significant uncertainty in the physical impacts customer solar installations provide relative to these categories, E3 provided a range of estimates for carbon emission reductions beyond the level of SMUD's compliance requirements, air pollution (criteria pollutants), and land and water use.

Table 4 below provides a summary of the estimated physical impacts and a range of societal values for these impacts, in $/kWh. E3 estimated the physical impacts from customer solar installations relative to these value components through our analysis of the avoided energy and other avoided costs. Ranges of impacts are provided given the difficult in precisely estimating these impacts as well as the difference in impacts between the *Helps Meet Clean Energy Goals* and *Incremental Clean Energy* scenarios. In the former, customer solar installations replace SMUD procurement of utility scale renewables, and therefore will not contribute to reductions in carbon emissions, fugitive methane emissions, criteria pollutants, or water usage. In this scenario the customer solar installations do contribute to the avoidance of land use which would otherwise have been necessary for the utility scale renewables.

In the *Incremental Clean Energy* scenario, the opposite is true. In providing incremental carbon-free energy the customer solar installations displace natural gas generation, therefore contributing to reductions in

carbon, fugitive methane, criteria pollutants, and water usage. However, in this case there is no avoided land use.

Table 4. Environmental Value Components

Societal Value Component	Description	Physical impacts per MWh	Societal Value ($/kWh solar)	Alternative Sources of Benefit
Carbon	Carbon emissions reductions beyond SMUD compliance requirements	600-900 lbs./MWh	Up to $0.072/kWh[11]	Can be provided by utility-scale solar under *Incremental Clean Energy* scenario at a cost of 2.7¢/kWh
Fugitive Methane	Reductions in methane leakage at SMUD's thermal generating plants when these plants are the marginal resource being offset by customer solar	.03 - .40 lbs. CO_2e/MWh of SMUD thermal generation	Up to $0.00003/kWh	
Criteria Pollutants	Reductions in air pollution due to decreased thermal power plant operation	.03 - .06 lbs. PM10/MWh .08 - .15 lbs. NOx/MWh	Up to $0.008/kWh	
Water	Reductions in water usage due to decreased thermal power plant operation	4 to 250 gallons	Up to $0.001/kWh[12]	
Land	Environmental value of avoided land use from reduced procurement of utility scale renewables	.003 acres	Up to $0.004/kWh	Provided only by customer solar under *Helps Meet Clean Energy Goals* scenario

E3 conducted a literature review to estimate the range of economic values provided by these components. Societal carbon value is based on a range of estimates including several from the U.S. Environmental Protection Agency[13] as well as various academic papers – the variation in estimates is quite broad. E3 calculated reductions in fugitive methane emissions at SMUD's thermal power plants using leakage

[11] We note that there are considerably higher social cost of carbon values in the literature, such as the estimate of $417/metric ton (in $2018) from Ricke et al. described in the methodology section of the Technical Report. This estimate is well above the range of other estimates considered.

[12] This is an estimate of the direct costs of capturing and storing more water due to the use in power generation. These costs are already included in the market price for power and are not a 'societal cost' of used water per se but the direct costs of delivering more water.

[13] U.S. EPA. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. August 2016. Available at: https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

measurements provided by the Electric Power Research Institute, who conducted a SMUD-specific study on behalf of the California Energy Commission. E3 estimated the societal value of reducing criteria pollutants using the California Public Utilities Commission's *Interim Air Quality Adder*.[14] The value of avoided water is based on the direct costs of capturing and storing additional water for use in power generation as the societal cost of this resource is not well differentiated from the direct costs of providing it. The value of avoided land use was based on two primary sources, one an evaluation of the value of developing utility scale renewables in California,[15] and the other an academic assessment of ecosystem services provided by different land types.[16]

E3 also qualitatively evaluated several value components which were not easily quantified, as summarized in Table 5 below.

Table 5. Summary of Qualitatively Evaluated Societal Value Components

Societal Value Component	Description	Qualitative Evaluation
Equity	Reduced energy burden for low income customers	Customer solar reduces energy burden for adopting customers but increases energy burden for non-adopting customers
Emotional/Political	Engaging customers through NEM, changing their relationship w/ energy	Customer solar adoption likely leads to more education and engagement with energy issues
Local Economy	Jobs and local economic growth resulting from rooftop solar	Customer solar adoption creates jobs in solar installation industry, while bill increases reduce jobs in other segments of the economy

Participant Perspective

Adopting solar or solar + storage systems may or may not be cost-effective for customers adopting these systems over the lifetime of the technology. Estimated costs and benefits levelized over the lifetime of the customer solar installations indicate what their value is to NEM customers over the full 20-year period, rather than for a single year. As such, these $/kWh values are not directly comparable with the values in the preceding sections, which reported annual values for 2020 and 2030.

E3 estimates that under current and planned SMUD retail rates, the participant benefits for residential customers on the RT02 rate are equivalent to the costs over an assumed 20-yr lifetime of a solar only system (using a nominal discount rate of seven percent). However, for solar + storage systems this is not the case, as system costs outweigh the benefits.

[14] More information can be found in the CPUC Integrated Distributed Energy Resources proceeding, R.14-10-003.

[15] Desert Renewable Energy Conservation Plan. *Appendix I: Cost Estimate Methodology and Categories for DRECP Mitigation Cost Estimation*. August 2014. Available at: https://www.fws.gov/carlsbad/PalmSprings/DRECP/Appendix%20I_Cost%20and%20Funding/Appendix%20I_Cost%20and%20Funding.pdf.

[16] R. Costanza et al. *Changes in the global value of ecosystem services*. Global Environmental Change. 2014.

In addition to customer bill savings, the benefits for solar + storage systems include an estimate of the resiliency value provided by reserving battery capacity in the event of a power outage. Costs incurred are the upfront expense of the solar or solar + storage system, along with ongoing operations and maintenance costs. These cost estimates include a reduction for state and federal incentives. The figures below show the benefit and cost comparisons for systems installed in 2020 and 2030. Note that in 2030 all customer solar systems are assumed to be paired with storage, and therefore there are no participant values estimated for the solar only configuration.

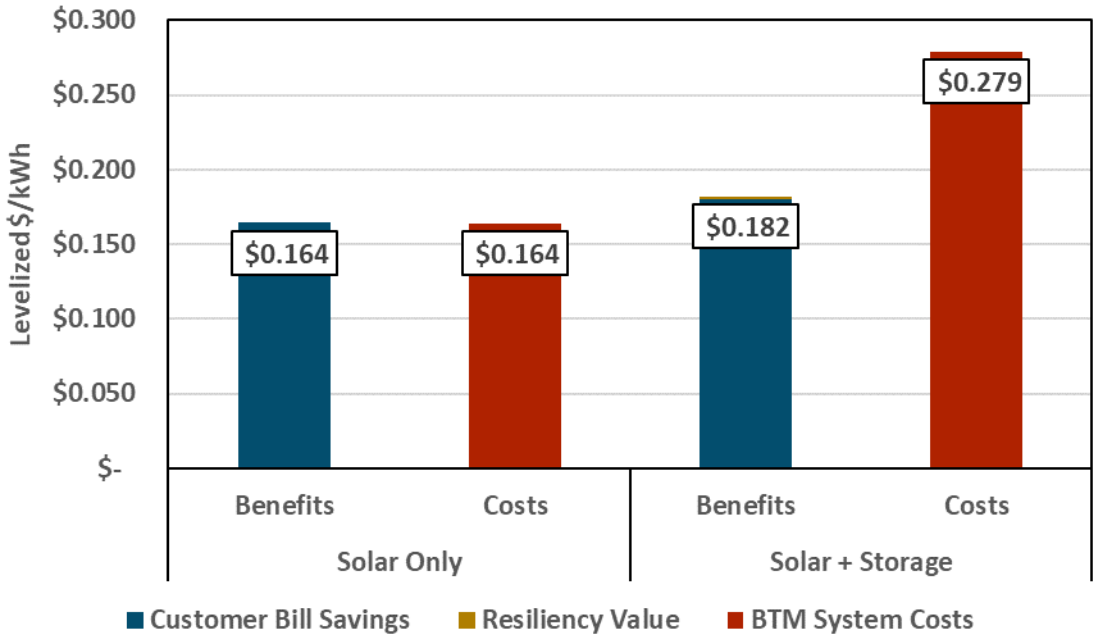

Figure 8. Participant Lifetime Benefits and Costs, Residential RT02 Rate, 2020 Installations

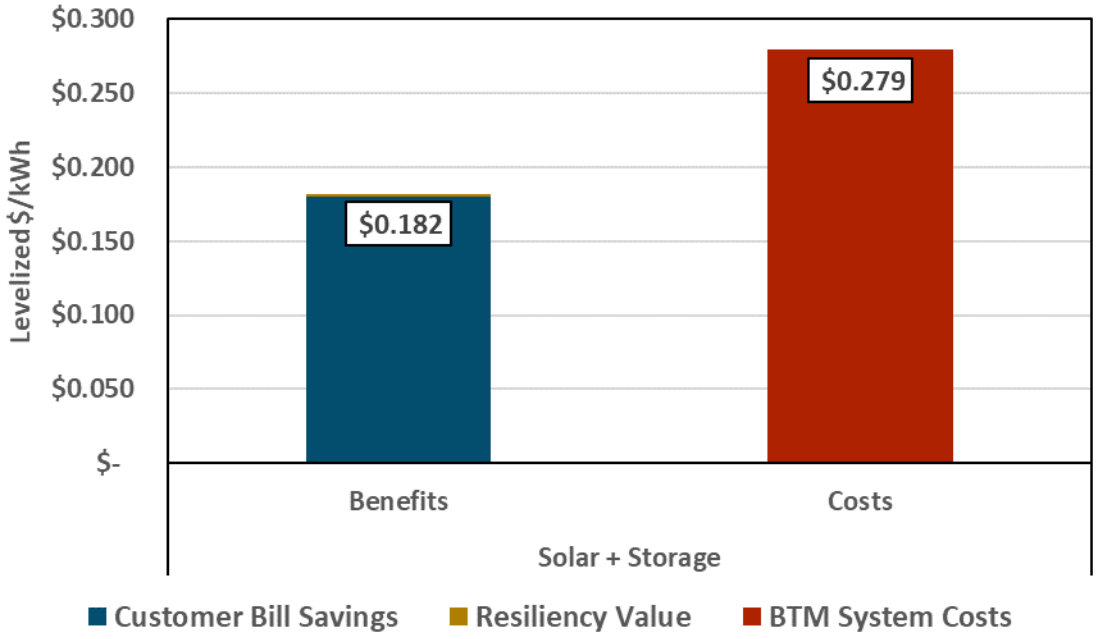

Figure 9. Participant Lifetime Benefits and Costs, Residential RT02 Rate, 2030 Installations

If battery storage costs fall more rapidly than anticipated the cost-effectiveness of these investments for adopting customers will improve. Similarly, if SMUD retail rates rise more rapidly than currently expected, the value proposition to individual NEM customers will improve. However, based on current expectations of technology costs and retail rates paired solar + storage systems are not cost effective from the perspective of NEM customers.

5. Conclusion

Customer solar and solar + storage systems provide a variety of benefits and costs. In assessing the VOS/S for SMUD and the Technical Working Group, E3 considered the distinct perspectives of SMUD ratepayers, society as a whole, and customers adopting solar.

E3's analysis found that the NEM program is not cost effective from the perspective of SMUD's ratepayers. If customer solar installations are assumed to contribute clean energy in excess of SMUD's goals, the value of solar and solar + storage is approximately $0.07 per kWh in 2020 and decreases to $0.04 per kWh by 2030, in nominal terms. The cost to SMUD ratepayers is $0.12 per kWh in 2020 and increases to $0.16 per kWh by 2030. The net effect is a cost shift to SMUD ratepayers of approximately $0.05 per kWh of solar generation in 2020, increasing to $0.12 per kWh by 2030. These values equate to approximately $24 million of shifted costs in 2020, increasing to $91 million by 2030.

If customer solar installations are instead assumed to help SMUD meet its clean energy goals, the value of these systems from the perspective of SMUD ratepayers is approximately $0.03 per kWh of solar generated in 2020, increasing slightly (in nominal terms) to $0.04/kWh in 2030. The cost to SMUD ratepayers is $0.12

per kWh in 2020 and increases to $0.16 per kWh by 2030. This equates to a cost shift of approximately $41 million in 2020, increasing to $91 million by 2030.

From the perspective of customers adopting solar, E3 found that solar only installations can be cost effective, depending on the customer and retail rate, while solar + storage systems currently are generally not cost-effective. This is due to the incremental costs of adding storage to a solar system outweighing the incremental benefits. Should system costs decline more quickly than anticipated, paired solar + storage systems may become cost effective.

E3 also estimated a range of societal values which can be provided by customer solar installations, depending on the scenario. E3 found that the largest potential environmental value was from carbon emissions reductions beyond those required by SMUD's compliance requirements, with smaller economic values provided by avoided fugitive methane emissions, criteria pollutant emissions, water usage and, for the *Helps Meet Clean Energy Goals* scenario, avoided land use.

While customer solar and solar + storage can provide these societal benefits, SMUD has a variety of means at its disposal to meet the clean energy targets set out by its Board of Directors. If achieving these societal benefits is a goal for the utility, the cost of achieving these benefits through customer solar must be weighed against the cost of achieving them through alternate means.

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The E3 team provides this summary report to document the key results of the VOS/S study. E3 and GridSME hope that these findings can help to inform discussion between SMUD, the TWG and other stakeholders on net energy metering and any potential changes to that program, leveraging the three perspectives taken in this analysis when considering the value of customer solar and solar + storage resources.