New England Electrification Load Forecast

Prepared for E4TheFuture

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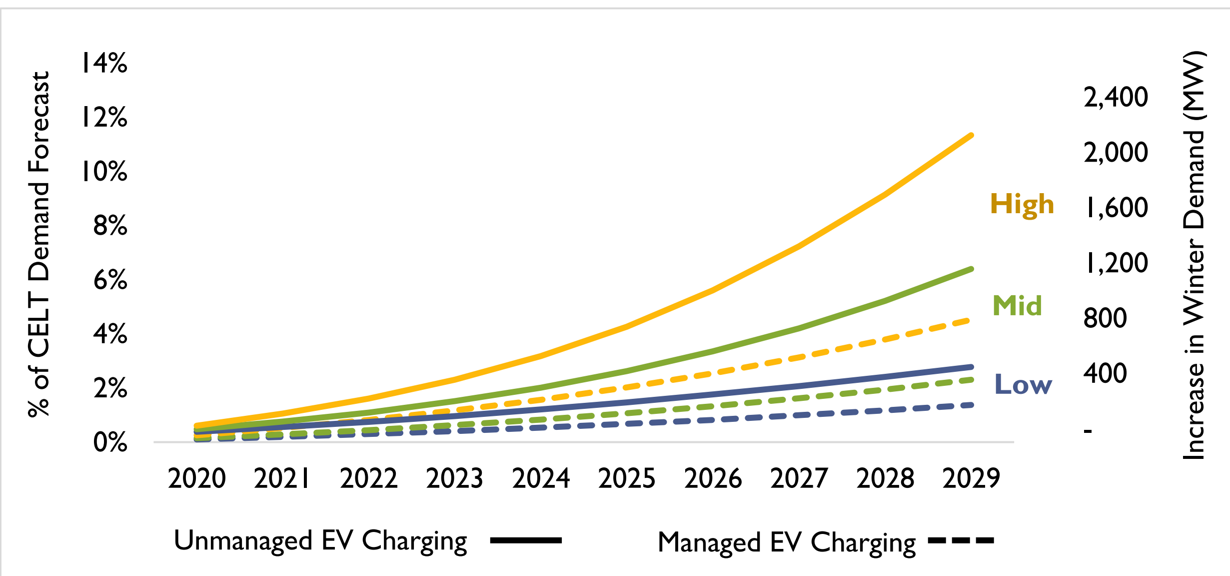
1. EXECUTIVE SUMMARY

A combination of technological advancements and policy directives in New England has led to increasing adoption of heat pumps and electric vehicles (EVs) in the region. Although they have had a slow start, these trends are likely to accelerate and the regional grid operator—ISO New England—has noticed. For the first time, ISO New England incorporated electrification load forecast projections for both air source heat pumps (heat pumps) and EVs into its 2020 Capacity, Energy, Loads, and Transmission (CELT) forecast.

This paper presents our research to independently forecast thermal and transportation electrification trends throughout the next decade. For both heat pumps and EVs, we present a range of possible adoption trajectories to highlight the dependence of these projections on state policy as well as technological change. We conclude by discussing the combined impact of our thermal and transportation load forecasts on the region's electric grid.

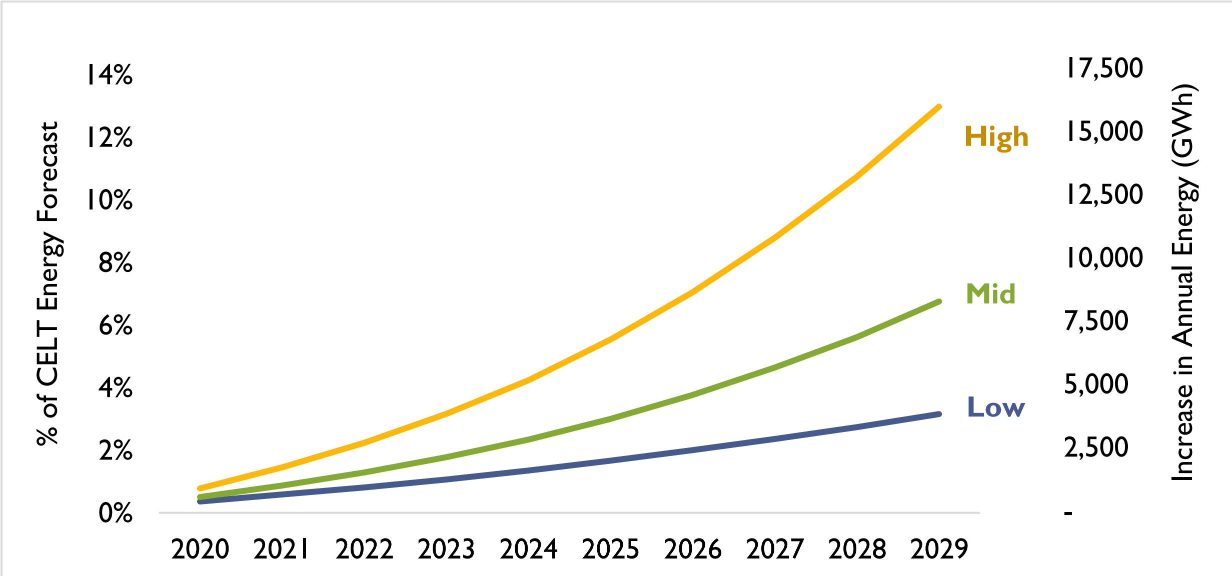
We found that the three potential adoption trajectories, High, Mid, and Low, for New England produce a wide range of results. For electric demand, results are also dependent on whether EV charging structures remain managed or unmanaged. As displayed in Figure ES-1, electrification adoption in New England could increase winter electric demand between 1 percent (260 MW) and 11 percent (2,200 MW).

Figure ES-1. Combined electrification winter demand increase by scenario and EV charged structure



The impacts of electrification on New England's annual energy consumption are similar. Our results, displayed in Figure ES-2, show that electrification from heat pumps and EVs could increase annual electricity consumptions by 2 percent (4 TWh) to 13 percent (16 TWh).

Figure ES-2. Combined electrification annual energy increase by scenario



While electrification will undoubtedly increase electric demand and energy consumption in New England, we conclude that the electric grid is well-suited to handle this transformation for the upcoming decade in the context of energy, capacity, and transmission system planning. In general, New England's electric resources are procured based on summer demand because the highest electric loads consistently occur on hot summer days. We conclude that increased winter demand from electrification will not cause the system to shift to winter-peaking in the next decade, even in our highest load scenario. Furthermore, New England states continue to expand existing energy efficiency and demand response programs designed to decrease both energy and demand usage.

After analyzing our results in the context of ISO New England's 10-year energy and capacity forecasts, we determine that electrification will not pose a threat to New England's existing regional power grid.

2. BACKGROUND

Every year New England's independent electric system operator, ISO New England, develops a Capacity, Energy, Loads, and Transmission (CELT) forecast. The CELT forecast helps inform planning and procurement decisions for New England's electric grid. 2020 is the first year in which ISO New England has included an electrification forecast within its CELT forecast. Specifically, ISO New England forecasted additional electric load from the adoption of cold climate air source heat pumps (heat pumps) and electric vehicles (EVs) and included the impacts in its 10-year energy and demand forecasts. On behalf of E4TheFuture, Synapse Energy Economics, Inc. (Synapse) developed an independent forecast of the impacts of electrification on New England's electric grid.[1] For heat pumps, this includes the number of heat pumps, the increase in winter demand, and the increase in annual electric energy consumption. For EVs, this includes the number of new EV sales and total EVs on the road each year, the total electric energy consumption of EVs, and the summer and winter peak impacts with managed and un-managed charging. For both cases, we developed Low, Mid, and High forecast scenarios to illustrate a broad range of potential heat pump and EV adoption trends.

In addition to ensuring ISO New England's forecast is reasonable for planning and procurement purposes, Synapse discusses the impact on the electric grid if states were to exceed planned electrification measures and instead hit targets consistent with policy and climate goals.

Electrification is a key strategy to reducing emissions and shifting away from fossil fuel reliance. Heat pumps and EVs are the two most prominent technologies to displace direct end use fossil fuel consumption. However, other low carbon and electrified technologies will be needed too for the states to meet their long term greenhouse gas emissions reduction goals. We focus on heat pumps and EVs because in the next decade these two technologies are positioned to have the greatest impacts on the electric grid.

3. HEAT PUMPS

3.1. Assumptions

This analysis includes load forecasts for the six New England states: Massachusetts, Connecticut, Maine, Rhode Island, New Hampshire, and Vermont.

We researched and analyzed increased energy and winter demand from air source heat pumps, but not other heating or cooling technologies. We only considered heat pumps used for space heating; water

[1] For the purposes of this analysis, we consider impacts from electrification on New England's regional electric grid to include all impacts on the region's generation and transmission infrastructure and capabilities. Our analysis does not have the locational specificity required to evaluate the impact on the distribution system.

heating impacts were not addressed. Our analysis includes heat pumps used to displace non-electric fuel as well as electric resistance heat. ISO New England's analysis excludes heat pumps that displace electric resistance heating which may lead to a deviation in the two projections. Our analysis does not include heat pumps used to replace existing heat pumps because our focus is the technology transition to heat pumps from fossil fuels and inefficient electric resistance heat. We consider the replacement of existing heat pumps with newer models akin to other energy efficiency measures, and thus we do not include that activity here. Further, given the current low penetration of heat pumps, excluding the replacement of existing heat pumps has little impact on the analysis. As you will see in the discussion and charts below, the focus of this report is increased energy and winter peak demands. We do not address summer peak load impacts from heat pumps for several reasons. Some customers who install heat pumps will retire existing air conditioning systems that are less efficient, causing a reduction in summer peak load. For some customers, heat pumps will some add air conditioning that was not installed previously, increasing load during cooling season. From a regional perspective, the six-state grid has seen a drop in peak load from the all-time high of more than 28,000 MW in 2006 to summer peaks near 25,000 MW in recent summers, primarily due to successful energy efficiency programs in New England. This provides us with many years of headroom before the regional power grid requires any concern about summer peak load.

In this analysis we assume that each customer will install their new heat pump as either a full fuel replacement or partial fuel displacement.[2] Full fuel replacement means that the customer has removed their existing system and relies exclusively on the heat pump for winter heating needs. This scenario yields the highest increases in electricity consumption and peak demand along with the elimination of any fossil fuel use for heating. For the partial fuel displacement choice, the customer primarily uses only the heat pump but keeps their existing heating system as backup for the coldest winter days.

Customers rarely report which heat pump use case they fall under, which means the distribution between the two use cases requires an estimation based upon limited survey responses. Survey data from the Massachusetts Clean Energy Center (MassCEC) Database reports that only 21 percent of respondents use the heat pump as the primary heating source, aligning with our full replacement scenario.[3,4] As the region starts to place a greater emphasis on fuel switching, we expect this percentage to increase. In Massachusetts, program administrator data for heat pump consumption is reported as either full fuel replacement or partial fuel displacement, while the evaluation studies on heat pumps in

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[2] A third scenario, which we are excluding, is the heating supplement scenario. This is when customers install heat pumps to supplement another heating source but relies on their primary heating source during most winter days. This scenario typically occurs if the customer purchased the heat pump primarily as a cooling resource or to heat a previously unheated section of their home. We are excluding this scenario because rebate programs typically have sizing requirements as a condition of participation. We assume a heat pump used exclusively for supplemental heating would not qualify for such a rebate, and that few of them will be installed.

[3] Massachusetts Clean Energy Center (MassCEC). ASHP Rebate Data 2014-2019. Provided for Synapse upon request.

[4] Synapse relied on a single source because we were unable to find other survey data for heat pump owners in New England relating to heat pump behavior.

Maine and Vermont provide blended values based on a range of use cases.[5,6,7] To create a blended value for Massachusetts, we assume 50 percent of homes will use their heat pumps for full fuel replacement and 50 percent for partial fuel displacement. We determined it is reasonable to group electric usage assumptions per unit into northern New England (Maine, New Hampshire, and Vermont) and southern New England (Connecticut, Massachusetts, and Rhode Island). The main determinant of heat pump performance is weather. The climates across the three states in each grouping are similar.

For the purposes of this analysis, we assume the majority of heat pumps installed over the next decade will be residential units, and therefore home heating demand is a sufficient approximation for electric load.

Our analysis includes both the increased electric usage from fuel switching to heat pumps and the savings associated with replacing electric resistance heaters. The heat pump evaluations studies we drew from for the northern New England states included customers with a range of existing heat systems, including electric resistance, and accordingly electric savings are embedded into the study values. For the southern New England states, we included electric savings in our demand and energy values based on the percentage of electric customers in each state.

For each state we assumed a consistent usage per unit for the three adoption scenarios described below. Only the number of installed units changes by adoption scenario.

3.2. Adoption Scenarios

We developed Low, Mid, and High adoption scenarios for each state to reflect the range of possibilities in New England. The three scenarios are as follows: The Business-as-usual (BAU) scenario (Low), the Policy scenario (Mid), and the Greenhouse Gas (GHG) Target scenario (High).

Low: BAU scenario

Every state in New England has a state-sponsored energy efficiency program. In the last several years, heat pumps and other fuel switching technologies have been incorporated into the suite of efficiency measures offered by the New England states. The BAU scenario applies the current statewide energy efficiency plans to the next 10 years. This scenario does not assume ratepayer-funded energy efficiency programs will continue to perform consistently with historical installations, but rather that the existing plans will be successfully implemented and see modest growth in the outyears. For years beyond the

[5] Mass Save. 2019-2021 Three-Year Energy Efficiency Plan. (October 31, 2018). Available at: http://ma-eeac.org/wordpress/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf.

[6] EMI Consulting. 2014. “Emera Maine Heat Pump Pilot Program.” Page 4. Available at: https://www.emeramaine.com/media/41789/emera-maine-heat-pump-pilot-final-report-nov-2014.pdf.

[7] Cadmus Group. 2017. "Evaluation of Cold Climate Heat Pumps in Vermont." Available at: https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf.

last plan year, we assume a 10 percent annual increase in adoption. See the Appendix for data sources by state.

Mid: Policy scenario

The Policy scenario accounts for state-by-state policy goals that directly relate to the installation of heat pumps.[8] The Policy scenario reflects these state goals, regardless of whether the infrastructure and funding are currently in place to achieve those goals. The Mid scenario reflects what states might consider ambitious but achievable. The source of the policy goals varies by state. See the Appendix for data sources by state.

High: GHG Target scenario

The GHG Target scenario for each state is based on state-by-state 2030 climate goals. We assume that if states will reach their GHG reduction goals in the next decade they need to reduce emissions in each sector, including home heating. For states that have climate goals tied to years other than 2030 (for instance, Rhode Island's target is 45 percent GHG reduction by 2035), we calculated an equivalent 2030 target.[9] The baseline years—the years from which the total reductions in emissions is measured—vary from 1990 to 2001. However, given the low penetration of electrification in the heating sector, we assume the bulk of the transformation must take place in the upcoming decade. Therefore, as a proxy for this illustrative scenario, we assume a new baseline year of 2019 (the year prior to the 10-year forecast). State-specific GHG reduction goals for 2030 are shown in Table 1.[10,11]

Table 1. GHG reduction targets for 2030 by state

State	GHG Reduction Target	Target Year	2030 GHG Reduction Equivalent
Connecticut	45%	2030	**45%**
Maine	80%	2030	**80%**
Massachusetts	25%	2020	**40%**
New Hampshire	20%	2025	**30%**
Rhode Island	45%	2035	**35%**
Vermont	40%	2030	**40%**

[8] Connecticut and New Hampshire do not appear to have specific policy goals for heat pumps. As such, we assume the Policy scenario is the same as the BAU scenario for these two states.

[9] For each state we assume a 10 percent annual ramp rate to hit the target.

[10] Opinion Dynamics. 2019. "Building Electrification in the Northeast: Overview of Policy, Programs, and Progress." Available at: https://cdn.ymaws.com/www.aesp.org/resource/resmgr/chapters/nechapter/ne_conference_presentations.pdf.

[11] Synapse estimated 2030 equivalent GHG reduction targets are based on the best available climate goals for each state.

To equate GHG reductions to heat pump adoption rates, we assume each state will need to switch an equivalent percentage of homes to heat pumps. The GHG Target scenario provides a simplified estimation for the number of homes that will need to switch to heat pumps for states to meet their climate goals. In every state, this scenario yields the highest projections.

3.3. Load Calculations

We calculated the increase in electric consumption from heat pumps based on two regions, northern New England and southern New England, by relying on existing studies as described below. For each region we calculated a per-unit value for winter demand and annual energy. To account for losses, we use the same gross up factors as ISO New England does in its forecasting: 6 percent for energy consumption and 8 percent for coincident peak demand.

Northern New England

We used existing evaluation studies that look at energy consumption and average winter on-peak demand in Maine and Vermont, performed by EMI Consulting and Cadmus, respectively.[12,13,14] EMI Consulting's Maine evaluation included 299 homeowners and Cadmus's Vermont study included 135 heat pump owners. Both studies include participants with varied heat pump use patterns and existing heating fuels, including some customers with existing electric resistance heating. The EMI Consulting evaluation study for Maine found that after installing a heat pump the average per-unit annual electricity consumption increased by 2,387 kWh per home and the average winter on-peak demand increased by 0.35 kW per home. The Vermont evaluation study yielded similar results, with an average annual electricity increase of 2,085 kWh per home and a winter on-peak demand increase of 0.52 kW per home. Absent extensive savings data from New Hampshire, we used an average of the Maine study and the Vermont study for the three northern New England states, yielding an annual energy consumption of 2,236 kWh and a winter on-peak demand value of 0.43 kW.[15] The studies include customers with existing electric resistance heating systems, making this value appropriate for our data set.

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[12] The ISO New England capacity market defines winter on-peak hours as between 5:00 and 7:00 PM on weekday non-holidays.

[13] Cadmus Group. 2017. "Evaluation of Cold Climate Heat Pumps in Vermont." Available at: https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf.

[14] EMI Consulting. 2014. "Emera Maine Heat Pump Pilot Program." Page 4. Available at: https://www.emeramaine.com/media/41789/emera-maine-heat-pump-pilot-final-report-nov-2014.pdf.

[15] For purposes of comparison with ISO New England forecast values, we have increased meter-level consumption values to account for line losses in the transmission and distribution systems. Line losses of 6 percent for energy and 8 percent for capacity are factored into the total load calculations, consistent with ISO New England's line loss factors.

Southern New England

The best available data to date for the southern New England states is from Massachusetts. The Massachusetts program administrators included fuel switching measures for the first time in their 2019–2021 Three-Year Plans. The plan provides the evaluated performance data for four scenarios based on two variables: whether the use case was full replacement or partial displacement and whether the existing heating system was non-electric fuel or electric fuel.

Based on a 50/50 distribution between full replacement and partial displacement scenarios, we developed a blended value for existing non-electric fuel and one for existing electric fuel. For non-electric heating fuel displacement, the average annual increase in electricity is 5,707 kWh and the average increase in winter demand is 0.481 kW. For electric resistance displacement, there is an annual *decrease* in consumption of 3,880 kWh and a *decrease* in winter demand of 1.30 kW. For each state, we calculated a weighted average of the values for fuel displacement and electric displacement based on the percentage of existing electrically heated homes in the state for energy and demand. This results in the following energy and demand values:

Table 2. Average per-unit energy and demand increases for heat pump installations in southern New England

State	Energy Consumption (kWh)	On-Peak Demand (kW)
Massachusetts	3,930	0.18
Rhode Island	4,424	0.27
Connecticut	3,922	0.18

Our per-unit savings results differ between northern New England and southern New England. The annual energy consumption values for northern New England are roughly half the values for southern New England. The primary reason is the distribution of participant behavior. The Cadmus and EMI Consulting studies both indicate that very few customers used the heat pump as their sole source of heat.[16,17] For southern New England we assume a 50/50 split between full replacement and partial displacement to reflect a likelihood of stricter program requirements in the future. This is an area for further research.

Meanwhile, the increase in winter on-peak demand is greater in northern New England than southern New England. Given the difference in climate between northern and southern New England, this may be a reasonable difference. This is also an area for further research when more heat pumps units have been installed and more data are available.

[16] Cadmus. 2017. Page 2.

[17] EMI Consulting. 2014. Page 15.

3.4. Results

Summary of results

Table 3 shows Synapse's projections for New England-wide heat pump installations with the corresponding grid impacts based on the BAU, Policy, and GHG Target scenarios from 2020 through 2029.

The BAU scenario, which is based on existing state-by-state efficiency plans, estimates more than 700,000 heat pumps will be installed in the next decade. The BAU scenario presents a likely outcome for New England if programs do not see additional policy intervention. Generally, we assume all heat pumps in this scenario will be funded consistent with the existing program structures.

The Policy scenario, which accounts for state-by-state policy goals relating to heat pumps, estimates nearly 1 million heat pump installations by 2029. The Policy scenario assumes every state can fund and administer enough heat pumps to meet their goals. For several states the Policy scenario is only slightly higher than the BAU scenario: for example, Vermont's Policy scenario is just 10 percent higher than its BAU scenario. In other states, policy goals are misaligned with statewide efficiency plans: for example, in Rhode Island, the policy scenario is 14 times greater than the BAU scenario. For each state, the policy scenario is possible if the New England states are serious about meeting their heat pump goals.

The GHG Target scenario, which approximates state-by-state GHG reductions goals through an equivalent percentage of homes switching to heat pumps, shows that more than 2 million heat pumps would need to be installed throughout the next decade to meet climate commitments.

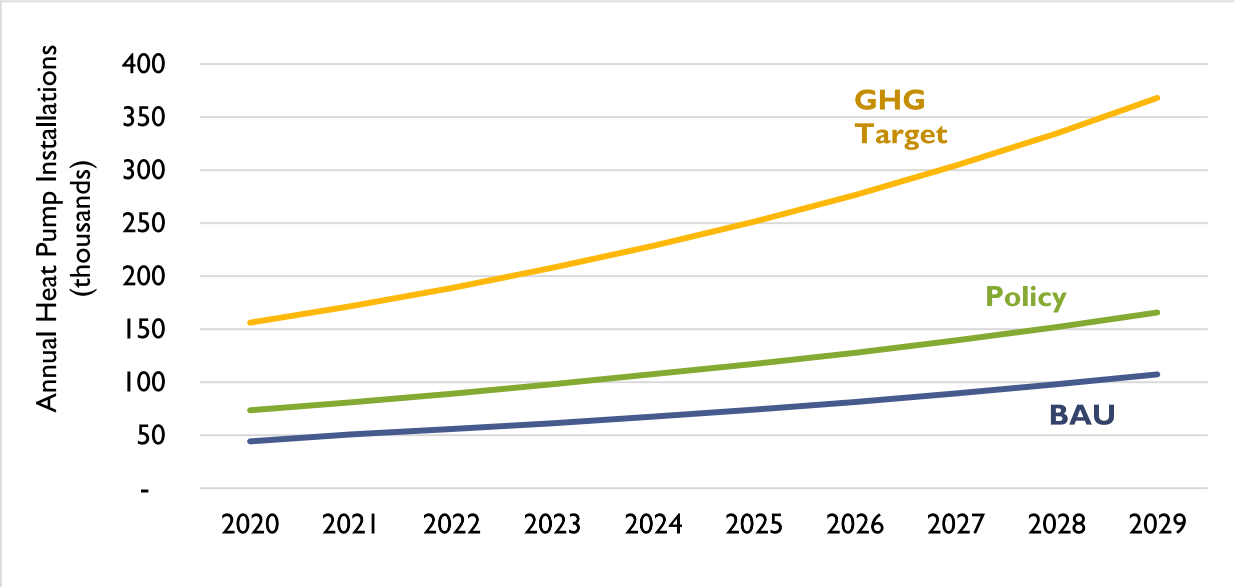
Table 3. Air source heat pump forecast (2020–2029)

Metric	BAU scenario	Policy scenario	GHG Target scenario
Number of Heat Pumps	730,554	1,152,351	2,489,615
Increased Annual Energy (GWh)	2,503	4,208	9,195
Increased Winter Demand (MW)	226	334	689

Adoption projections

Figure 1 shows the annual heat pump installations in New England for the three adoptions scenarios. For all three scenarios we assumed a 10 percent annual ramp where incremental data was unavailable. As seen below, this translates to annual targets in 2029 that are more than twice those in 2020. For the region to stay on track with climate goals, states would need to install three times more heat pumps than currently planned.

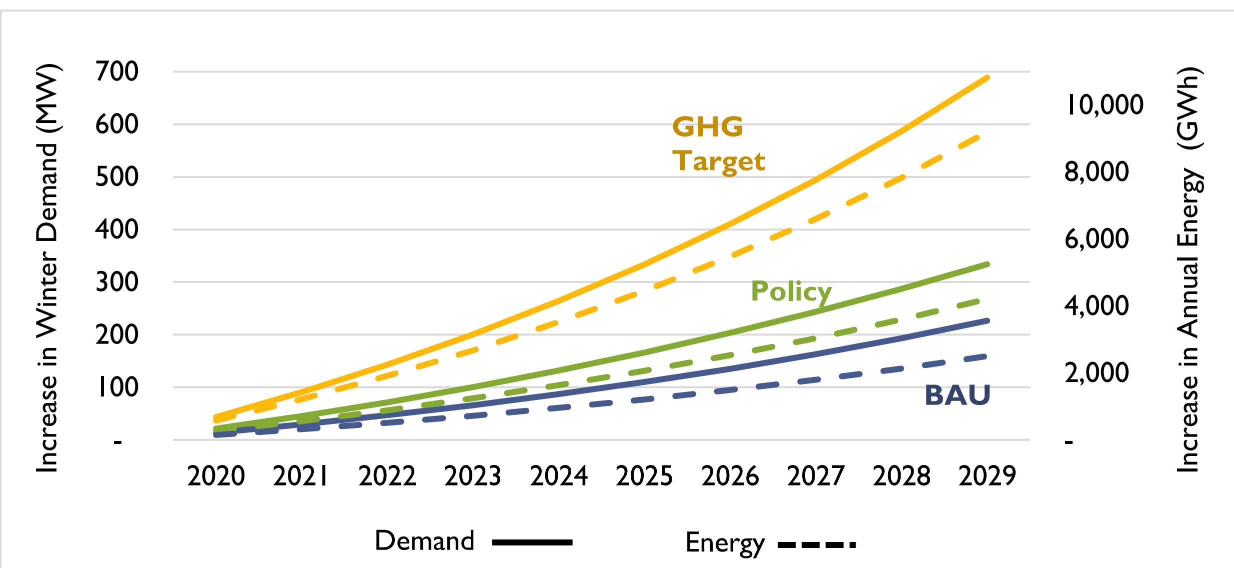
Figure 1. Annual heat pump installations in New England



Energy and demand impacts

Building off the annual installations above and publicly available evaluation studies, Figure 2 shows the cumulative increase in winter demand and annual energy resulting from heat pump adoption in New England. By 2029, winter demand will increase 200 MW in the BAU scenario, 250 MW in the Policy scenario, and 600 MW in the GHG Target scenario. On the energy side, the results show a 3 terawatt-hour (TWh) increase in the BAU scenario, a 4 TWh increase in the Policy scenario, and a 10 TWh increase in the GHG Target scenario. The two datasets, demand and energy, follow the same trend because we calculate the impacts on a per-unit basis.

Figure 2. Cumulative increase in demand and energy from heat pumps in New England



To contextualize our results, ISO New England's 2020 CELT Forecast projects that by 2029 the region will have winter peak demand of 19 GW and annual electric energy usage of 125 TWh (ISO New England 2020).[18] We calculated the percent increase in the demand and energy forecasts as a result of the three heat pump adoption scenarios.[19] Figure 3 shows the demand heat pumps would add to winter peak hours. By the end of the forecast period, the BAU scenario reaches a 1.2 percent increase in forecasted demand, the Policy scenario reaches 1.75 percent, and the GHG Target scenario reaches 3.6 percent. We find that the impacts in this decade to be manageable with current system planning assumptions. Through 2030, only the GHG Scenario would increase winter peak demand to levels that require attention by system planners and state regulators.

Figure 3. Demand increase from heat pumps as a percent of CELT demand forecast

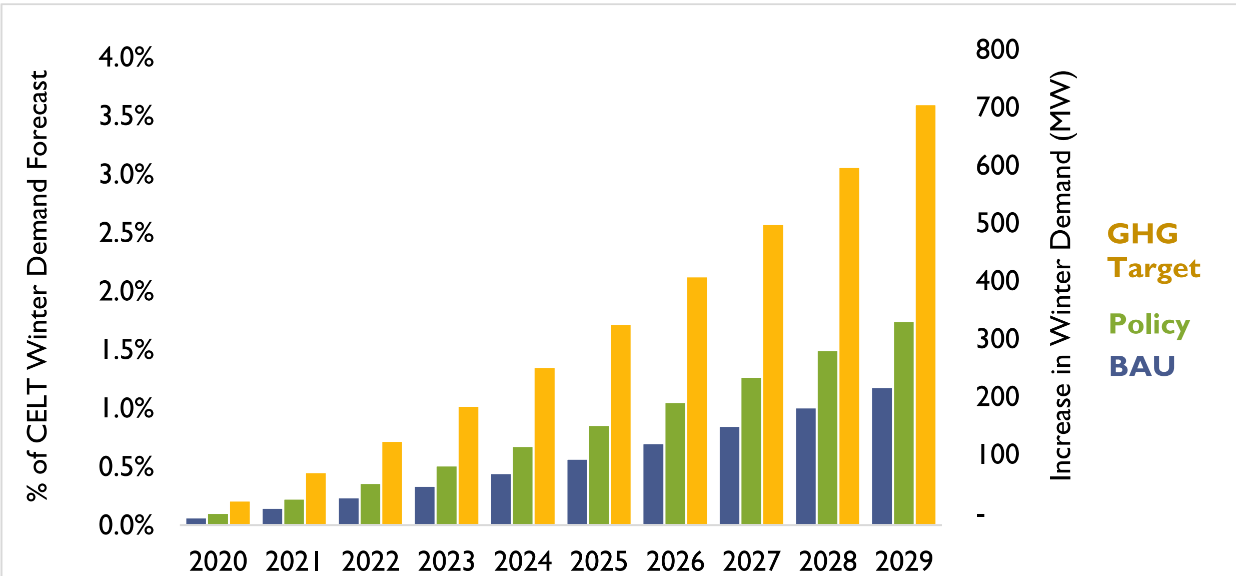
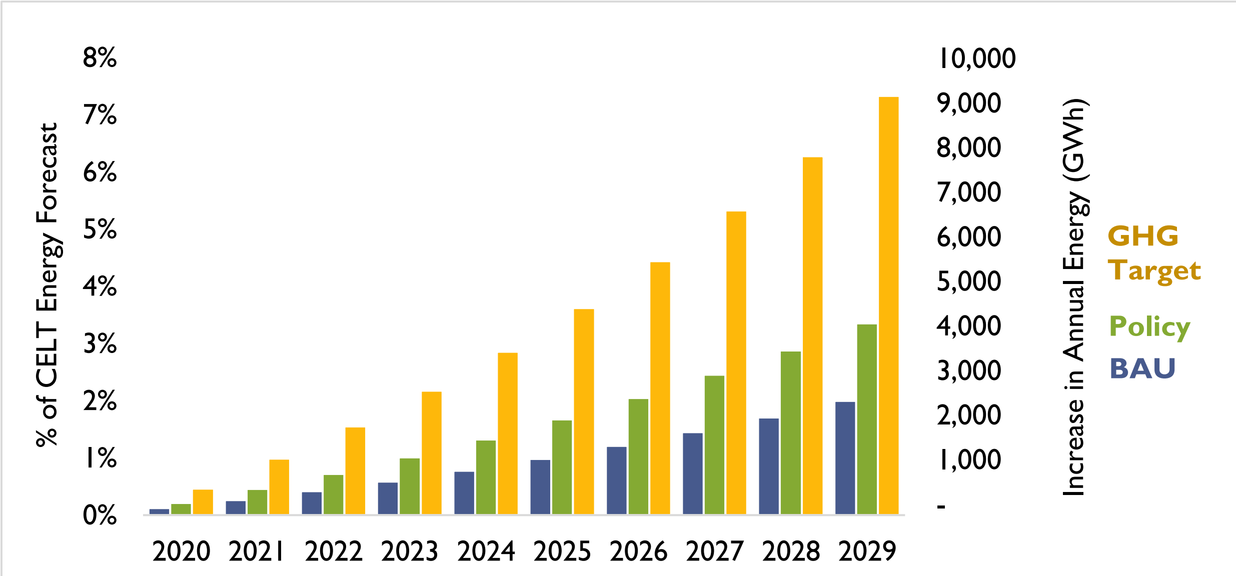


Figure 4 shows the annual energy consumption (as a result of heating) heat pumps would add to the annual energy forecast, according to the 2020 CELT report. The energy impacts are greater than the demand impacts with respect to New England's electric grid. By the end of the forecast, the BAU scenario increases annual energy consumption by 2.0 percent, the Policy scenario by 3.4 percent, and the GHG Target scenario by 7.3 percent.

[18] For demand, we use the CELT 50/50 winter peak demand forecast because ISO New England used this forecast distribution in its electrification projections. We used the net forecast (which includes energy efficiency and behind-the-meter PV) less ISO New England's electrification forecast to avoid understating the energy and demand impacts. For reference, the 50/50 summer peak load forecast is a key input to capacity market purchases, but the ISO uses its 90/10 forecast distribution for transmission planning.

[19] ISO New England. 2020. *2020 CELT Report.* (ISO NE CELT 2020) Available at: https://www.iso-ne.com/system-planning/system-plans-studies/celt/.

Figure 4. Energy increase from heat pumps as a percent of CELT annual energy forecast



Evaluation data considerations and industry trends

The New England evaluation studies on heat pump performance that we used to develop the above results relied on data for units already installed in homes. Therefore, they are subject to older technology performance, installation techniques, and variable customer behavior. In particular, cold-climate heat pumps have only recently gained traction as a whole-home heating solution that can operate without backup heating under New England's cold winter season. More recently, larger heat pumps are being installed. We predict this trend will continue throughout the decade, and this is not well-reflected in studies that examined historical installations. These changes have yet to be accounted for in published, publicly available studies for heat pump performance in New England.

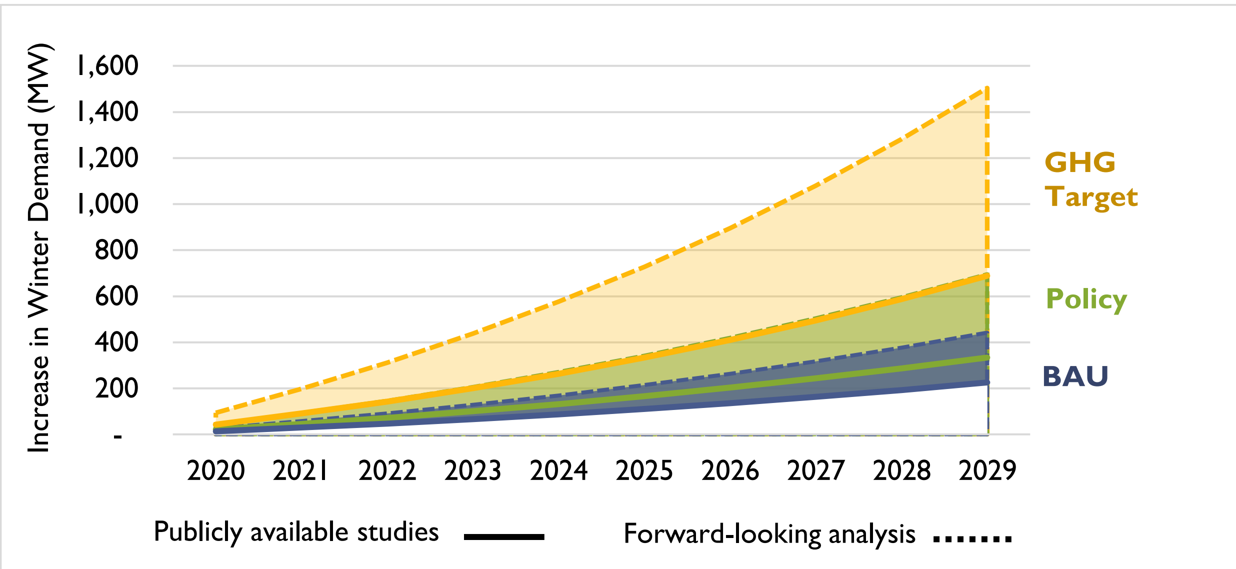
Cadmus, an industry leader in heat pump evaluation, provided Synapse with updated heat pump performance data based on technology Cadmus predicts will be installed throughout the next decade. However, the results are not yet publicly available. Although this paper primarily discusses the results based from publicly available sources, we explore a range of demand impacts to demonstrate the uncertainty of trends in the region. In Section 6 of this report, we also use the heat pump performance data provided by Cadmus to calculate the impact electrification could have on the electric grid during an extreme cold weather event.

Table 4 displays the results for increased winter demand by 2029 from the existing studies and with insight from Cadmus for a forward-looking analysis. Figure 5 shows the range of demand impacts each year between the two sources. The forward-looking analysis implies demand could be twice as high as indicated from the values available in existing New England studies.

Table 4. Demand results for forward-looking analysis by scenario

Metric	BAU scenario	Policy scenario	GHG Target scenario
Number of Heat Pumps	730,554	1,152,351	2,489,615
Increased Winter Demand (MW) from existing studies	226	334	689
Increased Winter Demand (MW) from forward-looking analysis	441	696	1,504

Figure 5. Range of winter demand impacts between forward-looking analysis and publicly available studies



There is uncertainty about heat pump sizing, performance, and customer behavior in the next decade. Existing evaluation studies have not yet caught up to the industry trends. As heat pumps gain in popularity, there will be more available data to inform forecasts. This is an area for more research.

3.5. ISO New England Heat Pump Forecast Comparison

On April 30, 2020, ISO New England released its first ever forecast of heat pump adoption.[20] ISO New England's forecast varies from Synapse's forecast for three primary reasons. First, our forecast included heat pumps intended for switching away from electric resistance heat in addition to fossil fuels. ISO New

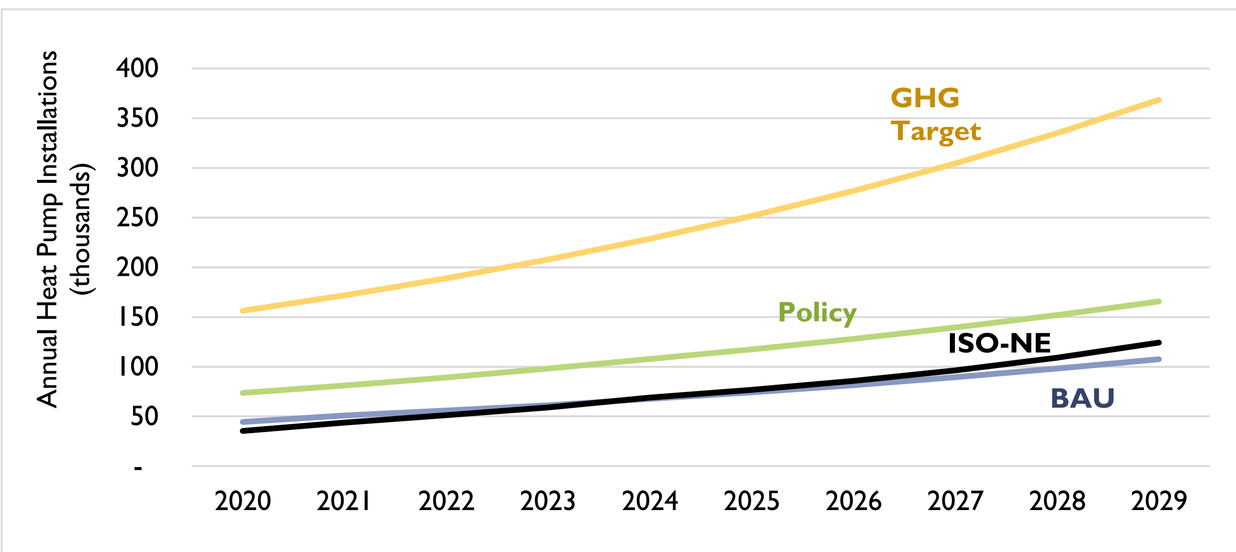
[20] ISO New England. 2020. "Final 2020 Heating Electrification Forecast." *Load Forecast Committee.* (ISO NE HP Forecast 2020) Available at: https://www.iso-ne.com/static-assets/documents/2020/04/final_2020_heat_elec_forecast.pdf.

England excluded these units. This impacts both the quantity projections and the per-unit net consumption calculations. Second, ISO New England analyzed a single scenario based on energy efficiency program administrator values and guidance whereas we developed three scenarios based on varying conditions.[21] In theory, ISO New England's scenario should line up most closely with our BAU scenario. Finally, ISO New England based its consumption data on 18 residential AMI profiles in northeastern Massachusetts. ISO New England recognizes this is a small sample size that is not necessarily reflective of the entire region.[22] Our approach is based on residential evaluation studies conducted for Maine, Vermont, and Massachusetts.

Adoption projections

ISO New England forecasts that a total of 750,000 heat pumps (excluding those replacing electric resistance systems) will be installed in the next 10 years.[23] Figure 6 breaks down ISO New England's projections annually and superimposes it onto Figure 1 from this report (which shows our three adoption scenarios by annual installations). ISO New England's annual installation forecast aligns very closely with our BAU scenario. Given that both Synapse and ISO New England used energy efficiency program administrator data to develop these calculations, the similarity in results are logical.

Figure 6. ISO New England's projections for annual heat pump installations in New England



[21] ISO NE HP Forecast 2020. Page 7.

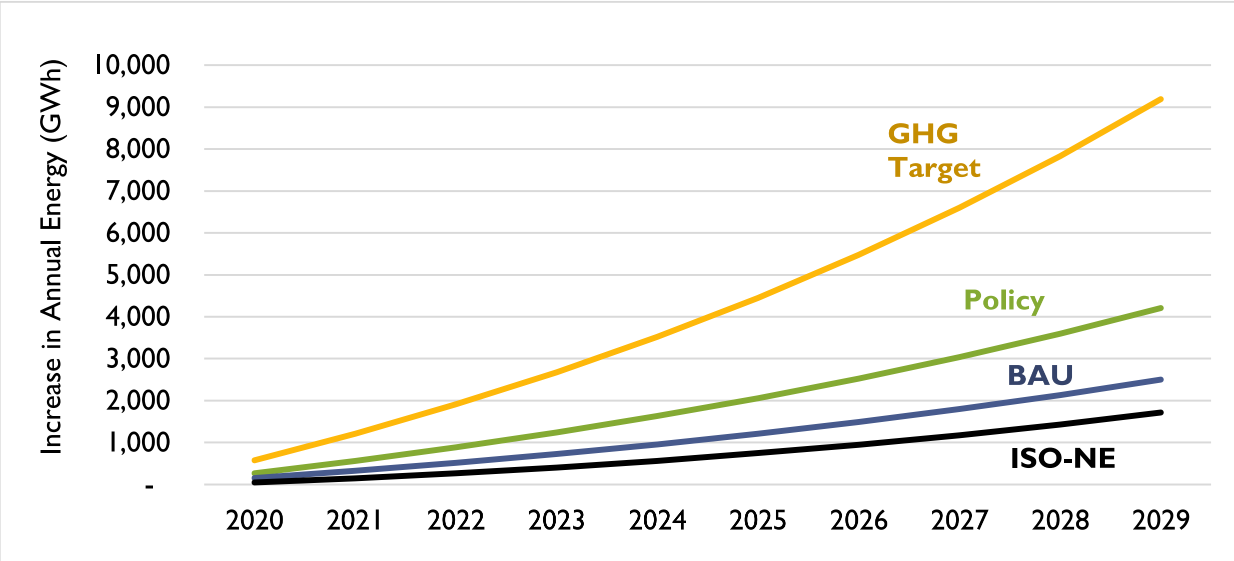
[22] ISO NE HP Forecast 2020. Page 11.

[23] ISO NE HP Forecast 2020. Page 9.

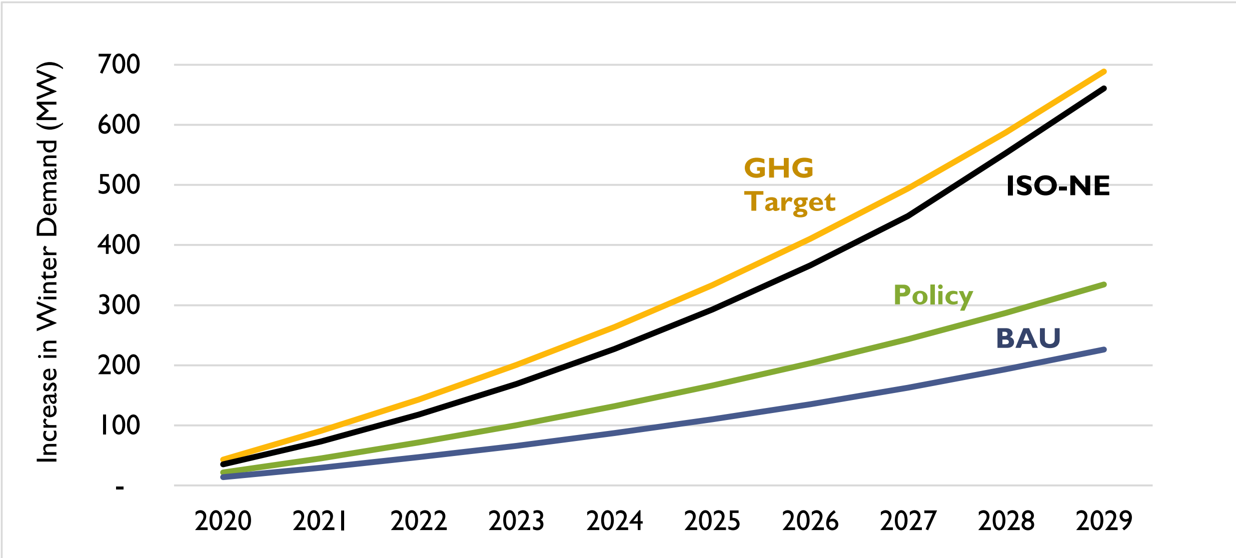
Energy and demand impacts

Figure 7 shows ISO New England's projections for increased annual energy usage from heat pumps in New England compared to Synapse's projections discussed in Section 3.4 of this report. ISO New England estimates that the annual energy impacts from heat pumps will be approximately two-thirds what Synapse projects for its BAU scenario.

Figure 7. Comparison of heat pump annual energy projections from Synapse and ISO New England



Meanwhile, Figure 8 shows that ISO New England's estimates for demand impacts from heat pumps are approximately three times greater than what we have identified from publicly available studies. Demand impacts are more variable than annual impacts. For example, demand impacts are more sensitive to customer behavior. More generally, as concluded both by ISO New England and this report, energy and demand consumption in New England requires more research. As more heat pumps are installed regionally, the evaluation data will improve.



3.6. Heat Pump Conclusions

Our projections indicate that increased demand from heat pumps, even with aggressive progress toward climate goals, may not significantly disrupt New England's electric grid. The 2020 CELT Report forecasts that by the winter of 2029–30 New England's winter peak will total 19,126 MW (accounting for energy efficiency and excluding electrification).[24] Figure 3 of our report shows that by 2029 heat pumps will increase winter peak by 1 to 3.5 percent, ranging by adoption scenario. The annual energy impacts are slightly higher.[25] Figure 4 of our report shows that by 2029 we project energy consumption in New England to increase by 2 to 7.5 percent, ranging by scenario.

New England is not currently on track to meet its climate goals through heat pump adoption. Accordingly, our GHG Target scenario will remain illustrative unless policymakers implement more aggressive strategies for adoption. The region is much more likely to see the impacts projected in the BAU and Policy scenarios.

ISO New England and Synapse project heat pump adoption rates that are well-aligned; however, our per-unit energy and demand projections vary. ISO New England and Synapse used different datasets, each with unique advantages and disadvantages. ISO New England's consumption data is based on results for newly installed heat pumps, yet the sample size is small and limited to a single state. Meanwhile, Synapse's consumption data is based on studies that represent a much larger quantity of homes from around New England, yet the data may be more representative of older industry trends. Still, ISO New England estimates grid impacts that are within or below the range of our three scenarios.

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[24] ISO NE CELT 2020.

[25] ISO NE CELT 2020.

4. Electric Vehicles

4.1. Assumptions

The individual New England states have generally not incorporated EVs into energy efficiency programs in the same way that some do for heat pumps. While some New England states do offer incentives for purchasing EVs, these incentives are intended to increase market adoption of EVs rather than ensure a specific number of sales. Thus, EV adoption is expected to be driven more by market factors like EV price, range, and availability. The New England light-duty vehicle market is not particularly segmented by state (even though incentives and model availability do vary), so our EV analysis focuses on New England as a region, rather than using state-by-state assumptions.

Energy consumption of EVs will depend on the types of EVs that are purchased and how they are driven, among other factors. This analysis incorporates electricity load associated with light-duty cars and trucks.

The analysis incorporates both all-electric battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). PHEVs have internal combustion engines and can be operated with gasoline. They also have shorter all-electric ranges and therefore do not drive all miles powered by electricity. We assume that 66 percent of PHEV miles traveled are powered by electricity, and the other 34 percent are powered by gasoline. We based this assumption on findings about PHEV driving habits from a 2017 journal article and the average electric range of PHEVs currently available on the market.[26] For BEVs, we assume that annual miles traveled are the same as they are for gasoline-powered vehicles because increasing vehicle range and charging speed will allow for increasingly long trips. Over time, the fraction of EVs that are BEVs is expected to increase, as declining battery costs allow for less expensive and longer-range BEVs. Based on the results of the Transportation and Climate Initiative's (TCI) modeling (described below) that we use for our Mid case, we assume that by 2030, 94 percent of new EV purchases will be BEVs and just 6 percent will be PHEVs.[27,28] For comparison, in 2018, 62 percent of new EVs sold nationally were BEVs.

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[26] Plötz P, Funke SA, Jochem P, Wietschel M. November 28, 2017. "CO2 Mitigation Potential of Plug-in Hybrid Electric Vehicles larger than expected." *Sci Rep*. 2017;7(1):16493. doi:10.1038/s41598-017-16684-9.

[27] Transportation and Climate Initiative. August 8, 2019. *Reference Case Results Webinar*. Available at: https://www.transportationandclimate.org/sites/default/files/20190808%20-%20TCI%20Webinar%20-%20Reference%20Case%20Results.pdf.

[28] TCI is a regional collaboration of 12 states and the District of Columbia to improve clean transportation. Participating states include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. States will choose individually whether to adopt the final proposed policy framework.

EV-REDI, a model developed by Synapse to forecast multiple impacts of transportation electrification, utilizes many data sources. [29] Some important inputs include the efficiency of EVs and the number of miles that vehicles travel each year. EV-REDI uses efficiency data from the National Renewable Energy Laboratory's *Electrification Futures Study*. Data for miles traveled per vehicle comes from the Federal Highway Administration and is scaled based on the total vehicle miles traveled in each state. Additional information about the sources used in EV-REDI can be found in the Appendix.

4.2. Adoption Scenarios

Our analysis considers three EV adoption scenarios to demonstrate the range of possible futures based on Low, Mid, and High adoption rates. For each scenario, we draw an EV adoption curve between historical 2018 sales and projected 2029 sales using EV-REDI. We utilize EV forecasts from several national and regional forecasts from government and industry sources.

Low: EIA Forecast

One of the lowest forecasts for EV adoption is the U.S. Energy Information Administration's (EIA) *2019 Annual Energy Outlook*.[30] After our analysis was completed, EIA released the 2020 *Annual Energy Outlook*, which continues to forecast a similarly low level of EV adoption.[31] The 2019 projection was used to produce the ISO New England electrification forecast referred to in this report. EIA uses battery costs that are higher than what recent studies, such as from Bloomberg New Energy Finance's (BNEF) *2019 Battery Price Survey*, have found.[32] This increases the cost of EVs and decreases adoption in the model. For these reasons, we use the EIA forecast as a low EV adoption scenario to model a future in which battery prices remain higher than expected or other factors lead to continued low adoption.

Mid: TCI Reference Case Forecast

For the Mid case, we selected the TCI Reference Case forecast, which was developed using EIA's National Energy Modeling System (NEMS).[33] NEMS is the same model that EIA uses for its own

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[29] Synapse's EV-REDI (Electric Vehicle Regional Emissions and Demand Impacts) tool models the impacts of electric vehicle sales on greenhouse gas emissions and electricity consumption. More information is available at https://www.synapse-energy.com/tools/electric-vehicle-regional-emissions-and-demand-impacts-tool-ev-redi.

[30] U.S. Energy Information Administration. January 24, 2019. *Annual Energy Outlook 2019*. Available at: https://www.eia.gov/outlooks/archive/aeo19/.

[31] U.S. Energy Information Administration. January 29, 2020. *Annual Energy Outlook 2020*. Available at: https://www.eia.gov/outlooks/aeo/.

[32] Bloomberg New Energy Finance. December 3, 2019. "Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/kWh In 2019." Available at: https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/.

[33] Transportation and Climate Initiative. August 8, 2019. *Reference Case Results Webinar*. Available at: https://www.transportationandclimate.org/sites/default/files/20190808%20-%20TCI%20Webinar%20-%20Reference%20Case%20Results.pdf.

projection. Through a stakeholder process overseen by the TCI states, some of the input assumptions (most notably battery prices) were adjusted to create a more reasonable reference case scenario. The TCI forecast is also in line with BNEF's EV sales projection in its *2019 EV Outlook*.[34] BNEF annually surveys the EV industry and produces an estimate of the most recent cost of lithium-ion batteries for EVs, which is used to inform BNEF's EV sales projection. BNEF also releases an *Electric Vehicle Outlook* annually, so the BNEF sales projection is based on the most recently available data.

High: Greenhouse Gas Target scenario

For a High case, we considered what might happen if states implemented aggressive carbon emissions reduction policies in the transportation sector. In a recent report titled *Transforming Transportation in New York*, Synapse found that motor vehicle emissions would need to be reduced by roughly 55 percent by 2035 for states to be on track to meet long-term climate goals.[35] To meet this target, just over half of new vehicles must be EVs in 2029. Figure 8 shows annual new EV sales between 2020 and 2029 in the three adoption scenarios. In 2018, 784,415 total new light-duty vehicles were sold in New England in 2018, according to the Alliance of Automobile Manufacturers.[36]

4.3. Load Calculations

Total electricity consumption due to EV charging is calculated using Synapse's EV-REDI tool. EV-REDI calculates the number of EVs on the road. It then considers the number of miles that vehicles are driven over their useful lives and the efficiencies of vehicles produced in each year to determine how much energy EVs will consume annually. Finally, transmission losses are added to the meter-level EV energy consumption to calculate the total amount of generation needed to serve EV load. To account for losses, we use the same gross up factors as ISO New England does in its forecasting: 6 percent for energy consumption and 8 percent for coincident peak demand.

Coincident peak demand is calculated based on data ISO New England acquired that includes average charging profiles for EVs in New England.[37] To evaluate peak demand impacts, we use the January and July weekday charging profiles for the winter and summer peak seasons. From these charging profiles we determine the typical charging load during each season's peak hours per vehicle. Peak hours for calculation of coincident demand impacts were identified as 5–7pm in the winter and 4–6pm in the summer based on ISO New England peak load data from recent years. These peak periods may change

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[34] Bloomberg New Energy Finance. 2019. *Electric Vehicle Outlook 2019*. Available at: https://about.bnef.com/electric-vehicle-outlook/.

[35] Knight, P. and J. Frost. September 2019. *Transforming Transportation in New York*. Prepared for the Sierra Club. Available at: https://www.synapse-energy.com/sites/default/files/Transforming-Transportation-in-NewYork-19-017.pdf.

[36] Alliance of Automobile Manufacturers. "Every State is an Auto State." Accessed January 17, 2020. Available at: https://autoalliance.org/in-your-state/.

[37] ISO New England. November 18, 2019. *Update on the 2020 Transportation Electrification Forecast*. See slide 11. Available at: https://www.iso-ne.com/static-assets/documents/2019/11/p2_transp_elect_fx_update.pdf.

over time as the adoption of heat pumps and behind-the-meter solar combined with storage increases. To evaluate the coincident peak demand impacts associated with EV charging, we include two cases that look at the demand impacts of unmanaged and managed charging.

Unmanaged Charging

In the Unmanaged Charging case, charging behavior remains the same as it is today. This case is representative of a business-as-usual future in which there are only limited managed charging programs, like those in place today. It does not assume that all EVs charge at the same time because we do not expect the fraction of on-peak charging to increase in the future. To calculate the peak demand impacts of unmanaged charging, we use load profiles that ISO New England developed for its own forecast based on New England charging data acquired from ChargePoint. The data demonstrates the charging behavior of a sample of vehicles in New England today. Average charging behavior may evolve over time due to technological change, different demographic profiles of later EV adopters, and other factors. However, we think this dataset represents the best estimate available of what charging behavior is like today and will continue to be like without further intervention.

Managed Charging

Managed charging refers to any policy, program, rate design, or incentive that affects the hours during which EV drivers choose to charge their vehicles. For example, time-of-use electric rates, rebates for reducing on-peak charging, or direct load control can be used to manage EV load. In this case, on-peak charging is assumed to be substantially reduced through aggressive policy mechanisms that shift most on-peak charging to other times. These mechanisms can be passive or active. Data availability is a challenge for managed charging load profiles and is an area in which further research would be valuable. Many utilities that have implemented managed charging programs have not made the resulting charging load profiles public. In other places, such as California, the load profiles have been published but include both EV charging and other household loads, making it difficult to accurately determine the EV charging profile. Due to the lack of empirical data, we utilize an illustrative managed charging profile from the California Electric Transportation Coalition's (CalETC) California Electrification Transportation Assessment.[38] In the Managed Charging case, the unmanaged peak demand contribution from EV charging is scaled down to match the fraction of charging that occurs during peak hours in the CalETC managed charging profile.

[38] Energy and Environmental Economics. "California Electrification Transportation Assessment Phase 2: Grid Impacts." October 23, 2014. Available at: https://caletc.com/wp-content/uploads/2016/08/CalETC_TEA_Phase_2_Final_10-23-14.pdf.

4.4. Results

Summary of results

Table 5 shows the total EV stock and charging demand at the end of the forecast period in 2029 for the Low, Mid, and High scenarios. The results indicate there will be between 300,000 and 1.4 million EVs on the road by 2029. This corresponds to an increase in annual energy consumption ranging from 1,461 GWh to 7,092 GWh. Demand impacts differ by season, scenario, and the inclusion of managed charging. In both seasons and all three scenarios, managed charging results in much smaller demand impacts than unmanaged charging. In the winter, demand impacts could be as small as 36 MW in a low-EV future with managed charging and as large as 1,480 MW in a high-EV future with unmanaged charging. In the summer, the full range of possible peak demand impacts is between 30 and 901 MW.

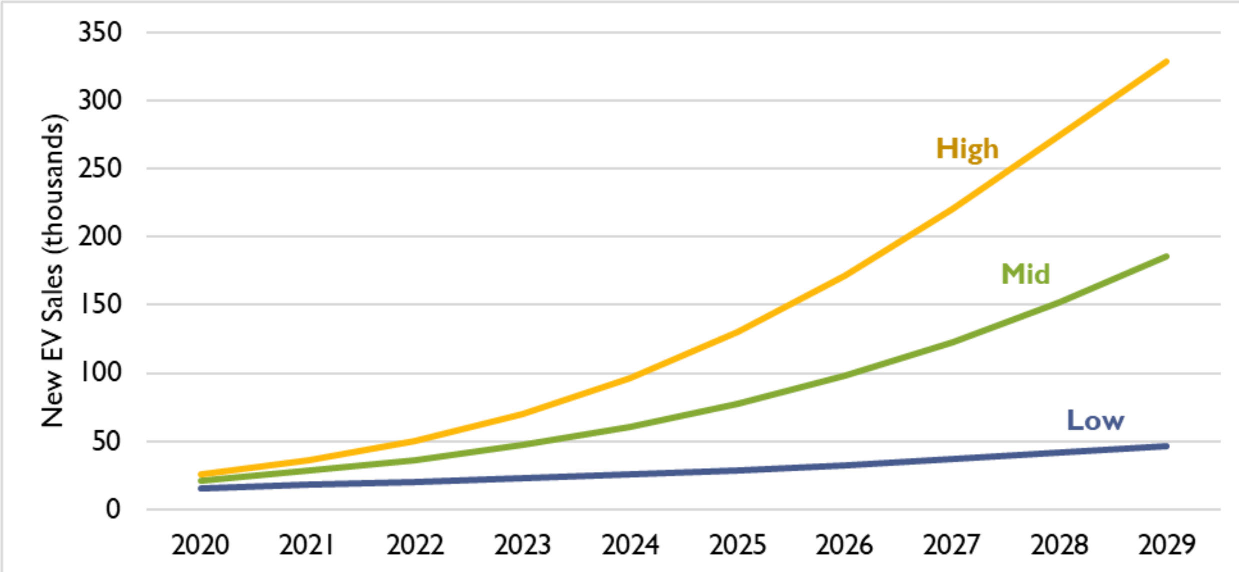
Table 5. New England EV forecast results for 2029

Metric	Low	Mid	High
EV Stock (thousands)	318	841	1,396
Energy Consumption (GWh)	1,461	4,268	7,092
Winter Demand Impact (MW)			
Unmanaged Charging	305	891	1,480
Managed Charging	36	107	177
Summer Demand Impact (MW)			
Unmanaged Charging	186	542	901
Managed Charging	30	86	144

Adoption projections

Figure 9 shows how the number of new EV sales in New England varies significantly between the adoption scenarios, which leads to a similar divergence in the total numbers of EVs on the road in 2029. Since EV adoption is forecasted to grow over the study period, the last few years of EV sales lead to rapid growth in EV stock in the Mid and High scenarios.

Figure 9. New England EV adoption scenarios



Energy and demand impacts

Figure 10 shows how electricity consumption also begins to grow quickly in the late 2020s. Notably, even in the Mid and High scenarios, load growth continues to accelerate in the final year of the forecast. This suggests that EV load is likely to continue growing rapidly at least into the early 2030s. While the 2020s are likely to be the first decade with substantial EV adoption, the slow turnover of the vehicle fleet means that most of the load growth will not appear until the 2030s.

Figure 10. Total New England EV electricity consumption

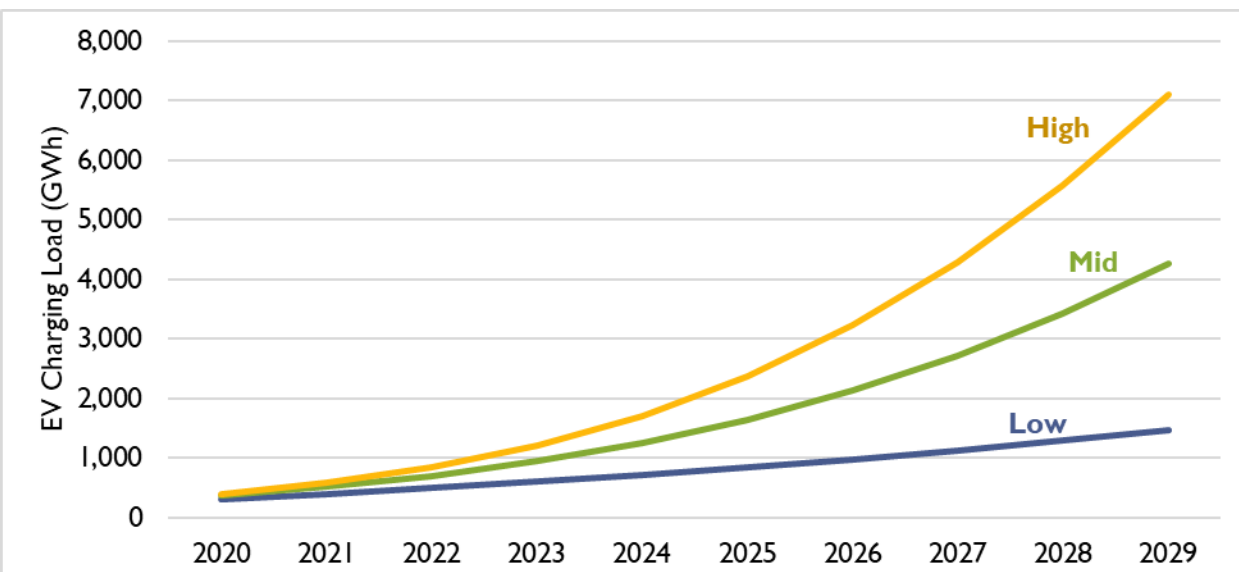


Figure 11 and Figure 12 show the corresponding winter and summer peak demand impact due to EVs, respectively. There is a substantial difference between the Unmanaged and Managed Charging cases for each season. By 2029, the EV contribution to winter peak is nearly 900 MW in the Mid case and nearly 1,500 MW in the High case. On the other hand, when charging is successfully managed, peak impacts in 2029 almost entirely disappear, falling to less than 180 MW even in the High scenario. In the summer of 2029, EV charging peak impacts fall from between 186 MW and 901 MW in the Unmanaged Charging case to between 30 MW and 144 MW in the Managed Charging case. For ease of comparison we have plotted the Unmanaged Peak Demand Impact on the primary vertical axis (left side), and the Managed Peak Demand Impact of charging on the secondary vertical axis (right side).

Figure 11. Total New England EV winter peak demand impact with unmanaged and managed charging

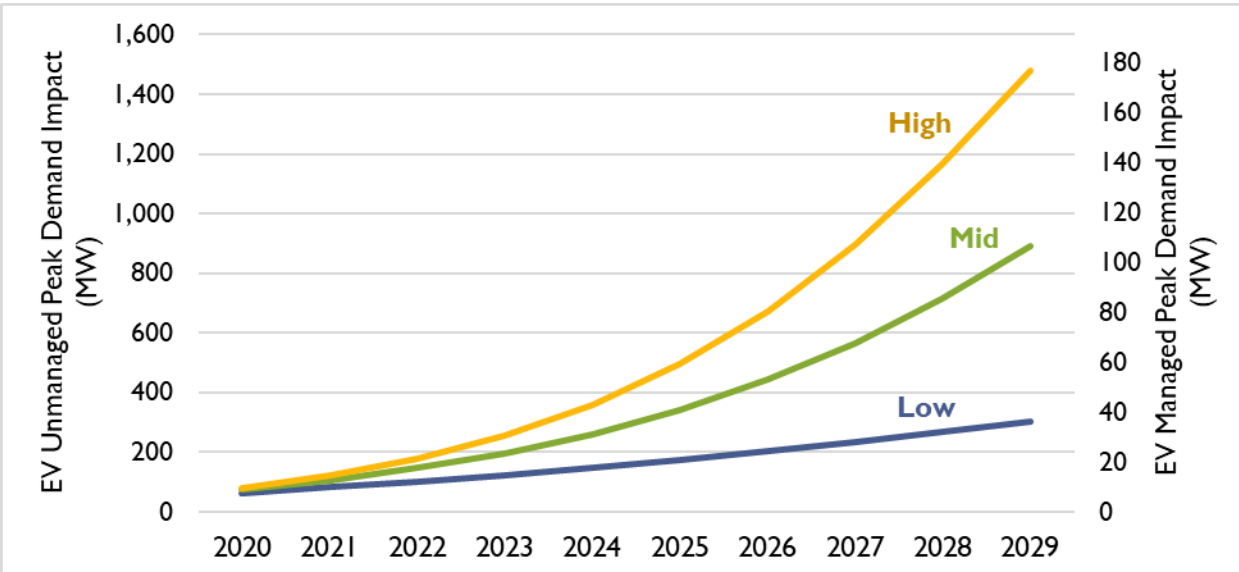


Figure 12. Total New England EV summer peak demand impact with unmanaged and managed charging

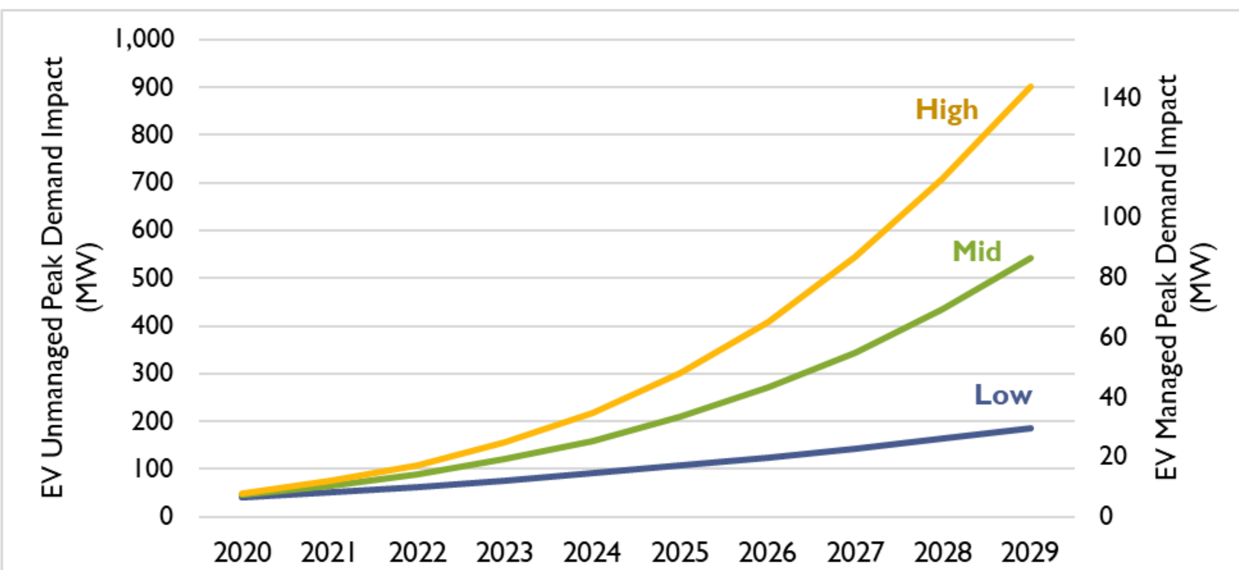
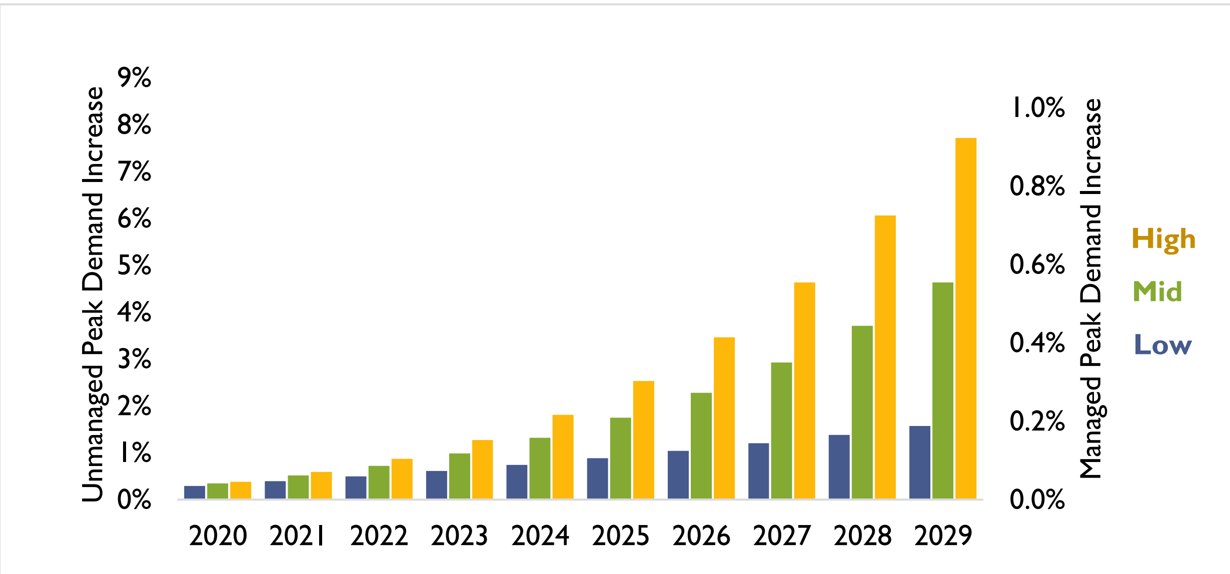


Figure 13 and Figure 14 show how the winter and summer peak demand impacts compare to the 2020 CELT summer and winter demand forecasts, respectively.[39,40] In the Unmanaged Charging case, winter peak demand increases by between 1.5 and 8 percent in 2029. In the Managed Charging case, by contrast, the impact is less than 1 percent in each adoption scenario. The summer peak impacts are smaller. The 2029 increase in peak demand in the High adoption scenario and Unmanaged Charging case is 3.6 percent. This falls to 0.6 percent in the Managed Charging case. Summer demand impacts are lower than the winter demand impacts for EVs due to the lower energy consumption of EVs in warmer weather and due to the difference in peak hours between the summer and winter seasons. EVs consume more energy in the winter primarily due to the use of energy for heating the interior of the vehicle.

Figure 13. Winter peak demand increase from managed and unmanaged EV charging as a percent of CELT demand forecast



[39] ISO NE CELT 2020

[40] For demand, we referenced the CELT 50/50 demand forecast because ISO New England calculated its electrification projections using this approach. We used the net forecast (which includes energy efficiency and behind-the-meter PV) less ISO New England's electrification forecast. For reference, the 50/50 summer peak load forecast is the basis for capacity market purchases the ISO uses in its 90/10 forecast for transmission planning.

Figure 14. Summer peak demand increase from managed and unmanaged EV charging as a percent of CELT demand forecast

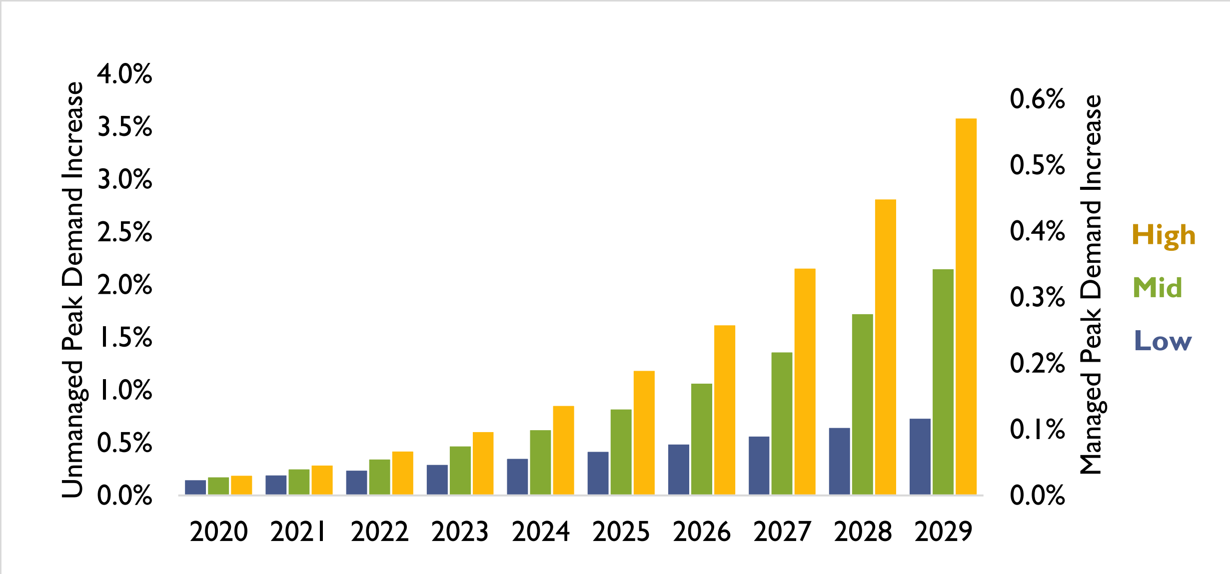
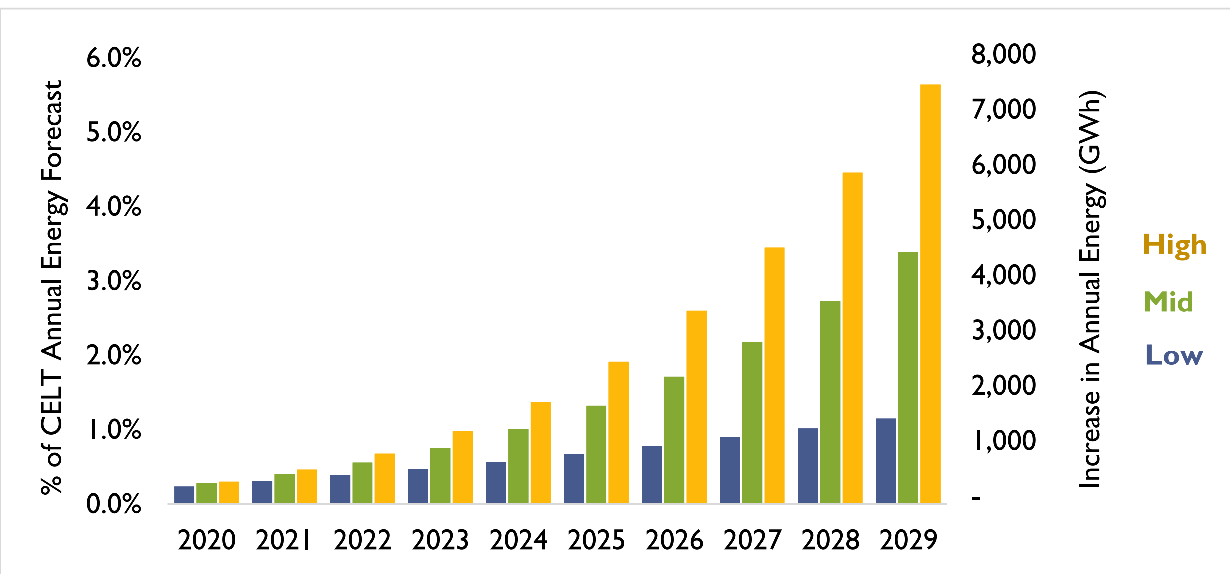


Figure 15 shows the change in energy consumption due to EV charging in each adoption scenario relative to the 2020 CELT energy forecast. By 2029, annual energy consumption increases between 1 and 6 percent.

Figure 15. Annual energy increase from EVs as a percent of CELT energy forecast



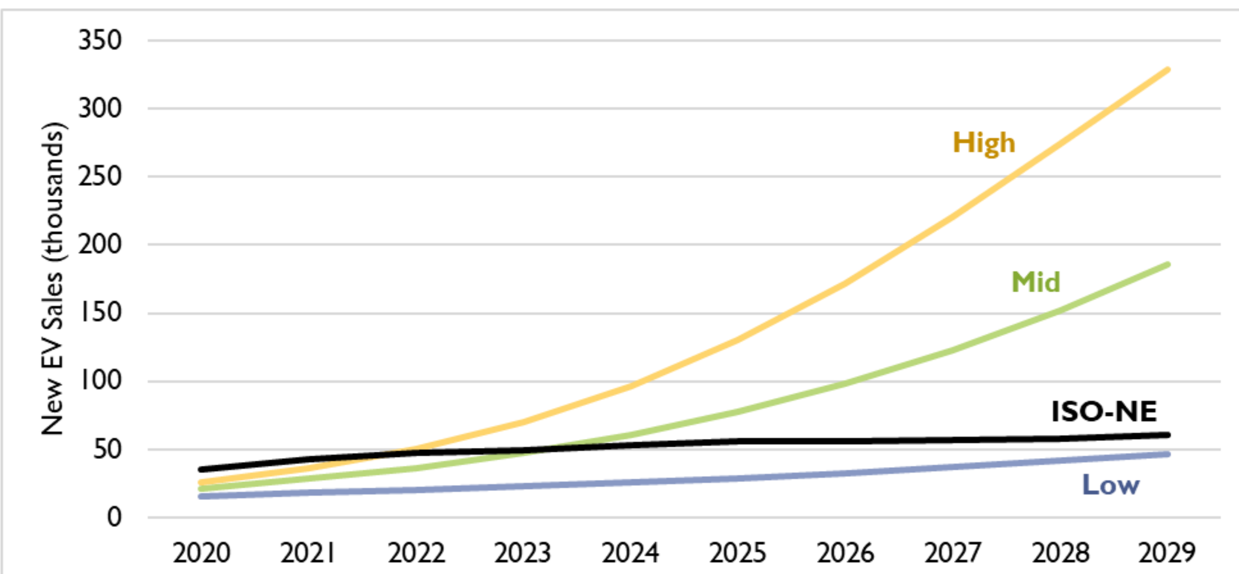
4.5. ISO New England EV Forecast

ISO New England's analysis utilizes the EIA EV adoption forecast that we use in the Low case. While the ISO uses EIA's annual sales projection, in our analysis we draw a smoother curve (typical of technology adoption) between historical sales levels and EIA's projection for 2029 sales. ISO New England also uses the ChargePoint charging data that we use for all three scenarios. However, we only use the charging data as a source for typical EV charging load profiles to understand the peak demand impacts. ISO New England uses the charging data as an empirical source of total EV energy consumption in New England. Our analysis provides a bottom-up calculation of EV load compared to ISO New England's more empirical approach and thus complements ISO New England's work in this area. In addition, we present a wider array of possible EV adoption trajectories to account for the possibility that EV adoption grows quickly either due to market forces or state policy goals.

Adoption projections

Projected EV sales trajectories from both ISO New England's and our analyses are shown in Figure 16. ISO New England's forecast projects more rapid adoption in the early years of the forecast than our three scenarios indicate, but by 2029 its forecast is similar to our Low scenario and far below the other two scenarios.

Figure 16. Comparison of ISO New England and Synapse New England EV sales projections



Energy and demand impacts

Figure 17 and Figure 18 show ISO New England's projections of energy consumption and winter peak demand impacts due to EV charging. Our Low scenario results for EV impacts are similar to those presented by ISO New England. By 2029, ISO New England forecasts total EV charging consumption to be approximately 1,700 GWh annually. This estimate falls just above our Low scenario value of 1,461

GWh, and well below our Mid and High scenarios in which we forecast consumption to be 4,268 GWh and 8,565 GWh, respectively.

Similarly, ISO New England's demand forecast is just above our Low scenario. ISO New England projects an increase in winter demand of 414 MW and Synapse's Low scenario projects 304 MW. Again, Synapse's Mid and High scenarios are much higher, with projected increases in demand of 891 MW and 1,480 MW, respectively.

Figure 17. Comparison of ISO New England and Synapse projections for annual energy increase in New England from EV charging

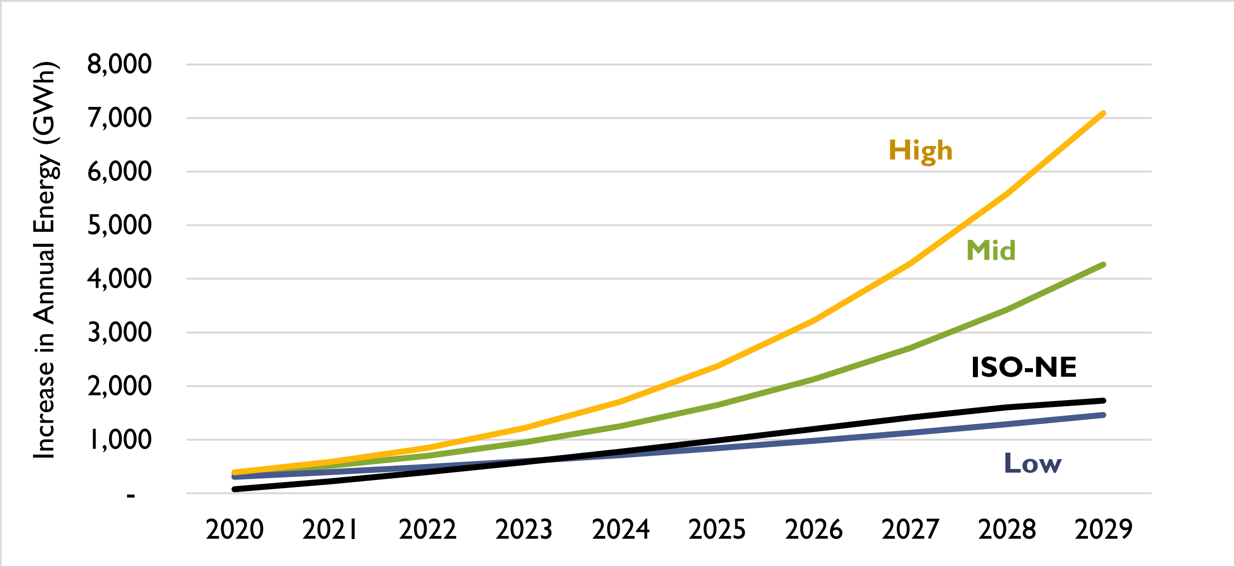
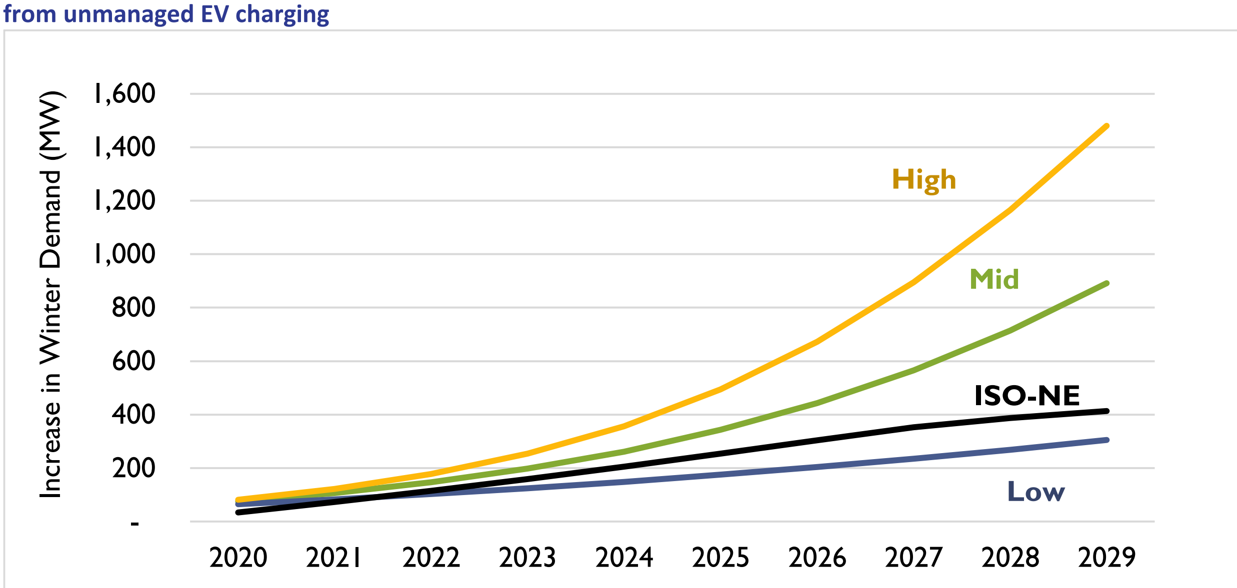


Figure 18. Comparison of ISO New England and Synapse projections for winter demand increase in New England from unmanaged EV charging



4.6. Electric Vehicle Conclusions

The three EV adoption scenarios and two charging cases demonstrate the array of possible grid impacts due to light-duty vehicle electrification. If EV adoption remains as limited as forecasted by EIA, EV charging will not have a noticeable impact on total energy consumption and peak demand. However, if the market advances more quickly as EV ranges, charging speeds, and battery prices improve, there is potential for substantial increases in load—particularly if charging is left unmanaged. In the Mid and High cases, peak winter demand in 2029 would increase by 5 percent and 9 percent, respectively. This means that if the states are going to meet their climate goals and attempt to follow the High adoption trajectory, managed charging will be important by the end of the 2020s to avoid nearly 10 percent peak demand increases, as all managed charging scenarios increase peak demand by less than 1 percent by 2029. On the other hand, all potential impacts due to EVs are smaller than 10 percent of the forecasted base demand, and only in the High scenario do the impacts exceed 5 percent. This means that the grid is likely capable of absorbing the new EV load that will appear in the 2020s. Beyond the 2020s, EV load is likely to increase at an even faster pace as EV adoption continues to accelerate.

5. Combined Results

Figure 19, Figure 20, and Figure 21 show the impacts on New England's electric grid of both heat pumps and EVs in the Low, Mid, and High scenarios. The baseline regional forecasts come from the 2020 CELT report. Figure 19 shows winter demand impacts from heat pumps and EVs with managed charging. By 2029, the Low scenario increases demand by just over 1 percent. Even the High scenario, which roughly translates to the region implementing electrification consistent with GHG reduction goals, is only 4 percent higher than system-wide demand as projected by the 2020 CELT winter demand forecast. With managed charging, EVs contribute much less to an increase in demand than heat pumps.

Figure 19. Winter demand impacts on New England's electric grid from heat pumps and EVs with managed charging

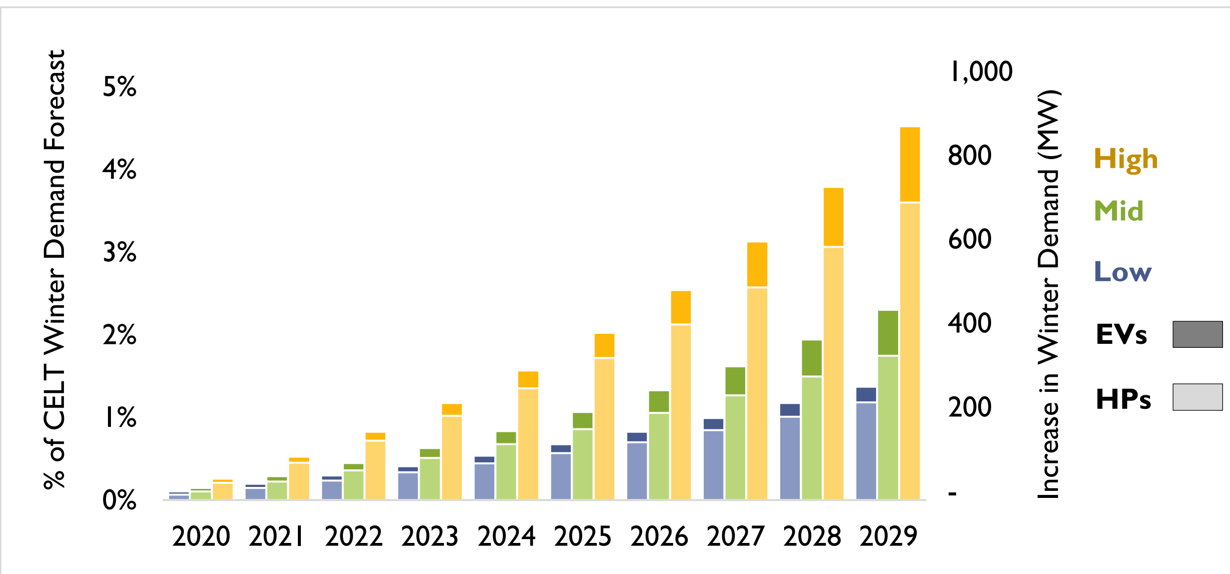


Figure 20 shows that when heat pumps are combined with EVs with unmanaged charging, the cumulative winter peak demand impact is much greater. In fact, the Low scenario peak demand impact by 2029 is roughly twice as large in the Unmanaged Charging case as it is in the Managed Charging case. Meanwhile, High scenario adoption of heat pumps and EVs without managed charging increases winter peak demand by 11 percent. In the Unmanaged Charging cases, EVs contribute more to demand impacts than heat pumps. To avoid high grid impacts in the future, policymakers in New England should consider the ramifications of leaving EV charging unmanaged.

Figure 20. Winter demand impacts on New England's electric grid from heat pumps and EVs with unmanaged charging

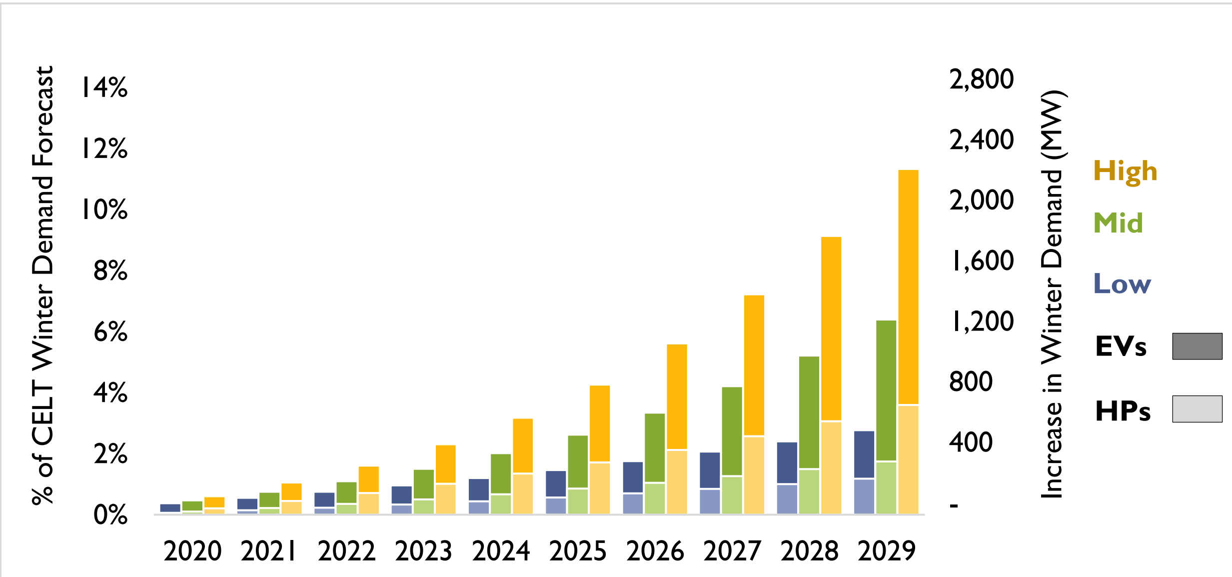
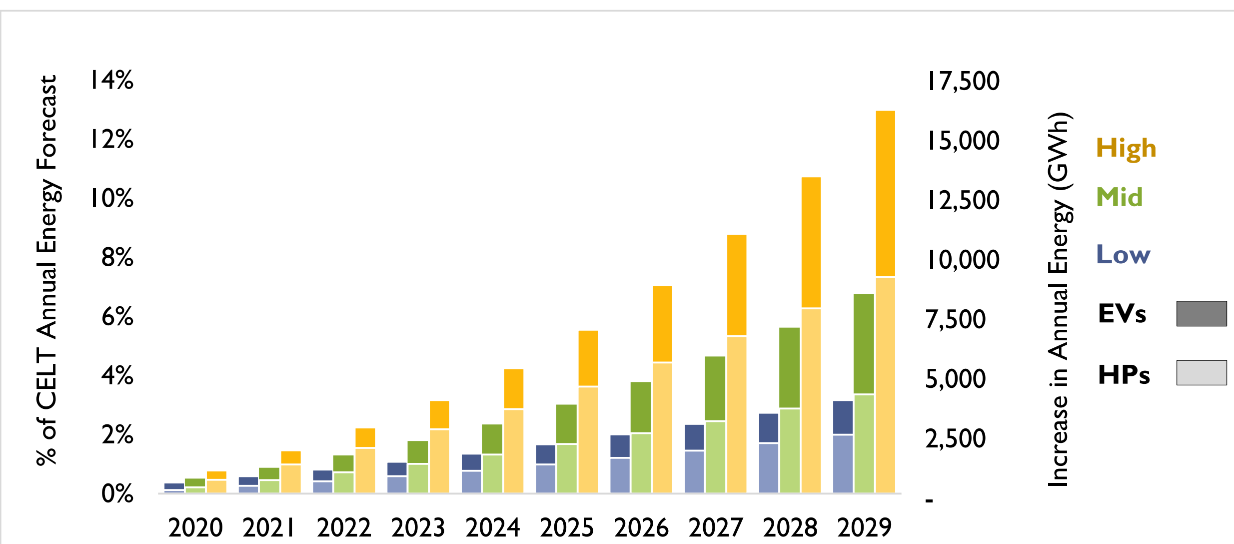


Figure 21 shows the annual electric energy impacts from heat pumps and EVs. The energy impacts of electrification are greater than the demand impacts relative to the CELT forecast. In the Low scenario, electrification leads to a 3 percent increase in annual energy consumption. In the High scenario, in which the region meets its 2030 GHG reduction goals, annual energy consumption increases by approximately 11 percent.

Figure 21. Annual energy impacts on New England's electric grid from heat pumps and EVs

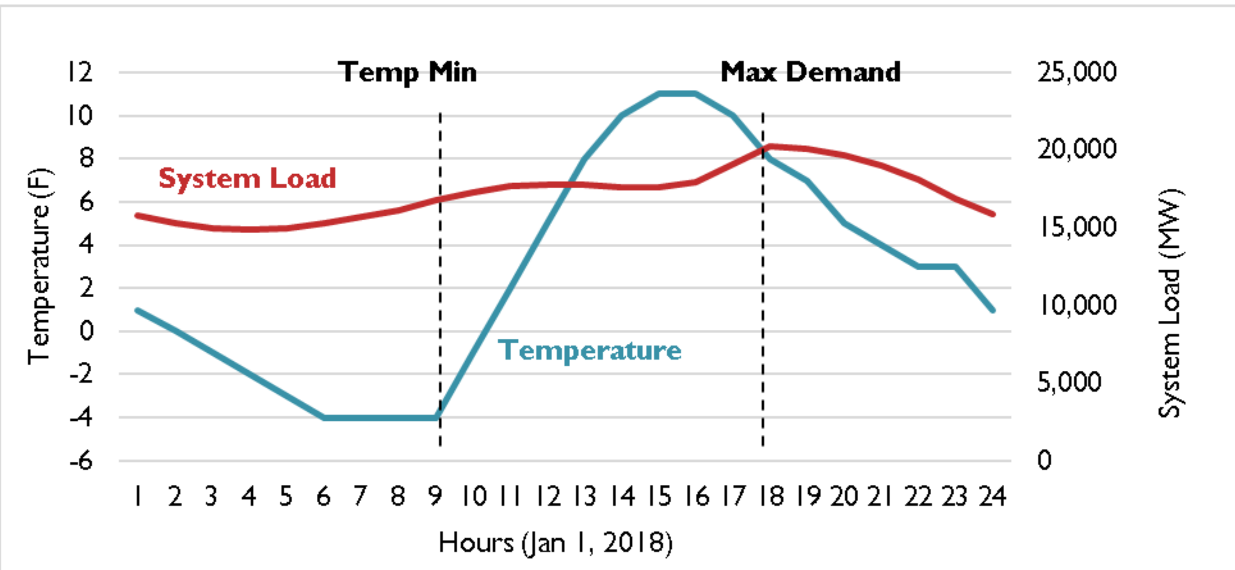


6. COLD SNAP SCENARIO

Our heat pump and EV adoption projections raise questions about whether New England's electric grid could transition from summer-peaking to winter-peaking during a cold snap. Just two years ago, the region saw the coldest weather wave in a century. The 2017–2018 winter brought extreme cold. For nearly two weeks, all major cities in New England recorded temperatures at least 10°F below normal.[41] We investigated how our High, Mid, and Low heat pump and EV scenarios would impact the electric grid if the region reached the temperatures recorded on January 1, 2018, the coldest day of the cold snap.[42]

Using ISO New England's database of historical hourly temperature and load data, we isolated the two most relevant hours on January 1, 2018: the coldest temperature hour and the highest electric demand hour.[43] Figure 22 shows the regional average temperature and the total system load throughout the day. The coldest average temperature in New England was -4°F, which occurred at 9AM. The maximum electric demand on the system was 20,271 MW, which occurred at 6PM.

Figure 22. Temperature and electric demand by hour on January 1, 2018



To estimate the impact that electrification could have during another cold snap, we analyzed the increased demand at the two inflection points. Heat pump performance degrades significantly at low

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[41] ISO Newswire. "Winter 2017/2018 recap: Historic cold snap reinforces findings in Operational Fuel-Security Analysis." (April 25, 2018). Available at: http://isonewswire.com/updates/2018/4/25/winter-20172018-recap-historic-cold-snap-reinforces-findings.html.

[42] The analysis focuses on the load on the electric grid. It does not investigate concerns related to New England's natural gas supply.

[43] ISO New England. 2019. *2018 SMD Hourly Data Rev 1*. Available at: https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info.

temperatures. In other words, on the coldest day of the year heat pumps will require more power to provide the same amount of heat than on a typical winter day. To compound the issue, cold temperatures mean greater home heating needs, regardless of the type of heating system.

As mentioned in Section 3.4, Cadmus developed calculations for full replacement heat pump performance that varies by temperature. The data for the two inflection points are displayed in Table 6. For full replacement homes, Cadmus advised that unless heat pumps are oversized, a home may require a supplemental heating system to maintain an ideal temperature throughout the house. We assume this would be an electric resistance space heater. We included this excess demand in Table 6 as supplemental heating.

Our analysis also accounts for the savings from homes switching from electric resistance heat to a heat pump. Synapse calculated these savings by converting heat pump demand to electric resistance demand using the relative efficiencies of the technologies at each inflection point.[44] Then, we calculated a weighted average electric demand value based on the percentage of existing electrically heated homes in New England.[45] To account for losses, we use the same gross up factor as ISO New England does in its forecasting of 8 percent. The total electric demand from heat pumps at -4°F is more than twice the total electric demand at 8°F.

Table 6. Full replacement heat pump performance during cold snap inflection points, per home

Inflection Point	Temp (F)	HP Demand (kW)	Suppl. Demand (kW)	Increased Electric Demand (kW)	Elec. Rest. Demand Savings (kW)	Weighted Avg. Electric Demand (kW)
Temperature min (9AM)	-4°	5.41	1.54	6.95	-4.27	4.82
Peak demand (6PM)	8°	4.22	0.00	4.22	-6.79	2.30

In Section 3.1 of this report, we assume that 50 percent of homes that install heat pumps will fully replace their existing heating systems and 50 percent will partially displace their existing heating systems. Full replacement homes rely exclusively on their heat pumps to provide heat, while partial displacement homes use their existing systems during extreme cold.

For partial displacement homes, we assume all units have set a temperature balance point. This is the temperature at which the heat pump shuts off and the backup system assumes operation, either via

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44 Cadmus calculated a heat pump COP of 1.79 at -4°F and 2.61 at 8°F. We assume electric resistance heat has a COP of 1.00 at all temperatures.

45 U.S. Census Bureau, American FactFinder, Table B25040, House Heating Fuel, 2017 American Community Survey 1-Year Estimates. Available at: https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.x html?src=bkmk.

controls or manually.[46] Typically, furnaces and boilers perform better than heat pumps in extreme cold and they are temporarily more cost-effective to operate. We assume that partial replacement heat pumps systems are designed to trigger a backup system when temperature drops below 10°F.[47] Given that the temperature at both inflection points is below 10°F, we assume these homes will not operate their heat pumps but instead rely entirely on their non-electric backup systems. Consistent with these assumptions, we assume half of the heat pumps in each adoption scenario will operate as indicated in Table 6, respectively for each inflection point, and half will not draw power from the electric grid.

For EVs, we assume hourly demand is consistent with the winter on-peak analysis above.[48] To be conservative we assume charging is unmanaged in all three scenarios.

To approximate the impact of our electrification projections during the coldest hour of a cold snap, we used the total system demand at 9AM, 17,760 MW, as the baseline demand on the system. Figure 9 shows the High, Mid, and Low adoption scenarios added to the baseline demand at the minimum temperature point. Heat pump demand is based on the per home demand values at 9AM in Table 6. We included projections for summer peak demand to demonstrate the year the system could become winter peaking. The summer peak demand displayed in Figure 9 is ISO New England's 2020 CELT report summer demand projections plus Synapse's projections for increased summer demand from EVs. The range in summer demand reflects the range in EV scenarios.

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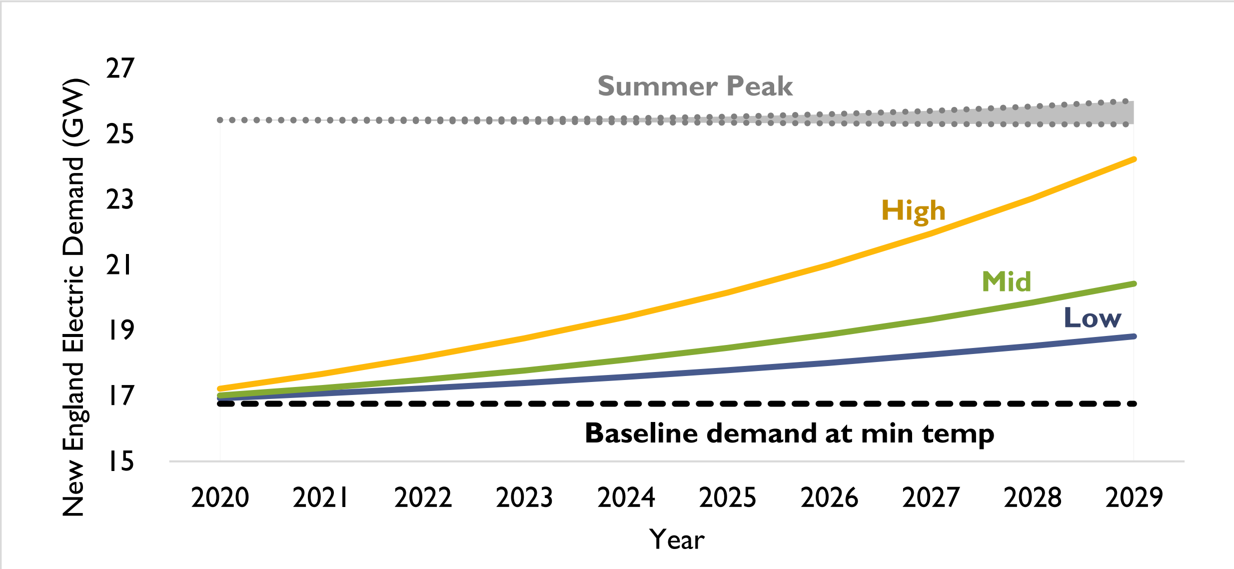
[46] Northeast Energy Efficiency Partnerships, Inc. 2017. *Assessment of Residential and Small Commercial Air-Source Heat pump (ASHP) Installation Practices in Cold-Climates.* Page 9. Available at: https://neep.org/sites/default/files/AssessmentofResandSmallCommASHPInstallationPracticesinCold-Climates.pdf.

[47] Schoenbauer, B., Bohac, D., Haynor, A. Center for Energy and Environment. *Field Assessment of Ducted and Ductless Cold Climate Air Source Heat Pumps*. Page 5.

[48] In reality, EV charging performance degrades moderately with temperature. However, driving behavior will likely be reduced during extreme weather events. Results consistent with typical winter demand are used as a proxy.

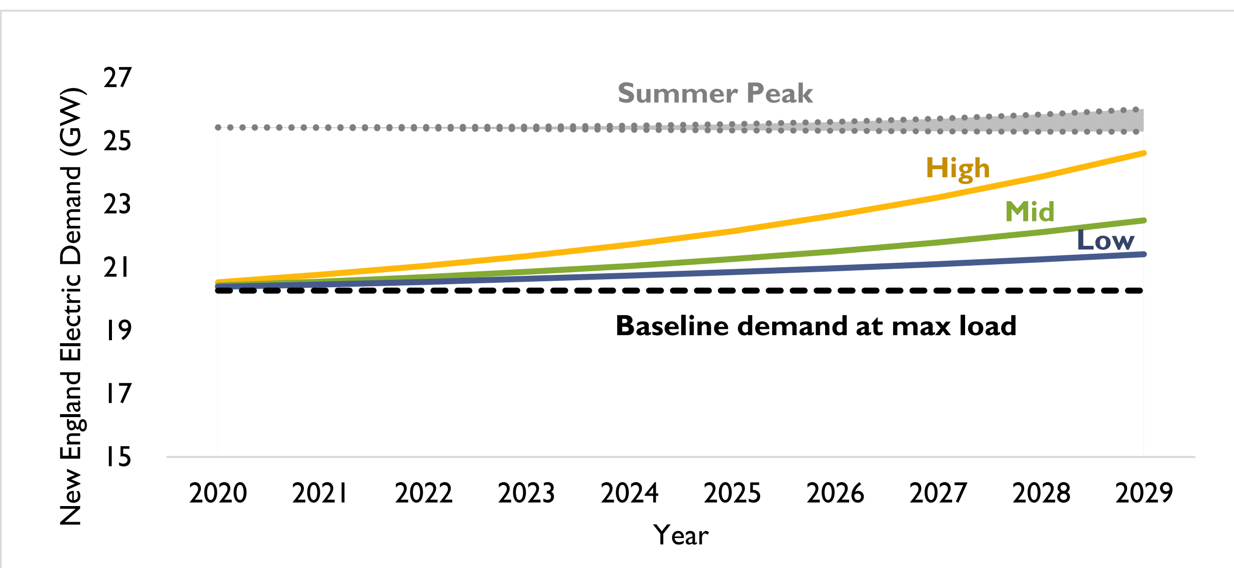
Figure 23. Estimated demand during historic cold snap's minimum temperature hour



The results displayed in Figure 23 indicate that during the coldest hour of a cold snap, none of the three adoption scenarios would cause the winter system peak to eclipse the summer system peak. Even the High scenario, in which all states meet their climate targets, remains under the summer peak demand threshold through 2029. The Medium and Low scenarios never approach the threshold.

In addition to modeling the coldest hour of January 1, 2018, when the impact from heat pumps is greatest, we modeled the highest demand hour. To estimate the impacts from electrification during the highest demand hour, we used the same methodology as above with values corresponding to 6PM, including a maximum system demand of 20,271 MW as the baseline. The results are displayed below in Figure 24.

Figure 24. Estimated demand during cold snap's maximum load hour



The maximum demand inflection point analysis yields similar results to the minimum temperature inflection point analysis. Despite starting with a higher baseline demand, winter peak demand in the High adoption scenario still does not surpass summer peak demand throughout the next decade. Heat pumps perform better in warmer temperatures and need to draw less electricity to operate–even a difference of 12°F between the two inflection points has a significant impact. Similar to the results at the minimum temperature inflection point, the Mid and Low scenarios never approach the summer peak demand threshold.

We focus briefly on the Cold Snap scenario because it is important to the reliable and efficient operation of the New England regional power grid. The natural gas system in New England, as elsewhere, is designed to meet heating needs. If winter electric loads increase without other changes to the power system, we would find ourselves with constrained natural gas pipelines and significant price spikes for the fuel that most directly affects electricity prices. The monumental increases in the amount of non-fuel electric power generators that are already planned and contracted will alleviate this issue. Any increased investment in electric, hot water, and heating efficiency will also have important benefits during our infrequent cold snaps.

7. OVERALL CONCLUSIONS

All six New England states have set goals to reduce carbon dioxide emissions drastically in the next few decades. These goals cannot be met without electrification of several end uses that are today powered directly by fossil fuels. Our heating systems and transportation will be the first end uses to undergo this necessary transformation, but the potential addition of electric load has raised questions. Our research and analysis show that during this decade the electric grid is already well positioned to meet the additional winter peak demand from electrification. New England has a summer-peaking electric grid which means capacity resources are procured and transmission capacity is constructed to meet summer demand. According to the 2020 CELT forecast, throughout the next decade summer demand in New England will be between 5,000 and 6,000 MW higher than winter demand. Our High scenario, in which all New England states remain on track to hit their climate targets *and* EV charging remains unmanaged, shows an increase in winter demand of 2,100 MW by 2029. We also quantified the impact of EVs in the summer, when New England experiences peak electric demand. We found EVs increase summer peak demand by between 0.6 and 3.6 percent by 2029 in the Unmanaged Charging case. These increases are relatively small and, if necessary, can be addressed between now and 2029. While we did not quantify the summer impacts of heat pumps, we anticipate many systems will replace less efficient cooling systems and therefore help reduce summer peak demand.

Still, while New England's generation and transmission resources could handle aggressive heat pump and EV adoption with unmanaged charging, managed EV charging would provide the region with substantial summer and winter benefits. Managed charging programs could virtually eliminate summer peak demand impacts of electrification and substantially reduce winter peak impacts as well. Decreasing peak demand reduces the amount of generation, transmission, and distribution capacity that needs to be procured and makes the system easier and less costly to operate. Reducing peak demand can also decrease reliance on less efficient peaker plants and reduce emissions. In the long term, managed charging can also help shift load to better match renewable generation profiles, and therefore help with the integration of clean intermittent resources. As electrification load and peak demand impacts grow into the 2030s, the managed charging will be even more important.

Just like with the demand forecast scenarios, annual energy increases from electrification vary by scenario. In our Low scenario, electrification would only increase forecasted electricity consumption by 3 percent, or 4,000 GWh, by 2029. However, if the region is aggressive about implementing electrification resources consistent with its climate goals, the electric grid will have to accommodate energy consumption increases of up to 13 percent, or 16,000 GWh. New England may already have the resources to tackle this challenge. Massachusetts, Connecticut, and Maine combined have over 5,000 MW of offshore wind commitments scheduled to come online in the next decade, with more under review.[49] Offshore wind generates more electricity in the winter, so it can help power technologies like heat pumps and EVs that use more energy in the winter when less solar energy is available. Not only will this overcome the increased energy requirements, it will supply newly electrified homes and vehicles with carbon-free electricity.

The prospect of load growth due to electrification also emphasizes the importance of energy efficiency. Energy efficiency reduces the region's summer and winter capacity needs as well as annual energy consumption. The 2020 CELT Report forecasts that by 2029 the region will have 5,000 MW of cumulative traditional energy efficiency, decreasing the winter gross load forecast by 20 percent.[50] By continuing to offer efficiency programs, states can mitigate or even eliminate the impact on the electric grid from electrification.

New England policymakers can set the region on an ambitious path to meeting its climate goals by increasing heat pump and EV adoption without significant disruption to the regional power grid.

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[49] Acadia Center. 2019. "Offshore Wind Makes Big Moves Across the Northeast Region." Available at: https://acadiacenter.org/offshore-wind-makes-big-moves-across-the-northeast-region/.

[50] ISO New England. 2020.

APPENDIX – DATA COLLECTION

Synapse has performed analysis on these topics for several clients recently, including the Cape Light Compact, Energy Foundation, and the Newfoundland and Labrador Public Utilities Board. Our work for E4TheFuture builds off previous efforts that are recent and still applicable. Our data sources include program administrator data, state policy, evaluation studies, technical specifications, and other publicly available studies and databases. Table A1 shows our data sources for the heat pump analysis by state. Table A2 shows our data sources for the EV analysis.

Table A1. Data sources by state for heat pump analysis

State	Application	Source	Link
All States	Census data estimating the population by fuel type for each state and for New England	U.S. Census Bureau, American FactFinder, All states within United States and Puerto Rico, Table B25040, House Heating Fuel, 2017 American Community Survey 1-Year Estimates.	https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.x html?src=bkmk
Maine	Policy goal for Maine of 100,000 heat pumps	State of Maine Legislature. LD 1766. "An Act To Transform Maine's Heat Pump Market To Advance Economic Security and Climate Objectives." (6/14/2019).	https://legislature.maine.gov/LawMakerWeb/summary.asp?ID=280074129
	2019-2022 planned heat pump installations through Efficiency Maine	Efficiency Maine. "Appendix G: Analysis for the Opportunity for High-Efficiency, Cold Climate Ductless Heat Pumps in Maine." Proposed Triennial Plan for Fiscal Years 2020-2022.	https://www.efficiencymaine.com/docs/Appendix_G_Analysis_of_the_Opportunity_for_High_Efficiency_Cold_Climate_Ductless_Heat_Pumps_in_Maine_in_Fiscal_Years_2020_2022.pdf
	Annual heating energy consumption and winter on-peak demand for Maine	EMI Consulting. 2014. "Emera Maine Heat Pump Pilot Program." Page 15.	https://www.emeramaine.com/media/41789/emera-maine-heat-pump-pilot-final-report-nov-2014.pdf
New Hampshire	NH Saves 2018-2020 planned heat pump quantities	VEIC. 2018. Driving the Heat Pump Market. Page 41.	https://www.veic.org/documents/default-source/resources/reports/veic-heat-pumps-in-the-northeast.pdf
Vermont	2020-2029 Efficiency Vermont heat pump projections	VEIC provided projections to ISO New England. ISO New	https://www.iso-ne.com/committees/reliability/load-forecast/

State	Application	Source	Link
		England Draft 2020 Heating Electrification Forecast.	
	Annual heating energy consumption and winter on-peak demand for Vermont	Cadmus. 2017. "Evaluation of Cold Climate Heat Pumps in Vermont." Page 3.	https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf
Connecticut	Heat pump quantities from Energize CT from 2016-2018	Connecticut Green Bank. 2018. "Heat Pump Market: Latest Trends and How to Engage Customers."	https://www.ctgreenbank.com/wp-content/uploads/2018/12/HeatPumpTrends_11.29.18.pdf
Massachusetts	Planned heat pump quantities, energy consumption, and winter on-peak demand from 2019-2021 through Mass Save	Mass Save. 2019-2021 Three-Year Energy Efficiency Plan. (October 31, 2018).	http://ma-eeac.org/wordpress/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf
	2019 heat pump pilot installations. Projections based on program budget and incentives	MassCEC. 2019. "Whole-Home Air-Source Heat Pump Pilot."	https://www.masscec.com/clean-heating-and-cooling/air-source-heat-pumps
	Primary versus supplemental heating patterns based on survey responses	MassCEC. ASHP Rebate Data 2014-2019. Provided for Synapse upon request.	N/A

State	Application	Source	Link
Rhode Island	National Grid no longer offering heat pumps in its 2020 plan as a result of an order from Commissioner Anthony	National Grid. (December 20, 2019). Docket 4979. *2020 Energy Efficiency Program Plan.*	http://www.ripuc.org/eventsactions/docket/4979-NGrid-Compliance-RevElecTables(12-20-19).pdf
	Estimated National Grid installations in 2025 and 2030	Meister Consultants Group. 2017. Rhode Island Renewable Thermal Market Development Strategy.	http://www.energy.ri.gov/documents/Efficiency/Rhode%20Island%20Renewable%20Thermal%20Market%20Development%20Strategy%20January%202017.pdf
	The planned percentage of ASHPs versus GSHPs	Rhode Island Greenhouse Gas Emissions Reductions Plan. 2016. Page 73.	http://climatechange.ri.gov/documents/ec4-ghg-emissions-reduction-plan-final-draft-2016-12-29-clean.pdf
	Executive order from Gov. Raimondo that requires DPUC and OER to provide heating recommendations by April 2020 serves as the basis for the Policy scenario	RI.GOV. "Raimondo Signs Executive Order to Transform RI's Heating Sector." Executive Order 19-06.	https://www.ri.gov/press/view/36269

Table A2. Data sources for EV analysis

Model Input	Description	Source	Link
Vehicle sales growth rate	Increases according to LDV sales growth rates in AEO 2019; LDV growth rate applied to all vehicle types (MDV, HDV, buses), and is census division-specific	U.S. Energy Information Administration. January 24, 2019. Annual Energy Outlook 2019.	https://www.eia.gov/outlooks/archive/aeo19/
Historical vehicle sales	National vehicle sales	U.S. Bureau of Economic Analysis. Auto and Truck Seasonal Adjustment.	https://www.bea.gov/national/xls/gap_hist.xlsx
	State shares of national vehicle stock (used to scale national sales)	U.S. Department of Transportation Federal Highway Administration. Highway Statistics 2017. Tables MV-1 and MV-9.	https://www.fhwa.dot.gov/policyinformation/statistics/2017/
VMT per vehicle	National average VMT per vehicle	U.S. Department of Transportation Federal Highway Administration. Highway Statistics 2017.	https://www.fhwa.dot.gov/policyinformation/statistics/2017/

Model Input	Description	Source	Link
	Total VMT in each state	U.S. Department of Transportation Federal Highway Administration. "Travel Monitoring."	https://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm
VMT change over vehicle lifetime	For LDVs, annual mileage decreases by roughly 25% after 10 years; source is for residential vehicles only, but data is used for all LDVs. HDV mileage is assumed to be independent of age	U.S. Department of Transportation Federal Highway Administration. National Household Travel Survey 2017.	https://nhts.ornl.gov/
Vehicle lifetime	Modeled as a distribution; about 80% of cars last more than 10 years and about 20% of cars last more than 20 years; light trucks last a bit longer than cars on average	RL Polk. National Vehicle Population Profile, 1975-2009.	
	Distribution scaled for each state so average vehicle age matches the state's average vehicle age	Alliance of Automobile Manufacturers. "Every State is an Auto State." Accessed January 29, 2020.	https://autoalliance.org/in-your-state/
EV efficiency	New vehicle efficiencies, specific to each vehicle type and changing over time	National Renewable Energy Laboratory. December 20, 2017. Electrification Futures Study Technology Data.	https://data.nrel.gov/submissions/78