Memorandum

TO: MAGGIE DOWNEY AND AUSTIN BRANDT, CAPE LIGHT COMPACT

FROM: ERIN MALONE AND DANIELLE GOLDBERG

DATE: OCTOBER 23, 2018

RE: SOLAR COST-EFFECTIVENESS ANALYSIS FOR 2019–2021 PLAN

Contents

1. Executive Summary

In preparation for the 2019–2021 Three-Year Energy Efficiency Plan, the Cape Light Compact (CLC or Compact) is investigating the cost-effective use of energy efficiency funding to better optimize customer energy use. Synapse Energy Economics, Inc. (Synapse) conducted a benefit-cost analysis of offering incentives for distributed solar photovoltaic (PV) to residential, income eligible, and small commercial customers on Cape Cod and Martha's Vineyard. Figure 1 summarizes the total costs and benefits of residential solar from our analysis. Every dollar spent on solar results in $1.91 in benefits, indicating it is cost-effective to incent and install PV systems on Cape Cod and Martha's Vineyard. Table 1 summarizes key cost-effectiveness results and analysis outputs.

Figure 1. Solar benefit-cost results

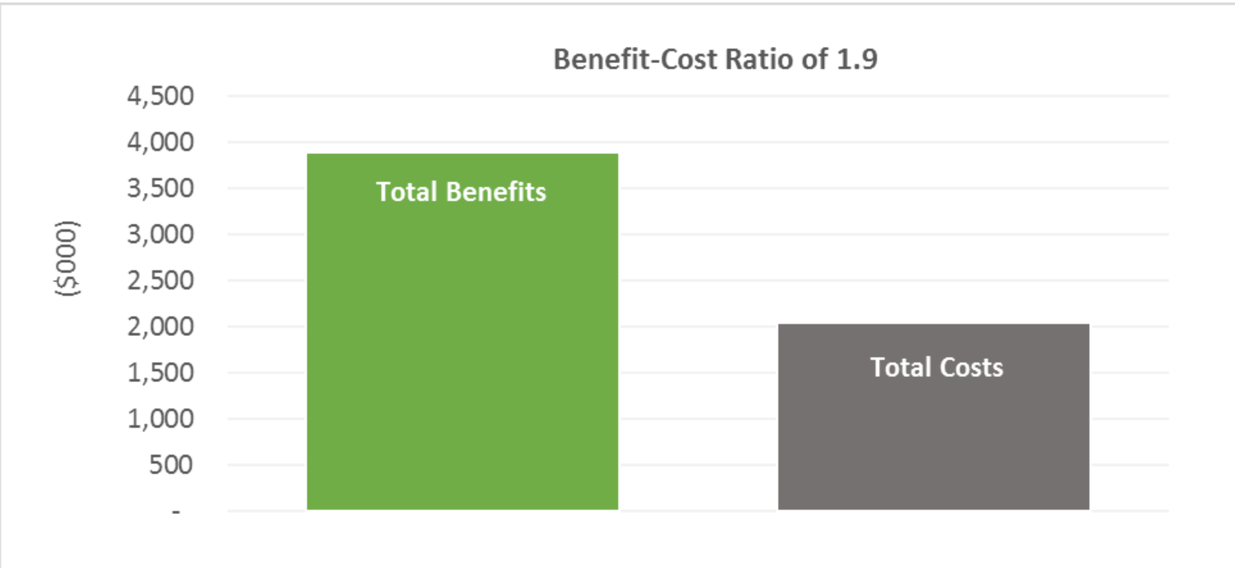

Table 1. Residential cost-effectiveness results

Results	Units	Value
Cost-Effectiveness		
Total Costs	*$000*	2,042
Total Benefits	*$000*	3,895
Net Benefits	*$000*	1,853
BCR	***ratio***	**1.91**
PV Generation		
Annual Energy	*MWh*	414
Lifetime Energy	*MWh*	10,353
Summer Capacity	*kW*	320
Costs		
Program Costs	*$000*	878
Cost of saved Summer Capacity	*$/kW*	2,747

2. Introduction

In preparation for the 2019–2021 Three-Year Energy Efficiency Plan, the Cape Light Compact is investigating the cost-effective use of energy efficiency funding to better optimize customer energy use. Optimization strategies would build off the Compact's existing successful energy efficiency programs. Those under consideration include technologies and services related to demand response, energy storage, and renewable energy generation.

The Compact engaged Synapse to conduct a benefit-cost analysis of offering incentives for distributed solar PV to residential, income eligible, and small commercial customers on Cape Cod and Martha's Vineyard. This memo summarizes Synapse's research, methodology, and results regarding the cost-effective analysis of distributed PV.

3. Background and Purpose

Distributed PV can offer the utility system, customers, and society a host of benefits, ranging from avoided energy and capacity costs to reduced environmental impacts. A cost-benefit analysis in which all relevant costs and benefits are quantified and analyzed is essential to determine the value of solar to the utility system and all electricity customers in Massachusetts.

Unlike energy efficiency resources that use less energy than baseline products, distributed PV generates electricity and thereby reduces the amount of utility scale generation required to serve load. From a utility system-perspective, distributed PV can be viewed as a reduction in load requirements.

The Cape Cod and Martha's Vineyard region has areas with distribution infrastructure constraints and customers in these areas are installing distributed PV at increasing rates. Additional renewable generation can provide benefits to all customers by aligning customer-sited sources of energy with peak load hours.

On August 9, 2018, Governor Baker signed into law An Act to Advance Clean Energy (AACE). AACE provides that an energy efficiency plan may include "programs that result in customers switching to renewable energy sources or other clean energy technologies."[1]

Consistent with the AACE, the Compact would like to offer incentives for distributed PV to an initial set of its residential, income eligible, and small commercial customers. The Compact is in the beginning stages of investigating the implementation of such a program, and program design details are still in development. We suspect the results of this cost-effectiveness analysis will further inform the Compact's program implementation decisions. Ultimately the Compact will propose for the Department of Public Utilities' (DPU or Department) approval a cost-effective distributed PV demonstration offering

[1] An Act to Advance Clean Energy, Bill H.4857, §4. Available at: https://malegislature.gov/Bills/190/H4857.

as part of its 2019–2021 Plan to be filed with the DPU in October 2018. This analysis is intended to support the cost-effectiveness of such an offering.

4. Total Resource Cost test

Synapse developed an Excel model to screen distributed PV for cost-effectiveness using the Massachusetts Total Resource Cost (TRC) test used to screen energy efficiency programs. Table 2 lists the benefits and costs that were considered and analyzed for this study, although not all costs or benefits are included in the results, as explained throughout this memo.

Table 2. Distributed solar Total Resource Cost test costs and benefits

Utility System Impacts	
Costs	PV system installation incentives Program administration Marketing Technical assistance Evaluation System integration System interconnection Loan interest
Benefits	Avoided energy Avoided RPS compliance Energy price suppression (DRIPE) Electric cross price suppression (DRIPE) Electric GWSA compliance Avoided capacity Capacity price suppression (DRIPE) Reliability Avoided transmission Avoided distribution Avoided T&D line losses Non-energy benefits
Participant Impacts	
Costs	PV system installation Application fee Annual maintenance
Cost Reductions	SMART program Federal tax credit State income tax credit
Benefits	Non-energy benefits

AACE stipulates that cost-effectiveness be determined at the customer sector level.[2] The Compact anticipates its solar offering will be contained within its programs for the residential, income eligible, and commercial and industrial (C&I) customer sectors. For the sake of this analysis, we have isolated all the costs and benefits from solar to determine cost-effectiveness on a measure-level basis.

5. Program Design

Overview

The Compact is still investigating and developing a solar program. Our assumptions are based on the best information available at the time we drafted the analysis. Many of the numbers and assumptions are subject to change as the Compact further details its offering.

Our analysis only focused on 2019 installation for the sake of limiting its scope. We expect the results can be extrapolated to 2020 and 2021 with minor modifications, such as adjusting PV system incentives and avoided costs.

We assume solar installers will continue to serve customers and install the solar panels. The Compact will simply provide an incentive and/or the HEAT Loan to customers to overcome the upfront costs of installing solar.

Target Customers

The Compact is investigating offering solar to residential, income eligible, and small commercial customers. This analysis focuses on residential customers only. The Excel model accompanying this memo can be adjusted to reflect results for income eligible and small commercial customers.[3]

We assume the Compact will serve 45 residential customers in 2019, which includes moderate-income, extended moderate-income, and market rate customers. We understand the Compact intends to ramp enrollment over the course of the three-year term. Table 3 summarizes planned participants by each residential customer group.

Table 3. Planned residential participants

Residential Customer Groups	2019	2020	2021	2019-2020
Moderate-Income	15	60	100	175
Extended Moderate-Income	15	60	100	175
Market Rate	15	60	100	175
Total Residential	**45**	**180**	**300**	**525**
Low-Income	15	60	100	175
Total Residential and LI Customers	**60**	**240**	**400**	**700**

[2] An Act to Advance Clean Energy, Bill H.4857, §6. Available at: https://malegislature.gov/Bills/190/H4857.

[3] Adjusting the model for income eligible customers produces similar cost-effectiveness results as residential customers.

Distributed PV system

The average PV system size in our analysis is 7.4 kilowatts (kW) DC. We derived this value using Massachusetts Clean Energy Center solar data for residential PV system installed on Cape Cod in 2017.[4] We assume the PV system produces 7.1 kW AC (96 percent DC to AC derating), has a 14 percent annual capacity factor, and generates about 9,200 kilowatt hours (kWh) per year for 25 years.

6. Cost Assumptions

Distributed PV system participant costs

Using the same Massachusetts Clean Energy Center solar data used for the PV system size, we calculated the weighted average cost per kW of installed PV, which is $4.14 per kW DC.[5] For our average residential 7.4 kW PV system, this results in total purchase and installation costs of about $31,000 per system.

We assume the customer's annual maintenance cost are $150 per year.[6] This assumption is meant to approximate maintenance costs over the life of the PV system. A customer is unlikely to incur $150 in expenses every year, because actual maintenance costs will vary annually, and may be zero for many years.

We assume the PV system is small enough to not require additional fees, such as for interconnection or for applying to the net metering cap.

Distributed PV system utility costs

Eversource could incur costs as greater volumes of solar PV operate on its electric distribution system. Specifically, Eversource could experience interconnection costs (customer-specific costs for interconnecting a solar facility to the distribution grid) and integration costs (costs for upgrading the distribution grid to account for the generation of the distributed solar facility). We researched industry average values to incorporate into our benefit-cost analysis but could not identify relevant sources. As a placeholder, and without better information available at this time, we guessed $1,000 per PV system for system interconnection and $1,000 per PV system for system integration costs.

[4] Massachusetts Clean Energy Center, Production Track System Data and Reports, filtered to residential facilities in the Compact's cities for 2017 as of August 31, 2018. Available at: http://www.masscec.com/data-and-reports

[5] The 2017 weighted average cost to install PV was $3.99, which we adjusted to 2019 dollars.

[6] Home Advisory, "How Much Does it Cost to Clean and Maintain Solar Panels?" Available at: https://www.homeadvisor.com/cost/cleaning-services/solar-panel-maintenance/

TRC costs

Market rate and extended moderate-income customers are likely to qualify for state and federal tax credits for solar installations (discussed below). We consider their upfront costs to be the cost of the PV system purchase and installation less the state and federal tax credits.

Low-income and moderate-income customers are less likely to qualify for state and federal tax credits. Therefore, their TRC costs are the cost of the PV system purchase and installation.

Table 4 summarizes our TRC assumptions for each residential customer group. These costs reflect the cost for the PV system only. The customer's annual maintenance costs and the utility's system costs are also incorporated into the benefit-cost analysis.

Table 4. Planned TRC costs for residential customers

Residential Customer Groups	PV Cost	Federal Tax Credit	State Tax Credit	TRC Cost
Low-Income	$30,760	$0	$0	$30,760
Moderate-Income	$30,760	$0	$0	$30,760
Extended Moderate-Income	$30,760	$9,228	$1,000	$20,532
Market Rate	$30,760	$9,228	$1,000	$20,532

Incentives

For market rate and extended moderate-income customers, the Compact intends to offer zero interest financing through the HEAT Loan used for energy efficiency measures. In this way the customer's costs are reduced, although this does not impact cost-effectiveness using the TRC test. For a customer who borrows the HEAT Loan maximum of $25,000 at a six percent interest rate for seven years, interest over the life of the loan is about $6,000.

For extended moderate-income customers, the Compact intends to offer a $5,000 incentive in addition to the HEAT Loan. For low-income customers, the Compact intends to offer a 100 percent incentive for the PV system purchase and installation. Table 5 summarizes incentives for each residential customer group.

Table 5. Planned incentive costs for residential customers

Residential Customer Groups	Incentive Cost	HEAT Loan
Low-Income	$30,760	n/a
Moderate-Income	$5,000	Yes
Extended Moderate-Income	$0	Yes
Market Rate	$0	Yes

Program costs

The Compact's cost to implement a solar program include customer incentives as discussed above, program administration and implementation, marketing, technical assistance, and evaluation. The administration, marketing, and technical assistance costs we assume will be roughly consistent with the Compact's cost for implementing its storage program. Evaluation costs are equal to administration costs.

In the model, all program-level costs can be adjusted to reflect sector-specific allocations of the total program costs. We assume 75 percent of the costs will be associated with the residential offering.

7. Benefit Assumptions

Solar provides benefits from avoiding energy, capacity, transmission, and distribution costs. Energy benefits include avoided energy costs, avoided Renewable Portfolio Standard (RPS) compliance costs, energy price suppression effects (DRIPE), cross DRIPE,[7] and avoided costs of complying with the Global Warming Solutions Act (GWSA).[8] Capacity benefits include the avoided capacity costs, capacity DRIPE, and improved reliability. Avoided energy costs include avoided line losses.

For the energy, capacity, and transmission benefits, we relied on the avoided cost values provided in AESC 2018.[9] While AESC estimates avoided costs from energy efficiency resources, we assume the values are within a reasonable range for the value of solar because we are assuming projects that primarily act as load reducers.

Avoided distribution costs are consistent with the Compact's 2016-2018 Planned avoided distribution costs, provided by Eversource. If Eversource can work with the Compact to reliably target those areas with distribution constraints, the average avoided distribution costs used in our model are too low and understate the benefits.

We assume participants and the utility system experience additional non-energy benefits from greater solar installations. While such values are likely non-zero, to be conservative we have not entered non-energy benefits into our analysis.

The Compact provides competitive supply rates to customers on Cape Cod and Martha's Vineyard. The Compact's wholesale supplier relies on average customer load profiles published by Eversource to settle load. The Compact's power supply contracts could be impacted by changes in customer load profiles from greater solar penetration. We suspect customers in the Compact's service territory would need to

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[7] Cross DRIPE measures the impact that a reduction in one commodity (i.e., electricity or natural gas) has on a different commodity. Electric-to-gas cross DRIPE measures the benefits to gas consumers from a reduction in electricity demand. Electric power accounts for 1/3 of the region's gas demand, so reducing electricity demand should reduce gas prices. See Synapse Energy Economics, "Avoided Energy Supply Costs in New England," June 1, 2018, at 185. Available at: http://www.synapse-energy.com/project/avoided-energy-supply-costs-new-england

[8] The user also has the option to include avoided non-embedded environmental costs, but such benefits are not included in our analysis. DRIPE stands for demand reduction induced price effects.

[9] Synapse Energy Economics, "Avoided Energy Supply Costs in New England," June 1, 2018. Available at: http://www.synapse-energy.com/project/avoided-energy-supply-costs-new-england

install significant levels of solar before the average load profile would be materially impacted. Therefore, we did not consider this benefit as part of our analysis.

8. PV System Incentives

Distributed PV is an expensive voluntary endeavor for an individual customer to undertake. Without incentives to overcome market barriers, customers would face significant financial hurdles to installing solar PV systems. As a result, there are multiple incentives available to customers to motivate solar installations. In this section, we discuss each incentive policy and explain how we treated the policy's impacts within the cost-effectiveness analysis.

Treatment of PV system incentives in analysis

We struggled with how best to treat incentive costs in our cost-effectiveness analysis. For efficiency measures, the total resource cost of a measure represents the incremental cost of an efficient technology relative to a baseline, non-efficient technology. For example, if a baseline furnace costs $10,000 and a more efficient furnace costs $12,000, then the incremental cost is $2,000. The incremental $2,000 is the total resource cost in the TRC test. A Program Administrator such as the Compact pays a portion of the incremental cost as an incentive to the customer to install the more efficient technology, and the customer pays the remaining balance. Both the Program Administrator and customer portions of the incremental costs are included in the Massachusetts Total Resource Cost test.

For distributed PV, there is no baseline technology to compare the cost of the distributed PV. With a theoretical application of the TRC test, the full cost of installation and maintenance of distributed PV are included in the TRC test. Incentives in the form of tax credits or other rebates motivate participation by reducing the customer's costs, but do not reduce the cost to install the distributed PV.

However, Massachusetts' policy indicates an alternative approach to customer incentives. The DPU was previously asked by the River Run Condominium Trust to rule that "in calculating the cost-effectiveness of a renewable energy project, distribution companies should calculate the net cost of project equipment by deducting the amount of the tax credit, rather than using its 100 percent initial cost."[10] The DPU determined:

> Although tax credits represent transfer payments from taxpayers to energy efficiency programs, the resulting liability constitutes a societal cost outside the scope of the Total Resource Cost Test. Because societal costs and benefits are excluded from the Total Resource Test, it is both proper and consistent to exclude the societal consequences of tax credits as well. Therefore, the Department finds that River Run's proposal to interpret "net cost of energy efficient equipment" from Section 3.2.3 of the Guidelines

[10] Massachusetts Department of Public Utilities, "Petition of River Run Condominium Trust for ruling on whether tax credits may be included in determining the net cost of energy efficient equipment under the guidelines for Energy Efficiency Programs, as approved in D.T.E. 98-100 and established by G.L. c. 25, § 19," July 9, 2008, D.P.U. 07-49, at 2.

as incorporating tax credits in benefit-cost analyses is consistent with the Department's interpretation and application of the Total Resource Cost Test.[11]

The National Standard Practice Manual (NSPM) provides guidance on this issue.[12] One of the NSPM's six universal principles states that "a jurisdiction's primary cost-effectiveness test should account for its energy and other applicable policy goals and objectives. These goals and objectives may be articulated in legislation, commission orders, regulations, advisory board decisions, guidelines, etc., and are often dynamic and evolving."[13]

Based on Massachusetts precedent and the NSPM, we have treated tax credits as a reduction in costs to the customer. However, the model user has the option to adjust whether any PV system incentive reduces costs.

Net metering

Policy

In Massachusetts, customers who generate electricity qualify for net metering. Net metering allows customers to offset their electric usage with energy they generate. Meters can track whether electricity is drawing from the grid or if electricity is exporting to the grid. If a customer imports more electricity than they export, the difference will appear in the form of a reduced electric bill. If a customer exports more electricity than they import, they will earn net metering credits. Facilities can generate net metering credits for 25 years from the date of interconnection.[14]

Along with most other renewable technologies, solar facilities must apply to net meter under a capacity cap. The cap stipulates the amount of resources that can net meter at a given time within each utility, based on the sum of their capacities. To receive net metering credits, a facility must be approved under the cap. Facilities that are exempt from the cap are those with a nameplate capacity less than 10 kW on a single-phase circuit or 25 kW on a three-phase circuit. Cap exempt facilities can net meter even if the relevant cap is full. Utilities implement net metering caps on private and public generation facilities. The caps are a percentage of the highest historical peak load, with the private cap set at 7 percent and the

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[11] Massachusetts Department of Public Utilities, "Petition of River Run Condominium Trust for ruling on whether tax credits may be included in determining the net cost of energy efficient equipment under the guidelines for Energy Efficiency Programs, as approved in D.T.E. 98-100 and established by G.L. c. 25, § 19," July 9, 2008, D.P.U. 07-49, at 11-12.

[12] The NSPM is a publication of the National Efficiency Screening Project (NESP), a group of organizations and individuals working to update and improve the way that utility customer-funded electricity and natural gas energy efficiency resources are assessed for cost-effectiveness and compared to other resource investments. The NSPM provides a comprehensive framework for assessing the cost-effectiveness of energy efficiency resources. It incorporates lessons learned over the past 20 years, responds to current needs, and addresses the relevant policies and goals of each jurisdiction undertaking efficiency investments.

[13] National Efficiency Screening Project, "National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources," May 18, 2017, at viii, available at: https://nationalefficiencyscreening.org/wp-content/uploads/2017/05/NSPM_May-2017_final.pdf

[14] Mass.Gov, "Net metering guide." Available at: https://www.mass.gov/guides/net-metering-guide

public cap set at 8 percent. Eversource (NSTAR) has a private cap of 350 megawatts (MW) and a public cap of 400 MW.[15]

Solar net metering credits are unique to other renewable distributed sources because of regulations that went into effect in 2017. For renewable resources other than solar and for solar projects that received a cap allocation before January 8, 2017, customers are compensated for 100 percent of the excess energy they produce. However, for solar net metering facilities that received a cap allocation after January 8, 2017, customers are only compensated for 60 percent of the energy produced beyond their electric bill. The distribution company calculates credits by multiplying 60 percent of the excess energy produced by the local basic service charge, the distribution charge, the transmission charge, and the transition charge, all on a per unit of energy basis (kWh).[16]

Modeling assumptions

In our cost-effectiveness analysis, we were careful to avoid double counting avoided energy costs and reduction in customer load. We assume a customer's reduction in load from solar generation is akin to reductions in load from installing energy efficiency measures. For efficiency, the Program Administrators use adjusted wholesale prices to calculate avoided energy costs. The participant's bill reductions are not accounted for, because doing so would double count the avoided energy costs. Similarly, we assume the energy benefits from solar account for the customer's net bill reduction.

For excess generation, we assume PV systems are sized roughly equal to or less than a customer's load on an annual basis. While this may not be true for every month, especially in the summer when a customer generates more solar energy, we assume it nets out over the course of a year.

Therefore, we do not include any impacts from net metering in our cost-effectiveness analysis.

We do, however, include calculations to estimate net metering credits in our modeling. This allows the user to see the extent of the credits, and the calculations are required to determine the SMART program incentives as discussed below.

SMART program

Policy

Historically, Massachusetts incented customers to install solar power through the Solar Carve-Out and Solar Carve-Out II programs. Customers enrolled in this program earn Solar Renewable Energy Certificates (SRECs) for each megawatt hour (MWh) produced from solar and sell them in a competitive

[15] Mass.Gov, "Net metering guide." Available at: https://www.mass.gov/guides/net-metering-guide

[16] Department of Public Utilities, 220 CMR 18, "Net Metering." Available at: https://www.mass.gov/files/220_cmr_18.00_final_12-1-17_1.pdf

SREC market. While this market will continue for existing solar producers, we assume enrollment in the SREC program is no longer an option for new solar installations.[17]

Instead, when the Compact's solar program begins implementation, we assume new Massachusetts solar customers will receive incentives through the SMART program.[18] Under this program, customers are incented through a fixed compensation rate per kWh of solar produced. A portion of the rate is based on the value of energy (as calculated by formula), and a portion is based on the incentive rates in the SMART program. Customers earn the compensation rate for a set period, typically 10 or 20 years, depending on the customer type and PV system.

Customer enrollment in the SMART program is managed in capacity blocks, each consisting of 200 MW of statewide solar capacity. There are eight blocks in total and 1,600 MW for the entire SMART program across blocks and utilities. Eversource's NSTAR territory has 91.5 MW of solar capacity in each of the eight blocks.[19]

The SMART compensation rate varies depending on several factors. The compensation rate varies depending on the customer type and size of the PV system. As more customers enroll in the program, the compensation rate decreases. Customers in the first block will have higher compensation rates than customers in the second block, and so on. Finally, each utility has distinct compensation rates for their service territory.

Table 6 shows Eversource's SMART compensation rates for the first capacity block by customer class and PV system size.[20] With the exception of income eligible customers, compensation rates decrease as system size increases.

As an example, a residential customer participating in the first block with an 8 kW PV system in Eversource's territory would be compensated a total of $0.34 per kWh of solar generated. However, the $0.34 per kWh includes the value of energy, which would be experienced as bill reductions, and the remainder would be a separate incentive provided through the SMART program.

[17] EnergySage, "Solar Massachusetts Renewable Target (SMART) Massachusetts' SREC II replacement program." Available at: https://news.energysage.com/solar-massachusetts-renewable-target-smart-massachusetts-srec-replacement-program/

[18] The DPU approved the SMART tariff with modifications on September 26, 2018.

[19] DOER, "Solar Massachusetts Renewable Target (SMART) Program Summary," April 26, 2018, slide 9. Available at: https://www.mass.gov/files/documents/2018/04/26/SMART%20Program%20Overview%20042618.pdf

[20] EnergySage, "Solar Massachusetts Renewable Target (SMART) Massachusetts' SREC II replacement program." Available at: https://news.energysage.com/solar-massachusetts-renewable-target-smart-massachusetts-srec-replacement-program/

Table 6. Eversource (NSTAR) SMART Incentives, Block 1

PV System Size	Compensation Term Length	Compensation Rate ($/kWh)
Residential		
Less than or equal to 25 kW	10-year	0.34
Income Eligible		
Less than or equal to 25 kW (low income)	10-year	0.39
Commercial and Industrial		
25 kW – 250 kW	20-year	0.26
250 kW – 500 kW	20-year	0.21
500 kW – 1,000 kW	20-year	0.19
1,000 kW – 5,000 kW	20-year	0.17

In addition to the solar incentive values above, customers can earn additional incentives through compensation adders that reward configurations deemed more valuable. One adder focuses on storage. Solar systems paired with batteries receive an additional benefit per kWh of solar generated. The adder varies primarily based on the ratio of solar capacity to battery storage.[21] Another adder focuses on the customer served. Solar panels providing energy to income eligible customers or to community or municipal buildings may be eligible for adders. Table 7 summarizes the available adders for the different customer types and system configurations.[22]

Like the solar capacity blocks, the adders have capacity tranches that fill as more customers enroll in the program. Each adder will decrease by four percent to the next tranche. The first tranche is 80 MW statewide per adder; the remaining tranches have yet to be quantified.[23]

[21] DOER, "Guideline on Energy Storage". Available at: https://www.mass.gov/files/documents/2018/07/13/Energy%20Storage%20Guideline%20DRAFT%20071318.pdf

[22] DOER, "Guidance on Capacity Blocks, Base Compensation Rates, and Compensation Rate Adders." January 11, 2018.

[23] DOER, "Solar Massachusetts Renewable Target (SMART) Program Summary." April 26, 2018. Available at: http://masmartsolar.com/_/documents/SMART-Program-Overview.pdf

Table 7. SMART Tariff Incentive Adders, Tranche 1

Configuration	Adder ($/kWh)
Energy storage	
Energy storage adder	0.025-0.076[24]
Off-taker based	
Community shared solar tariff generation unit	0.05
Low income property solar tariff generation unit	0.03
Low income community shared solar tariff generation unit	0.06
Public entity solar tariff generation unit	0.02
Solar tracking	
Solar tracking adder	0.01
Location based	
Building mounted solar tariff generation unit	0.02
Floating solar tariff generation unit	0.03
Solar tariff generation unit on a brownfield	0.03
Solar tariff generation unit on an eligible landfill	0.04
Canopy solar tariff generation unit	0.06
Agricultural solar tariff generation unit	0.06

Modeling assumptions

We only considered the SMART tariff and did not consider SRECs because they are no longer available to new solar customers.

We assume SMART credits will not reduce the cost to install solar PV because there is no Department precedent to indicate otherwise. However, our cost-effectiveness model allows the user to include SMART credits as a cost reduction.

The following assumptions are applicable if the user chooses to incorporate SMART credits into the benefit-cost analysis. The net present value of the future stream of SMART incentives offsets up-front PV system costs. We multiplied the annual PV generation by the compensation rate less the net metering rate. We used Eversource's residential block one compensation rate of $0.34 per kWh.[25] The value of energy rate is from DOER's SMART tool.[26] The model user can include assumptions for a battery storage adder as desired.

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[24] EnergySage, "Solar Massachusetts Renewable Target (SMART) Massachusetts' SREC II replacement program." Available at: https://news.energysage.com/solar-massachusetts-renewable-target-smart-massachusetts-srec-replacement-program/

[25] It is possible that by the time the Compact implements a solar program, customers could be enrolling in the second block.

[26] DOER, "SMART BTM Value of Energy Workbook," Eversource, South Shore CC Vineyard, R-1. Available at: https://www.mass.gov/doc/smart-btm-value-of-energy-calculator-0

Federal tax credits

Policy

The Bipartisan Budget Act of 2018 extended federal tax credits for solar power through 2021.[27] The federal government provides a solar tax credit to residential and commercial customers who purchase solar panels. The solar credit, also referred to as the investment tax credit (ITC), deducts a percentage of the total cost of a solar installation from the customer's federal taxes with no cap. The credit may be carried over to subsequent filings if the credit exceeds the federal tax.

The current credit is 30 percent of the upfront PV system purchase and installation costs, however this decreases after 2019. Table 8 lists the available credit by year and sector. Customers can claim the tax credit as soon as system construction is complete.[28]

Table 8. Federal tax credits by year

Year	Sector	Solar credit
2019	Residential and commercial	30%
2020	Residential and commercial	26%
2021	Residential and commercial	22%
2022+	Commercial	10%

Modeling assumptions

We calculated 30 percent of the upfront PV system purchase and installation costs (not including additional fees or annual maintenance costs) and subtracted that value from the upfront PV system purchase and installation costs. Our analysis focuses on 2019, so we did not model the decrease in the credit for each year. The model user can adjust the start year of the analysis and the credit will update accordingly.

State tax credits: residential renewable energy income tax credit

Policy

A residential renewable energy income tax credit is available to any owner or occupant of a residential property. Massachusetts will provide a 15 percent tax credit up to $1,000 for the net expenditure of a renewable energy system. The net expenditure includes the installation costs, but not the costs recovered through federal tax credits and rebates/grants from the U.S. Department of Housing and

[27] Energy.Gov, "Residential Renewable Energy Tax Credit." Available at: https://www.energy.gov/savings/residential-renewable-energy-tax-credit

[28] EnergySage, "Solar tax credit – everything you need to know about the federal ITC for 2018." Available at: https://news.energysage.com/congress-extends-the-solar-tax-credit/

Urban development. The credit is subtracted from the resident's state income tax and may be carried over to subsequent filings if the credit exceeds the income tax.

Technologies that qualify for this credit are photovoltaics, solar water and space heating, and wind energy systems. The technology should be expected to operate for at least five years.[29]

Modeling assumptions

We assume that distributed PV qualifies for the income tax credit. We calculated 15 percent of the net costs up to a maximum of $1,000 and reduced the cost to install PV by that amount. The net costs remove the federal tax credit, but we do not account for any additional rebates or grants in our analysis.

State tax credits: sales and property tax incentives

Policy

Additional tax incentives exist for Massachusetts residents looking to install solar. Equipment directly related to solar is fully exempt from the Massachusetts sales tax. The exemption qualifies that the solar installation is the primary or auxiliary heat or energy source at the customer's main residence.[30] Similarly, the owner does not have to pay property taxes on the installation for 20 years. This can apply to customers in the residential, commercial, industrial, and agricultural sector. Once again, the system must be used as the primary or auxiliary heat or energy source on the property.[31]

Modeling assumptions

We assume the costs used in our analysis, as explained above, do not include sales tax.

We do not account for property taxes in our analysis.

Solar finance loan

Policy

Massachusetts offers fixed interest loans for residential customers who install solar panels. Customers can choose from a list of participating banks or credit unions whose terms and conditions may vary slightly. The loans range between $3,000 and $35,000, with lenders maintaining the option to go as high

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[29] DSIRE, NC Clean Energy Technology Center, "Residential Renewable Energy Income Tax Credit." Available at: http://programs.dsireusa.org/system/program/detail/144

[30] Mass.Gov, "Sales and Use Tax." Available at: https://www.mass.gov/guides/sales-and-use-tax

[31] DSIRE, NC Clean Energy Technology Center, "Renewable Energy Property Tax Exemption." Available at: http://programs.dsireusa.org/system/program/detail/146

as $60,000, and feature 10-year repayment plans at low interest rates. For customers who do not qualify as income eligible, the maximum allowable interest rate is 7.75 percent.[32]

Additional benefits exist for income eligible customers. Customers who qualify as income eligible have a maximum allowable interest rate of 6.25 percent, or 1.5 percent below the market rate charged by the lender. Low- and moderate-income customers may also qualify for income-based loan support. Income eligible customers (defined as below 80 percent of state median income) are eligible for 30 percent loan principal reduction, and moderate-income customers (defined as below 120 percent of state median income) are eligible for 10 percent loan principal reduction.[33]

Modeling assumptions

The Compact proposes to enroll solar customers in the HEAT Loan, which has different financial factors than the solar finance loan, therefore we did not consider the solar finance loan directly. We included the HEAT Loan interest costs as a cost to the Compact in our cost-effectiveness analysis.

Summary

Table 9 summarizes how we approached each PV system incentive in the cost-effectiveness analysis and our rationale for that decision.

Table 9. PV system incentive treatment in cost-effectiveness analysis

PV system incentive	Modeling assumption	Rationale
Net Metering	Not included in analysis	Not double counting energy benefits
SMART Program	Not included in analysis	No MA policy indicating otherwise
Federal Tax Credit	Reduces costs	Consistent with MA policy
State Income Tax Credit	Reduces costs	Consistent with MA policy
State Sales Tax Credit	Not included in analysis	Assumed not included in installation costs
States Property Tax Credit	Not included in analysis	Not considered in analysis
Solar Finance Loan	Included as a cost	Consistent with HEAT Loan

Figure 2 illustrates how each PV system incentive impacts the benefit-cost ratio. All scenarios are cost-effective with a benefit-cost ratio greater than 1.0. The modeled scenarios are as follows.

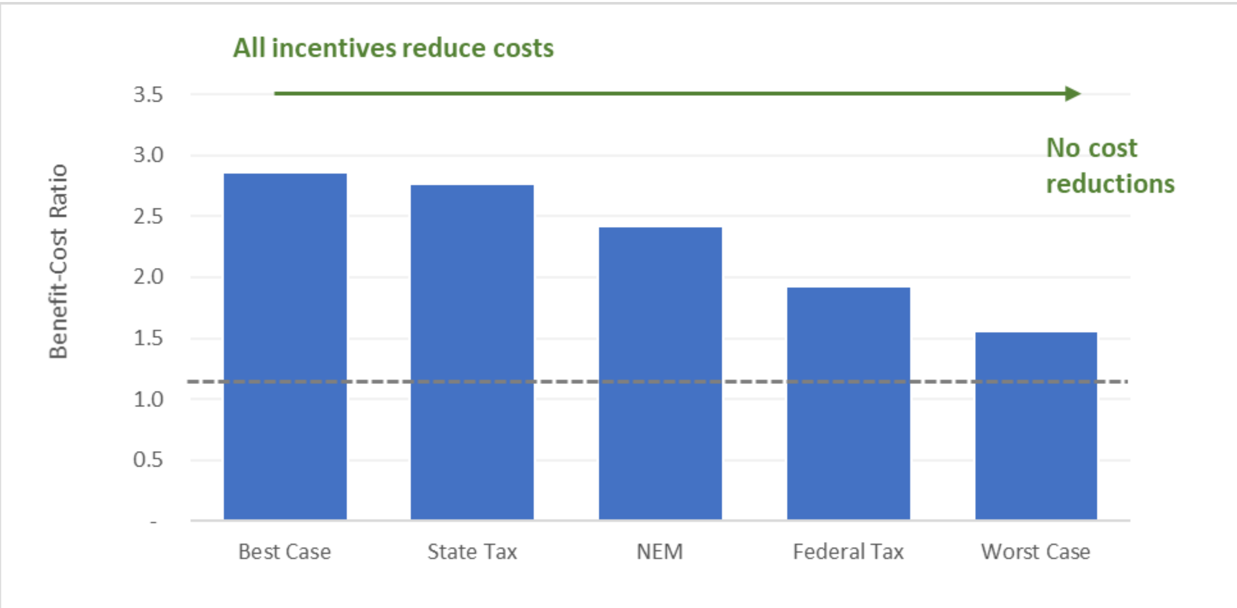
- **Best Case**. All incentives (SMART program, federal tax credit, net metering, and state income tax credit) reduce system costs.

[32] Mass Solar Loan, "For Consumers and Residents." Available at: http://www.masssolarloan.com/

[33] Mass Solar Loan, "Looking for an affordable clean energy option?" Available at: http://files.masscec.com/solar-loan/MassSolarLoanFlyer.pdf

- **State Tax**. Consistent with the best case scenario, except that the state income tax credit does not reduce system costs.
- **NEM**. Consistent with the state tax scenario, except that net metering credits do not reduce system costs.
- **Federal Tax**. Consistent with the NEM scenario, except that the federal tax credit does not reduce system costs.
- **Worst Case**. No incentives (SMART program, federal tax credit, net metering, and state income tax credit) reduce system costs.

Figure 2. PV incentives impact on cost-effectiveness



9. Cost-Effectiveness Results

Primary results

The assumptions discussed in this memo produce a solar benefit-cost ratio of 1.9, meaning solar is cost-effective for the Compact to incent for residential customers. Table 10 summarizes key cost-effectiveness results and analysis outputs. Figure 3 summarizes the magnitude of each benefit, while Figure 4 summarizes the magnitude of each cost. The customer PV installation costs reflect reductions for federal and state credits.

Table 10. Cost-effectiveness results

Results	Units	Value
Cost-Effectiveness		
Total Costs	*$000*	2,042
Total Benefits	*$000*	3,895
Net Benefits	*$000*	1,853
BCR	***ratio***	**1.91**
PV Generation		
Annual Energy	*MWh*	414
Lifetime Energy	*MWh*	10,353
Summer Capacity	*kW*	320
Costs		
Program Costs	*$000*	878
Cost of saved Summer Capacity	*$/kW*	2,747

Figure 3. Solar benefits

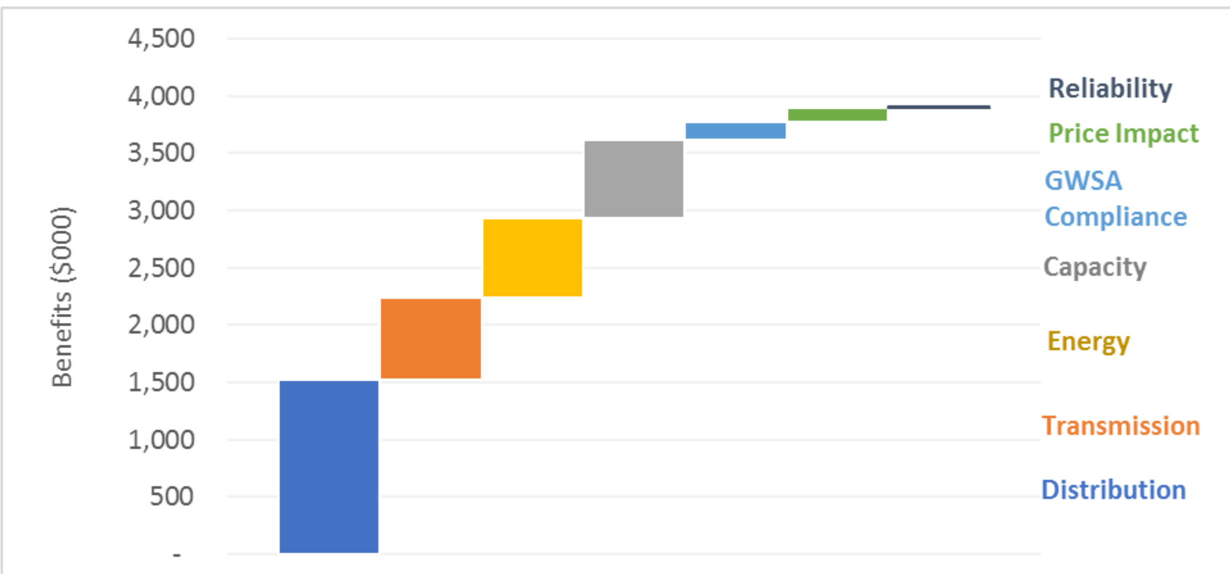


Figure 4. Solar costs

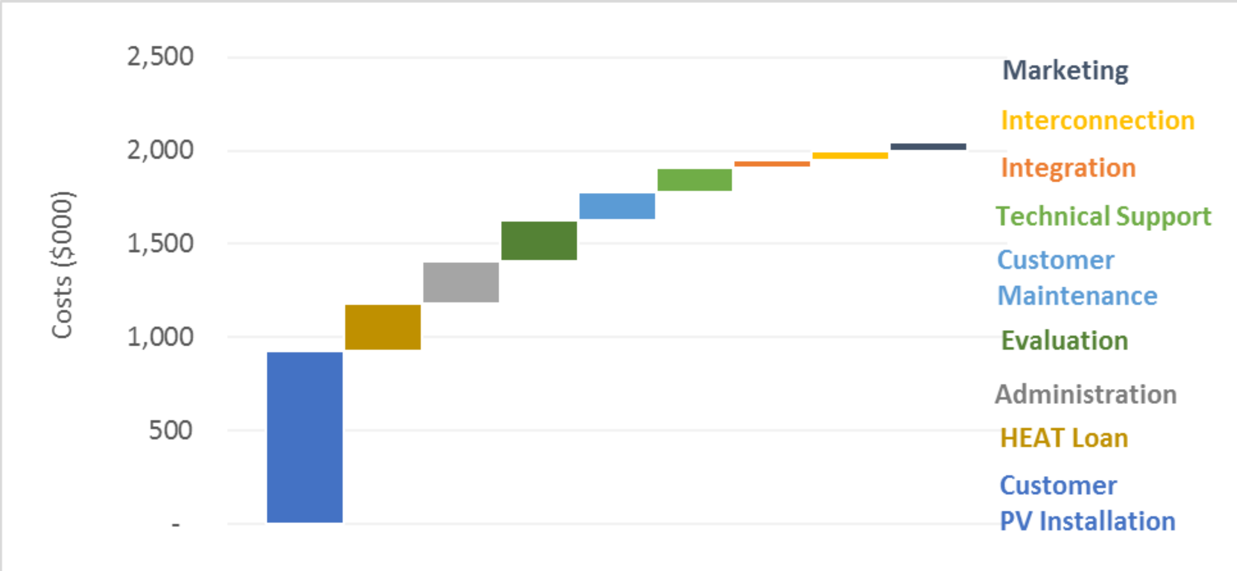
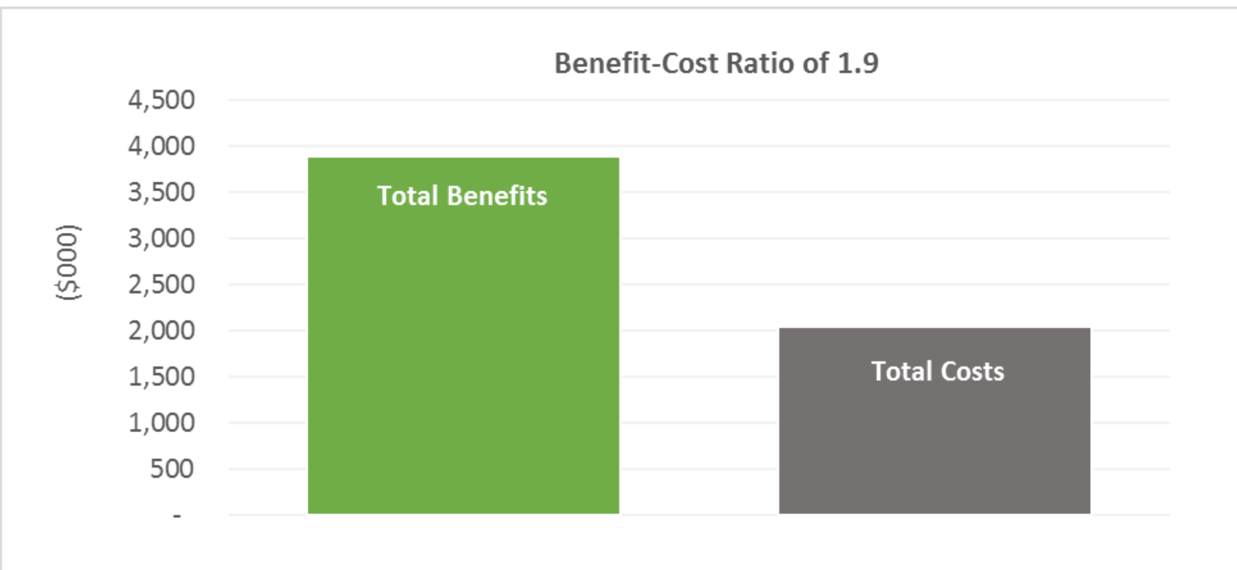


Figure 5 summarizes the total costs and benefits of solar. Every dollar spent on solar results in $1.91 in benefits, indicating it is cost-effective to incent and install PV systems in the Compact's service territory.

Figure 5. Solar benefit-cost results



Ultimately, we find that solar is cost-effective and the Compact should include incentives for residential customers in its 2019–2021 Three-Year Plan.

Forward Capacity Market sensitivity

The DPU is currently investigating how solar capacity is bid into ISO-NE's Forward Capacity Market (FCM).[34] Due to the uncertainty of that on-going proceeding, we ran a sensitivity to see whether benefit-cost results are materially impacted by bidding solar capacity into the FCM.

Bidding capacity into the FCM only impacts the avoided capacity, capacity price impacts (DRIPE), and reliability components of our analysis. Regardless of how capacity is bid into the FCM, avoided capacity costs make up about 22 percent of total benefits, capacity price impacts are $0 because solar has a long measure life (25 years) and benefits only extend out 15 years, and reliability makes up one percent or less of total benefits. The capacity price impacts are likely understated due to the way ISO forecasts load requirements and the way capacity DRIPE is presented in AESC.

We found that bidding capacity into the FCM produces a slightly lower benefit-cost ratio than not bidding capacity into the FCM. This counter intuitive result is a function of how the AESC calculates capacity benefits and how it accounts for the lag in ISO-NE's forecasting process. We recommend bidding solar capacity into the FCM to ensure ISO-NE has the most accurate information and data for system planning, regardless of what the cost-effectiveness results may indicate.

Ultimately, whether solar capacity is bid into the FCM has little impact on cost-effectiveness results. Our analysis assumed that all capacity is bid into the FCM.

10. Cost Impact Analysis

Synapse analyzed the monthly cost impact to moderate-income and extended moderate-income customers installing solar PV, a battery,[35] and a cold climate air source heat pump (ccASHP). Customer installation of all three technologies is the premise of the Compact's proposed Cape and Vineyard Electrification Offering (CVEO).[36]

A customer can install a ccASHP to replace or displace an existing oil furnace heating system.[37] We looked at both options for moderate- and extended moderate-income customers, for a total of four scenarios. We considered the multiple ways the CVEO would impact customers' monthly costs, as described in this section.

The technology assumptions used in this cost impact analysis are consistent with the Compact's 2019–2021 plan. Specifically, solar inputs are consistent with this memo, ccASHP inputs are consistent with

[34] See D.P.U. 17-146.

[35] See Synapse's Storage Cost-Effectiveness memo dated October 23, 2018.

[36] See the Compact's Pre-Filed Joint Testimony of Downey, Song, and Brandt in D.P.U. 18-116.

[37] Our analysis focused on an oil furnace. A similar analysis could be conducted for a propane furnace, oil boiler, or propane furnace.

the energy efficiency benefit-cost screening tool, battery inputs are consistent with the active demand management benefit-cost screening tool, and billing inputs are consistent with the bill impacts calculated in support of the energy efficiency surcharge.

Bill impact

Installing a ccASHP will result in a decreased oil bill ($0 for a customer that replaces their oil heating system) and increased electric bill. The net effect should be a bill decrease.

Massachusetts customers can net meter their solar generation against their electricity consumption, as discussed in Section 8. *PV System Incentives*. The solar generation offsets electricity consumption, thereby lowering the electric bill.

A battery will slightly increase electricity consumption, because less electricity can be retrieved from a battery compared to the electricity used to charge a battery. This will result in an increased electric bill.

The combination of the ccASHP bill savings, solar net metering bill savings, and battery bill increase substantially reduce a customer's total bills. Annually, we found bills decrease about $2,160 per year when replacing an oil furnace, or about $2,450 per year when displacing an oil furnace. This is the case for both moderate- and extended moderate-income customers, because we assume both customer types consume similar levels of oil and electricity and that they install similarly sized solar PV systems. Most of the bill savings are from solar PV.

The ccASHP bill savings primarily occur during the winter, while solar bill savings are likely to be greater in the summer. For our analysis, we calculated monthly savings simply by dividing annual savings by the 12 months of the year. A customer replacing their heating system saves about $180 per month and a customer displacing their heating system saves about $200 per month.

SMART credit

The solar PV and battery will earn a customer financial credit through the SMART program, as discussed in Section 8. *PV System Incentives*. We determined a customer will receive about $1,840 per year in SMART payments, or about $154 per month from the SMART program.

Equipment costs

Based on the Compact's proposed 2019–2021 plan, a customer can use the HEAT loan to finance the cost of solar and ccASHP not covered by incentives. The HEAT loan is repaid over seven years at zero percent interest. Different incentives are available to moderate- and extended moderate-income customers, so the total loan amount varies between the customer types.

We found the HEAT loan will increase costs by about $4,000 per year or $330 per month for a moderate-income customer, and about $4,800 per year or $400 per month for an extended moderate-income customer.

Net impact

Table 11 summarizes the impact of the Cape and Vineyard Electrification Offering for each of the scenarios. The net impact of installing a ccASHP, solar PV, and a battery is that moderate-income customers will see monthly savings ranging from $3 to $28 per month, while extended moderate-income customers will see increased costs ranging from $41 to $66 per month for seven years. Extended moderate-income customers will only see increased costs for the seven years it takes to repay the HEAT loan. After repayment, both moderate- and extended moderate-income customers will experience only cost decreases from bill savings and SMART credits ranging from $330 to $360 per month.

Table 11. Cost impact of Cape and Vineyard Electrification Offering

	Moderate Income		Extended Moderate Income	
Heat Pump option:	**Replacement**	**Displacement**	**Replacement**	**Displacement**
BILL SAVINGS				
Bill before ccASHP and PV	$3,101	$3,101	$3,101	$3,101
Bill after ccASHP and PV	$947	$648	$947	$648
Annual bill savings	-$2,155	-$2,453	-$2,155	-$2,453
Monthly bill savings	-$180	-$204	-$180	-$204
SMART CREDIT				
Annual SMART credit	-$1,846	-$1,846	-$1,846	-$1,846
Monthly SMART credit	-$154	-$154	-$154	-$154
EQUIPMENT COSTS				
ccASHP and PV costs after incentives	$27,760	$27,760	$33,509	$33,509
Annual loan (7 years, 0% interest)	$3,966	$3,966	$4,787	$4,787
Monthly loan payment	$330	$330	$399	$399
NET MONTHLY IMPACT - first seven years				
Bill Savings	-$180	-$204	-$180	-$204
SMART Credit	-$154	-$154	-$154	-$154
Loan Payment	$330	$330	$399	$399
Net Impact	**-$2.93**	**-$27.79**	**$65.51**	**$40.65**
NET MONTHLY IMPACT - after seven years				
Bill Savings	-$180	-$204	-$180	-$204
SMART Credit	-$154	-$154	-$154	-$154
Loan Payment	$0	$0	$0	$0
Net Impact	**-$333.40**	**-$358.26**	**-$333.40**	**-$358.26**

Note: Savings/Credits are negative. Costs/Payments are positive.

Synapse Energy Economics, Inc.

Memorandum

TO: MAGGIE DOWNEY, BRIANA KANE, AUSTIN BRANDT – CAPE LIGHT COMPACT

FROM: ERIN MALONE, DOUG HURLEY, DANIELLE GOLDBERG

DATE: OCTOBER 23, 2018

RE: STORAGE COST-EFFECTIVENESS ANALYSIS FOR 2019–2021 PLAN

Contents

1. Executive Summary

Synapse Energy Economics, Inc. (Synapse) studied the cost-effectiveness of small-scale energy storage technologies for potential implementation on Cape Cod and Martha's Vineyard. Batteries can provide benefits to all customers by aligning customer-sited sources of energy with peak-load hours.

We found that the value of a battery is in its ability to reduce peak demand, and thus avoid capacity and T&D costs. Batteries use a bit more energy than they save because of round-trip efficiency losses,[1] so energy benefits are minimal.

Table 1 summarizes the cost-effectiveness of the residential program, small commercial program, and the two programs combined. The result is a benefit-cost ratio of 2.5.

Table 1. Cost-Effectiveness Summary

Results	Units	Residential	Small Commercial	Total
Benefit-Cost Results				
Total Costs	$000	4,855	697	5,552
Total Benefits	$000	12,304	1,538	13,843
Net Benefits	$000	7,449	841	8,290
BCR	**ratio**	**2.53**	**2.21**	**2.49**
Savings				
Annual Energy	MWh	(146)	(18)	(165)
Lifetime Energy	MWh	(1,464)	(182)	(1,647)
Summer Capacity	kW	1,620	203	1,823
Cost Detail				
Program Costs	$000	4,855	697	5,552
Cost of saved Summer Capacity	$/kW	2,997	3,443	3,047

Figure 1 summarizes the composition of benefits for the program in total. Capacity and distribution benefits comprise most of the total benefits, while energy and price impact (DRIPE) benefits are negligible.

[1] Definitions for key terms used throughout this memo are provided in Appendix A.

Figure 1. Benefit Composition

2. Introduction

In preparation for the 2019–2021 Three-Year Energy Efficiency Plan, the Cape Light Compact (Compact or CLC) is investigating approaches to reducing customers' energy consumption and/or shifting peak usage through demand response resources. The Compact engaged Synapse to conduct a cost-benefit analysis of offering small-scale energy storage technologies to residential and small commercial customers on Cape Cod and Martha's Vineyard. This memo summarizes Synapse's research, methodology, and results regarding the cost-effective implementation of small-scale energy storage.

We first analyzed storage cost-effectiveness for the Compact in October 2017. We updated the analysis in October 2018 to reflect current information and assumptions in preparation for the 2019–2021 Plan filing to the Department of Public Utilities' (Department or DPU) on October 31, 2018 (see D.P.U. 18-116).

3. Background and Purpose

As discussed by the Compact and Eversource staff, the Cape Cod and Martha's Vineyard region has areas with distribution infrastructure constraints, and customers are installing solar panels at increasing rates. Storage technology has the potential to act like a demand response resource and better integrate solar resources. Batteries can provide benefits to all customers by aligning customer-sited sources of energy with peak-load hours.

On August 9, 2018, Governor Baker signed into law *An Act to Advance Clean Energy* (AACE). AACE provides that an energy efficiency plan may include "energy storage and other active demand management technologies."[2] Consistent with the AACE, the Compact proposes in its 2019–2021 Plan for

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[2] *An Act to Advance Clean Energy*, Bill H.4857, §2. Available at: https://malegislature.gov/Bills/190/H4857.

the Department's approval to offer small-scale energy storage, such as the Tesla Powerwall, to an initial set of its residential and small commercial customers. The Compact is still investigating and developing its storage program. Our assumptions are based on the best information available at the time we drafted the analysis.[3] Many of the numbers and assumptions are subject to change as the Compact further details its offering.

4. Methodology and Assumptions

Research Summary

We attempted to base our analysis on models and assumptions used in other states, but we were unable to find sufficiently detailed examples. The most notable example is the Green Mountain Power (GMP) pilot, on which we relied as much as reasonable. A summary of our research is presented in Appendix B.

Battery Technology

We completed a cursory search of small-scale storage technologies, as summarized in Appendix C. For this analysis, we chose to focus only on the Tesla Powerwall 2.0 for its name recognition with customers. Appendix C summarizes the technology details of the Tesla Powerwall 2.0. Other storage technologies are available to customers, and our reliance on the Tesla Powerwall is not meant to limit the technologies that the Compact could offer to customers as part of a potential storage program. The Compact should investigate competing products for their abilities and cost.

Program Design Assumptions

Synapse investigated and modeled several potential program design options. The most obvious ones included dispatch based upon customer's peak-load hours and dispatch based upon wholesale prices. After several rounds of internal review, we settled upon an initial, cost-effective program that charges the battery each night, and discharges each day from June through September. This is an initial program design that we found to be both simple to understand and model, and cost-effective. There are likely other dispatch scenarios that could further optimize cost-effectiveness or customer appeal. Further investigation and discussion may inform improvements to this design. Our intent here is to describe the simple design that we have modeled.

[3] There are ongoing proceedings at the DPU that could impact storage as well as solar deployment in Massachusetts. See, e.g., D.P.U. 17-146.

Cycling

We assume the battery will cycle once per day, charging at night (2am–5am) and discharging in the afternoon (4pm–7pm). We assume this cycle repeats for every day in June through September and in December through March, without customer or other dispatch intervention.

This is an over-simplified approach, intended to be illustrative and easier to model. Our understanding is that the Powerwall is capable of being dispatched by a centralized controller or managed directly by the customer. Further, it is dynamic enough to charge and discharge at different hours then we assumed. We also understand the Compact intends to follow a different dispatch strategy for winter, where it will target fewer peak event days, rather than cycle batteries daily. However, the Compact will follow a similar dispatch strategy in the summer.

We analyzed a few alternative approaches to battery cycling, including cycling in response to the customer's peak load and in response to system peak pricing. Ultimately, these scenarios proved overly complicated while producing similar results to cycling regularly once per day.

Customer incentives

We assume the Compact will pay 100 percent of the customer's initial cost to purchase and install the Tesla Powerwall. The customer will own the battery but will grant the Compact the authority over the battery's dispatch and operation for 10 years. After 10 years, the customer can operate the battery as they choose.

Back-up generation

Customers are more likely to install batteries if they can be used as back-up power during system outages. We have built into our model the ability for a program designer to set the amount of back-up power they would like to reserve in the battery for customer use. As an initial assumption, we assume 10 percent of the energy is available for back-up power.

Solar

We assume the installed batteries can operate independently of the customer's onsite load profile and can directly discharge to and charge from the electric grid. We assume the batteries are not required to charge only from solar generation. We also assume the batteries can discharge more energy than the customer's on-site load at the time of dispatch. We find such a structure is in the best interest of the electric grid.

Based on this assumption, whether a customer has installed solar PV does not impact how a battery will cycle or perform. In our analysis, cost-effectiveness is not impacted by whether a customer has installed solar PV, provided that a customer can obtain an interconnection agreement with the local distribution company without having or installing solar PV. It is likely that a customer with a battery and solar PV will have a flatter load shape than a customer without either technology, but we found no incremental savings resulting from synergies between the two technologies (just additive).

Customers with solar PV are likely more aware of their energy consumption and impact, and therefore could be more likely to participate in an energy storage program. In that regard, we view customers with solar PV as a promising market to achieve the desired adoption.

If a customer has not already installed solar PV, there may be cost savings from installing solar PV and storage at the same time. We do not account for any such cost savings in our analysis.

Rates

Consistent with the electric rates currently available to customers on Cape Cod and Martha's Vineyard, we assumed a fixed rate structure without time variation or demand charges.

Time of use (TOU) rates would encourage greater battery participation, because customers could potentially see bill savings if they shift usage from high to low priced periods. TOU rates are not currently available in the Compact's service territory due to lack of advanced meter availability.

Under DOER's SMART tariff approved by the DPU on September 26, 2018, customers who install both solar PV and storage would be eligible to receive a higher renewable compensation rate via a variable storage adder. The storage adder is based on the ratio of storage capacity to solar capacity as well as the duration for which the battery can provide power. We do not account for the SMART tariff in our current analysis, but we do in our solar cost-effectiveness analysis for the Compact dated October 23, 2018. Such a revenue stream is likely to increase customers' battery adoption but is not likely to impact cost-effectiveness.

We assume small commercial customers do not pay a demand charge, consistent with current rate structures. If a customer with a demand charge installed a battery, they could potentially see bill savings if they use the battery to reduce their peak consumption.

Customer eligibility

We assume that any customer within the Compact's Cape Cod and Martha's Vineyard territory can participate in a potential Compact storage program, regardless of whether the customer takes service under the Compact's power supply program or participates in the Compact's energy efficiency programs.

It is our understanding that Massachusetts' utilities currently require batteries to undergo the interconnection review process, but that such a practice has not been formally adjudicated by the Department.

Costs

We accounted for three types of costs: one-time installation costs, annual costs, and one-time program costs.

One-time installation costs are the cost to purchase the battery and supporting hardware, and the cost to install the system. The costs for the battery and hardware are consistent with Tesla's stated

Powerwall costs. The cost to install the system are estimated by the model user. We assume these costs total $10,000 per battery. As stated above, we assume the Compact will pay for these costs, although the user can adjust this assumption in the model.

Annual costs are the participant's annual operation and maintenance costs. These costs are estimated by the model user and are assumed to be incurred by participants every year for the life of the battery.

One-time program costs are the Compact's cost to administer, implement, market, and study the program. These costs are based on the Compact's current research and estimated program costs for each budget category.

Savings

Because all batteries currently available on the market have a round-trip efficiency of less than 100 percent, a customer is likely to use more total energy with a battery. Ideally the customer's energy use will be shifted to different hours, resulting in a flatter load shape and energy cost savings. The battery should also allow the customer to use less energy during system peak periods.

For energy savings, we assume a customer will experience overall increased energy use equivalent to the round-trip efficiency losses. In aggregate, a customer will use more energy during off-peak hours as the battery charges but will save energy during peak hours, when the battery is discharged.

For capacity savings, we assume the battery will discharge the most energy it can during the peak hour of the year (i.e., it is 100 percent coincident with summer peak) because our chosen program design discharges the battery every day from 4pm–7pm in the summer, and dispatch hours can be adjusted as needed based on load forecasts. This approach is most likely to involve discharging the battery during the annual and monthly system peak-load hours, although it is possible that peak hours may occur outside this timeframe. Using the terminology common with energy efficiency programs, it has a 100 percent coincidence factor.[4]

Benefits

We use the same avoided costs as used for active demand management measures for the 2019–2021 plan.

If targeting specific, capacity-constrained areas in coordination with Eversource, then batteries could result in greater T&D benefits. In the model, we allow the user to adjust avoided T&D costs to account for this. The default value in the model is the same avoided T&D cost rate as used for energy efficiency measures, which we understand to be a utility-specific, system-wide average.

[4] Note that a customers' peak usage is likely to occur at a different time from the electric system's peak. Customers with demand charges would experience bill savings from reducing their peak consumption. This benefit would be separate from and incremental to the avoided system capacity peak costs.

Batteries are likely to result in non-energy benefits, both to the utility system and to the participant. Such benefits could include, but are not limited to: increased reliability, increased property value, availability of back-up generation, or reduced risk in energy prices from a flatter load shape.

The cost-effectiveness model allows the user to account for non-energy benefits using an adder applied to the energy and capacity benefits. We used a percentage adder for ease of application and due to lack of supporting documentation. We applied a zero percent adder both for participant and utility system related benefits to be conservative, but this value is easily adjusted in the model.

5. Cost-Effectiveness Results

One key finding is that a battery's ability to avoid capacity charges drives its overall cost-effectiveness. Batteries use a bit more energy than they save because of round-trip efficiency losses, so energy benefits are minimal. The real value of a battery is in its ability to reduce peak consumption, and thus avoid capacity and T&D costs.

Consistent with Massachusetts' energy efficiency policy, we relied on the Total Resource Cost (TRC) test to determine cost-effectiveness, including all costs and benefits to the utility system and the participant.

Table 2 summarizes the cost-effectiveness of the residential program, small commercial program, and the programs combined. The result is a benefit-cost ratio of 2.5.

Table 2. Cost-Effectiveness Summary

Results	Units	Residential	Small Commercial	Total
Benefit-Cost Results				
Total Costs	$000	4,855	697	5,552
Total Benefits	$000	12,304	1,538	13,843
Net Benefits	$000	7,449	841	8,290
BCR	**ratio**	**2.53**	**2.21**	**2.49**
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Annual Energy	MWh	(146)	(18)	(165)
Lifetime Energy	MWh	(1,464)	(182)	(1,647)
Summer Capacity	kW	1,620	203	1,823
Cost Detail				
Program Costs	$000	4,855	697	5,552
Cost of saved Summer Capacity	$/kW	2,997	3,443	3,047

Figure 2 summarizes the composition of benefits for the program in total. Capacity and distribution benefits comprise most of the total benefits, while energy and price impact (DRIPE) benefits are negligible.

Figure 2. Benefit Composition

Appendix A: Definition of Key Terms

- **Round-Trip Efficiency.** The round-trip efficiency is the amount of energy that can be retrieved from a battery compared to the amount of energy used to charge the battery. In other words, energy out divided by energy in. Round-trip efficiency is expressed as a percentage. If a battery's round trip efficiency is 90 percent and is charged with 100 kWh, it would be able to discharge 90 kWh of electricity.[5]

- **Depth of Discharge (DOD).** Depth of discharge is the percentage a battery has been discharged. A DOD of 0 percent means the battery is fully charged, while a DOD of 100 percent means the battery is fully discharged. If a battery's DOD is 80 percent and is charged with 100 kWh, it would be able to discharge 80 kWh of electricity.[6]

- **State of Charge (SOC).** The state of charge is available capacity stored in a battery at any given time, expressed as a percentage. An SOC of zero percent indicates an empty battery, while an SOC of 100 percent indicates a fully charged battery.[7]

- **Cycling.** Cycling is the switch from charging to discharging, regardless of how much energy is being charged or discharged at a given point in time.

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[5] Homer Energy. "Battery Roundtrip Efficiency." http://www.homerenergy.com/support/docs/3.10/battery_roundtrip_efficiency.html.

[6] Best Go Power. "What is Depth of Discharge (DOD)?" http://www.bestgopower.com/faq/30-what-is-depth-of-discharge-dod.html.

[7] Electropaedia. "State of Charge (SOC) Determination." http://www.mpoweruk.com/soc.htm.

Appendix B: Research Summary

Overview

We researched other small-scale battery programs and non-wire alternatives (NWA), focusing on how program administrators addressed cost-effectiveness. Specifically, we looked at Green Mountain Power (GMP) in Vermont, a 2016 study on residential PV and the Powerwall I in the German energy market,[8] the Brooklyn Queens Demand Management (BQDM) NWA project through Consolidated Edison in New York,[9] as well as Eversource's Mashpee substation upgrade.[10] The most closely analogous project to our analysis is GMP's pilot, which is summarized in more detail below.

Green Mountain Power

In 2016, Green Mountain Power in Vermont started offering Tesla Powerwall batteries to customers on a pilot basis. The program is designed to lower energy bills through reduced transmission and capacity costs during peak times, while increasing reliability. GMP has one of the few small-scale energy storage programs in the country, and it is the one of the first US utilities to partner with Tesla.

Tesla and GMP will install and operate the Powerwall for $15/month for 10 years for an upfront price of $1,500.[11] The standard price for a Powerwall purchased directly through Tesla is $5,500. While the Powerwall can provide up to 100 percent backup reserve, with GMP's program, 20 percent backup reserve is available 95 percent of the time. The Powerwall can be charged with solar panels, or from the grid. Tesla's standard Powerwall allows users to shift their load for TOU rates, however GMP's program does not allow for that feature.

GMP uses the Powerwall to reduce grid load when it is most congested and lower the overall system cost. The amount of backup power available to a customer is dependent on how the battery was most recently dispatched and will likely be only a few hours of power. If the Powerwall is used in conjunction with solar panels, a customer may be secure for an extended outage.

GMP charges customers a fine of $450 to remove the Powerwall if they no longer wish to continue with the program. GMP owns the battery under the arrangement but will transfer it to a new owner if the house is sold.

We continue researching the details of this pilot's cost-effectiveness to improve our analysis.

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[8] Electrical Energy Storage Technology and the Technical University of Munich, "The Economics of Residential Photovoltaic Battery Systems in Germany: The Case of Tesla's Powerwall."

[9] Utility Dive, "ConEd awards 22 MW of demand response contracts in Brooklyn-Queens project," 2016.

[10] See, D.P.U. 14-03.

[11] See, https://www.tesla.com/green-mountain-power.

Appendix C: Storage Technologies

The Tesla Powerwall is one of the most recognized small-scale storage technologies available and is the model used by GMP in its pilot.

Other small-scale at-home batteries exist apart from the Tesla Powerwall. These are summarized in the table below.[12] As battery technology continues to evolve and the popularity of at-home storage grows, more companies will develop competitors to the Tesla Powerwall.

Using other technologies could result in different costs and savings, and therefore cost-effectiveness results.

The table below provides some of our initial research into other storage technologies, as compared to the Tesla Powerwall.

Table C.1: Tesla Powerwall and Competitor Comparison

Company/Battery	Storage (kWh)	Price ($)	Inverter Included?
Tesla's Powerwall	**13.5**	**5,500**	**Yes**
RESU by LG Chem	6.5	4,000	No
Orison	2.2	1,600	N/A
Sonnen	4-16	Start at 5,950	Yes
Sunverge	6-23	8,000-20,000	N/A
Mercedes	2.5	9,000-10,000	No
ElectrIQ	10	13,000	Yes
Nissan's xStorage	4.2	4,500	N/A
Pika Energy	10.6-15.9	N/A	N/A

[12] Business Insider. "11 Home Batteries that Rival Tesla's Powerwall 2.0". http://www.businessinsider.com/home-battery-rival-tesla-powerwall-2-2016-10/#1-teslas-powerwall-20-is-a-269-pound-lithium-ion-battery-that-you-can-mount-on-your-wall-panasonic-makes-the-cells-for-the-battery-while-tesla-builds-the-battery-module-and-pack-the-whole-thing-costs-5500-including-the-inverter-and-stores-135-kwh-of-energy-1.