Assessing the Impacts Climate Change May Have on the State's Economy, Revenues, and Investment Decisions: Volume 4: Economic Analyses of Adaptation and Mitigation Strategies

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1. INTRODUCTION TO ECONOMIC ANALYSIS

ERG's economic analyses of adaptation and mitigation strategies for the State of Maine consist of a variety of metrics that depend on data availability and what is being measured.

The goal of performing economic analyses is to inform whether an economic case exists to implement strategies. Economics alone should not inform the decision, as the feasibility of analysis (e.g., data availability, credible methods) and resource constraints often make it impossible to monetize all the benefits and costs as well as the equity, political feasibility, and other factors that the State of Maine needs to consider.

We divided our analyses by working group area. Reported results for each of these sub-analyses include an overview of the proposed strategy and a description of the benefits (as well as a cross-reference to the list of working group strategies), quantitative results from the economic analysis, methods and limitations, and recommendations for future studies.

We performed several types of economic analyses in this volume that vary depending on the strategy:

- **Benefit-cost analysis:** This could include both market and non-market (e.g., the value to recreate even though it is free, and no money may change hands) benefits and costs. The output is often presented as a ratio of benefits to cost or a net benefit over some period of time.
- **Cost-effectiveness analysis:** Particularly for the greenhouse gas reduction and sequestration strategies, we present the lifetime cost—which could be a cost increase or cost savings (and be a negative cost-effectiveness value—per metric ton of carbon dioxide (CO_2) reduced.
- **Economic impact analysis:** This could refer to the change in wages, number of jobs, or revenue as a result of implementing a strategy.

2. COASTAL AND MARINE

This section includes three strategies from the Maine Climate Council Coastal and Marine Working Group's (2020a) *A Report from the Coastal & Marine Working Group of the Maine Climate Council*:

- **Strategy 3:** Enhance mitigation by conserving and restoring coastal habitats that naturally store carbon (blue carbon optimization).
- **Strategy 4:** Promote climate-adaptive ecosystem planning and management using nature-based solutions.
- **Strategy 6:** Create climate-ready working waterfronts.

2.1 Blue Carbon Optimization

Coastal blue carbon is the carbon that coastal resources such as salt marshes and eelgrass sequester, with sequestration rates that exceed the rate of terrestrial ecosystems such as forests (Mcleod, 2011; Pendleton, 2012). As these resources diminish due to sea level rise, the accompanying carbon sequestration is also lost. Strategy 3 of the Coastal and Marine Working Group calls for increased conservation and restoration of coastal habitats to support blue carbon.

Benefits: The actions outlined within this strategy support carbon sequestration as well as a range of ecosystem services, including storm protection, water quality, and biodiversity. Outside of these economic benefits, restoration project funding would likely go to increase in-state jobs while the projects are ongoing. These temporary jobs would likely be a mix of both less-specialized and some higher-paying, more-specialized positions; however, we did not analyze the construction-time impacts as part of this analysis.

2.1.1 Economic Analysis Results

ERG performed a benefit-cost analysis of salt marsh and eelgrass restoration as compared to:

- The amount of CO_2 these resources sequester.
- The monetized value of that CO_2, using both the social and market cost of carbon.
- The monetized value of other ecosystem services that these resources provide.

This analysis builds on Eastern Research Group's (ERG's) (2020) *Cost of Doing Nothing Analysis* by estimating the cost to restore salt marsh and eelgrass and comparing this cost against the monetized benefits of these resources (carbon sequestration and other ecosystem services). The results of this analysis are summarized in Table 1, and discussed in more detail in Section 2.1.2. Overall restoration is more cost-efficient for eelgrass because eelgrass sequesters more carbon than salt marsh. The State of Maine should consider the carbon sequestration cost-effectiveness information along with ERG's additional evaluation of ecosystem services presented below. Considering co-benefits of ecosystem services encourages us to select restoration sites that can maximize sequestration and additional co-benefits. While we focused on the costs of restoration for this analysis, the costs of protecting existing resources will typically be much cheaper and more cost-effective than restoration while providing a similar level of benefits.

Table 1. Summary of Blue Carbon Restoration Cost-Effectiveness

Year	Restoration Cost/Metric Ton CO_2 Equivalent		Restoration Cost/Value of Carbon Sequestered		Restoration Cost/Other Ecosystem Services Values	
	Low	High	Low	High	Low	High
Eelgrass						
2030	$1,673	$6,200	481	16,238	22	11
2050	$3,043	$11,880	487	12,676	22	10
2100	$13,058	$53,186	735	6,825	22	10
Salt Marsh						
2030	$15,929	$76,065	262	11,742	5	17
2050	$22,876	$112,061	273	9,288	5	17
2100	$52,788	$321,933	378	5,635	5	17

Sources: Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020; Costanza et al., 2008; Drake et al., 2015; Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Kroeger et al., 2017; Maine Climate Council Coastal and Marine Working Group, 2020a; Bartow-Gillies et al., 2020; Maine Dept of Marine Resources, 2010; Maine Natural Areas Program, 2014; McLeod et al., 2011; National Oceanic and Atmospheric Administration Office for Coastal Management, New Hampshire Department of Environmental Services Coastal Program, and Eastern Research Group, Inc., 2016; Roman et al., 1997; Synergy Energy Economics, 2020; Troy, 2012.

Note: For the cost of carbon, the low estimate uses the market cost of carbon, and the high estimate uses the social cost of carbon.

2.1.2 Methods and Limitations

ERG's (2020) *Cost of Doing Nothing Analysis*, in part based on data provided by the Maine Climate Council Coastal and Marine Working Group (2020b), presented the amount of carbon buried by salt marsh and eelgrass, the social and market cost of the carbon burial lost, and a valuation of other ecosystem services that salt marsh and eelgrass provide. Here we estimate the cost of restoration and compare that cost to the carbon and monetized benefits derived in the *Cost of Doing Nothing Analysis*. As mentioned above, the costs would be reduced, likely dramatically, when considering protection of existing eelgrass beds or salt marsh through a conservation fee, easement, or other mechanism to protect the land.

2.1.2.1 Eelgrass

In our *Cost of Doing Nothing Analysis*, we estimated that up to 12 of Maine's nearly 100 km^2 of eelgrass could be lost by 2100, resulting in up to 60,874 metric tons of lost carbon sequestration.

To estimate the costs to restore eelgrass, we rely on data from the database that Bayraktarov et al. (2015) developed in preparation for their (2016) review of primary literature, reports, and databases of restoration projects performed over a 40-year period. The database includes a list of projects by resource type, including the location, cost estimate, year of the cost estimate, and other information.

To estimate the cost of restoring salt marsh in Maine, we limited the entries in the Bayraktarov et al. (2015) data to projects in the Northeast United States for seagrass.[1] We then converted the cost of each project to 2019 dollars using the Bureau of Economic Analysis (2020) implicit price deflator for gross domestic product, resulting in an average of $65,932.14 per hectare. We projected the cost in future years (2030, 2050, and 2100) using the average annual increase in the implicit price deflator for gross

[1] For seagrass, this includes six projects undertaken between 1995 and 2004 in New Hampshire and Massachusetts.

domestic product: 1.89 percent. This yields the value to multiply the cost by in a given year to track the projected future growth of gross domestic product. We refer to this multiplier as the "GDP multiplier" in the tables below. Finally, we converted from a cost per hectare to a cost per km^2—the area unit that the *Cost of Doing Nothing Analysis* used for blue carbon (see Table 2).

Table 2. Eelgrass Restoration Unit Cost

Year	GDP Multiplier	$/ha	$/km^2
2019	1.0000	$313,918	$31,391,767
2030	1.2286	$385,683	$38,568,317
2050	1.7864	$560,794	$56,079,391
2100	4.5543	$1,429,667	$142,966,666

Sources: Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020.

The *Cost of Doing Nothing Analysis* estimated the amount of carbon burial lost under four scenarios, depending on the amount of marsh area lost and amount of carbon buried (Maine Dept of Marine Resources, 2010; Mcleod, 2011). Using those figures, we divided the aggregate amount of carbon buried statewide by the km^2 of salt marsh lost under each scenario in each year to estimate the carbon burial per km^2 (see the top of Table 7).[2]

After estimating the cost to restore 1 km^2 of eelgrass (Table 2), we compared the cost of restoration with the amount of carbon buried by salt marsh (top of Table 3) to estimate the cost of restoration per metric ton of CO_2 (results shown in the bottom of Table 3).

Table 3. Eelgrass Restoration Cost-Effectiveness ($/Metric Ton CO_2 Equivalent)

Year	Low Burial Amount Scenario		High Burial Amount Scenario	
	Low Loss	High Loss	Low Loss	High Loss
Burial Amount Lost (Metric Tons CO_2 Equivalent/km^2/Year)				
2030	13,098.90	6,220.80	23,054.06	10,948.61
2050	10,469.53	4,720.32	18,426.37	8,307.77
2100	6,220.80	2,688.07	10,948.61	4,731.01
Restoration Cost-Effectiveness ($/Metric Tons CO_2 Equivalent)				
2030	$2,944.39	$6,199.89	$1,672.95	$3,522.67
2050	$5,356.44	$11,880.41	$3,043.43	$6,750.23
2100	$22,982.03	$53,185.55	$13,057.97	$30,219.06

Sources: Maine Dept of Marine Resources, 2010; McLeod et al., 2011; Maine Climate Council Coastal and Marine Working Group, 2020b; Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020.

Next, we consider how the cost of restoration compares to the monetized benefits that salt marsh provides, as measured using the social cost of carbon, market cost of carbon, and a valuation of other ecosystem services. Our calculations for deriving these values can be found in Appendix A of the *Cost of Doing Nothing Analysis* (the calculations are from the following sources: Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Synergy Energy Economics, 2020; National Oceanic and Atmospheric Administration Office for Coastal Management, 2016). Dividing the results from that analysis by the number of km^2 of salt marsh lost under each scenario and year results in the values shown in Table 4.

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[2] Note that the amount buried varies by year because the estimated number of tidal marsh crossings with restrictions varies as the sea level rises, and that influences the amount of carbon buried.

Table 4. Eelgrass Cost of Carbon and Other Ecosystem Services/km²

Year	Low Burial Amount Scenario		High Burial Amount Scenario	
	Low Loss	High Loss	Low Loss	High Loss
Social Cost of Carbon/km²				
2030	$22,269.95	$45,522.39	$39,195.11	$80,119.41
2050	$30,732.53	$65,465.74	$54,089.25	$115,219.70
2100	$51,268.60	$110,559.44	$90,232.74	$194,584.62
Market Cost of Carbon/km²				
2030	$2,375.22	$4,855.24	$4,180.39	$8,545.21
2050	$4,424.08	$9,424.08	$7,786.39	$16,586.39
2100	$20,946.95	$45,171.57	$36,866.63	$79,501.96
Other Ecosystem Services/km² [a]				
2030	$1,776,762.98	$3,631,912.56	$1,776,762.98	$3,631,912.56
2050	$2,583,462.12	$5,503,232.91	$2,583,462.12	$5,503,232.91
2100	$6,586,180.06	$14,202,931.46	$6,586,180.06	$14,202,931.46

Sources: Maine Dept of Marine Resources, 2010; McLeod et al., 2011; Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Synergy Energy Economics, 2020; Bureau of Economic Analysis, 2020; Maine Climate Council Coastal and Marine Working Group, 2020b; National Oceanic and Atmospheric Administration Office for Coastal Management, New Hampshire Department of Environmental Services Coastal Program, and Eastern Research Group, Inc., 2016.

[a] The other ecosystems services valuation is based on the area lost and does not depend on carbon burial.

Table 5 shows the results of our comparison of the cost of restoration (from Table 2) to the social cost of carbon, market cost of carbon, and monetized value of other ecosystem services (from Table 4).

Table 5. Eelgrass Restoration Cost-Benefit Ratio

Year	Low Burial Amount Scenario		High Burial Amount Scenario	
	Low Loss	High Loss	Low Loss	High Loss
Ratio, Restoration Cost to Social Value of Carbon Sequestered				
2030	1,732	847	984	481
2050	1,825	857	1,037	487
2100	2,789	1,293	1,584	735
Ratio, Restoration Cost to Market Value of Carbon Sequestered				
2030	16,238	7,944	9,226	4,513
2050	12,676	5,951	7,202	3,381
2100	6,825	3,165	3,878	1,798
Ratio, Restoration Cost to Other Ecosystems Values [a]				
2030	22	11	22	11
2050	22	10	22	10
2100	22	10	22	10

Sources: Maine Dept of Marine Resources, 2010; McLeod et al., 2011; Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Synergy Energy Economics, 2020; Bureau of Economic Analysis, 2020; Maine Climate Council Coastal and Marine Working Group, 2020b; National Oceanic and Atmospheric Administration Office for Coastal Management, New Hampshire Department of Environmental Services Coastal Program, and Eastern Research Group, Inc., 2016; Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020.

[a] Other ecosystems services are based on the area lost and do not depend on carbon burial.

2.1.2.2 Salt Marsh

In our *Cost of Doing Nothing Analysis*, we estimated that up to 60 of Maine's approximately 70 to 100 km^2 of salt marsh could be lost to sea level rise, resulting in up to 30,868 metric tons of lost carbon sequestration.

To estimate the costs to restore salt marsh, we rely on data from Bayraktarov et al. (2015) (which we also used for eelgrass).

To estimate the cost of restoring salt marsh in Maine, we limited the entries in the Bayraktarov et al. (2015) data to projects in the Northeast United States for salt marsh.[3] We then converted the cost of each project to 2019 dollars using the Bureau of Economic Analysis (2020) implicit price deflator for gross domestic product, resulting in an average of $65,932.14 per hectare. We projected the cost in future years (2030, 2050, and 2100) using the average annual increase in the implicit price deflator for gross domestic product: 1.89 percent. Finally, we converted from a cost per hectare to a cost per km^2, the area unit that the *Cost of Doing Nothing Analysis* used for blue carbon (see Table 6).

Table 6. Salt Marsh Restoration Cost

Year	GDP Multiplier	$/ha	$/km²
2019	1.0000	$65,932	$6,593,214
2030	1.2286	$81,005	$8,100,505
2050	1.7864	$117,784	$11,778,356
2100	4.5543	$300,273	$30,027,294

Sources: Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020.

The *Cost of Doing Nothing Analysis* estimated the amount of carbon burial lost under four scenarios, depending on the amount of marsh area lost and amount of carbon buried (Drake, 2015; Roman, 1997; Kroeger, 2017; Maine Climate Council Coastal and Marine Working Group, 2020c).[4] We divided those figures for the aggregate amount of carbon buried statewide by the km^2 of salt marsh lost under each scenario in each year to estimate the carbon burial per km^2 (see the top of Table 7).[5]

After estimating the cost to restore 1 km^2 of salt marsh (in Table 6), we compared the cost of restoration with the amount of carbon buried by salt marsh (in the top of Table 7) to estimate the cost of restoration per metric ton of CO_2 (results shown in the bottom of Table 7).

Next, we consider how the cost of restoration compares to the monetized benefits that salt marsh provides, as measured using the social cost of carbon, market cost of carbon, and a valuation of other ecosystem services. These values were derived in the *Cost of Doing Nothing Analysis* (Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Synergy Energy Economics, 2020; Costanza, 2008; National Oceanic and Atmospheric Administration Office for Coastal Management, 2016; Troy,

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[3] For salt marsh, this includes 17 projects undertaken between 1997 and 2003 in New Hampshire, Massachusetts, Rhode Island, New York, and "the glaciated northeast."

[4] The four scenarios in the *Cost of Doing Nothing Analysis* were low area lost/low carbon burial, low area lost/high burial, high area lost/low burial, and high area lost/high burial.

[5] Note that the amount buried varies by year because the estimated number of tidal marsh crossings with restrictions varies as the sea level rises, and that influences the amount of carbon buried.

2012). Dividing the results from that analysis by the number of km^2 of salt marsh lost under each scenario and year results in the values shown in Table 8.

Table 7. Salt Marsh Restoration Cost-Effectiveness ($/Metric Ton CO_2 Equivalent)

Year	Low Burial Amount Scenario		High Burial Amount Scenario	
	Low Marsh Area	High Marsh Area	Low Marsh Area	High Marsh Area
Burial Amount Lost (Metric Tons CO_2 Equivalent/km^2/Year)				
2030	106.49	152.24	343.33	508.54
2050	105.11	153.99	338.31	514.87
2100	93.27	168.93	295.57	568.82
Restoration Cost-Effectiveness ($/Metric Tons CO_2 Equivalent)				
2030	$76,064.65	$53,209.09	$23,594.06	$15,928.94
2050	$112,061.01	$76,486.99	$34,814.87	$22,876.39
2100	$321,932.69	$177,749.41	$101,590.72	$52,788.43

Sources: Drake et al., 2015; Roman et al., 1997; Kroeger et al., 2017; Maine Climate Council Coastal and Marine Working Group, 2020b; Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020.

Table 8. Salt Marsh Cost of Carbon and Other Ecosystem Services/km^2

Year	Low Burial Amount Scenario		High Burial Amount Scenario	
	Low Marsh Area	High Marsh Area	Low Marsh Area	High Marsh Area
Social Cost of Carbon/km^2				
2030	$6,468.10	$9,246.43	$20,852.46	$30,886.79
2050	$8,809.62	$12,906.96	$28,356.12	$43,154.29
2100	$13,041.61	$23,620.44	$41,327.79	$79,534.85
Market Cost of Carbon/km^2				
2030	$689.86	$986.19	$2,224.04	$3,294.26
2050	$1,268.18	$1,858.01	$4,081.99	$6,212.25
2100	$5,328.45	$9,650.67	$16,885.41	$32,495.77
Other Ecosystem Services/km^2 [a]				
2030	$1,639,935.85	$486,306.92	$1,639,935.85	$486,306.92
2050	$2,384,511.71	$707,103.61	$2,384,511.71	$707,103.61
2100	$6,078,983.46	$1,802,663.04	$6,078,983.46	$1,802,663.04

Sources: Drake et al., 2015; Roman et al., 1997; Kroeger et al., 2017; Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Synergy Energy Economics, 2020; Bureau of Economic Analysis, 2020; Maine Climate Council Coastal and Marine Working Group, 2020b; McLeod et al., 2011; Costanza et al., 2008; National Oceanic and Atmospheric Administration Office for Coastal Management, New Hampshire Department of Environmental Services Coastal Program, and Eastern Research Group, Inc., 2016; Troy, 2012.

[a] The valuation of other ecosystem services is based on the area lost and an "Estimate A" and "Estimate B" for the valuation of ecosystem services, not the baseline marsh area or burial amounts.

Table 8 shows the results of our comparison of the cost of restoration (from Table 6) to the social cost of carbon, market cost of carbon, and monetized value of other ecosystem services. Table 9 presents these values in terms of cost-benefit ratios, where the restoration cost is divided by the social cost of carbon, market cost of carbon, or monetized value of other ecosystem services. Based on the data, limitations, and caveats provided by the Coastal and Marine Working Group, restoration of eelgrass and marsh strictly for carbon sequestration is *much less* cost-effective and has a much worse cost-benefit ratio than most mitigation and sequestration strategies proposed by the Maine Climate Council.

Additionally, these findings highlight the importance of selecting targeted restoration projects that, because of their location, provide a high value of other ecosystem services, as well as the importance of preserving salt marsh where possible, rather than restoring it after it has been inundated (as the cost of preservation should be far less than restoration to achieve the same benefit). Specific analyses of eelgrass and marsh restoration and preservation in sites in Maine with the potential for high co-benefits (e.g., flood protection for a populated area) would likely show a cost-effective measure with a favorable benefit-cost ratio. We provide examples of natural infrastructure benefit-cost ratios in the Gulf of Mexico in Section 2.2 ("Use Nature-Based Solutions") of this report.

Table 9. Salt Marsh Restoration Cost-Benefit Ratio

Year	Low Burial Amount Scenario		High Burial Amount Scenario	
	Low Marsh Area	High Marsh Area	Low Marsh Area	High Marsh Area
Ratio, Restoration Cost to Social Value of Carbon Sequestered				
2030	1,252	876	388	262
2050	1,337	913	415	273
2100	2,302	1,271	727	378
Ratio, Restoration Cost to Market Value of Carbon Sequestered				
2030	11,742	8,214	3,642	2,459
2050	9,288	6,339	2,885	1,896
2100	5,635	3,111	1,778	924
Ratio, Restoration Cost to Other Ecosystems Values [a]				
2030	5	17	5	17
2050	5	17	5	17
2100	5	17	5	17

Sources: Drake et al., 2015; Roman et al., 1997; Kroeger et al., 2017; Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Synergy Energy Economics, 2020; Bureau of Economic Analysis, 2020; Maine Climate Council Coastal and Marine Working Group, 2020b; Maine Dept of Marine Resources, 2010; McLeod et al., 2011; Costanza et al., 2008; National Oceanic and Atmospheric Administration Office for Coastal Management, New Hampshire Department of Environmental Services Coastal Program, and Eastern Research Group, Inc., 2016; Troy, 2012; Bayraktarov et al., 2015; Bureau of Economic Analysis, 2020.

[a] The valuation of other ecosystem services is based on the area lost and an "Estimate A" and "Estimate B" for the valuation of ecosystem services, not the baseline marsh area or burial amounts.

2.1.3 Recommendations for Further Analysis

Future analyses might include:

- Conducting a cost-effectiveness analysis of eelgrass and marsh restoration for specific sites in Maine with high potential for high-impact co-benefits (e.g., flood protection for a populated area) to evaluate how the cost-effectiveness ratios may differ from those presented above. Studies in the Gulf of Mexico have shown a favorable benefit-cost ratio, and we might expect the same in Maine.
- Integrating the probability of project success to calculate an expected value for restoration. Bayraktarov et al. (2016) estimate that only 38 percent of seagrass restoration projects and 64.8 percent of salt marsh projects are successful. We did not incorporate this into our analysis, but it would make the cost-benefit ratio less favorable than it already is.
- Performing other actions that the Maine Climate Council Coastal and Marine Working Group (2020a) identified as part of this strategy:

- Inventorying Maine's blue carbon resources to inform baseline estimates of current storage and sequestration.
- Tracking changes in sequestration/emissions over time.

2.2 Use Nature-Based Solutions

Strategy 4 of the Maine Climate Council Coastal and Marine Working Group (2020a) identifies specific actions to promote coastal community and ecosystem resiliency. The following actions will help communities adapt to changing environmental conditions; harness natural resources; and protect jobs, infrastructure, and biodiversity:

- Foster climate-adaptive planning.
- Promote nature-based solutions.
- Conserve and restore ecosystems to foster resiliency.
- Restore hydrological connectivity.
- Protect and restore beaches and sand dunes.
- Characterize and map marine and coastal habitats.
- Strengthen stormwater management.
- Recalibrate and strengthen protections of inland natural resources.
- Improve other regulatory approaches

Benefits: These actions promote ecosystem services protection and biodiversity resiliency, which result in co-benefits to coastal communities. The co-benefits range from important natural changes such as improving air quality, protecting water quality, and restoring healthy fish and wildlife populations, to changes that directly affect Maine's economy, such as stimulating the tourism industry and decreasing costs associated with community infrastructure.

2.2.1 Economic Analysis Results

ERG performed a literature review to identify typical costs and benefits associated with Strategy 4's activities. Case studies and higher-level literature on cost-benefit ratios for nature-based adaptation provided helpful insight into the following approaches suggested by the working group:

- Promote nature-based solutions:
  - ***Cost:*** Up to $1,000 per linear foot construction and $100 per linear foot annual maintenance costs for vegetated living shorelines versus between $5,000 and $10,000 per linear foot for initial construction and over $500 per linear foot annually for harder infrastructure such as a seawalls (NOAA, 2015).
  - ***Benefit:*** $2.06 million benefit[6] from a 2,800-foot vegetated living shoreline in Piscataway Park, Maryland, over the lifetime of the project (2019$ converted from 2012$) (Samonte et al., 2017).

[6] The report did not specify the time period over which the benefit accrued.

- Protect and restore beaches and sand dunes:
  - ***Cost:*** $318 to $1,061 per linear foot or between $5 and $32 per cubic yard of sand costs for beach nourishment projects.
  - ***Benefit:*** Projects to successfully protect at-risk beaches in Maine, such as beach nourishment, would prevent up to $39 million in lost consumer surplus in case of a 50 percent decrease in beach width due to sea level rise (under a scenario of highest astronomical tide plus 1.6 feet of sea level rise relative to 2000).
  - ***Benefit:*** Avoiding costs to rehabilitate a species on the endangered list, which on average reach $15.9 million (mean) or $1.4 million (median).

Benefit-cost ratios for these types of beach nourishment projects have been found to range from 0.3 to 1.7 for projects along the U.S. Gulf Coast. On the other hand, nature-based wetland restoration projects in this region have benefit-cost ratios ranging from about 2 to 9. The higher returns tended to be for wetland restoration projects that focused on risk reduction, such as those around real estate with high flood risk, while the lower returns tended to be for conservation projects (Reguero et al., 2018).

Federal grants are available for many projects that apply nature-based solutions to address climate change in areas such as water quality, habitat restoration, and natural infrastructure. In 2020, the U.S. Fish and Wildlife Service Coastal Program granted Massachusetts between $800,000 and $1 million for projects that restore freshwater wetlands and fish habitats and improve water connectivity. This program also awarded Texas $715,000 to construct a 3,236-foot living shoreline.

By researching hazard mitigation and adaptation projects funded over the last couple decades, the Federal Emergency Management Agency (FEMA) found that we can expect an average benefit-cost ratio of 6:1 when we invest in these kinds of projects (National Institute of Building Sciences, 2019). When leveraging federal funding, this could increase the expected benefit-cost ratio to around 12:1 (e.g., for an even match). However, these funds can be hard to win, and state and local matches can be an obstacle. Moreover, other requirements can make the application process burdensome.

2.2.2 Methods and Limitations

ERG conducted a literature review focused on the typical costs and benefits of promoting nature-based solutions and protecting and restoring beaches and sand dunes.

2.2.2.1 Nature-Based Solutions: Living Shorelines

Samonte et al. (2017) used the Impact Analysis for Planning (IMPLAN) Input-Output analysis framework to extract direct, indirect, and induced effects on the local economy of conservation and restoration projects carried out under the American Reinvestment and Recovery Act. The projects included fish habitat, salt marsh, and wetland restorations; waterway reconnections; and nature-based solutions such as living shorelines.

Living shorelines restore eroding shorelines by installing organic infrastructure instead of "hard" shoreline protection infrastructure like seawalls. Living shorelines tend to cost less for both initial construction and operations and maintenance than hard shorelines. Vegetation-only shorelines cost on average up to $1,000 per linear foot for initial construction and up to $100 per linear foot each year for operations and maintenance, while seawalls may cost between $5,000 and $10,000 per linear foot for initial construction and over $500 per linear foot each year for operations and maintenance (National Oceanic and Atmospheric Administration, 2015).

Living shorelines allow for natural accretion of tidal wetlands, but they do not prevent inland wetland migration as a result of sea level rise. The benefits of living shorelines also include dissipating wave energy and slowing inland water transfer while preserving wildlife habitats and ecosystem services. In Piscataway Park, Maryland, a 2,800-foot vegetated living shoreline was constructed along the Potomac River, creating habitats for various fish species, improving water quality, and protecting freshwater wetlands. The total economic output (total value of all goods and services produced from the project) of constructing this living shoreline was $2.06 million (2019$ converted from 2012$) (Samonte et al., 2017).

Implementation of living shorelines mainly occurs in low energy areas that are protected from storm surge and large waves; however, in cases where they are feasible, living shorelines may be a cost-effective, nature-based solution to coastal erosion.

2.2.2.2 Protect and Restore Beaches and Sand Dunes

Coastal beaches, dunes, and marshes face the risk of sea level rise and erosion from climate change and will thus need to migrate inland to continue supporting biodiversity and community resilience. Protecting and restoring beaches and dunes will be a key action in protecting communities from severe storms and flooding. This approach can also limit the need for far less desirable approaches such as hard infrastructure (e.g., seawalls) or retreats from the coast. Beach nourishment, or adding beach sand volume to increase beach width, projects can range from $318 to $1,061 per linear foot or between $5 and $32 per cubic yard of sand (2019$ converted from 2016$) according to the National Park Service (2016).

Maine's beaches provide flood protection, habitats for rare species, and recreation and tourism activities. ERG captured these benefits by identifying the costs and losses that Maine would avoid by implementing protection and restoration activities at its beaches and sand dunes. If sea level rise destroys dune habitats, biodiversity may decrease, and it can be costly to recover those populations. The mean and median costs over the project lifetime to recover an endangered species can be $15.9 and $1.4 million, respectively (U.S. Government Accountability Office, 2006). Disappearing beaches and dunes would also affect Maine's beach tourism industry. In the *Cost of Doing Nothing Analysis*, we estimated that if 10.4 million people go to beaches in Maine, and 50 percent of beach area is lost in a 1.6 feet of sea level rise scenario (relative to the level in 2000), the state may lose up to $39 million in consumer surplus associated with beach trips (Eastern Research Group, Inc., 2020).

2.2.3 Recommendations for Further Analysis

Future analyses might include:

- Evaluating a parking or sales tax to go toward managing beaches. Because a high consumer surplus is associated with a positive experience, these taxes could continue to ensure positive beach experiences while bringing some funding into the region.
- Incorporating a comprehensive case study of the implementation and benefits of living shorelines, hybrid (natural and built) approaches, and nature-based solutions—ideally in Maine— for a cost-benefit analysis. This could be a study of an existing project or a proposed project and could model the net-present value of benefits (focused on avoided damages but incorporating other co-benefits if possible, such as increased property values and taxes or support for fishing and recreation) over the anticipated lifetime of the project.

- Performing benefit-cost and economic impact analyses associated with the following beach restoration benefits:
  - Biodiversity and habitat protection.
  - Flood and storm protection.
  - Other ecosystem services offered.
- Incorporating existing planning, regulation, and management activities in Maine and how those activities impact climate adaptation and preparedness. There may be an opportunity to incorporate the typical return on investment of these activities.

2.3 Climate-Ready Working Waterfronts

Strategy 6 of the Coastal and Marine Working Group prioritizes climate-ready planning, land use planning, infrastructure funding support, and resilience guidance and conservation efforts for facilities that truly rely on a waterfront location to conduct operations, such as commercial fishing fleets and aquaculturists, recreational fishing fleets, and marinas and boatyards (to name a few).

Benefits/Impacts: This strategy preserves the important cultural and economic benefits that working waterfronts provide for coastal communities. Lobster, the highest-value fishery in the state, brought in $485 million in landings in 2019 (Maine Department of Marine Resources, 2020). The Coastal Marine Working Group designed this strategy to help this sector adapt to flooding, storm surge, and sea level rise while also reducing greenhouse gas emissions and realizing new opportunities such as ocean energy.

2.3.1 Economic Analysis Results

ERG conducted a literature review of the costs and benefits of climate-ready working waterfronts to inform investment in this strategy. We focused on components of the strategy where cost and benefit information were readily available, specifically expanding participation in the Green Marine program and development of a Working Waterfront Infrastructure Trust Fund.

ERG reviewed the costs and benefits of the Green Marine program and found that an investment of annual program costs (standard fees for all participants) of $2,842 to $10,335 for port authorities and terminals (and up to $17,227 for global multi-sector companies and shipowners) (Green Marine, 2020) reduces greenhouse emissions and provides co-benefits such as reduced nitrogen oxide (NO_X), sulfur oxide (SO_X), and particulate matter emissions, as well as improved waste management.

ERG also reviewed the costs and benefits of a Working Waterfront Infrastructure Trust Fund. In terms of costs, the Coastal and Marine Working Group estimates that a state fund of $1 million could likely finance resiliency improvements at two to 10 medium-sized working waterfronts (e.g., by retrofitting ports and harbors and their attendant docks, sheds, shops, and yards) (Maine Climate Council Coastal and Marine Working Group, 2020a). It is challenging to predict whether such improvements could address all major vulnerabilities along a waterfront community. Regardless, when we look to a waterfront community such as Vinalhaven as an example, waterfront adaptation measures clearly have major benefits. Last year, multiple ferry trips were canceled because of high seas, which make it dangerous to load or unload passengers and cargo from the ferry. As sea levels continue to rise, trips for 140,000 people and 45,000 vehicles to the island are expected to be canceled each year, having economic repercussions and raising emergency access issues (Island Institute & Vinalhaven Sea Level

Rise Comittee, 2020). Cancelations and delays will increase over time as sea level rises, with service limited by high and then lower tides.

2.3.2 Methods and Limitations

Green Marine certification program: ERG conducted a literature review focused on the costs and benefits of the Green Marine certification program. This voluntary environmental certification program for the marine industry uses performance indicators to address key environmental issues, including greenhouse gas emissions.

The Coastal Marine Working Group identified reduced greenhouse gas emissions as a primary benefit of the program.[7] At present, two Maine entities participate in the program: Federal Marine Terminals in Eastport (since 2007) and Bay Ferries Limited in Bar Harbor (since 2018). On a level of performance rating of 1 to 5 (with 5 being best performance) for greenhouses gases and air pollutants, Federal Marine Terminals received a rating of 4 in 2019. This rating indicates that Federal Marine Terminals completed a detailed inventory of its greenhouse gas and air pollutant emissions footprint within the last five years, and that it adopted a performance plan for air emissions resulting directly from its activities—including reduction targets and measures. Bay Ferries Limited received a rating of 2, indicating that it implemented policies and communications that discourage vehicle idling, implemented measures to reduce track congestion and idling, and promoted sustainable transportation practices for employees (Green Marine, 2020).

Overall, the Green Marine progress reports state that the levels of achievement for program participants increase over time, with some of the most improvements seen in the number of terminals, ports, and shipyards that increase their greenhouse gas ratings. Facilities achieve these higher ratings primarily by setting up inventories to benchmark and then reduce emissions (Green Marine, 2020). Public data quantifying emissions reductions are not available to date at the two Maine terminals, nor are there projections for reductions in the event of widespread adoption of the program. However, these broader findings of steady progress by participants over time are promising. Notable, the Green Marine program also encourages responsible environmental performance on other issues such as NO_X, SO_X, and particulate matter emissions and waste management (Green Marine, 2020).

These benefits compare to a relatively moderate annual cost of participation in the program ranging from $2,842 to $10,335 for port authorities and terminals (and up to $17,227 for global multi-sector companies and shipowners) (Green Marine, 2020). A limitation of this review is that we were not able to look at costs beyond annual fees. Participants undoubtedly invest additional resources into conducting the communications activities and emissions inventories required to achieve higher ratings within the program, as well as in implementing improvements to reduce greenhouse gas emissions.

Working waterfront infrastructure: ERG reviewed literature on the costs and benefits of a Working Waterfront Infrastructure Trust Fund to increase the resilience of waterfronts to flooding. Currently, there is no comprehensive assessment of Maine's working waterfront sites that are most vulnerable to sea level rise, flooding, and storm surge impacts, nor are there associated benefit-cost studies. Therefore, we do not have a complete view of where the state should direct funds. However, studies focused on segments of coast, such as the *Penobscot Bay Vulnerability Assessment and Resilience*

[7] It should also be noted that marine emissions per the Maine Department of Environmental Protection are a very small part of the transportation sector, but that greenhouse gas emissions reductions are possible.

Planning Summary Report and the "*Adaptation Planning Study: Downtown Waterfront Area Damariscotta, Maine*" (which each include some cost estimates to improve resiliency), provide a helpful starting point (Wood Environment & Infrastructure Solutions, Inc., 2019; Anon, 2014). We also know that as of 2007, the state has 81 prime working waterfront access points (Island Institute, 2007), which by their nature are situated in areas susceptible to sea level rise impacts.

Studies such as those by Vinalhaven Sea Level Rise Committee looking at sea level rise impacts to ferry transport show that there will undoubtedly be major economic and cultural benefits in preventing damage to or loss of these remaining working waterfronts (Island Institute & Vinalhaven Sea Level Rise Comittee, 2020). In addition, any infrastructure project that would help protect or adapt many fish houses at risk of flooding at 1.6 feet of sea level rise (relative to the level in 2000) would benefit the community. Vinalhaven landed the second most lobsters (by value) every year over the past 5 years compared to all other ports in Maine (Island Institute & Vinalhaven Sea Level Rise Comittee, 2020), and a large portion of the city's workforce is employed in lobstering and fishing. While Vinalhaven provides a case study of a particular community that could benefit from the Working Waterfront Infrastructure Trust Fund, it is challenging to extrapolate this example to communities across the state.

In terms of costs, the Coastal and Marine Working Group provided estimates for how many resiliency improvement projects a state fund of $1 million could likely finance (improvements at two to 10 medium-sized working waterfronts). The proposed fund would be revolving, serving more sites over time.

2.3.1 Recommendations for Further Analysis

Future analyses might include:

- Completing a vulnerability assessment for more working waterfront sites along the Maine coast and analyzing the costs and benefits of adapting some of these sites.
- Conducting a quantitative analysis of greenhouse gas emissions reductions achieved by the two Maine terminals participating in the Green Marine program.
- Analyzing potential reductions for Portland through participation in the Green Marine program.
- Performing case studies on the cost and benefits of technical guidance and assistance materials for municipalities, the State of Maine, and water-dependent business owners as initial program results (related to this strategy) become available.

3. COMMUNITY RESILIENCE, PUBLIC HEALTH, AND EMERGENCY MANAGEMENT

This section includes strategies from the Maine Climate Community Resilience, Public Health, and Emergency Management Working Group, which the following subgroups developed:

- Community Resilience Planning Subgroup (Maine Climate Council Community Resilience Planning Subgroup, 2020d):
  - **Strategy 1:** Perform comprehensive review of Maine laws to achieve resilience and economic security in the face of climate change.
  - **Strategy 2:** Improve the system for delivering technical assistance on resilience to municipalities.
  - **Strategy 3:** Develop funding mechanisms to achieve resilience.
- Emergency Management Subgroup (Maine Climate Council Emergency Management Subgroup, 2020):
  - **Strategy 1:** Develop and implement a non-disaster-related State Infrastructure Climate Adaptation Fund that would allow municipalities and state agencies to access the funds they need to supplement the often excessive local cost shares associated with adaptation projects.
- Public Health Subgroup (Maine Climate Council Public Health Subgroup, 2020):
  - **Strategy 1:** Improve public health behavior related to climate impacts through investments in public health monitoring and education.
  - **Strategy 2:** Conduct public education about climate change health effects and resources.
  - **Strategy 3:** Reduce impacts from high-intensity weather events.
  - **Strategy 4:** Improve health systems' capacity to mitigate and adapt to climate change.

3.1 Perform Comprehensive Review of Maine Laws to Achieve Resilience and Economic Security

Strategy 1 from the Community Resilience Planning Subgroup calls for a comprehensive review and revision of several Maine statutes and their associated regulations that are integral to supporting municipal, regional, and state-level adaptation and resilience.

Benefits: The review and revision will lead to reduced regulatory burdens on projects that achieve resilience, resulting in faster implementation of resilience projects, faster approval and financing of development in city and community centers, and faster realization of associated economic recovery. The strategy calls for linking rule changes with improved technical assistance and training to inform implementation and obtain ongoing input from impacted communities (Maine Climate Council Community Resilience Planning Subgroup, 2020d).

3.1.1 Economic Analysis Results

ERG conducted a literature review focused on the benefits and costs of reviewing and revising Maine statutes related to adaption and resilience. The review provides a qualitative look at benefits, noting that this strategy supports time- and cost-efficient implementation of many other adaptation and resilience strategies mentioned throughout this report. Other sections provide more detailed economic analyses of these strategies. In addition, ERG determined that other states, such as New York, have found that state lawmaking provides an opportunity to benefit municipal adaptation (Adams-Schoen, 2018).

In considering the cost of this strategy, ERG used the Community Resilience Planning Subgroup's estimated minimum costs of statutory review and trainings of $350,000 to $480,000 (Maine Climate Council Community Resilience Planning Subgroup, 2020d). The subgroup indicated that key activities (and costs) can be implemented by 2022. Additional costs to consider in the future include local-level updates to ordinances and maps as well as impacts to town tax bases when some properties become unbuildable.

3.1.2 Methods and Limitations

On the benefits side, this strategy supports time- and cost-efficient implementation of many other resilience strategies promoted by the working groups (ranging from coastal protection to actions to reduce incidence of vector-borne disease). While no economic benefit information is available for reviewing state statutes, examples from other states point to the need for and benefit of state lawmaking to support and empower local government work to promote resilience. New York State's Community Risk and Resiliency Act of 2014 provides an example of state mandates and incentives that help local governments overcome obstacles to decreasing development in vulnerable areas (Adams-Schoen, 2018).

The Community Resilience Planning Subgroup estimated the following initial costs for implementing this strategy:

- Contracted services to develop/revise statutes and rules if beyond the capacity of existing agency staff ($100,000 to 130,000 paid by the state).
- Training costs (at the state level) associated with:
  - An expanded code enforcement and planning board training program ($50,000).
  - Training of review staff in state agencies ($50,000).
  - Partnerships or contracts with Maine Municipal Association and regional planning agencies ($100,000 to $200,000).
  - Certification for contractors in resilient design practices ($50,000).

These costs sum to $350,000 to $480,000. In addition, there will be costs at the local level to update ordinances and maps. There will also be economic consequences at the local level to town tax bases when some properties become unbuildable. These costs have not yet been estimated.

3.1.3 Recommendations for Further Analysis

Future analyses might include:

- Analyzing avoided damages versus lost tax base when revised state and local statutes make properties unbuildable.

- Estimating the cost of local level updates to ordinances and maps.
- Analyzing project cost savings due to reduced regulatory burden and faster implementation.
- Analyzing increased speed of economic recovery (post disaster) due to reduced regulatory burden.

3.2 Improve Technical Assistance

Strategy 2 of the Community Resiliency Planning Subgroup improves the system for delivering technical assistance on resilience to municipalities and establishes institutional infrastructure at the state and regional levels to support resilience in all municipalities. The strategy applies existing governance structures, provides access to the most recent data and tools, and tailors assistance to municipal needs and capacity.

Benefits: By investing in technical capacity building for municipalities and creating funding mechanisms, these strategies will provide the foundation to support the resilience strategies developed by each subgroup.

3.2.1 Economic Analysis Results

To determine the costs and benefits of Strategy 2, ERG evaluated the avoided costs of each region and large municipality hiring their own resilience planning/technical assistance staff. We found that by focusing grant and operating support to regional agencies and hiring planners who can play many roles (in addition to resilience planning), the State of Maine can avoid up to $425,000 in annual costs.

3.2.2 Methods and Limitations

ERG conducted a literature review focused on the benefits and costs of building technical capacity for adaption and resilience.

The Land Use Planning Commission led a survey to determine municipal planning capacity, specifically asking about staff training on resilience planning issues. The survey results indicate that while the largest Maine cities have in-house planning staff with resilience training, most other municipalities do not. Many municipalities fill this gap with regional planning staff.

However, all the municipalities marked in red in Figure 1 receive neither local nor regional resilience planning staff support. If the State were to fill this capacity gap by hiring 12-15 regional planners and 10 local planners (with resilience training) for larger municipalities at a salary cost of $65,000[8], the annual cost would be $1, 430,000 to $1,6250,000. However, Strategy 2 (budgeted at $1.2 million_ focuses on increasing grant and operating support to regional agencies so they can hire planners who can support resilience planning among other needs. This approach could avoid up to $425,000 in annual costs (these avoided costs are a key benefit of Strategy 2).

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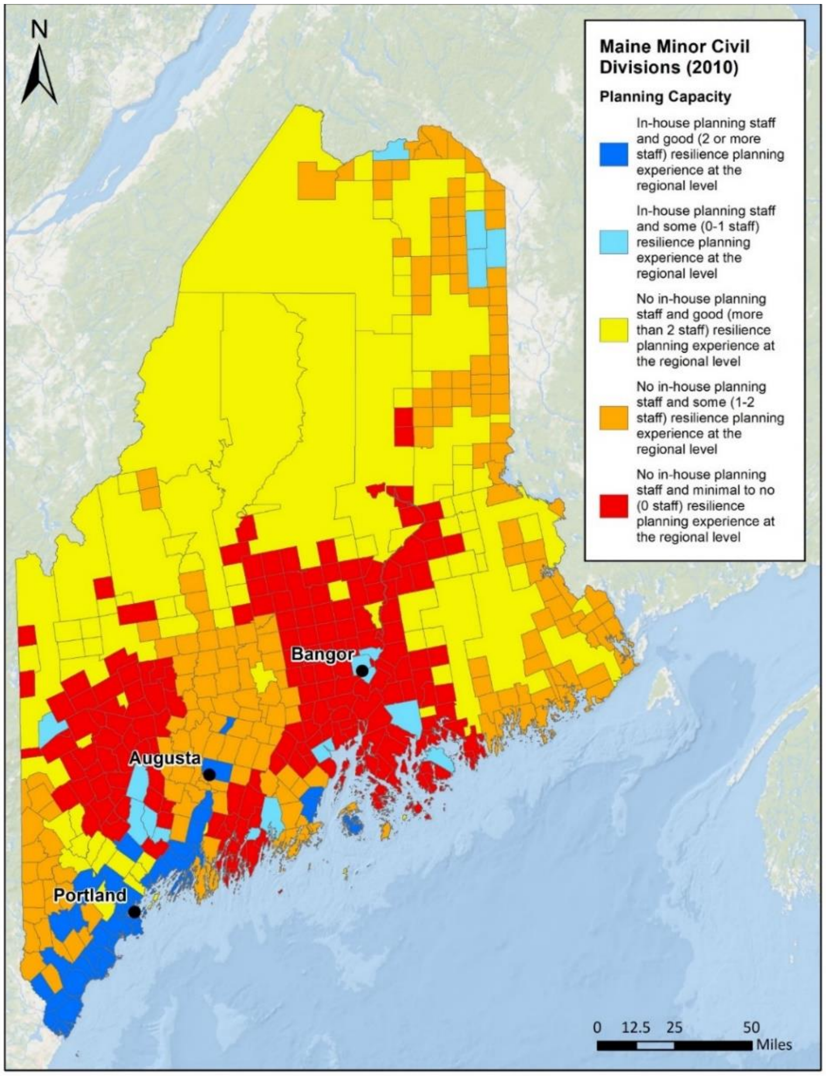
[8] Salary estimate provided by Land Use Planning Commission. If all salary benefits are included, cost to state budgets may be higher.



Service Layer Credits: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 1. Municipal resilience planning capacity across the state (by minor civil division).

The Community Resiliency Planning Subgroup has estimated the costs of implementing Strategy 2 as follows:

- $600,000 for new state personnel
- $500,000 for additional contractual support for regional staffing
- $100,000 for development of training programs

This sums to a total of $1.2 million from the State of Maine’s General Fund to implement the strategy.

3.2.3 Recommendations for Further Analysis

Future analyses might include:

- Assessing equitable distribution of this technical support.

- Performing a benefit-cost analysis of the outcomes of technical assistance.

3.3 Develop Funding Mechanisms for Resilience

Strategy 3 of the Community Resiliency Planning Subgroup creates funding mechanisms to achieve resilience. It recommends executive orders to establish cabinet-level coordination across state agencies so that funding priorities are consistent and can reach communities and regional organizations that are ready to implement adaptation solutions.

Benefits: Funding resilience projects will encourage job creation (in design, construction, project management, operations, and maintenance) and support additional benefits to communities, including avoided economic disruptions, social continuity, and reduced response times after disasters.

3.3.1 Economic Analysis Results

ERG conducted a literature review on qualitative costs and benefits related to Strategy 3. Benefits and impacts of the strategy are wide-ranging, as it provides funding support across resilience projects. Coastal resiliency planning through the Southern Maine Regional Planning Commission provides an example of how further support and funding for regional bodies can support local-level resilience planning. More detailed planning and costing is necessary to identify the increased staff capacity and size of revolving funds and grant programs that the State of Maine will create moving forward. More broadly, ERG looked at national-level literature, which shows an average benefit-cost ratio for investing in hazard mitigation strategies of 6:1 (National Institute of Building Sciences, 2019).

3.3.2 Methods and Limitations

A key benefit of Strategy 3 is the creation of consistent funding priorities and streams that enable communities and regional organizations to implement adaptation solutions. The strategy provides a range of funding options from public and private sources as well as creative financing ideas within and beyond Maine's borders, including support for the Emergency Management Subgroup's proposed State Infrastructure Climate Adaptation Fund. The specific benefits achieved will depend on specific projects and initiatives that receive funding.

Broadly, we can look to existing examples of regional organizations providing benefits to local municipalities in the state. For example, the Southern Maine Regional Planning Commission conducts economic development, environmental, land use, and transportation planning and provides technical assistance to 39 municipalities. The Commission also increasingly provides climate resilience planning support. In January 2020, the Commission hired a new Coordinator for Regional Sustainability and Coastal Resiliency to develop local and regional climate action and coastal resiliency plans. This increased regional planning capacity will benefit several jurisdictions (Sullivan, 2020). In addition, the Southern Maine Regional Planning Commission was awarded a Coastal Communities Grant in July 2020 to develop a model ordinance for community resilience that could be adapted to a variety of local circumstances. This is another example of how the State of Maine can cost-effectively use resources to update local ordinances.

In terms of the costs to implement Strategy 3, the Community Resiliency Planning Subgroup outlined several overarching budget needs that will require detailed costing moving forward. These include:

- Funding the administrative costs associated with issuing executive orders, involving the public, and engaging state agencies around revised program criteria. Example costs include hiring additional staff across several agencies and developing online and in-person engagement materials.
- Providing funding support to municipalities to coordinate with neighbors.
- Increasing financial support to regional planning agencies.
- Developing new mechanisms to finance natural infrastructure for risk reduction.
- Establishing a State Infrastructure Climate Adaptation Fund (as recommended by the Emergency Management Subgroup).
- Establishing a Maine Climate Corps (Maine Climate Council Community Resilience Planning Subgroup, 2020d).

As we await more detailed budgeting, existing studies indicate that we can expect a positive benefit-cost ratio when we invest in hazard mitigation projects. A recently updated study from the National Institute of Building Sciences (2019) found that benefit-cost ratios for updating building codes and adapting to hazards ranged from 11:1 to 4:1 (based on codes and federal grant applied), indicating that these projects are a wise investment.

3.3.3 Recommendations for Further Analysis

Future analyses might include detailed costing of each Strategy 3 action for creating financing mechanisms.

3.4 Develop and Implement a State Infrastructure Climate Adaptation Fund

Strategy 1 of the Emergency Management Subgroup calls for developing and implementing a non-disaster-related State Infrastructure Climate Adaptation Fund that would allow municipalities and state agencies to access the funds they need to supplement the often excessive local cost shares associated with adaptation projects. The subgroup explains that Maine currently has a backlog of 1,798 projects to mitigate climate impacts at a proposed cost of $325 million across all 16 counties, with many projects deferred due to lack of local cost shares. This Emergency Management Subgroup strategy will help solve this problem (Maine Climate Council Emergency Management Subgroup, 2020).

Benefits: Key benefits of the strategy include increased participation in the National Flood Insurance Program and development of a funding pipeline for adaptation projects, leading to implementation on the ground. Ultimately, this strategy will support implementation of many adaptation strategies recommended by the other working groups and lead to reduced disaster recovery costs and damages.

3.4.1 Economic Analysis Results

ERG approached this strategy by reviewing literature on the return on investment for similar state funds as well as the costs and benefits of investing in adaptation more generally. Reviewing similar state funds showed the opportunity to leverage these dollars into a larger federal grant for hazard mitigation (given that many federal grants require a local match). Moreover, the National Institute of Building Sciences (2019) reports a cost-benefit ratio of 1:6 for several major federal funds related to disaster mitigation.

3.4.2 Methods and Limitations

The return on investment for the adaptation fund can be calculated in terms of additional dollars leveraged from federal funding. Looking to many other state examples, we can see a range of state disaster and emergency relief funds that provide a portion of non-federal cost shares under FEMA's Hazard Mitigation Grant Program, with those cost shares generally ranging from 10 percent to 25 percent state and 0 percent to 13 percent local (Maine Climate Council Emergency Management Subgroup, 2020). Should Maine follow a similar example and give municipalities matching funds, we will see them leverage federal adaptation dollars several times larger than the budgets provided by local or state funding.

Broadly, the State Infrastructure Climate Adaptation Fund will support implementation of a range of adaptation strategies, many of which have proven to show net benefits over time. The National Institute of Building Sciences' *National Hazard Mitigation Saves: 2018 Interim Report* considers the benefits of FEMA post-disaster funds as well as several other federal disaster mitigation-related funds over a 23-year period and reports benefit-cost ratios. The study found that these grants returned $6 in value for every $1 invested (National Institute of Building Sciences, 2019).

Through County Hazard Mitigation Plans, $325 million dollars in backlogged project needs have been identified. Assuming a 25% percent municipality/state cost share requirement for federal hazard mitigation grants, $325 million accessed through a state climate adaptation find over time can open an additional $975 million in federal dollars (about $1.3 billion total). For a project with a 6 to 1 benefit-cost ratio overall, this could be about a $7.8 billion benefit and approximately a 24 to 1 benefit-cost ratio based on the state and local contributions ratio.

A recent engineering analysis of the Saco Water Resource Recovery Facility exemplifies the need for such a match. Engineering consultant Tighe and Bond (2019) estimated that it will cost $10,800,000 ("opinion of probable cost") to protect the facility from 3 feet of sea level rise and a 1 percent annual change storm. If the City of Saco's Water Resource Recovery Department identifies federal funds for 75 percent of the costs, securing funds for the remaining $2,700,000 presents a major challenge (Maine Climate Council Emergency Management Subgroup, 2020). This is where the State Infrastructure Climate Adaptation Fund could assist. If match requirements are reduced or eliminated in the future, state funds could be used to top off project funding.

The Emergency Management Subgroup does not expect costs to develop and implement the fund beyond the dollars allocated to the fund itself (no major developmental or administrative costs are expected).

3.4.3 Recommendations for Further Analysis

Moving forward, an economic analysis focused on those $325 million in backlogged projects could help further prioritize projects.

3.5 Improve Public Health Behavior Related to Climate Impacts through Investments in Monitoring and Education

Strategy 1 of the Public Health Subgroup calls for improved statewide public health monitoring and education capacity related to climate change impacts, including air allergens, particulate matter, ozone depletion, harmful algal blooms, vector-borne diseases, and increased browntail moth populations and *Vibrio* infections.

Benefits: The strategy provides public health programs the data they need to appropriately identify and address emerging public health issues. In addition, it supports efficient use of resources, ensuring that the most pressing issues receive funding. Ultimately, the strategy will lead to disease prevention—for example, through an emergency shellfish fisheries closure due to a harmful algal bloom or long-term management of Lyme disease risk (Maine Climate Council Public Health Subgroup, 2020).

3.5.1 Economic Analysis Results

ERG conducted a literature review focused on the costs and benefits of a subset of the activities recommended by the Public Heath Subgroup under this strategy—specifically, improved vector monitoring to limit the spread of Lyme disease and eastern equine encephalitis.

Increased incidences of Lyme disease are associated with the range expansion of deer ticks, which is attributed to expanding white-tailed deer populations, suburban development in forested areas, and warmer/shorter winters. ERG found that actions to limit Lyme disease can avoid costs of treating patients with Lyme disease across the state. In 2018, the Maine Center for Disease Control (CDC) reported 1,405 new patients with Lyme disease. We estimate that cost to treat these patients is approximately $11.5 million (based on 2018 patient numbers), and these patient numbers (and associated costs) are expected to grow without intervention. These increasing costs juxtapose the cost of expanded and consistent monitoring and public education around tick-borne illness and prevention (cost estimates will be needed from Maine CDC moving forward).

ERG found that actions to limit eastern equine encephalitis is another benefit of improved vector monitoring. While outbreaks in Maine have been limited to date, the science indicates that they are likely to rise (Birkel & Mayewski, 2018). Climate change leads to increases in summer precipitation and humidity, increased frequency of extreme rain events, earlier degree day accumulation, and warmer falls, which create conditions that exacerbate eastern equine encephalitis transmission (Birkel & Mayewski, 2018). In 2018, patients who suffered a transient episode faced approximately $40,360 (2018$ converted from 1995$) in direct medical costs, while those who suffered from residual sequela from eastern equine encephalitis faced direct intervention costs of about $5.76 million (2018$ converted from 1995$) per patient over their lifetimes (Villari, 1995).

Maine can avoid some of these health costs by spending on consistent vector disease monitoring and control measures. For example, mosquito control districts in Massachusetts have an annual budget of more than $2 million.

3.5.2 Methods and Limitations

A key benefit of Strategy 1 is the avoided costs of treating patients with Lyme disease across the state. In 2018, Maine CDC reported 1,405 new patients with Lyme disease. As discussed in the *Cost of Doing Nothing Analysis*, the cost to treat these patients is approximately $11.5 million. Both these case numbers and total treatment costs are expected to continue rising without major interventions in tick monitoring and control (or without major reductions in global greenhouse gas emissions to limit climate change). These increases juxtapose the costs of expanded and consistent monitoring and public education around tick-borne illness and prevention. Maine CDC and partners will work on costing these activities as the strategy moves forward.

Avoided costs of treating future eastern equine encephalitis patients is another benefit of improved vector monitoring. While outbreaks in Maine have been limited to date (and the specifics of future outbreaks are hard to project), the science indicates that outbreaks are likely to rise (Birkel & Mayewski, 2018). As discussed in the *Cost of Doing Nothing Analysis*, patients who suffered a transient episode faced approximately $40,360 (2018$) in direct medical costs, whereas those who suffered from residual sequela due to eastern equine encephalitis faced direct intervention costs of about $5.76 million (2018$) per patient over their lifetimes (Villari, 1995). Clearly, costs would quickly multiply in the case of a major outbreak. With a monitoring program in place across the state, public health officials could quickly identify the emergence of an outbreak or prime conditions for an outbreak and respond rapidly and appropriately to keep the public safe.

The costs of treating eastern equine encephalitis juxtapose the costs of more consistent mosquito disease monitoring and control measures. The annual budget of mosquito control districts in Massachusetts—amounting to more than $2 million—provides a point of reference in terms of costs (Maine Climate Council Public Health Subgroup, 2020), with increased costs to spray during an outbreak.

3.5.3 Recommendations for Further Analysis

Future analyses might include:

- Identifying specific costs for the state for spray programs that could impact commercially important industries such as commercial fisheries and the lobster industry.
- Performing detailed costing of an expanded tick and Lyme disease monitoring and education program.

3.6 Conduct Public Education About Climate Change Health Effects and Resources

Strategy 2 of the Public Health Subgroup calls for actions to increase the statewide capacity to provide public health education about climate change effects and resources. Specifically, this action recommends investing in Maine's Center for Disease Control and Prevention and Department of Environmental Protection's public education efforts around the health effects of climate change, such as vector-borne diseases and wood smoke, and the State's available programs and resources, including air quality alerts, and high heat and cold warnings, which can help the public stay safe under adverse environmental conditions.

Benefits: Public health programs and outreach will ultimately help the public adapt to the impacts of climate change. For example, the public will have the information and tools needed to reduce their exposure to vector-borne diseases and to know when and where to go to cool off on an extreme heat day (Maine Climate Council Public Health Subgroup, 2020).

3.6.1 Economic Analysis Results

ERG conducted a literature review focused on the costs and benefits of a subset of the education and outreach activities recommended by the Public Heath Subgroup under this strategy—specifically, improved woodstove exchange and outreach around managing high heat index days.

Old wood stoves emit a mixture of harmful gases and small particles that can cause asthma attacks and severe bronchitis, aggravate heart and lung disease, and increase the likelihood of respiratory illnesses

(Burn Wise, 2019). ERG found that a program to exchange old wood stoves can help avoid some of the health costs associated with treating these illnesses. Costs range from a few hundred dollars for an asthma-related hospital visit to up to $50,100 for cardiovascular symptoms or a respiratory hospital admission (Black, 2006).

Vermont's woodstove exchange program provides an example of the costs for the State of Maine to create such a program. As of May 2019, Vermont used $700,000 in funds to replace 359 stoves (Amy Kolb, 2019), with some funding remaining for additional replacements.

ERG also found that by educating residents about the risks of high heat index days, Maine can save an estimated $1.9 to $3.2 million in healthcare costs in 2050 and $2.9 to $8.1 million in 2100, given projected increases in high heat days. Additional work is needed to estimate staff needs (and associated budget needs) to adequately expand public health outreach.

3.6.2 Methods and Limitations

Strategy 2 highlights the need for a broad woodstove exchange program across the state (and a public education campaign to encourage participation). Such a program would lead homeowners to use clean-burning, high-efficiency stoves, which could reduce greenhouse emissions (although this was not calculated) and provide the co-benefit of avoiding the health impacts of poor indoor air quality. Studies assessing the economic cost of particulate matter-related illnesses estimate the following direct costs (each study's methods vary) (Black, 2006):

- Hospitalization for cardiovascular symptoms: $28,300 to 50,100 (2019$)
- Respiratory hospital admission: $8,500 to 50,100 (2019$)
- Asthma (no hospital admission): $240 to 410 (2019$)

More information is needed about the number of Maine residents living with outdated stoves as well as an analysis of the number of health incidents avoided by replacing those stoves. These initial health costs provide a starting point for considering costs to avoid in the future.

In terms of costs to implement the program, the stove exchange program in Vermont provides an example. Its first round of funding ($300,000) in 2016–2017 supported the replacement of 247 stoves. Vermont is in the midst of a second round of stove funding ($400,000)—as of May 2019, the program exchanged 112 additional stoves (Amy Kolb, 2019).

Strategy 2 also emphasizes the need for outreach and education around preparing for and responding to high heat index days. As discussed in ERG's (2020) *Cost of Doing Nothing Analysis*, high heat index days (which feel like 90 °F or hotter) are increasing in Maine. Moreover, exposure to extreme heat is linked to a range of negative health outcomes, including heatstroke and heat exhaustion; renal failure; dehydration; exacerbations of existing cardiovascular, respiratory, cerebrovascular, and diabetes-related conditions; effects on fetal health; preterm births; and mental health conditions .

Each year, Mainers experience an average of just over 200 emergency department visits and almost 15 hospitalizations for heat-related illnesses (Maine CDC, 2020). These health care costs sum to at least $224,000 per year. If emergency room visits and hospital visits are directly proportional to the number of days with a heat index over 90 °F, health care costs will be nine to 14 times higher in 2050 (costing

$1.9 to $3.2 million) and 13 to 36 times higher (costing $2.9 to $8.1 million) in 2100. Through public health education and related steps, the State of Maine can avoid some of these costs.

In terms of the costs to implement public education around high heat days, the Public Health Subgroup explained that the primary costs for all activities under this strategy would be for increased staffing. Moving forward, a specific assessment of staffing needs will be necessary.

3.6.3 Recommendations for Further Analysis

Future analyses might include:

- Assessing the number of staff needed to expand public health education programming (and the associated costs).
- Researching the number of Maine residents living with outdated woodstoves.
- Determining expected health incidents that can be avoided if woodstoves are replaced.

3.7 Reduce Impacts from High-Intensity Weather Events

Strategy 3 from the Public Health Subgroup will increase preparedness for—and thus decrease the impacts of—high-intensity weather events on water systems and public health. The strategy will specifically aim to regulate activities that may release chemical contaminants into drinking water supplies, abate combined sewer overflow discharges, monitor corresponding harmful algal blooms, and assess vulnerability of drinking water wells from flood inundation due to climate change.

Benefits: The outlined actions for this strategy will protect water sources, ensure the sustainability of drinking water in Maine, and prevent health risks to both humans and shellfish from water contaminants. By growing and improving infrastructure around land use measures and shellfish habitats, this strategy will also increase land values and promote a sustainable shellfish industry. Investing in preventive measures such as those outlined above will also reduce costs associated with remediation, treatment, and monitoring of these high intensity weather impacts.

3.7.1 Economic Analysis Results

ERG performed a literature review to identify the benefits and costs of taking mitigating actions to prevent combined sewer overflow discharges. Combined sewer overflows occur most frequently during high-intensity weather events that cause excessive precipitation or seasonal flooding.

The costs of this strategy will be associated with replacing and improving combined sewer infrastructure to prevent discharges. The Maine Department of Environmental Protection estimates that over the next five years, continued combined sewer overflow abatement actions will cost approximately $232 million (2019$), adding to the $634 million spent throughout Maine since 1989. The current combined sewer overflow abatement projects, however, may not consider the effect of climate change on precipitation levels.

The benefits of this strategy are, in part, the avoided costs from overflow damages. Examples of costs that Maine would avoid by preventing discharges include:

- $2.2 million loss from shellfish harvesting closures in Machias Bay (revenue lost between 2001-2009, 2019$ figure converted from 2014$) (Evans et al., 2016).
- $10,000 to $10 million annually for harmful algal bloom treatment (Maine Climate Council Public Health Subgroup, 2020).
- $10,000 to $1 million or more per watershed chemical pollution cleanup (Maine Climate Council Public Health Subgroup, 2020).

3.7.2 Methods and Limitations

ERG performed a literature review focused on common costs associated with combined sewer overflow abatement. The Maine Department of Environmental Protection tracks the state's combined sewer overflow discharges each year in a status report, eliciting spending updates from communities on their combined sewer system abatement activities (Maine Department of Environmental Protection, 2020b; Maine Department of Environmental Protection, 2019). These activities include installing wastewater storage tanks, separating sewer systems, and permanently closing combined sewer overflow locations and would be part of the costs of implementing this strategy.

ERG quantified the benefits associated with reducing combined sewer overflow discharges using the costs of such overflows that communities would avoid. Discharges of untreated sewage water may release solids, industrial pollutants, or bacteria such as *E. coli* into public water bodies, which may then contaminate drinking water supplies and worsen harmful algal blooms (Madoux-Humery et al., 2016; Maine Climate Council Public Health Subgroup, 2020; Maine Department of Environmental Protection, 2020b). The chemical pollution cleanup from such an event may cost from tens of thousands to millions of dollars depending on the amount of chemicals, area polluted, and complexity of the cleanup effort (Maine Climate Council Public Health Subgroup, 2020). Similarly, when a harmful algal bloom occurs, it may cost $10,000 to $10 million dollars to relocate the water source's intakes, treat the water for the algal bloom, and conduct long-term water quality monitoring (Maine Climate Council Public Health Subgroup, 2020).

If these contaminants also enter recreational or fishing waters, they can cause beach and shellfish area closures. Evans et al. (2016) found that combined sewer overflows led to the closure of waters in Machias Bay, Maine, to shellfish harvesting for 89 months between 2001 and 2009. These closures resulted in a loss of 1.3 million pounds of clams, or $2 million in revenue.

Maine can decrease or eliminate the costs presented above by preventing combined sewer overflow discharges and thus realize the benefits of this strategy.

These avoided costs do not represent the full range of benefits of mitigating and preventing future combined sewer overflow discharges to Maine communities. The potential overflow impacts that ERG has presented may not occur with every event, making it difficult to calculate the generalized cost of a combined sewer overflow discharge and the subsequent costs avoided by implementing this strategy. This analysis also does not quantify benefits such as increased land value or reduced health risks.

3.7.3 Recommendations for Further Analysis

Future analyses might include:

- An investigation into the other benefits of this strategy, such as reducing health risks to humans by ensuring clean and sustainable drinking water.
- An investigation into the benefits associated with promoting green space, recreational areas, and land value with better regulated land use.

3.8 Improve Health Systems' Capacity to Mitigate and Adapt to Climate Change

Strategy 4 of the Public Health Subgroup focuses on developing and implementing adaptation and mitigation strategies that enable health systems to respond to climate change. The goal is for Maine's four largest health systems to reach carbon neutrality within the next six years. The ability of these health systems to develop and implement adaptation plans for extreme weather events is also a key goal of this strategy.

Benefits: Key benefits of this strategy include energy cost savings, reduced energy consumption coupled with less significant impacts on hospital profitability, and improved awareness of energy consumption on the part of both hospital workers and patients. For this analysis, ERG focused on mitigation efforts and did not include the potential adaptation benefits of this strategy.

3.8.1 Economic Analysis Results

ERG conducted a literature review of the costs and benefits of energy conservation measures that hospitals can implement. Additional aspects of this strategy are not recognized monetarily, such as positive health outcomes as a result of reduced emissions or the secondary effects of implementing initiatives to reduce energy consumption (e.g., health system staff's increased awareness of energy usage, which is subsequently passed onto patients). As presented in the below case study from the Gundersen Health System, Fort HealthCare Hospital in Wisconsin cut its energy costs by identifying and implementing multiple energy conservation measures. To estimate CO_2 reductions for Maine's health systems based on the Fort HealthCare example, we need a combination of data on their annual energy usage per square foot, their size, and the amount of CO_2 they emit per kilowatt-hour (kWh).

SUCCESS STORY: FORT HEALTHCARE HOSPITAL
The Fort HealthCare facility in Fort Atkinson, Wisconsin, represents an example of the cost savings that can be recognized by instituting measures to reduce energy use. The hospital identified a wide array of energy conservation measures, including retro-commissioning air handling units and upgrading LED lighting systems and heating, ventilation, and air conditioning (HVAC) units. Before implementing these measures, Fort HealthCare used about 78.7 kWh per square foot, which amounts to spending approximately $1 million a year on energy (Gundersen Health System, 2020). After implementing the energy conservation measures, recognized energy cost savings totaled $361,000 a year, and CO2 emissions decreased by nearly 4,000 metric tons.

3.8.2 Methods and Limitations

ERG searched for literature on energy conservation measures and their resulting cost savings. ERG also looked for case studies of hospitals that instituted plans for reducing emissions and cut energy costs. One paper presented a theoretical project to reduce carbon emissions and estimated the cost savings resulting from these efforts (Bookhart, 2008). Gundersen Health System provided the most concrete examples of the cost-effectiveness of climate change adaptation and mitigation plans. While ERG presented a case study at only the Fort HealthCare facility, Gundersen has multiple others that highlight the measures hospitals implemented and the cost savings they achieved. These case study hospitals are located in the Midwest.

Error! Reference source not found. shows the framework of the benefits that the Fort HealthCare facility experienced. Maine could use this framework to estimate CO_2 emission reductions for a health system in the state given certain variables (such as the size of the facility and how much energy it uses per square foot). The CO_2 emissions metric shown in this table is a national average of CO_2 emissions per kWh of electricity usage as of 2018 (EIA, 2020).

Table 10. CO_2 Emissions Reduction Framework – Fort HealthCare Facility

Parameters		Value
Health system size (square feet)	a	310,000
Energy use (kWh per square foot)	b	0.07872
CO_2 emissions (metric tons per kWh)	c	0.00045
kWh used at the facility	d = a*b	24,403
Metric tons of CO_2 reduced daily	e = c*d	10.96
Metric tons of CO_2 reduced annually	f = e*365	4,000

Source: Gundersen Health System, 2020; EIA, 2020.

3.8.3 Recommendations for Further Analysis

This analysis looked at the complete cost savings and CO_2 reductions as a result of multiple, simultaneous actions. One suggestion for future analysis is to cost out specific measures and the impacts that they have on CO_2 emissions. Studies into the cost-effectiveness of actions such as HVAC system replacement and protocols for automatic computer shut-off within health systems could help identify individual measures that are the most impactful and cost-effective.

4. NATURAL AND WORKING LANDS

This section evaluates the costs and benefits of investing in the protection and conservation of natural and working lands. The key findings described below apply (at a high level) to each strategy developed by the Maine Climate Council Natural and Working Lands Working Group (2020):

- **Strategy 1:** Protect and conserve natural and working lands and waters through a dedicated, sustained funding source to support a robust forest product and an agricultural economy, increase carbon storage opportunities, avoid future emissions, and enhance climate adaptation and resilience.
- **Strategy 2:** Create new and update existing financial incentives and support for private land management and infrastructure that supports climate mitigation and adaptation.
- **Strategy 3:** Provide technical assistance on natural climate solutions to landowners, land managers, and agricultural producers.
- **Strategy 4:** Update and refocus state programs and policies to address climate mitigation and resilience.
- **Strategy 5:** Strengthen research and development, as well as monitoring of climate mitigation and adaptation practices.

Many of these strategies do not lend themselves to monetization; however, together, they ultimately help to conserve land and sequester CO_2. Thus, we have focused our economic analysis on the cost-effectiveness of protecting and conserving natural and working lands to provide quantitative insight into the decision-making for protecting those lands as a sequestration strategy. Additionally, nature-based solutions from natural and working lands could similarly play a key role in mitigating flooding impacts. See Section 2.2, which references the approximately 6:1 benefit-cost ratio for flood mitigation strategies. We have not captured this below in detail because of the overlap with the likely return on investment presented in Section 2.2.

4.1 Protect and Conserve Natural and Working Lands

The strategies from the Natural and Working Lands Working Group protect and conserve these lands and waters through a dedicated, sustained funding source to support a robust forest product and agricultural economy, increase carbon storage opportunities, avoid future emissions, and enhance climate adaptation and resilience.

Benefits: A dedicated funding stream could implement an array of projects to reduce emissions by protecting lands that store carbon. Forests currently sequester around 75 percent of current CO_2 emissions in Maine, storing 13 million metric tons of carbon per year. In addition, Maine's forest and agricultural industries comprise 7 percent of Maine's workforce and account for $12 billion in sales every year (Maine Climate Council Natural and Working Lands Working Group, 2020). These substantial economic contributions depend on forests and farmland remaining available and affordable (Maine Climate Council Natural and Working Lands Working Group, 2020).

4.1.1 Economic Analysis Results

ERG analyzed several scenarios for cost-effectiveness of carbon storage given different rates of land conservation between 2020 and 2100. The results can be found in Table 11. These strategies for preserving land from development are relatively cost-effective, ranging from about $4 to $19 per metric ton of carbon sequestered. A high initial investment is the most cost-effective, conserving 100 percent of lands that would have been developed between 2020 and 2040. This plan of conserving 100 percent of forests (10,000 acres per year until 2030 and 15,000 acres per year until 2040) until 2040 would cost $4 per metric ton of carbon sequestered when considering all sequestration through 2100.

Out of our modeled scenarios, the plan that would sequester the most carbon by 2100 would be a slow increase in conserved land of 2 percent each year starting in 2020, which would reach 100 percent in the year 2069, effectively prohibiting the development of forests (Table 11). The timberland scenarios that protect forests from being harvested for wood products are slightly less cost-effective for sequestering carbon during the same time period. This is because the land still sequesters a relatively high amount of carbon from wood harvesting even if it is not conserved.

It is harder to establish emissions changes for agricultural lands because they serve as a source of both emissions and sequestration. Currently, farms are an overall source of emissions, but they can reduce their emissions by increasing crop cover, reducing tillage, and increasing nutrient management practices. Additionally, agricultural land covers much less area (about 3 percent compared to forests); therefore, forests will have a vastly greater ability to sequester carbon compared to agricultural land. For example, a scenario that increases crop cover by 25 percent, the use of reduced or no-till adoption by 75 percent, and the adoption of nutrient management practices by 25 percent would reduce carbon emissions and increase carbon sequestration by a net 66,000 to 133,000 metric tons of carbon per year at a societal cost of $3.37 to $6.79 million (based on the lower limit of the social cost of carbon in 2020).

Table 11. Cost-Effectiveness of Carbon Sequestration

	Acreage Conserved [a]	Carbon Sequestered [a]	Cost (USD)	Cost (USD) per Metric Ton of Carbon Sequestered		
				By 2030	By 2050	By 2100
Forest Development Model	-	-	-	-	-	-
1% increase each year	636,100	6,789,504	$72,933,452	$65	$27	$11
2% increase each year	1,073,800	12,687,365	$123,118,913	$65	$27	$10
10% + 1% each year	763,000	8,701,936	$87,483,452	$53	$24	$10
20% annually	282,000	4,249,849	$32,333,333	$47	$19	$8
Initial investment	260,000	7,429,678	$29,810,875	$47	$14	$4
50% until 2050	205,000	5,415,473	$23,504,728	$47	$19	$4
Timberland Model	-	-	-	-	-	-
1% increase each year	637,632	3,809,857	$73,109,106	$123	$48	$19
2% increase each year	1,084,800	7,167,246	$124,380,142	$123	$48	$17
10% + 1% each year	777,600	5,049,208	$89,157,447	$100	$41	$18
20% annually	311,040	2,754,113	$35,662,979	$88	$33	$13
Initial investment	403,200	6,182,449	$46,229,787	$88	$25	$7
50% until 2050	297,600	4,241,882	$34,121,986	$88	$33	$8

[a] Over the entire study period from 2020 to 2050.

4.1.2 Methods and Limitations

Impacts from land-use change: ERG created two models to capture the amount of carbon that Maine could sequester if it increases land conservation. The first model is based on conserving forests that would otherwise be developed. The Maine Climate Council Natural and Working Lands Working Group estimated that about 10,000 acres will be developed each year between 2020 and 2030, approximately 15,000 acres each year after 2030 until 2050, and 20,000 acres each year after 2050 until the end of our analysis in 2100. The parameters for the model can be found in Table 12. ERG ran the following six scenarios for each model:

- Start with 1 percent conservation and increase 1 percent each year (1 percent increase).
- Start with 2 percent in year 2020 and increase 2 percent each year (2 percent increase).
- Start with 10 percent conservation in year 2020 and increase 1 percent each year (10 percent initial + 1 percent annually).
- Conserve 20 percent each year with no annual change (static 20 percent).
- Conserve 100 percent of lands until 2040 while conserving nothing after that (100 percent until 2040).
- Conserve 50 percent until 2050 with no conservation after 2050 (50 percent until 2050).

In the timberland model, ERG calculated the amount of land that would have been lost by averaging the acreage of timberlands lost per year.

ERG also conducted a literature search of other ways that Maine could reduce emissions. Maine's forests cover nearly 17.6 million acres (Butler, 2016), and roughly 94 percent of that land is privately owned (Outdoor Partners, 2020). There are two main tools to change landowning behavior: regulations and incentives. Overall, Maine landowners seem accepting of environmental regulations and understand why these regulations exist (Quartuch & Beckley, 2014).

Agricultural lands in Maine could potentially reduce carbon emissions. To date, there have been challenges incorporating solar energy on farms (Berguin, 2018), and crops emit nitrous oxide from hay, forage corn, and potato production. Farms with dairy and beef cattle also emit methane, and nitrous oxide and methane emissions are related to livestock manure (MCC STS, 2020). Maintaining cover crop acreage or using no-till or low-till production methods can increase carbon sequestration on agricultural lands (MCC STS, 2020).

Table 12. Parameters of the Carbon Sequestration Models

Parameters	Value	Source
Cost of land per acre	$114.66	Maine Climate Council Natural and Working Lands Working Group (2020)
Development Model		
Acres developed annually 2020–2030	10,000	Provided by the working group; Maine Department of Conservation (2010)
Acres developed annually 2031–2050	15,000	
Acres developed annually 2051–2100	20,000	
Annual metric tons of carbon sequestered per acre	0.41	Bai et al. (n.d.)
Timberland Model		
Acres lost per year	19,200	Maine Department of Conservation (2010)
Annual metric tons of carbon sequestered per acre	0.22	Bai et al. (n.d.)

Impacts of adopting more wood chip heating systems: Reducing heating oil while replacing fossil fuel-based boilers with wood chip heating systems would benefit Maine by increasing jobs, reducing dependence on out-of-state resources, decreasing carbon emissions, and saving money in the long term. Though burning biomass still emits CO_2, replacing fossil fuel systems with forest harvesting byproduct in high-efficiency systems could reduce 750,000 metric tons of CO_2 emissions each year (Buchholz & Gunn, 2017). In addition, Maine's forest and wood processing industry produces wood chips and sawmill waste that is currently not used on a large scale. Using this byproduct could reduce the state's heating oil use by over 20 percent (Buchholz & Gunn, 2017)As Maine imports heating oil from other states, this reduction in heating oil would save $274 million per year from leaving the state.

The combination of reducing energy dependence on other states, saving money, and increasing local energy production could create over 2,000 jobs over a five-year period for installation of wood chip boilers alone, with the addition of over 4,000 indirect jobs (Buchholz & Gunn, 2017). Energy conversion would also benefit the environment by reducing annual carbon emissions from transportation by 10 percent (Buchholz & Gunn, 2017). Though the state's upfront costs would be considerable at over $2.1 billion (Buchholz & Gunn, 2017), if Maine makes this transition over five years, it would only take 10 years for the state to save money.

4.1.3 Recommendations for Further Analysis

To continue this research, it would be beneficial to break down Maine's developed areas into agricultural lands and different types of forests composed of varying tree species. Though that was beyond the scope of this research, such an analysis could improve the level of accuracy of the carbon sequestration models summarized in Table 11 and Table 12. Additionally, analyzing how different land conversion policies impact development would increase our understanding of how Maine could implement these land protections through legislation.

5. ENERGY

This section includes three strategies from the Maine Climate Council Energy Working Group (2020):

- **Strategy 1**: Ensure an adequate, affordable clean energy supply to meet Maine's 100 percent renewable portfolio standard.
- **Strategy 3:** Encourage use of the Maine Public Utilities Commission's highly efficient combined heat and power production facilities.
- **Strategy 4:** Institute a renewable fuel standard.

5.1 Ensure Adequate, Affordable Clean Energy Supply to Meet Maine's Goals

Strategy 1 of the Energy Working Group for an adequate, affordable, clean energy supply to meet Maine's 100 percent Renewable Portfolio Standard goal and any increased load through the development of centralized generating resources, distributed energy resources, and other measures. This strategy outlines the economic benefits to the State of Maine if it adopts a decarbonization policy, as well as affordable clean energy sources that Maine can use to achieve these benefits and reach its renewable portfolio standard goal.

Benefits: A major benefit of increased renewable energy use would be reduced carbon dioxide emissions to achieve Maine's 2030, 2045, and 2050 goals, along with the associated market and social benefits of reduced emissions. Major health benefits are also associated with cleaner air from reduced NO_x, sulfur dioxide (SO_2), and particulate matter, as associated emissions are reduced to achieve these goals. Additionally, jobs could be created when implementing and maintaining clean energy generating resources, particularly if Maine can incentivize manufacturing of these resources within the state. Because of the uncertainty of where these jobs could be located, we did not perform an analysis of job creation at this time.

5.1.1 Economic Analysis Results

ERG's economic analysis focused on two components: 1) levelized cost of energy, and 2) benefits of a 100 percent renewable portfolio standard.

Levelized cost of energy literature review: ERG conducted a literature review focused on providing a range of costs for renewable energy sources that can be compared to the costs of traditional non-renewable energy sources. The levelized cost of energy (referred to simply as "cost" in the remainder of this section) is often used to consistently compare electricity generation methods and to estimate the cost per unit of electricity generated over the entire lifespan of the generating plant—including capital and operating costs. Table 13 provides selected cost estimates for various renewable energy sources, as well as the minimum and maximum cost values per megawatt-hour (MWh) that we determined from the literature review for each energy source. The table also includes natural gas and coal costs for reference prices of non-renewable energy sources.

Table 13. Selected Levelized Costs of Electricity (LCOE) for Energy Sources (2019$)

Strategy (Min – Max) [a]	Cost (US$/MWh)	Geographic Location	Source
Non-Renewable Sources			
Natural gas (min – max) [b]	$32 – $104		NREL, 2015
Coal (min – max) [c]	$43 – $204		NREL, 2015
Solar — Concentrated/Utility-Scale Photovoltaic (PV) ($41/MWh – $268/MWh)			
Median	$193		NREL, 2015
Median LCOE in 2030	$129		NREL, 2015
Median LCOE in 2050	$107		NREL, 2015
LCOE without federal tax credit [d]	$61	New York	Fu, Feldman, & Margolis, 2018
LCOE with federal tax credit [e]	$41	New York	Fu, Feldman, & Margolis, 2018
Tracking PV LCOE for a 1 MW reference plant	$76	Quebec	Doluweera et al., 2018
Fixed PV LCOE for a 1 MW reference plant	$87	Quebec	Doluweera et al., 2018
Solar — Distributed PV ($31/MWh – $601/MWh)			
Median LCOE	$290		NREL, 2015
Median LCOE in 2030	$129		NREL, 2015
Median LCOE in 2050	$97		NREL, 2015
Subsidized (min – max)	$31 – $111	United States	Lazard, 2019b
Wind — Onshore ($11/MWh – $129/MWh)			
Average for good to excellent sites [f]	$50	United States	DOE, 2015
Subsidized [g] (min – max)	$24 – $46	United States	Lazard, 2019b
Wind — Offshore ($56/MWh – $225/MWh)			
2032 hypothetical 600 MW wind farm	$56	Maine	Musial, Beiter, & Nunemaker, 2020
Median LCOE in 2030	$97		NREL, 2015
Median LCOE in 2050	$75		NREL, 2015
Distributed Generation ($11/MWh – $515/MWh)			
Biomass LCOE [h]	$39	Quebec	Doluweera et al., 2018
Biomass LCOE (2025 projection)	$95	United States	U.S. EIA, 2020
Biomass LCOE (2040 projection)	$87	United States	U.S. EIA, 2020
Geothermal LCOE (2025 projection)	$37	United States	US EIA, 2020
Geothermal LCOE (2040 projection)	$37	United States	US EIA, 2020
Energy Storage — Battery ($102/MWh – $3,989/MWh)			
Residential PV + storage (min – max)	$457 – $663	Global	Lazard, 2019a
Commercial and industrial PV + storage (min – max)	$223 – $384	Global	Lazard, 2019a
Wholesale PV + storage (min – max)	$102 – $139	Global	Lazard, 2019a
Transmission and distribution (min – max)	$2,351 – $3,989	Global	Lazard, 2019a
Demand Management ($0.00001/MWh – $0.01971/MWh)			
Nudge [i]	$0.00004	Vermont	Pratt, 2020
Financial incentive [j]	$0.00029	Vermont	Pratt, 2020

Strategy (Min – Max) [a]	Cost (US$/MWh)	Geographic Location	Source
Non-Renewable Sources			
Financial incentive and education [k]	$0.00007	Vermont	Pratt, 2020
Pro-social [l]	$0.00821	Vermont	Pratt, 2020

[a] The minimum and maximum values reported next to the strategy name are based on the findings of the complete literature review. **Error! Reference source not found.** presents a portion of these findings, and therefore may not include the strategy leading to the minimum/maximum cost estimates.

[b] Natural gas combustion turbine.

[c] Pulverized coal—scrubbed and unscrubbed.

[d] Based on ground-mounted systems, fixed tilt, and one-axis tracker PVs capable of generating greater than 2 MW.

[e] Based on ground-mounted systems, fixed tilt, and one-axis tracker PVs capable of generating greater than 2 MW and with a 30 percent federal investment tax credit applied.

[f] "Good to excellent sites" are those with average wind speeds of 7.5 meters per second or higher at hub height.

[g] Calculated with U.S. federal tax subsidies taken into consideration.

[h] Considers agricultural biomass, forest biomass, and urban wood waste.

[i] Sent reports to customers comparing usage to neighbors and providing energy conservation tips.

[j] Consumer received bill discounts if they reduced energy consumption by 20 percent from the previous summer.

[k] Consumer received bill discounts if they reduced energy consumption by 20 percent from the previous summer, as well as education materials regarding peak management and energy efficiency.

[l] Utilities donated to local charities when users responded in aggregate to demand response events.

Notably, the cost of renewable energy varies greatly by the type of energy source, geographic location, year of analysis, and method of estimation. For example, based on the literature review, the costs for concentrated/utility photovoltaic (PV) systems range from $41/MWh to $268/MWh. These values differ greatly due to their associated estimation techniques. NREL (2015) provides the minimum, median, and maximum cost estimates based on data compiled from published reports. The maximum cost estimate for concentrated solar power that NREL reports is $268/MWh. Fu et al. (2018) found that the cost for utility-scale PV in New York is $41/MWh when a 30 percent federal investment tax credit is applied. The **Error! Reference source not found.** notes provide additional information regarding the assumptions associated with these cost estimates.

More recent studies indicate that the price of utility-scale PV has continued to fall. For example, in their assessment of 60 power purchasing agreements from 2018, Bolinger et al. (2019) found that the median cost is $39.1/MWh (or $53.8/MWh without the 30 percent federal investment tax credit). Additionally, they found that prices declined by 65 percent from 2011 to 2018.

As Maine makes progress toward reaching its 100 percent renewable portfolio standard goal, electric power use will rise due to the increase in renewable energy sources, as well as the decrease in dependence on non-renewable sources of power such as natural gas and oil. The State of Maine may prevent costly investments to the grid as a result of increased electricity use by implementing energy storage systems and demand management techniques that decrease peak demand, which determines the grid's required electricity capacity. Table 13 provides cost estimates for battery energy storage and various demand management strategies (Lazard, 2019a; Pratt & Erickson, 2020). Energy storage systems can be used to store energy during low use times of the day and then provide electricity to the grid during high use times. Demand management strategies decrease peak demand by altering when people use energy through incentives and education.

As renewable energy technology advances, the cost of renewable energy has decreased globally—including in the United States—and is expected to continue decreasing as the technology is refined (IRENA, 2020). These trends can be seen in the lower costs associated with future projections and the generally lower costs that more recent publications have estimated (see Table 13).

Based on the extensive literature review conducted and presented in Table 13, renewable energy sources can provide energy at a cost comparable to non-renewable sources. Natural gas and coal, based on an NREL (2015) review of the literature, costs between $32/MWh and $104/MWh and $43/MWh and $204/MWh, respectively. Although costs for concentrated/utility-scale solar and distributed solar sources are variable, many more recent publications estimate that the cost is less than $100/MWh (NREL, 2015; Fu et al., 2018; Doluweera et al., 2018; Lazard, 2019b). Similarly, cost estimates for onshore and offshore wind vary, but many estimate the cost to be less than $100/MWh (Musial & Butterfield, 2004; Wiser & Bolinger, 2008; IRENA, 2012; DOE, 2015; NREL, 2015; Lazard, 2019b; Musial et al., 2020). Biomass and geothermal energy provide opportunities for distributed generation of electricity and can be very cost-effective, generally priced at less than $100/MWh (NREL, 2015; Doluweera et al., 2018; Lazard, 2019b; U.S. EIA, 2020). Publications that estimate costs of biomass and geothermal energy greater than $100/MWh are reporting the maximum estimated cost (NREL, 2015; Lazard, 2019b).

Benefits of a 100 percent renewable portfolio standard: Synapse Energy Economics (2020c) modeled emissions from a sustained policy baseline and a decarbonization pathway. ERG used the results of this modeling to monetize the health impacts from reductions of particulate matter with a diameter of less than 2.5 micrometers ($PM_{2.5}$), SO_2, and NO_x; the social and market value of reducing CO_2; and the overall benefits of the decarbonization scenario.

The sustained policy baseline scenario assumes that Maine achieves an 80 percent renewable portfolio standard by 2030, while the decarbonization scenario assumes it achieves a 100 percent renewable portfolio standard by 2050. The scenarios also differ in the assumptions made in the transportation and buildings sectors. The reader is referred to Volume 3 for more details regarding the assumptions of these scenarios.

Figure 2 presents Maine's greenhouse gas emissions from the sustained policy baseline scenario and the decarbonization scenario. The decarbonization scenario leads to lower greenhouse gas emissions than the sustained policy scenario.

The decarbonization scenario not only reduces greenhouse gas emissions, but it also significantly reduces $PM_{2.5}$, SO_2 emissions, and NO_x emissions. Table 14 presents the cumulative monetized benefits of each pollutant reduction over 10-year time periods from 2020 to 2050, as well as the total benefit over the entire time period of nearly $945 million. Figure 3 shows the annual benefit from reductions in these pollutants. Emissions from the sustained policy scenario are much greater than the decarbonization scenario post-2030 largely due to the increased power plant electricity generation required to meet the electricity load in the sustained policy scenario. The reader is referred to Volume 3 for more detailed information.

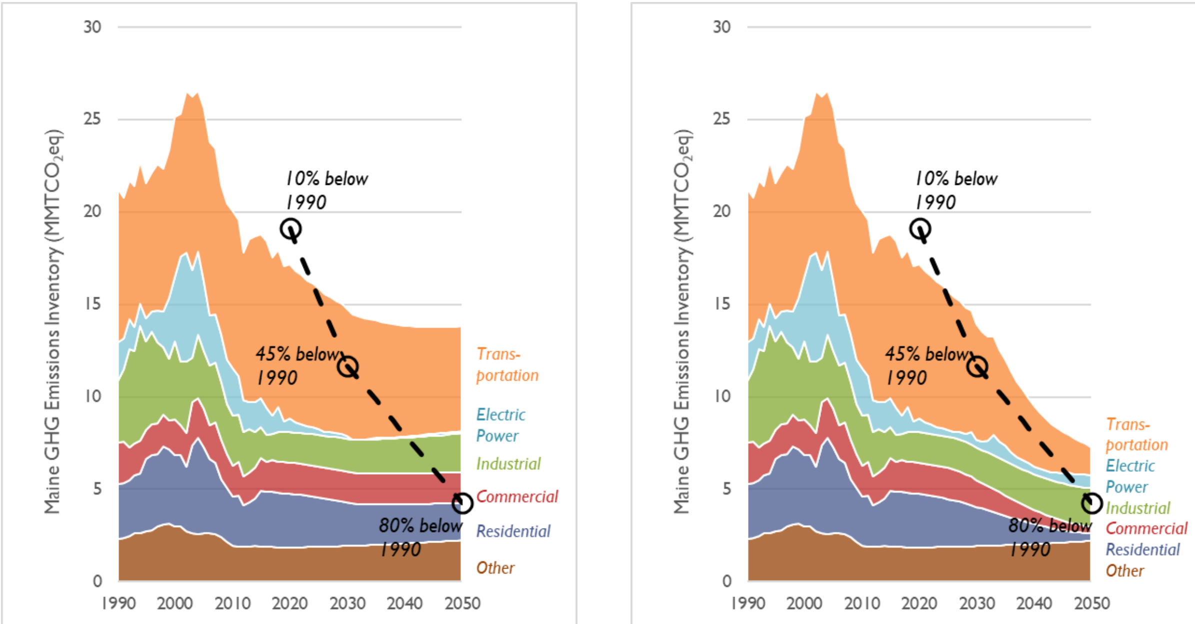


Figure 2. Emissions from sustained policy baseline (left) and decarbonization (right).

Table 14. Monetized Benefit of Pollutant Reductions in 10-Year Increments (Millions of 2019$)

Pollutant	2020–2029	2030–2039	2040–2050	Total
$PM_{2.5}$	$22.0	$61.4	$50.2	$133.5
SO_2	$0.0	$439.7	$324.6	$764.3
NO_x	$2.9	$23.3	$20.0	$46.2
Total	$24.8	$524.3	$394.8	$944.0

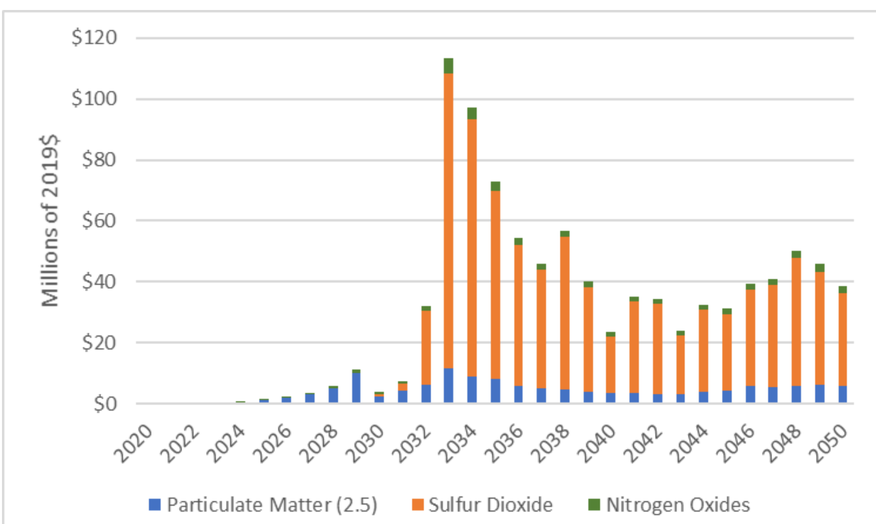


Figure 3. Annual monetized benefit of reductions in pollutants (2019$).

The decarbonization scenario reduces Maine's CO_2 emissions. Table 15 presents the monetized benefit of this reduction for consumption- and production-based emissions using the market value of CO_2 and the minimum and maximum estimates of the social value of CO_2. Production-based emissions consider emissions from power plants that are physically located in Maine. Consumption-based emissions consider all New England emissions that are associated with Maine's electricity sales. Based on the market value of CO_2, the decarbonization scenario results in consumption- and production-based emissions that provide a benefit of around $100 million from 2020 to 2050. When considering the social cost of carbon, we estimate that the decarbonization scenario provides a benefit ranging from $950 million to nearly $3 billion for consumption-based emissions reductions, and between $850 million and $2.5 billion for production-based emissions reductions.

Table 15. Monetized Benefit of Reduction in CO_2 (Millions of 2019$)

Cost	2020–2029	2030–2039	2040–2050	Total
Consumption-Based				
Market value	$7.7	$42.3	$55.6	$105.5
Social value (min)	$81.3	$412.2	$460.4	$954.0
Social value (max)	$244.4	$1,257.4	$1,412.8	$2,914.6
Production-Based				
Market value	$6.0	$39.7	$48.4	$94.1
Social value (min)	$63.7	$388.3	$395.9	$848.0
Social value (max)	$192.6	$1,184.5	$1,215.9	$2,593.0

Synapse Energy Economics (2020c) also modeled the annual production and renewable program costs for both scenarios. These two cost types vary based on the factors that they consider. The production costs include both the energy costs and capacity costs, which are intended to approximate system costs from ISO New England's energy and capacity markets, respectively. The renewable costs represent the suite of different policies related to renewable energy payments outside of the energy and capacity markets. Examples in this category include the costs of complying with renewable portfolio standards or renewable energy standards (either through purchases of renewable energy certificates on the spot market or through longer-term agreements to purchase certificates), or the costs of complying with other renewable program costs (such as requirements to contract for offshore wind).

Production and renewable program costs are components of consumer costs; however, they are not proxies for consumer costs. The components of production and renewable program costs listed above ultimately go into rates and consumer costs via complicated ratemaking processes. These costs for the sustained policy and decarbonization scenarios are shown in

Table 16, aggregated by decade.

Table 16 also presents the net benefit, calculated as the cost difference between the sustained policy scenario and the decarbonization scenario, based on production and renewable program costs. The total net benefit is the sum of the net benefits from the production and renewable program costs. The annual benefits are shown in Figure 4. The decarbonization scenario can provide a total net benefit of nearly $2.8 billion from 2020 to 2050.

Table 16. Monetized Benefit by Production and Renewable Program Costs (Millions of 2019$)

Cost Type	2020–2029	2030–2039	2040–2050	Total
Sustained Policy Scenario				
Production costs	$1,439.1	$1,826.9	$1,900.9	$5,166.9
Renewable program costs	$125.6	$384.1	$795.5	$1,305.2
Decarbonization Scenario				
Production costs	$1,307.3	$982.3	$1,133.5	$3,423.1
Renewable program costs	$115.0	$70.2	$86.0	$271.2
Net Benefit (Sustained Policy Scenario – Decarbonization Scenario)				
Production costs	$131.8	$844.6	$767.4	$1,743.8
Renewable program costs	$10.5	$313.9	$709.5	$1,034.0
Total Net Benefit	**$142.3**	**$1,158.5**	**$1,476.9**	**$2,777.8**

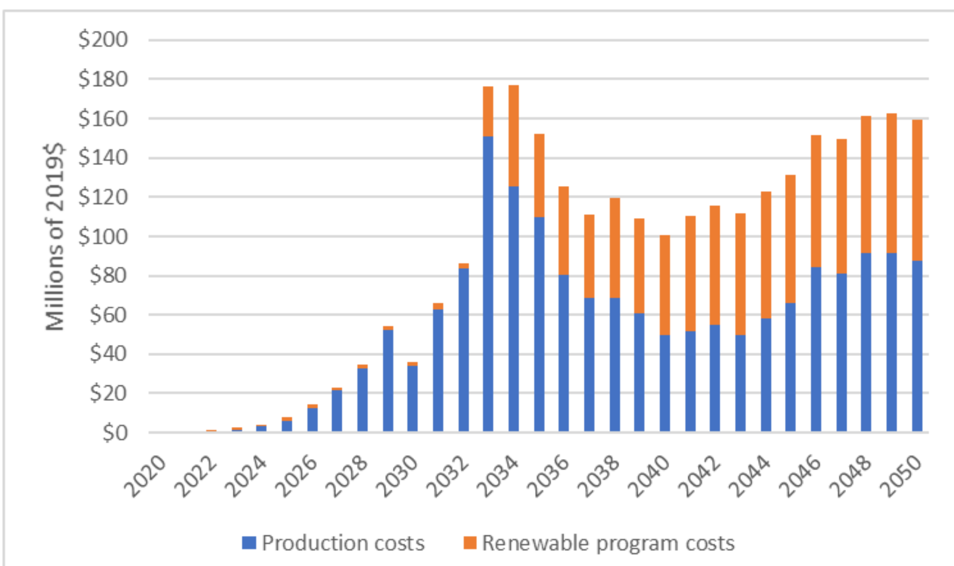


Figure 4. Annual monetized benefit by production and renewable program costs.

5.1.2 Methods and Limitations

ERG performed a literature review to assess typical levelized costs of energy to provide context for the tradeoffs between various types of energy production. This literature review included both historical and projected levelized costs, and it resulted in a variety of cost estimates (e.g., capital cost, levelized cost of energy, and annual operations and maintenance cost) of renewable energy sources that covered a range of geographic locations. Table 17 provides a selection of the results from the literature review. The specific cost estimates presented in Table 17 were chosen due to a number of considerations. First, we only considered publications that reported the levelized cost of energy, because this cost estimate allows for easy comparison across sources. Second, we emphasized presenting costs from geographically relevant studies. In some cases, the study did not provide the geographic area it considered. We also prioritized presenting a variety of sources, cost projections, and recent publications.

The literature review provides cost estimates that can give a reasonable range of costs associated with different energy sources and technologies; however, the performance of these technologies highly depends on the geographic location and conditions in which they are implemented. The literature review emphasized studies that were geographically close to Maine, but the actual costs for Maine will depend on more locally specific factors such as weather, wind speed and consistency, available biomass, geothermal potential, and others. Additionally, technological advancements affect the price of renewable energy. Therefore, cost estimates of renewable energy vary based on the year of the study and the assumptions made regarding future costs of renewable energy.

To assess the benefits of the decarbonization scenario, ERG monetized the health impacts from reduced $PM_{2.5}$, SO_2, and NO_x; the social and market value of reducing CO_2; and the change in fuel costs from the two scenarios. We followed these methods:

1) ERG used the $PM_{2.5}$, SO_2, and NO_x emissions estimates from the Synapse (2020c) modeling to determine reductions for the decarbonization scenario and the sustained policy baseline scenario. We determined the emissions reduction by taking the difference in emissions for each pollutant between the two scenarios. ERG used a U.S. Environmental Protection Agency (EPA) study (EPA, 2013) to convert those $PM_{2.5}$, SO_2, and NO_x reductions into a dollar value based on the anticipated health impacts (i.e., average estimated reduction in mortality and morbidity). We then converted the EPA values from 2010$ to 2019$ using the GDP deflator. Table 17 presents the estimated value of a per-ton reduction from on-road mobile sources in both 2020 and 2030. For simplicity, we assumed 2050 had the same value per ton as 2030.

Table 17. Value of Each Ton of Pollutant Reduced for Electricity Generating Units (2019$)

Category	Value of 1 Ton Reduction of $PM_{2.5}$	Value of 1 Ton Reduction of SO_2	Value of 1 Ton Reduction of NO_x
2020 value per ton reduced for electricity generating units	$362,362	$97,019	$14,027
2030 value per ton reduced for electricity generating units	$420,807	$113,384	$16,365

2) ERG used both a market and social cost of carbon to estimate the benefit of the CO_2 reduction.

3) The market cost and the minimum and maximum estimated social cost of carbon from 2020 to 2050 are presented in Figure 5. Synapse (2020c) modeled the production- and consumption-based CO_2 emissions from both the decarbonization scenario and the sustained policy baseline scenario. ERG determined the reduction in production- and consumption-based CO_2 emissions by taking the difference in emissions between the two scenarios. We then calculated the monetized benefit from these reductions by applying the market cost and social cost of carbon.

4) ERG assessed the benefit of switching from the sustained policy scenario to the decarbonization scenario based on the annual production and renewable program costs of the scenarios modeled by Synapse (2020c). We calculated the difference in the production costs between the scenarios, and we similarly calculated the difference in the renewable program costs between the scenarios. The differences represent the benefit of switching to the decarbonization scenario. The total cost of each scenario is the sum of the production and renewable costs. Therefore, we summed the production and renewable benefits to determine the total benefit from switching to the decarbonization scenario.

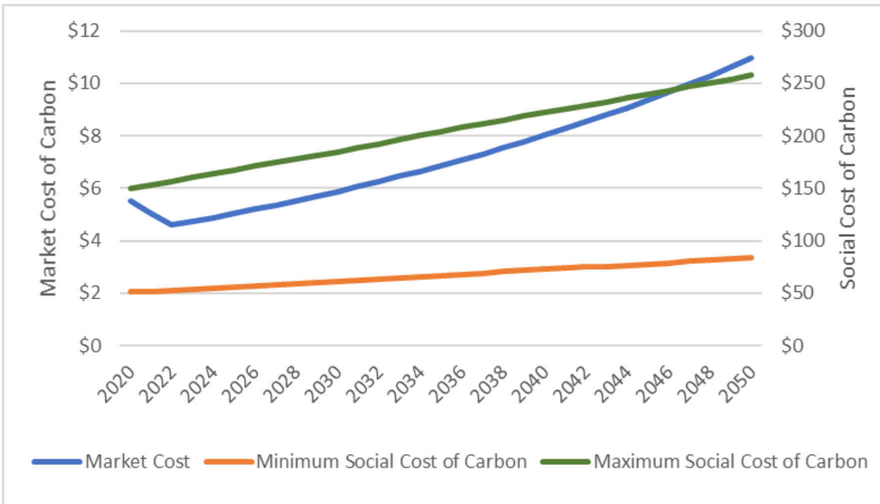


Figure 5. Market and social cost of carbon (2019$).

Limitations: The value of $PM_{2.5}$, SO_2, and NO_x emissions reductions depends on geography, where the pollution occurs relative to population density, and the existing levels of pollution. The values ERG used are national averages for electricity generating units.

5.1.3 Recommendations for Further Analysis

As noted in the introduction, this strategy may impact jobs in Maine. We recommend an economic impact analysis to assess jobs lost by moving away from some energy generating resources compared to jobs gained by the new forms of electricity. This analysis was beyond the resources available for this report.

5.2 Encourage Highly Efficient Combined Heat and Power Production Facilities

Strategy 3 of the Energy Working Group recommends actions to encourage combined heat and power facilities, because they are more efficient than the current systems used in Maine. Maine has 42 combined heat and power sites with a capacity of over 668 megawatts as of 2020 (U.S. Department of Energy, 2020). ERG performed a literature review of combined heat and power facilities to gather insight into how these facilities could benefit Mainers.

Benefits: Combined heat and power facilities recycle the heat byproduct from power generation and use it to warm areas, thus reducing emissions and redundancy. Because of this dual use, combined heat and power also saves costs and is economically beneficial in the long term.

5.2.1 Economic Analysis Results

Between 2005 and 2010, Maine built two new combined heat and power sites across all industries that have a combined capacity of 4.5 megawatts of energy (Chittum & Kaufman, 2011). Though Maine is uniquely capable of handling these facilities based on current regulations, it has largely stayed away from them. One barrier to incorporating these facilities is the lack of natural gas infrastructure throughout the state. Maine highly relies on oil to heat its homes. Oil accounts for 62 percent of the market, while propane accounts for 11 percent, natural gas accounts for about 8 percent, and electricity accounts for about 7 percent (Energy Information Administration, 2020). Though Maine may be well suited to take on these projects, the upfront costs are still a deterrent. Even with optimistic payback thresholds, Maine would experience challenges to develop these facilities for industrial use (Chittum & Kaufman, 2011).

Massachusetts created 34 new combined heat and power facilities between 2005 and 2010, for a combined total of 41.8 megawatts (Chittum & Kaufman, 2011). The increased construction of facilities is in part due to financial incentives from the state (Chittum & Kaufman, 2011). However, some found the studies and paperwork necessary to take advantage of the incentives to be cumbersome (Chittum & Kaufman, 2011). Although many facilities are being created, there is still room to improve.

Because combined heat and power facilities provide electricity near the facility while capturing waste heat to use for water or space heating, they are more efficient than alternative facilities that only produce electricity. One study found that these facilities can reduce emissions of CO_2 by over 21 percent, though these numbers highly depend on the specific efficiency of the combined heat and power system installed as well as the system it replaces (Mago & Smith, 2012).

5.2.2 Methods and Limitations

ERG performed a literature review to gain qualitative insights into the benefits of combined heat and power facilities. ERG focused the literature review on the reduced emissions from and costs of combined heat and power systems compared to using two independent systems. Although running a quantitative model of the benefits of replacing the current infrastructure with high-efficiency combined heat and power facilities would be useful, it was outside the scope of the current project, and we did not find any Northeast-specific benefit-cost analyses during our literature review.

5.2.3 Recommendations for Further Analysis

We recommend Maine perform a benefit-cost and cost-effectiveness analysis for a few of its 42 combined heat and power facilities. These data would help inform any needed subsidies to promote combined heat and power and could provide useful data to potentially drive decision-making toward its wider adoption.

5.3 Institute a Renewable Fuel Standard

Strategy 4 of the Energy Working Group includes implementing incentives to produce rapid reductions in heating-related emissions, as well as creating pilot programs to study the impacts that renewable natural gas[9] and power-to-gas solutions have on Maine's emissions. This strategy also includes biofuels

[9] Renewable natural gas is a biogas largely composed of methane that comes from animal waste, food waste, and the decomposition of other organic matters.

to power anaerobic digesters (e.g., capturing and burning biomethane emissions released from dairy waste, landfills, and wastewater treatment facilities for power instead of just releasing them into the atmosphere), biofuel from woody biomass, and biodiesel from used vegetable oils. This is an important strategy, as Maine currently has the greatest dependence on oil for home heating of any U.S. state (Maine Climate Council Energy Working Group, 2020).

Benefits: This strategy would increase economic activity related to the development of domestic renewable fuels within Maine, as well as new technologies required for such fuels. A reduction of groundwater pollutants because of more environmentally friendly farming practices could potentially improve health outcomes as well.

5.3.1 Economic Analysis Results

ERG performed a cost-benefit analysis of anaerobic digesters, researched the cost-effectiveness of integrating biodiesel into home heating oil, and assessed the cost-effectiveness of ethanol usage compared to petroleum gasoline.

Anaerobic digesters: Implementation of an anaerobic digestion system would reduce CO_2 emissions by an estimated 47.2 percent (Artrip et al., 2013). With total capital costs of implementing such a system estimated at $403,200 (Navaratnasamy et al., 2008), the cost of reducing CO_2 emissions per metric ton is $1,442. However, this cost is only recognized the first year after implementing the system. The cost to operate an anaerobic digestion system in any given year is estimated at $9,263 (Navaratnasamy et al., 2008), which means that, on a per-year basis, the operating cost of reducing 1 metric ton of CO_2 emissions is $33. Table 18 shows these cost figures per metric ton.

Table 18. Cost-Benefit Analysis of Anaerobic Digestion System

Variable	Cost
Reduction in emissions as a result of anaerobic digester (metric tons of CO_2e)	280
Cost of system (capital cost)	$403,200.00
Operating cost per year	$9,262.50
Capital cost per metric ton of CO_2e reduced	$1,441.54
Operating cost per metric ton of CO_2e reduced	$33.12

Biodiesel: Biodiesel is another renewable energy source that can reduce emissions. Biodiesel can also be used for home heating by mixing it with petroleum diesel. B20 is a common blend that is composed of 20 percent biodiesel and 80 percent petroleum diesel. The National Oilheat Research Alliance found that B20 blends with ultra-low sulfur heating oil are lower in CO_2 emissions than natural gas when evaluated over a 100-year time period (NORA, 2015), and Krishna (2004) found that the addition of biodiesel can lead to lower emissions of NO_x. Win Lee et al. (2004) found a 20 percent and 13 percent reduction in SO_2 and particulate matter emissions, respectively, when using a B20 blend in a residential-scale hot water boiler. Macor and Pavanello (2009) report that pure biodiesel has shown a 50 percent average reduction of carbon monoxide and particulate matter emissions. The national average price of B20 biodiesel is $2.36/gallon, which is slightly cheaper than the national average price of petroleum diesel at $2.61/gallon (Department of Energy, 2020).

Ethanol: Wang et al. (2012) found that ethanol from corn can reduce CO_2 emissions by between 19 and 48 percent compared to emissions from petroleum gasoline. When considering costs to consumers, ethanol is, on average, less expensive than gasoline. The cost of ethanol is 9 percent lower than gasoline: $1.75 per gallon compared to $1.91 per gallon, respectively (Department of Energy, 2020a). However, ethanol burns 27 percent less efficiently than gasoline (Department of Energy, n.d.).

5.3.2 Methods and Limitations

For the anaerobic digestion system analysis, ERG pulled data from two different sources. The cost figures shown in Table 19 come from the Agriculture Stewardship Division of the Alberta Agriculture and Rural Development Department (Navaratnasamy et al., 2008).

Table 19. Capital and Operating Costs of Anaerobic Digester

Variable		Value
Total electricity production from dairy manure and animal fat (kWh)	a	463,125
Number of days operating (assumed 30 days inactive)	b	335
Hours of operation per day	c	24
Electricity generator capacity (kWh)	d = a/b/c	57.6
Capital cost per kWh	e	$7,000
Capital cost	f = d x e	$403,200
Operating cost (per kWh)	g	$0.02
Operating cost per year	h = g x a	$9,262.50

We pulled the emissions reductions numbers in Table 20 from a 2013 article in the *Applied Engineering in Agriculture Journal* (Artrip et al., 2013).

Table 20. Emissions Reductions of Anaerobic Digester

Variable		Cost
Baseline model CO_2 emissions (metric tons per 100 cows)	i	592.6
Real anaerobic digester model CO_2 emissions (metric tons per 100 cows)	j	312.9
CO_2 emissions reduction	k = i - j	279.7
Percentage reduction in CO_2 emissions	L = k/i	47.2%

ERG was also able to pull in additional values (Table 21) from an energy savings analysis (Navaratnasamy et al., 2008).

Table 21. Energy Cost Savings from Anaerobic Digester

Variable		Cost
Cost of electricity (per kWh)	m	$0.06
Cost of heat (per GJ)	n	$5.50
Number of dairy cows	o	100
Annual electricity potential (kWh)	p	1,227
Annual heating potential	q	5.5
Savings on electricity	r = m*o*p	$7,362
Savings on gas	s = n*o*q	$3,025
Total annual energy savings	t = r + s	$10,387

5.3.3 Recommendations for Further Analysis

We recommend performing Maine-specific analyses on the cost-effectiveness of reducing CO_2 emissions by using biofuels to power anaerobic digesters, biodiesel for home heating, and biofuel from woody biomass. This will be important to monitor as some of these technologies are relatively new and the costs may change as the technologies improve.

6. TRANSPORTATION

This section includes three strategies from the Maine Climate Council Transportation Working Group's (2020) *Strategy Recommendations to Mitigate Emissions and Support Resilience in Maine Buildings*:

- **Strategy 1:** Expand electrification of transportation.
- **Strategy 2:** Reduce vehicle miles traveled (VMT).
- **Strategy 3:** Explore mechanisms to fund transportation needs and facilitate emissions reduction.

While other sectors have reduced CO_2 emissions since 1990, the transportation sector in Maine has increased emissions by 2.5 percent during that same timeframe (Maine Department of Environmental Protection, 2020a). In 2017, the transportation sector was responsible for 54 percent of Maine's CO_2 emissions.

6.1 Expand Electrification of Transportation

The State recommended expanding electrification of light-duty vehicles to between 50 and 90 percent and heavy-duty vehicles to between 55 and 80 percent of the total fleet by 2050. To achieve these expansions, this strategy emphasizes:

- Providing equitable incentives and grants that encourage voluntary consumer conversion from gasoline vehicles to electric vehicles (including electric bicycles).
- Designing a comprehensive and consistent approach to expand electric vehicle charging infrastructure and overseeing electrification efforts (an electric vehicle roadmap) to support Maine's zero emission vehicle targets.

Benefits: A major benefit of electrification is reduced CO_2 emissions, which will help Maine achieve its 2030, 2045, and 2050 goals, along with the market and social benefits of reduced emissions. Substantial charging can be done during flexibility hours when the electricity grid is less utilized. As the grid becomes cleaner, this will further reduce emissions. Major health benefits are associated with cleaner air from reduced NO_x, SO_2, and particulate matter as electric vehicles do not emit tailpipe emissions.

6.1.1 Economic Analysis Results

Benefit-cost analysis for consumers: Consumers will generally purchase electric vehicles if they find them to be a net financial benefit. Other co-considerations that might affect the consumer's decision to purchase an electric vehicle include range anxiety if the infrastructure is not in place—especially for Maine's large rural population—and batteries could run out, as well as the satisfaction of contributing to positive health and environmental impacts.

Battery electric vehicles tend to cost more than conventional internal combustion engine vehicles and require the purchase of an at-home charging station. However, the annual costs for charging the vehicle are lower than the annual costs for fueling conventional vehicles. ERG quantified the net benefit of owning an electric vehicle and the amount of time for the cost to break even with a conventional vehicle in three cases:[10] 1) the state offers no incentive to buy an electric vehicle, 2) the state offers a $2,000 incentive for an electric light-duty vehicle and a $10,000 incentive for an electric heavy-duty vehicle, and 3) the state offers a $5,000 incentive for an electric light-duty vehicle and a $20,000 incentive for an electric heavy-duty vehicle.

ERG assumed the same low and high incentive scenarios for 2030 and 2050, though incentives will likely decrease with continued electrification. The results are presented in Table 22 below. Maintenance costs for electric vehicles are also significantly lower than those for conventional vehicles (Logtenberg et al., 2018), but ERG did not quantify these costs (e.g., oil changes, battery replacements) in this analysis. Table 22 shows that with no subsidy, a consumer would pay about $1,868 more to purchase an electric light-duty vehicle over 10 years in 2030. Therefore, to break even over 10 years of primary ownership, a customer should receive a $2,000 subsidy to offset this cost. In 2050, however, an electric vehicle owner is projected to break even in less than five years with no subsidy.

Table 22. Consumer Benefit-Cost Analysis for Light-Duty Vehicles in 2030 and 2050

Category	2030 Electric Light-Duty Vehicle	2030 Conventional Light-Duty Vehicle	2050 Electric Light-Duty Vehicle	2050 Conventional Light-Duty Vehicle
No Incentive				
Purchase cost [a]	$34,983	$28,449	$31,641	$28,583
Home charging unit cost [b]	$700	—	$700	—
Annual fuel/electricity cost [c]	$392	$928	$323	$960
Net benefit of 10 years of ownership	—	$1,868	$2,609	—
Number of years to break even	12.2	—	4.8	—
Low Incentive ($2,000 Subsidy)				
Net benefit of 10 years of ownership ($)	$132	—	$4,609	—
Number of years to break even	8.4	—	1.7	—
High Incentive ($5,000 Subsidy)				
Net benefit of 10 years of ownership ($)	$3,132	—	$7,609	—
Number of years to break even	2.9	—	N/A	—

N/A = Not applicable

[a] Capital cost (equilibrium retail price) of light-duty battery electric car with 200-mile range in 2030 and 2050 (2019$ converted from 2016$) (Jadun et al., 2017).

[b] Cost of a Level 1 charger in 2020 for a detached house (Nicholas, 2019).

[c] Based on gasoline costs for conventional vehicles and electricity charging costs of electric vehicles assuming 11,895 miles traveled per year for light-duty vehicles (Maine Department of Environmental Protection).

Table 23 shows that with no subsidy, a consumer would accrue a net benefit of $8,315 to purchase an electric heavy-duty vehicle over 10 years in 2050.

[10] The State of Maine did not recommend these subsidy amounts. We simply selected them as part of a sensitivity analysis to understand how subsidies change the decision-making process.

Table 23. Consumer Benefit-Cost Analysis for Heavy-Duty Vehicles in 2030 and 2050

Category	2030 Electric Heavy-Duty Vehicle	2030 Conventional Heavy-Duty Vehicle	2050 Electric Heavy-Duty Vehicle	2050 Conventional Heavy-Duty Vehicle
No Incentive				
Purchase cost [a]	$242,129	$136,416	$213,425	$137,920
Home charging unit cost [b]	$1,400	—	$1,400	—
Annual fuel/electricity cost [c]	$16,853	$21,256	$14,044	$22,566
Net benefit of 10 years of ownership	—	$63,082	$8,315	—
Number of years to break even	24.0	—	8.9	—
Low Incentive ($10,000 Subsidy)				
Net benefit of 10 years of ownership ($)		$53,082	$18,315	—
Number of years to break even	21.7	—	7.7	—
High Incentive ($20,000 Subsidy)				
Net benefit of 10 years of ownership ($)	—	$43,082	$28,315	—
Number of years to break even	19.5	—	6.5	—

[a] Average capital cost (equilibrium retail price) of a medium-duty and heavy-duty battery electric truck in 2030 and 2050 (converted from 2016$) (Jadun et al., 2017).

[b] Cost of a Level 2 charger in 2020 for a detached house (Nicholas, 2019). Heavy-duty vehicles will likely not use Level 2 chargers.

[c] Based on an approximation of 50,000 miles per year for heavy-duty vehicles based on delivery trucks, refuse trucks, and class 8 trucks (U.S. Department of Energy, 2020b).

Benefit-cost analysis for the state and people: The State of Maine and its constituents benefit from health impacts from reduced NO_x, SO_2, and $PM_{2.5}$, as well as environmental impacts from reduced CO_2. These benefits are shown in Table 24 and Table 25, which represent two different scenarios that Synapse modeled: the baseline scenario—which projects only 11 percent of light-duty vehicles and 0 percent of heavy-duty vehicles being electric by 2050—and an alternative scenario (T1) where 90 percent of light-duty vehicles and 80 percent of heavy-duty vehicles are electric by 2050. The primary cost to Maine would include subsidies to incentivize consumer purchases and any costs to plan and support electric vehicle infrastructure.

Table 24. Total Annual Benefit from the Reduction of NO_x, SO_2, and $PM_{2.5}$ (Under T1 Scenario)

Year	NO_x Reduced (Metric Tons)	Value of NO_x Reduced	SO_2 Reduced (Metric Tons)	Value of SO_2 Reduced	$PM_{2.5}$ Reduced (Metric Tons)	Value of $PM_{2.5}$ Reduced	Total Value of Reduction
2030	145.1	$3,228,660	4.3	$265,311	5.3	$5,629,684	$9,123,654
2050	1,995.4	$44,402,918	31.7	$1,949,911	55.2	$58,527,818	$104,880,647

Source: EPA, 2013; Synapse, 2020.

Table 25. Total Annual Benefit from the Reduction of CO_2 (Under T1 Scenario)

Timeframe	Market Benefit of CO_2 Reductions	Social Benefit of CO_2 Reductions
2030 lower bound	$3,883,214	$40,113,334
2030 upper bound	$3,883,214	$121,938,196
2050 lower bound	$45,605,156	$349,098,098
2050 upper bound	$45,605,156	$1,072,533,313

Source: EPA, 2016; Synapse, 2020.

Table 26 shows the costs that Maine would incur for subsidizing electric vehicle purchases.

Table 26. Cost of Electric Vehicle Incentives to the State

Year	Incentive	Cost to the State	
		Light-Duty Electric Vehicle [a]	Heavy-Duty Electric Vehicle [b]
2030	Low incentive	$63,315,500	$9,520,899
	High incentive	$158,288,749	$19,041,798
2050	Low incentive	$105,234,881	$38,589,081
	High incentive	$263,087,202	$77,178,162

Source: Synapse, 2020.
[a] Based on 2030 and 2050 light-duty vehicle battery electric vehicle sales under the T1 scenario.
[b] Based on 2030 and 2050 heavy-duty vehicle battery electric vehicle sales under the T1 scenario.

If the State of Maine provides a $2,000 incentive for all light-duty vehicles and a $20,000 incentive for all heavy-duty vehicles purchased in 2030, the cost would be approximately $82 million per year compared to a benefit of $13 million per year when considering improved health from reduced NO_x, SO_2, and $PM_{2.5}$, as well as the market cost of carbon (not including benefits to individual buyers). If the social cost of carbon is considered, this becomes a benefit-cost ratio of about $130 million to $82 million each year.

CASE STUDY: THE 12 LARGEST UTILITY SERVICE TERRITORIES

A recent analysis of the 12 largest utility service territories across seven states (California, Georgia, Maryland, Massachusetts, New York, Ohio, and Pennsylvania) shows the need for electric vehicle infrastructure to accommodate the expansion of electric vehicle usage (Lowell et al., 2018). Table 27 shows the status of electric vehicle charging stations as of 2018. According to this analysis, between 121,000 and 754,000 publicly available charge ports are needed to support anywhere from 2.9 million to 19.1 million electric vehicles on the road in the year 2035. The estimated cost of implementing all public chargers is approximately $228 per plug-in electric vehicle—which, depending on whether we use the low or high estimate, amounts to $661 million or $4.3 billion, respectively.

Table **27**. Number of Charging Stations and Ports Currently Accessible to the Public Within 12 Utility Service Territories

State	Stations	Total Ports
California	3,876	13,370
Georgia	606	1,779
Maryland	448	1,118
Massachusetts	484	1,278
New York	766	1,595
Ohio	283	580
Pennsylvania	323	690

6.1.2 Methods and Limitations

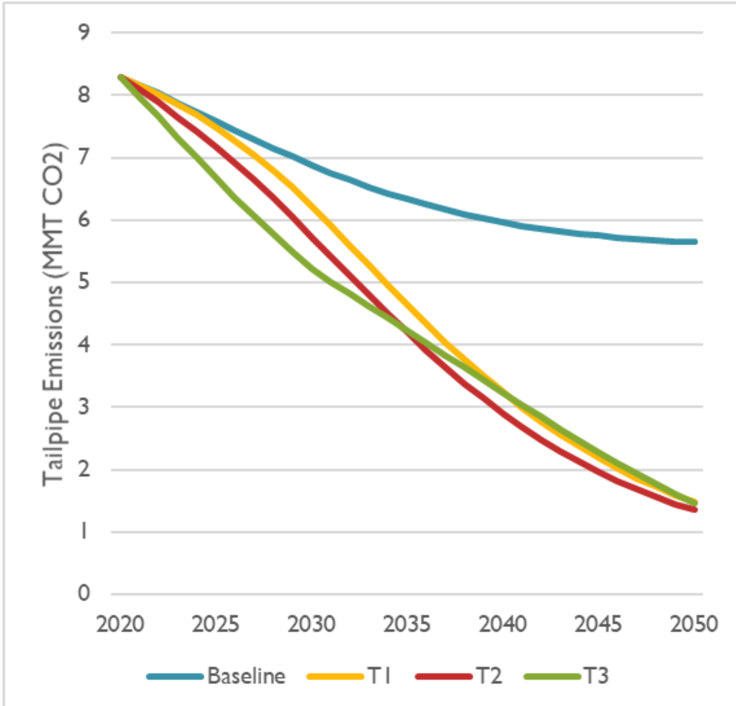


Figure 6. Projections of CO_2 emissions under different scenarios, 2020–2050.

Figure 6 represents the trajectory of CO_2 emissions that Synapse developed in a few different modeling scenarios. The T1 and T3 scenarios outlined in yellow and green, respectively, show an emissions reduction of 82 percent from 2020 to 2050, while the red line representing the T2 modeling scenarios shows an 84 percent emissions reduction over the same time period. The T2 scenario puts a greater emphasis on reduced VMT and increased fuel efficiency, resulting in a larger impact on emissions earlier than the T1 and T3 scenarios. As the proportion of vehicles that are electric increases over time, the difference between these scenarios will become less noticeable. The assumptions for the baseline, T1, T2, and T3 scenarios are shown in Table 28.

Table 28. Electrification Analysis Scenarios

Baseline	T1	T2	T3
Worst-Case Electrification — CAFE Standards Remain	**Electrification — Baseline Efficiency**	**Electrification — Aggressive Efficiency**	**Reduced Electrification – Extreme Efficiency and Low Carbon Fuels**
• 11% of LDVs are electric by 2050. • 0% of HDVs are electric by 2050. • VMT per LDV remains constant through 2050. • VMT per HDV remains constant. • Fuel efficiency reaches 42 MPG for new cars and 30 MPG for new light trucks by 2050.	• 90% of LDVs are electric by 2050. • 80% of HDVs are electric by 2050. • VMT per LDV remains constant through 2050. • VMT per HDV remains constant. • Fuel efficiency reaches 42 MPG for new cars and 30 MPG for new light trucks by 2050. • Managed EV charging is implemented.	• 90% of LDVs are electric by 2050. • 80% of HDVs are electric by 2050. • VMT per LDV declines 12.1% by 2030 and 27.2% by 2050. • VMT per HDV declines 2.1% by 2030 and 4.2% by 2050. • Fuel efficiency reaches 45 MPG for new cars and 33 MPG for new light trucks by 2050. • Managed EV charging is implemented.	• 65% of LDVs are electric by 2050. • 55% of HDVs are electric by 2050. • VMT per LDV declines 25% by 2030 and 40% by 2050. • VMT per HDV declines 2.1% by 2030 and 4.2% by 2050. • Fuel efficiency reaches 45 MPG for new cars and 33 MPG for new light trucks by 2050. • Managed EV charging is implemented. • 20% of LDVs use low carbon fuels. • 20% of HDVs use low carbon fuels.

EV = electric vehicle; HDV = heavy-duty vehicle; LDV = light-duty vehicle; MPG = miles per gallon

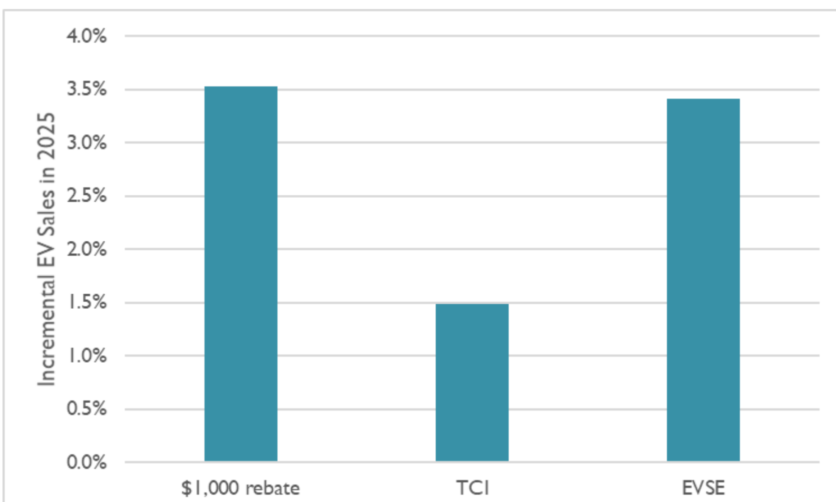


Figure 7. Increases in electric vehicle sales, 2025.

Figure 7 represents the results of a linear regression that Synapse (2020) conducted using the MA3T model. Each bar shows the percent increase in the number of electric vehicles sold in the year 2025 if the given policy is implemented. For every $1,000 in rebates offered on an electric vehicle, sales can expect to increase by 3.5 percent. The implementation of a carbon tax such as that of the Transportation and Climate Initiative ($0.17 per gallon, which is expected to increase to $0.28 per gallon by 2032) is forecasted to increase electric vehicle sales by 1.5 percent. An increased trajectory of electric vehicle supply equipment—100 percent availability instead of 15 percent by 2030—is expected to increase sales by 3.4 percent. The impacts of these policies might be near additive if implemented together—though this was not assessed in this analysis.

6.1.2.1 Cost-Benefit Analysis for Consumers

ERG conducted a literature review to identify the following costs related to electric vehicles for consumers:

- Price of gasoline (Energy Information Administration, 2020):
  - In 2030: $2.81 per gallon (2019$)
  - In 2050: $3.43 per gallon (2019$)
- Average fuel economy of a light-duty car (only includes cars, not light-duty trucks) (Jadun et al., 2017):
  - Efficiency of a light-duty battery electric car with a 200-mile range:
    - In 2030: 133 miles per gallon gasoline equivalent (MPGe) or 3.95 miles per kWh
    - In 2050: 155 MPGe or 4.60 miles per kWh
  - Efficiency of a light-duty internal combustion engine car:
    - In 2030: 36 miles per gallon (MPG)
    - In 2050: 42.5 MPG
- Average fuel economy of a heavy-duty vehicle (Jadun et al., 2017):
  - Main efficiency of a heavy-duty battery electric vehicle:
    - In 2030: 13 MPGe or 0.39 miles per kWh
    - In 2050: 15 MPGe or 0.45 miles per kWh
  - Main efficiency of a heavy-duty internal combustion engine vehicle:
    - In 2030: 6.61 MPG
    - In 2050: 7.6 MPG
- Price of electricity (Energy Information Administration, 2020):
  - In 2030: $0.13 per kWh (2019$)
  - In 2050: $0.125 per kWh (2019$)
- Predicted cost of purchasing a light-duty car (only includes cars, not light-duty trucks) (Jadun et al., 2017):
  - Capital cost of a light-duty battery electric car with a 200-mile range:
    - In 2030: $34,983 (2019$)
    - In 2050: $31,641 (2019$)
  - Capital cost of a light-duty internal combustion engine car:

- In 2030: $28,449
- In 2050: $28,583

- Predicted cost of purchasing a medium/heavy-duty vehicle (Jadun et al., 2017):
  - Average capital cost of a medium/heavy-duty battery electric truck
    - In 2030: $242,129
    - In 2050: $213,425
  - Average capital cost of a medium/heavy-duty internal combustion engine truck
    - In 2030: $136,416
    - In 2050: $137,920
- Cost of installing a home charging unit (Nicholas, 2019):
  - Level 1 (120V) unit with new wiring and a charger in a detached house is $700
  - Level 2 (240V) unit with new wiring and a charger in a detached house is $1,400

ERG then used the following equations to determine annual fuel cost for each car assuming 11,895 miles per year:

$$\textbf{\textit{conventional vehicle annual fuel cost}}\left(\frac{\$}{year}\right) = \frac{\textit{price of gas}\left(\frac{\$}{gallon}\right) \times \textit{annual distance}\left(\frac{miles}{year}\right)}{\textit{fuel efficiency}\left(\frac{miles}{gallon}\right)} \quad (1)$$

$$\textit{electric vehicle annual charging cost}\left(\frac{\$}{year}\right) = \frac{\textit{price of electricity}\left(\frac{\$}{kWh}\right) \times \textit{annual distance}\left(\frac{miles}{year}\right)}{\textit{fuel efficiency}\left(\frac{miles}{kWh}\right)} \quad (2)$$

ERG calculated the net benefit of 10 years of ownership by finding the difference between the purchase cost and 10 years of annual fuel costs for a conventional vehicle and the purchase cost, home charging unit cost and 10 years of annual electricity costs for an electric vehicle. A negative benefit resulted in a benefit to the conventional car. We assumed a Level 1 home charger for a light-duty vehicle and a Level 2 home charger for a heavy-duty vehicle for this analysis, though heavy-duty vehicles will likely utilize faster, megawatt-scale charging stations that are currently in development (National Renewable Energy Laboratory, 2020). ERG used the same data to estimate the number of years before the total cost to date of an electric vehicle would be the same as a conventional car. ERG assumed the price of the home chargers would remain constant in 2030 and 2050 for this analysis. ERG also did not include any benefits based on resale value or secondary ownership, though resale benefits are not likely to greatly affect this analysis.

ERG repeated these benefit calculations in situations where the state offered incentives for purchasing an electric vehicle. In 10 of the top 12 major cities with the highest electric vehicle ownership, the state offered consumer purchase incentives for electric vehicles, such as tax credit, that averaged between $2,000 and $5,000 (Lowell et al., 2018). We used these values as low and high incentive scenarios for light-duty vehicles. Though heavy-duty electric trucks are not widely on the market, some states like

Colorado have offered tax credit incentives for consumer purchases (U.S. Department of Energy, 2020c). We used $10,000 and $20,000 for the low and high incentive scenarios. ERG assumed these incentives were the same in 2030 and 2050 for this analysis, but with increasing electrification, there will likely be less of a need for state incentives by 2050.

6.1.2.2 Cost-Benefit Analysis for the State and People

To estimate the benefits of reduced air pollutants ($PM_{2.5}$, SO_2, and NO_x), ERG:

1) Used the CO_2, $PM_{2.5}$, SO_2, and NO_x emissions reductions from modeling Synapse (2020) performed for the Maine Climate Council. This modeling estimated the reduction in emissions for electrification scenarios compared to a baseline.

2) Used an EPA study (EPA, 2013) to convert those reductions for $PM_{2.5}$, SO_2, and NO_x into a dollar value based on the anticipated health impacts (i.e., average estimated reduction in mortality and morbidity). ERG converted the values in the EPA study from 2010$ to 2019$ using the GDP deflator. Table 29 presents the estimated value of a per-metric-ton reduction from on-road mobile sources in both 2020 and 2030. ERG assumed the value per ton reduction remained constant between 2030 and 2050.

Table 29. Dollars per Ton of Reduced Pollutant from On-Road Mobile Sources

Category	Value of 1 Metric Ton Reduction $PM_{2.5}$	Value of 1 Metric Ton Reduction of SO_2	Value of 1 Metric Ton Reduction of NO_x
2020 value per metric ton reduced for on-road mobile sources	$911,309	$49,804	$18,014
2030 value per metric ton reduced for on-road mobile sources	$1,059,661	$61,460	$22,253

3) Used both a market and social cost of carbon to estimate the benefit of the CO_2 reduction. In producing the results in Table 30, ERG multiplied the social and market costs of carbon for both 2030 and 2050 by the difference between Synapse's projected CO_2 reductions for the baseline and T1 scenarios in 2030 and 2050, respectively.

Table 30. Summary of Social Cost of Carbon Versus Market Price of Carbon, Extrapolated to 2050

Year	Lower Bound Social Cost of Carbon in 2019$ (EPA, 2016)	Upper Bound Social Cost of Carbon in 2019$ (EPA, 2016)	Market Price of Carbon in 2019$ (Synapse, 2020)
2020	$51.02	$149.41	$5.53
2025	$55.88	$167.63	$5.03
2030	$60.74	$184.64	$5.88
2035	$66.81	$204.07	$6.87
2040	$72.88	$222.29	$8.02
2045	$77.74	$239.30	$9.37
2050	$83.82	$257.52	$10.95

Along with the costs of implementing public charging ports, which are outlined in the earlier case study of the largest 12 utility service territories, Maine would also incur costs related to incentivizing electric vehicle purchases. ERG multiplied the low and high incentive estimates by Synapse's projected number of electric vehicle sales in 2030 for light-duty vehicles and in 2050 for medium- and heavy-duty electric vehicles.

6.1.3 Recommendations for Further Analysis

Given resource requirements, ERG focused its quantitative analysis on the costs to consumers and how much incentive Maine may need to provide to make electric vehicle adoption cost-effective.

Future analyses may include:

- Calculating consumer costs and benefits of plug-in hybrid vehicles along with gas and fully electric vehicles.
- Analyzing infrastructure needed for urban versus rural populations in Maine.
- Incorporating future projections of:
  - Charging station voltage and pricing.
  - Public charging infrastructure needed.
  - Changing incentives for electric vehicles.
- Accounting for other typical annual costs and maintenance costs for electric and conventional vehicles such as oil changes and part replacements.

6.2 Reduce Vehicle Miles Traveled

Strategy 3 of the Transportation Working Group will work to make the goals of Strategy 1 (expand electrification of transportation) attainable. It focuses on supporting the development of key infrastructure in people's daily lives, expanding public transportation that is easily accessible and climate-friendly, and expanding opportunities for telework and teleservices.

Benefits: By acting on these key elements, Maine will experience several benefits related to air quality, health, cost savings, safety, and more. Reduced emissions related to this strategy will result in less air pollution and better health outcomes. Easier access to critical destinations will reduce travel fuel costs and promote more active means of travel, such as bicycling. Additionally, increased telework opportunities will also reduce travel fuel costs and time spent traveling to and from work.

6.2.1 Economic Analysis Results

ERG performed a literature review of the costs and benefits of the public transportation expansion component of this strategy. Inflating the cost per mile figure from Kille (2009) to 2019 dollars results in $18.07 million spent per mile on bus rapid transit. The difference between CO_2 emissions as a result of traveling by car versus bus rapid transit is a reduction of 0.0003 metric tons per mile.

6.2.2 Methods and Limitations

ERG performed a literature review to find other studies that analyzed the impacts of the Transportation Working Group's three key initiatives on reducing VMT and, by connection, carbon emissions. In a study looking at the co-benefits of reduced VMT in California, researchers found that a 10 percent decrease in on-road emissions would reduce total statewide CO_2 emissions by 3.3 percent (Fang & Volker, 2017).

This amounts to nearly 14.5 million metric tons of CO_2 emissions reduced per year. Table 31 shows the results of carrying this same trend over to Maine, which has fewer registered vehicles and thus a smaller impact on CO_2 reductions overall. Maine's emission numbers are also based on the average emissions per vehicle as of 2018, 4.6 metric tons of CO_2, and the number of registered vehicles in the state, 390,506 (FHWA, 2019).

A brief article on the costs of urban transit systems represented the cost of a bus rapid transit system as $10.24 million per mile in 1990 dollars. Inflated to 2019 dollars, this cost represents $18.07 million per mile (Vincent & Calleghan Jerram, 2006).

Table 31. Comparison of On-Road Transportation CO_2 Emissions and Potential Emission Reductions Between California and Maine

Metric	California (2014)	Maine (2018)
Total CO_2 emissions (metric tons/yr)	441,499,873	5,478,954
On-road CO_2 emissions	144,749,959	1,796,328
If On-Road Transportation Emissions Decrease by…	**CO_2 Emissions Decrease by…**	
1%	1,447,499	17,963
5%	7,237,498	89,816
10%	14,474,996	179,633
15%	21,712,493	269,449

Source: Fang and Volker, 2017; FHWA, 2018.

Table 32 shows CO_2 emissions for various transportation methods according to a 2006 analysis (Vincent & Calleghan Jerram, 2006). We converted these values to metric tons from the original table within the represented research study.

Table 32. National Total Commute Trip CO_2 Emissions, 40-ft Compressed Natural Gas

Mode	Emissions (Metric Tons per Passenger Mile)	Subtotal (Metric Tons)
Bus rapid transit	0.00006607	7,219.18
Existing buses	0.0002942	70,566.78
Private vehicles	0.00039789	2,000,227.90
Reduction from no-build option		32,705.7
Reduction over 20-year project life		654,114.0

Source: Vincent & Calleghan Jerram, 2006.

6.2.3 Recommendations for Further Analysis

Future analysis should include the cost implications/benefits of telework opportunities and critical infrastructure construction in priority areas, which represent greater benefits from this overall strategy. Potential increases in the dollar value spent per metric ton of CO_2 reductions emissions may increase, but future analysis can determine that cost impact.

6.3 Explore Mechanisms to Fund Transportation Needs and Facilitate Emissions Reduction

Strategy 5 of the Transportation Working Group focuses on solving the challenges of funding for state transportation construction and maintenance. The mechanisms for collecting revenue for state transportation should be stable, sufficient, and sustainable, and funding solutions should support emissions reductions.

Benefits: The use of multiple funding mechanisms will increase revenue for transportation projects that reduce greenhouse gas emissions. Certain revenue mechanisms will also contribute to CO_2 reductions due to their structure (e.g., fuel tax increase).

6.3.1 Economic Analysis Results

ERG performed a cost-benefit analysis of various funding mechanisms that the Transportation Working Group proposed, including a fuel tax increase, a fee based on VMT, a carbon tax, and carbon allowances under the Transportation and Climate Initiative. As context, the current annual unmet funding need in Maine is $232 million (Maine, 2020).

The current fuel tax is 30 cents per gallon. A fuel tax increase in Maine of 10 cents per gallon results in 127,500 metric tons of CO_2 reduced. The revenue from this tax is about $20.4 million, and the revenue generated to the state (and cost to consumers) is $160 per metric ton.

By 2030, administering the VMT fee through safety inspections will cost between $250 and $718 per metric ton of carbon dioxide equivalent (CO_2e) reduced, while the revenue generated per metric ton (and cost to consumers) will be between $1,149 and $1,321. This would generate about $90 million to $224 million per year in revenue and reduce emissions by 90,000 to 224,000 metric tons of CO_2 each year.

With a price per metric ton of CO_2 emitted between $30 and $50 and revenue generation to the state (and cost to consumers) of approximately $230 per metric ton of CO_2, the carbon tax policy would reduce carbon emissions by about 314,500 metric tons by the year 2030, as well as generate between $54 million and $90 million in revenue to the state.

One analysis of the Transportation and Climate Initiative for the eastern states reported that the initiative's potential benefits are between $3 billion and $10 billion for public health and between $250 million and $892 million in avoided costs as a result of worsening storms and other climate impacts (Massachusetts DOT, 2019).

6.3.2 Methods and Limitations

According to the National Bureau of Economic Research, a 10-cent increase to gas taxes results in a 1.5 percent decrease in CO_2 emissions from the transportation sector (Davis & Kilian, 2009). The Maine Department of Environmental Protection recently released a report stating that transportation activities resulted in 8.5 million metric tons of CO_2 (Bureau of Air Quality, 2020). Based on these two reports and their highlighted metrics, CO_2 reductions in a single year would be 127,500 metric tons. Based on 390,506 registered passenger vehicles throughout Maine, an average of 22 miles per gallon, and 11,500 miles driven per year per driver, revenue from this plan would total about $20.4 million (FHWA, 2019; EPA, 2018).

The VMT fee is projected to reduce greenhouse gas emissions between 0.8 percent and 2.3 percent by the year 2030 (National Academies of Sciences, Engineering, and Medicine, 2012). This analysis used a fee range of 2 cents and 5 cents per mile charged. Again, using the number of public and private registered passenger vehicles in Maine (390,506)[11] and the average number of miles driven per year per vehicle (11,500), revenue from this initiative falls between $89.9 million and $224.5 million per year (FHWA, 2019; EPA, 2018). This policy would result in between 68,000 and 195,000 metric tons of CO_2 reduced by the year 2030. Therefore, the VMT fee would cost between $250 and $718 per metric ton of CO_2e reduced, given the cost to implement the fee is represented by the cost of a safety inspection for every registered vehicle in Maine (Maine DPS, 2019).

Table 33. Costs and Benefits of a VMT Fee

Metric	Low Estimate	High Estimate
Rate of CO_2e reductions by 2030	0.8%	2.3%
Fee charged per VMT	$0.02	$0.05
State revenue	$89,816,380	$224,540,950
Metric tons of CO_2e reduced by 2030	68,000	195,500
Expenditures	$48,813,250	$48,813,250
Dollars spent per CO_2e reduced	$718	$250

Source: National Academies of Sciences, Engineering, and Medicine, 2012; FHWA, 2019; EPA, 2018; Maine DPS, 2019.

The carbon tax policy proposal is expected to reduce emissions by between 2.8 percent and 4.6 percent (National Academies of Sciences, Engineering, and Medicine, 2012). Using a low and high price for the tax of $30 and $50 per metric ton of CO_2e emitted, revenue generated from this proposal would be between $54 million and $90 million. At the same time, CO_2e reductions would amount to between 238,000 and 391,000 metric tons by the year 2030 if current transportation sector-related emissions of 8.5 million metric tons of CO_2e remain constant (Bureau of Air Quality, 2020).

This analysis did not estimate the health benefits related to these funding mechanisms. The reduction of other air pollutants like $PM_{2.5}$, SO_2, and NO_x is a co-benefit of these proposed funding mechanisms.

Table 34 provides a cost-benefit comparison of the VMT fee, carbon tax, and fuel tax strategies.

Table 34. Comparison of Funding Strategies

Metric	VMT Fee		Carbon Tax		Fuel Tax
	Low Estimate	High Estimate	Low Estimate	High Estimate	Estimate
Revenue	$89,816,380	$224,540,950	$53,889,828	$89,816,380	$20,412,814
Cost	$48,813,250	$48,813,250	N/A	N/A	N/A
Metric tons of CO_2 reduced	68,000	195,500	238,000	391,000	127,500
Revenue per metric ton of CO_2 reduced	$1,321	$1,149	$226	$230	$160
Cost per metric ton of CO_2 reduced	$250	$718	N/A	N/A	N/A

[11] This includes public and private passenger vehicles. It excludes motorcycles, buses, trucks. The total of all these registered vehicles is 1.125 million.

6.3.3 Recommendations for Further Analysis

This analysis assumed that 2018 values for registered vehicles, CO_2 emissions, average miles traveled, and vehicle miles per gallon would remain the same for all future years. Future analysis should consider projected trends of these variables. Moreover, this analysis only accounts for passenger vehicles and would benefit from including commercial trucks and buses. Further research into the costs of implementing such a policy would be beneficial. Results from the Transportation and Climate Initiative should be analyzed as time passes.

7. BUILDINGS, INFRASTRUCTURE, AND HOUSING

This section includes five strategies from the Maine Climate Council Buildings, Infrastructure, and Housing Working Group's (2020) *Strategy Recommendations to Mitigate Emissions and Support Resilience in Maine Buildings*:

- **Strategy 1:** Improve the design and construction of new buildings.
- **Strategy 2:** Transition to cleaner heating and cooling systems.
- **Strategy 3**: Improve the efficiency and resiliency of existing building envelopes.
- **Strategy 4:** Lead by example in publicly funded buildings.
- **Strategy 5:** Accelerate the decarbonization of industrial uses and processes.

Heating and cooling in commercial and residential spaces in Maine accounts for a combined 30 percent of combustion CO_2 emissions (Maine Department of Environmental Protection, 2020a). Therefore, reducing the building sector's contribution to these emissions could have a significant impact.

7.1 Improve the Design and Construction of New Buildings

Strategy 1 of the Buildings, Infrastructure, and Housing Working Group would improve the design and construction of new buildings to increase energy efficiency, in part by adopting more stringent building codes over time. This will help Maine reach net zero emission building codes by 2035. While constructing according to a higher energy efficiency standard typically results in higher initial costs, benefits of this approach include lower energy use costs over time and reduced CO_2 emissions.

7.1.1 Economic Analysis Results

ERG performed a benefit-cost analysis of constructing new single- and multi-family homes that are more energy-efficient than what the Maine Uniform Building and Energy Code currently requires. While initial construction costs are higher, the reduced energy costs mean that a higher energy efficiency standard results in a net reduction in costs over time.

For new single-family homes, ERG used the National Renewable Energy Laboratory's (NREL's) (2018) Building Energy Optimization Tool (BeOpt) to analyze the incremental cost of construction compliant with the International Code Council's (2015) International Energy Conservation Code for 2015 (commonly known as IECC 2015) as compared to the more stringent U.S. Department of Energy (DOE) (2019) Zero Energy Ready Home National Program requirements. Although building to a higher energy efficiency standard adds to the initial cost, the reduced operating costs over time lead to net cost savings for each location modeled (Portland, Bangor, and Caribou). Converting the energy savings to CO_2 savings, the zero energy ready scenario would save between 0.0039 and 0.00063 metric tons of CO_2 per ft^2 per year (see Table 35).

Table 35. New Single-Family Homes—Summary of Incremental Cost and CO_2 Saved per ft^2

Location	Incremental Cost (Present Value)/ft^2	Million British Thermal Units /ft^2/Year Savings	CO_2/Year Savings (Metric Tons/ft^2)	Cost/CO_2 Saved ($/Metric Ton)
Portland	-$0.61	0.0089	0.00060	-$1,021.44
Bangor	-$0.62	0.0093	0.00063	-$989.66
Caribou	-$0.75	0.0058	0.00039	-$1,937.38

Sources: ERG analysis using NREL's BeOpt; IECC, 2015; DOE, 2019.

For new multi-family homes, we analyzed data provided by Avesta Housing (2020a; 2020b; 2020c) on construction and operating costs for 12 buildings constructed between 2005 and 2016. Overall, initial construction costs were higher for buildings built to more stringent requirements than they were for code compliance, but operating costs were lower. Additionally, these more stringent designs saved an average of 0.0025 metric tons of CO_2 per ft^2 per year, as compared to code-compliant buildings (see Table 36).

Table 36. New Multi-Family Homes—Summary of Incremental Cost and CO_2 Saved per ft^2

Building Design	Incremental Initial Costs/ft^2	Incremental Operating Costs/ft^2/Year	Million British Thermal Units/ft^2/Year Savings	CO_2 Savings (Metric Tons/ft^2/Year)	Cost/CO_2 Saved ($/Metric Ton)
Passive design	$0.87	-$0.81	-0.0617	-0.0028	-$309.09
High performance	-$3.19	-$0.96	-0.0522	-0.0026	$1,246.14
Leadership in Energy and Environmental Design	$6.02	-$0.85	-0.0462	-0.0023	-$2,654.87
All non-code compliance	**$0.37**	**-$0.89**	**-0.0526**	**-0.0025**	**-$146.85**

Source: ERG analysis based on Avesta Housing (2020a-c) data on multi-family projects in Maine 2015–2019.

Note that the square footage per unit varies for each building analyzed, with an average of 725 square feet per unit for buildings built to code compliance, 840 square feet per unit for passive design, 963 for high performance, 792 square feet for LEED, and 879 square feet for all buildings that exceed code compliance combined.

7.1.2 Methods and Limitations

7.1.2.1 Single-Family Homes

ERG used NREL's (2018) BeOpt to compare the costs of building a new single-family home to either the baseline IECC 2015 code or the more stringent DOE (2019) Zero Energy Ready Home requirements. BeOpt integrates NREL's National Residential Efficiency Measures Database, which is a centralized source of residential building measures and costs. It allows the user to select from a number of options, such as insulation, windows, space conditioning, etc. After selecting the desired inputs, running the simulation results in outputs with the present value cost and energy use of the modeled scenario (see Appendix A for an illustration of these inputs and outputs). The present value cost for each item considers the initial value, future replacement cost, and energy costs.

In selecting **site options**, all scenarios that ERG modeled used the following parameters:

- A 2,200 ft^2, three-bedroom, two-bathroom single-family detached home with a two-car garage.
- Energy prices from the Maine Governor's Energy Office (2020) for April 28, 2020.
- A 3 percent discount rate, 30-year period of analysis, and 2.4 percent inflation rate.

For the **baseline scenario**, ERG modeled three paths to comply with IECC 2015:[12]

1) Meet the requirements in sections R401–R404 of the 2015 code.
2) Show that proposed design is above the standard reference model with inputs marked in section R405 and mandatory provisions in R401 and R404.
3) Use the energy rating index approach in section R406, which is built into BeOpt.

Because multiple sources conflict with regard to their recommended BeOpt options, ERG applied the following hierarchy of recommendations:

1) IECC 2015 sections R401–R404.
2) IECC 2015 R405 standard reference design (Table R405.5.2).
3) NREL's (2014) Building America House Simulation Protocols.

For the **proposed scenario**, ERG modeled compliance with the DOE (2019) Zero Energy Ready Home requirements, which has two paths to compliance:

1) Prescriptive path with outlined requirements.
2) Modeling path that defines a target home; if the modeled home meets or exceeds the performance level of the target home, then it is certified.

ERG followed the second of these two compliance paths, modeling the target home from the modeling path.

Appendix A shows the options we selected for both the baseline IECC 2015 and proposed DOE Zero Energy Ready scenarios.

For both the baseline and proposed scenarios, ERG modeled houses in **three locations** in Maine (Portland, Bangor, and Caribou) by using BeOpt's built-in function to import weather data in the EnergyPlus weather format.[13]

By comparing the cost and energy consumption outputs of each baseline simulation (IECC 2015) and proposed scenario (DOE, 2019), we derive the incremental present value cost and energy usage of switching to the more stringent Zero Energy Ready Home requirements.

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[12] While the current Maine Uniform Building and Energy Code only requires compliance with the IECC for 2009 (Maine Office of State Fire Marshal, 2020), the Maine Climate Council Buildings, Infrastructure, and Housing Working Group anticipates that the 2015 code will be adopted by the time the Maine Climate Council delivers its report to the legislature.

[13] Both Portland and Bangor are in IECC climate zone 6, while Caribou is in climate zone 7. However, the options required for compliance with both the IECC 2015 and DOE Zero Energy Ready Home requirements is the same for climate zones 6 and 7.

To convert energy savings (expressed in million British thermal units) to CO_2 savings, we use the same conversion factors as the analysis prepared by the Efficiency Maine Trust (2020),[14] shown in Table 37 (but converted from pounds to metric tons of CO_2).

Table 37. Million British Thermal Units to CO_2 Conversion

Energy Source (Unit)	CO_2 (Metric Tons)	Million British Thermal Units Equivalent	Fuel Mix	Million British Thermal Units to Metric Tons CO_2 Multiplier
Oil (gallon)	0.01016	0.139000	69.8%	0.07310
Natural gas (ft^3)	0.00005	0.001039	9.0%	0.05112
Electricity (kWh)	0.00030	0.003412	3.8%	0.08708
Propane (gallon)	0.00576	0.091330	13.1%	0.06307
Kerosene (gallon)	0.00975	0.135000	0.0%	0.07224
Wood (cord)	0.00000	20.000000	4.3%	0.00000
Weighted average	—	—	—	**0.06719**

Table 38 shows the **results of this analysis** per house and per ft^2. For all three locations, construction to the DOE (2019) Zero Energy Ready Home requirements results in net cost savings of between about $1,000 and $2,000 and CO_2 savings of between 0.00038 and 0.00062 metric tons per ft^2 per year per home.

Table 38. New Single-Family Homes—Summary of Incremental Cost and CO_2 Saved per House and per ft^2

Location	Incremental Cost (Present Value)	Million British Thermal Units/Year Savings	CO_2/Year Savings (lbs.)	Cost (Present Value)/ CO_2 Saved ($/lb.)
Per House				
Portland	-$1,345.00	19.60	1.31677	-$1,021.44
Bangor	-$1,363.00	20.50	1.37724	-$989.66
Caribou	-$1,653.00	12.70	0.85321	-$1,937.38
Per ft^2				
Portland	-$0.61	0.0089	0.00060	-$1,021.44
Bangor	-$0.62	0.0093	0.00063	-$989.66
Caribou	-$0.75	0.0058	0.00039	-$1,937.38

Sources: ERG analysis using NREL's BeOpt; IECC 2015; DOE, 2019.

The primary limitation of this analysis is that BeOpt only outputs the present value cost and does not disaggregate the initial cost, replacement cost, and ongoing energy cost savings.

7.1.2.2 Multi-Family Homes

To analyze the incremental cost of building multi-family homes to a more stringent energy efficiency standard, ERG used data provided by Avesta Housing (2020a; 2020b; 2020c) on construction and operating costs for 12 multi-family buildings constructed in Maine between 2005 and 2016. These include seven code-compliant, one passive design, two high-performance, and two Leadership in Energy and Environmental Design (LEED) buildings. Avesta tracks initial construction costs, operating costs, and energy use for each of these buildings (with construction year costs updated to 2020 dollars). ERG

[14] Spreadsheet analysis titled "BIH_MCC data request_DRAFT_v2_05.11.2020.xlsx."

converted the energy use into pounds of CO_2 using the conversion factors from Table 37 above, specific to the fuel type used in each building for heat and hot water (natural gas, propane, and/or electricity, depending on the building). We assume that 43.86 percent of the energy use in each building is for heating and 56.14 percent is for hot water, based on the Energy Information Administration's (2018) estimates for multi-family buildings with more than five units.

Table 39 presents the average cost per apartment unit and per ft^2 for buildings built to each design standard, as well as energy use (in Million British Thermal Units) and CO_2 emissions. Initial costs per unit were higher for each non-code compliant design, but operating costs, energy use, and CO_2 emissions were significantly lower. When considered on a per-ft^2 basis, the same conclusions hold, with the exception of initial costs for the high-performance design—which, in the case of the two buildings included in the data, were actually *lower* on average than for the code-compliant buildings.

Table 39. New Multi-Family Homes—Summary of Incremental Cost and CO_2 Saved per ft^2

Building Design	Initial Costs	Operating Costs/Year	Million British Thermal Units / Year	CO_2 /Year (lbs.)	Initial Cost/CO_2 Savings ($/lb.)
Average per Unit					
Code compliance	$119,034	$1,303.87	65.77	3.4471	—
Passive design	$138,655	$832.76	24.33	1.6277	—
High performance	$155,032	$806.18	37.09	2.1121	—
LEED	$134,697	$750.90	35.21	1.9666	—
All non-code compliance	**$144,679**	**$794.79**	**33.49**	**1.9515**	—
Average per ft^2					
Code compliance	$164	$1.80	0.09	0.0048	—
Passive design	$165	$0.99	0.03	0.0048	—
High performance	$161	$0.84	0.04	0.0048	—
LEED	$170	$0.95	0.04	0.0048	—
All non-code compliance	**$165**	**$0.90**	**0.04**	**0.0048**	—
Incremental Difference from Code Compliance per Unit					
Passive design	$19,621	-$471.12	-41.44	-1.8194	$10,784.10
High performance	$35,997	-$497.70	-28.68	-1.3350	$26,965.10
LEED	$15,662	-$552.97	-30.56	-1.4804	$10,579.45
All non-code compliance	**$25,644**	**-$509.09**	**-32.28**	**-1.4956**	**$17,147.10**
Incremental Difference from Code Compliance per ft^2					
Passive design	$0.87	-$0.81	-0.06	-0.0028	$309.09
High performance	-$3.19	-$0.96	-0.05	-0.0026	-$1,246.14
LEED	$6.02	-$0.85	-0.05	-0.0023	$2,654.87
All non-code compliance	**$0.37**	**-$0.89**	**-0.05**	**-0.0025**	**$146.85**

Source: ERG analysis based on Avesta Housing (2020a-c) data on multi-family projects in Maine 2005–2016.

Note that the square footage per unit varies for each building analyzed, with an average of 725 square feet per unit for buildings built to code compliance, 840 square feet per unit for passive design, 963 for high performance, 792 square feet for LEED, and 879 square feet for all buildings that exceed code compliance combined.

7.1.3 Recommendations for Further Analysis

Future analysis could focus on:

- Disaggregating the initial and ongoing costs for single-family buildings.

- Estimating the costs and benefits for commercial and industrial buildings.
- Investigating costs for multi-family buildings with other building designs than those used by Avesta Housing, such as the IECC 2015 and DOE (2019) requirements.
- Performing additional actions identified in the Buildings, Infrastructure, and Housing Working Group's (2020) *Strategy Recommendations to Mitigate Emissions and Support Resilience in Maine Buildings*, such as training, requiring proof of code compliance to insure new properties, amending the Maine Uniform Building and Energy Code to require disclosure of energy performance characteristics, and authorizing Efficiency Maine to include energy savings beyond baseline compliance levels.

7.2 Transition to Cleaner Heating and Cooling Systems and Improve the Efficiency and Resiliency of Existing Building Envelopes

This section combines two strategies of the Buildings, Infrastructure, and Housing Working Group:

- **Strategy 2** would replace outdated, inefficient heating and cooling systems in existing buildings with newer, **more efficient heating and cooling systems** that reduce costs for the consumer as well as greenhouse gas emissions. Fifty-six percent of Maine's housing stock was built before 1980 (with inefficient heating systems) (Maine Housing, 2019), providing an ample opportunity to retrofit existing housing with more efficient systems.
- **Strategy 3** would target the **building envelopes of existing buildings** to reduce the amount of energy needed for heating and cooling, i.e., "**weatherization**." This could include increasing insulation or reducing the amount of air leakage (Maine Climate Council Buildings, Infrastructure, and Housing Working Group, 2020).

7.2.1 Economic Analysis Results

Using calculations and data provided by the Efficiency Maine Trust (2020a), Table 40 presents several cleaner heating and cooling systems alongside weatherization of existing building envelopes on the basis of cost effectiveness in reducing CO_2 emissions (second column from left), the benefit cost ratio (second column from right), and annual CO_2 savings. For example, a new heat pump hot water heater has the second highest cost effectiveness per metric ton of carbon dioxide saved (second column), highest benefit-cost ratio at 2.91 (fourth column), and one of the lower CO_2 savings per year at 0.6 metric tons (far right column).

The key takeaway is all of these strategies save costs and reduce CO_2 (based on their negative cost-effectiveness value in the second column); thus, they are cost-effective actions that Maine should focus on to reduce emissions in the near term. It should be noted that the cost-effectiveness metric can sometimes be misleading when dealing with cost savings as an increasingly negative number is not necessarily a benefit; rather, it could be an indication of a very high cost savings and a very small CO_2 savings. Thus, the measures should not simply be implemented based on the cost-effectiveness as the benefit-cost ratio and overall capacity for CO_2 savings (among other factors), should be considered.

Table 40. Summary of Cleaner Cooling and Heating Systems and Existing Building Envelope Results

Measure	Δ Total Cost/CO_2 Savings (Metric Tons)	CO_2 Savings (Metric Tons)/Δ Total Cost	Benefit-Cost Ratio	CO_2 (Metric Tons) Savings Per Year
One heat pump - New	-$234.2	-0.0043	2.50	0.576
One heat pump - Retrofit	-$90.3	-0.0111	1.29	2.049
Two heat pumps - Retrofit	-$59.9	-0.0167	1.03	3.189
Whole home heat pumps - New	-$117.8	-0.0085	1.94	4.704
Heat pump water heater - New	-$362.6	-0.0028	2.91	0.600
Heat pump water heater - Retrofit	-$209.3	-0.0048	1.14	0.618
High efficiency natural gas boiler - New	-$434.1	-0.0023	1.28	3.018
High efficiency natural gas boiler - Retrofit	-$361.2	-0.0028	0.33	3.018
Pellet boiler - New	-$19.9	-0.0502	0.72	8.102
Geothermal - New	-$62.1	-0.0161	1.16	6.052
Weatherization	-$112.7	-0.0089	1.02	0.994

Source: Efficiency Maine (2020a) and other sources noted in text. This table illustrates different ways of comparing costs and benefits for each measure. Assumptions about the baseline fuel type and efficiency, and the avoided costs, may vary across each of the four columns.

7.2.2 Methods and Limitations

Transitioning to cleaner cooling and heating systems and weatherizing existing building envelopes both include a one-time, upfront cost of installing the system or weatherization (i.e., the "measure cost"). Cleaner cooling and heating systems also have operational costs over time, but they are lower than the older, inefficient systems. Both strategies should subsequently result in reduced energy use over their lifetimes. This reduced energy use results in lower energy costs, as well as reduced CO_2 emissions. By comparing the initial measure cost plus any operational lifetime costs to the operational costs of the existing alternative, we can assess the change in costs and compare it to the energy/CO_2 savings to calculate the cost-effectiveness in terms of dollars per metric ton of CO_2 reduced.

The measure costs shown here consider whether the measure is installed as "new" or as a "retrofit." New installations are performed when a piece of equipment has burned out, or if the equipment is a new addition to the building; in this case, the cost is the incremental cost difference between a baseline new system and the new efficient option. Retrofits, by contrast, are performed when the existing system is working, in which case the measure cost is the full cost of purchasing and installing the new efficient option. None of the measure costs presented integrate any incentives paid to consumers.[15]

The operating costs consider the annual operating cost of the baseline system and the new efficiency option over the lifetime of the measure (which ranges from 13 to 25 years, depending on the measure). This includes avoided costs achieved through energy conservation or fuel switching (e.g., avoided costs from no longer using oil to meet the old energy requirements plus new costs from using electricity to meet the new energy requirements). Propane, distillate fuel oil, and natural gas energy prices are based on the Energy Information Administration's (2020) Annual Energy Outlook for residential energy prices in New England. We calculated the average cost (in 2019$ per Million Metric British Thermal Unit) over the measure lifetime by averaging the Energy Information Administration estimate from 2020 onward

[15] This approach is consistent with Efficiency Maine Trust's (2020b) Retail/Residential Technical Reference Manual.

(through 2032 for measures with a 13-year lifetime, 2037 for measures with an 18-year lifetime, and 2044 for measures with a 25-year lifetime).

Because Maine's electricity prices are significantly lower than the average of prices in other New England states, we use the Maine Governor's Energy Office (2020) estimate for 2019 and project it forward using the growth rate of electricity prices in the Energy Information Administration's (2020) Annual Energy Outlook. We then calculate the 13-, 18-, and 25-year averages. For wood pellets, we also use the Maine Governor's Energy Office (2020) estimate for the 13-, 18-, and 25-year averages.

We used CO_2 emissions from the Energy Information Administration (2016) for all but the electric grid, which uses the most recent emissions report from ISO New England (2020).

Table 41 shows the cost, lifetime operational costs and savings, and lifetime CO_2 savings for each measure. For example, a new heat pump has a lifetime cost savings of $2,429, a lifetime CO_2 savings of 10.4 metric tons, a cost savings of $234.20 for each ton of CO_2 saved, and saves -0.0043 tons of CO_2 per dollar saved.

Table 41. Summary of Lifetime Carbon and Investment Savings

Measure	Measure Cost	Lifetime Operational Cost	Lifetime Operational Savings	Δ Total Cost	Lifetime CO_2 Savings (Metric Tons)	Δ Total Cost/CO_2 Savings (Metric Tons)	CO_2 Savings (Metric Tons)/Δ Total Cost
Formula	**a**	**b**	**c**	**d = a - c**	**e**	**f = d ÷ e**	**g = e ÷ d**
One heat pump— New	$682	$865	$3,111	-$2,429	10.37	-$234.2	-0.0043
One heat pump—Retrofit	$3,800	$12,167	$7,132	-$3,332	36.89	-$90.3	-0.0111
Two heat pumps—Retrofit	$7,600	$19,076	$11,041	-$3,441	57.41	-$59.9	-0.0167
Whole home heat pumps—New	$3,900	$33,698	$13,874	-$9,974	84.67	-$117.8	-0.0085
Heat pump water heater—New	$700	$2,158	$3,527	-$2,827	7.80	-$362.6	-0.0028
Heat pump water heater—Retrofit	$2,000	$2,158	$3,682	-$1,682	8.03	-$209.3	-0.0048
High efficiency natural gas boiler—New	$1,500	$36,079	$34,249	-$32,749	75.44	-$434.1	-0.0023
High efficiency natural gas boiler— Retrofit	$7,000	$36,079	$34,249	-$27,249	75.44	-$361.2	-0.0028
Pellet boiler—New	$12,924	$53,368	$16,960	-$4,036	202.56	-$19.9	-0.0502
Geothermal—New	$31,000	$29,101	$40,391	-$9,391	151.30	-$62.1	-0.0161
Weatherization	$6,800	N/A	$9,601	-$2,801	24.86	-$112.7	-0.0089

Source: Efficiency Maine (2020a) and other sources noted in text.

Note: All $ estimates are in 2019 dollars based on an Energy Information Administration (2020) energy forecast for New England and not adjusted for net present value. Social cost of carbon estimates are also not included.

Table 42 compares the measures using the benefit-cost test that the Efficiency Maine Trust employed in its regulatory filings and pursuant to the Code of Maine Rules governing the Trust's conservation programs. A benefit-cost ratio greater than 1 indicates that benefits (lifetime avoided energy costs) exceed costs. By this metric, heat pump hot water heaters and heat pumps are among the best performers, with benefits exceeding costs by a factor of two to three times. The high efficiency natural gas boiler retrofit measure, while having a relatively high ratio of the change in total cost to CO_2 savings (in Table 41 above), has a benefit-cost ratio of less than 1, as does the pellet boiler.

Table 42. Efficiency Maine Primary Benefit Cost Test [a]

Measure	Measure Cost	Net Benefits [b]	Incentive Per Unit	Benefit-Cost Ratio
Heat pump water heater—New	$700	$2,186	$750	2.91
One heat pump—New	$682	$2,890	$1,000	2.50
Whole home heat pumps—New	$3,900	$21,598	$1,500	1.94
One heat pump—Retrofit	$3,800	$5,339	$1,000	1.29
High efficiency natural gas boiler—New	$1,785	$2,282	$1,000	1.28
Geothermal—New	$31,000	$37,778	$3,000	1.16
Heat pump water heater—Retrofit	$2,000	$2,278	$750	1.14
Two heat pumps—Retrofit	$7,600	$7,927	$1,500	1.03
Weatherization	$6,800	$6,950	$3,400	1.02
Pellet boiler—New	$12,924	-$7,152	$3,400	0.72
High efficiency natural gas boiler—Retrofit	$7,000	$2,282	$1,000	0.33

Source: Efficiency Maine (2020a) and other sources noted in text. This table applies different baseline assumptions about efficiency and fuel type for natural gas boilers and single heat pump – new than were applied in Tables 41 and 43.

[a] All estimates come from the 2018 Avoided Energy Supply Component study with baselines and values matching Efficiency Maine's assumptions.

[b] Benefits include energy and water benefits and fuel costs.

Table 43 summarizes the annual savings of CO_2 emissions and annual savings of Million British Thermal Units (MMBTU) per year. Please note that these are not apples-to-apples comparisons because some are whole house solutions and others are partial house solutions. This table is presented in this methods section to show how we calculated these annual savings.

Table 43. Cleaner Heating and Cooling Systems—CO_2 Reduction and Cost Efficiency

Measure	Operating CO_2 (Metric Tons) per MMBTU	Baseline CO_2 (Metric Tons) per MMBTU	MMBTU Consumed per Year	MMBTU Saved per Year	CO_2 (Metric Tons) Savings Per Year
Formula	**a**	**b**	**c**	**d**	**e = ((c + d) × b) - (a × c)**
One heat pump—New	0.087	0.073	0.9	8.1	0.576
One heat pump—Retrofit	0.087	0.073	13.1	30.5	2.049
Two heat pumps—Retrofit	0.087	0.073	20.5	47.6	3.189
Whole home heat pumps—New	0.087	0.073	36.3	71.3	4.704
Heat pump water heater—New	0.087	0.079	3.2	7.9	0.600
Heat pump water heater—Retrofit	0.087	0.079	3.2	8.2	0.618
High efficiency natural gas boiler—New	0.051	0.073	99.5	11.4	3.018
High efficiency natural gas boiler—Retrofit	0.051	0.073	99.5	11.4	3.018
Pellet boiler—New	0.000	0.073	131.4	-20.6	8.102
Geothermal—New	0.087	0.073	22.4	87.1	6.052
Weatherization	N/A	0.067	N/A	14.8	0.994

Source: Efficiency Maine (2020a) and other sources noted in text.

Note: This calculation also considers baseline system efficiency estimates that are not included in this table.

7.2.3 Recommendations for Further Analysis

For measures that switch from combustion to electrical end uses, this analysis used the most recent average marginal emission factors from ISO New England (2020) and (notwithstanding various state policies to increase the share of renewable energy on the grid) does not apply forecasts of cleaner emissions over time. As the grid gets cleaner, these measures will offset more carbon each year. Future analyses could factor this into the estimates presented in Table 41.

7.3 Lead by Example in Publicly Funded Buildings

Strategy 4 of the Buildings, Infrastructure, and Housing Working Group will highlight the State of Maine's leadership role in climate resilience and mitigation by accelerating the timeline of Strategy 1 (improve the design and construction of new buildings) in publicly funded buildings. It will amend the rules and policies for procurement of affordable housing; state government buildings; and schools at the K-12, community college, and university levels.

Benefits: Swiftly adopting best practices in these highly visible, collectively funded, and collectively used buildings will demonstrate the feasibility of practices outlined in Strategy 1, offer important experience and learning for statewide implementation, and maximize the economic and climate benefits of high-performance construction for taxpayers.

7.3.1 Economic Analysis Results

The return on investment for these projects will depend on their nature (return on investment estimates and cost-effectiveness analyses can be found throughout Section 7 of this report). In addition to the return on investment of the projects themselves, demonstrating the cost-effectiveness of these projects to the public offers a huge additional value to Maine, as they help change minds and increase the chance that others will similarly implement cost-effective, emissions-reducing projects. While it is hard to quantify the value of leading by example, we present a case study that qualitatively demonstrates how these types of projects lead to additional projects, which in turn provide an economic benefit.

SUCCESS STORY: TOWN OF BRISTOL SOLAR ARRAY PROJECT
The Town of Bristol added a solar array at its transfer station (financed by Coastal Enterprises, Inc.), and Bristol's school system also purchased an array. Both arrays are in highly visible locations in town. These were both relatively small projects in terms of the overall impact on the grid; however, the projects got the people of the town talking and asking questions about their cost-effectiveness. To change the minds of skeptics and enhance the confidence of proponents, the Town of Bristol demonstrated the cost-effectiveness of lead-by-example projects, which helped justify more substantial future investment. Approximately a year later, the Town of Bristol decided to implement a much more substantial solar array (Egan, 2020). *ERG interviewed John Egan with Coastal Enterprises, Inc., a company that has financed sustainable energy products throughout the state. They financed the lead-by-example project at the transfer station in Bristol, which they worked with SunDog Solar to place.*

7.3.2 Recommendations for Further Analysis

Developing a baseline of energy use in publicly funded buildings could help identify opportunities to maximize the effectiveness of this strategy. Additionally, it will be useful to compile additional examples of success stories to not only see project returns on investment, but also what types of building projects generate these positive outcomes, which could help motivate implementation.

7.4 Accelerate the Decarbonization of Industrial Use and Processes

Strategy 5 of the Buildings, Infrastructure, and Housing Working Group calls for a literature review on the benefits of different fuels for a long-term plan for fuel switching in the industrial sector.

Benefits: Benefits primarily include potential cost savings and a decrease of emissions in the industrial sector.

7.4.1 Economic Analysis Results

Fuel switching can result in cost-effective measures over time that reduce emissions. Natural gas is becoming more cost-effective as technologies improve. Though it has been expanding as a heating fuel for residential use, it is also a viable candidate to expand into the industrial space, especially in industries that rely on heating oil (Dickerson, 2012). First generation biofuels are not currently a viable source of energy because of their limited scale. Second generation biofuels are currently in the research and development phase, and research shows that they may have trouble reaching a competitive price (Dickerson, 2012). Biomass accounts for 41 percent of Maine's industrial energy (Dickerson, 2012). Additional sources of energy could be cost-effective for Maine, such as wind, solar, tidal, and hydroelectric projects. However, the overall benefits of fuel switching far outweigh the negative impacts. Switching to state-based energy production over imported energy would give Maine more autonomy and create less sensitivity to market fluctuations—in addition to creating and retaining jobs—and improve the quality of life for Mainers (Dickerson, 2012).

7.4.2 Methods and Limitations

ERG performed a literature review to find the quantitative and qualitative benefits of reducing emissions and pursuing a long-term plan for industrial fuel switching in process heating. Although large-scale fuel switching involves large upfront costs, it can beneficially transform Maine's industrial sector. Therefore, it is important to characterize the impacts of projects that include fuel switching on a large scale.

7.4.3 Recommendations for Further Analysis

Expanding a model to cover different fuel types over various timeframes could help Maine estimate several benefits and costs for different fuel and system switching scenarios.

8. CONCLUSION

The State of Maine should use these economic analyses to determine whether there is an economic case to implement a strategy, or if one might be made in the future given additional research. In addition, although there may not be a clear economic case to implement a strategy on a statewide scale, we have highlighted instances in which there is a very compelling case to implement the strategy at key sites (e.g., maximizing co-benefits) with additional analysis. The economic analysis results in this report should not be the deciding factor in whether Maine prioritizes a strategy. Instead, Maine must consider these results along with variables such as political feasibility, equity, and community support.

9. WORKS CITED

Adams-Schoen, S. J., 2018. Beyond Localism: Harnessing State Adaptation Lawmaking to Facilitate Local Climate Resilience. *Michigan Journal of Environmental & Administrative Law,* 8(1), p. 185.

Adler, M., Anthoff, D., Bosetti, V., Garner, G., Keller, K., and Treich, N., 2017. Priority for the worse-off and the social cost of carbon. *Nature Climate Change.*

Adrion, E., Aucott, J., Lemke , K. & Weiner, J., 2015. Health Care Costs, Utilization and Patterns of Care following Lyme Disease. *PLoS One,* p. 1–14.

Amy Kolb, N., 2019. 'Did It Work?': Vermont's Wood Stove Change-Out Program. *Vermont Public Radio*, 17 May.

Anon., 2014. *Adaptation Planning Study: Downtown Waterfront Area Damariscotta, Maine,* s.l.: Milone & MacBroom, Inc.

Arnell, N. & Gosling, S., 2016 . The impacts of climate change on river flood risk at the global scale.. *Climate Change, 132 (3),* pp. 387-401.

Artrip, K., Shrestha, D., Coats, E. & Keiser, D., 2013. GHG Emissions Reduction from an Anaerobic Digester in a Diary Farm: Theory and Practice. *Applied Engineering in Agriculture,* 29(5), pp. 729-737.

ASMFC, 2017. *2017 Review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for American Lobster,* s.l.: ASMFC.

Avallon, E., 2019. *Presentation on Carbon Pricing and Market Design,* Rensselaer, NY: https://www.nyiso.com/documents/20142/7129597/6.20.2019_MIWG_Carbon_Pricing_MDC_FINAL.pdf/cf67ebb8-d0fc-7b4b-100f-c3756d6afae8.

Avesta Housing, 2020a. *New Construction in Maine 2005-2016 - Operating Costs per Unit.* s.l.:s.n.

Avesta Housing, 2020b. *New Construction in Maine 2005-2016 - Energy Consumed per Square Foot.* s.l.:s.n.

Avesta Housing, 2020c. *New Construction in Maine 2005-2016 - Capital Costs.* s.l.:s.n.

Bai, X. et al., n.d. *State of Maine's Carbon Budget, 2006-2016,* Orno, ME: The University of Maine.

Bartow-Gillies, M. E. S. E. C., 2020. *The Maine Tidal Restriction Database: A desktop assessment of tidal restrictions in Maine to facilitate community resilience and habitat restoration. Maine Coastal Program..* s.l.:s.n.

Bayraktarov, E. S. M. I. A. S. M. M. B. J. P. H. P. .. &. L. C. E., 2015. Data from: The cost and feasibility of marine coastal restoration, Dryad, Dataset.

Bayraktarov, E. S. M. I. A. S. M. M. B. J. P. H. P. .. &. L. C. E., 2016. The cost and feasibility of marine coastal restoration. *Ecological Applications,* 26(4), pp. 1055-1074.

Berguin, A., 2018. *Maine Farmland: Sprouting Solor Crops Needs Policy,* Orono: University of Southern Maine: USM Digital Commons.

Birkel, S. D. & Mayewski, P. A., 2018. *Coastal Maine Climate Futures,* Orno, ME: Climate Change Institute, University of Maine.

Black, R., 2006. *Supplemental Economic Impact Statement for Vermont's Proposed Rule on Outdoor Wood-Fired Boilers,* s.l.: Vermont Department of Environmental Conservation Air Pollution Control Division.

Bolinger, M., Seel, J. & Robson, D., 2019. *Utility-Scale Solar Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States,* s.l.: Lawrence Berkeley National Laboratory.

Bookhart, D., 2008. Strategies for Carbon Neutrality. *Sustainability: The Journal of Record,* 1(1), pp. 34-40.

Buchholz, T. & Gunn, J., 2017. *Economic Impact Assessment of Wood Chip Heat in Maine,* Augusta: Natural Resources Council of Maine.

Bureau of Air Quality, 2020. *Eighth Biennial Report on Progress toward Greenhouse Gas Reduction Goals,* s.l.: Maine Department of Environmental Protection.

Bureau of Economic Analysis, 2020. *Table 1.1.9. Implicit price deflators for Gross Domestic Product. March 26, 2020.* [Online]
Available at:
https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=2&isuri=1&1921=survey

Burn Wise, 2019. *Wood Smoke Awareness Kit,* s.l.: U.S. Environmental Protection Agency.

Butler, B. J., 2016. *Forests of Maine, 2016,* Newtown Square, PA: United States Department of Agriculture.

Cai, Y., and Lontzek, T.S., 2019. The Social Cost of Carbon with Economic and Climate Risks. *Journal of Political Economy, University of Chicago,* pp. 1-79.

California Air Resources Board, 2017. *California's 2017 Climate Change Scoping Plan: the strategy for acheiving California's 2030 greenhouse gas target,* s.l.: s.n.

Cavanaugh, C. et al., 2017. Fatal deer tick virus infection in Maine.. *Clinical Infectious Diseases,* pp. 1043-1046.

Chittum, A. & Kaufman, N., 2011. *Challenges Facing Combined Heat and Power Today: A State-by-State Assessment,* Washington, D.C.: American Council for an Energy-Efficient Economy.

Cole, S. G. &. M. P. O., 2016. Valuing multiple eelgrass ecosystem services in Sweden: fish production and uptake of carbon and nitrogen. *Frontiers in Marine Science,* Volume 2, p. 121.

Commission, M. P. U., 2015. *Maine Distributed Solar Valuation Study,* s.l.: Clean Power Research.

Conservation, Maine Department of, 2010. *Maine State Forest Assessment and Strategies,* Augusta: Maine Forest Service, Department of Conservation.

Costanza, R. P.-M. O. M. M. L. S. P. A. S. J. &. M. K., 2008. The value of coastal wetlands for hurricane protection. *AMBIO: A Journal of the Human Environment,* 37(4), pp. 241-248.

Daigneault, A. et al., 2020. *Maine Forestry and Agriculture Climate Change Mitigation Potential; Preliminary Results for Distribution and Review,* Orno, ME: University of Maine.

Davis, L. W. & Kilian, L., 2009. *Estimating the Effect of a Gasoline Tax on Carbon Emissions,* s.l.: National Bureau of Economic Research.

Daymark Energy Advisors, R. E. a. E. G., 2018. *Benefits and Costs of Utility-Scale and Behind-the-Meter Solar Resources in Maryland,* s.l.: Maryland Public Service Commission.

Demaria, E., Palmer, R. & Roundy, J., 2016a. Regional climate change projections of streamflow characteristics in the Northeast and Midwest US. *Journal of Hydrology: Regional Studies,* pp. 309-323.

Department of Energy, 2019. *DOE Zero Energy Ready Home National Program Requirements (Rev. 07) May 1, 2019.* s.l.:s.n.

Department of Energy, 2020a. *Fuel Prices.* [Online]
Available at: https://afdc.energy.gov/fuels/prices.html

Department of Energy, 2020. *Alternative Fuels Data Center.* [Online]
Available at: https://afdc.energy.gov/fuels/prices.html
[Accessed August 2020].

Department of Energy, n.d. *Ethanol Benefits and Considerations.* [Online]
Available at: https://afdc.energy.gov/fuels/ethanol_benefits.html

Dickerson, K., 2012. *Energy in Maine,* Orono: Margaret Chase Smith Policy Center.

Dickson, S., Slovinsky, P. & Kelley, J., in preparation. Sea Level Rise and Storm Surge. In: *Scientific Assessment of Climate Change and Its Effects in Maine.* s.l.:s.n.

DOE, 2015. *Wind Vision: A New Era for Wind Power in the United States,* s.l.: U.S. Department of Energy.

Doluweera, G. et al., 2018. *A Comprehensive Guide to Electricity Generation Options in Canada,* s.l.: Canadian Energy Research Institute.

Dornisch, V. D., Ankersen, T. T. & Swett, R. A., 2015. *Florida beach users' perceptions of beach ownership, erosion management, and sea level rise,* s.l.: University of Florida Conservation Clinic, University of Florida Levin College of Law.

Drake, K. H. H. A. S. C. &. C. C., 2015. Carbon sequestration in tidal salt marshes of the Northeast United States. *Environmental management,* 56(4), pp. 998-1008.

Eastern Research Group, Inc., 2020. *Assessing the Impacts Climate Change May Have on the State's Economy, Revenues, and Investment Decisions: Volume 1, Cost of Doing Nothing Analysis.* s.l.:s.n.

Ebi, K. et al., 2018. *2018: Human Health. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* Washington, DC, USA: U.S. Global Change Research Program.

Efficiency Maine Trust (EMT), 2020b. *Retail/Residential Technical Reference Manual,* s.l.: s.n.

Efficiency Maine Trust, 2020a. *Corrected MCC Data 8.24.20.xlsx.* s.l.:s.n.

Efficiency Maine Trust, 2020. *BIH_MCC data request_DRAFT_v2_05.11.2020.xlsx.* s.l.:s.n.

Egan, J., 2020. *Coastal Enterprises, Inc.* [Interview] (8 July 2020).

EIA, 2020. *How much carbon dioxide is produced per kilowatthour of U.S. electricity generation?.* [Online]
Available at: https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

Energy Information Administration (EIA), 2016. *Carbon Dioxide Emissions Coefficients.* [Online]
Available at: https://www.eia.gov/environment/emissions/co2_vol_mass.php
[Accessed 22 August 2020].

Energy Information Administration (EIA), 2020. *Annual Energy Outlook 2020. Table 3. Energy Prices by Sector and Source.* [Online]
Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2020&cases=ref2020&sourcekey=0
[Accessed 21 May 2020].

Energy Information Administration, 2018. *Space heating and water heating account for nearly two thirds of U.S. home energy use.* [Online]
Available at: https://www.eia.gov/todayinenergy/detail.php?id=37433
[Accessed 29 May 2020].

Energy Information Administration, 2020. *Annual Energy Outlook 2020. Table 8. Electricity Supply, Disposition, Prices, and Emission.* [Online]
Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=8-AEO2020&region=0-0&cases=ref2020&start=2020&end=2044&f=A&linechart=ref2020-d112119a.6-8-AEO2020&map=&chartindexed=2&sourcekey=0
[Accessed 17 July 2020].

Energy Information Administration, 2020. *Maine State Profile and Energy Estimates.* [Online]
Available at: https://www.eia.gov/state/data.php?sid=ME#ConsumptionExpenditures
[Accessed August 2020].

Environment, S. o. M. D. o. t., 2019. *2019 Greenhouse Gas Emissions Reduction Act Plan,* s.l.: State of Maryland Department of the Environment.

EPA, 2013. *Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors,* Research Triangle Park, NC: Office of Air and Radiation.

EPA, 2016. *Fact Sheet: Social Cost of Carbon.* [Online]
Available at: https://www.epa.gov/sites/production/files/2016-12/documents/social_cost_of_carbon_fact_sheet.pdf

EPA, 2018. *Green Vehicle Guide: Greenhouse Gas Emissions from a Typical Passenger Vehicle.* [Online]
Available at: https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle#:~:text=typical%20passenger%20vehicle%3F-,A%20typical%20passenger%20vehicle%20emits%20about%204.6%20metric%20tons%20of,8%2C887%20grams%20of%20CO2.

EPA, 2018. *Regulatory Impact Analysis for the Proposed Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guideline Implementing Regulations; Revisions to New Source Review Program,* s.l.: Office of Air Quality Planning and Standards.

Evans, K. et al., 2016. Measuring the impact of pollution closures on commercial shellfish harvest: The case of soft-shell clams in Machias Bay, Maine. *Ocean & Coastal Management,* Volume 130, pp. 196-204.

Executive Order 13783: Promoting Energy Independence and Economic Growth (2017).

Fang, K. & Volker, J., 2017. *Cutting Greenhouse Gas Emissions Is Only the Beginning: A Literature Review of the Co-Benefits of Reducing Vehicle Miles Traveled,* s.l.: UC Davis.

Fernandez, I. et al., 2020. *Maine's Climate Future: 2020 Update,* Orono: University of Maine.

FHWA, 2019. *Highway Statistics 2018,* s.l.: s.n.

Flanagan, B. & et al., 2011. A Social Vulnerability Index for Disaster. *Journal of Homeland Security and.*

Fu, R., Feldman, D. & Margolis, R., 2018. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018,* Golden, CO: National Renewable Energy Laboratory.

Geisler, E., Rittenhouse, C. D. & Rissman, A. R., 2016. Logger Perceptions of Seasonal Environmental Challenges Facing Timber Operations in the Upper Midwest, USA.. *Society & Natural Resources,* 29(5), pp. 540-555.

Glass Door, 2020. [Online]
Available at: https://www.glassdoor.com/Salaries/maine-planner-city-salary-SRCH_IL.0,5_IS758_KO6,13_KE14,18.htm

Green Marine, 2020. *2020 Membership Fee Schedule.* [Online]
Available at: https://green-marine.org/wp-content/uploads/2019/09/GM-Fee-Schedule-2020.pdf
[Accessed 22 July 2020].

Green Marine, 2020. *Green Marine Performance Report 2019,* s.l.: s.n.

Green Marine, 2020. *Performance Indicators.* [Online]
Available at: https://green-marine.org/certification/scope-and-criteria/
[Accessed 22 July 2020].

Gundersen Health System, 2020. *Energy conservation.* [Online]
Available at: https://www.gundersenenvision.org/envision/our-programs/energy-conservation/

Hahn, R.W., and R.A. Ritz, 2015. Does the Social Cost of Carbon Matter? Evidence from US Policy. *The Journal of Legal Studies,* pp. 229-248.

Hirabayashi, Y. et al., 2013. Global flood risk under climate change.. *Nature Climate Change,* p. 816.

Howard, P. and Schwartz, J., 2017. Think Global: International Reciprocity as Justification for a Global Social Cost of Carbon. *Columbia Journal of Environmental Law,* pp. 204-245.

ICF, 2018. *2017 RGGI Model Rule - NJ Rutgers 2018 Policy Case - VA+NJ (18) in RGGI.* s.l.:s.n.

Institute for Policy Integrity, 2017. *Policy Brief on the Social Costs of Greenhouse Gases,* s.l.: NYU School of Law.

Interagency Working Group on Social Cost of Greenhouse Gases, 2016. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.* [Online]
Available at: https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf
[Accessed 4 May 2020].

International Code Council, 2015. *International Energy Conservation Code (IECC).* s.l.:s.n.

IRENA, 2012. *Renewable Energy Technologies: Cost Analysis Series,* s.l.: The International Renewable Energy Agency.

IRENA, 2020. *Renewable Power Generation Costs in 2019,* Abu Dhabi: International Renewable Energy Agency.

Island Institute & Vinalhaven Sea Level Rise Comittee, 2020. *Cost of Sea Level Rise - Vinalhaven, StoryMap,* s.l.: s.n.

Island Institute, 2007. *The Last 20 Miles: Mapping Maine's Working Waterfront,* s.l.: s.n.

Island Institute, 2020. *Edible Seaweed Market Analysis. March 3, 2020.* [Online]
Available at: http://www.islandinstitute.org/edible-seaweed-market-analysis-2020
[Accessed 5 May 2020].

ISO New England Inc., 2020. *2018 ISO New England Electric Generator Air Emissions Report. May 2020.* [Online]
Available at: https://www.iso-ne.com/static-assets/documents/2020/05/2018_air_emissions_report.pdf
[Accessed 22 August 2020].

Jadun, P. et al., 2017. *Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050,* Golden, CO: National Renewable Energy Laboratory.

Janowiak, M. K. et al., 2018. *New England and northern New York forest ecosystem vulnerability assessment and synthesis: a report from the New England Climate Change Response Framework project,* Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

Johnson, E. et al., 2018. A lifeline and social vulnerability analysis. *Shore & Beach,* pp. 36-44.

Johnson, M., O'Neil, C., Rizk, K. & Walsh, K., 2014. *The State of Coastal and Island Wildlife in Maine.* [Online].

Kille, L., 2009. *Bus versus rail: Costs, capacities and impacts,* s.l.: Journalist's Resource.

Krause-Jensen, D. &. D. C. M., 2016. Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience,* 9(10), pp. 737-742.

Krishna, C., 2004. *Biodiesel Blends in Space Heating Equipment,* Golden, Colorado: NREL.

Kroeger, K. D. C. S. M.-V. S. &. T. J., 2017. Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention. *Scientific reports,* 7(1), pp. 1-12.

Kuloglu, T. Z., Lieffers, V. J. & Anderson, A. E., 2019. Impact of Shortened Winter Road Access on Costs of Forest Operations. *Forests,* 10(5), p. 447.

Lazard, 2019a. *Lazard's Levelized Cost of Storage Analysis - Version 5.0,* s.l.: Lazard.

Lazard, 2019b. *Lazard's Levelized Cost of Energy Analysis - Version 13.0,* s.l.: Lazard.

LD1652: An Act To Support Solar Energy Development in Maine (2014).

Le Bris, A. et al., 2018. Climate vulnerability and resilience in the most valuable North American fishery. *Proceedings of the National Academy of Sciences,* pp. 1831-1836.

Logtenberg, R., Pawley, J. & Saxifrage, B., 2018. *Comparing Fuel and Maintenance Costs of Electric and Gas Powered Vehicles in Canada,* s.l.: 2 Degrees Institute.

Lowell, D., Jones, B. & Seamonds, D., 2018. *Accelerating Investment in Electric Vehicle Charging Infrastructure,* Concord: M.J. Bradley & Associates LLC.

MacDonald, S. et al., 2019. Bridging the rural efficiency gap: expanding access to energy efficiency upgrades in remote and high energy cost communities.. *Energy Efficiency,* Volume 13, pp. 503-521.

Macor, A. & Pavanello, P., 2009. Performance and emissions of biodiesel in a boiler for residential heating. *Energy,* 34(12), pp. 2025-2032.

Madoux-Humery, A. et al., 2016. The effects of combined sewer overflow events on riverine sources of drinking water. *Water research,* Volume 92, pp. 218-227.

Mago, P. J. & Smith, A. D., 2012. Evaluation of the Potential Emissions Reductions from the use of CHP Systems in Different Commercial Buildings.. *Building and Environment,* Volume 53, pp. 74-82.

Maine CDC, M. C. f. D. C. a. P., 2020. *Maine Tracking Network.* [Online]
Available at: https://data.mainepublichealth.gov/tracking/

Maine Climate Council Buildings, Infrastructure, and Housing Working Group, 2020. *Strategy Recommendations to Mitigate Emissions and Support Resilience in Maine Buildings - Report to the Maine Climate Council. June 5, 2020.* s.l.:s.n.

Maine Climate Council Coastal and Marine Working Group, 2020a. *A Report from the Coastal & Marine Working Group of the Maine Climate Council. June 5, 2020.* s.l.:s.n.

Maine Climate Council Coastal and Marine Working Group, 2020b. *MCC CMWG DATA NEEDS.* s.l.:s.n.

Maine Climate Council Coastal and Marine Working Group, 2020c. *Promote Climate-Adaptive Ecosystem Planning and Management Using Nature-Based Solutions,* s.l.: s.n.

Maine Climate Council Community Resilience Planning Sub-Group, 2020d. *Community Resilience Planning Subgroup Recommendations.* s.l.:s.n.

Maine Climate Council Emergency Management Subgroup, 2020. *Emergency Management Subgroup Recommended Climate Strategies, Actions and Measurable Outcomes.* s.l.:s.n.

Maine Climate Council Emergency Management Subgroup, 2020. *Emergency Management Sub-Group Recommended Climate Strategies, Actions and Measurable Outcomes.* s.l.:s.n.

Maine Climate Council Energy Working Group, 2020. *Energy Working Group Recommendations.* s.l.:s.n.

Maine Climate Council Natural and Working Lands Working Group, 2020. *Natural and Working Lands Work Group Final Strategy Compilation.* s.l.:s.n.

Maine Climate Council Public Health Subgroup, 2020. *MCC Public Health Subgroup Strategies,* s.l.: s.n.

Maine Climate Council Public Health Subgroup, 2020. *MCC Public Health Subgroup Strategies.* s.l.:s.n.

Maine Climate Council Transportation Working Group, 2020. *Transportation Working Group Recommended Climate Strategy Actions and Measurable Outcomes.* s.l.:s.n.

Maine Department of Environmental Protection, 2019. *Annual CSO Progress Report Instructions,* Augusta, Maine : s.n.

Maine Department of Environmental Protection, 2020a. *Eighth Biennial Report on Progress toward Greenhouse Gas Reduction Goals. January 13, 2020,* s.l.: s.n.

Maine Department of Environmental Protection, 2020b. *Maine Combined Sewer Overflow 2019 Status Report,* Augusta, Maine: s.n.

Maine Department of Marine Resources, 2020. *Historical Maine Fisheries Landings Data.* [Online]
Available at: https://www.maine.gov/dmr/commercial-fishing/landings/historical-data.html

Maine Department of Marine Resources, 2020. *Most Recent Maine Commercial Landings.* [Online]
Available at: https://www.maine.gov/dmr/commercial-fishing/landings/index.html

Maine Dept of Marine Resources, 2010. *2010 GIS Layer (2001-2009 Survey Years).* s.l.:s.n.

Maine DPS, 2019. *Motor Vehicle Inspections.* [Online]
Available at: https://www.maine.gov/dps/msp/investigation-traffic/crash-investigations/mv-inspections

Maine Governor's Energy Office, 2020. *Maine Retail Heating Fuel Prices.* [Online]
Available at: https://www.maine.gov/energy/fuel_prices/

Maine Governor's Energy Office, 2020. *Maine Retail Heating Fuel Prices, as of April 28, 2020.* [Online]
Available at: https://www.maine.gov/energy/fuel_prices/

Maine Housing, 2019. *Characteristics of Housing in Maine.* [Online]
Available at: https://www.mainehousing.org/docs/default-source/policy-research/research-reports/housing-profiles/characteristics-of-housing-in-maine---january-2019.pdf?sfvrsn=5a63a815_10&sfvrsn=5a63a815_10
[Accessed 17 July 2020].

Maine Natural Areas Program, 2014. *Current Maine Tidal Marshes Map.* [Online]
Available at: https://www.maine.gov/dacf/mnap/assistance/tidal_marshes.htm
[Accessed 5 May 2020].

Maine Office of State Fire Marshal, 2020. *Building Codes.* [Online]
Available at: https://www.maine.gov/dps/fmo/building-codes
[Accessed 11 May 2020].

Maine Office of Tourism , 2020c. *The Maine Beaches.* [Online]
Available at: https://visitmaine.com/places-to-go/the-maine-beaches

Maine Office of Tourism, 2018a. *2018 Regional Tourism Impact Estimates.* [Online]
Available at: https://motpartners.com/wp-content/uploads/2019/06/Maine-Beaches-Visitation-and-Economic-Impact-2018.pdf

Maine Office of Tourism, 2018b. *Visitor Tracking Research 2018 Calendar Year Annual Report.* [Online]
Available at: https://motpartners.com/wp-content/uploads/2019/06/2018-Annual-Report.pdf

Maine, S. o., 2020. *Final Report of the Blue Ribbon Commission to Continue Studying and Recommend Funding Solutions for the State's Transportation System,* s.l.: s.n.

Massachusetts DOT, 2019. *Transportation and Climate Initiative Agreement to Deliver Northeast At Least $1.4 Billion in Transit System Investment.* [Online]
Available at: https://www.mass.gov/news/transportation-and-climate-initiative-agreement-to-deliver-northeast-at-least-14-billion-in

MCC STS, 2020. *Scientific Assessment of Climate Change and Its Effects in Maine ,* s.l.: s.n.

Mcleod, E. C. G. L. B. S. S. R. B. M. D. C. M. .. &. S. B. R., 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment,* 9(10), pp. 552-560.

Metcalf, G., and Stock, J., 2015. The Role of Integrated Assessment Models in Climate Policy: A User's Guide and Assessment. *Harvard Kenneday School: Harvard Project on Climate Agreements,* pp. 1-29.

Minnesota Public Utilities Commission, 2017. *Docket Number E999/CI-14-643: In the Matter of the Further Investigation into Environmental and Socioeconomic Costs Under Minn. Stat. 216B.2422, Subd. 3.,* s.l.: s.n.

Moore, F.C., and Diaz, D.B., 2015. Temperature impacts on economic growth warrant stringent mitigation policy. *Nature Climate Change,* pp. 127-131.

Musial, W., Beiter, P. & Nunemaker, J., 2020. *Cost of Floating Offshore Wind Energy Using New England Aqua Ventus Concrete Semisubmersible Technology,* Golden, CO: National Renewable Energy Laboratory.

Musial, W. & Butterfield, S., 2004. *Future for Offshore Wind Energy in the United States.* Golden, CO: National Renewable Energy Laboratory.

National Academies of Sciences, Engineering, and Medicine, 2012. *Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Process,* Washington, DC: The National Academies Press.

National Institute of Building Sciences, 2019. *Natural Hazard Mitigation Saves: 2019 Report,* Washington, D.C.: Multi-Hazard Mitigation Council .

National Oceanic and Atmospheric Administration Office for Coastal Management (NOAA OCM), Undated. *Shoreline Mileage of the United States.* [Online]
Available at: https://coast.noaa.gov/data/docs/states/shorelines.pdf
[Accessed 9 June 2020].

National Oceanic and Atmospheric Administration Office for Coastal Management, N. H. D. o. E. S. C. P. a. E. R. G. I., 2016. *How People Benefit from New Hampshire's Great Bay Estuary. A Collaborative Assessment of the Value of Ecosystem Services and how our Decisions might affect those Values in the Future,* s.l.: s.n.

National Oceanic and Atmospheric Administration, 2015. *Natural and Structural Measures for Shoreline Stabilization.* [Online]
Available at: https://coast.noaa.gov/data/digitalcoast/pdf/living-shoreline.pdf

National Park Service, 2016. *Coastal Adaptation Strategies Handbook,* s.l.: s.n.

National Renewable Energy Laboratory, 2014. *Building America House Simulation Protocols.* [Online]
Available at:

https://www.energy.gov/sites/prod/files/2014/03/f13/house_simulation_protocols_2014.pdf
[Accessed 6 July 2020].

National Renewable Energy Laboratory, 2018. *Building Energy Optimization Tool (BeOpt) Version 2.8.0.0 (January 4, 2018).* s.l.:s.n.

National Renewable Energy Laboratory, 2020. *Medium-and Heavy-Duty Electric Vehicle Charging.* [Online]
Available at: https://www.nrel.gov/transportation/medium-heavy-duty-vehicle-charging.html
[Accessed 2020].

Navaratnasamy, M., Edeogu, I. & Papworth, L., 2008. *Economic Feasibility of Anaerobic Digesters,* s.l.: Agriculture Stewardship Division, Alberta Agriculture and Rural Development.

Nevada Public Utilities Commission: Investigation and Rulemaking to Implement Senate Bill 65 (2017) (2018).

Nicholas, M., 2019. *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas ,* s.l.: International Council on Clean Transportation.

NOAA, 2020. *ENOW Explorer.* [Online]
Available at: https://coast.noaa.gov/enowexplorer/#/

NORA, 2015. *Developing a Renewable Biofuel Option for the Home Heating Sector,* s.l.: s.n.

Northern Forest Center, 2016. *Greenhouse Gas Emissions of Wood Pellet Heat in the Northern Forest.* [Online]
Available at: https://northernforest.org/images/resources/energy/Northern-Forest-Center-Greenhouse-Gas-Analysis-10-18.pdf
[Accessed 27 May 2020].

Novak, A. P. P. P. C. J. S. N. G. A. A.-O. M. C. P. M. a. P. V., Accepted in April 2020. Factors influencing carbon stocks and accumulation rates in eelgrass meadows across New England, USA. *Estuaries and Coasts.*

NREL, 2015. *Transparent Cost Database.* [Online]
Available at: https://openei.org/apps/TCDB/
[Accessed 15 May 2020].

Outdoor Partners, 2020. *Exploring the Outdoors on Private Lands.* [Online]
Available at: https://www.maine.gov/ifw/programs-resources/outdoor-partners-program/explore.html#:~:text=Roughly%2094%25%20of%20Maine's%20forest,of%20working%20farms%20and%20forests.
[Accessed 12 July 2020].

Pendleton, L. D. D. C. M. B. C. C. S. J. W. A. S. S. .. &. M. P., 2012. Estimating global “blue carbon” emissions from conversion and degradation of vegetated coastal ecosystems. *PloS one,* 7(9).

Peranzi, C. & Robinson, S., 2020. *Report to Maine Legislature: Lyme and other Tickborne Illnesses,* s.l.: Maine Department of Health and Human Services, Maine Center for Disease Control and Prevention (Maine CDC), Division of Disease Surveillance, Infectious Disease Epidemiology Program.

Pindyck, R. S., 2019. The social cost of carbon revisited. *Journal of Environmental Economics and Management,* pp. 140-160.

Pizer, W., Adler, M., Aldy, J., Anthoff, D., Cropper, M., Gillingham, K., Greenstone, M., Murray, B., Newell, R., Richels., R., Rowell, A., Waldhoff, S., and Weiner, J., 2014. Using and improving the social cost of carbon: Regular, institutionalized updating and review are essential. *Environmental Economics.*

Pratt, B. W. & Erickson, J. D., 2020. Defeat the Peak: Behavioral insights for electricity demand response program design. *Energy Research & Social Science,* Volume 61.

Quartuch, M. R. & Beckley, T. M., 2014. Carrots and sticks: New Brunswick and Maine forest landowner perceptions toward incentives and regulations.. *Environmental management,* 53(1), pp. 202-218.

Regional Ecosystem Services Research Program, 2015. *An Ecosystem Services Assessment Using Bioextraction Technologies for Removal of Nitrogen and Other Substances in Long Island Sound and the Great Bay/Piscataqua Region,* s.l.: s.n.

Reguero, B. G. et al., 2018. Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States. *PLoS ONE ,* 13(4).

Revesz, R.M., Greenstone, M., Hanemann, M., Livermore, M., Sterner, T., Grab, D., Howard, P., Schwartz, J., 2017. Best cost estimate of greenhouse gases. *Science.*

RGGI, 2020. *Regional Greenhouse Gas Iniative.* [Online]
Available at: https://www.rggi.org/program-overview-and-design/elements

Riahi, K., Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Samir, K.C., Leimbach, M., Leiwen, J., Kram, T., Rao, S., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change,* pp. 153-168.

Ricke, K., Drouet, L., Caldeira, K., Tavoni, M., 2018. Country-level social cost of carbon. *Nature Climate Change,* pp. 895-900.

Rittenhouse, C. D. & Rissman, A. R., 2015. Changes in winter conditions impact forest management in north temperate forests. *Journal of environmental management,* Volume 149, pp. 157-167.

Roman, C. T. P. J. A. A. J. R. K. J. W. &. A. P. G., 1997. Accretion of a New England (USA) salt marsh in response to inlet migration, storms, and sea-level rise. *Estuarine Coastal and Shelf Science,* 45(6), pp. 717-727.

S2313: Establishes zero emission certificate program for nuclear power plants (2018).

Sagurova, I. et al., 2019. Predicted northward expansion of the geographic range of the tick vector Amblyomma americanum in North America under future climate conditions. *Environmental Health Perspectives.*

Samco, 2017. *How Much Does an Industrial Water System Cost?.* [Online]
Available at: https://www.samcotech.com/how-much-does-an-industrial-water-treatment-system-cost/
[Accessed 15 May 2020].

Samonte, G. et al., 2017. *Socioeconomic Benefits of Habitat Restoration,* s.l.: National Oceanic and Atmospheric Administration (NOAA).

SB5116: Supporting Washington's clean energy economy and transitioning to a clean, affordable, and reliable energy future (2019).

State of Minnesota Office of Administrative Hearings, 2016. *Environmental and Socio-Economic Costs Report: In the Matter of the Further Investigation into Environmental and Socioeconomic Costs Under Minnesota Statutes Section 216B.2422, Subdivision 3,* s.l.: MN Public Utilities Commission.

Sullivan, S., 2020. *Maine towns pool resources to fund coastal resiliency coordinator.* s.l.:s.n.

Synapse Energy Economics, 2020c. *Volume 3c: Electric Sector Scenario Results Prepared for the State of Maine.* s.l.:s.n.

Synapse, 2020. *Assessing the Impacts Climate Change May Have on the State's Economy, Revenues, and Investment Decisions: Volume 3, Maine Emissions Analysis.* s.l.:s.n.

Synergy Energy Economics, 2020. *RGGI Prices Spreadsheet.* s.l.:s.n.

TNC Maine, T. N. C., n.d. *Maine Statewide Aquatic Barrier Prioritization Data.* s.l.:s.n.

Topinka, J. T. L. &. K. W., 1981. The distribution of fucoid macroalgal biomass along central coastal Maine. *Botanica Marina,* Volume XXIV, pp. 311-319.

Troy, A., 2012. *Valuing Maine's Natural Capital,* s.l.: Report for Manomet Center for Conservation Services.

U.S. Department of Energy, 2020b. *Maps and Data - Average Annual Vehicle Miles Traveled by Major Vehicle Category.* [Online]
Available at: https://afdc.energy.gov/data/10309
[Accessed 2020].

U.S. Department of Energy, 2020c. *Plug-In Electric Vehicle (PEV) Tax Credit.* [Online]
Available at: https://afdc.energy.gov/laws/11702
[Accessed 2020].

U.S. Department of Energy, E. E. &. R. E., 2020. *Combined Heat and Power Installations in Maine.* [Online]
Available at: https://doe.icfwebservices.com/chpdb/state/ME
[Accessed 27 August 2020].

U.S. Energy Information Administration, 2020. *Annual Energy Outlook 2020,* s.l.: s.n.

U.S. Fish and Wildlife Service, 2020. *2020 National Coastal Wetland Conservation Grants Project Summaries.* [Online]
Available at: https://www.fws.gov/coastal/CoastalGrants/pdfs/2020-Coastal-Wetlands-Grants-Project-Summaries-Final.pdf

U.S. Government Accountability Office, 2006. *Endangered Species: Time and Costs Required to Recover Species Are Largely Unknown,* s.l.: s.n.

U.S. Office of Management and Budget, 2003. *Circular A-4: Guidance to Federal agencies on the development of regulatory analysis,* s.l.: s.n.

US EIA, 2020. *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020,* s.l.: U.S. Energy Information Administration.

Villari, P. e. a., 1995. The Economic Burden Imposed By A Residual Case of Eastern Encephalitis. *The American Journal of Tropical Medicine and Hygiene,* pp. 8-13.

Vincent, W. & Calleghan Jerram, L., 2006. The Potential for Bus Rapid Transit to Reduce Transportation-Related CO2 Emissions. *Journal of Public Transportation.*

Wang, M. et al., 2012. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. *Environmental Research Letters,* 7(4), p. 045905.

Wang, P. D. X. Z. H. a. Y. S., 2019. Estimates of the social cost of carbon: A review based on meta-analysis. *Journal of Cleaner Production,* pp. 1494-1507.

Win Lee, S., Herage, T. & Young, B., 2004. Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel. *Fuel,* 83(11-12), pp. 1607-1613.

Wiser, R. & Bolinger, M., 2008. *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007,* s.l.: Energy Efficiency and Renewable Energy.

Witman, J. D. &. L. R. W., 2018. Persistent differences between coastal and offshore kelp forest communities in a warming Gulf of Maine. *PloS one,* 13(1).

Wolfe, D. W. et al., 2018. Unique challenges and opportunities for northeastern US crop production in a changing climate. *Climatic change,* 146(1-2), pp. 231-245.

Wood Environment & Infrastructure Solutions, Inc., 2019. *Penobscot Bay Vulnerability Assessment and Resilience Planning – Draft Summary Report,* s.l.: Maine Coastal Program, Maine Department of Marine Resources.

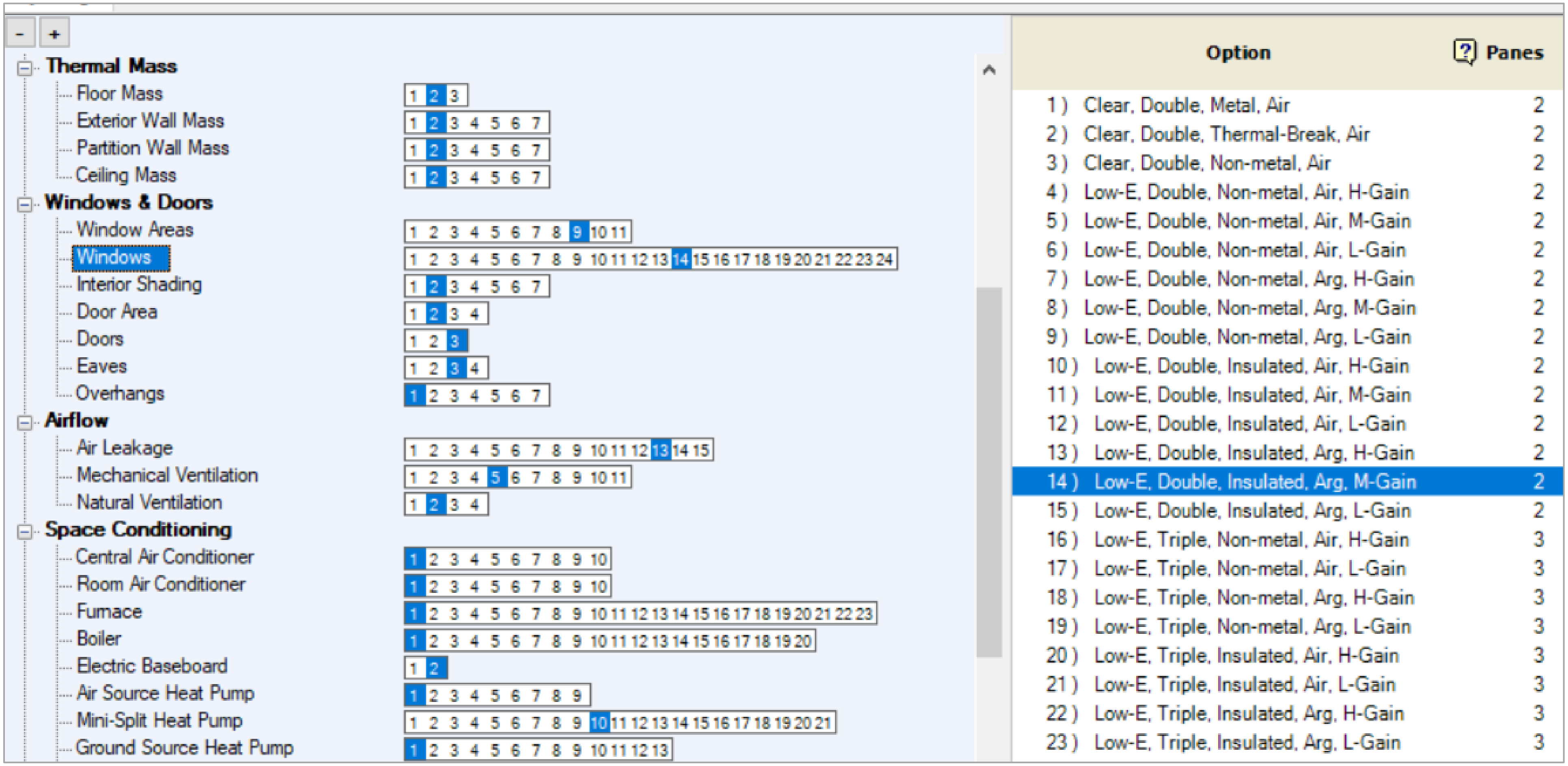
Yang, P., Yao, Y.F., Mi, Z., Cao, Y.F., Liao, H., Yu, B.Y., Liang, Q.M., Coffman, D.M., and Wei, Y.M., 2018. Social cost of carbon under shared socioeconomic pathways. *Global Environmental Change,* pp. 225-232.

Zhang, X. et al., 2006. *Economic impact of Lyme disease,* s.l.: Emerg Infect Dis. Centers for Disease Control and Prevention .

APPENDIX A. BUILDING ENERGY OPTIMIZATION TOOL INTERFACE

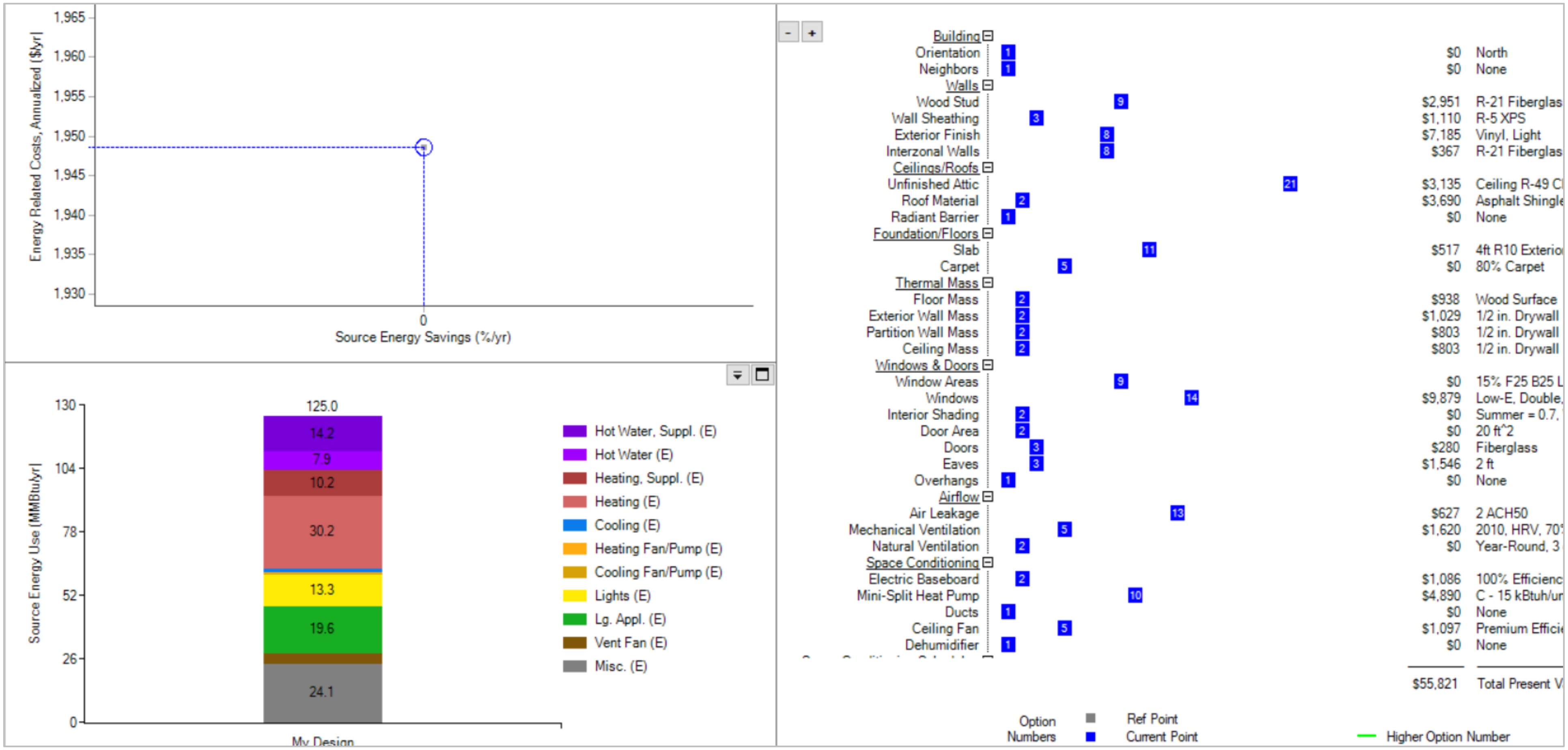
For the analysis of new single-family homes (Section 7.1.2.1), ERG used the National Renewable Energy Laboratory's (2018) Building Energy Optimization Tool. It allows the user to select from a number of options, such as insulation, windows, space conditioning, etc. (see Figure A-1).

Figure A-1. Building Energy Optimization Tool Options Screen



After selecting the desired inputs, running the simulation results in outputs with the present value cost and energy use of the modeled scenario (see Figure A-2). The present value cost for each item considers the initial value, future replacement cost, and energy costs.

Figure A-2. Building Energy Optimization Tool Outputs Screen



APPENDIX B. NEW SINGLE-FAMILY HOMES: OPTIONS CHOSEN IN THE BUILDING ENERGY OPTIMIZATION TOOL

For Buildings, Infrastructure, and Housing Strategy 1, "Improve the design and construction of new buildings," Table B-1 shows the options chosen in the National Renewable Energy Laboratory's (2018) Building Energy Optimization Tool to compare the costs of constructing a single-family home to either the International Code Council (2015) International Energy Conservation Code for 2015 (IECC 2015) or the more stringent U.S. Department of Energy (2019) Zero Energy Ready Home National Program Requirements.

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Building							
Orientation	North	North	$0	$0	$0		
Neighbors	None	None	$0	$0	$0	NREL (2014) Building Americas Housing Simulations Protocol (BAHSP) recommends no neighbors.	
Walls							
Wood Stud	R-21 Fiberglass Batt, 2x6, 24 in o.c.	R-21 Fiberglass Batt, 2x6, 24 in o.c.	$2,951	$2,951	$0	IECC 2015 R402 allows R-13+R-10 sheathing or R-20+R-5 sheathing and based on unit cost the latter package is a cheaper option.	DOE ZER target home to follow IECC 2015.
Wall Sheathing	R-5 XPS	R-5 XPS	$1,110	$1,110	$0	IECC 2015 R402 allows R-13+R-10 sheathing or R-20+R-5 sheathing and based on unit cost the latter package is a cheaper option.	DOE ZER target home to follow IECC 2015.

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Exterior Finish	Vinyl, Medium/Dark	Vinyl, Light	$7,185	$7,185	$0	Absorptance of .75 and emittance of .9 are input requirements per R405 standard reference design which is best matched by Vinyl, Medium/Dark.	DOE ZER target home to follow IECC 2015.
Interzonal Walls	R-21 Fiberglass Batt, 2x6, 24 in o.c.	R-21 Fiberglass Batt, 2x6, 24 in o.c.	$367	$367	$0	Match R-20/5 compliance path for unit cost rationale noted above.	DOE ZER target home to follow IECC 2015.
Ceilings/Roofs							
Unfinished Attic	Ceiling R-49 Closed Cell Spray Foam, Vented	Ceiling R-49 Closed Cell Spray Foam, Vented	$3,135	$3,135	$0	IECC 2015 R402.1.2 requires R-49 for zones 6 and 7. There is a later allowance for R-38 to be used if insulation extends over the wall top plate at the eaves but it isn't certain this is how it is modeled. BAHSP concurs with this.	
Roof Material	Asphalt Shingles, White or cool colors	Asphalt Shingles, Medium	$3,690	$3,690	$0	Shingle on wood sheathing with solar absorptance of .75 and emittance of .9 are input requirements per R405 standard reference design.	

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Radiant Barrier	None	None	$0	$0	$0		
Foundation/Floors							
Slab	4ft R10 Exterior XPS	4ft R10 Exterior XPS	$517	$517	$0		
Carpet	80% Carpet	80% Carpet	$0	$0	$0		
Thermal Mass							
Floor Mass	Wood Surface	Wood Surface	$938	$938	$0		
Exterior Wall Mass	1/2 in. Drywall	1/2 in. Drywall	$1,029	$1,029	$0		
Partition Wall Mass	1/2 in. Drywall	1/2 in. Drywall	$803	$803	$0		
Ceiling Mass	1/2 in. Drywall	1/2 in. Drywall	$803	$803	$0		
Windows & Doors							
Window Areas	15% F25 B25 L25 R25	15% F25 B25 L25 R25	$0	$0	$0		
Windows	Low-E, Double, Insulated, Air, H-Gain	Low-E, Double, Insulated, Arg, M-Gain	$8,744	$9,879	$1,135		DOE ZER target home requires any SHGC with U-Value of .27 or less for both Climate 6 and 7.
Interior Shading	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	$0	$0	$0		
Door Area	40 ft^2	20 ft^2	$0	$0	$0	40 sq ft is input requirement per IECC 2015 R405 standard reference design.	
Doors	Fiberglass	Fiberglass	$560	$280	-$280		
Eaves	2 ft	2 ft	$1,546	$1,546	$0		
Overhangs	None	None	$0	$0	$0		

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Airflow							
Air Leakage	3 ACH50	2 ACH50	$525	$627	$102		DOE ZER requirements are 2 ACH50 for both Climates 6 and 7.
Mechanical Ventilation	None	2010, HRV, 70%	$0	$1,620	$1,620	Maine IRC-2015 does not require whole home ventilation and Standard Reference Design states "None" is default unless proposed design has ventilation then you match proposed system.	DOE ZER requires 1.2 cfm/w (.833W/cfm) and 60% sensible recovery (HRV in BeOpt) for both Climates 6 and 7.
Natural Ventilation	Year-Round, 3 days/wk	Year-Round, 3 days/wk	$0	$0	$0		
Space Conditioning							
Central Air Conditioner	SEER 13	100% Efficiency	$5,207	$1,086/$1,086/$814	-$4,121/-$4,121/-$4393		
Furnace	Gas, 80% AFUE	C - 15 kBtuh/unit - SEER 20, 10.3 HSPF	$2,798/$2,816/$2,834	$4,890	$2,092/$2,074/$2056	IECC 2015 requires efficiency meets federal requirements. Federal requirements established by 10 CFR 430.2 which is currently 80% for furnaces but they are proposing to move to 92% in 2021.	
Ducts	4 CFM25 per 100ft2, R-8	None	$2,476	$0	-$2,476		Ducts are not required with mini-split.

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Ceiling Fan	National Average	Premium Efficiency	$1,842	$1,097	-$745		
Dehumidifier	None	None	$0	$0	$0		
Space Conditioning Schedules							
Cooling Set Point	75 F	76 F w/ Setup 85 F (wkday)	$0	$0	$0	Setpoint required for Standard Reference Design.	DOE ZER requires smart thermostat which is option 14 or 15. Option 14 seems most typical (no setback on weekend).
Heating Set Point	72 F	71 F w/ Setback 65 F (wkdy)	$0	$0	$0	Setpoint required for Standard Reference Design.	DOE ZER requires smart thermostat which would be option 15 or 16. Option 16 seems most typical (setback on weekday).
Humidity Set Point	None	None	$0	$0	$0		
Electric Baseboard	None	100% Efficiency	$0	$0	$0		
Mini Split Heat Pump	None	D - 15 kBtuhunit - SEER 22, 12 HSPF	$0	$0	$0	DOE ZER only requires 10 HSPF for Climates 6 and 7 which is more cheaply accomplished by the mini-split option.	

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Water Heating							
Water Heater	Gas Benchmark	HPWH, 50 gal	$1,921	$3,162	$1,241	Recommended option in BAHSP.	DOE ZER requires electric EF>2.0.
Distribution	R-2, TrunkBranch, Copper, Demand	Uninsulated, TrunkBranch, Copper	$1,952	$1,619	-$333	IECC 2015 sections R403.5.2 and 3 require hot water above ¾ inch to be insulated to R-3 minimum and require a demand-based control system. Most similar options are R-2 with demand control or R-5 with timer control. Recommend R-2 with demand control which seems most similar.	
Solar Water Heating	None	None	$0	$0	$0		
Solar Water Heating Azimuth	Back Roof	Back Roof	$0	$0	$0		
Solar Water Heating Tilt	Roof Pitch	Roof Pitch	$0	$0	$0		

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Lighting							
Lighting	80% CFL	80% LED	$103	$227	$124	IECC 2015 R404.1 requires 75% or more fixtures need to be high efficacy lamps. High efficacy is defined in definitions section as fluorescents or lamps that meet specific lumen/watt requirements.	DOE ZER Requires 80 energy star which are LEDs.
Appliances & Fixtures							
Refrigerator	Top freezer, EF = 17.6	Top freezer, EF = 17.6	$932	$932	$0		
Cooking Range	Electric	Electric	$1,715	$1,715	$0		
Dishwasher	318 Rated kWh	290 Rated kWh, 80% Usage	$1,874	$2,045	$171		DOE ZER requires energy star which is currently rated 270 kwh/yr which is not an option, so 290 kWh/yr at a reduced usage is selected to approximate this.
Clothes Washer	Standard	EnergyStar	$1,030	$1,155	$125		DOE ZER requires Energy Star.
Clothes Dryer	Electric	Electric	$1,413	$1,413	$0		
Hot Water Fixtures	100%	100%	$0	$0	$0		

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Appliances & Fixtures Schedules							
Refrigerator Schedule	Standard	Standard	$0	$0	$0		
Cooking Range Schedule	Standard	Standard	$0	$0	$0		
Clothes Dryer Schedule	Standard	Standard	$0	$0	$0		
Miscellaneous							
Plug Loads	100%	100%	$0	$0	$0		
Extra Refrigerator	None	None	$0	$0	$0		
Freezer	None	None	$0	$0	$0		
Pool Heater	None	None	$0	$0	$0		
Pool Pump	None	None	$0	$0	$0		
Hot Tub/Spa Heater	None	None	$0	$0	$0		
Hot Tub/Spa Pump	None	None	$0	$0	$0		
Well Pump	None	None	$0	$0	$0		
Gas Fireplace	None	None	$0	$0	$0		
Gas Grill	None	None	$0	$0	$0		
Gas Lighting	None	None	$0	$0	$0		
Miscellaneous Schedules							
Plug Loads Schedule	Standard	Standard	$0	$0	$0		
Extra Refrigerator Schedule	Standard	Standard	$0	$0	$0		
Freezer Schedule	Standard	Standard	$0	$0	$0		

Table B-1. Differences between 2015 International Energy Conservation Code and Zero Energy Ready Scenarios

Parameter	Selected Option		Cost (PV) [a]			Notes	
	IECC 2015	DOE ZER	IECC 2015	DOE ZER	Increment	IECC 2015	DOE ZER
Pool Heater Schedule	Standard	Standard	$0	$0	$0		
Pool Pump Schedule	Standard	Standard	$0	$0	$0		
Hot Tub/Spa Heater Schedule	Standard	Standard	$0	$0	$0		
Hot Tub/Spa Pump Schedule	Standard	Standard	$0	$0	$0		
Well Pump Schedule	Standard	Standard	$0	$0	$0		
Gas Fireplace Schedule	Standard	Standard	$0	$0	$0		
Gas Grill Schedule	Standard	Standard	$0	$0	$0		
Gas Lighting Schedule	Standard	Standard	$0	$0	$0		
Power Generation							
PV System	None	None	$0	$0	$0		
PV Azimuth	Back Roof	Back Roof	$0	$0	$0		
PV Tilt	Roof, Pitch	Roof, Pitch	$0	$0	$0		

Note: The BeOPT software outputs present value costs, which are based on a 30-year analysis period, 2.4% inflation rate, and 3% discount rate. Where costs differ between the three locations, the costs for each city are shown.