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RPS-16-03 Certainty of enduring contracts

RPS-16-03 Certainty of enduring contracts

Perhaps the recent rolling blackouts, resulting in concern that planning systems did not immediately identify countermeasures, the State Legislature may be wise to rethink the necessity of long term contracts for eligible renewable resources.

Certainty that there will be paying customers for the renewable resources is low. This is reflected in current prices for renewable resources.

A recent study points to values of $0.03 to $0.07 per kWh of solar power generated. The study is not clear on the value of any renewable energy credits associated with the solar power. See attached below.

Adding long term contracts to develop additional renewable generation that does not load follow appears to be unwise.

When the Energy Commission identifies deficiencies of the planning systems that lead to the rolling blackouts, they will also identify the methods to determine the usable renewable resource capacity while ensuring reliability is invalid.

Methods of planning are far from appropriate. The use batch and queue planning processes in a just in time demand environment must end. The models are not appropriate.

Energy Commission staff are not confident enough to define electricity as a product for the paying end use customer.

How can the public trust the Energy Commission to make wise decisions about any contracts for products, when the Energy Commission fails to define electricity as a product for the paying end use customer.

All contracts should start with product's value to the paying customer, no customer, no contract.

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Additional submitted attachment is included below.

Sacramento Municipal Utility District

September 2020

Value of Solar and Solar + Storage Study

Technical Report

Energy+Environmental Economics

Contents

Figures

Tables

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.

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:

+ **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 customer 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 to customers with customer 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).

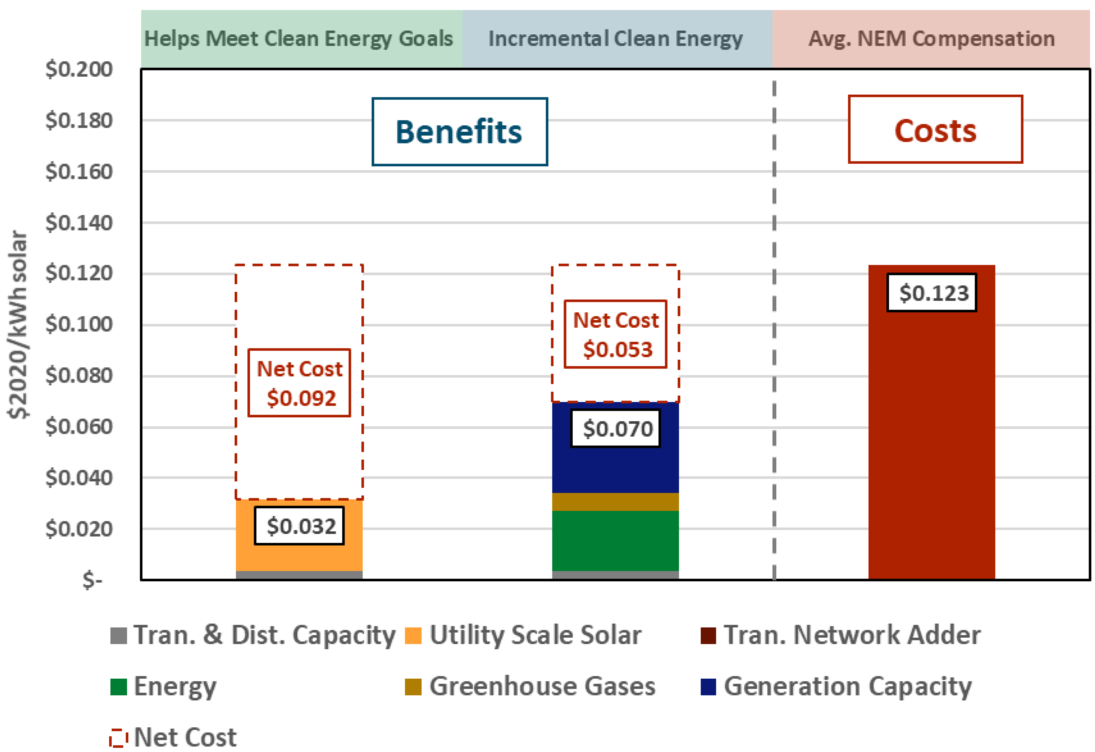

Figure 1. Value of Customer Solar, SMUD Ratepayer Perspective, 2020

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 approximately $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.

The significant increase in net costs between 2020 and 2030 is due to the declining value of solar generation which is anticipated over this period, driven by changes in wholesale electricity market prices due to the large additions of solar resources planned by many utilities throughout the Western U.S. in the coming years. 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, under the *Incremental Clean Energy* value scenario. This table reports combined results for customer solar and solar + storage systems under 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.

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

Solar & Solar + Storage (Cust. Dispatch)	*NPV*[1]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	**n/a**	**263**	**340**	**445**	**445**[2]
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.**

Table 2, below, presents an alternative, forward-looking value scenario in which customer solar and storage are utilized as tools to help the utility meet its increasingly aggressive clean energy goals. Under the *Helps Meet Clean Energy* scenario, customer solar and storage displace utility investments in clean energy resources. Customer storage is dispatched in partnership with the utility, maximizing its value for SMUD ratepayers while preserving a portion of the storage to provide backup power services to the system owner. Under this system configuration and valuation scenario, the total estimated bill increases attributable to customer solar and storage systems by 2030 is $81 million, or approximately $79 per year for the average residential customer.

[1] 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.

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

Table 2. Summary of Ratepayer Impacts: Helps Meet Clean Energy Goals Scenario, Utility Partnership Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Util. Partner)	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 ($/kWh solar)	***0.053***	0.032	0.040	0.047	0.069
SMUD Revenue Reduction ($/kWh solar)	***0.178***	0.123	0.132	0.157	0.224
Net Cost Shift ($/kWh solar)	***0.125***	0.091	0.092	0.110	0.154
Total Change in SMUD Costs & Revenues					
Value of Solar and Solar + Storage	***$552 MM***	$14 MM	$23 MM	$35 MM	$49 MM
SMUD Revenue Change	***-$1,850 MM***	-$56 MM	-$76 MM	-$116 MM	-$157 MM
Net Cost Shift	***$1,297 MM***	$41 MM	$53 MM	$81 MM	$108 MM
Change in SMUD Average Rates (%)	*n/a*	3.0%	3.5%	3.9%	3.7%
Approximate Annual Bill Impact (non-solar residential customer @ 750 kWh/month)	*n/a*	$44/yr.	$61/yr.	$79/yr.	$107/yr.

E3 also estimated the value of several societal benefits including reductions in carbon emissions beyond SMUD compliance requirements, avoided fugitive methane emissions, reduced air pollution, and reduced land usage, as depicted in Table 3 below. In the *Incremental Clean Energy* scenario where customer solar and solar + storage is assumed to displace natural gas there is a range of societal values from carbon reductions of approximately $0.018 to $0.072/kWh.[5] Avoided fugitive methane emissions have a small value of considerably less than $0.001/kWh. Avoided criteria pollutants from reduced thermal power plant operations are estimated to have a value of approximately $0.008/kWh, while avoided water use is estimated at up to $0.001/kWh. In the alternative *Helps Meet Clean Energy Goals* scenario where customer solar is considered to displace utility scale clean energy resources, the avoided land use is estimated to have a value of approximately $0.004/kWh.

While these environmental and societal benefits are based on the best available information, it is important to keep in mind that customer solar is not the only way to achieve these benefits. Many of these benefits can also be provided by energy efficiency, utility-scale solar, wind, or other clean energy resources at a much lower cost than the compensation to customer systems that is implicit in the NEM program. It should also be noted that many of these benefits, particularly air quality, accrue to citizens far beyond the Sacramento area.

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[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.

[5] We note that there are considerably higher social cost of carbon values in the literature (as high as $417/metric ton in 2020). Please see discussion in the *TWG Value Component #12: Carbon Emission Reductions* section (page 31).

Table 3. 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[6]	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 $0.008an /kWh	
Water	Reductions in water usage due to decreased thermal power plant operation	4 to 250 gallons	Up to $0.001/kWh[7]	
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* scenario

From the NEM customer perspective E3 found that some customer solar and solar + storage systems are cost-effective today, while others are not. Solar only system costs and benefits are roughly equivalent over a 20-year system life for residential customers on the RT02 rate, with cost-effectiveness improving for installations in later years given anticipated increases in retail rates and declines in solar costs. Adding a

[6] 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 this report (see Table *15* and Figure 17 on page 32). This estimate is well above the range of other estimates considered.

[7] 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.

battery storage system does not provide sufficient additional benefit to outweigh the additional system costs.

Most non-residential solar only systems are cost-effective from the customer perspective today. For some of these customers adding a battery storage system can provide sufficient benefit in the form of reduced demand charges that paired systems are cost-effective.

The “utility partnership” configuration, where customer batteries are dispatched to provide maximum value to all SMUD ratepayers, is not cost-effective for either residential or non-residential customers. Additional incentives would likely be required to incent customer participation in such a program.

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.[8] 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.

This transition is not limited to SMUD. Over the next decade the electricity grid in the Western U.S. will also see significant investments in solar, wind and battery storage 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. Energy market prices will change dramatically in the coming years.

At the same time, SMUD anticipates significant growth in customer solar and solar + storage systems in its service territory, which must be considered when making resource planning decisions. To evaluate the contributions of these customer-owned resources, SMUD engaged Energy and Environmental Economics (E3) and GridSME (collectively, "the E3 team") to conduct an analysis of the Value of Solar and the Value of Solar + Storage (VOS/S), specifically focused on behind the meter systems.

Over 25,000 of SMUD's customers participate in the net energy metering (NEM) program, through which on-site generation of electricity from customer 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 BTM 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 BTM solar will increase to approximately 445 MW by 2030, with a growing share of these systems paired with battery storage.

[8] 2018 SMUD Annual Report. Available at: https://www.smud.org/-/media/About-Us/Reports-and-Statements/2018-Annual-Report/2018-Annual-Report.ashx.

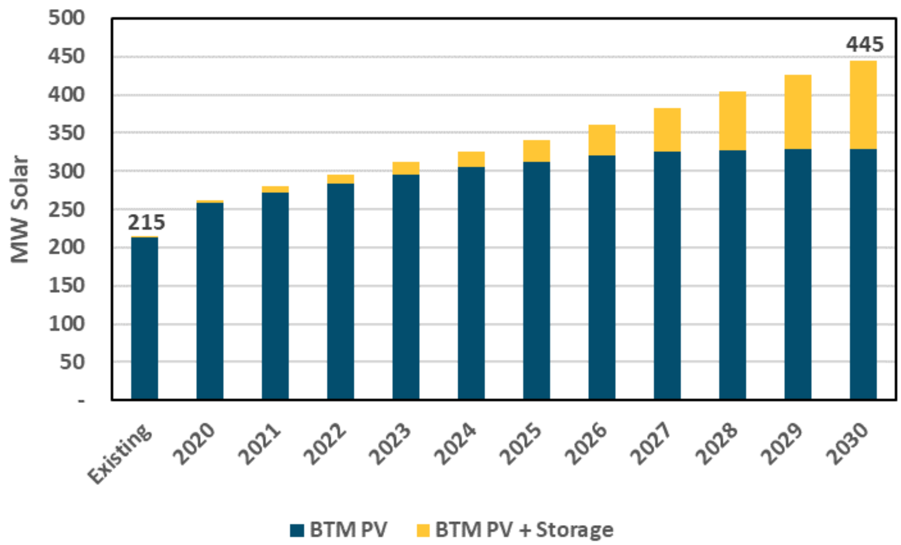

Figure 2. Cumulative Customer Solar and Solar + Storage Forecast

As the amount of BTM 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 solar customers 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 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).[9] 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.

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

The E3 team's scope of work was informed directly by the TWG report. Table 4 summarizes the components recommended by the TWG and notes which value E3 has explored that component through. E3 analyzed these value components quantitatively where possible, and qualitatively where appropriate. Components marked as "qualitative" were not quantified directly and are instead discussed in the relevant report section(s) for that category. Additionally, to capture the fact that not all value components flow to all parties equally, E3 used three different beneficiary perspectives through which to consider each value component:

+ **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.

Table 4. TWG Value Components

Category	ID [10]	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	✓	✓	

System Configurations

As requested by the TWG, E3 considered three different system configurations in this analysis:

- **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

Evaluating these system configurations allows for exploration of the different benefits and costs that can be offered by solar only vs. paired solar + storage systems, which are anticipated to become increasingly prevalent in the coming years. The "utility partnership" configuration further explores the value which customer solar + storage systems could potentially provide if operated in conjunction with SMUD, allowing for dispatch of the system in a more targeted fashion.

Value Scenarios

In order to assess a range of potential values, E3 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:

- **Helps Meet Clean Energy Goals:** Customer solar installations help SMUD achieve the clean energy goals specified by SMUD's Board of Directors, by 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.

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.

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

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

3.1. Methodology Overview

At a summary level, E3's analysis for each of the system configurations can be thought of as taking place in several primary steps:

1) **Develop avoided costs:** hourly marginal avoided cost of the different value components
2) **Characterize representative solar (+ storage) customers:** hourly loads and customer solar system profiles
3) **Calculate value of solar (+ storage) systems:** calculated using E3's optimal storage dispatch model, using the avoided costs to assess value
4) **Calculate solar (+ storage) customer bill savings:** assess how the savings relate to the avoided cost value provided by the customer solar systems
5) **Scale results up to the NEM population level:** based on existing systems and the customer solar system forecast included in SMUD's IRP

The following section describes each of these steps in detail.

3.2. Avoided Cost Development

Avoided costs represent the monetary benefits to the utility due to reductions in customer usage associated with solar or solar + storage. Typical examples are reductions in power procurement costs or a reduced need for new infrastructure to meet customer peak demands. Avoided costs have long been used in the utility industry to evaluate projects and programs to determine if they would be net beneficial for utility customers as a whole, as well as estimate potential financial impacts for customers.

Note that terms "marginal cost" and "incremental cost," also refer to changes in costs due to changes in usage and may be used interchangeably with "avoided cost" in the discussion below.

A summary of average hourly avoided cost values by component across all hours from 2020 – 2040 is shown in Figure 3 below. Note that Ancillary Services and Integration costs, while included, are difficult to visually detect given the magnitude relative to the other avoided cost values.

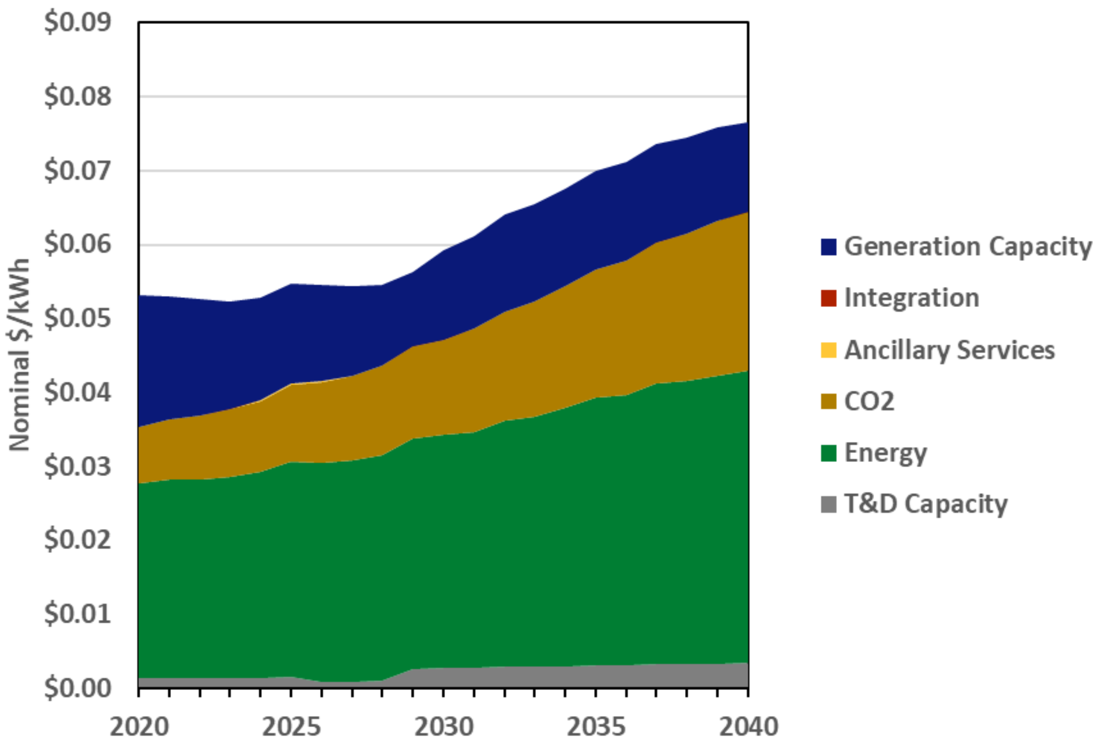

Figure 3. Average Hourly Avoided Costs, All Hours (Nominal $/kWh)[11]

As this figure shows hourly avoided costs across all hours, it represents annual averages of all resource types which compose SMUD's resource mix, including SMUD-owned generation, market purchases and sales, and long-term contracts.

The following sections provide a description of the methodology used to develop each avoided cost component.

TWG Value Component #1a & 9: Energy

TWG Description
1a: Avoided purchase of energy that would otherwise be needed, including SMUD's obligations to comply with California's RPS and carbon emissions cap-and-trade system
9: Decreased thermal power plant operations will decrease variable operating costs (i.e., water, waste, etc.)

[11] Avoided distribution capacity value varies by distribution planning area. Figure 3 includes the hourly avoided distribution capacity value (within the T&D Capacity component) from one distribution planning area as an example, although the differences between the areas is not large relative to the total avoided costs shown in this figure.

E3 Evaluation

Hourly marginal energy prices were sourced from SMUD's resource planning team, who generated them using the PLEXOS production simulation model. The PLEXOS model run optimized SMUD resource dispatch electricity trading with other electricity systems in the Western Interconnection, including the neighboring California Independent System Operator (CAISO). The external energy prices which were input to PLEXOS are E3 market price forecasts as of May 2020 and reflect the outlook for resource buildout in California as well as the rest of the Western Interconnection to serve loads and meet state Renewable Portfolio Standard (RPS) targets, many of which have increased recently. Hourly prices are produced for 2020-2040.

The marginal energy prices from the PLEXOS analysis reflect the costs of fuel, operations, and maintenance (O&M), and carbon cap and trade compliance. Given the importance of greenhouse gas emissions to SMUD and its customers, E3 decomposed the marginal energy prices to show the cap and trade costs as a separate component (see next section), and used the remaining non-carbon portion of the prices as the input for hourly avoided energy value per MWh of customer solar system output. Figure 4 shows the average hourly energy prices for select years from 2020 – 2040. These prices reflect the non-carbon portion of the market prices and are therefore net of the greenhouse gas emissions costs.

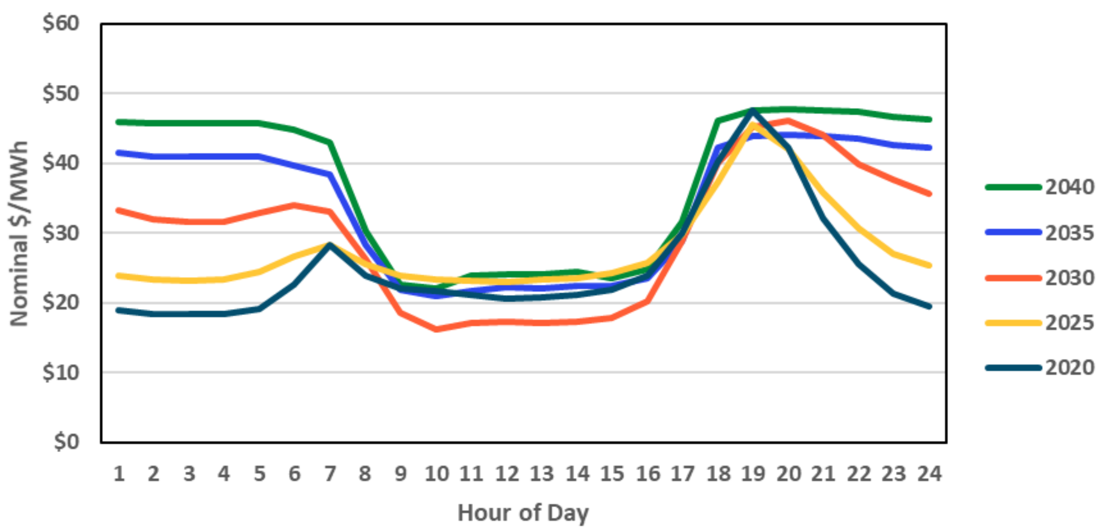

Figure 4. Average Hourly Energy Prices, select years

Figure 4 above depicts the change in annual average prices, in nominal terms. However, there are also important seasonal variations which impact the value of solar generation over time. As Western states add significant amounts of solar capacity in the coming years to help meet clean energy goals the daytime hours will become saturated with energy production, reducing the marginal value of solar resources.

Figure *5* below compares the average energy prices (net of GHG costs) by month and hour of day for both 2025 and 2030, shaded to highlight the high (red) and low (blue) priced hours. As can be seen by the darker sections in the lower, 2030 chart, the peak solar production hours during the springtime are expected to become negatively-priced, while the evening peak hours after solar production tails off are expected to become increasingly expensive. Due to this dynamic the energy value of incremental solar installations decreases over the study period. These month-hour charts also include the effect of the significant buildout of storage resources anticipated across the West, without which the price disparity between daytime solar hours and the high-priced evening periods would be even greater.

2025

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	26.4	25.8	25.8	25.8	27.5	32.1	36.7	35.0	29.6	26.9	25.9	24.9	24.8	24.8	24.7	25.7	30.8	41.0	42.2	38.3	36.0	34.7	31.4	29.2
Feb	26.4	25.9	25.8	25.9	27.8	31.7	38.3	33.2	28.8	27.6	25.6	25.0	24.4	24.3	24.2	24.7	28.7	35.8	48.4	40.3	36.0	34.4	30.9	29.2
Mar	24.4	23.8	23.8	23.9	25.5	29.8	34.1	26.9	24.6	23.8	23.9	23.1	22.7	22.4	22.3	23.0	25.0	30.1	37.0	40.4	36.0	30.2	26.4	24.8
Apr	20.5	20.2	20.0	20.3	21.2	22.2	22.5	19.6	19.1	19.1	19.1	19.0	17.9	18.3	17.9	18.7	20.9	22.1	29.4	34.5	30.2	23.7	22.0	21.1
May	16.6	16.3	16.5	16.4	16.3	16.8	16.6	15.9	14.7	15.3	15.5	15.4	15.9	15.1	15.7	16.3	17.9	20.7	24.9	29.8	27.2	20.2	17.8	16.3
Jun	21.6	21.3	20.9	21.0	21.0	19.8	19.7	18.6	18.9	19.9	19.9	20.2	21.1	21.4	22.0	22.7	24.5	28.6	39.6	47.7	34.5	26.2	22.4	22.2
Jul	23.9	23.4	23.1	23.2	23.4	22.7	22.6	22.0	22.4	22.5	24.2	25.0	26.2	28.2	29.2	32.7	38.4	49.0	59.5	59.5	47.8	34.9	28.1	26.1
Aug	24.0	23.4	23.3	23.2	23.6	24.3	23.5	22.3	22.2	22.8	22.8	23.3	24.1	25.2	28.1	30.8	35.8	47.1	73.7	56.2	39.2	31.8	26.5	25.4
Sep	24.6	22.9	22.7	23.0	25.2	27.6	27.3	23.1	22.8	22.4	22.4	23.3	25.7	26.7	29.3	30.8	33.8	41.4	61.3	44.1	37.1	32.3	27.5	25.7
Oct	27.7	27.2	26.8	27.0	28.4	31.5	33.0	27.6	26.3	26.2	26.3	26.0	26.7	27.1	27.6	29.6	34.2	42.4	43.9	40.0	35.1	32.9	30.3	28.9
Nov	23.8	23.2	23.1	23.1	25.1	28.2	31.1	28.2	25.4	23.8	23.6	23.5	22.8	22.6	22.8	23.9	32.6	39.8	40.5	35.5	33.5	32.0	29.0	26.3
Dec	27.5	27.2	27.2	27.2	28.4	33.1	35.5	34.6	31.7	29.6	28.4	27.7	27.1	26.5	26.7	29.0	35.6	48.3	45.8	38.5	36.6	35.5	33.1	30.4

2030

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	38.8	37.6	36.5	37.1	38.3	40.7	41.8	41.5	31.8	24.9	25.4	25.0	24.4	23.1	22.8	25.6	35.7	42.7	43.4	43.1	42.7	42.2	40.8	40.0
Feb	41.0	38.7	38.1	38.0	41.5	44.1	44.2	40.5	30.5	22.7	22.6	22.3	21.1	21.3	22.0	22.0	33.6	44.7	46.6	46.3	46.3	46.4	45.5	43.2
Mar	36.8	35.3	35.7	36.2	36.5	37.3	37.4	30.1	8.0	0.9	(0.1)	0.4	(0.7)	0.6	0.1	0.3	15.3	35.3	38.0	38.5	38.2	37.8	36.9	36.1
Apr	27.4	27.0	26.9	27.6	28.0	30.2	28.3	9.9	(2.2)	(2.8)	(3.2)	(3.4)	(3.7)	(3.2)	(3.2)	(2.9)	5.8	26.6	31.6	33.2	32.7	29.2	28.4	27.0
May	12.3	11.7	11.4	11.4	12.3	11.7	10.1	(1.5)	(4.0)	(3.9)	(3.7)	(4.2)	(4.1)	(3.8)	(3.7)	(3.7)	1.7	16.1	18.6	20.2	19.9	16.6	14.6	13.3
Jun	26.8	26.0	26.2	26.0	26.0	25.2	23.9	17.9	14.9	15.5	17.9	18.6	18.7	18.9	20.5	22.7	25.2	30.9	34.4	37.3	39.3	32.0	28.7	27.4
Jul	32.0	30.8	29.7	29.7	29.4	27.2	26.8	23.7	20.3	20.1	24.8	25.3	25.7	26.5	27.1	29.4	32.7	42.5	50.2	54.7	51.7	43.2	38.0	35.6
Aug	32.5	31.7	31.2	30.9	31.4	31.6	27.7	25.9	23.9	23.3	24.7	25.5	25.9	26.8	28.6	30.9	34.2	46.6	72.8	72.9	61.0	43.1	41.0	36.7
Sep	36.9	34.4	33.2	33.1	35.7	37.1	33.8	25.6	23.7	23.1	24.4	24.9	25.7	26.0	27.2	30.0	36.1	55.0	64.9	65.2	58.4	51.2	45.6	40.9
Oct	37.3	36.5	35.6	36.0	37.7	39.0	38.7	28.5	21.1	20.0	21.0	21.7	21.6	22.3	22.4	27.5	38.3	47.6	49.1	48.5	47.1	45.3	43.3	42.3
Nov	39.0	38.0	38.0	37.9	39.3	40.8	41.3	31.7	21.3	18.6	19.4	19.6	19.0	18.8	18.8	28.3	43.4	45.6	45.6	45.6	45.8	45.4	44.0	42.4
Dec	39.6	37.4	36.8	36.5	39.3	43.2	44.4	42.0	33.6	32.2	32.1	31.4	31.2	31.3	31.0	33.6	45.5	47.0	47.2	47.2	47.2	46.5	45.1	43.1

Figure 5. Average Hourly Energy Prices by Month and Hour, 2025 and 2030 (Nominal $)TWG Value Component #1b: Greenhouse Gases

TWG Description: Avoided purchase of energy that would otherwise be needed, including SMUD's obligations to comply with California's RPS and carbon emissions cap-and-trade system

E3 Evaluation

The marginal cost of greenhouse gas emissions is calculated as the cap and trade allowance price multiplied by the marginal emission rate (the emissions from the last plant to dispatch in each hour). Table 5 below shows the forecast of cap and trade costs used in the analysis. As the bulk of statewide carbon emission reductions are expected to occur through specific mandates and programs as opposed to the cap and trade program, this will put downward pressures on cap and trade prices. Therefore, E3 assumes carbon prices are based on the California Air Resources Board (CARB) allowance price floor.

Table 5. Cap and Trade Price Forecast, based on CARB GHG Allowance Price Floor (nominal $/metric ton CO_2)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
CO_2 Price	16.68	17.96	19.31	20.79	22.36	24.04	25.85	27.84	29.98	32.28
2030	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
34.75	37.38	40.21	43.25	46.52	50.04	53.82	57.89	62.28	67.00	72.08

To determine the hourly marginal emission rate, E3 started with the energy market clearing price forecast from PLEXOS, with the cap and trade cost already removed. Using the capacity-weighted average variable

O&M costs for SMUD's thermal generators and the monthly market price forecast for natural gas in Northern California and the Pacific Northwest to derive the hourly implied market heat rate (IMHR). Multiplying the IMHR by the CO_2 content of natural gas yields the emission rate in metric tons per kWh.

$$Emission\ Rate[h]\left(\frac{metric\ tons}{kWh}\right) = IMHR[h] * NGCO_2\left(\frac{metric\ tons}{MMBtu}\right)$$

$$IMHR[h] = \frac{\left[MP[h]\left(\frac{\$}{kWh}\right) - OM\left(\frac{\$}{kWh}\right)\right]}{NG[mo]\left(\frac{\$}{MMBtu}\right)}$$

With ceiling constraints.

where:

h = hour

IMHR = Implied Marginal Heat Rate (MMBtu/kWh),

MP = Market Price,

OM = Operation and Maintenance Costs (weighted average of SMUD thermal generators),

NG = Monthly natural gas forecast corresponding to hour *h*,

$NGCO_2$ = CO_2 content of natural gas in metric tons per MMBtu (0.0532).

Table 6 contains a summary of E3's natural gas market price forecast. E3's natural gas price forecast is based on market forward data for local gas trading hubs (such as PG&E City Gate & Malin) in the near term (first 3 years of forecast) and then transitions over time to a long run forecast based on EIA Annual Energy Outlook Projections in 2040. These gas price forecasts are used when creating the electricity price forecast.

Table 6. E3 Natural Gas Price Forecast, Annual Average for trading hubs in Northern California and the Pacific Northwest (nominal \$/MMBtu)[12]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
N. CA	2.73	2.90	2.98	3.02	3.17	3.31	3.46	3.61	3.77	3.94
PNW	1.79	2.04	2.13	2.18	2.27	2.40	2.52	2.65	2.79	2.93
2030	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
4.11	4.29	4.49	4.68	4.90	5.12	5.34	5.59	5.84	6.10	6.38
3.08	3.24	3.41	3.58	3.77	3.97	4.17	4.38	4.60	4.84	5.09

The gas prices used to generate avoided energy prices additionally include an assumption that gas pipeline transportation rates will increase over time due to reduced throughput under California's climate policies.

[12] Northern California (N. CA) and Pacific Northwest (PNW) prices for PG&E Citygate and Malin trading hubs, respectively.

Specifically, gas transportation costs have been escalated to reflect anticipated reductions in natural gas throughput as well as increasing revenue requirements, resulting in upward pressure on gas transportation costs. Figure 6 depicts the assumed increase in gas tariffs underlying the price forecast used to generate avoided energy prices.

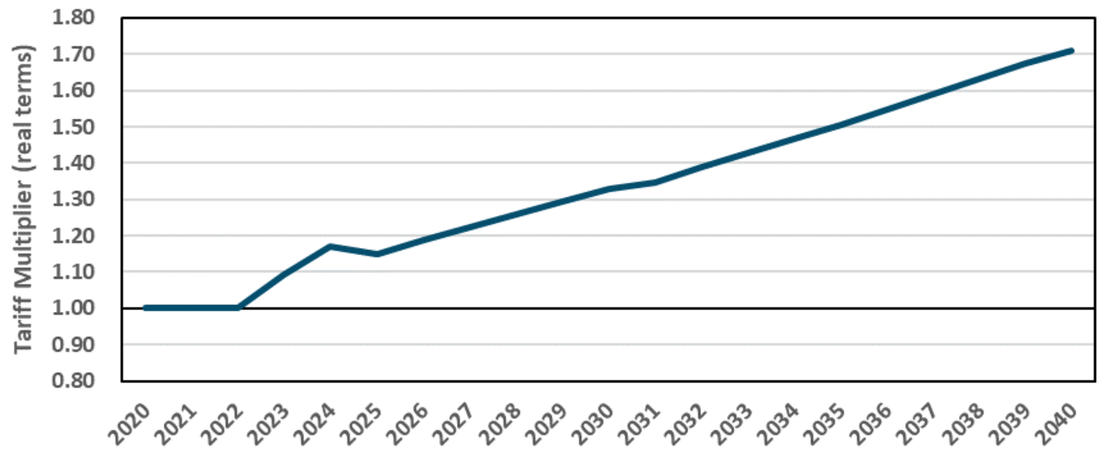

Figure 6. Natural Gas Tariff Multiplier (in real terms relative to 2020)

The IMHR derivation is premised on the market clearing price being based on the fuel and O&M costs of the marginal plant. This paradigm is valid while there is market competition, but some market prices reflect bidding distortions. To adjust for such distortions and constrain the IMHR to a realistic range, E3 capped the IMHR values at 12,500 Btu/kWh to reflect the upper range of typical operating heat rates in California's thermal fleet. There was no minimum threshold heat rate used, reflecting that IMHR below the realistic operating range of thermal power plants can reflect averaging of resources within an hour (i.e., marginal generation from a combination of thermal and zero-carbon resources within that hour). This is aligned with the assumptions used in the California Public Utilities Commission's Avoided Cost Calculator. In hours with negative prices the energy (rather than CO_2) price was set to the negative renewable energy credit (REC) value implied by the hourly electricity prices and the levelized cost of utility scale solar generation.

Prior to 2030, importing power from the Pacific Northwest via COB was assumed to entail carbon emissions at the CARB unspecified import emissions rate of 0.428 metric tons CO_2/MWh. After 2030 E3 assumed that carbon pricing between California and the Pacific Northwest harmonizes around the CARB cap-and-trade allowance price, and therefore emissions rates from COB were calculated using the IMHR approach as described above.

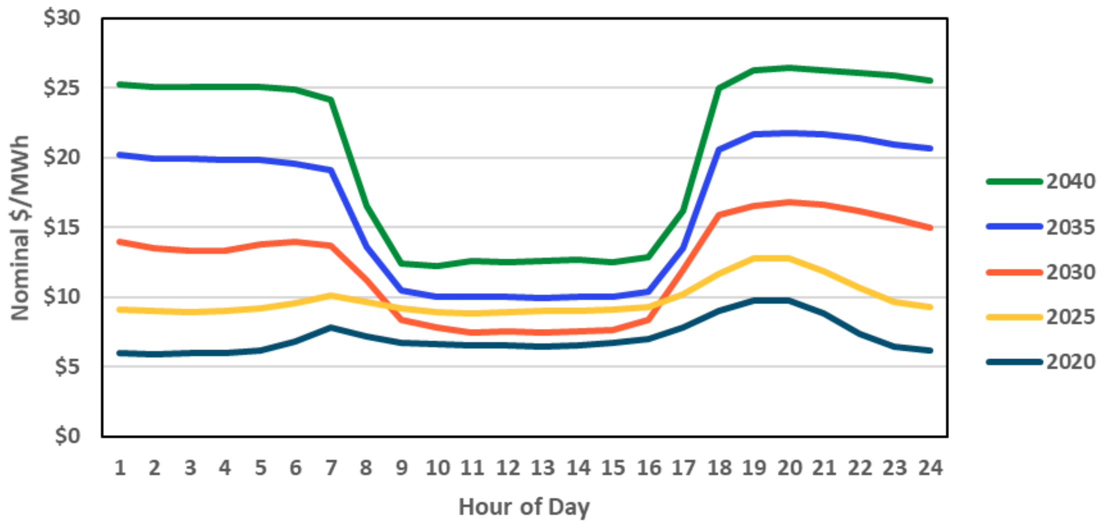

Figure 7. Average Hourly Avoided CO_2 Costs, select years

TWG Value Component #3: Higher Marginal Cost of Emissions

TWG Description: Higher marginal cost of emissions due to intermittent resources

E3 Evaluation

As SMUD transacts with wholesale market energy prices in the CAISO and the Pacific Northwest, the marginal impact of intermittency from SMUD's customer solar systems is likely to be small. Any increase in the cost of emissions due to SMUD's decreased net load would also be coincident with solar production in the broader region (both rooftop solar and utility scale solar), and therefore the portion of any increases in marginal emissions costs attributable to SMUD's NEM customers would be de minimis.

TWG Value Component #6, 7 & 8: Financial Risk

TWG Description:

6: Reduces fuel price risk

7: Increases energy price volatility

8: Assigned criteria pollutant Emission Reduction Credits are sunk cost (no financial impact)

E3 Evaluation

The TWG recommended three different value components be assessed within the *Financial Risk* category: Fuel Price Risk, Energy Price Volatility, and the sunk cost of Emission Reduction Credits. Given that the cost of Emissions Reduction Credits is not avoidable, E3 did not assess this component.

Fuel price risk and energy price volatility are related risks. Owners of thermal generators are exposed to price fluctuations in the cost of fuel such as natural gas, while utilities or other entities buying or selling electric power are exposed to price fluctuations in wholesale electricity markets. For a price, either type of risk can be addressed through hedging by entering into contracts which lock in a certain cost for the relevant commodity (natural gas or electricity). The price premium utilities are generally willing to pay is relatively small, on the order of several percentage points.

As customer solar systems reduce SMUD's net load they also reduce the risk inherent in natural gas and electricity market prices. To assess the potential value of reducing this financial risk, E3 calculated the risk premium reductions using the avoided energy and GHG costs attributable to customer solar systems. E3 assumed a risk premium of five percent, informed by empirical analysis of electricity forward prices.[13] Note, the value of avoided financial risk is only applicable under the *Incremental Clean Energy* scenario, as in the *Helps Meet Clean Energy Goals* scenario the assumption is that customer solar systems displace SMUD's procurement of utility scale solar (which is not subject to the same price risk).

As an example of the magnitude of this effect, in 2020 the total avoided energy and GHG costs from NEM customers' customer solar and solar + storage systems (in the customer dispatch configuration) are approximately $13.2 million, or $0.029/kWh of solar generated. Five percent of this figure is approximately $660,000, or $0.002/kWh. The incremental value of the financial risk reduction therefore increases the total value of avoided energy and GHG in that year to $0.031/kWh. Throughout the results presented in this report E3 has included the additional value due to the five percent risk premium directly within the energy and GHG values for the *Incremental Clean Energy* scenario.

TWG Value Component #1c: Ancillary Services

TWG Description: Avoided purchase of energy that would otherwise be needed, including SMUD's obligations to comply with California's RPS and carbon emissions cap-and-trade system

E3 Evaluation

Avoided ancillary services were based on the hourly ancillary services price forecast produced through SMUD's PLEXOS modeling. Through its participation in the Northwest Power Pool, SMUD holds contingency reserves for three percent of its load and three percent of its generation, meaning that a reduction in load due to customer solar generation reduces the required contingency reserves that SMUD must hold. E3 applied this percentage to SMUD's hourly spinning and non-spinning ancillary services costs to yield a $/MWh avoided cost. Figure 8 below provides the resulting combined avoided ancillary services costs, on an average hourly basis for select years.

[13] DeBenedictis, A., D. Miller, J. Moore, A. Olson and C.K. Woo. *How Big Is the Risk Premium in an Electricity Forward Price? Evidence from the Pacific Northwest*. The Electricity Journal. 2011.

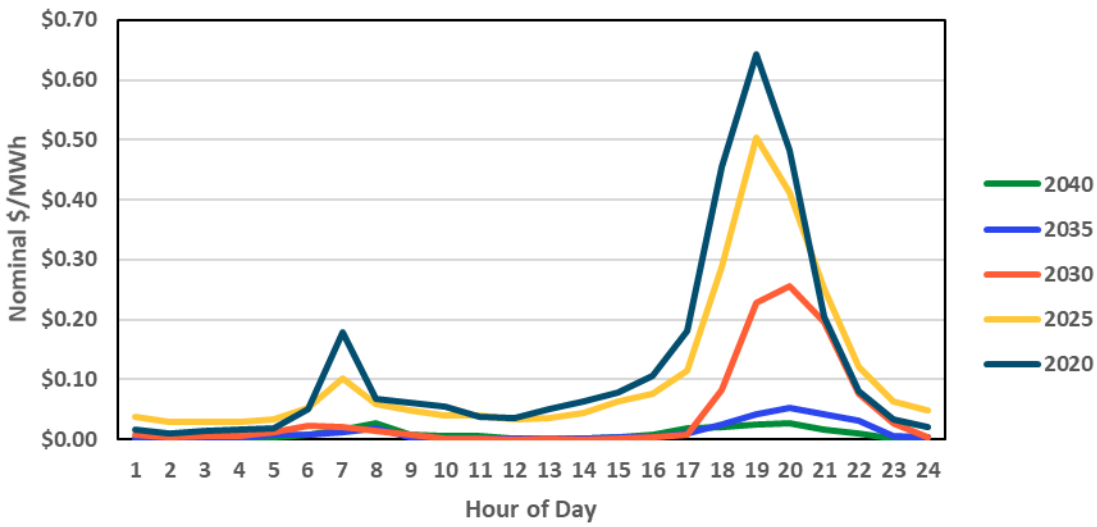

Figure 8. Average Hourly Avoided Ancillary Services Costs, select years

TWG Value Component #2, 5 & 10: Integration

TWG Description:
2: Integration costs
5: Increases need for intra-hour flexibility
10: Increased power plant standby/station power costs and higher operations and maintenance (O&M) costs due to cycling

E3 Evaluation

E3 estimated the marginal integration costs of customer solar and solar + storage systems based on the increase in "load following" and "regulation" requirements on the SMUD system resulting from additional intermittent solar. Unlike most other marginal costs described in this section, integration costs for solar installations result in a cost increase for SMUD rather than a cost reduction.

Using its RESERVE tool[14], E3 calculated the load following and regulation requirements associated with solar using the following methodology.

+ **Load Following:** Calculate difference between day-ahead solar forecast and actual solar generation to derive upward (97.5th percentile of differences) and downward (2.5th percentile of differences) load following requirements
+ **Regulation:** Calculate difference between subsequent 5-minute solar generation periods after accounting for expected changes in solar generation based on time of day and weather forecasts

[14] RESERVE is E3's tool for determining dynamic ancillary services needs of highly renewable electricity grids. It uses intelligent selection of causal variables to help grid operators predict reserves needs and better manage forecast error and short-term variability in load and in wind and solar production. For more information on RESERVE please see https://www.ethree.com/tools/reserve-model/.

to derive regulation up (97.5th percentile of differences) and regulation down (2.5th percentile of differences) regulation requirements.

Load following and regulation requirements were calculated for each hour of an average day for each month of the year and normalized to yield a MW load following and regulation requirement per MW of installed solar.

All values were calculated using publicly available historical CAISO data from 2015 – 2018, which was chosen as a proxy for SMUD solar given the project scope and budget, as well as the geographic similarity in SMUD and CAISO service territories.

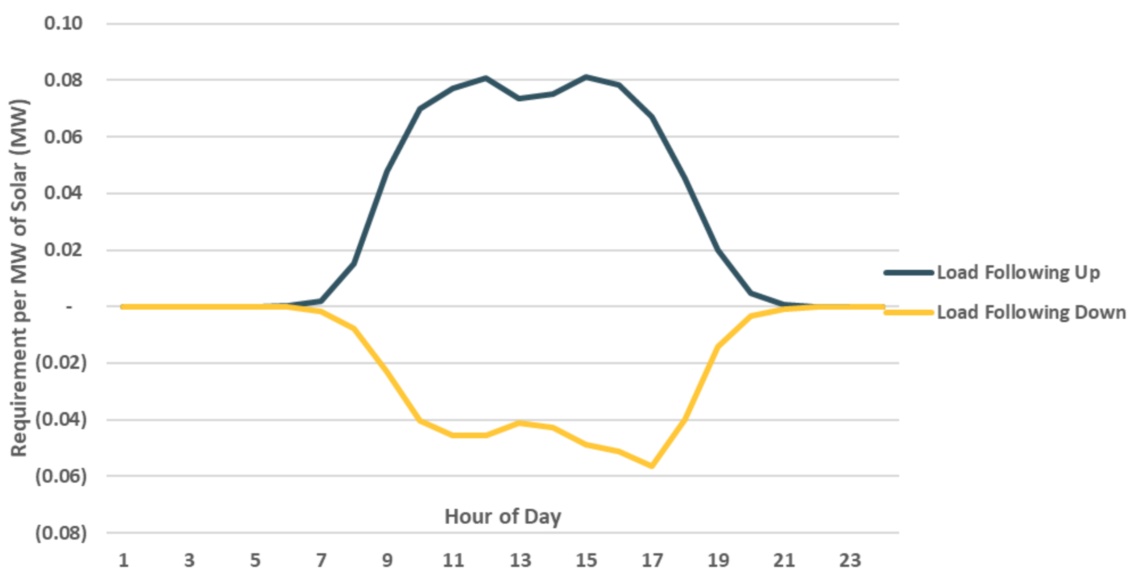

Figure 9. Average Hourly Load Following Requirements per MW of solar

These month/hour load following and regulation requirements per MW of installed solar were then multiplied by the cost of providing these services. For load following the cost of non-spinning reserves was used as a proxy. For regulation, values from SMUD's PLEXOS runs were used. Together the change in load following and regulation costs were used to estimate the integration costs due to deploying additional solar and solar + storage systems. As shown in Table 7 below, the resulting costs are small relative to other avoided cost components.

Table 7. Annual Average Integration Costs (Nominal $/MWh)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
	0.04	0.04	0.03	0.04	0.03	0.03	0.03	0.04	0.05	0.06
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.05

TWG Value Component #4: Generation Capacity

TWG Description: Provides resource adequacy

E3 Evaluation

The industry standard for calculating the marginal cost of generating capacity in periods of resource deficiency is the net cost of new entry (Net-CONE) of a capacity resource. Specifically, Net-CONE is based on the resource with the lowest net cost of capacity, defined as the gross cost of the capacity resource less the benefits it provides to the system, such as energy and ancillary services. Traditionally natural gas combustion turbines (CT) have been the lowest net cost capacity resource. However, decreasing battery storage costs paired with increasing policy limitations on fossil fuel resources are beginning to change this paradigm.

In periods of resource sufficiency – where additional capacity is not required because sufficient resources are available to maintain system reliability – other lower estimates are used. As SMUD is a net importer in the summer months and relies upon the market during that period of the year, the utility is not in a state of resource sufficiency. For this analysis, E3 therefore used the full Net-CONE value of a new capacity resource, in this case battery storage.

Figure 10 depicts the Net-CONE for both a battery storage and a CT resource, for the years 2020-2040. E3 calculated these values using SMUD's marginal energy and ancillary services prices from PLEXOS, run through our RESTORE optimal dispatch model to evaluate the net energy and ancillary service benefits each resource would provide to the SMUD system. These net benefits were subtracted from the fixed costs of these resources to estimate annual Net-CONE values. Specifically, annual Net-CONE values were calculated as follows:

$$NetCONE = Fixed\ Costs - Net\ Revenue$$

$$Fixed\ Costs = Capital + \ Fixed\ O\&M + Replacement$$

$$Net\ Revenue = (Energy + RegUp + RegDown + Spin + NonSpin) * Tax\ Rate$$

where:

Capital = upfront capital costs for the asset,

Fixed O&M = annual operations and maintenance costs,

Replacement = periodic replacement and augmentation costs,

Energy = market energy revenues,

RegUp = market regulation up revenues,

RegDown = market regulation down revenues,

Spin = market spinning reserves revenues,

NonSpin = market non-spinning reserves revenues,

TaxRate = effective tax rate of 28 percent (21 percent federal tax rate and 8.84 percent state tax rate).

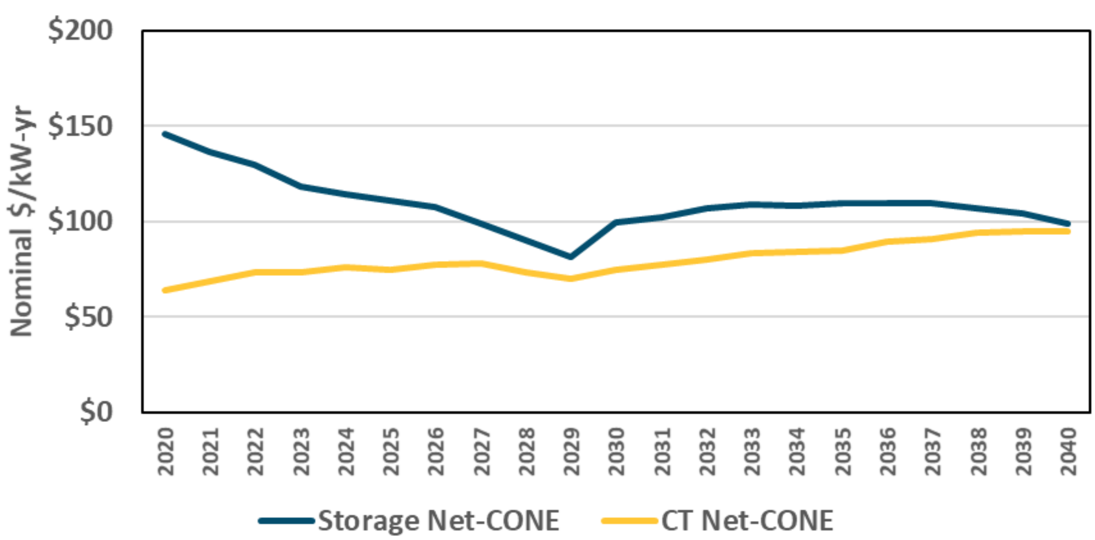

Figure 10: Net-CONE of Battery Storage and Combustion Turbine Assets

While the figure shows that a CT resource is anticipated to have a lower Net-CONE value throughout the time frame, E3 chose to use the battery storage-based Net-CONE as the basis for the avoided capacity value provided by customer solar systems as a conservatively high estimate, as resource costs and market prices in future years are uncertain. Using this conservatively high estimate of avoided capacity value is consistent with the difficulty in siting new CT's and is consistent with the California Public Utilities Commission's view on new capacity in California. In the event that new CT's are a viable capacity option, this approach may overstate the value provided by customer solar systems.

The annual $/kW-yr Net-CONE values were allocated to specific hours of the year using loss-of-load probability (LOLP) estimates generated by SMUD using E3's Renewable Energy Capacity Planning (RECAP) model for assessing system reliability.[15]

E3 identified the ten highest peak days for each year from SMUD's load forecast and allocated the $/kW-yr Net-CONE value to the hours on each of these peak days based on the relative LOLP in each hour. Figure 11 depicts this allocation for the years 2020-2040. A theoretical resource which produced its full nameplate capacity in each of these peak hours would earn the full $/kW-yr amount. As customer solar and solar + storage systems are in reality not able to produce their full nameplate capacity in each of those hours due to limitations on generation (daily insolation patterns) and system operation (battery state of charge, serving on-site load, etc.), the customer solar systems are valued at the portion of the annual Net-CONE value which their generation and/or dispatch contributes to SMUD's avoided capacity requirements.

Year \ Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2020	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.006	0.030	0.037	0.022	0.004	0.000	0.000	0.000	-	-
2021	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.002	0.017	0.023	0.031	0.023	0.003	0.000	0.000	-	-
2022	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.003	0.022	0.023	0.028	0.020	0.003	0.000	0.000	-	-
2023	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.003	0.021	0.022	0.028	0.022	0.004	0.000	0.000	-	-
2024	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.002	0.019	0.020	0.029	0.025	0.005	0.000	0.000	-	-
2025	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.001	0.015	0.017	0.030	0.030	0.006	0.000	0.000	-	-
2026	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.001	0.013	0.015	0.031	0.033	0.008	0.000	0.000	-	-
2027	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.005	0.009	0.032	0.041	0.012	0.000	0.000	0.000	-
2028	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.001	0.002	0.025	0.050	0.022	0.000	0.000	0.000	-
2029	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.001	0.020	0.050	0.029	0.001	0.000	0.000	-
2030	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.001	0.015	0.047	0.036	0.001	0.000	0.000	-
2031	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.000	0.011	0.043	0.044	0.001	0.000	0.000	-
2032	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.000	0.009	0.037	0.051	0.002	0.000	0.000	-
2033	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.000	0.007	0.032	0.058	0.003	0.000	0.000	-
2034	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.000	0.005	0.026	0.065	0.004	0.000	0.000	-
2035	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.000	0.003	0.021	0.071	0.005	0.000	0.000	-
2036	-	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.002	0.017	0.075	0.006	0.000	0.000	-
2037	-	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.001	0.013	0.078	0.008	0.000	0.000	-
2038	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.001	0.009	0.080	0.010	0.000	0.000	-
2039	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.000	0.007	0.081	0.011	0.000	0.000	-
2040	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000	0.005	0.079	0.015	0.000	0.000	-

Figure 11. Hourly Generation Capacity Allocation for Top Ten Peak Days, by Year (% of capacity allocated to each hour of the top ten peak days for each year)

TWG Value Component #21: Subtransmission and Distribution Capacity

TWG Description: Reduces daytime demand and may reduce traditional distribution upgrades

[15] Developed in 2011 to meet system reliability planning needs under high renewable penetration, RECAP assesses generation resource adequacy for a power system based on loss-of-load probability analysis. For more information on RECAP please see https://www.ethree.com/tools/recap-renewable-energy-capacity-planning-model/.

E3 Evaluation

The subtransmission and distribution marginal capacity costs represent the potential cost impacts on utility subtransmission and distribution investments from changes in peak loadings on the utility systems. The paradigm is that reductions in peak loadings via customer demand reductions, distributed generation, or energy storage discharge could reduce the need for some projects and allow for deferral or avoidance of those projects. The ability to defer or avoid capacity projects would depend on multiple factors, such as the ability to obtain sufficient dependable aggregate peak reductions in time to allow prudent deferral or avoidance of the project, as well as the location of those peak reductions in the correct areas within the system to provide the necessary reductions on the impacted facilities.

E3 and GridSME utilized SMUD's five-year plan for capital investments in subtransmission and distribution capacity to develop avoided costs for these value components for the period 2020-2025. For 2026 and later years, E3 used the marginal capacity costs from SMUD's 2020 Rate Costing Study and adjusted them for the likelihood of a customer solar installation being able to provide capacity benefits.

Marginal Costs for 2020- 2025

For 2020-2025 E3 and GridSME identified which planned subtransmission and distribution capacity investments were potentially deferrable by customer solar systems, based on the type of project and information provided by SMUD on the need driving each scheduled investment. Using the resulting subset of planned investments, categorized by distribution planning area (DPA), and the forecast load growth in that DPA, E3 derived the annualized $/kW-yr marginal deferral value for each DPA from 2021-2025 (the period over which SMUD's planned capital investments are scheduled), using the "Present Worth" method.[16]

The Present Worth method calculates the marginal capacity cost as the financial savings from being able to defer the investment by one year. The deferred investment is higher in cost due to escalation, but this is more than made up for by time value of money of being able to delay the investment outlay. In addition, the deferral of the project avoids one year of O&M costs that would have otherwise been incurred for the project. This total value of deferral is then divided by the load reduction that would be needed to attain the deferral (generally one year of load growth) to yield the $/kW deferral value. As a final step, the deferral value is converted to a $/kW-yr value to match standard marginal cost conventions by levelizing the cost over the length of the planning period used to identify the capacity projects. The levelization factor is a real economic carrying charge that results in an annual $/kW-yr marginal cost that is constant in real dollars.

The value of deferring capacity in year 1 for Δt years is:

$$PW\ Deferral\ Value = \sum_{t=1}^{n} \frac{K_t}{(1+r)^t}\left[1 - \left(\frac{1+i}{1+r}\right)^{\Delta t}\right]$$

where:

n = finite planning horizon in years,

[16] The avoided subtransmission and distribution capacity value for 2020 was based on the calculated 2021-2025 values.

K_t = distribution investment in year t,

i = inflation rate net of technological progress,

r = a utility's cost of capital (discount rate),

Δt = deferral time = peak load reduction divided by annual load growth.

The PW deferral value can be divided by the associated incremental load change that produced the deferral to obtain a $/kW estimate of the marginal distribution capacity cost (MDCC):

$$\$/kW\ Marginal\ Cost = \frac{PW\ Deferral\ Value}{Deferral\ kW}$$

The deferral-based marginal capacity $/kW-yr values are shown in Table 8 below. Note that not all DPAs have deferrable opportunities in each year due to a lack of planned investments that could potentially be deferred by customer solar systems.

Table 8. Subtransmission and Distribution Deferral Value by Distribution Planning Area ($/kW-yr, nominal)

Distribution Planning Area	2020	2021	2022	2023	2024	2025
21kW	$ -	$ -	$ -	$ -	$ -	$ -
Area A – East	$ 37.57	$ 38.45	$ 39.34	$ 40.24	$ 41.17	$ 42.12
Area A – West	$ 6.08	$ 6.22	$ 6.37	$ 6.51	$ 6.66	$ 6.82
Area C – East	$ 11.11	$ 11.37	$ 11.63	$ 11.90	$ 12.17	$ 12.45
Area C – West	$ 3.91	$ 4.00	$ 4.09	$ 4.18	$ 4.28	$ 4.38
Carmichael	$ -	$ -	$ -	$ -	$ -	$ -
Folsom	$ -	$ -	$ -	$ -	$ -	$ -
Mid	$ 5.45	$ 5.58	$ 5.71	$ 5.84	$ 5.97	$ 6.11
North	$ 8.43	$ 8.63	$ 8.82	$ 9.03	$ 9.23	$ 9.45
Orangevale	$ 1.81	$ 1.85	$ 1.90	$ 1.94	$ 1.98	$ 2.03
South	$ 15.27	$ 15.63	$ 15.99	$ 16.36	$ 16.73	$ 17.12

The above analysis is based on the current topology and forecasted future investments for the SMUD system. An alternate approach would have involved the remodeling of the entire SMUD system based of theoretical system loadings if there were no BTM solar installations in the SMUD territory. Such an analysis, however, would have required the SMUD engineers to conduct an extensive re-engineering of the subtransmission and distribution systems, and was determined to be beyond the scope of work that could be done for this analysis.

Also, it is important to note that if such work had been done, it is not clear that the resulting marginal costs using the theoretical no-BTM investments would have been significantly higher than the marginal costs used herein. To be sure, the number of investments affected by BTM solar would be higher, so the deferral value of investments would be higher. However, marginal costs are expressed in $/kW-yr values, and one therefore needs to divide that deferral value by the kW needed to attain that deferral. In the case of the theoretical no-BTM investments, more load reduction would be needed to defer the investments absent the load reductions provided by BTM solar. So, one is dividing a larger numerator (deferral value) by the larger denominator (deferral kW) and the net effect may not differ substantially from the current results.

This may be clearer with a backyard example. Consider a raised planter bed. The current planter is large enough for eight tomato plants, but space for two more is wanted. It costs $100 to expand the size of the planter box to allow for two more plants. If I decided to not add the two plants, I could save $100, so the marginal cost for adding plant capacity is $50/kW. Now if I wanted to look at the marginal cost associated with all of the tomato plants (not just the incremental two plants), I would divide the total cost of the planter (the old and new sections) by all ten plants. If the original planter bed cost $380, the marginal cost would be $48/plant (($380 + $100) / (8 plants + 2 plants)).

So, to finish the analogy, under the current marginal cost method that used future investments as the basis of the marginal raised bed cost, the marginal cost for all tomato plants is $500 ($50/plant * 10 plants). Whereas if we used the marginal cost that started from zero existing tomato plants as the basis, the marginal cost for all tomato plants is $480 ($48/plant * 10 plants). Of course, we do not know how much subtransmission and distribution marginal costs based on a no-BTM basis might have varied from the values in Table 8, but this analogy (despite its simplifications) illustrates that one cannot automatically assume that any differences would be substantial.

Marginal Costs for 2026 and beyond

As the investment period is only planned on a five-year basis (in this case, ending in 2025), beginning with 2026 E3 leveraged data from SMUD's 2020 Rate Costing Study to reflect the avoidable substransmission and distribution capacity value. The marginal capacity cost in that study is based on the unit cost per kW of capacity added.[17] Due to the method used in the SMUD study, the marginal costs therein can overestimate the value of subtransmission and distribution capacity for load reductions in locations that do not need such capacity, or in years that do not require capacity additions.

To account for this E3 applied a locational adjustment factor to reflect the percent of load reductions that are likely to affect a subtransmission or distribution project. In this way, the marginal cost provides a better quantification of the system average subtransmission and distribution capacity value that could be provided by customer solar installed across the SMUD system. E3 leveraged data from the CPUC 2020 Avoided Cost

[17] Note that the per kW unit cost of additional capacity sourced from the SMUD rate costing study excludes the estimated costs for recurring annual cable and pole replacements, as these are not costs that are affected by customer solar systems.

Calculator for the California Investor-owned Utilities (IOUs) as a proxy for an adjustment factor.[18] As shown in Figure 12 below, through analysis completed in creation of the calculator E3 found that between 9.2 percent and 20.4 percent of incremental installed DER capacity is forecast to be effective in contributing to the reduced need for a substation or distribution capacity project.

Line	Number of Overloads	PG&E	SCE-Substations (B-Bank)	SCE-Circuits	SDG&E	Notes:
1	Actual Overloads	224	35	226	11	[1]
2	Counterfactual Overloads	271	50	349	30	[2]
3	Number of Proposed Projects	180	N/A	N/A	10	[3]
4	Percentage of Overloads addressed by Load Transfers	20%	20%	20%	9%	[4] = 100% - ([3]/[1])
	Overload Capacity					
5	Actual Overloads (kW)	289,880	269,140	634,702	10,039	[5]
6	Counterfactual Overloads (kW)	349,018	286,660	643,360	25,320	[6]
7	Deferrable Counterfactual Overloads (kW)	280,461	229,328	514,688	23,018	[7] = [6] x (100% - [4])
	Project & Planned Investment Costs					
8	Total Cost of Planned Investments in DDOR Filing ($)	$390,416,858	$350,016,877	$288,412,287	$17,800,000	[8]
9	Capacity Deficiency that Planned Investments Mitigate (kW)	323,844	269,140	634,702	17,178	[9]
10	Unit Cost of Deferred Distribution Upgrades ($/kW)	$1,205.57	$1,300.50	$454.41	$1,036.21	[10]* = [8] / [9]
	System Level Avoided Distribution Costs					
11	Deferrable Capital Investment	$338,114,662	$298,241,326	$233,877,317	$23,851,370	[11] = [10] x [7]
12	5 Year Total forecasted DER (kW)	2,285,003	2,911,430	3,113,110	625,460	[12]
13	Distribution Deferral Value ($/kW)	$147.97	$102.44	$75.13	$38.13	[13] = [11] / [12]
14	IOU Specific RECC	9.79%	11.49%	11.45%	7.65%	[14]
15	Capacity Deferral Value ($/kW of DER installed-yr)	$14.49	$11.77	$8.60	$2.92	[15] = [13] * [14]
	O&M Distribution Costs					
16	O&M Deferral Value ($/kW-yr)	$0.00	$6.74	$21.98	$20.26	[16]
17	O&M Deferral Value ($/kW of DER installed -yr)	$0.00	$0.53	$3.63	$0.75	[17] = [16] * [7] / [12]
18	**Unspecified Marginal Cost ($/kW of DER installed-yr)**	**$14.49**	**$12.30**	**$12.24**	**$3.66**	[18] = [15] + [17]
19	**Marginal Cost of Planned Investments($/kW of Deficiency - yr)**	**$118.03**	**$156.17**	**$74.01**	**$99.53**	**[19] = [10] x [14] + [18]**
	Line 9 / Line 12	14.2%	9.2%	20.4%	2.7%	

Figure 12. California IOU Marginal Distribution Costs and Percentage of Installed DER Capacity Forecast to Effectively Contribute to Reduced Substation or Distribution Capacity Projects

To derive the portion of marginal subtransmission and distribution capacity costs potentially deferrable by customer solar systems, E3 used an adjustment factor of 15 percent, roughly the average of the PG&E and SCE factors shown in the final line of the figure above. The unadjusted nominal $/kW-yr subtransmission and distribution capacity value (combined) from SMUD's 2020 Rate Costing Study in 2026 is $51.49; after the de-rate the resulting value is $8.26/kW-yr. This escalates to $10.62 by 2040.

The resulting $/kW-yr values were allocated to specific hours of the year using the Peak Capacity Allocation Factor (PCAF) methodology. E3 first weather matched historical substation meter data from 2019 to the weather from 2012 in order to align with the assumptions used in SMUD's PLEXOS modeling. E3 then identified the highest load (i.e., peak) 150 hours in each of SMUD's DPAs based on this substation meter data, and allocated the $/kW-yr subtransmission and distribution capacity value to each of these hours according to its proportion of the aggregated load across all 150 of these top hours. In this way, the avoided capacity value attributable to different customer solar systems is directly proportional to the system generation or dispatch during the hours of highest local capacity strain for the specific DPA in which that

[18] For more information on the Avoided Cost Calculator please see https://www.cpuc.ca.gov/General.aspx?id=5267.

system is located. Figure 13 provides an example of the PCAFs for one particular DPA, highlighting peak loads occurring in summer afternoon and early evening hours.

Month \ Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	0.001	0.001	0.002	0.002	0.001	0.001	0.000	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	0.000	0.001	0.002	0.003	0.002	0.001	0.000	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	0.000	0.001	0.002	0.002	0.003	0.003	0.002	0.001	0.000	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	0.000	0.000	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 13. Peak Capacity Allocation Factors, Distribution Planning Area A – East

Figure 14 provides a map of the different DPAs.

Planning Regions	Abbreviated Name
21kV	21kV
Area A-East	A-E
Area A-West	A-W
Area C-East	C-E
Area C-West	C-W

Planning Regions	Abbreviated Name
Carmichael	C
Folsom	F
Mid	M
North	N
Orangevale	O
South	S

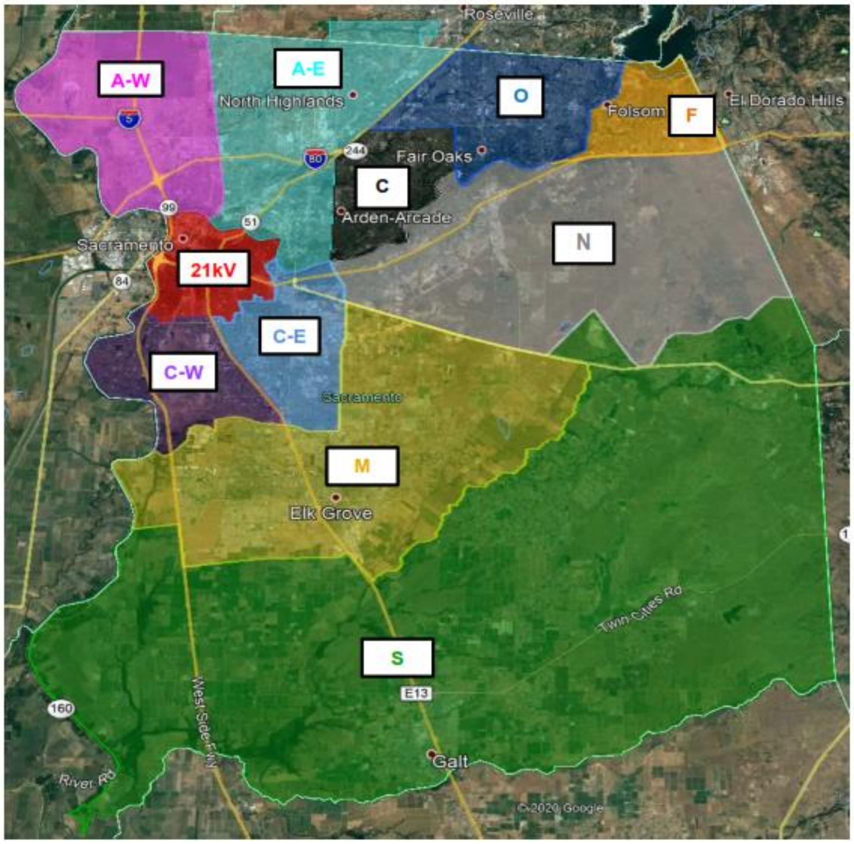

Figure 14. SMUD Distribution Planning Areas

To determine the reasonableness of the 15 percent locational adjustment, and the PCAF allocations, we compared those impacts to the GridSME analyses. The GridSME analysis showed that about nine percent of solar capacity could contribute to the reduction in the need for distribution projects. The PCAF allocation factors estimate an average coincidence factor of 60 percent for solar, in other words, 60 percent of solar nameplate capacity can affect the need for capacity projects. Multiplying the 60 percent PCAF coincidence factor by the 15 percent locational adjustment factor yields a combined solar impact factor of nine percent.

TWG Value Component #23: Grid Modernization

TWG Description: The costs of tools and infrastructure used by the utility to support DER at the distribution level

E3 Evaluation

One of the value components recommended by the TWG was the cost of grid modernization. Grid modernization investments are costs that SMUD incurs to support distributed energy resources (DERs) like customer solar and solar + storage systems at the distribution level. These costs can include advanced metering infrastructure (AMI) to more accurately track and monitor DERs, advanced distribution management systems (ADMS) or distributed energy resource management systems (DERMS) which can help to coordinate various interconnected resources at the distribution level, and other tools and infrastructure to help the utility better accommodate and/or manage increasing levels of DERs.

While these are real costs to SMUD and its ratepayers which the utility may increasingly incur as the total capacity of customer solar and solar + storage systems grows, E3 did not estimate a specific cost associated with this value component. Grid modernization investments are not generally associated with a specific increment of DERs and are instead made strategically in order to enable the utility to better manage both existing and anticipated DERs. Additionally, the GridSME load flow analysis did not find that the anticipated growth in customer solar systems, while significant, remains fairly small relative to anticipated load growth on SMUD's distribution system. As such, while E3 anticipates SMUD will incur some level of costs for grid modernization we have not included a quantitative assessment of these costs in our analysis.

TWG Value Component #18: Transmission Capacity

TWG Description: Reduces daytime demand and may reduce traditional upgrades

E3 Evaluation

E3 leveraged SMUD's 2020 Rate Costing Study to develop avoided transmission capacity costs. The basis for the SMUD transmission capacity cost in that study is a $/kW value that reflects the average unit cost to add transmission load serving capacity (LSC). However, this marginal cost does not consider the *need* for that LSC. As shown in the table below, there is no forecast need for transmission capacity projects after 2020. A direct use of the marginal transmission capacity cost from the SMUD study would therefore overestimate the value of peak load reductions provided over this time period.

Table 9. Transmission Capacity and Investment Costs (SMUD 2020 Rate Costing Study, Table 3.4)

Line	Description	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
1	Investment costs in thousands Transmission Investment	$7,239	$1,904	$0	$0	$0	$0	$0	$0	$0	$0	$9,143
2	*Trans Cost Inflator*	*1.000*	*1.039*	*1.062*	*1.082*	*1.106*	*1.132*	*1.156*	*1.182*	*1.208*	*1.236*	
3	Nominal Investment	$7,239	$1,978	$0	$0	$0	$0	$0	$0	$0	$0	$9,217
4	*Cost Adjustment*	*1.000*	*0.999*	*1.010*	*1.034*	*1.060*	*1.088*	*1.117*	*1.145*	*1.173*	*1.201*	
5	Year 2019$ Investment	$7,239	$1,980	$0	$0	$0	$0	$0	$0	$0	$0	$9,219
5	Year 2019$ Investment	$7,239	$1,980	$0	$0	$0	$0	$0	$0	$0	$0	$9,219
6	Added LSC (MW)	80	90	-	-	-	-	-	-	-	-	170
7	Capacity @ 90% Utilization	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
8	***Marginal Cost ($/kW)***	***$90.49***	***$22.00***	***$0.00***	***$0.00***	***$0.00***	***$0.00***	***$0.00***	***$0.00***	***$0.00***	***$0.00***	***$54.23***

Long-lived assets that provide load reductions past 2028 could provide capacity value, but crediting of such value should only occur for the years of operation past 2028 wherein there is a need for transmission peak load reductions. Accordingly, E3 used a value of $0/kW-yr for the period 2020 – 2028.

Beginning with 2029 E3 used SMUD's marginal transmission capacity cost reported in the rate costing. The nominal $/kW-yr value in 2029 is $13.48.[19] This escalates to $16.93 by 2039.

To allocate the resulting annual avoided transmission capacity value (in $/kW-yr) to specific hours of each year, E3 utilized the same allocation approach described above in the *Generation Capacity* section (p. 23). Transmission capacity value was allocated to the top ten peak days in each year of the study period based on SMUD's load forecast, with hourly allocations on those days based on SMUD's loss-of-load probability (LOLP) estimates generated using the E3 RECAP model.

Transmission Network Upgrade Costs

For the *Helps Meet Clean Energy Goals* scenario E3 has additionally incorporated a transmission network adder to reflect the cost of upgrades to the transmission system which may be required to deliver utility scale solar or other clean resources to SMUD. To derive this value, E3 utilized the anticipated high voltage transmission buildout anticipated in the CPUC's Reference System Plan from the most recent Integrated Resource Planning process. E3 developed a $/MWh transmission upgrade value by dividing the total forecast spending on transmission by the anticipated generation from new utility scale solar for each reference year modeled in the IRP. Values for interim years were interpolated.

Figure 15 below reports the resulting $/MWh values, showing an increasing cost of transmission upgrades over time. Significant values are anticipated beyond 2030, driven by expectations of transmission project construction required to accommodate renewables which will be needed to meet state clean energy and carbon reduction goals.

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[19] SMUD 2020 Rate Costing Study, Table 3.6.

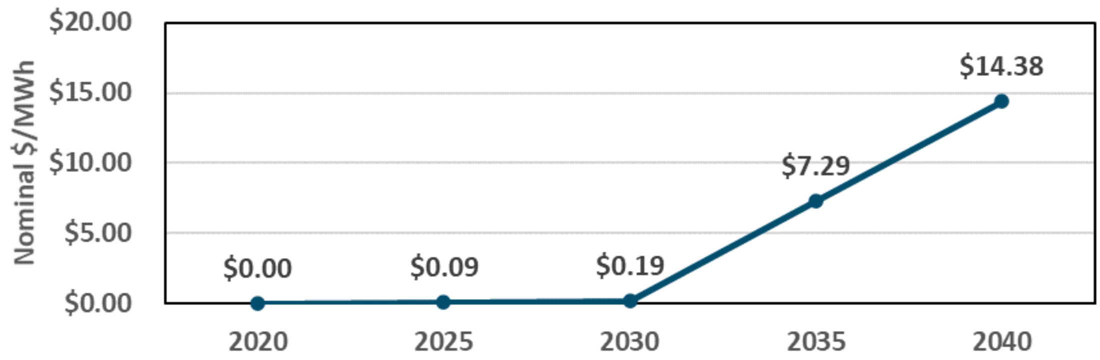

Figure 15. High Voltage Transmission Upgrade Costs

TWG Value Component #20 & 22: Transmission Line Losses & Distribution Line Losses

TWG Description:

20: Local generation reduces losses on the transmission grid

22: Local generation reduces losses on the distribution grid; excess generation increases losses at local level

E3 Evaluation

Hourly avoided costs were adjusted for transmission and distribution line losses prior to being used in calculations of customer solar system generation and dispatch value. E3 sourced marginal line loss factors from SMUD's 2020 Rate Costing Study. Representative customers were associated with either primary or secondary voltage levels, depending on retail rate. Table 10 contains the line loss adjustment factors used to scale up hourly avoided energy, GHG, ancillary services, integration, and generation capacity costs.

Table 10. Line Loss Adjustment Factors for Energy, GHG, Ancillary Services, Integration and Generation Capacity Costs

Time of Use Period	Winter Off	Winter On Peak	Spring	Summer Off	Summer Peak	Summer Super Peak
Primary Voltage	1.035	1.039	1.036	1.036	1.044	1.051
Secondary Voltage	1.054	1.059	1.055	1.055	1.064	1.073

Table 11 below provides the hours which align with these different periods (Table 2.3 in the rate costing study).

Table 11. Time Periods for Loss Adjustment Factors

Months	Time Periods	Monday - Saturday	Sundays and Holidays
July & August Only	Summer Super-Peak	Noon-8pm	
June-Sept	Summer On-Peak	6am-8pm unless Super-Peak	
June-Sept	Summer Off-Peak	All Other Hours	All Hours
March-May	Spring	All Hours	All Hours
October - February	Winter On-Peak	6am-9pm	
October - February	Winter Off-Peak	All Other Hours	All Hours

For transmission and distribution capacity, separate loss factors were used, also taken from SMUD's 2020 Rate Costing Study. Consistent with the combined treatment of subtransmission and distribution capacity deferral value described above in the *TWG Value Component* #21: Subtransmission and Distribution Capacity

TWG Description: Reduces daytime demand and may reduce traditional distribution upgrades

E3 Evaluation

section, E3 used a single loss adjustment factor to scale up losses from the distribution and subtransmission grid; one factor was used for customers served at the primary voltage level and another factor was used for customers served at the secondary voltage level. This single adjustment factor is based on the distribution loss adjustment factor from SMUD's 2020 Rate Costing Study.

Table 12. Line Loss Adjustment Factors for Transmission & Distribution Capacity

	Distribution & Subtransmission	Transmission
Primary Voltage	1.025	1.038
Secondary Voltage	1.043	1.057

Reduction in Line Losses

E3 also incorporated the results of GridSME's Load Flow Analysis into our development of avoided costs. As detailed in the *GridSME Reliability Analysis* section, GridSME found that by 2030 the anticipated customer solar systems contribute to a reduction in observed line losses during peak periods of approximately 5.06 percent, relative to line losses during peak periods in 2020. E3 derived the implied annual improvement in the efficiency of energy delivery by interpolating between the 2030 improvement of five percent and the 2020 baseline of 2.49 percent. This annual improvement percentage was then applied to the annual cost of SMUD's energy deliveries during hours of solar production, to provide an estimate of the total annual value attributable to the customer solar systems due to the reduction in the level of line losses. Table 13 provides the resulting annual values for the entire customer solar population. These values are incorporated into the results as part of the avoided distribution capacity cost component.

Table 13. Estimated Annual Value of Improvement in Delivery Efficiency (Nominal $, '000s)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Value ('000s)	$108	$120	$132	$144	$157	$169	$182	$195	$209	$222	$236

TWG Value Component #16 & 24: Reliability & Voltage/Power Quality

TWG Description:

16: Restoring service or preventing outages in an emergency

24: Local power quality can be maintained with appropriate smart inverter settings; distribution wear and tear (voltage regulators and capacitors)

E3 Evaluation

Reliability and voltage/power quality are addressed in the *GridSME Reliability Analysis* chapter beginning on page 79.

3.3. Societal and Solar Customer Values

TWG Value Component #15: Resilience

TWG Description: Customer can meet critical needs during outage if the system is configured to function during grid outages

E3 Evaluation

The Resilience provided by battery storage is a benefit which accrues specifically to customer solar customers that have invested in a battery. These customers enjoy the benefit of improved access to electricity during grid outage events. In theory it is possible to configure these systems in a microgrid that provides backup power to other homes or businesses, however this configuration is rare and possibly non-existent today on the SMUD system. Therefore, E3 evaluates Resilience as a Solar Customer value.

In modeling the operation of customer solar + storage systems, E3 assumed that systems were configured to provide backup power to the customer solar customer in the event of an unexpected outage, and that 25 percent of the battery capacity would be reserved to meet electricity needs in such an event.[20] To calculate the resilience value to customers of having this battery capacity available, E3 utilized a Lawrence Berkeley National Laboratory (LBNL) report which provides estimates of the value of service reliability to different types of customers and for different outage durations (Figure 16, below).[21] Note that the values

[20] 25 percent is a working assumption to facilitate cost-benefit analysis which accounts for customer preferences for reserving battery capacity. This figure is based on pilot project experience, including work conducted in partnership with Sunverge and SMUD for the 2500 R Street PV Integrated Storage project.

[21] Lawrence Berkeley National Laboratory. *Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States*. January 2015. Available at: https://eta-publications.lbl.gov/sites/default/files/lbnl-6941e.pdf.

for small commercial and industrial (C&I) customers are considerably higher per kWh than those for the medium and large C&I customers and for the residential customers.

Table ES-1: Estimated Interruption Cost per Event, Average kW and Unserved kWh (U.S.2013$) by Duration and Customer Class

Interruption Cost	Interruption Duration					
	Momentary	30 Minutes	1 Hour	4 Hours	8 Hours	16 Hours
Medium and Large C&I (Over 50,000 Annual kWh)						
Cost per Event	$12,952	$15,241	$17,804	$39,458	$84,083	$165,482
Cost per Average kW	$15.9	$18.7	$21.8	$48.4	$103.2	$203.0
Cost per Unserved kWh	$190.7	$37.4	$21.8	$12.1	$12.9	$12.7
Small C&I (Under 50,000 Annual kWh)						
Cost per Event	$412	$520	$647	$1,880	$4,690	$9,055
Cost per Average kW	$187.9	$237.0	$295.0	$857.1	$2,138.1	$4,128.3
Cost per Unserved kWh	$2,254.6	$474.1	$295.0	$214.3	$267.3	$258.0
Residential						
Cost per Event	$3.9	$4.5	$5.1	$9.5	$17.2	$32.4
Cost per Average kW	$2.6	$2.9	$3.3	$6.2	$11.3	$21.2
Cost per Unserved kWh	$30.9	$5.9	$3.3	$1.6	$1.4	$1.3

Figure 16. LBNL Estimates of Interruption Costs, in $2013

SMUD reliability data from 2019 was used to calculate the average outages per year and the average duration of these outages, inclusive of major outage events. Given that SMUD's reliability data indicates an average outage duration of 1.33 hours, E3 used the one-hour duration values in the figure above as the base case for assessing resilience value to customer solar system owners. Table 14 below provides an example of the resilience value calculation for several customers, using this one-hour duration value.

Table 14. Resilience Value, Example Customers in 2020

	Residential	Small Commercial	Large Commercial
Battery Size (kWh)	12.5	51.0	3,079
Reserved Battery Capacity (kWh)	3.1	12.7	769
Value of Lost Load ($2020/kWh)	$3.87	$345.94	$25.56
Outage Hours/year		1.91	
Annual Resilience Value (2020)	$23	$8,409	$37,560

TWG Value Component #12: Carbon Emission Reductions

TWG Description: Benefits of reducing carbon emissions beyond those achieved in support of SMUD's compliance with California cap and trade system

E3 Evaluation

Beyond the monetized carbon price included in the hourly electricity market price forecast, E3 estimated a range of societal values for the avoided carbon emissions attributable to customer solar NEM systems under the *Incremental Clean Energy* scenario. Two distinct types of estimates were used, representing fundamentally different values for avoided carbon emissions beyond SMUD's compliance requirements:

+ **Social Cost of Carbon (SCC):** estimates of the value of avoided societal damages due to the avoidance of carbon emissions; reported as the net present value of the lifetime damages from carbon emissions
+ **SMUD Cost of Carbon Reduction:** an estimate of the compliance cost SMUD would incur to achieve the carbon emissions reductions provided by the customer solar systems from other sources

To estimate the societal value of avoided carbon emissions attributable to the customer solar systems, E3 multiplied the avoided emissions (in metric tons) in different years of the study period by these estimates of either the social cost of carbon or the SMUD compliance cost to produce a range of values.

Social Cost of Carbon

E3 used seven different estimates of the social cost of carbon. Four estimates come from the U.S. Environmental Protection Agency which are widely used estimates of the social cost of carbon in the United States.[22] The fifth estimate is the United Kingdom "target consistent" price of CO_2 which is the value that reflects the level of stringency in the UK policy making context.[23] The UK estimate is therefore not an estimate of the damage of CO_2, but a level that is consistent with the cost of achieving the abatement levels targeted in the UK. The sixth estimate is from Nordhaus (2017) which presents a global SCC estimate using DICE, a global climate assessment model.[24] The seventh estimate comes from a recent academic review of a range of SCC values published in *Nature Climate Change*.[25] E3 used the median value reported in this study, $417/metric ton (in $2018) for the United States, and a 2.5% real discount rate consistent with the high range estimate that this study represents which is considerably higher than either of the EPA estimates.

We recognize that the societal economic impact of CO_2 varies widely by study, and that of the societal cost components estimated in this study it constitutes the majority of the societal benefits of reduced combustion in electricity generation.

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[22] 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.

[23] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/245334/1_20090715105804_e____carbonvaluationinukpolicyappraisal.pdf

[24] https://www.pnas.org/content/pnas/114/7/1518.full.pdf

[25] Ricke et al. *Country-level social cost of carbon*. Nature Climate Change. 2018. Available at: https://www.nature.com/articles/s41558-018-0282-y.epdf.

Table 15. Estimates of the Social Cost of Carbon, 2020-2050 ($2018/metric ton CO_2)

Year	EPA 5%	EPA 3%	EPA 2.5%	EPA High	UK Target Consistent Carbon Price	Nordhaus 2017, 3% Disc. Rate	Ricke et al, 2018
2020	$15	$51	$76	$150	$44	$100	$417
2025	$17	$56	$83	$168	$84	$109	$472
2030	$20	$61	$89	$185	$124	$120	$534
2050	$32	$84	$116	$259	$354	$179	$875

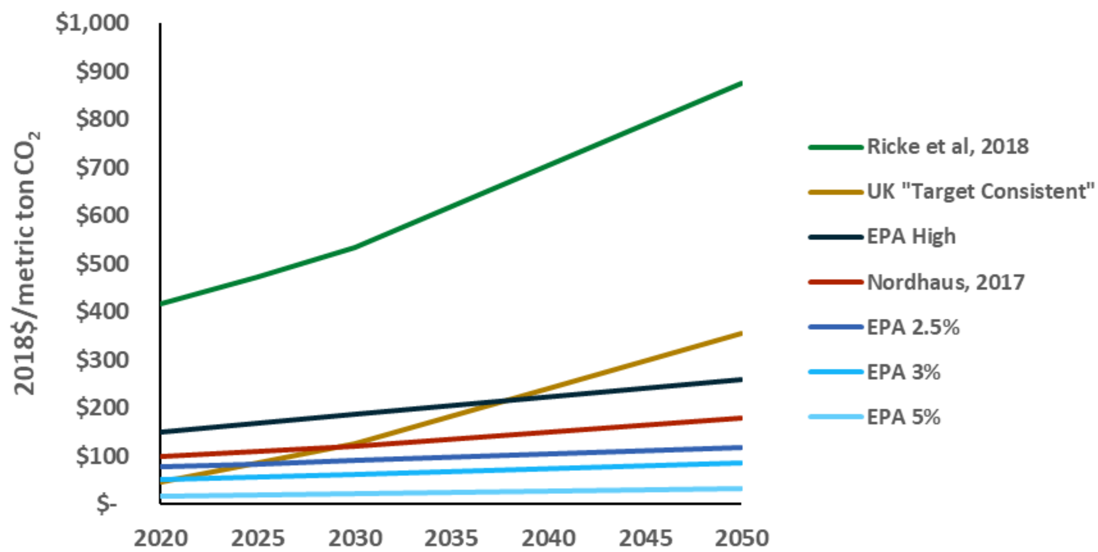
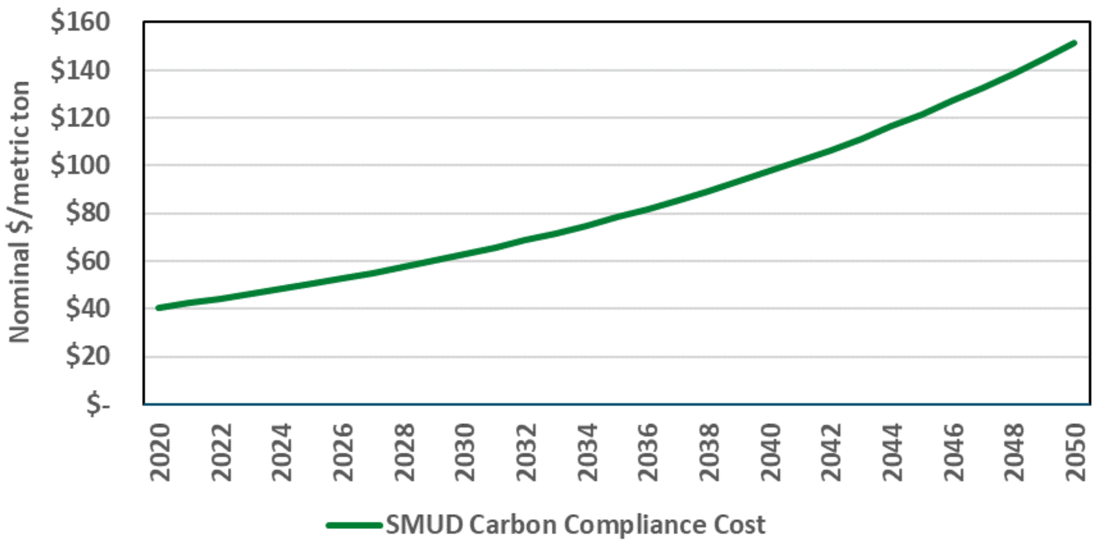


Figure 17. Estimates of the Societal Cost of Carbon

SMUD Carbon Compliance Cost

As an alternative estimate of the value of incremental carbon reductions, E3 estimated SMUD's own cost of reducing carbon emissions for its portfolio using the RESOLVE resource planning tool that was utilized in SMUD's 2018 IRP.[26] Rather than estimating the environmental damages of carbon emissions, this estimates the cost SMUD would incur to avoid this level of emissions in the absence of the customer solar systems, but beyond its compliance requirements. The values are shown in the chart below:

[26] RESOLVE is E3's resource investment model that identifies optimal long-term generation and transmission investments in an electric system, subject to reliability, technical, and policy constraints. For additional information please see: https://www.ethree.com/tools/resolve-renewable-energy-solutions-model/.



Fugitive Methane Emissions

In addition to the societal cost of carbon estimates described above, E3 calculated the value of avoided fugitive methane emissions from SMUD's thermal power plants. While additional fugitive methane leakage exists upstream of SMUD's thermal plants, those emissions are outside of SMUD's control and are the responsibility of the entities who own those assets. This is in line with SMUD's GHG targets under its SD9 principles.

A recent study conducted for the California Energy Commission by the Electric Research Power Institute (EPRI) provided a range of methane leakage rates at SMUD's Cosumnes power plant, specifically during high-capacity factor hours. An aggregated leakage rate of 0.385 kg CH_4/hr was measured at the plant's major natural gas components, and this served as the basis for E3's estimation of the avoided fugitive methane leakage.

Separately, E3 identified the number of hours in each year of the study period during which SMUD's thermal generating plants are expected to be on the margin based on the market price forecasts used to develop avoided energy costs for the VOS/S study. Of these marginal hours, the subset occurring during solar production times was used to calculate the fugitive methane emissions avoidable by customer solar. The following figure depicts the resulting marginal hours used for this assessment.

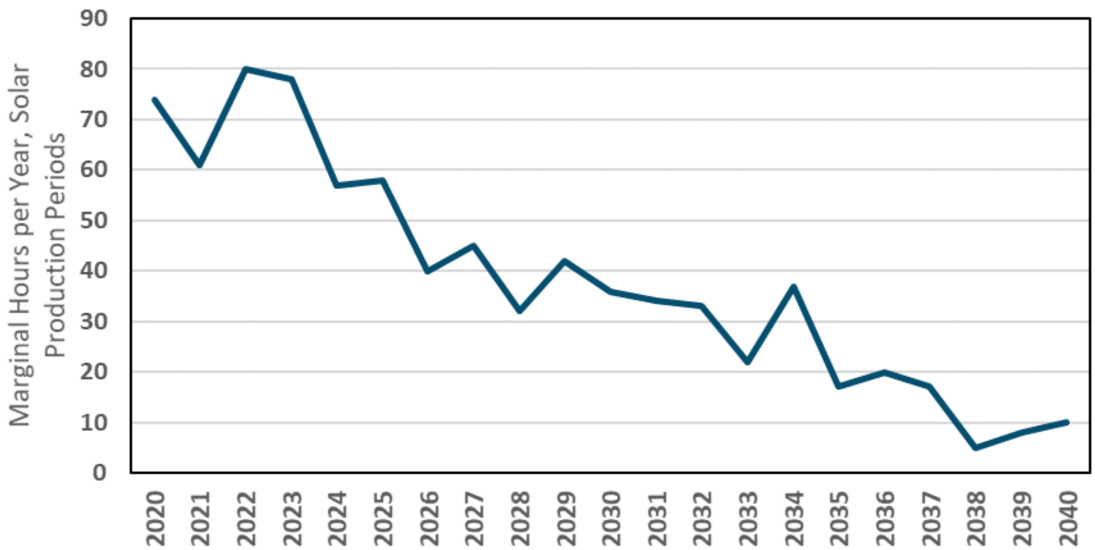


Figure 18. SMUD Thermal Generator Marginal Hours During Solar Production

E3 calculated the total methane leakage during these marginal hours using the leakage rate described above and the generation capacity of SMUD's thermal fleet. Fugitive methane emissions from SMUD's thermal fleet in 2020 are estimated at 63 pounds, or 1,570 pounds of carbon dioxide equivalent (CO_2e) using a global warming potential of 25 as per the California Air Resources Board.[27] This decreases to 31 pounds of methane (764 pounds of CO_2e) by 2030 as SMUD's thermal generators are decreasingly on the margin.

Customer solar was assumed to be able to offset a portion of these annual total leakage amounts, based on the available solar generation capacity during the identified hours. This proportion ranges from approximately 30 percent of the total in 2020 to approximately 45 percent by 2030.

TWG Value Component #11: Criteria Emissions

TWG Description: Overall decreased emissions contribute to societal benefits

E3 Evaluation

E3 used the implied marginal heat rate (IMHR, see TWG Value Component #1b: Greenhouse Gases section on page 16 for additional detail) to estimate hourly criteria pollutant emissions. Using the emissions rates for particulate matter (PM10) and nitrogen oxide (NOx) for a low efficiency thermal generator included in the CPUC Avoided Cost Calculator (0.0896 lbs./MWh and 0.2320 lbs./MWh, respectively), E3 linearly interpolated the hourly emissions rate for each pollutant based on the hourly implied marginal heat rate. These emissions rates were then scaled up to account for line losses, producing an avoided hourly emissions rate applicable for customer solar system generation and dispatch. Note, given emissions control

[27] https://ww2.arb.ca.gov/ghg-gwps.

technologies which make modern, more efficient thermal generators produce less criteria pollutants, this approach may be an overestimate of the actual criteria emissions reductions attributable to the customer solar systems. E3 explored this consideration through sensitivity analysis, adjusting the hourly rates of criteria pollutant emissions downwards by incremental percentages to produce a range of estimated reductions over the lifetime of the systems. E3 also validated that the resulting emissions fell in a realistic range by comparing the resulting NOx rate from this interpolation approach to the reported emissions rate for SMUD's Cosumnes power plant as reported by the U.S. Energy Information Administration.[28]

E3 estimated the societal value of reducing criteria pollutants using the California Public Utilities Commission's *Interim Air Quality Adder*.[29] This $6/MWh adder (in $2017) was escalated for inflation and then applied to the customer solar system generation to assess the air quality health benefits from avoided thermal generation. As the *Interim Air Quality Adder* is intended to represent the costs of criteria pollution from power plants during hours of thermal generation, E3 applied an annual de-rate to the estimated air quality value provided by customer solar systems by multiplying the estimate by a factor of (1 – *percentage of curtailment hours*), where curtailment hours are identified as zero- and negative-priced hours from SMUD's PLEXOS modeling.

TWG Value Component #13a: Water Use

TWG Description: Water use reductions

E3 Evaluation

Water use in electricity generation varies widely across generators depending on their characteristics. California has had a focus on 'dry cooling' in natural gas generation since the 1990s so the amount of water used for cooling water in these types of power plants is approximately 95 percent lower than in other situations and on the order or 4 gallons per MWh as opposed to 250 gallons/MWh with a cooling tower.[30] That said, the water consumption from the specific marginal generation unit being offset by the customer solar systems was not available in the PLEXOS production simulation results, and therefore E3 used a range of water consumption values from an academic review to estimate the reductions in water attributable to the solar and solar + storage systems.[31] E3 specifically used the estimates for water consumption rather than for water withdrawal, with a resulting range of 4 – 250 gallons per MWh of electricity generation. As rooftop solar systems generally produce approximately 1,600 – 1,800 kWh per kW of installed capacity, this equates to a range of approximately 7 – 470 gallons of avoided water per kW each year, once accounting for line losses. For the entire SMUD customer solar system population of 255 MW in 2020 this range is approximately 2 – 113 million gallons; by 2030 it has increased to a range of 3 – 184 million gallons due to the growth in customer solar system capacity to 445 MW.

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[28] https://www.eia.gov/electricity/data/emissions/.

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

[30] See https://www.eia.gov/todayinenergy/detail.php?id=36773 for more information on dry cooling from DOE EIA

[31] James Meldrum et al, "Life Cycle Water Use for Electricity Generation: a Review and Harmonization of Literature Estimates." 2013.

The societal value of water, as opposed to the direct costs to society to capturing and storing, pumping, or desalinating more water, is not well differentiated. Either you have water available, and the cost is that of attaining it, or there is no life at all due to its absence. The cost of the water that would be saved by reduced thermal power generation is already included in the directly avoided costs through the estimates of operations and maintenance costs of generation and the market price of energy. The costs of this water ranges depending on the source of water for the particular power generator. We use a recent publication "The cost of urban water supply and efficiency options in California," which identifies the direct costs of capturing water through a broad set of means to provide a range of values.[32] At the high end, the water in California for power generation is likely well below $1/m^3. With a cooling tower (wet cooling) this would translate to $1/MWh, however, with dry cooling this would amount to $0.004/MWh which is de minimis. Based on the paper, which takes an in-depth look at the costs of alternative sources of supply, the extreme end would be small-scale desalinization projects with a total cost of $3.47/m^3. We do not use this estimate because there are no power projects that would use such expensive water (and the energy content is enormous), and still the cost for a power plant with dry cooling would be $0.014/MWh (or $0.000014/kWh).

The direct cost of water saved from reduced thermal generation is very small. Additionally, as we are estimating these values based on the direct costs, they are already included in the operations and maintenance costs of power generation.

TWG Value Component #13b: Land Use

TWG Description: Use of the built environment

E3 Evaluation

To estimate the avoided land use acreage E3 used an estimate from recent work completed with The Nature Conservancy, which found that utility scale solar has a land use intensity of approximately seven acres per MW.[33] This aligns with estimates from the Solar Energy Industries Association, which reports a range of five to ten acres per MW for utility scale solar.[34]

E3 compared the capacity factor for SMUD's customer solar systems (approximately 20 percent when weighted by the incremental residential and non-residential capacity additions and scaled up for line losses) to a 30 percent capacity factor for utility scale solar in Northern California. Multiplying incremental capacity additions in each year of the study by the seven acres per MW figure and the ratio of capacity factors (adjusted for line losses) provides an estimate of approximately 0.003 acres per MWh of solar generation from customer solar systems, when displacing utility scale solar.

This avoided acreage figure can be used to estimate the societal or environmental value of avoided land. Estimates of this value vary broadly. E3 conducted a literature review to establish a range of values to utilize

[32] Heather Cooley et al. 2019. Environ. Res. Commun. 1 042001

[33] https://www.nature.org/en-us/about-us/where-we-work/united-states/california/stories-in-california/clean-energy/.

[34] https://www.seia.org/initiatives/siting-permitting-land-use-utility-scale-solar.

in estimating the potential avoided land use from SMUD's customer solar systems, and elected to utilize two primary sources for these estimates, summarized in Table 16 below. Note, unlike the societal values for carbon, criteria pollutants and water use, the societal value of avoided land use is only applicable in the *Helps Meet Clean Energy Goals* scenario, in which the customer solar systems are offsetting utility scale solar rather than market purchases.

Table 16. Land Use Values

Source	Value ($2020/acre-yr)	Description
Desert Renewable Energy Conservation Plan[35]	$360	Low Cost per Acre Impacted
	$495	Mid Cost per Acre Impacted
	$773	High Cost per Acre Impacted
Costanza et al.[36]	$1,246	Grass/Rangelands
	$938	Temperate/Boreal Forests
	$1,136	All Forests

The *Desert Renewable Energy Conservation Plan (DRECP)* provides estimated land values based on the total costs to develop utility scale renewable energy projects in California. Costs assessed include land acquisition, environmental site assessment, biological and boundary surveys, and long-term management and maintenance, among others. While these estimates are therefore not based on the direct environmental value provided by the land, they are directly reflective of the cost to develop utility scale solar in California and therefore serve as a useful estimate of the avoided costs in the *Helps Meet Clean Energy Goals* scenario.

Alternatively, *Costanza et al.* provide a useful review of estimated ecosystem services values and how they have changed over time. As shown in Table 16 above these estimates place a considerably higher value on land than the DRECP values, providing an upper bound for use in assessing the societal value of avoided land use. The values per acre-year used in E3's analysis are based on the more recent (and higher) estimates included in the *Costanza et al.* paper.

TWG Value Component #14: Equity

TWG Description: Reduced energy burden for low income customers who have solar/storage

[35] 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.

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

E3 Evaluation

Customer solar and solar + storage systems may contribute to equity by reducing the bills of low-income customers that adopt solar. Low income customers who spend a larger proportion of their income on energy bills stand to gain significantly from the bill reductions offered by NEM, if they own their homes and are able to access the financing needed for home solar installations. Lower monthly electricity bills for customers that do not have large disposable incomes can provide a meaningful improvement in the quality of life, increasing the equity of our society.

However, E3 finds that SMUD's current NEM leads to bill increases for non-solar customers due to the compensation solar customers receive through NEM, raising retail rates for all customers. This increases the energy burden that non-solar lower income customers who already spend disproportionately on electricity and other utilities must bear.

TWG Value Component #17: Emotional/Political

TWG Description: Engaging customers with their bill through NEM changes the way they use energy

E3 Evaluation

The adoption of a customer solar or solar + storage system likely leads to more education and engagement with energy issues by participating customers. This can have a lead to more educated decisions about how individuals use energy – for example, paying greater attention to conservation through behavioral changes or investment in energy efficient appliances – as well as how these individuals engage with energy issues. Customers adopting rooftop solar may learn more about energy, which may encourage more active participation in or education about local (or broader) energy issues, such as the resource mix used by their utility or the direction of state energy policy in the face of climate change.

E3 recognizes the value that this type of increased engagement can provide to customers and, by extension, the local community or society more broadly. However, E3 is not aware of any methods to quantify a dollar amount on such values and instead merely recognize them as a further potential benefit provided by customer solar and solar + storage.

TWG Value Component #18: Local Economy

TWG Description: Jobs and local economic growth resulting from rooftop solar

E3 Evaluation

A full study of the potential macroeconomic benefits and costs of customer solar is well beyond the scope of this study. E3 has participated in a number of macroeconomic impacts studies in the past and believes that the outputs of the VOS/S study would be suitable to use as inputs into such a study. Inputs to the study, which would use a regional macroeconomic model such as REMI or IMPLAN, would include:

+ Changes to capital investments over time – higher investment in customer solar and storage, lower investment in utility-scale solar and storage resources, and lower investment in transmission and distribution facilities, relative to a base case scenario without customer solar;

- In the "Incremental Clean Energy" scenario, lower fuel, variable O&M, and carbon allowance expenditures over time, relative to a base case scenario without customer solar; and
- Changes in electricity rates paid by all SMUD customers over time, relative to a base case scenario without customer solar.

The net impact of these changes would depend on the relative size of the different components in each time period. Based on our experience participating in these types of studies in the past, E3 believes that:

- In the short term, the customer solar scenario would likely result in higher economic activity in the Sacramento area, because (a) customer solar is more costly than the resources it replaces; and (b) the customer solar scenario may result in a higher proportion of investment activity occurring in the Sacramento area. Installation of customer solar and solar + storage systems leads to increased economic activity and jobs for solar and storage installation companies and related services (such as financing partners). These companies employ installers, system designers, sales and operations teams, and other staff positions required to provide installation, maintenance, and ongoing support for their customers.
- In the long term, customer solar would likely result in lower economic activity in the Sacramento area in the long term, because the installation of customer solar and solar + storage systems leads to bill increases for non-solar customers due to the compensation solar customers receive through NEM, which raises retail rates for all customers. These increased bills have a negative effect on the local economy, as non-solar customers have less income to spend on non-energy goods and services. Local businesses' costs increase due to these increases in electricity rates, reducing their ability to hire staff and create further economic growth.

The net effect of the short-term economic stimulus and the long-term economic drag depends on the relative size of each effect and the size of any "multiplier effects", i.e., ripple effects of the changes throughout the broader local economy. As such, it cannot be known in advance whether the study result would show a positive or negative net effect.

Solar Customer System Costs

E3 used customer solar and solar + storage cost data from the National Renewable Energy Laboratory's Annual Technology Baseline.[37] Figure 19 provides the different system costs assumed for residential and non-residential customer solar systems.[38] These costs include upfront system costs, annual fixed operations and maintenance costs, storage replacement costs after ten years, and the incentives of the federal Investment Tax Credit (ITC) and state Self Generation Incentive Program (SGIP), where applicable. The cost increase between 2021 and 2022 is due to the expiration of the ITC for residential systems, with a smaller increase for non-residential installations due to the scheduled reduction in ITC value for those systems

[37] https://atb.nrel.gov/. 2019 ATB data used in the VOS/S study.

[38] This figure depicts the net present value of upfront installation costs, available state and federal incentives, and ongoing fixed operations and maintenance costs. The values shown in this figure use a solar customer discount rate of seven percent nominal; for societal costs a discount rate of 4.5 percent nominal was used instead, and state incentives were excluded.

beginning in 2022. Similarly, the increase in solar + storage system costs between 2025 and 2026 is due to the scheduled expiration of the SGIP.

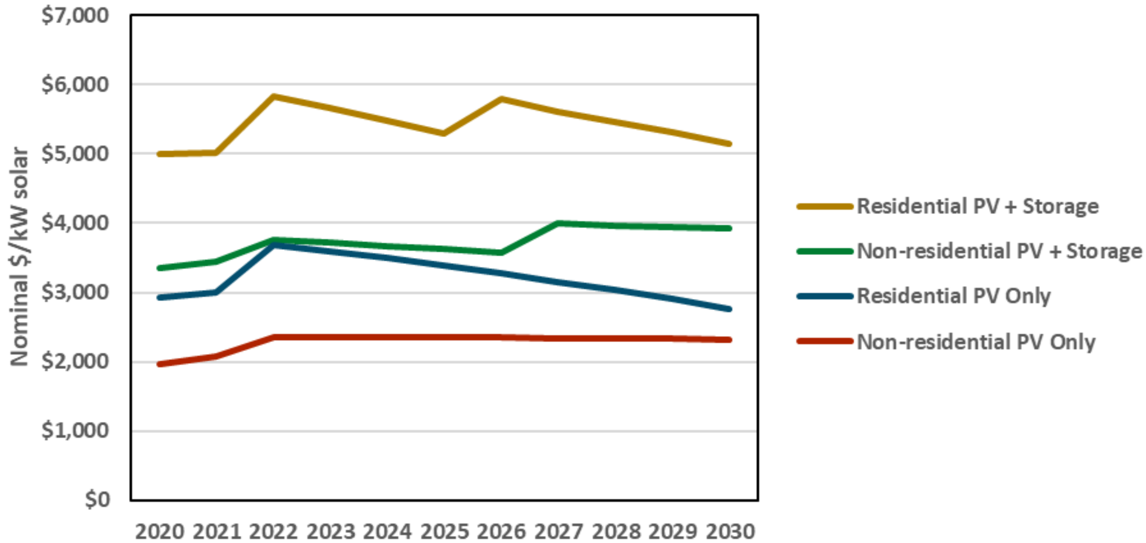

Figure 19. Customer Solar and Solar + Storage System Costs, Net Present Value by Installation Year

3.4. Representative Solar Customers

Representative customer solar customer system sizes, load profiles and solar generation profiles were used to reflect the larger population of SMUD NEM customers. These representative customer characteristics were used to model the hourly operation of customer solar systems and to calculate the avoided cost value provided, as well as the bill changes due to the presence of a solar or solar + storage system.

E3 developed representative customer load and solar generation profiles using a sampling of current SMUD NEM customers. In order to maintain data privacy, E3 requested anonymized summary statistics for the current NEM population, including retail rate, annual gross energy consumption, customer solar system size, and presence of an electric vehicle, among other data. Using this summary data E3 created bins of similar customers which consolidated individual customers into groups based on retail rate, gross annual electricity consumption, solar system size, and the presence or absence of an electric vehicle. E3 then conducted a statistical analysis of the different bins to identify the number of individual customer load and solar generation profiles which would be required to accurately reflect the overall NEM population. This analysis informed a subsequent data request, through which SMUD provided detailed, hourly meter data for a random sampling of customers within each of the bins described above.

From the approximately 500 individual customer meter datasets provided, E3 developed 25 representative customer load and customer solar generation profiles, 18 which represented different residential customers and seven which represented different non-residential customers. Three sets of hourly meter data from the full 2019 calendar year were provided for each randomly selected customer provided: SMUD's net sales to the customer, the energy sold back to SMUD from customers, and the gross generation from the customer solar system. Using these datasets E3 derived customers' hourly gross load profiles (net sales plus solar generation minus exported energy).[39] E3 then calculated statistics for each gross load profile within a particular bin, including the mean and standard error of the load, and a related standard score (Z), assuming a normal distribution. For bins with a small number of profiles (five or fewer), E3 calculated the average hourly gross load directly. For bins with a larger number of profiles, outliers were removed prior to averaging to ensure the resulting representative profile was a robust representation of the underlying population. A similar process was used for developing the gross solar generation and export profiles, with some adjustments to account for different binning processes. Through this process E3 also calculated the average solar system size for each of the 25 representative customers.

Once gross load, solar generation and export profiles were finalized for each representative customer, these profiles were weather matched to 2012 in order to align with the weather assumptions used in SMUD's PLEXOS production simulation modeling. Solar generation profiles were matched based on insolation data, while load profiles were matched based on temperature and weekday vs. weekend / holiday. These 25 customer profiles were then used to represent a total of 572 customer rate and location permutations based on retail rate, including the Energy Assistance Program Rate (EAPR) and the Medical Equipment Discount (MED) rate, presence of an electric vehicle (a significant load modifier), and distribution planning area within SMUD's system.

Hourly and annual results produced from the modeling (described in the following section) were then scaled back up to the population level to reflect the estimated annual and lifetime impacts of the total customer solar system capacity forecast over the study period of 2020-2030. Figure 20 provides an overview of how the representative customers were developed from anonymized NEM customer data.

[39] E3 excluded the small number of customers with paired storage systems from this analysis in order to develop profiles based on customer load and solar generation, without the influence of battery storage. Battery storage system dispatch was modeled on top of these representative profiles.

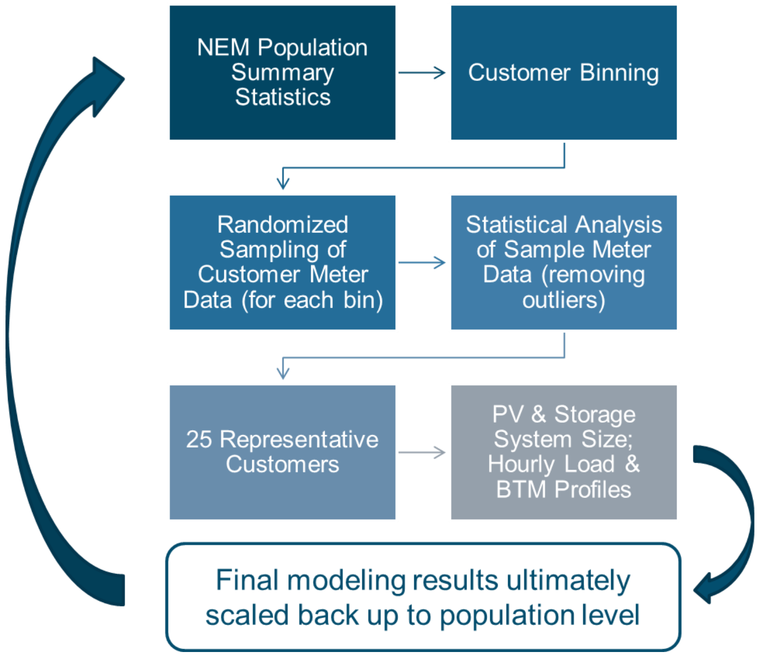

Figure 20. Development of Representative NEM Customers

3.5. Customer Solar System Operation and Value

Once hourly avoided cost values and representative customer profiles were finalized, E3 utilized its RESTORE tool to model the different costs and benefits associated with SMUD's customer solar systems under the three different configurations of interest: 1) solar only; 2) solar + storage responding to SMUD's retail rates; and 3) solar + storage responding to SMUD dispatch signals in order to maximize value for all customers.

RESTORE simulates optimal operation over the life of different types of DER assets, including standalone energy storage and solar + storage; it can also be used to evaluate standalone solar (which is not optimized, as the generation cannot be controlled in the way that storage dispatch can). RESTORE is based on a price-taker optimal dispatch algorithm, which identifies the profit-maximizing operation pattern for the storage asset given its size and performance characteristics, the revenue streams to which it has access, the market(s) in which it is expected to operate, and a forecast of the applicable market prices for the services the asset will be providing (i.e., behind-the-meter bill savings or front-of-meter energy, capacity, regulation, reserves, resource adequacy prices, etc.).[40]

Using the representative customer system sizes and load and generation profiles, E3 created hundreds of model runs to evaluate the costs and benefits of customer solar systems over the study period. Each run reflects the operation of a single representative customer NEM system in a specific year. E3 evaluated each representative customer and rate combination for all years between 2020 and 2049 in order to be able to

[40] For additional information on the RESTORE tool please see the appendix on page 29.

produce lifetime estimates of the VOS/S over twenty years (i.e., as the last systems in the study period would be installed in 2030, their 20th year of operation would be 2049).

The main use of RESTORE was to evaluate how paired solar + storage systems operate based on different price signals. In the customer dispatch configuration, customer solar systems were dispatched against SMUD's time of day rates with the goal of minimizing customer bills. Alternatively, in the utility partnership configuration customer solar systems were dispatched against the avoided cost price streams, aiming to maximize value to all SMUD ratepayers.

Figure 21 provides an example of a residential customer's gross load, PV generation and battery operation based on TOD rates over a single 24-hour period in 2020. Excess solar generation during the middle of the day is used to charge the battery until the evening peak period begins. During the peak period, the battery then discharges to offset customer load in excess of PV generation, avoiding the highest-priced hours of the retail rate.

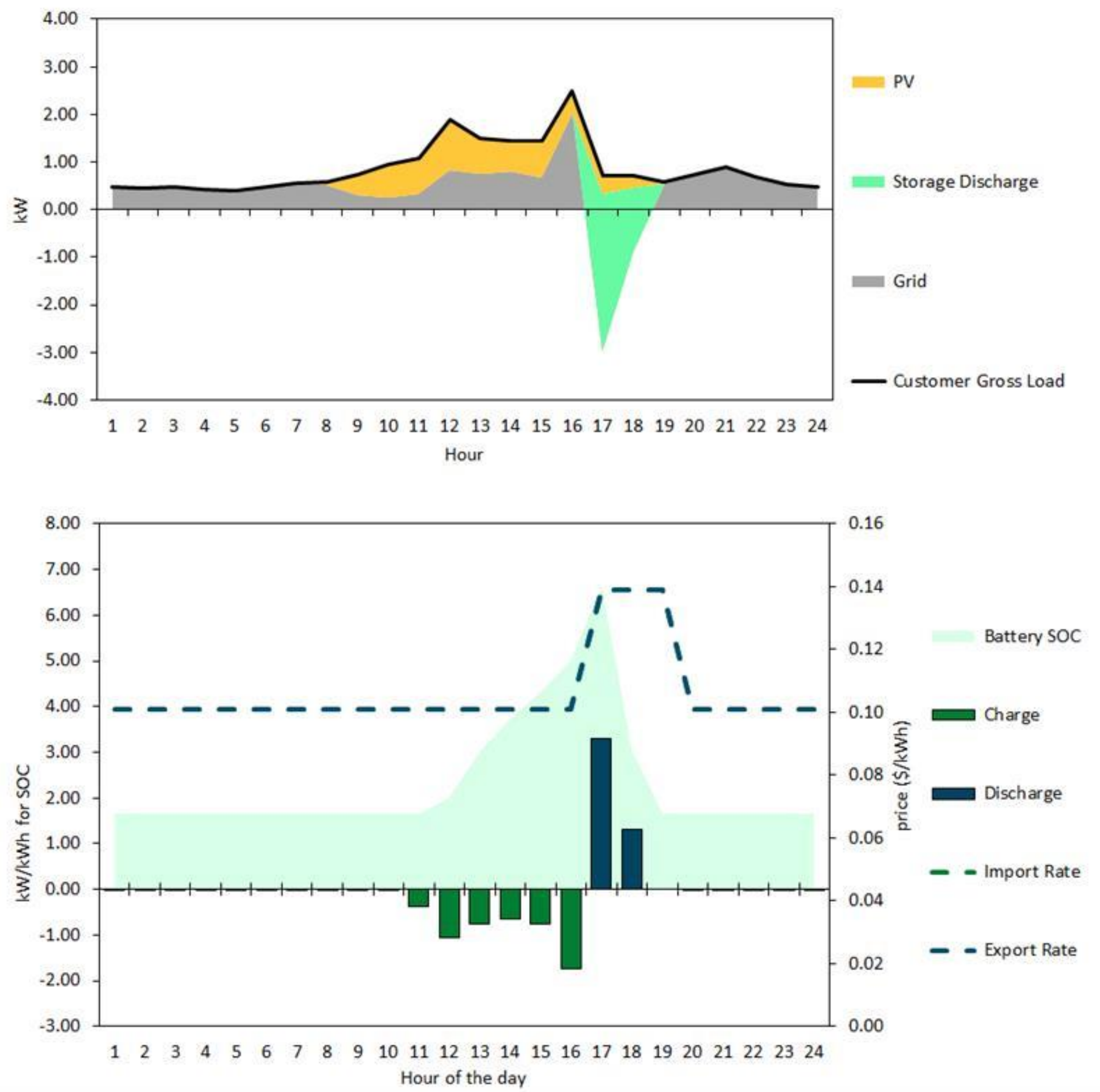

Figure 21. Sample Battery Storage Dispatch Over a Single 24-hr Period[41]

For all battery storage systems in both the customer dispatch and utility partnership configurations, E3 assumed that 25 percent of the battery SOC was maintained to provide resiliency value to the customer, as detailed further in the *Resilience* section of this report (see page 36).

[41] Note that in this figure the “Import Rate” and “Export Rate” are identical (this is a feature of RESTORE not utilized for the VOS/S study).

Population Scaling

After completing the RESTORE model runs, the results were scaled up to represent the entire NEM population. Scaling results up to the population level was done using the anticipated capacity additions in each year. Using the customer solar and solar + storage system forecast for 2020 – 2030 provided by SMUD, E3 allocated the annual capacity additions to different customer types proportionally based on the existing distribution of NEM capacity among SMUD's rates. This was done separately for solar only vs. solar + storage capacity and was also differentiated by customer class (residential vs. non-residential). As several residential rates are no longer open to NEM customers, E3 allocated the residential capacity only to representative customers on open rates.

Additionally, in order to account for solar system degradation over time E3 applied an annual degradation factor of 0.5 percent to each tranche of installations. Due to this the cumulative nameplate capacity included in SMUD's customer solar and solar + storage forecast is somewhat greater than the capacity used to scale up the representative NEM customers in each year.

4. Results

4.1. Value of Solar and Solar + Storage to SMUD Ratepayers

Benefits and Costs of Behind the Meter Systems

The following figures detail the cost-benefit analysis conducted for customer solar systems under net energy metering, for each of the three system configurations and across the two scenarios explored. These estimates are based on current and approved retail rates and the existing NEM program; rates include an annual escalation factor of 3.5 percent.

Note that for presentation purposes several of the avoided costs have been combined:

+ **Transmission & Distribution Capacity:** combined transmission and distribution capacity value
+ **Energy:** combined energy, financial risk, ancillary services, and integration value
+ **Line losses:** each value component has been scaled up by the appropriate line loss factor to reflect this benefit

Additionally, the transmission network adder (trans. network adder) included for the *Helps Meet Clean Energy Goals* scenario is incorporated into the total values, despite being difficult to pick out on the charts due to its small magnitude relative to other value components.

The benefits attributable to customer solar systems under the two different valuation scenarios – *Helps Meet Clean Energy Goals* and *Incremental Clean Energy* – are shown on the left side of the charts, while the costs to SMUD ratepayers in the form of NEM customer compensation are shown on the right. The difference between the two is shown as the net cost or net benefit on top of the benefit columns.

2020 Solar Only

In 2020, the value of solar only systems ranges between $0.032 and $0.070 across the two scenarios, while the cost through NEM compensation is $0.123. As shown in Figure 22 below, this equates to a range of net costs from $0.053 to $0.092. In the *Incremental Clean* Energy scenario, a significant portion of the value is provided by avoided generation capacity (shown in blue). Solar systems are able to provide this value more effectively in the early years of the study period given there is less solar production on the bulk power grid than in the later years of the study, when the incremental contributions of solar resources provide decreasing generation capacity value. Most of the remaining value provided by the solar only systems in 2020 is avoided energy.

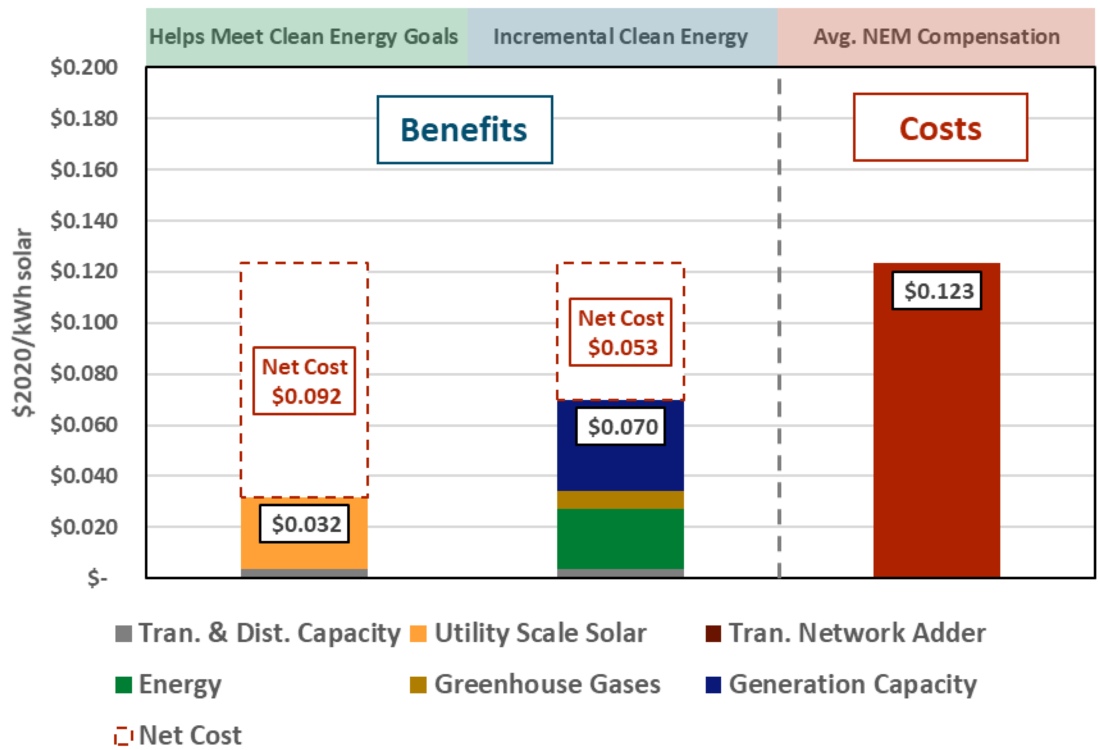

Figure 22. Ratepayer Benefits and Costs, Solar Only, 2020 Installations

As there are relatively few paired solar + storage systems in 2020, the solar only systems represent the majority of the total cost shift in that year at $23.6 million.

2020 Solar + Storage (Customer Dispatch)

Figure 23 depicts the value of solar + storage systems dispatched by customers against retail rates in 2020. Relative to the solar only configuration, in the *Incremental Clean Energy* scenario these systems provide greater generation capacity value as customers on time-of -day rates are able to store the energy generated by their solar systems during the day for use during the evening hours. Reducing gross load in these hours provides greater generation capacity value given that is when SMUD's capacity needs are greatest due to peak system loads. These paired customer solar systems also provide slightly more distribution value for the same reason. In the *Helps Meet Clean Energy Goals* scenario the solar + storage systems provide approximately $0.007/kWh in additional value compared to the solar only systems, given that they help to offset more expensive utility-scale solar + storage. Through this increase in the value provided by the customer solar system the net cost is reduced slightly in the *Incremental Clean Energy* scenario, from $0.053/kWh to $0.044/kWh, despite the increase in average NEM compensation which occurs because customers are better able to target their load reductions to higher-priced periods. However, this increase in average NEM compensation outweighs the small increase in value in the *Helps Meet Clean Energy Goals* scenario.

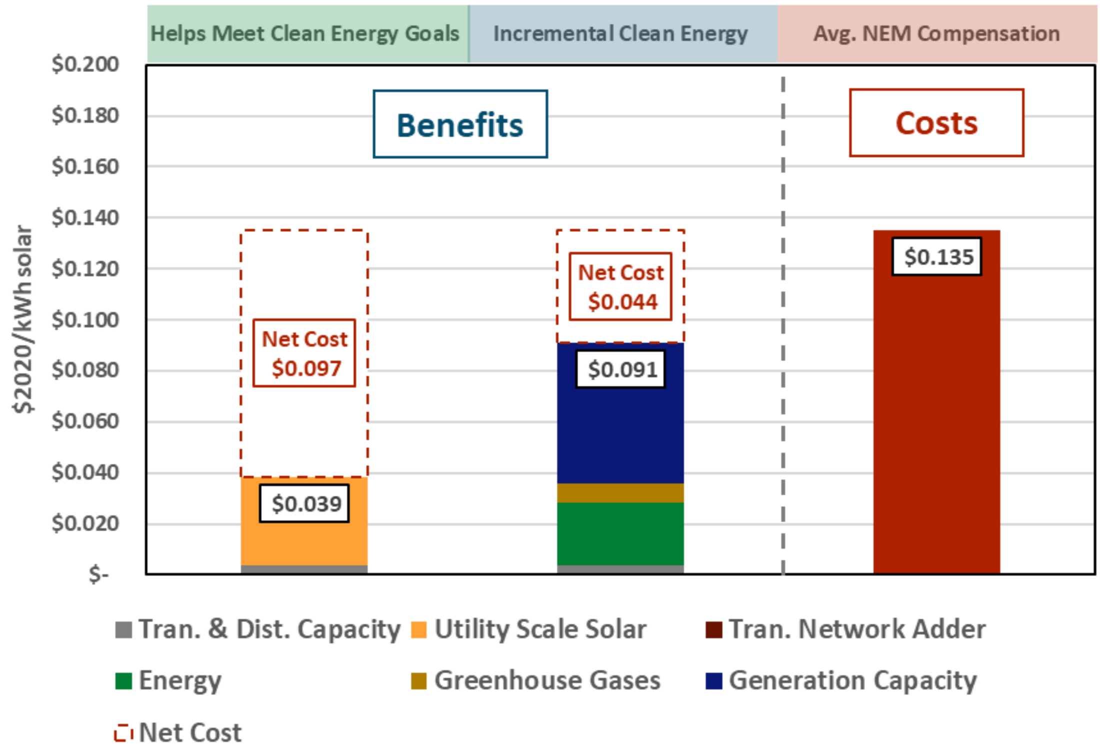

Figure 23. Ratepayer Benefits and Costs, Solar + Storage (Customer Dispatch), 2020 Installations

2020 Solar + Storage (Utility Partnership)

The system configuration with SMUD partnership to dispatch paired customer solar + storage systems significantly increases the value provided by these NEM resources in both scenarios, as shown in Figure 24 below. With the storage assets targeted specifically at the hours with the most value to SMUD ratepayers, all of the avoided cost value components increase in the *Incremental Clean Energy* scenario. In this configuration for 2020 the paired customer solar systems are able to provide enough value to SMUD that they exceed the cost of the average NEM compensation by a small amount.

However, as these costs do not include any payments to customers to incent participation in such a utility partnership program, and the net benefit is relatively small ($0.007/kWh), it is likely that this configuration would not be cost-effective once considering such programmatic costs. Additionally, for solar + storage systems under utility partnership E3 assumed that any increases in demand charges due to the dispatch against avoided costs would not be charged to the customer, given that a program of this nature would not be viable with such charges. Accordingly, any demand charge increases were removed from these calculations.

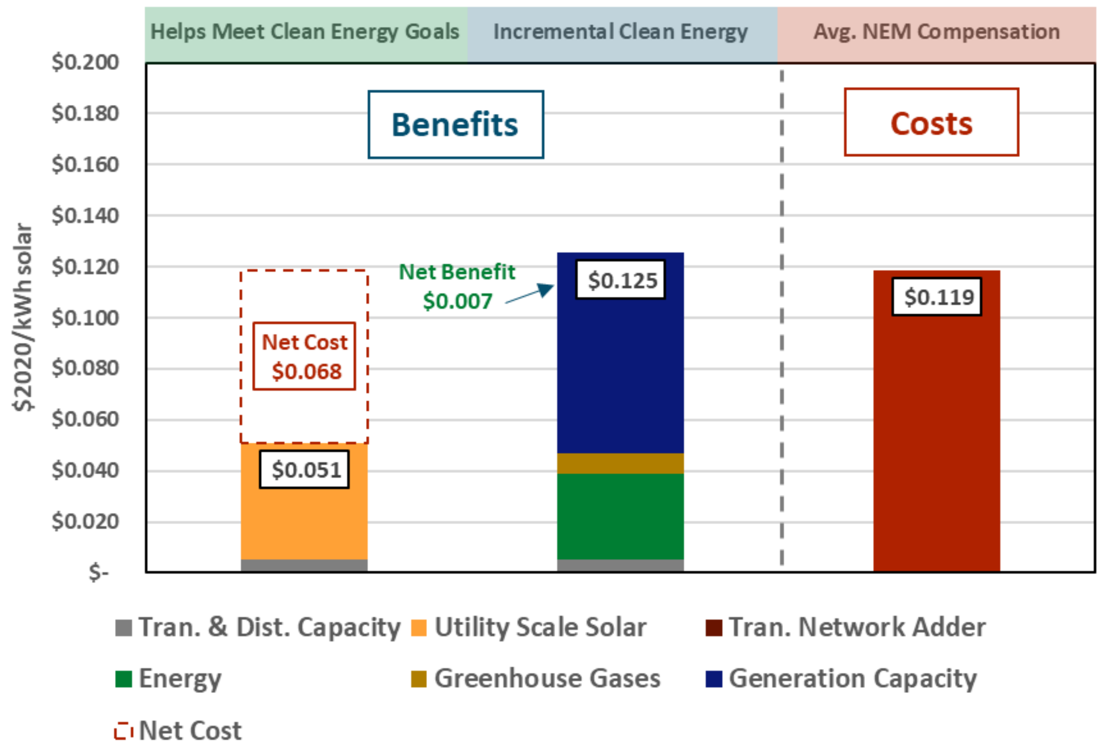

Figure 24. Ratepayer Benefits and Costs, Solar + Storage (Utility Partnership), 2020 Installations

2030 Solar Only

By 2030 the value provided by customer solar systems under the *Incremental Clean Energy* scenario has declined significantly. As described in the *Energy* value component section (see page 14), this is due to the large increase in solar generating capacity anticipated throughout the Western Interconnect in the coming years and the effect that resource buildout will have on the marginal value of all solar resources. The solar only systems are able to provide some value, but considerably less in nominal terms than earlier in the study period. The value of customer solar only systems in the *Helps Meet Clean Energy Goals* scenario, represented by the cost of utility scale solar, has increased slightly in nominal terms (while decreasing in real terms). The avoided costs provided by solar under the *Incremental Clean Energy* scenario in 2030 has declined to the point that it is less than the valuation through the *Helps Meet Clean Energy Goals* scenario, the opposite relationship from earlier years in the study period, which highlights the significant change in the energy market anticipated over the coming decade.

At the same time, average NEM compensation has increased, from $0.12/kWh in 2020 to $0.16/kWh in 2030 due to anticipated annual rate increases of 3.5 percent. The net effect is an increase in the net cost per kWh from a range of $0.05 - $0.09 in 2020 to $0.11 - $0.12 in 2030 (in nominal terms).

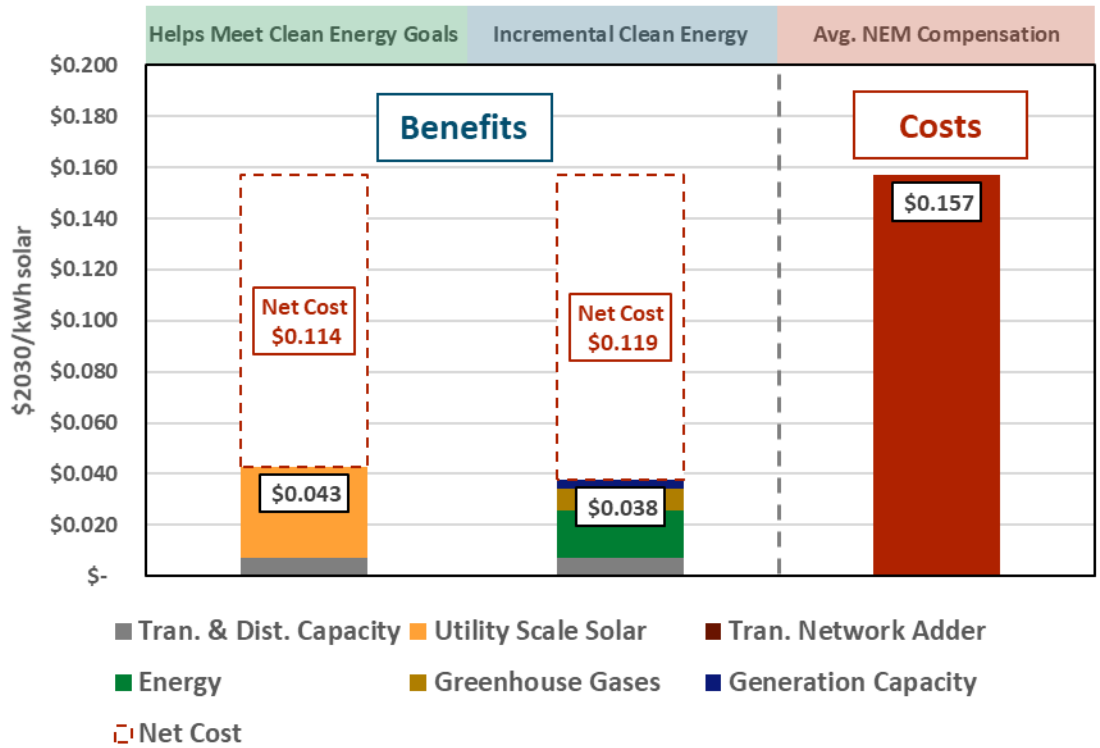

Figure 25. Ratepayer Benefits and Costs, Solar Only, 2030 Installations

2030 Solar + Storage (Customer Dispatch)

Under the *Incremental Clean Energy* scenario, paired customer solar + storage systems operated to minimize customer bills in 2030 provide considerably less value than they do in 2020, for the same reasons discussed above for the solar only configuration. While the value provided is greater than for systems without battery storage, the NEM compensation provided to these systems is greater given that the addition of the battery storage system provides customers another tool by which to lower their bills. Given the decline in value and the increase in rates – which causes a widening gap between costs and benefits – the effect is a net cost greater than for the solar only systems, the opposite of the relationship between these two configurations in 2020.

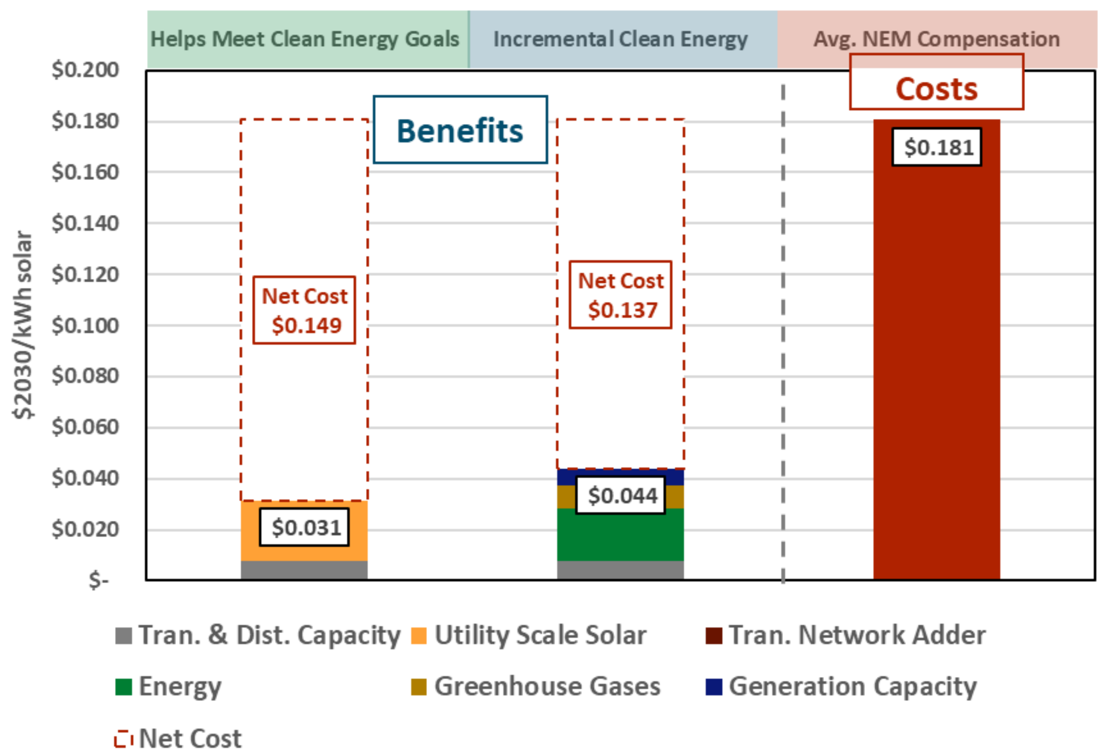

Figure 26. Ratepayer Benefits and Costs, Solar + Storage (Customer Dispatch), 2030 Installations

2030 Solar + Storage (Utility Partnership)

As in 2020, under the *Incremental Clean Energy* scenario the utility partnership configuration in 2030 provides considerably more value than the customer dispatch configuration, more than doubling from $0.044 to $0.089/kWh. Figure 27 details this configuration, showing a large increase in the amount of generation capacity value provided, along with smaller increases in the other avoided cost components. As NEM compensation is reduced given the battery is not being operated to minimize bills, the net cost is considerably lower than in the customer dispatch configuration, $0.067/kWh rather than $0.137/kWh. However, the customer solar system value is still significantly below the cost paid by SMUD ratepayers in the form of NEM compensation to solar customers.

The *Helps Meet Clean Energy Goals* scenario shows a similar dynamic between the utility partnership and customer dispatch configurations, with nearly double the amount of value provided by the former. This reduces the net cost significantly yet given the magnitude of NEM compensation by 2030 a sizeable gap remains.

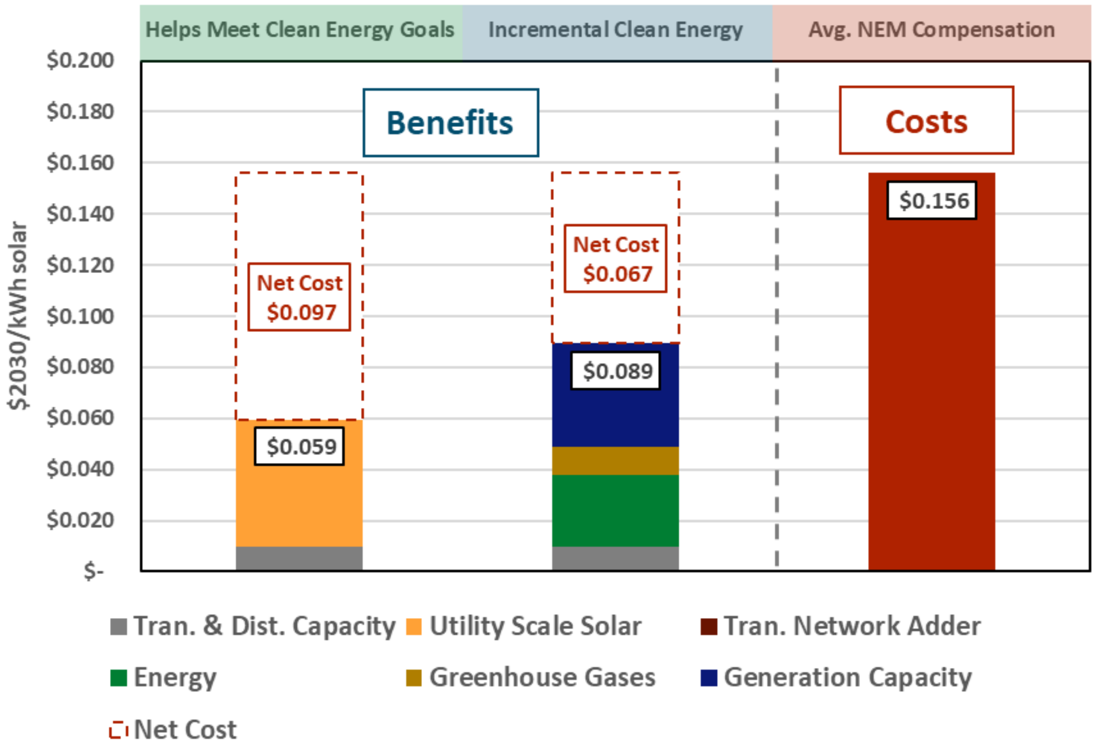

Figure 27. Ratepayer Benefits and Costs, Solar + Storage (Utility Partnership), 2030 Installations

Annual Cost Impacts to SMUD Ratepayers

The total cost impact to SMUD customers from customer solar systems grows significantly over time, as shown in the tables below. This growth is driven by the combination of an increasing amount of nameplate customer solar capacity throughout the study period, declining value of these systems, and increasing costs of NEM compensation based on anticipated annual rate increases.

The estimated annual value of customer solar and solar + storage (customer dispatch) systems across the entire NEM population in 2020 ranges between $14 and $32 million. The annual cost to SMUD ratepayers in the form of NEM compensation is approximately $56 million. The net annual cost to SMUD ratepayers is therefore in the range of $24 to $41 million for 2020, depending on the valuation scenario. These figures do not vary meaningfully for the utility partnership system configuration for paired solar + storage systems in 2020 due in part to the small amount of customer paired system capacity early in the study period.

By 2025 the value of customer solar and solar + storage systems (customer dispatch) has increased to between $22 and $32 million, while the cost of NEM compensation has increased to $77 million, for a net cost to SMUD ratepayers of $44 to $54 million. When considering the utility dispatch system configuration, the net cost range changes to $42 to $53 million.

In the final year of the study period, 2030, the value of the customer solar systems (customer dispatch) has increased to approximately $29 million, while the cost of NEM compensation has increased to $121 million, for a net cost of approximately $91 million. In the utility partnership scenario, the range of net costs is lower at $78 to 81 million due to the additional value which can be provided by customer storage systems when operated in coordination with SMUD.

The following tables provide detailed value and cost figures for both valuation scenarios and the two different customer storage dispatch configurations. Annual values are provided for 2020, 2025, 2030 and 2040. Levelized values over the lifetime of the customer solar and solar + storage systems are also provided, along with the total net present value for the lifetime of these systems.

Table 17. Summary of Ratepayer Impacts: Helps Meet Clean Energy Goals Scenario, Customer Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Cust. Dispatch)	*NPV*[42]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	**n/a**	**263**	**340**	**445**	**445**[43]
Benefits and Costs per kWh of Solar Output					
Value of Solar & Solar + Storage ($/kWh solar)	***0.047***	**0.032**	**0.039**	**0.040**	**0.060**
SMUD Revenue Reduction ($/kWh solar)	***0.184***	**0.124**	**0.134**	**0.163**	**0.232**
Net Cost Shift ($/kWh solar)	***0.137***	**0.092**	**0.095**	**0.124**	**0.172**
Total Change in SMUD Costs & Revenues					
Value of Solar and Solar + Storage	***$492 MM***	**$14 MM**	**$22 MM**	**$29 MM**	**$42 MM**
SMUD Revenue Change	***-$1,910 MM***	**-$56 MM**	**-$77 MM**	**-$120 MM**	**-$163 MM**
Net Cost Shift	***$1,417 MM***	**$41 MM**	**$54 MM**	**$91 MM**	**$120 MM**
Change in SMUD Average Rates (%)	***n/a***	**3.1%**	**3.6%**	**4.4%**	**4.1%**
Approximate Annual Bill Impact (non-solar residential customer @ 750 kWh/month)	***n/a***	**$45/yr.**	**$63/yr.**	**$90/yr.**	**$120/yr.**

[42] 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.

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

Table 18. Summary of Ratepayer Impacts: Incremental Clean Energy Scenario, Customer Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Cust. Dispatch)	*NPV*[44]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	**n/a**	**263**	**340**	**445**	**445**[45]
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.**

[44] 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.

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

Table 19. Summary of Ratepayer Impacts: Helps Meet Clean Energy Goals Scenario, Utility Partnership Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Util. Partner)	NPV[46]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	*n/a*	263	340	445	445[47]
Benefits and Costs per kWh of Solar Output					
Value of Solar & Solar + Storage ($/kWh solar)	***0.053***	**0.032**	**0.040**	**0.047**	**0.069**
SMUD Revenue Reduction ($/kWh solar)	***0.178***	**0.123**	**0.132**	**0.157**	**0.224**
Net Cost Shift ($/kWh solar)	***0.125***	**0.091**	**0.092**	**0.110**	**0.154**
Total Change in SMUD Costs & Revenues					
Value of Solar and Solar + Storage	***$552 MM***	**$14 MM**	**$23 MM**	**$35 MM**	**$49 MM**
SMUD Revenue Change	***-$1,850 MM***	**-$56 MM**	**-$76 MM**	**-$116 MM**	**-$157 MM**
Net Cost Shift	***$1,297 MM***	**$41 MM**	**$53 MM**	**$81 MM**	**$108 MM**
Change in SMUD Average Rates (%)	*n/a*	**3.0%**	**3.5%**	**3.9%**	**3.7%**
Approximate Annual Bill Impact (non-solar residential customer @ 750 kWh/month)	*n/a*	**$44/yr.**	**$61/yr.**	**$79/yr.**	**$107/yr.**

[46] 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.

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

Table 20. Summary of Ratepayer Impacts: Incremental Clean Energy Scenario, Utility Partnership Storage Dispatch (Values in nominal dollars)

Solar & Solar + Storage (Util. Partner)	*NPV*[48]	2020	2025	2030	2040
Total Cust. Solar Capacity (MW Nameplate)	*n/a*	263	340	445	445[49]
Benefits and Costs per kWh of Solar Output					
Value of Solar & Solar + Storage ($/kWh solar)	***0.060***	**0.071**	**0.059**	**0.052**	**0.062**
SMUD Revenue Reduction ($/kWh solar)	***0.178***	**0.123**	**0.132**	**0.157**	**0.224**
Net Cost Shift ($/kWh solar)	***0.119***	**0.052**	**0.074**	**0.105**	**0.162**
Total Change in SMUD Costs & Revenues					
Value of Solar and Solar + Storage	***$618 MM***	**$32 MM**	**$34 MM**	**$38 MM**	**$43 MM**
SMUD Revenue Change	***-$1,850 MM***	**-$56 MM**	**-$76 MM**	**-$116 MM**	**-$157 MM**
Net Cost Shift	***$1,231 MM***	**$24 MM**	**$42 MM**	**$78 MM**	**$113 MM**
Change in SMUD Average Rates (%)	*n/a*	**1.7%**	**2.8%**	**3.7%**	**3.9%**
Approximate Annual Bill Impact (non-solar residential customer @ 750 kWh/month)	*n/a*	**$25/yr.**	**$49/yr.**	**$76/yr.**	**$113/yr.**

The figures below illustrate the magnitude of average NEM compensation and the value of customer solar and storage resources over time, on a $/kWh basis. This comparison highlights the increasing gap between the value of customer solar and storage resources and the NEM compensation received by owners of these systems, driven by anticipated increases in retail rates without an analogous increase in customer solar and storage resource value. This increasing disparity between compensation and value produces an increasing shifting of costs from solar customers to non-solar customers over time, explaining both the increasing annual cost shift figures and the large net present cost of NEM to SMUD ratepayers detailed in the tables above.

[48] 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.

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

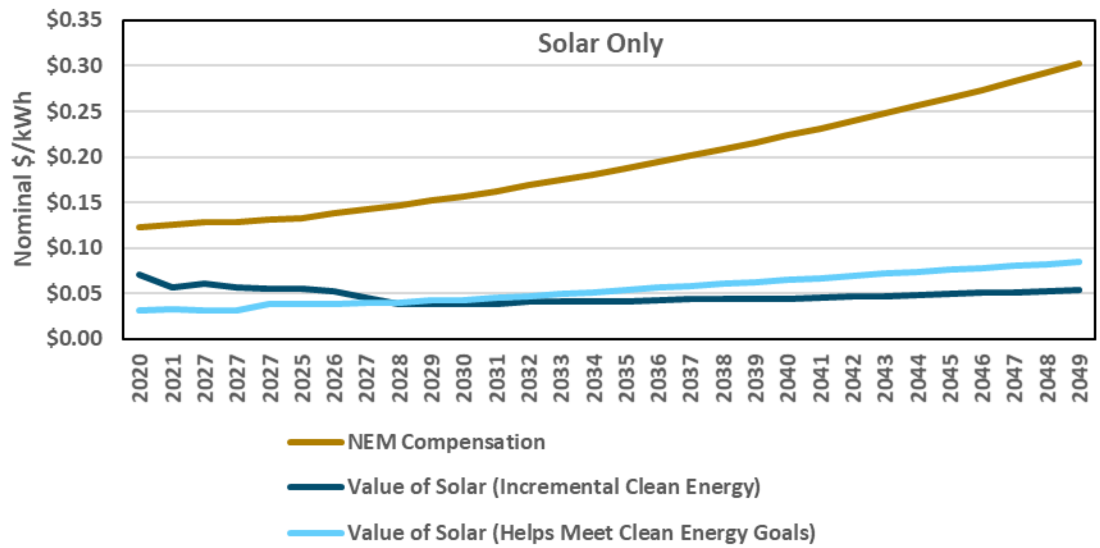

Figure 28.NEM Compensation and Value of Solar Only, 2020-2049

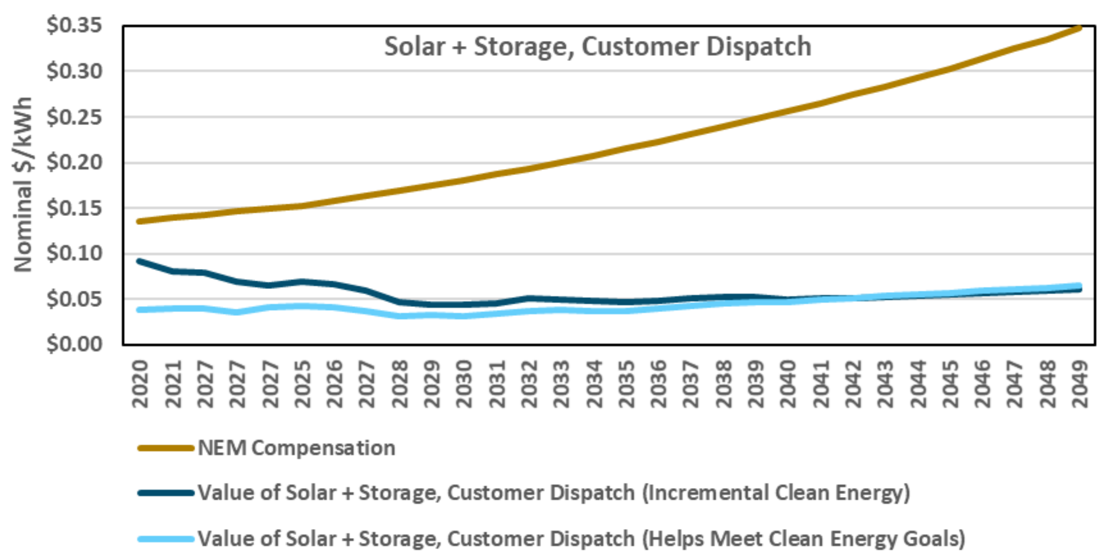

Figure 29.NEM Compensation and Value of Solar + Storage (Customer Dispatch), 2020-2049

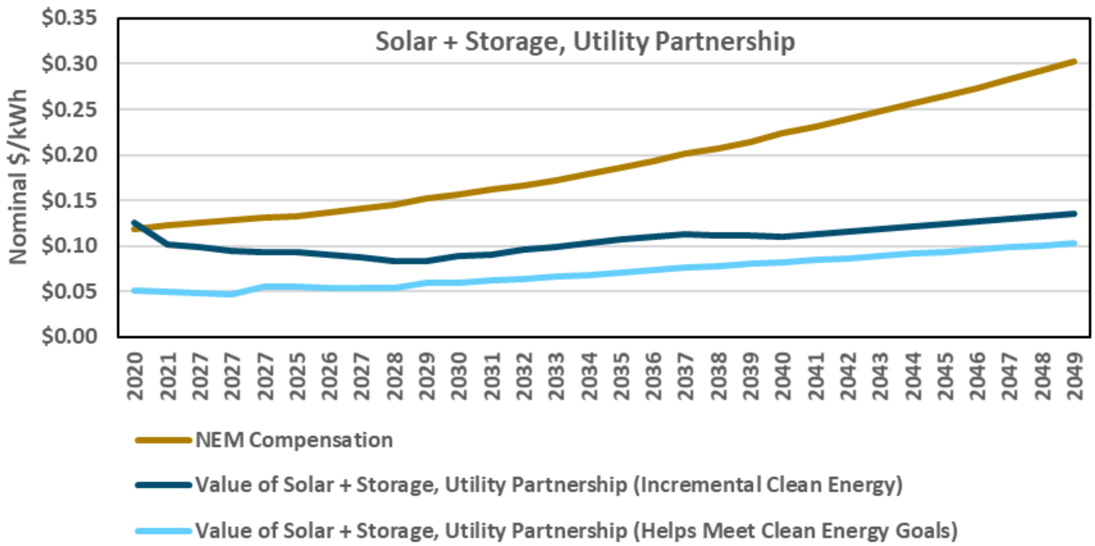

Figure 30. NEM Compensation and Value of Solar + Storage (Utility Partnership), 2020-2049

Sustained Capacity Value Sensitivity

As described previously in this report, one of the contributors to the declining value of solar and solar + storage throughout the study period is the increasing saturation of solar generation throughout the West and the downward pressure that puts on the value of incremental solar capacity. While this is an accurate depiction of current expectations for the development of energy markets across the Western U.S., E3 also explored a sensitivity through which customer solar and solar + storage systems were credited continuously throughout the system life for the capacity value provided in the first year of installation, rather than receiving declining generation capacity values over time. This was done to assess the net benefit or cost of the customer solar systems if it were assumed that they should be allocated capacity based on their installation year rather than their annual contribution to capacity needs

In this "sustained capacity value" sensitivity, customer solar installations under the *Incremental Clean Energy* valuation scenario were allocated the annualized present value of their generation, transmission, and distribution capacity value from the year of installation over an assumed 20-year lifetime. Due to this levelization, results in this section are shown on an annualized basis for the 20-year customer solar system life, rather than as single-year "snapshots" as shown in the *Benefits and Costs of Behind the Meter Systems* section above. This levelization uses a nominal discount rate of 4.5 percent, reflective of SMUD's weighted average cost of capital.

The figures below provide several comparisons between the allocation of annual capacity values throughout the system life (left column) to this "sustained capacity value" treatment (middle column). The right column reflects the levelized cost of NEM compensation borne by non-solar SMUD customers.

2020 Solar Only

Allocating this "sustained" capacity value to solar only systems installed in 2020 increases the generation capacity value component from $0.012 to $0.035/kWh, resulting in a decrease in the net cost of these systems from $0.103/kWh to $0.081/kWh; an improvement in cost-effectiveness, although as shown by the remaining net cost this still leaves the customer solar systems well short of contributing the value necessary to account for the cost of the NEM compensation.

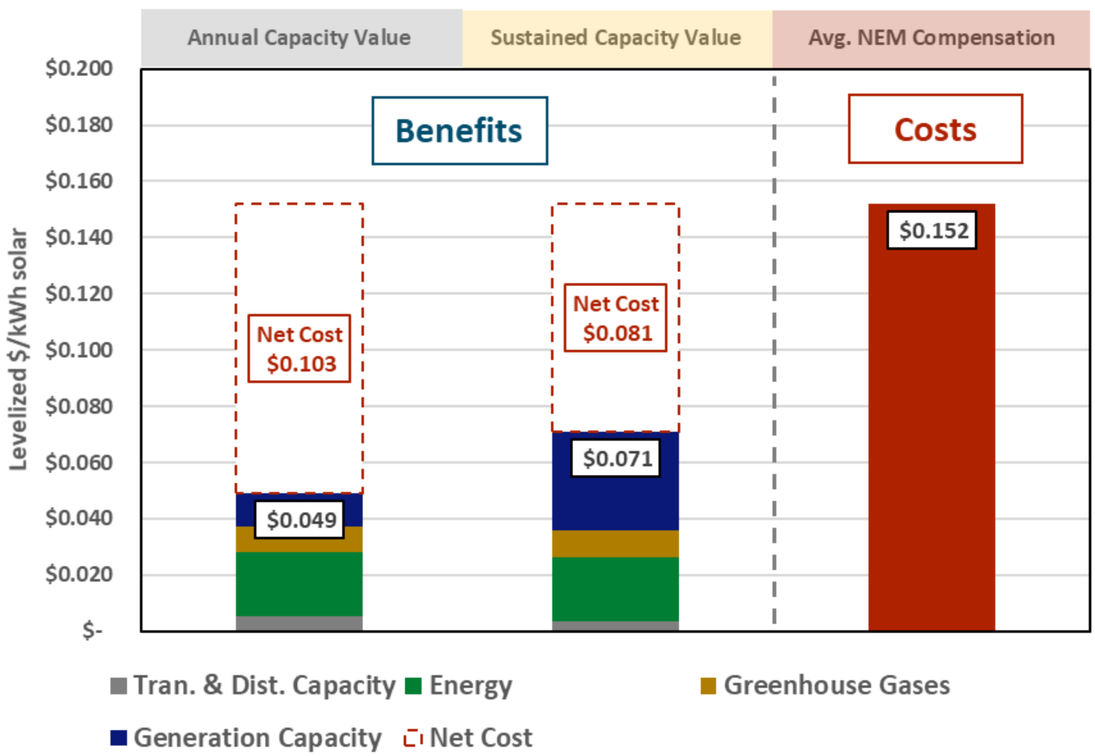

Figure 31. Value of Solar Only, 2020 Installations, Sustained Capacity Sensitivity

2020 Solar + Storage (Customer Dispatch)

A similar dynamic occurs when comparing the annual capacity value to the "sustained" capacity value for solar + storage systems installed in 2020 which are operated under customer dispatch (Figure 32). There is a significant increase in the generation capacity value component, bringing the total levelized value of solar + storage up from $0.061 to $0.096/kWh. However, the net cost to SMUD ratepayers remains significant at $0.078/kWh.

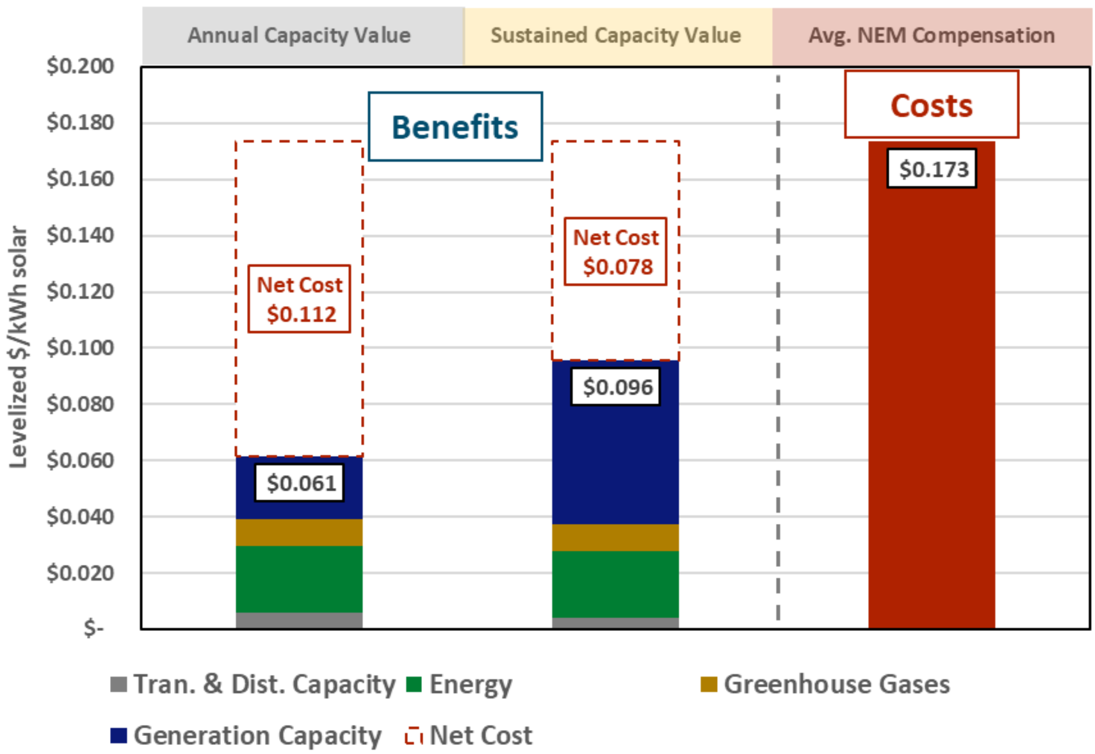

Figure 32. Value of Solar + Storage (Customer Dispatch), 2020 Installations, Sustained Capacity Sensitivity

2020 Solar + Storage (Utility Partnership)

For solar + storage systems operated in partnership with SMUD, the annual capacity value is significantly higher than for the customer dispatch scenario, especially for generation capacity. As shown in Figure 33 below, once the “sustained” capacity value treatment is included, this raises the levelized value of the customer solar systems from $0.099 to $0.126/kWh. However, as the levelized value of the NEM compensation is $0.151/kWh, a net cost of $0.025/kWh remains.

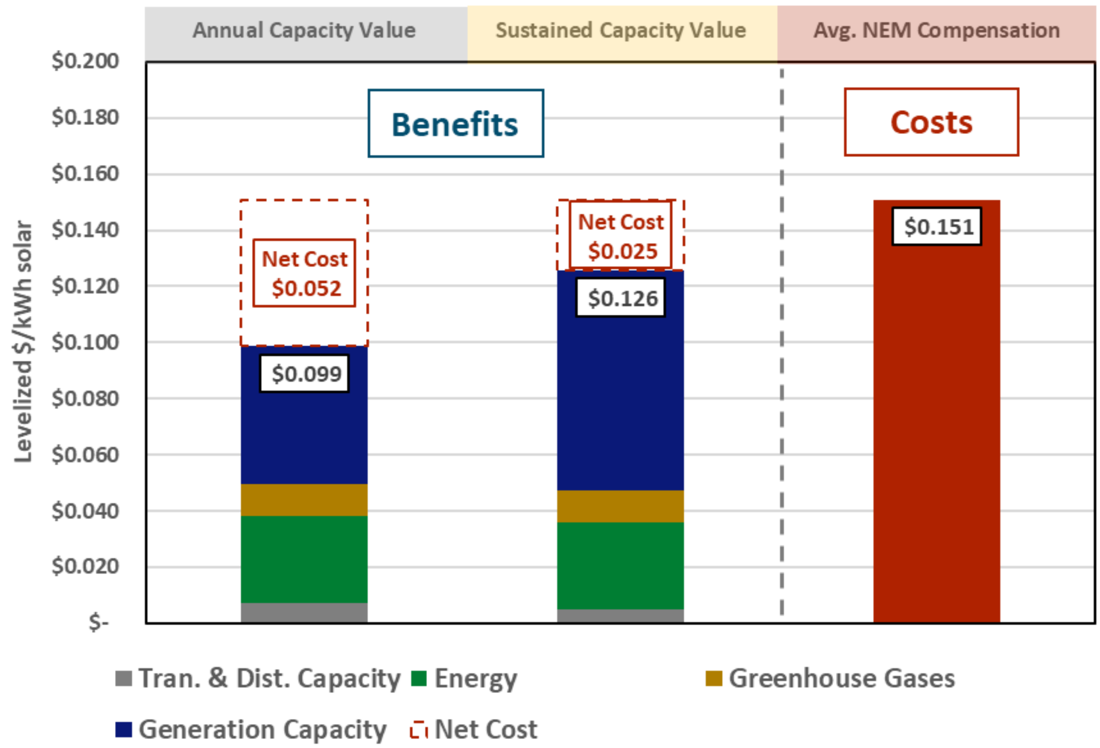

Figure 33. Value of Solar + Storage (Utility Partnership), 2020 Installations, Sustained Capacity Sensitivity

2025 Solar Only

To provide a single example of how the comparison between the annual and "sustained' capacity value treatments changes over time, Figure 34 below shows solar only installations in 2025. A similar relationship between the two capacity treatments as is seen for the 2020 installations is apparent, with the "sustained" generation capacity value allocating an additional $0.009/kWh of value to these systems, decreasing the net cost slightly from $0.133 to $0.124/kWh.

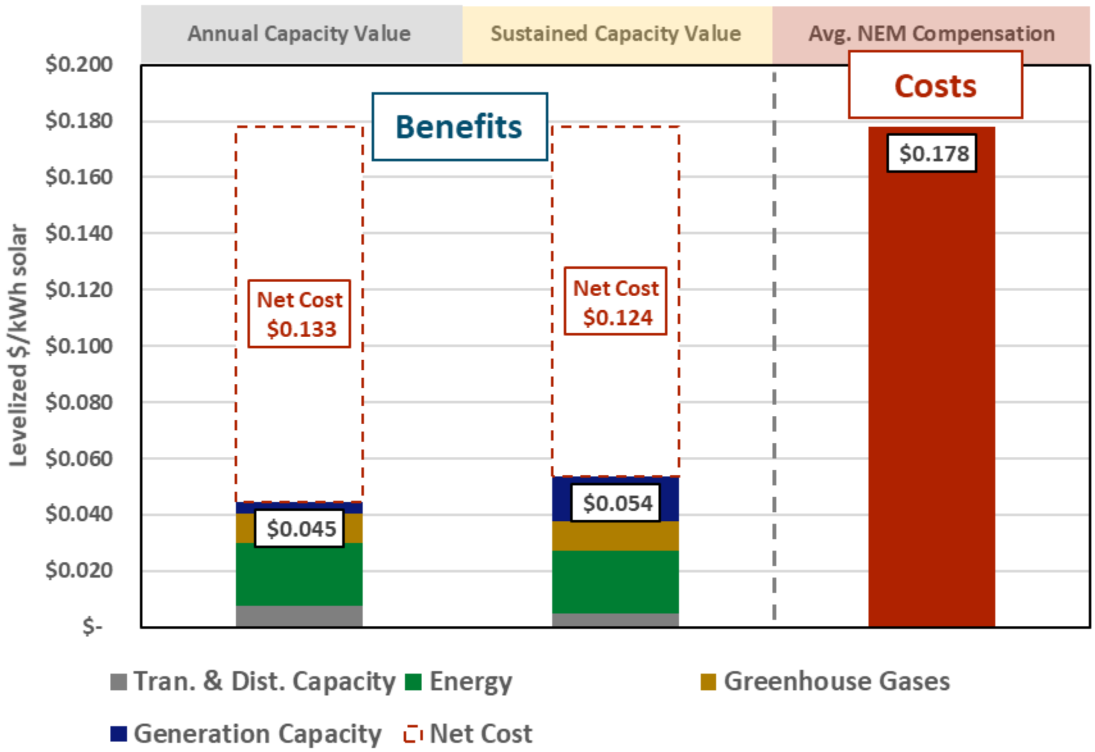

Figure 34. Value of Solar Only, 2025 Installations, Sustained Capacity Sensitivity

4.2. Value of Solar and Solar + Storage to Society

Range of Societal Values

As described in the *Societal and Solar Customer Values* section of the methodology, E3 quantified a range of physical impacts for carbon emissions, fugitive methane emissions, criteria pollutants, water usage and land usage. The avoided carbon, fugitive methane, criteria pollutant and water estimates are relevant in the *Incremental Clean Energy* scenario where the customer solar systems are assumed to be displacing natural gas generation at the margin. The avoided land acreage, alternatively, is relevant in the *Helps Meet Clean Energy Goals* scenario, where customer solar systems are assumed to enable SMUD to procure less utility-scale clean energy.

E3 also estimated a range of economic values for these components.

The results in the following tables are for the combined solar and solar + storage (customer dispatch) configurations.

Table 21 provides the estimated physical impacts of the entire SMUD NEM population for three different years.

Carbon emissions reductions increase from 2020 to 2025 due to growth in customer solar systems. Despite continued growth in these systems from 2025 to 2030, annual emissions reductions decrease due to the increasingly carbon-free energy which they displace (in the *Incremental Clean Energy* scenario). The same dynamic is evident in the avoided criteria pollutant emissions, for which the range of estimates also increases from 2020 to 2025 and then decreases again by 2030; this is because the transition to a lower-carbon resource mix will also reduce emissions of other air pollutants. Fugitive methane emissions reductions from SMUD's thermal plants, alternatively, decline over time given that these thermal plants are on the margin less and less over time, providing fewer opportunities for customer solar systems to displace their generation and the small amount of associated methane leakage.

The broad range of reductions in water usage is due to the uncertainty in the consumption levels of different generation sources. As described further in the *Water Use* section of the methodology (page 42), E3 used a range of water usage estimates from 4 to 250 gallons/MWh, which results in the broad range of annual estimates shown in the table below.

The avoided land use in the *Helps Meet Clean Energy Goals* scenario ranges between 1,260 acres in 2020 and 2,040 acres in 2030, directly reflective of the amount of installed customer solar capacity in each year.

Table 21. Range of Physical Impacts, Annual Snapshots

Societal Value Component	Units (avoided)	2020	2025	2030
Carbon	Metric tons	188,000	223,000	206,000
Fugitive Methane	Lbs.	Methane: 63 CO_2e: 1,570	Methane: 49 CO_2e: 1,231	Methane: 31 CO_2e: 764
Criteria Pollutants	Lbs. (thousand)	PM10: 16 to 27 NOx: 41 to 69	PM10: 18 to 29 NOx: 45 to 76	PM10: 13 to 22 NOx: 34 to 58
Water	Gallons (million)	2 to 113	2 to 145	3 to 184
Land	Acres	1,260	1,590	2,040

Table 22 provides a summary of the physical impacts in each category, per MWh, as well as the range of estimated $/kWh values calculated using inputs from E3's literature review.

Table 22. 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[50]	Can be provided by utility-scale solar under *Incremental Clean Energy* scenario at a cost of $0.027/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[51]	
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

Societal Values Provided by Utility-Scale Solar and Other SMUD Actions

With the exception of land-use savings, the societal values described in this section can be provided through a number of means in addition to customer solar. These include:

- Additional utility-scale solar (under the *Helps Meet Clean Energy Goals* scenario)
- Other utility-scale renewable and energy storage resources (wind, geothermal, utility-scale battery installations, and others)
- Additional investments in energy efficiency or demand response
- Additional electrification of buildings, vehicles, or industrial loads

[50] 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 this report (see Table *15* and Figure 17 on page 32). This estimate is well above the range of other estimates considered.

[51] 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.

Simply adding these societal values to the total ratepayer values derived from customer solar installations incorrectly assumes that customer solar is the only means to achieve these benefits. In reality, 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 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. This type of analysis is beyond the scope of this report and is best conducted as part of a comprehensive utility planning process such as an Integrated Resource Plan.

4.3. Value of Solar and Solar + Storage to Solar Customers

In addition to the Ratepayer and Societal perspectives, E3 considered the value of customer solar and solar + storage systems to NEM customers. Given that customers invest in these systems upfront and then accrue benefits in the form of electricity bill savings over the following years, the results in this section are presented in levelized $/kWh values, with the assumption of a 20-year system lifetime. A solar customer discount rate of seven percent nominal was used for the levelization.

Solar Only

Solar only systems installed in 2020 are estimated to be cost-effective for some but not all NEM customers. Figure 35 below shows the lifetime benefits and costs for residential customers on the RT02 rate, indicating that over the assumed 20-year lifetime of the system the benefits provided by electricity bill savings are about equal to the system costs.

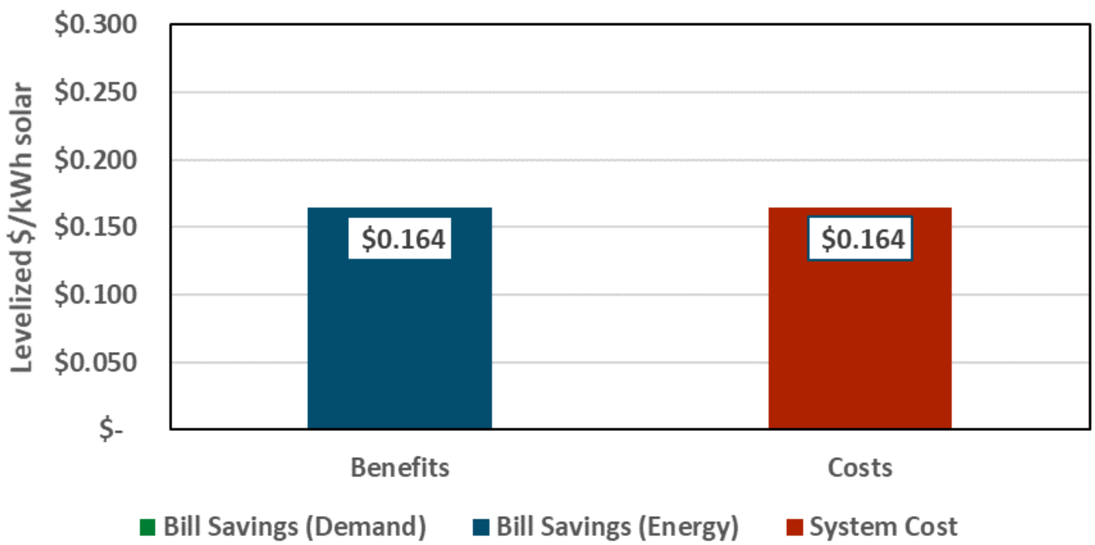

Figure 35. Solar Customer Benefits and Costs, Solar Only, RT02, 2020 Installations

The same RT02 installations in 2025 become more cost effective for adopting NEM customers, as electricity rates have increased (providing greater bill savings opportunities from NEM) while the customer solar system costs have declined.

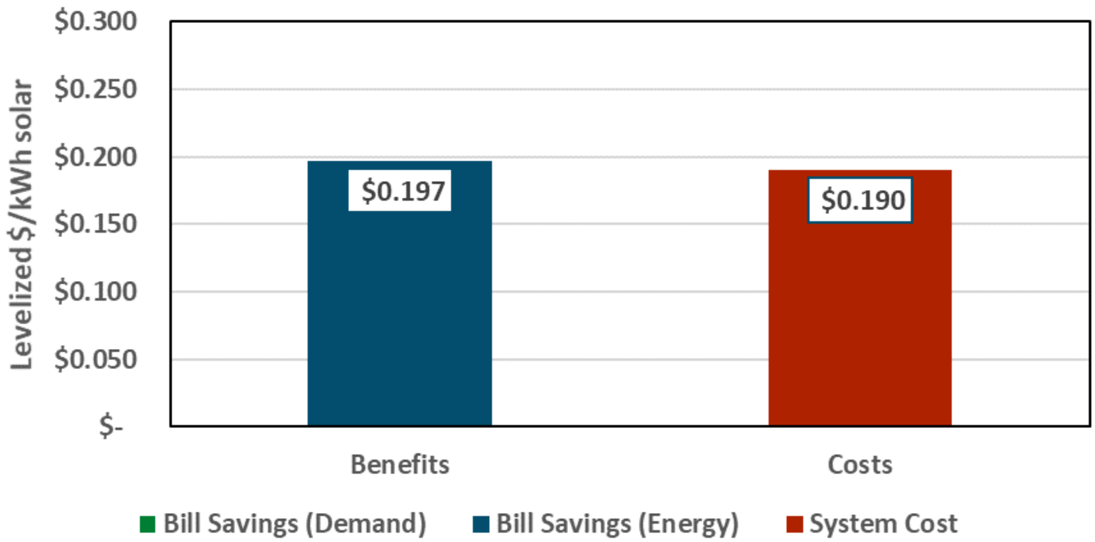

Figure 36. Solar Customer Benefits and Costs, Solar Only, RT02, 2025 Installations

Solar Customer cost-effectiveness for non-residential, solar only installations depends upon the customer rate, although most 2020 installations are cost-effective for NEM customers over the lifetime of the system. As an example, Figure 37 below shows significant cost savings for NEM customers on the GUS_M rate installing a customer solar system in 2020. Most of the benefits come from bill reductions from energy charges, with some additional benefit provided by demand charge savings.

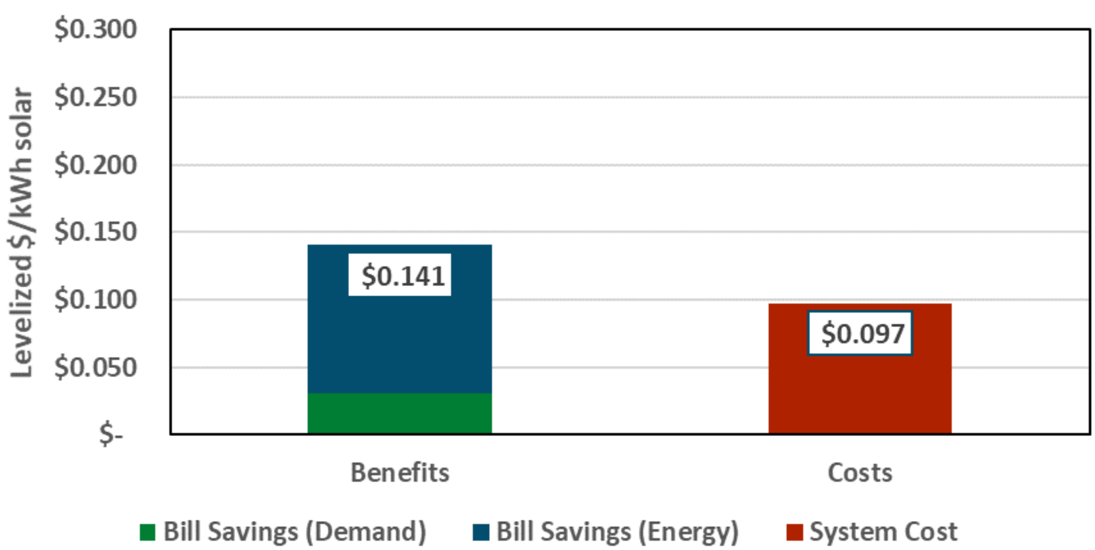

Figure 37. Solar Customer Benefits and Costs, Solar Only, GUS_M, 2020 Installations

This relationship holds true for most non-residential, solar only installations in the later years of the study.

Solar + Storage (Customer Dispatch)

Residential solar + storage systems under customer dispatch are not cost-effective for NEM customers. Customers receive greater bill savings than in the solar only configuration, but the additional system cost for battery storage outweighs these benefits considerably. Figure 38 below shows a significant gap between the levelized system costs of $0.280/kWh and the benefits of $0.182. Note that there is a small amount of resilience benefit customers gain from battery storage systems, but it is insufficient to make up for the additional storage system costs, relative to the solar only configuration.

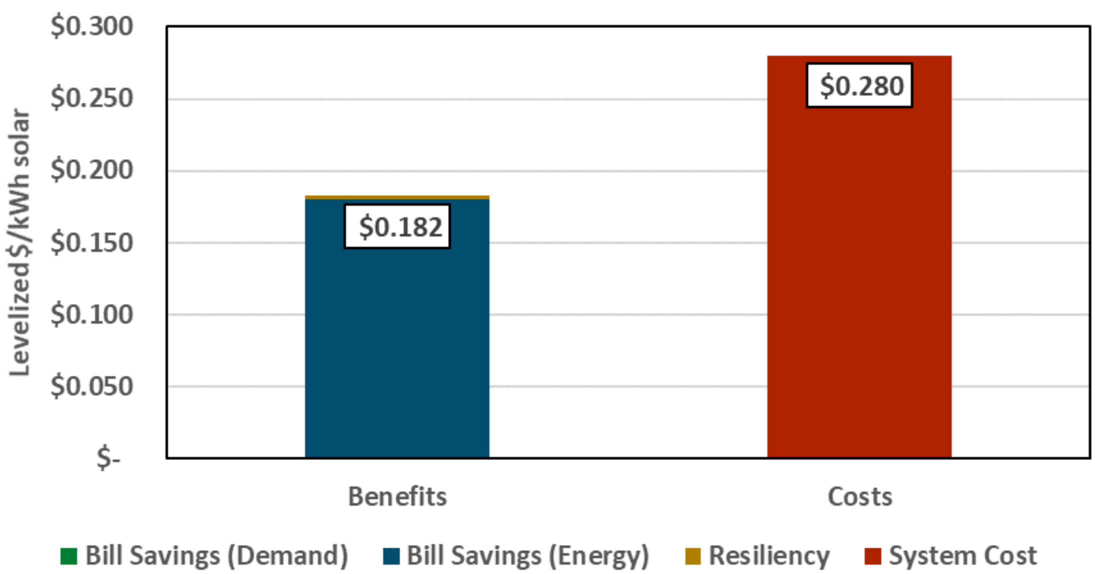

Figure 38. Solar Customer Benefits and Costs, Solar + Storage (Customer Dispatch), RT02, 2020 Installations

For RT02 installations in 2025, the relationship is similar, although the benefits relative to the costs have increased slightly from the solar customer perspective, as customer solar system costs have fallen while retail rates have increased.

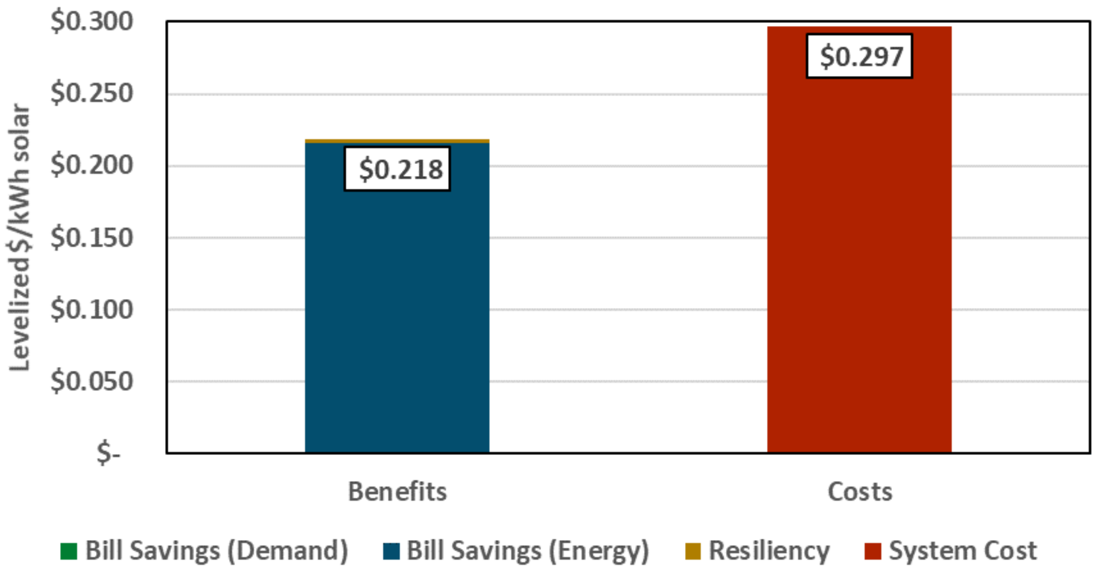

Figure 39. Solar Customer Benefits and Costs, Solar + Storage (Customer Dispatch), RT02, 2025 Installations

The cost-effectiveness of non-residential solar + storage systems under the customer dispatch configuration for NEM customers depends upon retail rates. While the GUS_M customer shown above in the solar only configuration remains cost-effective for installations throughout the study period, customers on other rates structures do not. The following figures contrast a 2025 GUS_M installation and a 2025 GSS_T customer, showing levelized net benefits of approximately $0.03/kWh for the former and net costs of a similar magnitude for the latter. A significant portion of the benefits the GUS_M customer accrues are due to demand charge reductions.

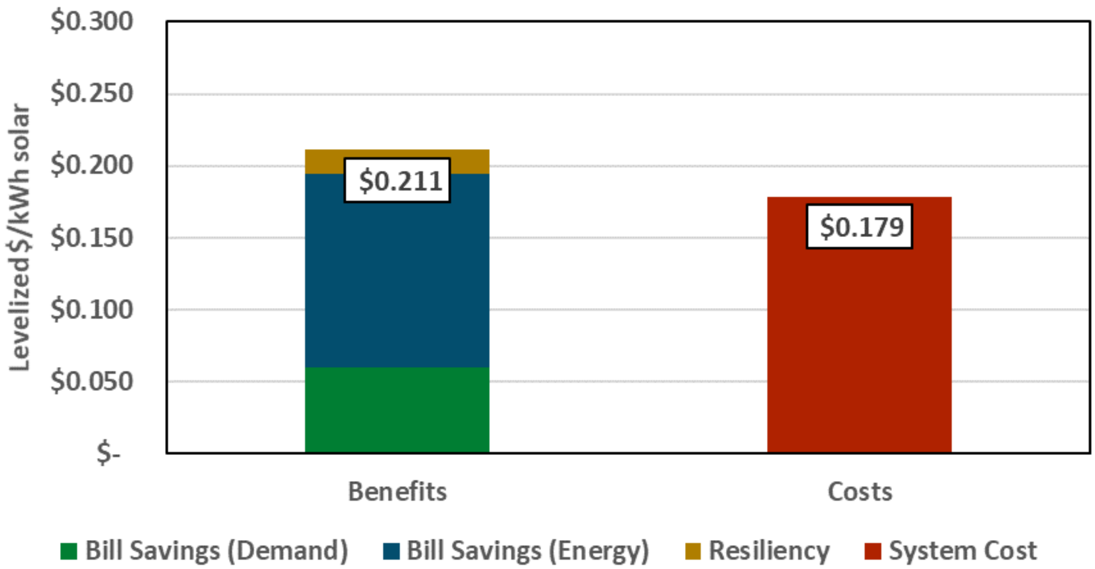

Figure 40. Solar Customer Benefits and Costs, Solar + Storage (Customer Dispatch), GUS_M, 2025 Installations

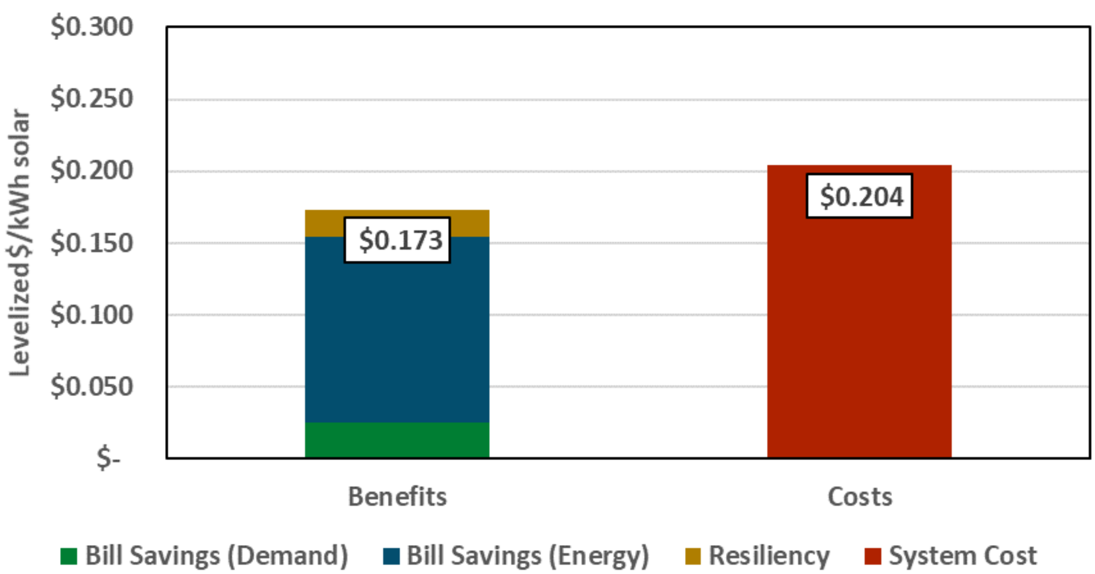

Figure 41. Solar Customer Benefits and Costs, Solar + Storage (Customer Dispatch), GSS_T, 2025 Installations

Solar + Storage (Utility Partnership)

Solar + storage systems under the utility partnership configuration are not cost-effective for NEM customers in the absence of additional incentives.

Figure 42 below presents the benefits and costs to residential RT02 customers installing customer solar systems in 2020, highlighting a significant gap between the system costs and the benefits provided by energy bill savings and resiliency. Notably, the benefits customer receive under this system configuration are lower than those received under the customer dispatch configuration, making this option less financially viable in the absence of additional incentives (which would reduce the cost-effectiveness for other SMUD ratepayers).

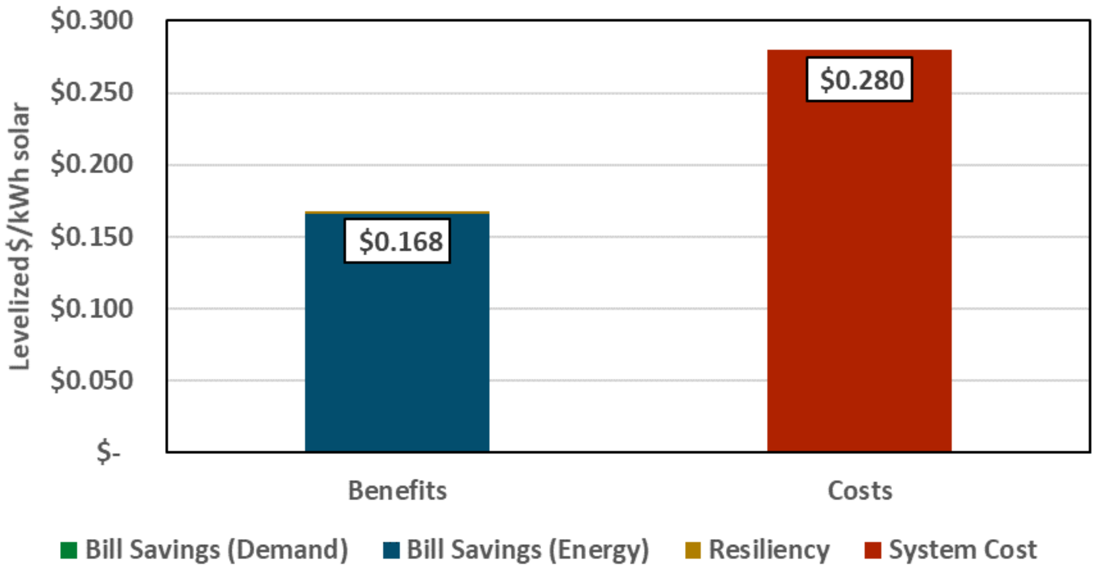

Figure 42. Solar Customer Benefits and Costs, Solar + Storage (Utility Partnership), RT02, 2020 Installations

This relationship is similar for 2025 and 2030, with solar + storage systems under utility partnership still considerably short of being cost-effective from a residential customer's perspective. As with the 2020 installations, the value proposition to NEM customers is better under the customer dispatch configuration than under the utility partnership configuration, given the different operational goals (bill minimization vs. avoided cost maximization).

Non-residential solar + storage installations throughout the study period are also not cost-effective under the utility partnership configuration. Figure 43 below shows the benefits and costs to the same GUS_M customer in 2025, for whom a paired customer solar + storage system *was* cost-effective under the customer dispatch scenario. The demand charge savings this customer benefitted from in the previous configuration do not occur in the utility partnership configuration, significantly eroding the value proposition from the NEM customer perspective. The results for other non-residential installations are similar throughout the study period.

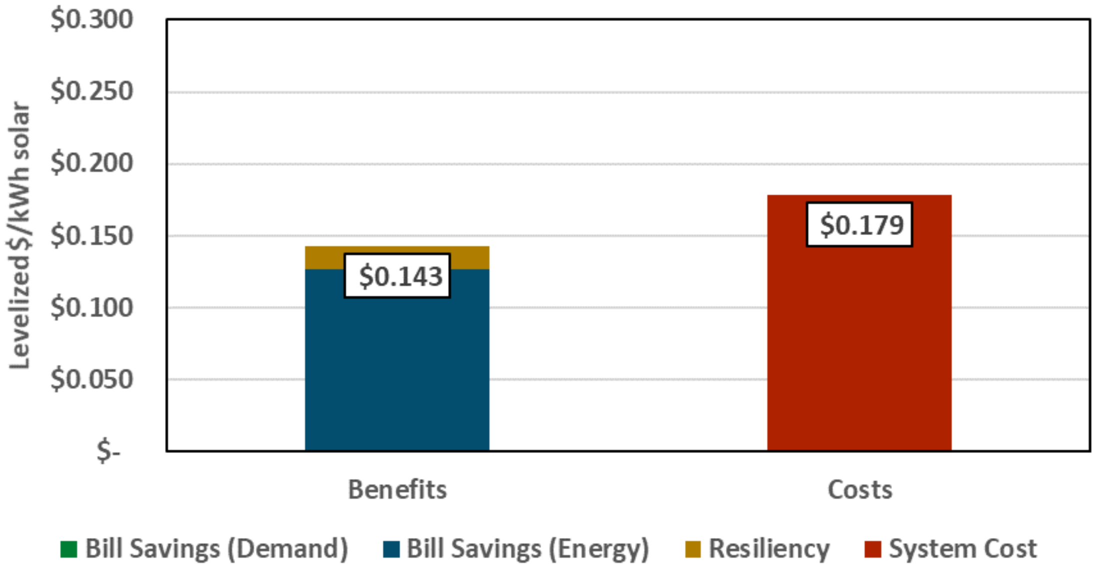

Figure 43. Solar Customer Benefits and Costs, Solar + Storage (Utility Dispatch), GUS_M, 2025 Installations

5. GridSME Reliability Analysis

GridSME conducted an analysis of the reliability impacts of customer solar and solar + storage NEM systems in SMUD's service territory. The analysis was conducted over the ten-year study period of 2020-2030. The key objective was to assess whether customer solar systems have benefit or cost impacts on the transmission and primary distribution system and to quantify those annually and cumulatively. The analyses were performed on the transmission system and the distribution system as aggregated up to the 69 kV and 21 kV level.

5.1. GridSME Assumptions and Methodology

GridSME obtained a GE positive sequence load flow (PSLF) base case from SMUD to use as a starting point for this analysis. This case was developed from the WECC heavy summer peak case updated by SMUD with the most updated SMUD information including summer 2020 peak load, generation levels and approved transmission projects with in-service dates before summer 2020. Therefore, this case represents a heavy summer generation dispatch; transmission system topology and distribution system aggregated up to the 69 kV and 21kV level; and load forecast for Year 2020 in SMUD's area. To enable scaling of the incremental customer solar systems over the study period, they were disaggregated from the load and modeled as distinct resources within SMUD's distribution planning areas (DPAs).

Next, new base and scenario cases were developed. The "solar only" scenario base cases were developed by scaling the customer solar outputs to reflect the cumulative output projected for each study year based on previous PV study projections. For the solar + storage scenarios, two sensitivities were applied. The first sensitivity was the effect on the grid when the customer controls the dispatch of their own customer solar system in response to Time of Use (TOU) rates. This was modeled for each year based on production curves obtained from E3's "customer dispatch" analysis. The second sensitivity was the effect when SMUD controls the dispatch of the customer's customer solar system based on signals from SMUD operators intended to maximize value for all ratepayers. This was modeled based on production curves produced by E3's "utility partnership" analysis. Altogether, forty-four cases were developed, including eleven control base cases. The control base cases did not include new customer solar systems beyond 2020 and were developed for comparison against the thirty-three scenario cases. Table 23 provides a description of the scenario base cases developed.

Table 23. GridSME Study Scenarios (2020-2030)

Study Year	Scenario	Base Case Description
2020	Solar only	SMUD 2020 load forecast; existing customer solar systems.
2020	Solar + Storage: Customer Dispatch	SMUD 2020 load forecast; customer solar systems dispatched by customer (E3 production curve).
2020	Solar + Storage: Utility Partnership	SMUD 2020 load forecast; customer solar systems dispatched by utility (E3 production curve).
:	:	:
2030	Solar only	SMUD 2030 load forecast; projected 2030 solar output.
2030	Solar + Storage: Customer Dispatch	SMUD 2030 load forecast; 2030 customer solar systems dispatched by customer (E3 production curve).
2030	Solar + Storage: Utility Partnership	SMUD 2030 load forecast; 2030 customer solar systems dispatched by utility (E3 production curve).

Once the scenario base cases were developed for each study year, analyses were completed based on NERC Reliability Standards for transmission planning under normal system conditions. The same criteria were applied to the aggregated distribution system by assessing whether any voltages, lines or transformers exceeded their ratings. Each of the base cases was assessed under normal operating conditions and no outages were taken.

5.2. GridSME Assessment Results

GridSME organized the results of the reliability analysis to align with the value components of the greater value of solar study for which these results serve as input. The two value components assessed in this analysis are voltage/power quality and reliability. Voltage and power quality were assessed based on NERC Reliability standards which require that under normal operating conditions, all voltages shall not be lower than 0.95 per unit or higher than 1.05 per unit. Any bus voltages violating this standard were documented in the results table. Reliability was assessed based on NERC Reliability Standards which require that flows through lines and transformers shall not exceed their normal facility ratings under normal operating conditions. Any lines or transformers violating this standard were also documented and are discussed below.

Voltage/Power Quality Results

Voltage and power quality were assessed based on whether all monitored buses were within their parameters as defined in the power flow base cases. Table 24 shows bus voltages under all three scenarios for each study year.

Table 24. Monitored SMUD T&D Bus Voltages Under Normal System Conditions[52]

Study Year	Solar Only		Solar + Storage Customer Dispatch		Solar + Storage Utility Partnership	
	V<0.95	V>1.05	V<0.95	V>1.05	V<0.95	V>1.05
2020	-	1	-	-	-	1
2021	-	1	-	-	-	1
2022	-	1	-	-	-	1
2023	-	1	-	-	-	-
2024	-	1	-	-	-	-
2025	-	1	-	-	-	-
2026	-	1	-	-	-	-
2027	-	1	-	-	-	-
2028	-	1	-	-	-	-
2029	-	1	-	-	-	-
2030	-	-	-	-	-	-

An analysis of the voltages in Table 24 reveals that the addition of customer solar systems over time has a minimal effect on voltages and power quality in SMUD's service territory. All SMUD buses at the transmission and aggregated distribution level were monitored. None of the monitored buses showed low voltages under 0.95 per unit in the starting base case and under any of the scenario base cases. This indicates that the addition of customer solar systems helps to balance voltages during the study period. Therefore, there were no issues with lack of reactive support. The load growth as forecasted over the study period is consistently larger relative to the customer solar output under all scenarios, therefore the impacts of the customer solar systems appear minimal and any impacts are seen in later years.

In the solar only scenarios, one bus voltage was slightly high at 1.05 per unit. This bus voltage decreased slightly over time and was reduced to within its parameters by 2030 as the addition of solar only BTM systems was small relative to load growth over the same period. Under the solar + storage scenario when customers control the dispatch, all voltages were within their parameters. The solar + storage, utility partnership scenarios show one bus that has a slightly high voltage. As the customer solar systems grew over time so did the load; therefore, this bus voltage decreased and was within parameters by 2023 and remained so for the duration of the study period.

Reliability Results

Reliability was determined by assessing whether any lines or transformers at the transmission and aggregated distribution level had flows through them that were in excess of their normal or continuous

[52] Distribution buses included 69 kV and 21 kV substations only.

ratings as defined in the power flow base case. Table 25 shows line and transformer flows under all three scenarios for each study year.

Table 25. Monitored SMUD T&D Line and Transformer Flows Under Normal System Conditions[53]

Study Year	Solar Only		Solar + Storage Customer Dispatch		Solar + Storage Utility Partnership	
	Line loading >99%	Transformer loading >99%	Line loading >99%	Transformer loading >99%	Line loading >99%	Transformer loading >99%
2020	-	-	-	-	-	-
2021	-	-	-	-	-	-
2022	-	-	-	-	-	-
2023	-	-	-	-	-	-
2024	-	-	-	-	-	-
2025	-	-	-	-	-	-
2026	-	-	-	-	-	-
2027	-	-	-	-	-	-
2028	-	-	-	-	-	-
2029	-	-	-	-	-	-
2030	-	-	-	-	-	-

Table 25 shows the results of the power flows through the lines and transformers at SMUD's transmission and aggregated distribution level. Similar to the results observed for bus voltages, the impact of customer solar systems on power flows is also minimal. This is because the customer solar systems are dispersed and relatively small compared to the loads. Although there were slight fluctuations in power flows observed in the scenario base cases, these were driven by load growth rather than by customer solar system growth. As the impacts of load growth are outsized compared to the impacts of customer solar systems growth over the ten-year study period, no discernable reliability benefit or cost could be attributed to customer solar systems.

Other system impacts that were observed in addition to the voltage/power quality and reliability value components were the relative changes in power flows and system losses. As shown above in Table 25, power flows were minimally impacted by customer solar system additions, however, small fluctuations were observed in power flows as loads were served by customer solar systems and this caused a slight reduction in overall system losses. Table 26 below shows that when system losses are compared for the scenario base cases against the comparison cases where new customer solar systems are not modeled beyond 2020, system losses are reduced over time and the change in losses accrues to average about 5

[53] Distribution transformer flows monitored were through 69 kV and 21 kV transformers only.

percent by 2030. This benefit is incorporated in E3's economic assessment of avoided line losses (see *Reduction in Line Losses* section).

Table 26. Change in SMUD System Losses Under Normal System Conditions

Study Year	Solar Only		Solar + Storage Customer Dispatch		Solar + Storage Utility Partnership		Average Delta in Losses
	Losses (MW)	Delta w/ no new customer solar (%)	Losses (MW)	Delta w/ no new customer solar (%)	Losses (MW)	Delta w/ no new customer solar (%)	Across all Scenarios (%)
2020	28.59	-3.15%	29.02	-2.25%	29.07	-2.07%	-2.49
:							
2030	29.55	-5.72%	29.66	-5.33%	30.00	-4.13%	-5.06

5.3. GridSME Conclusion

GridSME analyzed the reliability and voltage/power quality value components as impacted by customer solar systems on SMUD's transmission and distribution system as aggregated up to the 69 kV and 21 kV level. The results reveal that the impacts on power flow are minimal as the effects of load growth are outsized relative to the effects of customer solar system growth. In addition to the magnitude being small compared to load, customer solar systems are also dispersed throughout the service territory, and there is therefore not enough aggregation or a high enough penetration in any one DPA to result in a significant impact. customer solar systems do provide support to the system, and while there are immaterial fluctuations in power flows, these result subsequently in the reduction of overall system losses over time.

6. Conclusion

The E3 team conducted this analysis of customer solar and solar + storage systems in SMUD's service territory to calculate the value provided from three different perspectives: SMUD ratepayers, society, and solar customers. In order to assess the range of potential values provided by these systems, E3 considered two distinct valuation scenarios to serve as bookends.

In one scenario customer solar installations are considered as helping to achieve clean energy goals specified by SMUD's Board of Directors, enabling SMUD to procure less utility-scale clean energy resources. The alternate scenario considers customer solar installations as providing incremental clean energy beyond SMUD's goals, in effect displacing marginal purchases of natural gas.

The E3 team found that customer solar and solar + storage under net energy metering is not cost-effective from the perspective of SMUD ratepayers. The value provided by these solar systems ranges between $0.03 - $0.07 per kWh in 2020 depending on how they are valued against other SMUD resources. The cost of compensation paid to NEM customers is approximately $0.12 per kWh, resulting in a net cost to other SMUD ratepayers of approximately of $0.05 to $0.09 per kWh. This is equivalent to an annual cost to SMUD ratepayers in 2020 of between $24 and $41 million. Absent a change in SMUD's rate designs, by 2030 this annual cost is anticipated to grow to approximately $91 million. Partnership between solar + storage customers and SMUD to dispatch these systems to increase their value for all SMUD ratepayers helps to reduce this net cost – for example, lowering the 2030 annual figure from $91 million to $78 million – however, a sizeable cost to non-solar customers remains.

The cost-effectiveness of customer solar and solar + storage systems from the perspective of customers adopting this technology varies by customer type. Solar only systems are cost-effective for many customers, while solar + storage systems generally are not. This dynamic could change if technology costs fall or retail electricity rates rise more rapidly than anticipated.

From a societal perspective, customer solar and solar + storage systems provide additional value beyond that which accrues directly to SMUD ratepayers. In the *Helps Meet Clean Energy Goals* scenario, customer systems displace utility scale renewables and therefore help to reduce land use. E3 has estimated a value for this avoided land use of approximately $0.004/kWh.

In the *Incremental Clean Energy* scenario customer systems are instead viewed as displacing natural gas generation, reducing carbon emissions beyond SMUD's compliance requirements while also reducing fugitive methane emissions, criteria emissions, and water usage. The estimated societal value of these components, especially carbon emissions, varies broadly across sources. E3 estimates that the societal carbon value provided by customer solar systems in this scenario ranges from $0.018/kWh up to $0.072/kWh. Avoided criteria pollutants are estimated to have a value of approximately $0.008/kWh. Avoided water usage is estimated at up to $0.001/kWh, while the value of avoided fugitive methane emissions is estimated at considerably less than $0.001/kWh.

While this range of societal values can be provided by customer solar and solar + storage, 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. This type of analysis is beyond the scope of this report and is best conducted as part of a comprehensive utility planning process such as an Integrated Resource Plan.

7. Appendix

7.1. RESTORE Model

As the market for energy storage (ES) assets has emerged, E3 developed the RESTORE tool[54], which simulates optimal operation over the life of different types of ES assets. The core "engine" of the tool is a price-taker optimal dispatch algorithm, which identifies the profit-maximizing operation pattern for the ES facility given its size and performance characteristics, the revenue streams to which it has access, the market in which it is expected to operate, and a forecast of the applicable market prices for the services the ES asset will be providing (i.e., behind-the-meter bill savings or front-of-meter energy, capacity, regulation, reserves, resource adequacy prices, etc.). The tool is quite flexible in the types of ES asset types that can be evaluated (e.g., lithium-ion, flow, pumped hydro, etc.) and it has been used for variety of purposes such as analyzing ES operational patterns and estimating lifecycle market revenues for developers, asset owners, and potential investors.

E3's RESTORE tool can dispatch both stand-alone storage and solar plus storage with co-optimization of multiple value streams by a mixed-integer linear programming (MILP) algorithm. Value streams can include system-level avoided costs, distribution avoided costs, ancillary services, customer demand charges, energy charges, and back-up power reliability values. The tool can be dispatched in customer or utility control mode. In customer control mode, the storage is dispatched to maximize customer revenue: reduce bills, increase back-up power reliability values, and increase ancillary services revenue if customers have access to AS markets. In utility control mode, storage is dispatched to reduce system costs.

The tool outputs hourly and annual dispatch and operational data, value streams and avoided costs.

[54] For more information on the RESTORE model please see https://www.ethree.com/tools/restore-energy-storage-dispatch-model/.