ANALYSIS GROUP

Carbon Pricing for New England

TECHNICAL APPENDIX

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Table of Contents
Technical Appendix

Table of Contents 0

I. Modeling Approach and Data Sources 1

II. Potential Pathways for GHG Reductions in New England 8

A. Introduction 8

B. State law and policy 8

C. GHG Reduction Strategies/Scenarios Studied in this Report 14

I. Modeling Approach and Data Sources

Our modeling approach combines the Enelytix security constrained unit commitment and hourly dispatch model[1] for the ISO-NE electricity sector with electrification models that simulate changes in gasoline consumption, heating fuels, electricity demand and GHG emissions stemming from electrification of the transportation and heating sectors. The baseline dispatch modeling analysis input data is primarily from ISO-NE's most recent 2019-2028 Forecast Report of Capacity, Energy, Loads, and Transmission (CELT Report) and associated analyses that form the basis of the CELT Report.[2] These data are then adjusted for known and expected generation resource additions and retirements, at-risk unit retirements (based on 2016 and 2017 ISO-NE Economic Studies),[3] and where necessary, additional zero-emission renewable resources needed to accommodate increased electrification and meet state GHG reduction requirements. Table A.1 summarizes our resource mix input assumptions for future years 2025, 2030 and 2035 for each of the scenarios that are studied.

For each of our scenarios we rely on gas and oil futures markets data for near-term fuel prices and extend these prices using the 2019 U.S. Energy Information Administration Annual Energy outlook base case regional growth rates.[4] We use historical daily natural gas demand and pipeline and liquefied natural gas (LNG) input capacities to establish maximum daily natural gas availability for power generation. The modeling results are used to evaluate CO_2 prices deemed necessary to support investment in zero-carbon resources needed to meet state goals, which are then incorporated into the analysis.[5] Finally, we do not incorporate any system transmission constraints in the analysis.

We first establish a baseline-no electrification scenario against which we can evaluate the electric sector impacts of increased electrification. We then estimate future annual New England CO_2 emission levels that are consistent with achieving the standards that have been established by the New England states. Figure A.1 compares the estimated economy-wide CO_2 emissions for the no electrification scenario and the projected CO_2 emission reductions needed for New England to make reasonable progress towards longer term decarbonization objectives over the next 15 years. As Figure A.1 shows, under the baseline scenario there will be significant CO_2 emission reductions associated with the increased generation from new renewable resources. However, while power sector CO_2 emission reductions allow for substantial progress by 2025, the region will fall considerably short of the 50 million metric ton per year reduction needed by 2035 in the absence of significant reduction in other sectors of the New England economy.

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[1] Enelytix, Newton Energy Group LLC and Polaris Systems Optimization, Inc.

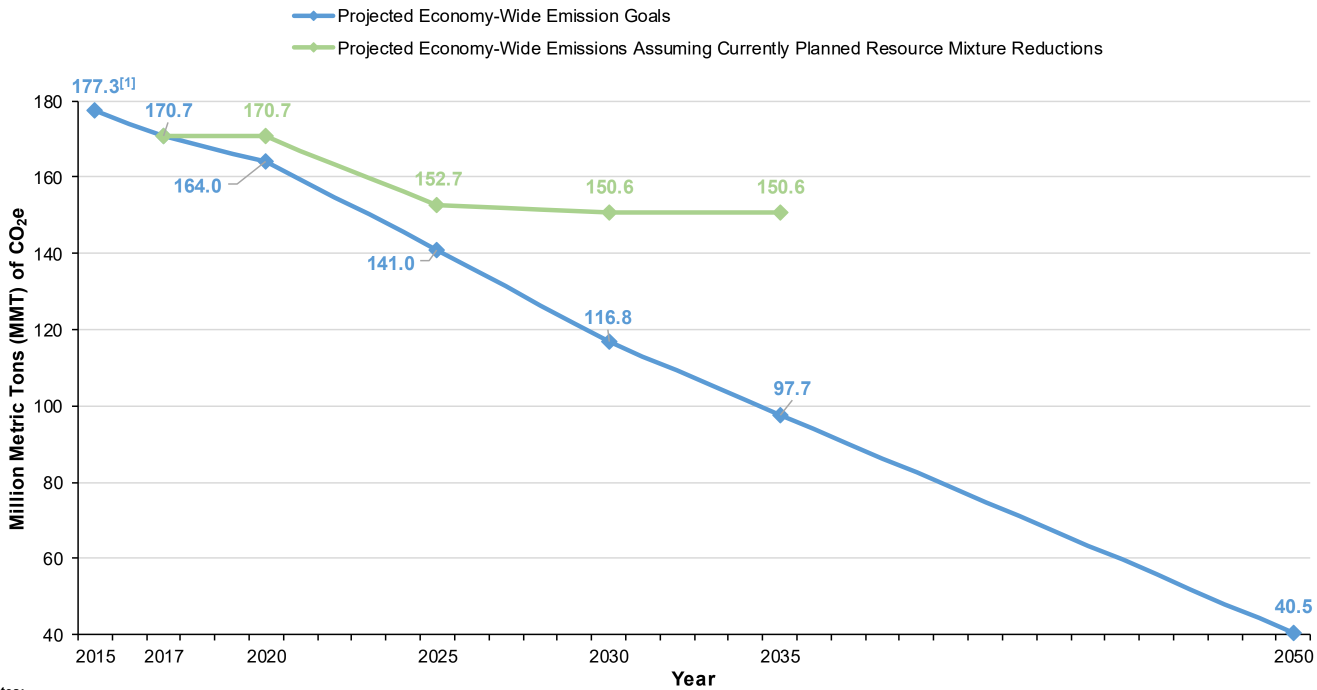
[2] ISO New England, CELT Report, May 31, 2019, available at https://www.iso-ne.com/static-assets/documents/2019/04/2019_celt_report.xls; ISO New England, Final 2019 Energy Efficiency Forecast, May 1, 2019; ISO New England, Final 2019 PV Forecast, April 29, 2019. See also, ISO New England, Energy-Efficiency Forecast Background Report, System Planning, May 1, 2016. ISO-NE energy efficiency and PV resource addition forecasts are extended to the year 2035 assuming that annual growth rate of these resources continues at a similar pace to that shown in ISO-NE's most recent forecasts.

[3] 2016 Economic Study: NEPOOL Scenario Analysis - Implications of Public Policies on ISO New England Market Design, System Reliability and Operability, Resources Cost and Revenues, and Emissions, ISO New England Inc., November 17, 2017 and 2017 Economic Study: Exploration of Least-Cost Emissions-Compliant Scenarios, ISO New England Inc., October 29, 2018.

[4] See S&P Global Market Intelligence, OTCGH Natural Gas and Crude Oil Futures, as of 10/29/2019, and EIA, Annual Energy Outlook 2019, Energy Prices by Sector and Source, New England Region, available at https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2019&cases=ref2019&sourcekey=0.

[5] For scenarios where we do not evaluate more appropriate CO_2 emission pricing we include the Regional Greenhouse Gas Initiative (RGGI) 2017 RGGI Model Rule Policy Scenario - (No National Program, Low Emissions Sensitivity Case) forecast as a source for CO_2 allowance prices. See RGGI Program Review, September 25, 2017 meeting materials,:https://www.rggi.org/program-overview-and-design/program-review

Figure A.1: Carbon Reductions Associated with Currently Approved Renewable Resource Additions--No Electrification



Notes:
[1] In 2015, total GHG emissions across New England were 177.3 MMT of CO_2e (43.8 in CT, 76.1 in MA, 19.1 in ME, 17.0 in NH, 11.3 in RI, and 10.0 in VT).
[2] Economy-wide emission reduction goals are determined by aggregating each New England state's historical emissions and annual emission targets. If data is unavailable for a given year, the goal is estimated by interpolating results from years where it is available by state.
[3] Resource mixture adjustments include the retirement of fossil-fuel plants and the addition of renewable resources.

We next modeled two electrification scenarios (low and high) that assumed increasing electrification of light-duty vehicles (LDV) and residential home heating systems over the next 15 years. Under each of these scenarios we assume a set percentage of LDVs and residential heating systems are switched from fossil fuel inputs to electricity. The Low Electrification/Contract Resources (LECR) scenario assumes (1) 12.5% (2025), 17.5% (2030), and 30% (2035) of residential homes currently heating with gas, oil, or propane switch to electric heating, and (2) 25% (2025), 35% (2030), and 60% (2035) of consumers driving LDVs switch to electric vehicles.

The High Electrification/Carbon Price (HECP) scenario assumes (1) 25% (2025), 50% (2030), and 75% (2035) of residential homes currently heating with gas, oil, or propane switch to electric heating, and (2) 25% (2025), 60% (2030), and 90% (2035) of consumers driving LDVs switch to electric vehicles.

For each of our electrification scenarios we evaluate the capacity resource mix that would be available to meet the projected increase in electricity peak demand and energy consumption. Table A.1 summarizes the resource mixes relied upon in the modeling scenarios. As Table A.1 notes, each of the modeling scenarios shares the assumption that the major zero-emission resource additions that are currently under contract are completed between now and the end of 2024, and the majority of older oil and oil/gas steam cycle generation capacity resources retire in 2024 (other existing fossil fuel resources remain operational).[6] In addition, each modeling scenario includes the following three assumptions:

- Off-shore wind electric generation resource developments are completed consistent with current legislative and regulatory commitments;
- energy efficiency investments continue with a longer-term annual growth of approximately 5-6% based on ISO-NE's most recent forecast;[7] and
- installation of BTM PV systems continues consistent with ISO-NE's most recent forecast.[8]

In effect, the Baseline and LECR scenarios incorporate resources in response to existing or expected state procurements and regulatory actions. However, these resources are not sufficient to represent reasonable progress towards the states' aggregate GHG emission reduction standards by 2035. Thus, the HECP scenario increases the growth in EE penetration by 25% over the baseline level for 2035, increases quantities of on-shore and off-shore wind, in front of the meter PV and storage resources, and adds a new transmission interconnection to access additional hydroelectric and zero carbon resources from Canada in 2035. These increased zero-emission resources are needed to accommodate the increased demand from greater electrification, and to maintain New England's progress toward meeting its GHG reduction standards.

Table A.1: Modeling Resource Mixtures (MW)[9]

Summary of Capacity (MW) Assumptions Used In the Low and High Electrification Scenarios
ISO New England

	Low Electrification/Contract Resources (LECR)			High Electrification/Carbon Pricing (HECP)		
	2025	2030	2035	2025	2030	2035
Existing Derated Capacity After Retirements (Excludes BTM PV)	28,818	29,895	30,923	28,818	30,465	32,543
Assumed Additions (Derated Capacity)						
Battery Storage Additions	50	250	700	50	250	2200
Onshore Wind Additions	0	182	0	0	182	182
Additional Renewable Resources Distant from Load	0	0	0	0	0	1090
Offshore Wind Additions	1020	480	0	1020	960	0
Installed Capacity (Derated Capacity)	**29,895**	**30,923**	**31,623**	**30,465**	**32,543**	**36,585**
Imports	1,188	1,188	1,188	1,188	1,188	1,188
Total Capacity	**31,083**	**32,110**	**32,810**	**31,653**	**33,730**	**37,772**
Assumed Behind-the-Meter PV and Energy Efficiency						
Behind-the-Meter PV	950	1,183	1,392	950	1,183	1,392
Energy Efficiency in Peak Hour	5,519	6,725	8,477	5,982	8,292	10,311

Notes:
[1] Capacity represents the total existing capacity at the start of each year prior to adding additional resources. Onshore wind, offshore wind, and solar capacity is derated at factors of 26%, 30%, and 28.5%, respectively. For additional detail, see source [B].
[2] Existing capacity as of 2025 includes approved renewable resource additions and expected or at-risk unit retirements of approximately 5,500 MW of capacity of aging coal-, oil- and gas-fired generation stations.
[3] Between 2019 and 2025, 5,238 MW of capacity is expected to come online. These additions include approved offshore wind, the Canadian Interconnection, and others.
[4] Import capacity is obtained from the 2019 CELT Report.
[5] The *2016 Act to Promote Energy Diversity* directed Massachusetts electricity distribution companies to procure 1,600 MW of offshore wind by 2027. In May 2018, it was announced that the 800 MW Vineyard Wind project had been selected. The *2018 Act to Advance Clean Energy* authorizes state officials to procure an additional 1,600 MW by 2035. See sources [C], [D], and [E].
[6] In June of 2019, the Connecticut state government passed *An Act Concerning the Procurement of Energy Derived from Offshore Wind* which enabled the Commissioner of Energy and Environmental Protection to issue solicitations totaling up to 2,000 MW. All 2,000 MW must be reached by the end of 2030. See sources [C], [F]
[7] In 2018, Rhode Island issued an RFP for 400 MW of offshore wind. In May 2018 it was announced they had selected Deepwater Wind's 400 MW Revolution Wind Project. See sources [C], [G].

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[6] While we carefully assess the seasonal and hourly impact of increased electrification, we have not evaluated whether or to what extent existing liquefied natural gas and generating unit dual-fuel capability may be needed to maintain power system reliability during extended periods of cold weather.
[7] ISO New England, Final 2019 Energy Efficiency Forecast, May 1, 2019. We base our longer-term growth assumptions on the middle years of ISO-NE's forecast 2023-2025.
[8] ISO New England, Final 2019 PV Forecast, April 29, 2019.
[9] Sources: [A] CELT Report, 2019. [B] ISO New England, 2016 Economic Study: NEPOOL Scenario Analysis, July 24, 2017. [C] U.S. Offshore Wind Project Pipeline, Public Policy Center UMass Dartmouth, available at http://publicpolicycenter.org/osw-project-pipeline-in-the-states/#toggle-id-5. [D] An Act to

The magnitude of electrification needed to meet the states' GHG reduction standards is significant, and will need to occur over a relatively short time frame. Consequently, we evaluate the peak demand impact of the increased electrification scenarios to confirm that the growth in electrification could be accommodated by the assumed resource mixes. In order to quantify the increase in electricity demand due to electrification and allocate that demand increase across hours, we first estimated the daily increase in energy consumption associated with the assumed levels of growth of LDV and residential heating electrification. We estimate the amount of electric energy that must be replaced based on average LDV characteristics and the percentage of vehicles that we assume are electrified. We then assume the increased electricity demand is allocated equally to all 365 days in the year with battery charging concentrated in the overnight hours (75 percent during the evening and nighttime hours (6 PM - 5 AM) and 25 percent during the daytime hours (5 AM - 6 PM)).[10]

For residential heating we first determine the annual increase in electric energy consumption associated with the assumed percentage levels of electrification.[11] We then allocate the annual increase in electricity consumption to the daily level based on a representative weather year, consistent with that assumed in the Enelytix model.[12] The increase in daily electricity demand is then distributed geographically based on a ratio of potential switching households in each ISO-NE zone to the total potential switching households in New England. Next, the daily increase in electric demand is allocated hourly using an estimated New England daily heating load profile from the Electric Power Research Institute (EPRI).[13]

Following the allocation of increased electrification demand to the hourly level, we determine the resulting coincident peaks and confirmed that the resource mix is sufficient to meet the projected peak demand. Figure A.2 shows the projected change in peak demand due to electrification, with two primary implications for future electric system hourly demand shapes. First, the charging pattern of LDV electric vehicles (EV) is likely to introduce large hourly load increases in the evening hours. Second, the major increase in electric heating and EV penetration will substantially increase base load during the winter months, eventually shifting the system peak demand from summer to winter. As Figure A.2 shows, the growth in the winter peak demand is substantial; even with aggressive additions of renewable resources the shift points to the ongoing need for existing fossil fuel resources and natural gas infrastructure to remain available and operational for decades, supporting reliable New England's power sector operations as the region achieves aggressive reductions in GHG emissions.[14]

Promote Energy Diversity, Chapter 188, 2016, available at https://malegislature.gov/Laws/SessionLaws/Acts/2016/Chapter188. [E] An Act to Advance Clean Energy, Chapter 227, 2018, available at https://malegislature.gov/Laws/SessionLaws/Acts/2018/Chapter227. [F] Request for Proposals for Long-Term Contracts for Offshore Wind Projects, Massachusetts Department of Energy Resources, May 23, 2019, available at https://macleanenergy.files.wordpress.com/2019/05/83c-ii-rfp_finalpackage.pdf. [G] An Act Concerning the Procurement of Energy Derived from Offshore Wind, Substitute House Bill No. 7156, Public Act No. 19-71, available at https://www.cga.ct.gov/2019/ACT/pa/pdf/2019PA-00071-R00HB-07156-PA.pdf.

[10] Consistent with findings in other studies, we assume that absent meaningful time of use incentives in electricity rate designs, consumers prefer to charge vehicles at home when possible (See, for example, Australian Electric Vehicle Market Study, Prepared by ENERGEIA for RENA AND CEFC, FINAL, MAY 2018 at 4, https://arena.gov.au/assets/2018/06/australian-ev-market-study-report.pdf). Greater precision in the allocation of charging energy would not be expected to materially change our findings as it would tend to concentrate more demand in off-peak hours, where peak demand would be lower than what results from our assumptions.

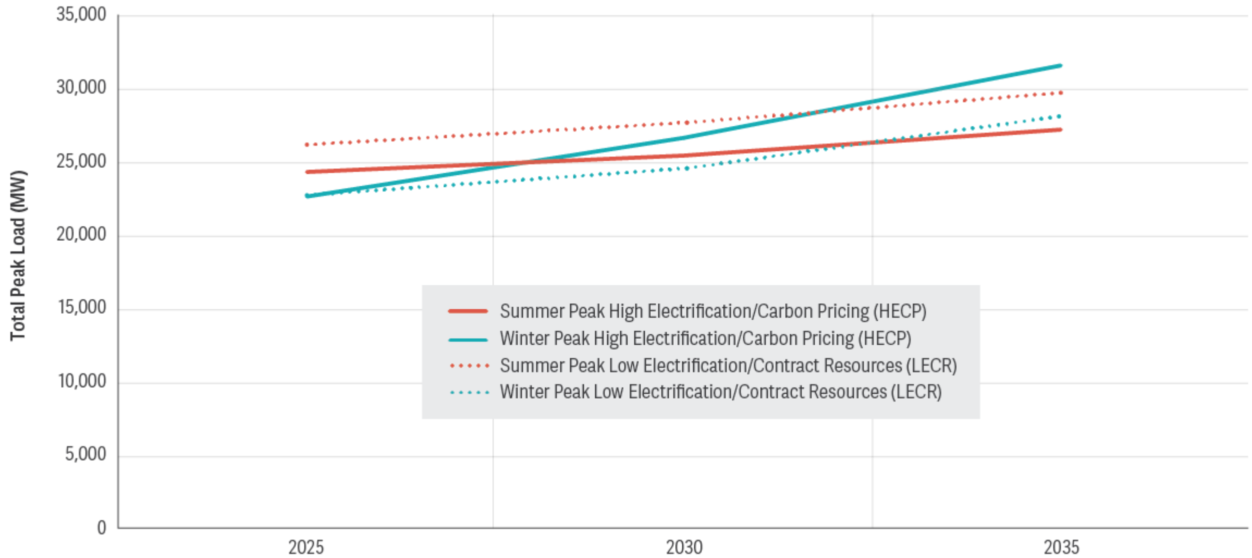
[11] We assume households heating with oil, gas, or propane could transition to an electric heat pump, and that there is no heating demand during the months of May-October. The average annual quantity of electricity used to heat a typical household (assumed to be a 2-story detached, 2300 square foot, 3 person home) is from the Gas Technology Institute Source Energy and Emissions Analysis Tool ("SEEAT"), http://seeatcalc.gastechnology.org/Default.aspx.

[12] Enelytix bases daily load shape on the weather characteristics of the year 2012, which is considered a nearly "normal" weather year by ISO-NE.

[13] EPRI, End Use Load Shapes, Load Shape Library 7.0, Average of on-peak and off-peak NPCC/NE residential heating load shapes, https://loadshape.epri.com/enduse.

[14] Our analysis focuses on the starting point set of resources and decarbonization options that appear practically achievable based on current information. We acknowledge that this could change if there is a break-through in ubiquitous and economic energy storage or an alternative fuel source (e.g., hydrogen).

Figure A.2: Annual Peak Load by Season and Electrification Level



Notes:

[1] The low electrification scenario assumes 12.5% (2025), 17.5% (2030), and 30% (2035) of residential homes currently heating with gas, oil, or propane switch to electric heating. The low electrification scenario also assumes 25% (2025), 35% (2030), and 60% (2035) of consumers driving light-duty vehicles switch to electric vehicles.

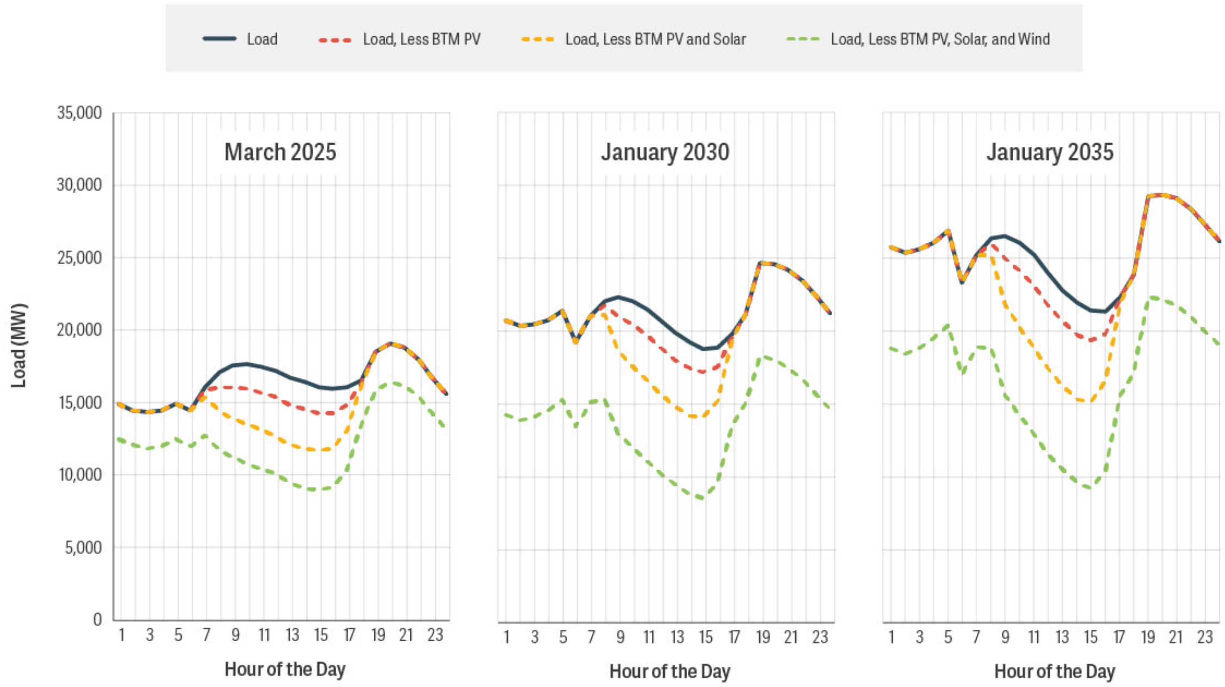
[2] The high electrification scenario assumes 25% (2025), 50% (2030), and 75% (2035) of residential homes currently heating with gas, oil, or propane switch to electric heating. The high electrification scenario also assumes 25% (2025), 60% (2030), and 90% (2035) of consumers driving light-duty vehicles switch to electric vehicles. The high electrification plus scenario is incremental to the high electrification scenario. It assumes additional EE (25% increase over assumed 2035 EE), and adds additional renewable resources to bring power sector emissions down by 50% relative to the high electrification case power sector emissions.

[3] The winter peak is the coincidental peak load for January, February, and March after netting out behind-the-meter solar and adding electrification load. Similarly, the summer peak is the coincidental peak load for June, July, and August after netting out behind-the-meter solar and adding electrification load.

The second important element of electrification relates to the increase in net load variability (net-load is equal to total system load minus solar and wind powered generation resources). As electrification increases, there will be hour-to-hour load variations that will require thousands of megawatts of resources available to ramp up and down over very short periods of time to accommodate changes in net-load. For example, Figure A.3 shows that estimates of system ramps will progressively grow from several thousand MWs in 2025 to between 10,000 and 15,000 MW in 2035, depending upon both renewable energy production patterns and EV charging schedules. It is clear that a significant quantity of flexible generation resources will be necessary to accommodate the large variations in net-load. In addition, as the use on the electric system evolves to support decarbonization, retail rate structures may need to evolve substantially to provide incentives for usage patterns that help mitigate or address the growing system ramping requirements.

However, absent significant technological change the need for the region's infrastructure remains an important element of an economic transition and reliable system operations.

Figure A.3: Average Ramp-Ups for the Month that the Peak Ramp Occurs High Electrification – Winter Season



Note:
[1] The reported months are those in which the maximum ramp-up net of renewables occurs.

As noted, there are three scenarios developed to explore the implications of practical pathways to achieve the states' GHG reduction objectives - the Baseline scenario, LECR scenario, and HECP scenario. For each scenario we model the dispatch of the ISO-NE electricity system using the Enelytix hourly dispatch model. The model simulates the impact of changes in the capacity resource mix and increased demand from electrification, taking into account the day-ahead unit commitment required to meet the daily hourly loads.[15] For each of the modeling scenarios we project changes in GHGs in equivalent CO_2 emissions ($CO_{2\text{-}e}$), energy prices, generation resource mix and revenues.

We use the results of the dispatch modeling to evaluate the progress made toward achieving reductions in CO_2 emissions.[16] In particular, as shown in Section III, we observe that under the LECR scenario the CO_2 emission reductions are insufficient to achieve reasonable progress towards the region's longer-term GHG reduction targets (see Figure 3). However, the HECP scenario makes reasonable progress toward achieving

[15] The model commits a sufficient quantity of dispatchable generation resources to meet the projected daily hourly net-load (demand) and operating reserves, but does not capture day-ahead to real-time forecast uncertainty that can impact intra-day ramping requirements.
[16] Note that total projected GHG emission reductions are a combination of changes in power sector emissions (which go up or down depending upon year and level of electrification) and the reductions in emissions from electrification of transportation and heating.

GHG emission reductions, involving an increase in the amount of electrification, continued growth in EE deployment, and the addition of new renewable resources enabled through the introduction of a carbon price in dispatch.

In the scenario that achieves the states' objectives - that is, the HECP scenario - we identify the CO_2 pricing level sufficient to cover these resources' revenue needs in the absence of state-sponsored long-term contracts or other subsidies. We use modeled generation resource revenues, estimated capacity market revenues, and estimates of the levelized costs ($/MWh) of renewable resources as inputs to this analysis. We focus our analysis on off- and on-shore wind and utility-scale solar renewable resources,[17] and consider the possibility of an additional transmission interconnection that could deliver incremental hydro-electric generation and/or low-carbon generation from Eastern Canada to New England. Through this analysis we evaluate the additional revenues that would be needed from the wholesale market to cover the costs that the modeled renewable resource additions do not otherwise receive through energy and capacity markets (with no additional subsidies). The renewable resource that requires the most supplemental revenue establishes the estimated CO_2 emission price level.

Solar and wind resource cost estimates are taken from the Lazard 2019 Levelized Cost of New Entry report, and adjusted to account for future cost reductions, inflation, and estimated transmission interconnection costs.[18] We then compare the costs and revenues at each five year interval to determine the additional revenue necessary to cover the resource's costs in $/MWh, and convert this value into $/ton of CO_2 emissions using the average system resource emission rate from the modeling results. We use this value as the carbon price input in the modeling and confirm that the carbon price results in sufficient additional revenues to meet the resource's estimated levelized costs.

In each of the three years of our analysis we assumed an annual capacity market price of $60/kW-Yr. The scenarios we analyze generally result in excess capacity resources even after accounting for assumed at-risk resource retirements. Under the ISO-NE capacity market structure this implies that the less efficient, relatively more expensive existing resources will be marginal in the capacity market auctions. In-depth analyses to date have shown that this will result in capacity market offers that are informed by balancing the expected costs of taking on a capacity obligation against the revenues that would be earned.[19] We assume that these offer dynamics will not change materially, and that the capacity market will continue to be an important source of revenue for existing resources to maintain reliable operations well into the future.

We recognize that over the longer-term there may be unanticipated technological change and any of a number of developments that will impact ISO-NE's wholesale power markets. Thus, while we may see higher or lower capacity market prices, and periods of energy market price volatility, the underlying structure of our analytical framework does not provide the granularity that will accompany assessing how these market outcomes trade-off over time. Regardless of how wholesale market capacity and energy prices evolve over time, the underlying market structures can be expected to ensure that resources that are necessary to

[17] We do not include energy storage resources in the carbon dioxide pricing analysis and assume that these will be continued to be supported by state directed programs that seek to capture those benefits that cannot be monetized in the wholesale markets.
[18] Lazard, Levelized Cost of Energy Analysis - Version 13.0, November 2019; NREL, 2019 Annual Technology Baseline; EIA, Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2019. We do not account for the cost of transmission infrastructure that may be necessary to integrate resources so that they can be deliverable throughout New England.
[19] Analysis Group, Capacity Market Impacts and Implications of Alternative Resource Expansion Scenarios: An Element of the ISO New England 2016 Economic Analysis (July 3, 2017), at 30 and 54, https://www.iso-ne.com/static-assets/documents/2017/07/final_analysis_group_2016_economic_analysis_capacity_market_impacts.pdf.

maintain reliable system operations will be compensated at levels that allow resource owners the opportunity to recover any needed ongoing costs of maintenance and major component refurbishment.

II. Potential Pathways for GHG Reductions in New England

A. Introduction

The purpose of this study is to review the potential value of carbon pricing - particularly in the power sector - in helping the New England states achieve their objectives for continuous decline in GHG emissions. The importance of the review at this time is driven by the state law and policy around climate change, as states have accelerated changes in recent years towards requirements for full decarbonization of the states' economies over just the next few decades. The pace and magnitude of change this implies for the systems, infrastructure, and operation of energy supply and delivery in all sectors will challenge the states, industry stakeholders, and consumers.

In this section we present the current status and scope of state policies related to emissions of GHGs – including both direct requirements related to the absolute level of GHG emissions over time and supporting policies to promote low- and zero-carbon technologies - and briefly summarize current impressions from the literature related to options for achieving decarbonization of energy supply and consumption. This discussion sets the stage for the analysis of power sector carbon pricing described in the sections that follow.

B. State law and policy

The New England (NE) states have established some of the most ambitious GHG emission reduction targets in the country. By 2014, all NE states had established state-wide GHG reduction goals. Under legislative mandates, regulations, and energy policy the NE states have initiated a wide array of policies to enforce and support achievement of GHG reduction targets. Though the specifics of states' GHG reduction targets and supporting state energy policies differ, they tend to employ four primary policy tools: (1) the setting of economy wide and/or sector-specific targets for progressive reductions in emissions of GHGs; (2) required procurement of renewable energy by suppliers of electricity (Renewable Portfolio Standards, or RPS); (3) electricity rate designs providing customer financial incentives for the adoption of behind-the-meter BTM PV and other energy generation (net metering); and (4) ratemaking and other monetary support for continuous investment in programs and measures to reduce energy demand in retail settings (energy efficiency, or EE).

I. GHG Standards

As early as 2002, NE states put forth voluntary GHG emission reduction plans. By 2014, four out of six NE states had set binding economy-wide GHG emission reduction standards to be met by 2050. New Hampshire and Vermont have established standards primarily backed by other state energy policy mechanisms, while other states have adopted binding legislative and/or policy GHG reduction requirements.[20] Because states

[20] As noted, the form taken with respect to GHG emission reduction targets varies across states in the level and pace of required reductions, their application to various sectors of the economy, and the vehicle for established targets (i.e., legislated or established through executive order, regulation, and/or regulatory policy). While there are different approaches taken by the states, and different levels of reductions in state standards, our goal is to take standards as described in state law, policy, or actions, and develop a reasonable approximation of the aggregate GHG reductions and resource development trajectories for the region

have often revised their reduction requirements (generally trending to earlier and greater reductions), the summary below lists standards from the most recently adopted form of state laws and policy. All of the New England states have a GHG reduction standard of 80 percent by 2050. Massachusetts has the largest immediate reduction goal, requiring economy-wide GHG emissions to decline by 25 percent by 2020 (see Figure A.4). The following represents the current form of GHG reduction standards across the New England states:

- Connecticut: 10% by 2020 below 1990 levels; 45% by 2030 and 80% by 2050 below 2001 levels. [21]
- Maine: 10% by 2020, 45% by 2030 and 80% by 2050 below 1990 levels.[22]
- Massachusetts: 25% by 2020 and 80% by 2050 below 1990 levels. [23]
- New Hampshire: 20% by 2025 and 80% by 2050 below 1990 levels. [24]
- Rhode Island: 10% by 2020, 45% by 2035, and 80% by 2050 below 1990 levels. [25]
- Vermont: 40% by 2030 and 80% by 2050 below 1990 levels. [26]

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that are largely consistent with all states meeting their stated GHG reduction standards. That is, we presume in this analysis that states are committed to and will meet the current status of their respective GHG reduction objectives, in the time frames set forth in state law and policy.

[21] Connecticut General Assembly, Public Act No. 18-82, June 6, 2018, available at https://www.cga.ct.gov/asp/cgabillstatus/cgabillstatus.asp?selBillType=Bill&which_year=2018&bill_num=7.

[22] The 129th Maine Legislature, An Act To Promote Clean Energy Jobs and To Establish the Maine Climate Council, June 26, 2019, available at http://legislature.maine.gov/bills/getPDF.asp?paper=SP0550&item=3&snum=129; The Maine Interagency Climate Adaptation Work Group, Maine Prepares for Climate Change, 2019 Update, January 2019, available at https://www.maine.gov/dep/sustainability/climate/MainePreparesforClimateChange2019Update.pdf.

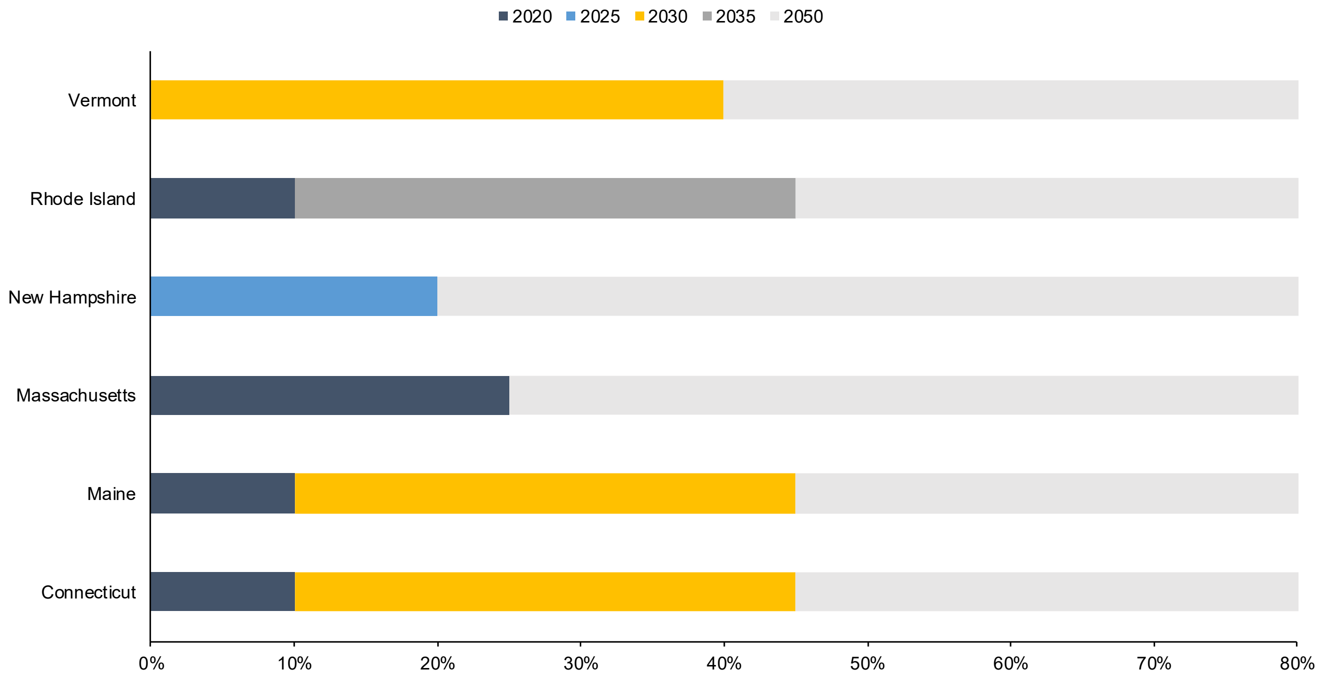
[23] Massachusetts Legislature, An Act Establishing The Global Warming Solutions Act, Aug 7, 2008, available at https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298.

[24] New Hampshire Department of Environmental Services, The New Hampshire Climate Action Plan, available at https://www.des.nh.gov/organization/divisions/air/tsb/tps/climate/action_plan/documents/nhcap_final.pdf.

[25] State of Rhode Island and Providence Plantations, Executive Order 20-01, Advancing a 100% Renewable Energy Future for Rhode Island by 2030, January 17, 2020.

[26] VT DEC, Vermont Greenhouse Gas Emissions Inventory Update: Brief 1990-2015, June 2018, available at https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2015.pdf. Note that Vermont's 2050 goal is flexible with a range of 80-95% below 1990 levels.

Figure A.4: GHG Emissions Reduction Standards in New England[27]



Notes:
[1] Emissions reduction goals are eonomy-wide.
[2] All GHG emissions goals except New Hampshire and Maine are legislated. New Hampshire has recommended GHG emissions goals by the the NH Climate Change Policy Task. Maine has a 10% reduction requirement by 2020 legislated, but for "reductions sufficient to eliminate any dangerous threat to climate in the long-term."
[3] Connecticut's 2030 and 2050 reduction goals are based on 2001 levels while all others are based on 1990 levels.

II. Renewable Portfolio Standards

Renewable portfolio standards are a primary policy tool adopted by New England states to support reductions in GHG emissions from the power sector. RPS typically requires utilities and other electricity suppliers in the state to obtain a minimum percentage of their electricity from qualifying renewable sources such as solar, wind, biomass, geothermal and some hydroelectric facilities.[28] These renewable targets have contributed significantly to renewable growth in the past two decades, in New England and many other states in the U.S.. In 2017, state RPS requirements accounted for 34 percent of renewable energy capacity additions nationally.[29] In the Northeast (New England States and New York), RPS was likely the primary driver of the addition of more than 15 terawatt-hours (TWh) of non-hydro renewable generation from 2000-2017.[30]

[27] Sources: [1] CT DEEP, Connecticut Greenhouse Gas Emissions Inventory, 2016. [2] MA DEP, Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business As Usual Projection, Regulatory Authority: MGL Chapter 21N, Section 3, July 1, 2009. [3] The 129th Maine Legislature, An Act To Promote Clean Energy Jobs and To Establish the Maine Climate Council, June 26, 2019, available at http://legislature.maine.gov/bills/getPDF.asp?paper=SP0550&item=3&snum=129. [4] NH DES, New Hampshire Greenhouse Gas Emissions Inventory, 2016. [5] RI DEM, Rhode Island Greenhouse Gas Emissions Reduction Plan, December 2016. [6] VT DEC, Vermont Greenhouse Gas Emissions Inventory Update: Brief 1990-2015, June 2018, available at https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2015.pdf. Note that Vermont's 2050 goal is flexible with a range of 80-95% below 1990 levels.
[28] National Conference of State Legislatures, States' Renewable Energy Ambitions, February 2019, available at http://www.ncsl.org/research/energy/states-renewable-energy-ambitions.aspx.
[29] Berkeley Lab, U.S. Renewables Portfolio Standards: 2018 Annual Status Report, p.15, November 2018, available at http://eta-publications.lbl.gov/sites/default/files/2018_annual_rps_summary_report.pdf.
[30] Berkeley Lab, U.S. Renewables Portfolio Standards: 2018 Annual Status Report, p.14.

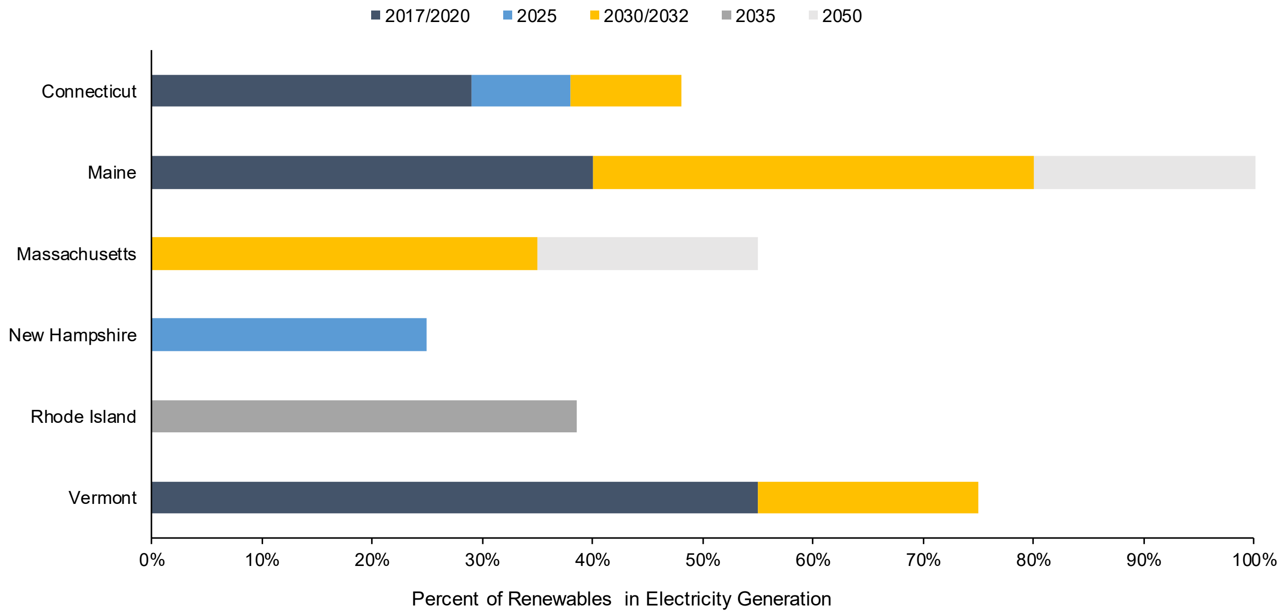
In order for utilities to meet their annual RPS, they can enter into direct contracts/purchases of eligible renewable generation and/or purchase renewable certificates (RECs), each REC representing the generation of one megawatt-hour (MWh) of eligible renewable energy. In Massachusetts and some other states, utilities that fail to procure sufficient renewable generation or RECs comply through payment of an alternative compliance payment.[31]

RPS policies in CT, MA, ME, RI, NH have been in place for more than a decade at least. However, states continue to make significant changes in the form and level of renewable energy requirements.[32] In 2018, both Massachusetts and Connecticut increased their RPS targets, and Massachusetts implemented a clean peak standard. Figure A.5 below shows the state RPS goals established by October 2018. The Renewable Portfolio Standards reported here include all classes of renewable energy as defined by each state (i.e. Class I, Class II, Class III, Thermal, and Solar-Carve Out). Because the number of classes and the meaning of each class differ across states, it is difficult to make state-to-state comparisons of the effective GHG reduction contributions of the stated state RPS percentages.

- Connecticut: 29% by 2020, 38% by 2025, 48% by 2030.[33]
- Maine: 40% by 2020, 80% by 2030, 100% by 2050.[34]
- Massachusetts: 35% by 2030, 55% by 2050.[35]
- New Hampshire: 25% by 2025.[36]
- Rhode Island: 38.5% by 2035.[37]
- Vermont: 75% by 2032.[38]

[31] Commonwealth of Massachusetts, Program Summaries, Summaries of all the Renewable and Alternative Energy Portfolio Standard Programs, available at https://www.mass.gov/service-details/program-summaries.
[32] Berkeley Lab, U.S. Renewables Portfolio Standards: 2018 Annual Status Report, p.8.
[33] State of Connecticut Department of Energy & Environmental Protection Public Utilities Regulatory Authority, Connecticut Renewable Portfolio Standard, available at https://www.ct.gov/pura/cwp/view.asp?a=3354&q=415186.
[34] Maine also has the aspirational goals of 80% by 2030 and 100% by 2050. *See* 129th Maine Legislature, LD1494, available at http://legislature.maine.gov/legis/bills/bills_129th/chapters/PUBLIC477.asp.
[35] The 191st General Court of Massachusetts, Acts 2018 Chapter 227, available at https://malegislature.gov/Laws/SessionLaws/Acts/2018/Chapter227.
[36] New Hampshire Department of Environmental Services, Renewable Portfolio Standards, available at https://www.des.nh.gov/organization/divisions/air/tsb/tps/climate/rps.htm.
[37] State of Rhode Island Public Utilities Commission, Renewable Energy Resources, available at http://www.ripuc.ri.gov/utilityinfo/RES-Annual-Targets.pdf.
[38] Vermont's classification of renewable energy source is unique in including large-scale hydropower. *See* State of Vermont Public Utility Commission, Renewable Energy Standard, available at https://puc.vermont.gov/electric/renewable-energy-standard.

Figure A.5: Renewable Portfolio Standards by State[39]



Notes:
[1] The Renewable Portfolio Standards reported here include all classes of renewable energy as defined by each state (i.e. Class I, Class II, Class III, Thermal, and Solar-Carve Out). Because the number of classes and the meaning of each class differ across states, one should be cautious about making simple comparisons of the aggregated percentages.
[2] Vermont's classification of renewable energy source is unique in including large-scale hydropower.

III. Additional Actions and Policies Promoting Reductions in GHG Emissions

NE states have developed many additional policy tools to promote reductions in GHG emissions. These policies can take place in varied forms of action plans, regulations and market incentives. Nevertheless, there are three widely adopted policies: renewable procurement, net metering, and energy efficiency standards.

A. Procurement and contracts

Examples of the actual and potential procurements that have come forward in recent years cover several states. Massachusetts, Maine and Rhode Island established policies for procuring renewable energy through long-term contracts (three years or more) and recent New Hampshire legislation established a commission to consider similar options.[40] In 2015, Massachusetts, Rhode Island and Connecticut also joined forces in selecting six contracts for projects totaling 450 megawatts (MW). More recently, Massachusetts utilities executed and received approval from state regulators for two 20-year power supply contracts that expect to supply of 9.5 TWh per year of hydro-electric power (roughly 1,100 MW) and approximately 3.5 TWh of off-

[39] Sources: [1] State of Connecticut, Connecticut Renewable Portfolio Standard, available at https://www.ct.gov/pura/cwp/view.asp?a=3354&q=415186. [2] 129th Maine Legislature, LD1494, available at http://legislature.maine.gov/legis/bills/bills_129th/chapters/PUBLIC477.asp. [3] The 191st General Court of Massachusetts, Acts 2018 Chapter 227, available at https://malegislature.gov/Laws/SessionLaws/Acts/2018/Chapter227. [4] New Hampshire Department of Environmental Services, Renewable Portfolio Standards, available at https://www.des.nh.gov/organization/divisions/air/tsb/tps/climate/rps.htm. [5] State of Rhode Island Public Utilities Commission, Renewable Energy Resources, available at http://www.ripuc.ri.gov/utilityinfo/res.html. [6] State of Vermont Public Utility Commission, Renewable Energy Standard, available at https://puc.vermont.gov/electric/renewable-energy-standard. [7] Barbose, Galen, U.S. Renewable Portfolio Standards 3028 Annual Status Report, Lawrence Berkeley National Laboratory, November 2018. [8] DSIRE, Renewable & Clean Energy Map, June 2019, available at https://s3.amazonaws.com/ncsolarcen-prod/wp-content/uploads/2019/07/RPS-CES-June2019.pdf.

[40] New Hampshire Senate Bill *167-FN*, an act establishing a clean energy resource procurement commission, June 27, 2019, available at http://gencourt.state.nh.us/bill_status/billText.aspx?sy=2019&id=1057&txtFormat=html.

shore wind powered (800 MW) energy, is currently reviewing offers for another 800 MW of off-shore wind powered energy, and has authorized the future procurement of an additional 1,600 MW of off-shore wind powered energy. Connecticut and Rhode Island utilities have similarly executed contracts for about 2.5 TWh of off-shore wind powered energy (600 MW), and CT announced the procurement of nearly 12 TWh per year of zero carbon energy (primarily nuclear) as well as an additional 804 MW of off-shore wind in December 2019. Finally, Rhode Island is reviewing offers for an additional 200-400 MW of off-shore wind resources and CT is expected to procure another 1,200 MW of offshore wind power to be installed by 2030. Other states have allowed for similar contracts.

B. Net metering

States have also provided incentives for growth in BTM renewable resources through the design and application of special rates and tariffs for consumers with solar PV and other renewable resources located on site, behind the utility meter. Conventional net metering allows commercial or residential utility customers who have installed small-scale distributed generation sources to sell excess electricity to a utility, and to avoid payment for power that otherwise would be supplied by the utility. Virtual (or aggregate) net metering allows customers, as a group or neighborhood, to be credited for electric production from their shared renewable system.[41] Solar is the most common type of net-metered source, while small wind, biogas, micro turbines are also qualified.[42]

In New England, all states except New Hampshire implement net metering. New Hampshire has statewide distributed generation compensation rules that can have the same effect. In addition, Massachusetts, Connecticut, Vermont and New Hampshire authorize virtual net metering. State net metering policies can differ in their eligible technology, credit retention rules and renewable energy credit ownership.[43] States also set different capacity limits to regulate the eligible system size of net-metered installations. Rhode Island allows the biggest renewable system size, followed by Connecticut and Massachusetts.

C. Energy Efficiency

In addition to the renewables-focused policies summarized above, states have long-standing policies promoting the installation of EE measures and programs in residential, commercial and industrial customer locations. These measures cover but are not limited to measures and programs addressing the use of electricity, heating, and cooling, and more recently have begun to include incentives for the development of electric vehicle charging infrastructure. In the residential sector, states may provide loans, rebates, sales tax incentives, grants and energy standards to drive their energy savings goals. The technologies that these policies apply to are comprehensive. Programs targeting residential users can cover building insulation, LED lighting and appliances standards. In the commercial sector, corporations can include building code, solar energy sales tax, and other rebates.

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[41] Center for Climate and Energy Solutions, Net Metering Programs, April 2019, available at https://www.c2es.org/document/net-metering-programs/.

[42] National Conference of State Legislatures, State Net Metering Policies, November 20, 2017, available at http://www.ncsl.org/research/energy/net-metering-policy-overview-and-state-legislative-updates.aspx.

[43] National Conference of State Legislatures, State Net Metering Policies, November 20, 2017.

In the electricity sector, states often employ Energy Efficiency Resource Standards (EERS) to establish energy savings targets that utilities must meet.[44] Five NE states have EERS adopted by state legislatures, while New Hampshire only has voluntary energy efficiency programs offered by its electric and natural gas companies. Massachusetts and Rhode Island have the strongest EERS requirements in the nation - more than 2.5% new savings annually. In the current planning period, Massachusetts expected 3,461 GWh of annual savings - the greatest in NE.[45] Connecticut has the second largest annual savings, 843 GWh, which can power 100,000 homes in a year.[46]

C. GHG Reduction Strategies/Scenarios Studied in this Report

The transformation of energy systems of the New England states that is implied by the magnitude of the states' objectives exceeds any transition previously experienced in scope, scale, or pace. Importantly, noone can suggest that they know what the region's energy systems will look like at the endpoint, thirty years from now; far too much will change over that timeframe in the technologies and practices for the supply, delivery, and consumption of energy in all sectors. Thus in this Report we focus more on what may be considered starting point - that is, the next ten to fifteen years - over which the region must find a technologically and economically practical pathway to reasonable progress based on current energy system technologies and costs. To evaluate this we develop and analyze scenarios for 2025, 2030, and 2035.

The literature on how the U.S. (and/or states) can achieve decarbonization of their economies by the middle of the century is deep in both identification of technologies and options for achieving reductions in GHG emissions, and current expectations of technical feasibility and costs.[47] Strategies and options include demand and supply side measures, and existing and new technologies. The reduction options range across the various economic sectors that contribute to a buildup of GHGs in the atmosphere, particularly in the electric, transportation and heating sectors, but also agriculture, industrial processes, and land use/forestry.

It is widely expected that across the U.S., and perhaps in particular in the Northeast, that electrification of the transportation and heating sectors in combination and simultaneous with aggressive decarbonization of the electric sector represents the pathway that is most technically and economically feasible at this time.[48] That is not to say that over the next 30 years as states approach full decarbonization of the economy there will not be significant contributions from all sectors, including forestry, agriculture and industrial, as well as strategies that reduce transportation and heating emissions through approaches outside of electrification (e.g., measures focused on decreasing vehicle miles traveled or introduction alternative transportation fuels such as

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[44] American Council for an Energy-Efficient Economy, Energy Efficiency Resource Standard (EERS), available at https://aceee.org/topics/energy-efficiency-resource-standard-eers.

[45] American Council for an Energy-Efficient Economy, Energy Efficiency Resource Standard (EERS), available at https://database.aceee.org/state/energy-efficiency-resource-standards.

[46] Connecticut's Energy Efficiency & Demand Management Plan, 2019-2021 Conservation & Load Management Plan, p.20, November 19, 2018, available at https://www.ct.gov/deep/lib/deep/energy/conserloadmgmt/final-2019-2021-clm-plan-11-19-18.pdf.

[47] See, e.g., Center for Climate and Energy Solutions, Pathways to 2050: Alternative Scenarios for Decarbonizing the U.S. Economy, May 2019; Energy and Environmental Economics, Pathways to Deep Decarbonization in the United States, November 2015; and Information Technology and Innovation Foundation, An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio, November 2018.

[48] See, e.g., Mckinsey & Company, Impact of the financial crisis on carbon economics, Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve, January 2010; Quantifying the multiple benefits from low-carbon actions in a greenhouse gas abatement cost curve framework, The New Climate Economy, The Global Commission on the Economy and Climate, January 2015;Gillingham, Kenneth, Carbon Calculus, Finance & Development, December 2019; 10-Year Action Plan Modeling, Center for Climate Strategies, July 30, 2012; Commonwealth of Massachusetts, Global Warming Solutions Act: 10-Year Progress Report, April 2, 2019; Governor's Council on Climate Change, Building a Low Carbon Future for Connecticut: Achieving a 45% GHG Reduction by 2030, December 18, 2018; and The Executive Climate Change Coordinating Council, Rhode Island Greenhouse Gas Emissions Reduction Plan, December 2016.

hydrogen). Indeed, while electrification may appear to be the primary initial approach to achieve reasonable progress, over time the need for even deeper reductions through other measure will increase in importance, and the advancement of low/zero-carbon technologies in other sectors will emerge.

Nevertheless, our review of decarbonization literature leads us to conclude that in the initial ten to fifteen years, making reasonable progress towards the states' longer-term targets will require major and rapid electrification of transportation and heating sectors, combined with investment in electric sector emission reduction strategies and technologies, and recent and ongoing policy initiatives in the New England states point in this direction.

Transportation

Replacing a conventional gasoline vehicle with an EV plugged in to the New England grid results in substantial net reductions in GHG emissions, even considering the GHG emissions associated with electricity generation. Therefore, many New England states have made expansion of the electric vehicles market a policy priority in their decarbonization plans.

Connecticut, Maine, Massachusetts, Rhode Island and Vermont have signed a memorandum of understanding (MOU) committing to promote zero emission vehicle (ZEV) programs and sales. In MOU states (which includes other states beyond New England), light-duty vehicles alone account for 24% of total emissions in 2015.[49] By 2025, about 15 percent of new vehicles sold in MOU states will be required to be EVs, in line with Title 13 of the California Code of Regulations.[50] This goal translates to about 600,000 annual EV sales in 2025.[51]

As a result of states' efforts and technology advancements, the EV market has grown significantly in the past decade. In 2018, EV sales were up 81% from 2017.[52] However, the total share of EVs relative to all vehicles remains low. Zero emission vehicles (ZEV) comprise 2.1% of total U.S. light vehicle sales, or about 361,000 vehicles out of 17.7 million new vehicles sold in 2018 (see Figure A.6). EV sales in the Northeast region share similar trends. EVs represent about 1% of vehicle sales across New York and New England in 2017,[53] but sales have grown fast. In 2019, EV sales in Massachusetts in the first three months already exceeded the annual sales in 2018 (see Figure A.7).

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[49] ZEV Task Force, Multi-State ZEV Action Plan, 2018, available at http://www.nescaum.org/documents/2018-zev-action-plan.pdf. In 2015, the biggest contributors of GHG emissions in the MOU states following lightweight vehicles are electricity generation (19%), industry use (17%) and heavy-duty vehicles (10%).

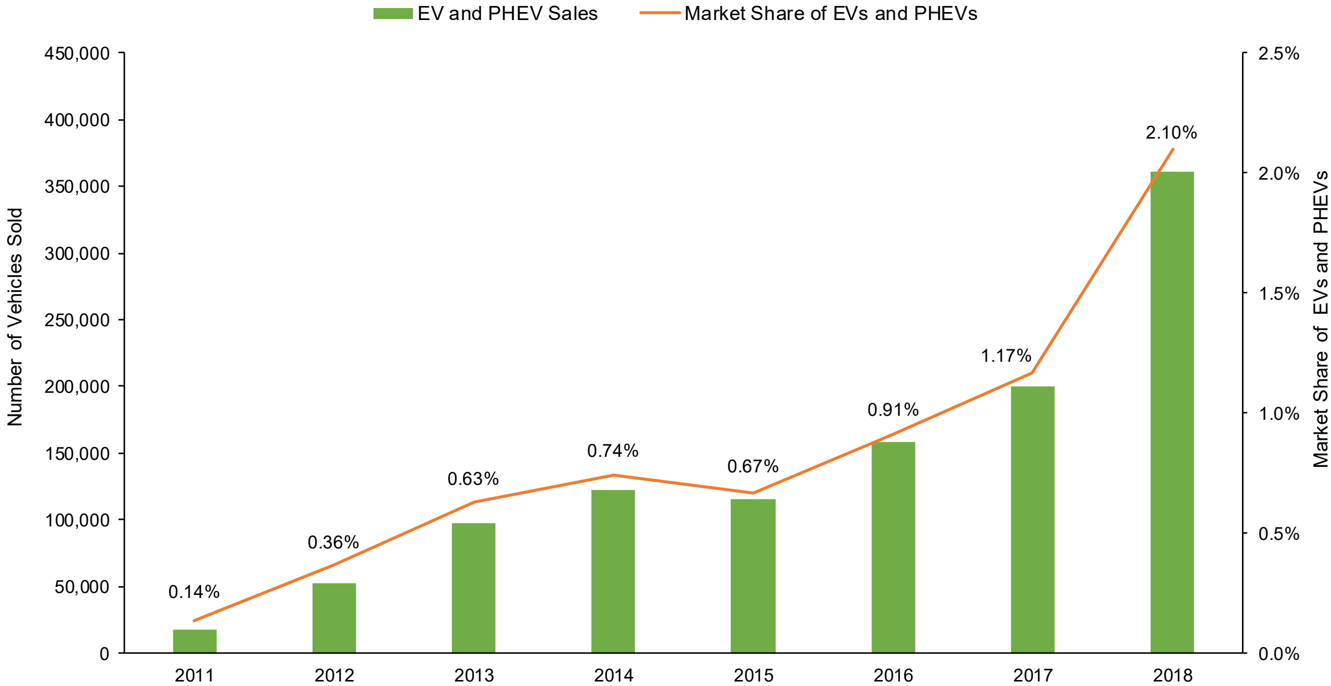
[50] ZEV Program Implementation Task Force, Multi-State ZEV Action Plan, p.4, May 2014, available at http://www.ct.gov/deep/lib/deep/air/electric_vehicle/path/multi-state_zev_action_plan_may2014.pdf.

[51] ZEV Program Implementation Task Force, Multi-State ZEV Action Plan, p.4, May 2014.

[52] Pyper, J, US Electric Vehicle Sales Increased by 81% in 2018, Green Tech Media, January 7, 2019, available at https://www.greentechmedia.com/articles/read/us-electric-vehicle-sales-increase-by-81-in-2018#gs.sxw1bw.

[53] NEEP, Northeastern Regional Assessment of Strategic Electrification: Summary Report, p.5, January 2017, available at https://neep.org/sites/default/files/resources/Strategic%20Electrification%20Regional%20Assessment%20-%20Summary.pdf.

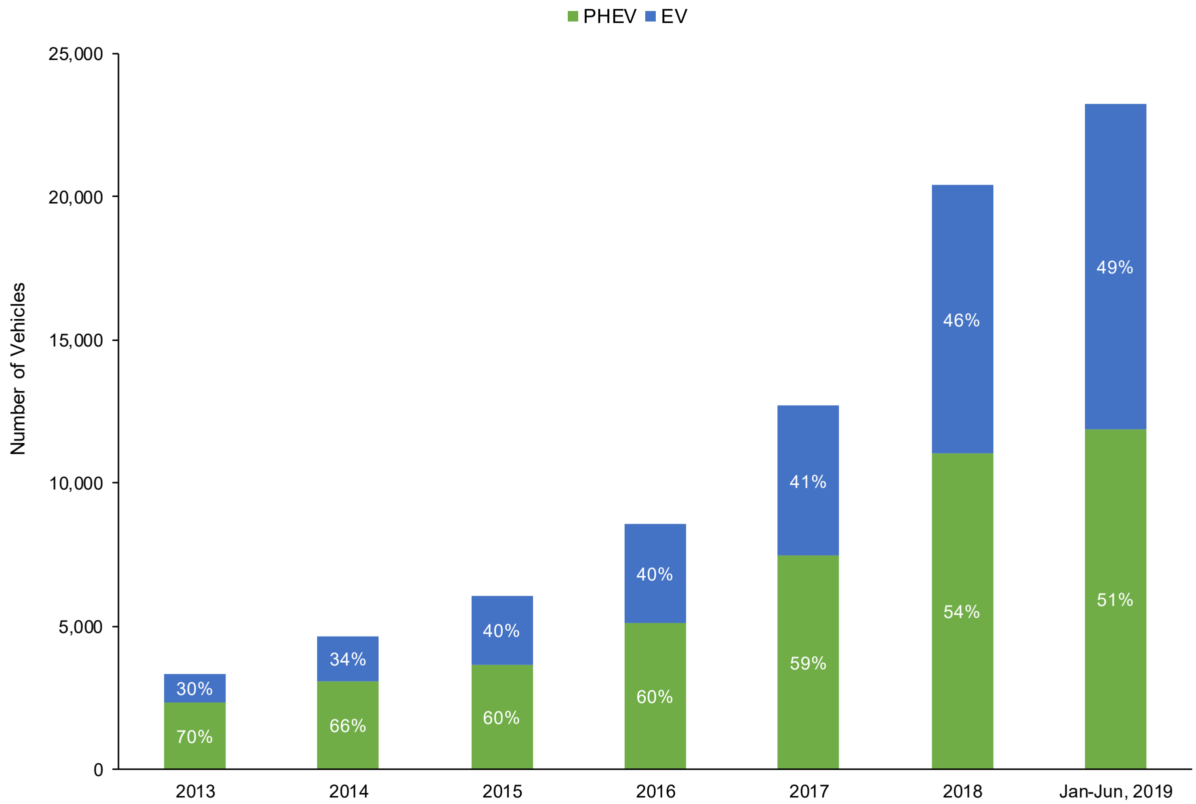
Figure A.6: U.S. Sales and Market Share of Electric (EVs) and Plug-In Hybrid (PHEV) Vehicles, 2011-2018[54]



Notes:
[1] Market share is the sales of EVs and PHEVs divided by the total number of lightweight vehicles sold, including autos and light trucks.

[54] Sources: [A] FRED Economic Data, Light Weight Vehicle Sales: Autos and Light Trucks, 2011-2018, available at https://fred.stlouisfed.org/series/ALTSALES. [B] Inside EVs, Monthly Plug-In EV Sales Scorecard: Historical Charts, Dec 2018, available at https://insideevs.com/news/344007/monthly-plug-in-ev-sales-scorecard-historical-charts/.

Figure A.7: Massachusetts Electric (EV) and Plug-In Hybrid Electric (PHEV) Vehicles, 2013-2019[55]



EVs face multiple challenges in its adoption, including high prices relative to comparable conventional vehicles, battery storage capacity limitations, and the need for development/installation of sufficient charging infrastructure. As battery costs have declined in recent years, state polices have focused on decreasing the high upfront costs of EVs (typically 40 percent more expensive than internal combustion vehicles) and the development of charging infrastructure.[56]

The most common public EV incentives in New England have been rebates, grants and tax incentives. The private sector is also contributing. For example, utilities in New England have offered discounted rates for charging electric vehicle at night, and insurance providers have introduced discounted rates for EVs.[57] In terms of charging infrastructure, private utilities often collaborate with states. Eversource, for example, has the goal of installing 3,500 individual EV ports in up to 400 locations across Massachusetts by 2020 through policies approved by the Massachusetts Department of Public Utilities.[58] Table A.2 displays a non-exhaustive list of public and private EV incentives in New England.

[55] Mass.Gov, MassEVIP Fleets Incentives, available at https://www.mass.gov/how-to/apply-for-massevip-fleets-incentives.
[56] NEEP, Northeastern Regional Assessment of Strategic Electrification, July 2017, p.27, available at https://neep.org/sites/default/files/Strategic%20Electrification%20Regional%20Assessment.pdf.
[57] See, e.g., TD Insurance, Green Car Discount, available at https://www.tdinsurance.com/products-services/auto-car-insurance/green-car-discount.
[58] Daily Energy Insider, Massachusetts Town Works with Eversource to Install EV Charging Stations, May 30, 2019, available at https://dailyenergyinsider.com/news/19639-massachusetts-town-works-with-eversource-to-install-ev-charging-stations/.

Finally, on December 17, 2019, a group of 12 states and the District of Columbia collaborating on transportation GHG initiatives (known as the Transportation Climate Initiative, or TCI[59]) issued a draft Memorandum of Understanding (MOU) and invited public input on a new draft proposal for a regional program to establish a cap on global warming pollution from transportation fuels and invest millions annually to achieve additional benefits through reduced emissions, cleaner transportation, healthier communities, and more resilient infrastructure.[60] The TCI aims to set a cap on GHG emissions from the transportation sector, and has focused on a number of initiatives to decrease transportation GHG emissions, with a strong focus on the electrification of LDVs in part through expanding charging infrastructure. To the extent implemented, a cap on this sector could constrain and reduce emissions, set a higher operational price for gasoline-powered vehicles, and increase investment to accelerate the development of EV charging infrastructure needed to spur adoption of EVs.

[59] While it is not yet known which states will adopt rules and participate in the TCI, the states that have participated in discussions to this point include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. Transportation and Climate Initiative of the Northeast and Mid-Atlantic States, "TCI's Regional Policy Design Process 2019," December 17, 2019, available at https://www.transportationandclimate.org/content/about-us.

[60] Transportation and Climate Initiative of the Northeast and Mid-Atlantic States (*TCI*), https://www.transportationandclimate.org/main-menu/tcis-regional-policy-design-process-2019.

Table A.2: State and Private Incentives for EVs in New England[61]

	Charging Infrastructure	Purchase	Public Fleets	Private Incentives
Connecticut		• CHEAPR Up to $5000 for the purchase of FECVs, PHEVs and BEVs. $9.6 M granted for 4961 rebates since 2015 • Free metered parking for PHEVs		• Groton Utilities $2,000 rebates for a new PEV $1,000 rebates for the lease of a new PEV $600 rebate for the installation of Level 2 EVSE
Massachusetts	• VW & MassEVIP 60% of funding up to $50,000 for the installation of level1/2 EV charging station to businesses with >15 employees or dwellings with >10 residential units	• MOR-EV Up to $2,500 rebate to eligible BEVs or FCEVs. Since 2014, over $24 M was spent to incentivize the purchase of over 11,000 EVs	• VW & MassEVIP $2,500 for dual port charging station per two BEVs funded	• Eversource Funding and installation support based on application, for non-residential customers and level 2 or DC fast EVSE. $5,000 rebates off a Nissan Leaf
Maine		• EV Accelerator Up to $3,000 for a BEV and $1,500 for a PHEV	• EV Accelerator Up to $7,500 for a BEV and $2,000 for a PHEV	• Central Maine Power $5,000 rebates off a Nissan Leaf
New Hampshire				• New Hampshire Electric Co-op Up to $1,000 rebate for the purchase or lease of a new or used EV $300 rebates for the installation of EV charging stations at home
Rhode Island	• Charge Up Up to $60,000 for purchasing and installing EVSE		• Charge Up Up to $15,000 for the purchase or lease of a new public electric vehicle	• National Grid Up to 100 percent of the electrical infrastructure and charging station equipment costs. $5,000 rebate off the purchase or lease of a new Nissan Leaf
Vermont	• EVSE Grants Approximate funding available is $2 million with a required 20% match made by applicant.	• Up to $5,000 for low and moderate income Vermonters purchasing or leasing an eligible electric vehicle		• Burlington Electric Department Up to $1,200 rebate on an EV purchase or lease and up to $400 toward a charger • Green Mountain Power Up to $1,500 rebate on an EV purchase or lease and free charging equipment with EV purchase • Stowe Electric Department Up to $500 credit for purchase of an EV and $250 credit for charging equipment when not charging between 5-9pm • Vermont Public Power Supply Up to $1,000 for the purchase or lease of an EV, $500 for public or workspace EV charging stations • Washington Electric Co-op Up to $1,200 on a new EV
Federal	• Fixing America's Surface Transportation Act (FAST) Up to $30,000 tax credit for alternative fuel vehicle refueling property for business use, and up to $1,000 for personal use property	• Federal Purchase Incentive Up to $7,500 for a federal income tax credit with a purchase of EV		

Note:

[1] PECVs stand for plug-in hybrid electric vehicles, BEVs stand for battery electric vehicles, and FCVEs stand for fuel cell electric vehicles. EVSE stands for electric vehicle supply equipment, which is typically a charging station.

[61] Sources: [1] NEEP, Northeaster Regional Assessment of Strategic Electrification: Summary Report, January 2017, p.80. [2] U.S. Department of Energy, Alternative Fuels Data Center, Laws & Incentives, available at https://afdc.energy.gov/laws/state_summary?state=RI. [3] MOR-EV, Program Statistics, July 2019, available at https://mor-ev.org/program-statistics. [4] Plug-In-America, State Incentives, available at https://pluginamerica.org/why-go-plug-in/state-

Building/Heating

Space and water heating are also among the largest direct uses of fossil fuels in the Northeast region (See Figure A.8). Over 80 percent of occupied housing units in New England as natural gas and oil as their primary heating fuel. In comparison, electricity takes up only 13% of heating fuel in New England according to the 2017 American Community Survey (See Figure A.9).

Conversion of existing fuels for heating and other household end-use applications (e.g., water heating, cooking) to lower-emitting fuels can generate immediate GHG emission reduction benefits. In many areas with access to natural gas, the conversion of heating/water systems currently using oil or propane – significant sources in New England – to natural gas can generate emission reduction benefits. In addition, many states are encouraging conversions to high-efficiency electric systems for heating and hot water, particularly conversions from the most polluting resources (i.e., oil, propane). Air-source heat pumps (ASHPs), ground-source heat pumps (GSHPs), and electric baseboard heating are potential electrification technologies. There has been a growing number of programs and rebates that promote the growth of ASHPs and GSHPs. These two thermal technologies are usually considered as alternative energy in states' energy plans, which usually includes other technologies such as solar thermal and biomass systems.[62]

New Hampshire, Massachusetts and Vermont have specified carve-outs in their Renewable Portfolio Standard (RPS), Alternative Portfolio Standard (APS) and Renewable Energy Standard (RES) for heat pumps. In New Hampshire, utilities must purchase renewable thermal generation equal to 1.3% of their electricity sales in 2016. This number will increase to 15.3% in 2023. GSHPs, solar hot water and biomass energy are considered Thermal Renewable Energy Certificates. Maine has passed a state legislation that requires 100,000 heat pumps to be installed by 2025.[63]

All states have rebates for the installation of heat pumps. Vermont and New Hampshire have loan or leasing programs for heat pumps. See Table A.3 for a non-exhaustive list of state mandates and incentives.

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federal-incentives/. [5] Department of Energy& Environmental Protection, EV Connecticut, available at https://www.ct.gov/DEEP/cwp/view.asp?q=525224. [6] State of Rhode Island, Office of Energy Resources, Electric Vehicles, available at http://www.energy.ri.gov/transportation/ev/. [7] CT Government, Electric Vehicle Charging Stations Tax Credit, January 8, 2016, available at http://www.ct.gov/deep/lib/deep/air/electric_vehicle/evse_fact_sheet.pdf. [8] Electrify Rhode Island, Office of Energy Resources, State of Rhode Island, available at http://www.energy.ri.gov/electrifyri.php. [9] Electric Vehicle Rebate Program, Groton Utilities, available at http://grotonutilities.com/electric-vehicle-rebate-program/. [10] Matrix of VW & MassEVIP Grant Programs, Massachusetts Department of Environmental Protection, available at https://www.mass.gov/doc/matrix-of-vw-massevip-grant-programs. [11] Nissan LEAF Rebate, Central Maine Power, https://www.cmpco.com/. [12] EV Accelerator, Rebate Process, Efficiency Maine, available at https://www.efficiencymaine.com/ev/rebate-process/. [13] Charge & Save, New Hampshire Electric Co-op, available at https://www.nhec.com/take-charge-save/. [14] Electric Vehicle Supply Equipment (EVSE) Grant Program, Agency of Commerce and Community Development, State of Vermont, available at https://accd.vermont.gov/community-development/funding-incentives/electric-vehicle-supply-equipment-evse-grant-program. [15] Statewide Vehicle Incentive Programs, Agency of Transportation, State of Vermont, available at https://vtrans.vermont.gov/planning/projects-programs/vehicle-incentives. [16] Drive Electric Vermont, Purchase Incentives, available at https://www.driveelectricvt.com/why-go-electric/purchase-incentives. [17] Federal Laws and Incentives, Alternate Fuels Data Center, U.S. Department of Energy, available at https://afdc.energy.gov/laws/fed_summary.

[62] The use of efficient electric heating systems can reduce net emissions of GHG, particularly if prioritized to replace the higher-emitting heating fuels (oil, propane), and if and to the extent the installations do not require the use of supplemental heating (that is, through existing fossil-fuel back up heating systems or electric baseboard heating) when temperatures get low. In this Report we do not evaluate where or the extent to which electrification of heating and hot water may require supplemental heating sources.

[63] Green Tech Media, Maine Decides to Go Big on Heat Pumps, June 27 2019, available at https://www.greentechmedia.com/articles/read/maine-wants-to-install-100000-heat-pumps-by-2025#gs.szcnds.

Figure A.8: Direct Fossil Fuel Use by End Use and Sector in New York and New England[64]

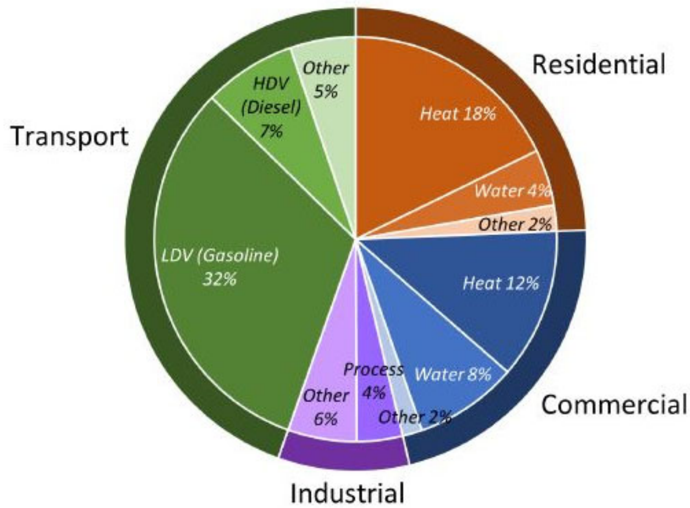
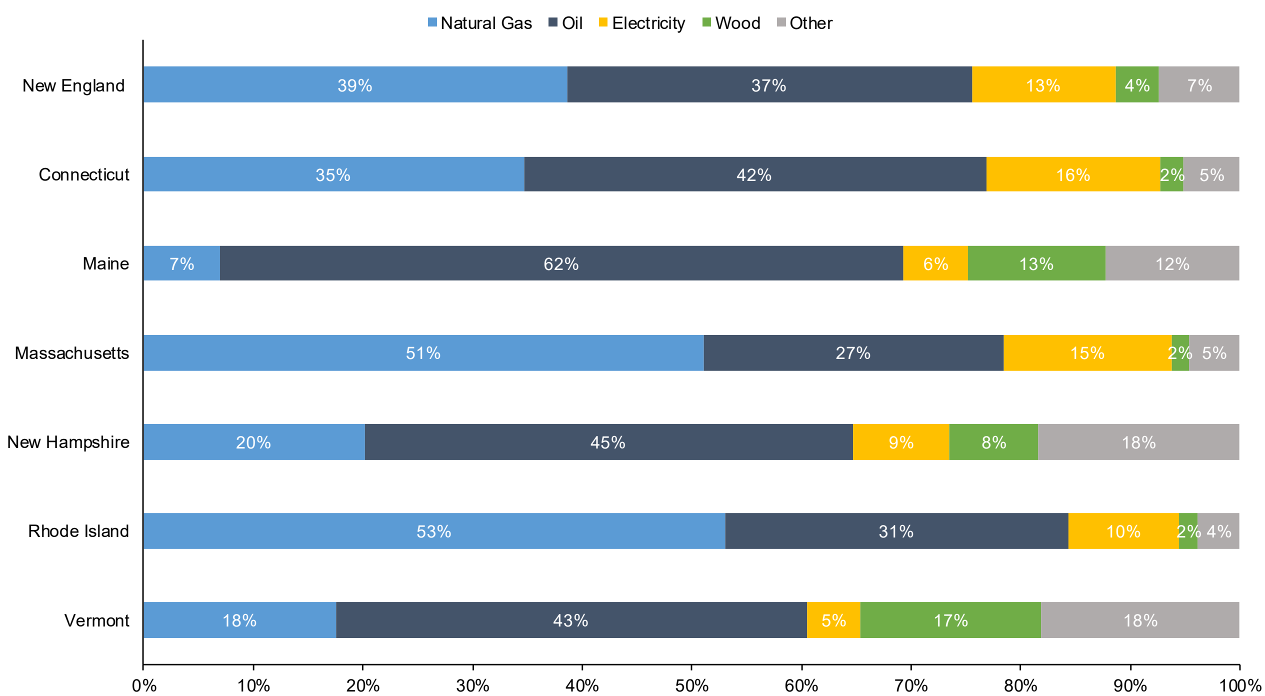


Figure A.9: House Heating Fuel in New England[65]



Notes:
[1] The "Other" category includes housing units that use bottled propane, coal or coke, solar energy, other fuel, and no fuel for heating.
[2] Estimates are based on a five-year period from 2013-2017.

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[64] Source: NEEP, Northeaster Regional Assessment of Strategic Electrification: Summary Report, January 2017, p.2, available at https://neep.org/sites/default/files/resources/Strategic%20Electrification%20Regional%20Assessment%20-%20Summary.pdf.
[65] Source: U.S. Census Bureau, House Heating Fuel for Occupied Housing Units, 2013-2017 American Community Survey 5-Year Estimates, available at https://factfinder.census.gov/faces/nav/jsf/pages/guided_search.xhtml.

Table A.3: State Incentives and Mandates for Heat Pumps and Thermal Energy[66]

	Mandates/Targets	State Rebate for Ductless Heat Pumps	Other
Connecticut		• $500/home	
Massachusetts	• Alternative Portfolio Standard 5% of MA electrical load need to come from eligible alternative technologies, including ASHPs, GSHPs, solar hot water, biomass and other select sources	• $1,000 per ton	
Maine	• LD 1766 Install 20,000 heat pumps per year Install 100,000 in total by 2025 (30,000 have been installed from 2013-2018)	• $500/$750 depending on HSPF	
New Hampshire	• Renewable Portfolio Standards(RPS) Utilities must purchase 2% of their electricity sales by 2023 from Class I Thermal Renewable Energy Certificates(T-RECs), which include GSHPs, solar hot water, and biomass energy	• $400/ton(based on cooling capacity)	•NEHC Third-Party Financing Loans Up to $15,000 of loans with the financing of a heat pump
Rhode Island		• $250/$500 depending on HSPF	•Sales tax exemption for heat pumps
Vermont	• Renewable Energy Standard 75% of total energy needs to be renewable by 2032. Utilities have adopted heat pumps to meet this requirement	• Up to $500 ($650 starting Feb. 1, 2020)	• Green Mountain Power Heat Pump Lease Program 15-year lease of cold climate ductless minisplit heat pump systems to customers. $600 rebate for paying monthly bills that range from $49-81

Notes:

[1] HSPF(Btu/Wh) stand for heating seasonal performance factor, the total space heating required during the space heating season in Btu's, divided by the total electrical energy consumed by the heat pump system in watt-hours(Wh).

[66] Sources: [1] NEEP, Northeaster Regional Assessment of Strategic Electrification, January 2017, p.37. [2] NEEP, Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report 2016 Update, January 2017, p.42. [3] Green Tech Media, Maine Decides to Go Big on Heat Pumps, June 2019, available at https://www.greentechmedia.com/articles/read/maine-wants-to-install-100000-heat-pumps-by-2025#gs.szcnds. [4] EnergizeCT, Ductless Split Heat Pump Rebates, available at https://www.energizect.com/your-home/solutions-list/ductless-split-heat-pump-rebates. [5] Efficiency Vermont, Available Rebates, available at https://www.efficiencyvermont.com/rebates/list?type=Residential. [6] State of Rhode Island -Office of Energy Resources, Heat Pumps, available at http://www.energy.ri.gov/heating/heat-pumps/. [7] New Hampshire Electric Co-op, High Efficiency Heat Pumps, available at https://www.nhec.com/home-energy-solutions/high-efficiency-heat-pumps/. [8] Electric Heating and Cooling Equipment, Mass Save, available at https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling.