Assessing the Impacts Climate Change May Have on the State's Economy, Revenues, and Investment Decisions: Summary Report

State of Maine
Department of the Governor's Office of Policy Innovation and the Future (GOPIF)
111 Sewall Street
Augusta, Maine 04330

Eastern Research Group, Inc.
110 Hartwell Avenue
Lexington, MA 02421

Synapse Energy Economics
485 Massachusetts Ave, Suite 3
Cambridge, MA 02139

September 1, 2020

TABLE OF CONTENTS

Table of Contents i

List of Figures and Tables iii

Introduction 1

Volume 1. Vulnerability Mapping 5

1.1. Community Vulnerability 5

1.2. Employment and Economic Vulnerability 6

1.3. Building and Infrastructure Vulnerability 8

Volume 2. Cost of Doing Nothing Analysis 9

2.1. Forests, Natural Working Lands, and Carbon Sequestration 9

2.2. Blue Carbon 10

2.3. Sea Level Rise, Coastal, and Riverine Flood Risk 10

2.4. Erosion of Beaches and Dunes 12

2.5. Vector-Borne Illness 12

2.6. What's at Stake for the Lobster and Aquaculture Industries? 12

2.7. High Heat Days and Heat Illness 13

Volume 3. Maine Emissions Analysis 14

3.1. Introduction 14

3.2. Baseline Scenario Results (Business as Usual) 14

3.3. Policy Scenario Results 16

Volume 4. Economic Analyses of Adaptation and Mitigation Strategies 20

4.1. Coastal and Marine 21

4.1.1. Blue Carbon Optimization 21

4.1.2. Use Nature-Based Solutions 21

4.1.3. Climate-Ready Working Waterfronts 22

4.2. Community Resilience, Public Health, Emergency Management 22

4.2.1. Comprehensive Review of Maine Laws to Achieve Resilience and Economic Security 22

4.2.2. Improve Municipal Technical Assistance 22

4.2.3. Funding Mechanisms for Resilience 23

4.2.4. Develop and Implement a "State Infrastructure Climate Adaptation Fund" 23

4.2.5. Improve Public Health Behavior Related to Climate Impacts Through Investments in Monitoring and Education 24

4.2.6. Conduct Public Education and Climate Change Health Effects and Resources 24

4.2.7. Reduce Impacts from High Intensity Weather Events 25

4.2.8. Improve Health Systems' Capacity to Mitigate and Adapt to Climate Change 25

4.3. Natural Working Lands 25
4.3.1. Protect and Conserve Natural and Working Lands 25
4.4. Energy 26
4.4.1. Ensure Adequate Affordable Clean Energy Supply to Meet Maine's Goals 26
4.4.2. Encourage Highly Efficient Combined Heat and Power Production Facilities 27
4.4.3. Institute a Renewable Fuel Standard 27
4.5. Transportation 28
4.5.1. Expand Electrification of Transportation 28
4.5.2. Reduce Vehicle Miles Traveled (VMT) 28
4.5.3. Explore Mechanisms to Fund Transportation Needs and Facilitate Emission Reduction 29
4.6. Buildings, Infrastructure, and Housing 29
4.6.1. Improve the Design and Construction of New Buildings 29
4.6.2. Transition to Cleaner Heating and Cooling Systems and Improve the Efficiency and Resiliency of Existing Building Envelopes 30
4.6.3. Lead-By-Example in Publicly Funded Buildings 30
4.6.4. Accelerate the Decarbonization of Industrial Use and Processes 31

LIST OF FIGURES AND TABLES

Figure 1. Jobs impacted by sea level rise (highest astronomical tide + 3.9 feet). 7
Figure 2. Economy-wide greenhouse gas emissions for the sustained policy scenario. 15
Figure 3. Electric dispatch: decarbonization policy scenario in New England. 16
Figure 4. New England and Maine's electric sector emissions: decarbonization policy scenario. 18
Figure 5. Economy-wide greenhouse gas emissions for the decarbonization policy scenario.................. 19

Table 1. Cost-Effectiveness of Strategies to Reduce or Sequester Carbon... 3
Table 2. High Social Vulnerability Communities Within the 1 Percent Annual Chance Flood Zone............ 6
Table 3. Statewide Annual GDP Loss Due to Job Loss from Flood Exposure 7
Table 4. Forests and Natural Working Lands—Key Costs of Doing Nothing.. 9
Table 5. Blue Carbon—Key Costs of Doing Nothing 10
Table 6. Flooding—Key Costs of Doing Nothing 11
Table 7. Maine's Supply and Demand: Electricity Generation and Capacity for the Decarbonization Policy Scenario.. 17

INTRODUCTION

This report summarizes work by Eastern Research Group, Inc. (ERG) and Synapse Energy Economics, Inc. to help the Maine Climate Council identify needed climate action plan updates and develop actionable strategies in response to climate change. Climate change will affect all sectors of Maine's economy. Warmer temperatures, more rain, and sea level rise will increase instances of flooding and damage to coastal property and infrastructure. The season for snow recreation will be shorter and agricultural growing seasons longer and more unpredictable. These expected changes to natural systems are detailed in a report by the Maine Climate Council's Science and Technical Subcommittee, titled *Scientific Assessment of Climate Change and Its Effects in Maine.*

To support the Maine Climate Council's work, ERG and Synapse have assessed the impacts climate change may have on the state's economy, revenues, and investment decisions. This assessment is presented in four volumes, which collectively make the case that without action on climate change, the impacts to Maine's economy, communities, and resources will be severe. Below we list each volume as well as some key findings from each one:

Volume 1, *Vulnerability Mapping:* A mapping analysis used to focus our economic assessment. The analysis identifies vulnerable communities, geographies, and economic sectors, and thus helped identify approaches for assessing the cost of doing nothing to prevent or prepare for climate change.

Volume 2, *Cost of Doing Nothing Analysis:* Estimates of losses that the State of Maine and its citizens could incur if the State does not take action to prevent or prepare for climate change. The cost of not adapting to a changing climate is large and will accelerate over time, with flooding serving as the largest overall threat. Key findings from this volume are below.

- The combination of 1.6 feet of sea level rise and storm surges by 2050 could lead to the loss of about 22,000 jobs by 2050 and building damage of $17.5 billion cumulatively between 2020 and 2050.
- Natural and working lands could lose over 500,000 metric tons of carbon, which could cost society over $50 million through 2100 or need to be offset by potentially costly engineered strategies to reduce emissions in the transportation, buildings, or energy sector.
- Sea level rise could contribute to the net loss of over 10 square kilometers of eelgrass and nearly 40 square kilometers of salt marsh, leading to $4 million in social costs and other ecosystem services losses in excess of up to $250 million through 2100.
- Sea level rise could cost Maine $1.67 billion in tourism spending annually by 2100, with 13 million fewer visitors due to narrowing beaches. Dune loss could lead to a loss of $70 million annually from diminished flood protection and loss of essential wildlife habitat
- Vector-borne disease currently costs Maine over $10 million annually for patient treatment alone and has the potential to get worse with warmer, shorter winters.
- Nearly $600 million of annual revenue in lobster and aquaculture is potentially at risk from warming ocean waters.
- Health care costs associated with high-heat days could be up to 36 times higher by 2100, costing nearly $10 million annually.

Volume 3, *Maine Emissions Analysis:* An energy use and emissions baseline based on current state and regional policies, as well as an assessment of options for meeting Maine's energy needs (and allowing economic growth) while reducing greenhouse gas emissions.

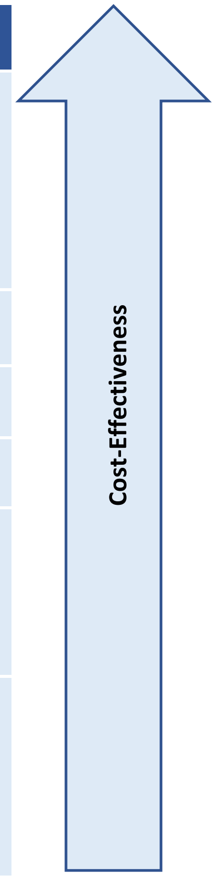
- Under a sustained policy scenario, Maine is nearly on track to meet the 2030 goals of a 45 percent emissions reduction from 1990 levels.
- Under a sustained policy scenario (business as usual based on current policies), greenhouse gas emissions are expected to be 13.8 million metric tons in 2050—9.6 million metric tons above the target of an 80 percent reduction from 1990 levels by 2050.
- Even with the aggressive decarbonization pathway, emissions are projected to fall slightly short, by 3 million metric tons, of Maine's 2050 target. This assumes widespread adoption of electric vehicles and heat pumps for space and water heating by 2050.
- To close this gap, the State may need to achieve reductions in the industrial and transportation sectors (aviation and marine), which Synapse did not model as part of this analysis. Specific model parameters and options for efficiency gains and fuel switching to close the gap are discussed in the Volume 4 report.

Volume 4, *Economic Analyses of Adaptation and Mitigation Strategies:* Economic analyses to provide context for the majority of the adaptation and mitigation strategies developed by the Maine Climate Council.

- Maine can reduce greenhouse gas emissions through many strategies that provide a cost savings. The table below provides examples of strategies from our analysis, with the most cost-effective strategies in the top rows. These strategies will be essential to meet the State's 2030 and 2050 greenhouse gas reduction goals.
- While many of these strategies reduce emissions, they do not eliminate them, and the cost of mitigation strategies will typically increase after the more cost-effective strategies (the low-hanging fruit) are implemented to their capacity.
- Maine will need to also focus on sequestering carbon to offset these emissions and achieve net carbon neutrality by 2045. Preserving natural working lands is a low-cost way to sequester.
- While restoring eelgrass and marsh is a higher-cost approach to sequestration, it can provide many important ecosystem service values such as support of commercial fisheries. Strategies that can protect existing "blue carbon" will typically be much more cost-effective than losing and restoring them later.

Table 1. Cost-Effectiveness of Strategies to Reduce or Sequester Carbon

Greenhouse Gas Reduction or Sequestration Strategy	Cost-Effectiveness to Reduce or Sequester Carbon Dioxide
• Building codes focused on energy efficiency • Geothermal heat and cooling for buildings • Heat pumps and heat pump water heaters • Building weatherization • A well-crafted work from home policy	**Highest cost-effectiveness:** These strategies have cost savings over their lifetimes and CO_2 reduction
• Electric vehicle adoption • Renewable energy adoption	**Very cost-effective, with potential for cost savings** over time with mass production
• Preserving natural working lands to sequester carbon	**Very cost-effective:** about \$4–\$20 per metric ton of CO_2 sequestered
• Methane to energy projects	**Medium cost-effectiveness:** about \$100–\$200 per metric ton of CO_2 reduced
• Fuel tax • Carbon tax	**Lower cost-effectiveness:** about \$150-\$250 per metric ton of CO_2 reduced (this is cost to consumers and revenue to state, and can improve cost effectiveness if revenue is used for projects that further reduce emissions)
• Restoring marsh and eelgrass to sequester carbon • Vehicle miles traveled fee	**Less cost-effective:** more than \$1,000 per metric ton of CO_2 reduced (but restoration can provide other value in flood protection and to commercial fisheries; and the revenue from the vehicle miles traveled fee can be used for projects that further reduce emissions)



Key findings on adaptation strategies are below.

- We were able to estimate substantial costs of doing nothing in response to climate change in the Volume 2 analysis. However, unlike many strategies proposed by the working groups to reduce greenhouse gas emissions, proposed adaptation strategies to reduce the damage from climate change lacked the detail on implementation plans, costs, and measurable outcomes we would need to report clear benefit-cost ratios. In addition, some of these strategies did not lend themselves to monetization.
- For strategies related to flooding, we point to studies by the National Institute of Building Sciences reporting benefit-cost ratios of 6 to 1 for several major federal disaster-mitigation-related funds, encompassing diverse approaches to hazard mitigation. The Coastal and Marine, Transportation, Community Resilience, and Emergency Management Working Groups have promoted a range of strategies, including funding mechanisms and technical assistance, in order to overcome obstacles to implementing hazard mitigation strategies and other adaptation strategies that have quite a measurable and favorable payback over time.
- In cases where information on economic benefits of strategy implementation were limited (e.g., enhancing the resiliency of fisheries and aquaculture, technical assistance to fishermen, monitoring

of harmful algal blooms and vector-borne disease, and public education about the public health impacts of climate change), the cost of doing nothing analysis gave us enough information about potential damages to public health from vector-borne disease, to jobs from sea level rise, and to lobster fishing from rising sea temperatures (to provide a few examples) to make it clear that inaction is not an option despite the expenses of implementing the adaptation strategies. While many of these strategies did not lend themselves to benefit-cost analyses, these strategies provide education, data, and outreach that will be essential to position the State to make systematic and smart investments going forward.

This summary report presents high-level takeaways from each of the four volumes—see those volumes for detailed results, methods, and citations. Decision makers should be sure to review these economic analyses of strategies alongside the detailed strategy write-ups provided by each working group: the write-ups include considerations of equity, feasibility, and community support. These considerations are also key in prioritizing strategies but were beyond the scope of this ERG and Synapse work.

Sea Level Rise Scenarios Applied Throughout Analyses

The Science and Technical Subcommittee recommends that the Maine Climate Council consider *committing* to manage sea level rise for a higher-probability, lower-hazard scenario: 1.6 feet of relative sea level rise by 2050 and 3.9 feet by 2100. The subcommittee also recommends that the Council consider *preparing* to manage for a lower-probability, higher-hazard scenario: 3.0 feet of relative sea level rise by 2050 and 8.8 feet by the year 2100. In the context of this concept should be the consideration for the risk tolerance of different kinds of infrastructure. Therefore, to explore climate impacts on communities, beaches, and marshes, we used sea level rise scenarios throughout these volumes that align with this subcommittee recommendation and best available sea level rise inundation maps (+/- 1/10 foot). This economic analysis focuses on 1.6 feet of sea level rise, 3.9 feet of sea level rise, and 8.8 feet of sea level rise. The rationale can be found in Volume 2.

Social and Market Cost of Carbon

Throughout Volume 2 and Volume 4, we reference both the social and market cost of carbon. The market cost of carbon is based on projected carbon price for the Regional Greenhouse Gas Initiative. The social cost of carbon is a more accurate depiction of the cost to society and attempts to capture the impacts associated with releasing an additional metric ton of CO_2 into the atmosphere in terms of agricultural productivity, changes in energy costs, human health, and damages from increased flooding. These costs are geographically dispersed, as the impacts of climate change are global. Volume 2 presents an analysis of how we derived these values.

VOLUME 1. VULNERABILITY MAPPING

ERG conducted a vulnerability mapping exercise to identify communities, economic sectors, infrastructure, and other assets most vulnerable to climate impacts. This enabled us to run the economic assessment of damages to the communities, economic sectors, infrastructure, and assets under a no-action alternative (the "cost of doing nothing analysis").

The vulnerability analysis overlaid maps of climate hazards with socioeconomic, natural environment, and infrastructure variables related to susceptibility to impacts. Sea level rise, coastal flood risk, and riverine flood risk were a major focus, given strong interest from working groups and availability of state-level geospatial data. To consider spatial distribution of future heat impacts, we applied current climate divisions as proxies. Specifically, we evaluated the following:

- Community vulnerability
  - Community social vulnerability ranking and predicted sea level rise inundation
  - Community social vulnerability ranking and exposure to a 1 percent or 0.2 percent annual chance flood
  - Populations vulnerable to high heat based on socioeconomic characteristics
  - Municipal resilience planning capacity for most socially vulnerable communities
- Employment and economic vulnerability
  - Jobs at risk from predicted sea level rise inundation (and related potential loss of GDP)
  - Jobs at risk from a 1 percent or 0.2 percent annual chance flood (and related potential loss of GDP)
  - Potential loss of natural resource sector jobs due to flood risk
- Building and infrastructure vulnerability
  - Building losses due to a 1 percent annual chance storm
  - Building losses due to sea level rise
  - Miles of road and rail, number of airports and ports facing flood risk
  - Culverts vulnerable to riverine and stream flow events
  - Wastewater treatment plants vulnerable to sea level rise

Volume 1 includes map outputs of these geospatial analyses (at the census tract and county subdivision scales). Below are high-level findings and key questions that emerged from each section of the vulnerability mapping work. The questions helped drive further investigation during the cost of doing nothing analysis described in Volume 2.

1.1. Community Vulnerability

Sea level rise and social vulnerability. Our social vulnerability index[1] is built on socioeconomic and demographic factors such as socioeconomic status, minority status, household composition and disability, and housing and transportation, related to a community's ability to prepare for and recover from a climate

[1] The Maine Social Vulnerability Index is a percentile ranking of vulnerability based on socioeconomic and demographic factors, calculated by county subdivision. The index is modified from the CDC's Social Vulnerability Index developed by Flanagan. It was developed by Eileen S. Johnson (Bowdoin College); Jeremy M. Bell, Daniel Coker, and Nicole LaBarge (The Nature Conservancy); and Gavin Blake (Colby College).

disaster. It indicates that a number of highly vulnerable communities are located along the coast of Washington and Hancock Counties and the eastern edge of Aroostook County. Lower topography and more erodible shorelines put southern Maine at higher risk in the next several decades. However, socioeconomic factors amplify risk for Downeast communities in later decades, despite more favorable topographies.

Riverine flood and social vulnerability. ERG intersected maps of the social vulnerability index with areas exposed to riverine flood risk (specifically the 1 percent annual chance flood) to identify areas where the impacts of flooding would be compounded by social vulnerability. These communities are spread across the state's watersheds as follows.

Table 2. High Social Vulnerability Communities Within the 1 Percent Annual Chance Flood Zone

Androscoggin	Leeds	Androscoggin River
Cumberland	Casco	Sebago Lake–Crooked River Direct Watershed
Penobscot	Howland, Greenbush	Penobscot River
Waldo	Burnham, Unity	Sebasticook River
Washington	Princeton	St. Croix River

High heat and social vulnerability. Populations vulnerable to high heat are people over 65 and living alone, under 5 years old, lacking air conditioning, living in areas with low population density, or located in warmer climate divisions. More vulnerable communities are generally concentrated in Washington County and eastern Aroostook County, with the most vulnerable communities in the towns of Cutler and Dublois.

Municipal resilience planning capacity and social vulnerability. Communities with a social vulnerability index rating of "most vulnerable"[2] are expected to be most challenged to prepare for and recover from climate-related hazards. Some of these areas also lack municipal planning capacity, putting them at an additional disadvantage. These capacity gaps are generally outside Maine's cities. Communities in the "most vulnerable" category include coastal communities such as Stonington, Deer Isle, and Gouldsboro as well as communities spread across central Maine such as Sangerville (Piscataquis County), Eustis (Franklin County), and Millinocket (Penobscot County).

1.2. Employment and Economic Vulnerability

Jobs and GDP at risk to flood impacts. Through evaluating job sites exposed to sea level rise and riverine flood risk, we were able to estimate number of jobs that could be lost due to sea level rise and a major riverine flood event. This mapping exercise also enabled estimates of annual GDP loss due to this job loss (assuming these jobs were lost for a year), as presented in Table 3.

[2] The "most vulnerable" designation is based on dividing county subdivisions into three quantiles of vulnerability, with "most vulnerable" being in the upper third.

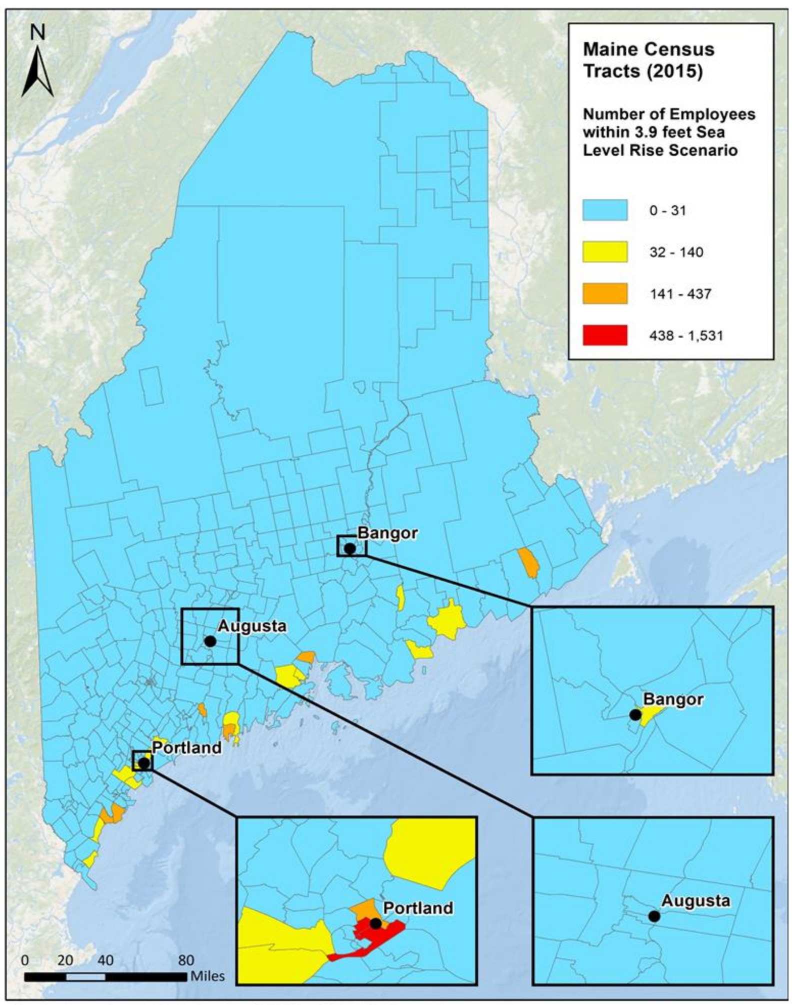
Table 3. Statewide Annual GDP Loss Due to Job Loss from Flood Exposure

Flood Hazard Scenario	Climate Projection	Potential Statewide Annual GDP Loss (Millions of 2019$)
Highest astronomical tide (HAT) + 1.6 feet of sea level rise (coastal)	Likely range 67% probability sea level rise is between 1.1 and 1.8 feet in 2050	$119
HAT + 3.9 feet of sea level rise (coastal)	Likely range 67% probability sea level rise is between 3.0 and 4.6 feet in 2100	$665
HAT + 8.8 feet of sea level rise (coastal)	Central estimate for a high sea level rise scenario for 2100	$2,415
1% annual chance flood (coastal and riverine)	Present	$1,197
0.2% annual chance flood (coastal and riverine)	Present	$1,449

As shown in Figure 1, sea level rise impacts to jobs may be felt far upstream (e.g., Bangor), because of tidal influence on rivers.

Natural resource sector jobs and flood impacts. Job losses were considered specifically in terms of impacts to natural-resource-based industries. In these analyses, the largest job losses (across all sea level rise and riverine flooding scenarios) were consistently seen in the tourism sector.

Figure 1. Jobs impacted by sea level rise (highest astronomical tide + 3.9 feet).



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

1.3. Building and Infrastructure Vulnerability

Building damages. ERG used FEMA's HAZUS[3] model to calculate building and inventory losses during a flood. In estimating losses from a 1 percent annual chance riverine flood, we found that damages are not restricted to cities: flood damages occur in smaller towns such as Fort Kent (home to the University of Maine at Fort Kent) and Farmington (an agricultural center). Under the 1 percent annual chance coastal flood scenario, the largest building and inventory loss is in Kennebunkport and Scarborough.

Transportation infrastructure. Many miles of roads and rail lie within flood zones. For example, under a scenario of highest astronomical tide plus 3.9 feet of sea level rise, we expect to see 116 miles of public roads and 23 miles of rail directly exposed to flooding, as well as inundation of parts of the Portland and Eastport port facilities. Many additional miles of transportation infrastructure and facilities may become unusable if they rely on a single access point that is inhibited.

The Maine Coastal Program conducted an analysis of sea level rise impacts on tidal crossings, evaluating current crossings and culverts that restrict tidal flow (and could thus experience infrastructure failure, flooding, and reduced blue carbon potential upstream) and the number of crossings that will become tidal under future sea level rise. Staff found that under a scenario of highest astronomical tide plus 3.9 feet of sea level rise, we can expect 977 to 1,022 crossings to restrict tidal flow.

Wastewater treatment plants. There are currently three wastewater treatment plants at risk of flooding at 1.6 feet of sea level rise, with the number of at-risk plants quickly multiplying as seas rise. The Emergency Management Working Group has identified 10 at-risk plants for priority action.

[3] While HAZUS is the best available program to reasonably measure damage at such a large geographic scale, the accuracy of local results can be dependent on how well the tool's building and infrastructure match reality. Additionally, the lack of precision in the digital elevation model can also contribute to error in measurement.

VOLUME 2. COST OF DOING NOTHING ANALYSIS

ERG's cost of doing nothing analyses for Maine generated estimates of the losses due to climate change that Maine and its citizens could incur if the State does not take action in response to climate change.

A cost of doing nothing analysis serves several purposes. First, it helps set an economic baseline—one component of determining the benefits of any strategy that helps reduce carbon dioxide (CO_2) emissions and mitigate climate change impacts. Second, it provides information about the potential benefits of adaptation strategies. (Many, if not most of the benefits of taking action to reduce or adapt to climate change will arise from avoiding the losses incurred if no action is taken.) Finally, it provides an economic justification for prioritizing actions by generating insights about the relative magnitude of different climate change hazard impacts.

For Maine, this analysis established that doing nothing is not "saving money," but rather costing the state and its communities more money in property, infrastructure, and economic damage; strain on health care systems; and disaster response.

2.1. Forests, Natural Working Lands, and Carbon Sequestration

Why should we care about forests, natural working lands, and carbon sequestration?

Forests in Maine sequester 75 percent of Maine's annual carbon emissions, making forest conservation an essential strategy to fight climate change. Forests and agricultural land cover nearly 18 million acres of Maine. Forests occupy over 17.5 million acres of Maine's land, with the vast majority being privately owned. The state is converting around 10,000 acres a year to development.

Table 4. Forests and Natural Working Lands—Key Costs of Doing Nothing

Lost Carbon Sequestration
• Natural and working lands are currently being developed at around 10,000 acres annually, a rate that is expected to increase. If trends continue, Maine will lose the ability to store large amounts of carbon at a significant social cost.
• Social cost of cumulative carbon storage lost: - 2030: \$2.4–\$7.1 million - 2050: \$10.8–\$32.9 million - 2100: \$54.1–\$168.6 million

What could be lost by doing nothing?

Each year, around 10,000 acres of natural and working lands are developed and thus lose the ability for carbon sequestration. The working group estimates that the rate of development will grow over time, to 15,000 acres a year starting in 2030 and 20,000 acres starting in 2050**. If trends continue unabated until 2050, Maine could lose the ability to sequester 5,781 metric tons of carbon annually, resulting in a cumulative loss to society (based on the social cost of carbon) of over \$10.8 million between 2020 and 2100. By 2100, Maine will have lost the potential to sequester 543,394 metric tons of carbon since 2020, with a cumulative cost to society of over \$54 million.** Every ton of carbon sequestered helps avoid the need for engineered solutions to mitigate carbon emissions, which become increasingly expensive after the most cost-effective solutions are implemented to their full capacity. While forests provide many values to ecosystems and economies, the ability to offset large portions of Maine's emissions is reason alone to conserve these lands.

2.2. Blue Carbon

Why should we care about blue carbon?

Coastal blue carbon is the carbon that is sequestered by coastal resources such as salt marshes and eelgrass beds. These resources also provide other important ecosystem service values such as flood protection and habitat support for fishing and aquaculture. With Maine's 3,478-mile coastline and sequestration rates per km^2 that exceed the rate of terrestrial ecosystems such as forests, Maine's coastal resources are an important contributor to carbon sequestration.

What could be lost by doing nothing?

Considering the carbon sequestered by eelgrass and salt marsh, **the cost to society based on cumulative lost sequestration amounts to $0.5–$4.0 million through 2100** (based on the social cost of carbon and depending on the year, with the lower estimate for 2030 and the higher for 2100). Up to 12 percent of Maine's 100 km^2 of eelgrass and 82 percent of Maine's 73 to 92 km^2 of salt marsh could be lost to sea level rise. As these resources are diminished, the accompanying carbon sequestration is also lost.

Table 5. Blue Carbon—Key Costs of Doing Nothing

Eelgrass
• Social cost of carbon storage lost: - 2030: $0.1–$0.2 million - 2050: $0.1–$0.4 million - 2100: $0.3–$1.1 million
• Ecosystem services lost are valued at: - 2030: $4.8 million - 2050: $8.7 million - 2100: $36.6 million
Salt Marsh
• Social cost of carbon storage lost: - 2030: $0.4–$1.9 million - 2050: $0.5–$2.5 million - 2100: $0.5–$2.9 million
• Ecosystem services lost are valued at: - 2030: $29.5–$99.5 million - 2050: $40.2–$135.4 million - 2100: $66.2–$223.1 million

The loss of other ecosystem services is valued at between $34.4 million and $259.7 million. Eelgrass and salt marsh also provide other ecosystem services, such as fish and spawning habitat that supports Maine's commercial fisheries and protection from coastal flooding and erosion.

2.3. Sea Level Rise, Coastal, and Riverine Flood Risk

Why should we care about riverine and coastal flooding?

Maine has 3,478 miles of coastline, excluding islands, and its communities and economy (e.g., the tourism, real estate, and fishing industries) are concentrated near the coast. Its residents and infrastructure will feel the effects of rising sea, coastal storms, and tides. We created a storm model that estimated concurrent effects of episodic storm surge (assumed to occur at the same intensity and frequency as the historic baseline) combined with sea level rise (to 1.6 feet by 2050) and ran thousands of simulations to estimate damage to buildings and job loss from 2020 to 2050. Based on the combination of sea level rise and storm surge, the median scenario (i.e., the point at which half of the scenarios are worse and half are better) would result in 21,549 fewer jobs in 2050 than in the absence of flooding impacts. Similarly, the median scenario would cause just over $17.5 billion in cumulative building damage between 2020 and 2050 (annual average loss of $564 million).

While future riverine flood risk is hard to predict given existing climate projections, it is also a concern as some Maine towns and important infrastructure have been built within historic floodplains and are not adequately protected. Socially vulnerable communities will be harder hit and have a harder time recovering from each of these impacts. **Cumulative building losses for a 1 percent annual chance riverine event would total over $1.8 billion across the state.**

What could be lost by doing nothing?

If seas rise by 1.6 feet in Maine by 2050, we can expect the following cumulative and annual losses, among many others:

- Based on simulating damage over a 30-year period, the cumulative impact of building damage and content losses due to permanent sea level rise (1.6 feet in 2050) and repeated storm surge is approximately $16.9–$18.2 billion.
- $118.8 million in annual GDP is vulnerable at 1.6 feet of sea level rise (an annual GDP loss of 0.2 percent).
- Between 2020 and 2050, 11,344 to 23,880 jobs (1.2 to 2.6 percent of total employment) will be lost due to the combined effects of permanent sea level rise and repeated storms.

Table 6 presents some additional flooding impacts from not adapting.

Table 6. Flooding—Key Costs of Doing Nothing

Coastal Flood Impacts on Communities and Buildings
• Building (and contents) damage due to coastal flooding are approximately: - $512.1 million with a 1.6-foot sea level rise - $671.0 million with a 3.9-foot sea level rise - $1.3 billion with an 8.8-foot sea level rise *These damages assume a single flood event and assume only a portion of the value of the building (based on the depth of flooding) needs to be replaced. The value of these buildings and contents that would eventually be inundated from sea level rise would be several times higher than these values.*
Coastal and Riverine Flood Impacts on Businesses
• Annual GDP loss due to sea level rise inundation of job sites at: - $118.8 million (0.2% GDP loss) with a 1.6-foot sea level rise - $664.9 million (1.1% GDP loss) with a 3.9-foot sea level rise - $2.4 billion (4.1% GDP loss) with an 8.8-foot sea level rise • Annual GDP loss due to 1 percent annual chance (riverine and coastal) flood–related job loss is valued at: - $1.2 billion (2.05% GDP loss)
• Jobs lost due to sea level rise inundation: - 856 with a 1.6-foot sea level rise - 5,691 with a 3.9-foot sea level rise - 25,420 with an 8.8-foot sea level rise
Coastal Flood Impacts on Infrastructure
• Total one-time replacement costs for selected wastewater treatment plants exposed to sea level rise inundation: - After 1.6 feet of sea level rise, six plants exposed: $31.0–$92.9 million across all six plants - 1.6–3.9 feet of sea level rise, another four plants exposed: $99.0–$297.0 million across all 10 plants • Transportation infrastructure exposed to sea level rise inundation: - After 1.6 feet of sea level rise, 26 miles of public roads and 6 miles of rail exposed, and 977 to 1,022 crossings and culverts with restricted flow (thus more susceptible to infrastructure failure) - After 3.9 feet of sea level rise, 116 miles of public roads and 23 miles of rail exposed, and 1,128 to 1,180 crossings and culverts with restricted flow - After 8.9 feet of sea level rise, 336 miles of public roads and 61 miles of rail exposed, and 1,348 to 1,410 crossings and culverts with restricted flow

2.4. Erosion of Beaches and Dunes

Why should we care about beaches and dunes?

Beaches and dunes on the coast of Maine bring in millions of tourists a year. The beaches and towns in York County (otherwise known as the Maine Beaches region) alone brought in over 13 million people in 2018. Additionally, dunes serve as essential ecosystem services, providing major flood protection benefits and supporting biodiversity in coastal communities.

What could be lost by doing nothing?

Tourism spending in the Maine Beaches region could drop by $1.67 billion annually with 8.8 feet of sea level rise. That amount of sea level rise could lead to a 97 percent dry beach area loss across Maine's coast, an 85 to 100 percent dune inundation, and 13.2 million fewer visitors to the region. In addition to the spending loss, there will be a further economic loss because narrower beaches will also degrade tourists' beach experience and enjoyment.

The lost value of dune ecosystem services could lead to an additional $71.8 million or more in losses annually. Erosion and inundation could destroy beach-dune systems that provide flood protection and essential habitats to endangered shorebird species such as piping plover and least terns.

2.5. Vector-Borne Illness

Why should we be worried about vector-borne illness?

Diseases like Lyme disease and Eastern equine encephalitis can have substantial impacts on the health of Mainers. Lyme disease is caused by tick bites and has the potential to severely impact joints, the heart, and the nervous system. Eastern equine encephalitis is caused by infected mosquitos and can potentially lead to death or ongoing neurological problems.

What are the costs of doing nothing?

Lyme disease cost $11.5 million in 2018 to treat 1,405 cases in Maine. While rare, Eastern equine encephalitis can cost nearly $6 million over the course of a patient's lifetime to treat neurological issues and leads to death in about 30 percent of cases. Both diseases could increase in frequency given our changing climate—warmer, shorter winters encourage ticks, and increases in summer precipitation and humidity (among other factors) encourage Eastern equine encephalitis. Additionally, with more development in forested areas, there is the likelihood for higher exposure of Mainers to these and other vector-borne diseases.

2.6. What's at Stake for the Lobster and Aquaculture Industries?

Why should we care about the lobster and aquaculture industry?

Maine's lobster industry generated $485 million in landings in 2019, and the industry is both economically and culturally vital to the state. Aquaculture harvesting of fish, shellfish, and macroalgae added another 622 jobs, with harvests valued at about $88 million. The living resources sector as a whole generates approximately 9,400 jobs and $670 million in revenue per year.

If ocean temperatures rise above their current levels, Maine's lobster industry may have the same fate as those in southern New England, with less lobster and more disease. Lobster forecast models and landings trends to date suggest that the wave of productivity may have crested in the Gulf of Maine (eastern Maine is a possible exception) and is heading toward Canada.

What could be lost by doing nothing?

Nearly $600 million in annual revenue from lobster and aquaculture harvesting is at risk due to changing ocean temperatures and conditions. Southern New England states have unfortunately seen this decline over the past 10 to 15 years as ocean temperatures increased, represented by the 6 percent decrease in lobster landings in Rhode Island and the 15 percent decrease in Connecticut. Lobster populations have moved northward into the cooler waters off the Gulf of Maine, benefitting Maine's lobster industry for the time being. However, continued ocean warming would likely cause lobster populations to move further northward, cutting into this current benefit.

If the lobster industry were hypothetically to decline by 50 percent by 2050, that would reduce Maine's state economic output by 0.7 percent. If the lobster and fishing industry were to reduce linearly between 2020 and 2050 due to climate impacts, reaching -50 percent output by the year 2050, the entire state economy would be affected, reducing cumulative GDP by $838 million and output by over $1.3 billion.

2.7. High Heat Days and Heat Illness

Why should we be worried about heat illness?

If global greenhouse gas projections continue on their current trajectory, Maine can expect 36 high heat index days (over 90°F) per year by 2100, compared to one average high heat day per year from 1971 to 2000. Mainers are particularly vulnerable to negative health effects of high heat days: Maine's housing stock is oriented toward heating, not cooling, and is often less equipped with air conditioning. In addition, vulnerable elderly Mainers are a larger and larger part of the population. Exposure to extreme heat is linked to a range of negative health outcomes, including heatstroke, exacerbation of existing respiratory and diabetes-related conditions, and effects on fetal health.

What could be lost by doing nothing?

Health care costs for heat illness were $224,000 in 2019 due to 200 emergency department visits and 15 hospitalizations in Maine for heat-related illness. **Health care costs will be nine to 14 times higher in 2050 (costing $1.9 to $3.2 million annually) and 13 to 36 times higher (costing $2.9 to $8.1 million annually) in 2100 i**f hospital visits are directly proportional to the number of days with a heat index over 90°F.

VOLUME 3. MAINE EMISSIONS ANALYSIS

3.1. Introduction

Synapse provided energy sector modeling services, focused on greenhouse gas reduction strategies, in support of the Maine Climate Council working groups. Modeling was performed for the three primary energy sectors: transportation, buildings, and electricity generation. Synapse used the following modeling tools for each sector:

- **Transportation sector.** EV-REDI is a custom-built stock-flow model for modeling multiple impacts of transportation electrification for individual states. EV-REDI contains data on vehicle sales, stock, efficiencies, CO_2 emissions, and criteria pollutant emissions. It allows the modeler to quickly develop different projections of electrification and emissions for light-, medium-, and heavy-duty vehicles and other parts of the transportation sector. Synapse used EV-REDI to evaluate the emissions impacts of light-duty electric vehicle (e.g., cars, pickup trucks, and SUVs) adoption trajectories, as well as the emissions impacts of non-light-duty vehicles (e.g., tractor trailers).
- **Buildings sector.** The Buildings Decarbonization Calculator (BDC) is a custom-built calculator for modeling the evolution of building energy consumption for space and water heating in the residential and commercial sectors. Synapse used the model to calculate the impact of changes in heating system technology market share on both total heating system stock and energy consumption by fuel type. It accounts for the expected lifetimes of space and water heating technologies, the efficiencies of systems installed each year, and changes in the total number of households and commercial buildings over time.
- **Electricity sector.** EnCompass is a linear optimization model of production cost and capacity expansion for the electricity sector. It combines inputs and constraints relating to electricity load projections (including impacts of energy efficiency and electrification), existing power plants, new renewable and conventional resources, state legislation and regulations (such as renewable portfolio standards), and transmission topology (i.e., spatial characteristics of the transmission asset) to analyze system dispatch, costs, and emissions. For this project, Synapse modeled the entire New England electric grid. Synapse also modeled imports and exports from adjacent power control areas because of the high level of interconnection among New England and its neighboring states and Canadian provinces, as well as the importance of keeping track of greenhouse gas emissions produced in other regions for electricity consumed in Maine and vice versa.

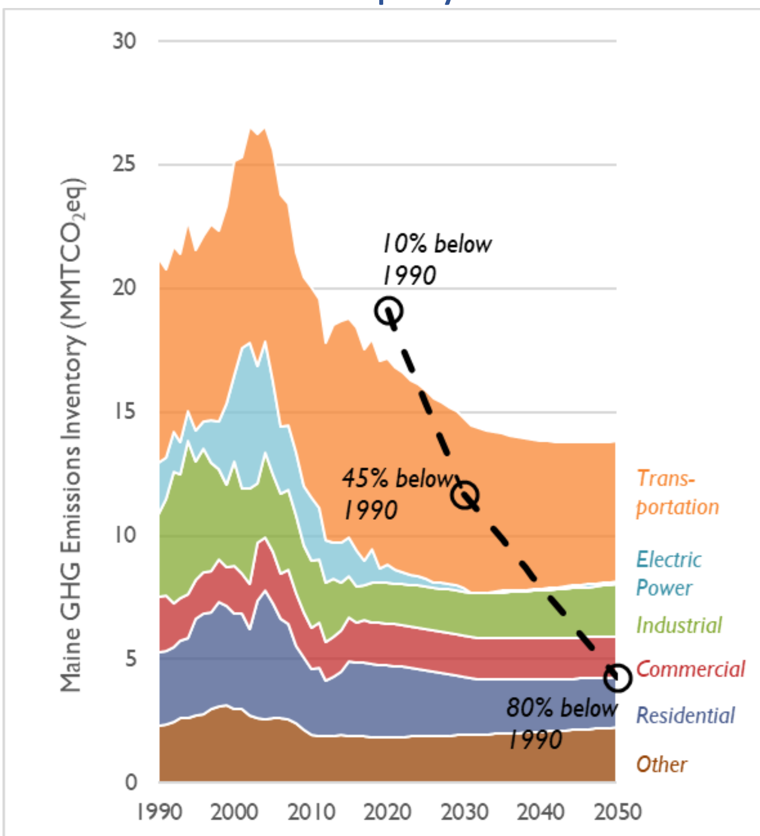
3.2. Baseline Scenario Results (Business as Usual)

Energy sector modeling established the mitigation efforts required to meet Maine's goal: reducing greenhouse gas emissions by at least 80 percent below 1990 levels by 2050. Maine also has an interim greenhouse gas emissions reduction target of 45 percent below 1990 levels by 2030. It is widely acknowledged in the literature that this aggressive target requires deep decarbonization across all sectors. The pathway to decarbonization requires switching from petroleum-based fuels and natural gas in the transportation and buildings sectors to clean renewable electricity. Thus, the focus of the energy sector modeling was the transition to an electric grid with low and zero carbon emissions generation sources and electrification of the transportation and buildings sectors.

The energy sector modeling was performed sequentially, starting with the transportation and buildings sectors. These models provide annual fuel use, including electricity consumption for electric vehicle charging and heat pumps in buildings. The increased load from these sectors is then integrated into the load profile used in EnCompass to model the New England grid.

For each sector, Synapse began its modeling by developing a baseline from which alternative scenarios would be evaluated. The baseline modeling featured a "sustained policy scenario": business as usual, with current policies staying in place. Figure 2 presents the economy-wide emissions associated with the sustained policy scenario.

Figure 2. Economy-wide greenhouse gas emissions for the sustained policy scenario.



"Other" includes emissions from industrial processes, agriculture, waste, and non-CO_2 emissions from energy. Emissions from industry, industrial processes, and agriculture were projected based on a 2013–2017 compounded annual growth rate. Non-CO_2 emissions from energy were projected based on the historical ratio of these emissions to CO_2.

The sustained policy scenario fails to meet Maine's greenhouse gas emissions reductions targets. Emissions are projected to decline through 2030 and flatten out in later years. Total emissions in 2050 are projected to be 13.8 million metric tons, which is 9.6 million metric tons above the 2050 target. The transportation sector continues to be the largest source of emissions in the state through 2050, representing 41 percent of economy-wide emissions.

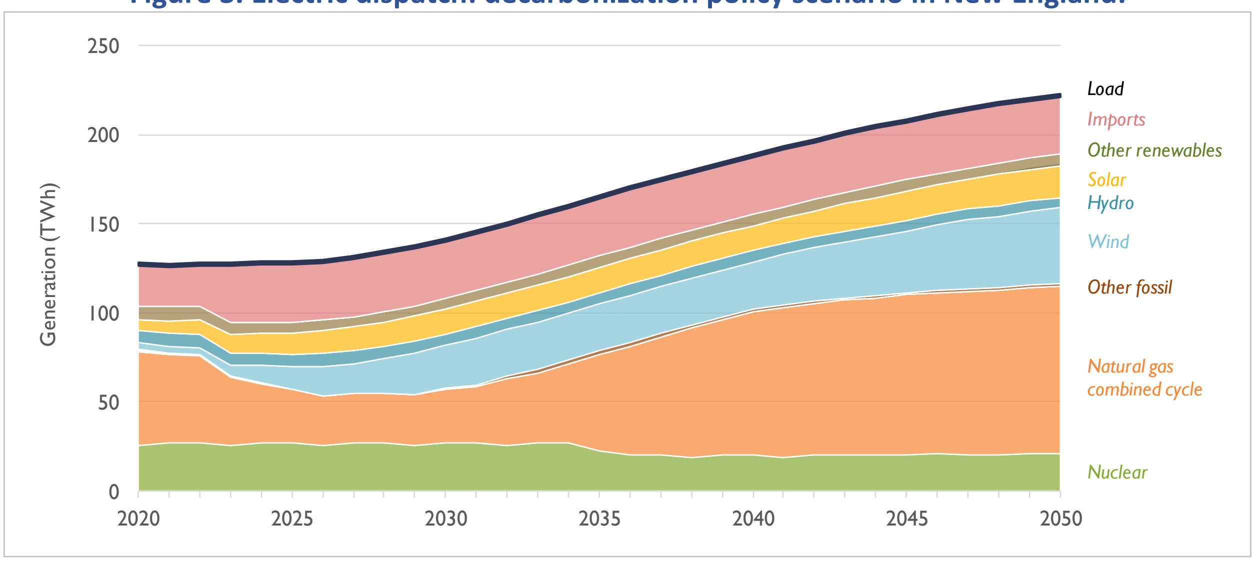
3.3. Policy Scenario Results

In collaboration with the Transportation; Buildings, Infrastructure, and Housing; and Energy Working Groups, Synapse developed several policy scenarios to explore pathways to achieve Maine's greenhouse gas targets.

- Transportation sector alternative scenarios included varying degrees of electrification of the vehicle fleet, reductions in vehicle miles traveled, light-duty vehicle fuel economy improvements, and replacement of gasoline and diesel fuels with low-carbon fuels.
- Building sector alternative scenarios included varying degrees of electrification of heating systems, building efficiency gains, and replacement of heating oil and natural gas with low-carbon fuels.
- The electricity sector alternative scenario (which incorporates decarbonization of both transportation and buildings) was termed the decarbonization policy scenario. The load growth associated with electric vehicle charging used in this scenario assumes that 90 percent of the light-duty vehicle fleet and 80 percent of the heavy-duty vehicle fleet are electrified by 2050. Similarly, the load growth from the buildings sector assumed that 90 percent of residential and commercial buildings adopt heat pumps for space and water heating.

The load growth across the transportation and building sectors increases electricity use in New England to 223.3 TWh in 2050.[4] This represents a 76 percent increase in electricity consumption across all New England states relative to the sustained policy forecast of 126.3 TWh in 2050. Figure 3 illustrates the sources of generation used to meet the demand for electricity across New England from 2020 to 2050.

Figure 3. Electric dispatch: decarbonization policy scenario in New England.



Combined cycle combustion technology uses both turbine technology and a steam generator to maximize the production of electricity from natural gas combustion. The "other renewables" category includes biomass, municipal solid waste, demand response, landfill gas, and other miscellaneous resources.

The decarbonization policy scenario assumes that Maine adopts a 100 percent by 2050 renewable portfolio standard, while other New England states maintain their existing policies. As illustrated in Figure

[4] The region-wide load was developed based on the assumption that all New England states pursue decarbonization goals similar to Maine's.

3, the natural gas combined cycle is selected through an economic optimization algorithm to replace generation from nuclear units that are decommissioned and meet the increased load associated with beneficial electrification.

Table 7 presents Maine's electricity supply and demand for generation, as well as peak capacity projections, for the decarbonization policy scenario. Maine accounts for 8 percent of New England's total generation and 10 percent of its electricity demand in 2020; in 2050 it accounts for 12 percent of its generation and 13 percent of its demand. Between 2020 and 2050, Maine's peak demand is projected to increase by nearly 8 GW. Maine is projected to see 7.6 GW of additional generation capacity and 1.2 GW of retired generation capacity between 2020 and 2050. Thus, Maine is projected to have a net increase of 6.4 GW in capacity additions over the 30-year time horizon.

Table 7. Maine's Supply and Demand: Electricity Generation and Capacity for the Decarbonization Policy Scenario

	2020	2030	2050
Generation and Load (TWh)			
Imports	—	—	—
Other	2.1	1.6	1.6
Wind	2.4	2.9	17.7
Solar	0.2	2.5	3.2
Other fossil	0.0	0.0	0.2
Natural gas combined cycle	1.7	0.9	1.3
Hydro	3.5	3.7	3.1
Nuclear	0.0	0.0	0.0
Battery	—	—	-0.2
Total supply	**9.9**	**11.6**	**26.9**
Demand	**12.9**	**15.6**	**28.6**
Peak Capacity and Demand (GW)			
Imports	—	—	—
Other	0.5	0.4	2.1
Wind	0.9	1.0	4.8
Solar	0.1	1.5	2.1
Other fossil	1.0	1.0	0.8
Natural gas combined cycle	1.4	0.7	0.5
Hydro	0.7	0.8	0.7
Nuclear	0.0	0.0	0.0
Total capacity	**4.7**	**5.5**	**11.1**
Demand	**2.1**	**2.7**	**6.5**

Figures may not add to totals due to rounding.

As shown in Figure 4, electric sector greenhouse gas emissions in New England increase over time, while Maine's emissions decrease. Maine's greenhouse gas emissions are presented from both a consumption-based and a generation-based perspective. (The generation-based emissions are only the emissions from generators in Maine, whereas the consumption-based emissions are the emissions from generators in Maine plus emissions associated with non-renewable electricity imports into the state.)

Figure 4. New England and Maine's electric sector emissions: decarbonization policy scenario.

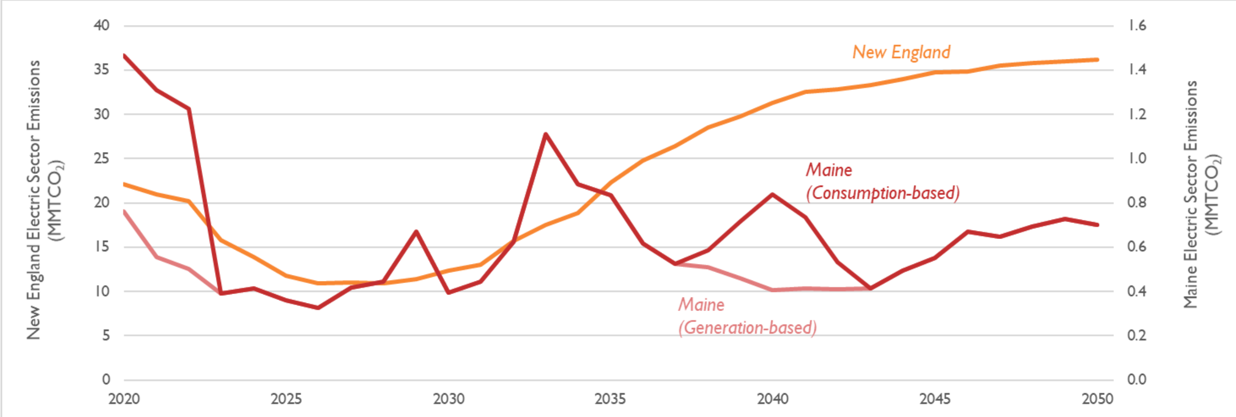
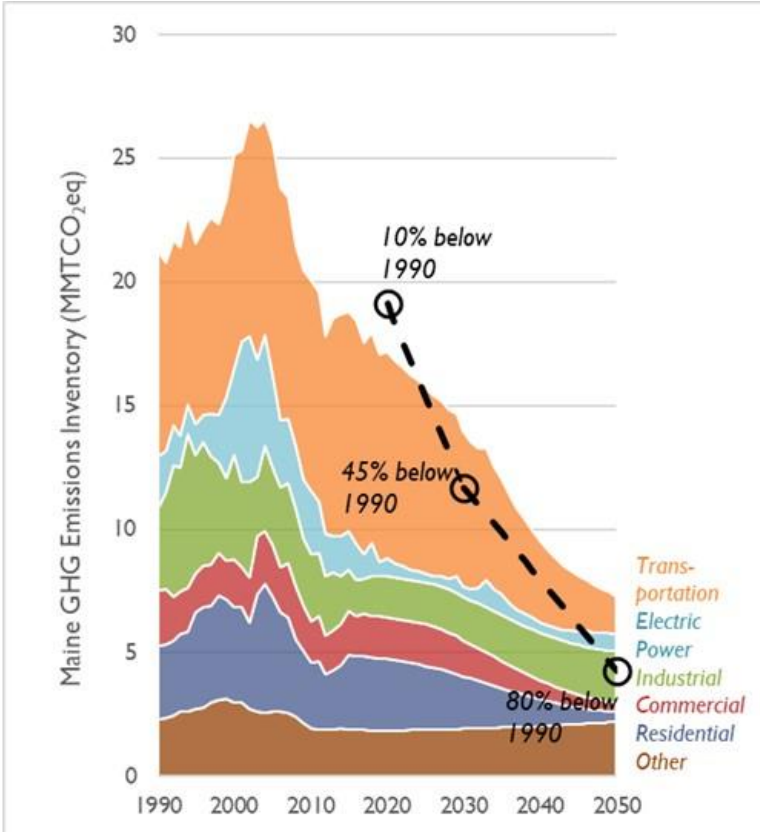


Figure 5 presents the economy-wide greenhouse gas emissions projections for the decarbonization policy scenario. **Even with the aggressive decarbonization pathway, Maine is projected to fall slightly short of its goal to reduce emissions by 80 percent below 1990 levels.** With the aggressive decarbonization pathway assumptions that 90 percent of the light-duty vehicle fleet and 80 percent of the heavy-duty vehicle fleet are electrified and 90 percent of residential and commercial buildings adopt heat pumps for space and water heating by 2050, total emissions in 2050 are 7.3 million metric tons, which is 3 million metric tons above the 2050 target. By 2050, the largest remaining sources of emissions are the industrial and other sectors, which were not modeled in depth for this project.

The remaining emissions reductions necessary to meet Maine's 80 percent goal must primarily be met by reductions in the industrial and other transportation sectors (aviation and marine) that we did not model. It is conceivable that efficiency gains in addition to fuel switching for industry, aviation, and marine transport could achieve the needed 3-million-metric-ton reduction. Technologies are being developed to electrify both the aviation and marine sectors. It is possible that technology will evolve in the next several decades to reduce the fuel used in air and sea travel using electricity or other low-carbon fuels. These are the most difficult sectors to decarbonize, so efforts in these areas should be weighed relative to additional reductions in motor vehicles, buildings, and electricity. **There is also considerable potential for efficiencies and decarbonization in the pulp and paper industry and the food and beverage industry.** In Maine, the former industry is considerable, and the latter is diverse; both industries are large and have significant greenhouse gas emissions.

Figure 5. Economy-wide greenhouse gas emissions for the decarbonization policy scenario.



"Other" includes emissions from industrial processes, agriculture, waste, and non-CO_2 emissions from energy. Emissions from industry, industrial processes, and agriculture were projected based on a 2013–2017 compounded annual growth rate. Non-CO_2 emissions from energy were projected based on the historical ratio of these emissions to CO_2.

VOLUME 4. ECONOMIC ANALYSES OF ADAPTATION AND MITIGATION STRATEGIES

Key Co-Benefits of Strategies

- **Carbon sequestration**
- **Flood protection**
- **Habitat protection**
- **Jobs**
- **Public health**
- **Recreation**
- **Reduced emissions**
- **Revenue or cost savings**
- **Happiness or comfort**

The goal of performing economic analyses is to help show whether there is an economic case to implement strategies. Economics alone should not inform the decision, as feasibility of analysis (e.g., data availability, credible methods) and resource constraints often make it impossible to monetize all the benefits and costs and equity, political feasibility, and other factors need to be considered.

ERG performed economic analyses—including benefit-cost analyses, cost-effectiveness analyses, qualitative analyses, and literature reviews—and gathered case studies to provide economic context for the majority of the adaptation and mitigation strategies developed by the Maine Climate Council. We did not perform analyses for all strategies as not all strategies lend themselves to monetization analysis, and we have only included discussions for the strategies for which we performed analysis.

This section briefly describes strategies[5] developed by the Maine Climate Council working groups, provides the key takeaways from the economic analysis, provides further considerations for recommended future work or implementation, and highlights the primary benefits of the strategies using icons (shown on the left).

[5] Note: we have sometimes shortened the strategy name in the section below.

4.1. Coastal and Marine

4.1.1. Blue Carbon Optimization

Strategy: Increase conservation and restoration of coastal habitat to support blue carbon.

Key economic findings: Marsh and eelgrass restoration do not prove highly cost-effective in terms of carbon sequestration alone (ranging from $1,673 to $321,933 per metric ton of CO_2 sequestered, with benefit-cost ratios typically worse than 1 to 1,000 when considering only the benefits associated with carbon sequestration and reducing the social costs associated with carbon emissions). However, marsh and eelgrass provide a range of other ecosystem services such as flood protection, better fishing, and higher nearby property value. Thus, blue carbon projects should be implemented based on where they can maximize ecosystem service values, but not implemented strictly as a way to sequester carbon. Cost-effectiveness of marsh and eelgrass restoration improves over the decades. Eelgrass proves more efficient than marsh because it sequesters more carbon than many types of marsh.

Further considerations: How might we maximize cost-effectiveness by strategically selecting restoration sites with high-value co-benefits?

4.1.2. Use Nature-Based Solutions

Strategy: Promote community and ecosystem resiliency though climate-adaptive planning strategies and nature-based solutions.

Key economic findings: Federal grants in the millions of dollars are available for nature-based solution projects; the National Institute of Building Sciences finds that investment in these projects returns an average benefit-cost ratio of 6 to 1. Similarly, living shorelines may cost up to 5 times less to construct than harder infrastructure like sea walls (making them a seemingly cost-effective nature-based solution to coastal erosion), while also providing ecosystem services such as improved water quality and wildlife habitats. Beach nourishment projects included in this strategy may also help avoid economic losses related to beach area decline from to sea level rise across Maine. These projects have been found to return benefit-cost ratios of 0.3–1.7 to 1 for projects along the U.S. Gulf Coast. On the other hand, wetland restoration projects along the Gulf Coast have returned benefit-cost ratios of 2–9 to 1. In this case, natural infrastructure projects like wetland restoration may offer longer-term solutions and higher returns on investments than beach nourishment.

Further considerations: More comprehensive value information is needed on the biodiversity, water quality, marine life, and flood protection benefits of nature-based solutions to determine the return on investment for climate adaptive planning, regulation, and management.

4.1.3. Climate-Ready Working Waterfronts

Strategy: Prioritize 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.

Key economic findings: The Green Marine Program's annual costs range from $2,842 to $10,335 for each port authority and terminal (member pricing differs based on type of marine institution and number of terminals managed). The program provides reduced greenhouse gas emissions as well as a range of co-benefits such as improved air quality and improved waste management.

A Working Waterfront Infrastructure Trust Fund of $1 million could likely finance resiliency improvements at two to 10 medium-sized working waterfronts. In towns like Vinalhaven where high seas interrupt ferry service, these improvements are increasingly needed.

Further considerations: Further financial planning is needed to determine how far $1 million in revolving funds can go toward meeting the infrastructure needs of all of the state's working waterfronts. The need for waterfront adaptation funding may go significantly beyond this $1 million fund.

4.2. Community Resilience, Public Health, Emergency Management

4.2.1. Comprehensive Review of Maine Laws to Achieve Resilience and Economic Security

Strategy: Conduct 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.

Key economic findings: This statute-focused strategy supports time- and cost-effective implementation of many of the other adaptation and resilience strategies. National-level literature (from the National Institute of Building Sciences) reports an average cost-benefit ratio of 6 to 1 for several major federal disaster-mitigation-related funds. New York State provides a case study of revisions to state law increasing efficiency of local adaptation planning. The cost of statewide statutory review is estimated to be $350,000–$480,000.

Further considerations: Detailed economic analysis will be needed if statutory review and revision makes some properties unbuildable (changing the tax base).

4.2.2. Improve Municipal Technical Assistance

Strategy: Improve the delivery system of technical assistance on resilience to municipalities and establish institutional infrastructure at the state and regional levels to support resilience in all municipalities.

Key economic findings: Over 180 municipalities in the state have neither local planners nor support from regional planning organizations with resilience training. By focusing grant and operating support to regional agencies and hiring state and regional planning staff (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. This is in comparison to the cost of filling capacity gaps by hiring 12–15 regional planners and 10 local planners (with resilience training) for larger municipalities at a salary cost of $65,000 per staff member. The Community Resilience Planning Subgroup estimates that initially it will cost $1.2 million annually to implement this strategy. The primary benefit of this strategy is the outcomes associated with improved technical assistance, which could be worth substantially more than the cost savings estimate.

Further considerations: More analysis may be needed to ensure equitable distribution of this technical support. Additionally, future work could assess the impacts and economic benefits of technical assistance to perform a benefit-cost analysis of the outcomes of technical assistance.

4.2.3. Funding Mechanisms for Resilience

Strategy: Create funding mechanisms to achieve resilience, through avenues such as executive orders to establish cabinet-level coordination across state agencies so that funding priorities are consistent.

Key economic findings: These funds will be used to implement a wide range of resilience measures. National-level literature reporting the benefit-cost ratio of pre-disaster investment in hazard mitigation strategies shows *an average benefit-cost ratio of 6 to 1.*

Further considerations: More economic analysis is needed on the specific project types to be funded.

4.2.4. Develop and Implement a "State Infrastructure Climate Adaptation Fund"

Strategy: Develop and implement a non-disaster related "State Infrastructure Climate Adaptation Fund" that would allow municipalities and state agencies to access the funds needed to supplement the often-excessive local cost shares associated with adaptation projects.

Key economic findings: FEMA and other federal grants in the millions of dollars are available for hazard-mitigation projects, and the National Institute of Building Sciences finds that investment in *these projects return an average benefit-cost ratio of 6 to 1*. Many of these grants require a state and/or local match which a state adaptation fund could provide. Review of similar state funds provides examples of states leveraging these state dollars in order to access larger federal grants for hazard mitigation.

Through County Hazard Mitigation Plans, $325 million in backlogged project needs have been identified. As federal hazard mitigation grants often require 25 percent cost share by municipalities, $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.

Further considerations: The $325 million in backlogged projects are an appropriate starting place for hazard mitigation projects, so an economic analysis focused on those projects could be helpful.

4.2.5. Improve Public Health Behavior Related to Climate Impacts Through Investments in Monitoring and Education

Strategy: Improve public health monitoring and education capacity across the state related to climate change, including air allergens, particulate matter, ozone, harmful algal blooms, vector-borne disease, browntail moths, and *Vibrio*s.

Key economic findings: Action to limit Lyme and Eastern equine encephalitis can avoid treatment costs.

In 2018, Maine treated its 1,405 reported new patients with Lyme disease at a cost of $11.5 million. Patient numbers (and associated costs) are expected to grow without intervention to limit the spread of the disease.

Outbreaks of Eastern equine encephalitis in Maine have been limited to date, but the science indicates that they are likely to increase. Patients who suffered a transient episode faced approximately $40,360 in direct medical costs; intervention for residual sequelae cost about $5.76 million per patient over their life. Some of these health costs can be avoided through spending on more consistent mosquito disease monitoring and control measures. For example, mosquito control districts in Massachusetts have a budget of over $2 million annually.

Further considerations: Additional information is needed on the costs of expanded outreach and education programs.

4.2.6. Conduct Public Education and Climate Change Health Effects and Resources

Strategy: Increase capacity across the state to provide public health education about climate change effects and resources. This strategy includes a woodstove exchange program to increase adoption of higher-efficiency, cleaner woodstoves.

Key economic findings: Related to the proposed woodstove replacement program in this public health strategy, ERG found that the avoided cost of hospital visits due to improved indoor air quality can 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. Vermont's woodstove exchange program provides an example of the costs to create a program: as of May 2019, the state had replaced 359 stoves and drawn on $700,000 of funds, with some of that funding left over for further replacements.

By helping residents address risks the risks from high heat index days, we can avoid an estimated $1.9–$3.2 million annually in healthcare costs in 2050 and $2.9–$8.1 million annually in 2100 given projected increases in high heat index days.

Further considerations: Currently available research would not allow an estimate of the number of hospital visits avoided through Vermont's woodstove program. More information is needed on the number of Mainers facing poor air quality due to outdated woodstoves. Further work is needed to estimate staff needs (and associated budget needs) to adequately expand public health outreach.

4.2.7. Reduce Impacts from High Intensity Weather Events

Strategy: Increase preparedness for high-intensity weather events and their impacts, such as flooding, to reduce long-term damage to communities.

Key economic findings: Continued combined sewer overflow abatement will help protect water sources from pollutants and bacteria during weather events and will cost approximately $232 million over the next five years. These efforts will result in health and economic benefits for humans and marine life. They will also allow communities to avoid costs related to overflow damages such as losses in shellfish harvesting revenue, $10,000 to $10 million annually in harmful algal bloom treatments, and $10,000 to $1 million or more per watershed in chemical pollution cleanup. The current combined sewer overflow abatement projects, however, may not consider the effect of climate change on precipitation levels.

Further considerations: Further economic benefit valuations of clean and safe water resources should be incorporated, including those for the benefit of clean drinking water to public health and the benefit of avoiding flood inundation to drinking water wells.

4.2.8. Improve Health Systems' Capacity to Mitigate and Adapt to Climate Change

Strategy: Support Maine's health systems in developing mitigation and adaptation strategies in response to climate change. In terms of mitigation, this includes incentivizing Maine's four major health systems (MaineHealth, Central Maine Medical Center, Northern Light Health, and MaineGeneral) to reach carbon neutrality within six years and enacting various methods to reduce energy usage. For adaptation, strategies include both an energy audit and a preparedness audit, as well as staff training and storm-resistant infrastructure.

Key economic findings: A case study from Fort HealthCare in Wisconsin suggests that the implementation of numerous energy conservation measures—including LED lighting upgrades, existing HVAC systems upgrades, and retro-commissioning of air-handling units—reduced the facility's annual emissions by nearly 4,000 metric tons of CO_2 and produced an annual cost savings of $361,000. With a payback period of approximately 2.3 years, these strategies both provide cost savings after just a few years and emissions reductions.

Further considerations: The case study used for this analysis can be used to estimate the CO_2 emission reductions of a Maine health facility given the facility's annual energy usage per square foot and the square footage of the facility. A more granular cost accounting of energy conservation measures, like upgrading ventilation and air conditioning units, would be helpful to determine the costs and benefits of specific measures.

4.3. Natural Working Lands

4.3.1. Protect and Conserve Natural and Working Lands

Strategy: Protect and conserve natural and working lands and waters through a dedicated funding source. This strategy will support a robust forest products and agricultural economy, increase carbon storage opportunities, avoid future emissions, and enhance climate adaptation and resilience.

Key economic findings: Conserving forests from development is one of the more cost-effective strategies to help reach carbon neutrality, with various scenarios ranging from about $4 to $20 per metric ton of CO_2 sequestered between 2020 and 2100. Conserving 2 percent incrementally until 2069, when 100 percent of lands that would have been developed would be conserved, led to 12.7 million tons of carbon sequestered at a social cost of over $123 million. Forest land is expected to be lost to development at increasing rates until at least 2100. Conserving this land is important for offsetting emissions, and high initial investments are often more cost-effective. Protecting forests through a climate fund can offset a large proportion of Maine's emissions compared to other land conservation strategies.

Emissions changes are harder to establish for agricultural lands because they serve as a source of emissions as well as a sequestration method. Farms are presently a net source of emissions, but increasing crop cover, reducing tillage, and increasing nutrient management practices can reduce those emissions. For example, increasing crop cover by 25 percent, increasing adoption of reduced tillage or no-till farming by 75 percent, and increasing 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–$6.79 million (based on the lower limit of the social cost of carbon in 2020). (Note, though, that agricultural land covers about 3 percent of the area that forests do—so forests will have a vastly greater ability to sequester carbon.)

Further considerations: The scenarios that had the lowest cost-effectiveness ratio were programs that had large initial investment. This shows the value of acting quickly, since forests continue to sequester carbon over time.

4.4. Energy

4.4.1. Ensure Adequate Affordable Clean Energy Supply to Meet Maine's Goals

Strategy: Increase the use of renewable energy sources and distributed generation sources to achieve Maine's 100 percent renewable portfolio standard by 2050.

Key economic findings: A decarbonization pathway along with a 100 percent renewable portfolio standard could provide about $945 million in human health benefits from reduced criteria pollutants, over $2.7 billion in overall net cost savings , and about another $100 million in market value from reduced CO_2 cumulatively from 2020 to 2050. The value of the CO_2 reduction could be almost $3 billion over this 30-year period, considering the overall social cost of carbon. This is based on Synapse's decarbonization model, which assumes that by 2050 Maine will have a 100 percent renewable portfolio standard, over 80 percent of heavy- and light-duty vehicles will be electric, 90 percent of commercial heating will be electrified, and increases in fuel efficiency and weatherization will be achieved.

Additionally, renewable energy is rapidly decreasing in price. For example, a study found the levelized cost (i.e., the cost considering capital cost, maintenance, and distribution) of utility-scale solar dropped about 65 percent in the United States from 2011 to 2018. While the levelized costs of coal and natural gas have ranged from about $43 to $204/MWh and $32 to $104/MWh, respectively, many solar and onshore wind projects now cost about $50/MWh (unsubsidized). Distributed solar and offshore wind have been closer to the top of the fossil fuel range, at a median price (across a number of study areas) of around $100/MWh.

Further considerations: This assumes that Maine's electrical grid can handle the increase in capacity. Although increased usage of microgrids and energy storage will help to lessen the need for large investments in expanding Maine's electrical grid, we recommend assessing the costs of building out electric grid infrastructure to meet the projected demand. Additionally, up-front costs associated with the decarbonization pathway should be assessed to provide capital-cost investment estimates.

4.4.2. Encourage Highly Efficient Combined Heat and Power Production Facilities

Strategy: Undertake actions to encourage combined heat and power facilities, which are more efficient than the systems now used in Maine. Commercial and institutional sites, such as hospitals and colleges, would provide opportunities to upgrade existing systems and develop more efficient combined heat and power systems.

Key economic findings: As of 2020, Maine has 42 combined heat and power sites with a total capacity of over 668 megawatts. Using more combined facilities would lower emissions and save costs by recycling the heat byproduct in power facilities to heat industrial spaces. An older study assessed the CO_2 emissions from two plants built between 2005 and 2010 and showed greenhouse gas reductions of 21 percent. That study also pointed to Massachusetts' 34 combined heat and power plants, with 42 megawatts of capacity, that reduced annual CO_2 emissions by over 150,000 metric tons.

Further considerations: Maine could 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 might be useful in driving decision-making toward wider adoption.

4.4.3. Institute a Renewable Fuel Standard

Strategy: Set a standard for using various renewable heating fuels that may help reduce both emissions and Maine's reliance on heating oil. Some potential solutions are the use of biofuels to power anaerobic digesters (e.g., capturing and burning biomethane released from dairy waste, landfills, and wastewater treatment facilities for power instead of just releasing into atmosphere), biofuel from woody biomass, and biodiesel from used vegetable oils.

Key economic findings: Based on one sample model, over a 10-year period, an anaerobic digestion system that burns captured methane would have a cost-effectiveness of about $177 per metric ton of CO_2 equivalent reduced. This was based on a high capital cost to purchase the anaerobic digester and an annual energy cost savings of over $10,000 from using the captured methane for energy.

Biodiesel, which can be manufactured from recycled cooking oil, can be used for home heating if mixed with petroleum diesel in up to a 20 percent blend. Studies have shown a 20 percent blend of biodiesel produces lower CO_2 emissions than natural gas; adding biodiesel to diesel can reduce nitrogen oxides, sulfur dioxide, and particulate matter—which all have negative impacts. The national average price of B20 biodiesel is $2.36/gallon, slightly cheaper than the national average price of petroleum diesel at $2.61/gallon.

Further considerations: Further Maine-specific analyses are needed on the cost-effectiveness of reducing CO_2 emissions by using biofuels to power anaerobic digesters, using biodiesel for home heating (an area that particularly lacks literature on cost-effectiveness), and using biofuel from woody biomass. These technologies will be important to monitor: some of them are relatively new and their costs may change as they rapidly improve.

4.5. Transportation

4.5.1. Expand Electrification of Transportation

Strategy: Expand electrification of both light-duty and heavy-duty vehicles by providing equitable incentives and infrastructure.

Key economic findings: If Maine were to provide a $2,000 incentive for all light-duty vehicles and a $20,000 incentive for all heavy-duty vehicles[6] purchased in 2030, the cost would be approximately $82 million per year; the benefit would be $130 million per year, considering improved health from reduced nitrogen oxides, sulfur dioxide, particulate matter, and the social cost of carbon. This becomes a benefit-cost ratio of about 1.6 to 1, not including benefits to individual buyers, though the total benefits from the pollution reduction could reach up to $1.2 billion in 2050. Each electric vehicle owner would also accrue a net benefit of $2,609 (light-duty vehicle) or $8,315 (heavy-duty vehicle) for 10 years of ownership over owning a conventional vehicle in 2050 when the need for state purchase incentives would likely not exist.

Further considerations: An analysis of the need for public charging stations would provide further context about the overall costs to Maine. For context, across areas serviced by the largest electric utilities in the states of California, Georgia, Maryland, Massachusetts, New York, Ohio, and Pennsylvania, an analysis showed it would cost a range of $600 million to $4 billion (per state) to implement public chargers in those states. Costs to Maine would include future projections of electric pricing at charging stations, along with the changing state purchase subsidies. Maine would not necessarily take on all of these costs; however, as private organizations will likely implement charges as electric vehicles become more widespread.

4.5.2. Reduce Vehicle Miles Traveled (VMT)

Strategy: Support the development of key infrastructure in people's daily lives, expand climate-friendly and easily accessible public transportation, and expand telework and teleservice opportunities.

Key economic findings: The cost of an expansive bus rapid transit system is $18.07 million per mile (based on a hypothetical system in a 2-million-person metropolitan area with an average commute of approximately 12 miles). If a Maine resident were to travel using the bus rapid transit system instead of driving a car, CO_2 emissions would be lower by an estimated 0.0003 metric tons per mile.

[6] Based on typical current subsidies in states that have implemented electric vehicle incentives.

Further considerations: This analysis only assessed expanded public transportation; we recommend Maine consider a benefit-cost analysis, cost-effectiveness analysis, and analysis of the capacity to reduce emissions through teleworking, as employees have become more adept at working from home during the COVID-19 pandemic.

4.5.3. Explore Mechanisms to Fund Transportation Needs and Facilitate Emission Reduction

Strategy: Fund transportation construction and maintenance projects through stable, sufficient, and sustainable methods of revenue collection for Maine. These funding strategies should also act as emissions reduction strategies.

Key economic findings: 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, with revenue for the State (and cost to consumers) of $160 per metric ton.

By 2030, the vehicle miles traveled fee costs $250–$718 per metric ton of CO_2 equivalent reduced to administer through safety inspections, while the revenue generated per metric ton (and cost to consumers) is $1,149–$1,321. This would generate about $90–$224 million per year in revenue and reduce emissions by 90,000–224,000 metric tons of CO_2 annually.

With a price per metric ton of CO_2 emitted between $30 and $50 and revenue for 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 2030, as well as generate $54–$90 million in revenue to the State.

Further considerations: Future analysis should take projected trends for registered vehicles, CO_2 emissions, average miles traveled, and vehicle miles per gallon into account; these trends should factor in changes to the baseline caused by the COVID-19 pandemic. A future analysis should also compare a carbon tax, vehicle miles traveled tax, and fuel tax. This analysis only included passenger vehicles; future analysis should look at the costs and benefits associated with all vehicle types. An analysis should also consider the economic impact and benefit-cost analysis of how the revenue is invested.

4.6. Buildings, Infrastructure, and Housing

4.6.1. Improve the Design and Construction of New Buildings

Strategy: Improve the design and construction of new buildings to increase energy efficiency, including by adopting more stringent building codes over time, reaching net zero emission building codes by 2035.

Key economic findings: For new single-family homes, taking into account both higher initial costs and lower operating costs, the present value over 30 years of costs and cost savings of building new buildings to higher energy efficiency standards over time are net cost savings of about $1,300 to $1,700 per house (or $0.60 to $0.75 per square foot) and roughly one metric ton of CO_2 is saved per house per year.

For new multi-family homes, building to a more stringent energy efficiency standard costs about \$26,000 more per unit (or \$0.37 per square foot), but annual operating costs are about \$500 lower per unit (or \$0.89 per square foot). Building new multi-family homes to a more stringent energy standard costs about \$300 to \$3,000 for the initial build per metric ton of CO_2 saved (depending which building standard is used).

Further considerations: While reduced energy bills mean cost savings for consumers over time, financial assistance or incentives may be required to help with the higher up-front construction costs, especially for buildings that will be occupied by renters.

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

Strategy: The first of these two strategies would replace outdated, inefficient heating and cooling systems in existing buildings with newer, more efficient systems that both reduce costs for the consumer and reduce greenhouse gas emissions. The second 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.

Key economic findings: Updating existing homes with new and more efficient heating and cooling systems and weatherization homes involve up-front installation costs (i.e., “measure costs), but every strategy reduced both energy costs and CO_2 emissions for the lifetime of the measure with a costs savings of between \$20 and just over \$400 per metric ton of CO_2 reduced.

Further considerations: As with the previous strategy, financial assistance or incentives may be required to help with the up-front project costs.

4.6.3. Lead-By-Example in Publicly Funded Buildings

Strategy: Accelerate the timeline of Strategy 1 (improve the design and construction of new buildings) in publicly funded buildings through demonstrating cost-effective lead-by-example projects to reduce greenhouse gas emissions.

Key economic findings: The cost-effectiveness shown in two lead-by-example projects (a solar array at a transfer station and at a school in Bristol) played a role in changing the minds of skeptics and putting more confidence in proponents, which were important steps to justify more substantial future investment. About a year later, the Town of Bristol decided to implement a much more substantial solar array. The return on investment for these projects will depend on the nature of the project itself.

Further considerations: Developing a baseline of energy use in publicly funded buildings could help identify opportunities to maximize the effectiveness of this strategy. As well, this was not a perfect example of reducing emissions in a publicly funded building, and it could be useful to compile additional success stories, not only to show return on investment but also to see what kinds of building projects generate these positive outcomes. This could help motivate implementation.

4.6.4. Accelerate the Decarbonization of Industrial Use and Processes

Strategy: Explore the benefits and costs of expanding incentives for efficient energy programs. Investigate the benefits of different fuels for long-term fuel switching in the industrial sector.

Key economic findings: Maine could implement several fuel switching strategies to reduce emissions. Natural gas is becoming more cost-effective with new technology. Biomass fuel currently accounts for around 41 percent of industrial energy. However, renewables such as solar, tidal, and hydroelectric could be cost-effective as well.

Further considerations: Expanding the model to cover different fuel types over various timeframes could help measure several different benefit and cost estimates for different fuel and system switching scenarios.