Analysis of the Avoided Costs of Compliance of the Massachusetts Global Warming Solutions Act

Supplement to 2018 AESC Study

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Executive Summary

This document supplements the 2018 Avoided Energy Supply Component (AESC) Study (2018 AESC). Specifically, this document provides estimates of the incremental avoided compliance costs with the Massachusetts Global Warming Solutions Act (GWSA)[1], beyond those already included in the main 2018 AESC study.[2]

Avoided compliance costs from this study are intended to be added to the avoided costs for energy, capacity, and other values determined in the 2018 AESC. The combined costs provide total avoided costs for demand-side measures installed by Massachusetts energy efficiency program administrators.

This supplemental study was commissioned by Massachusetts Department of Energy Resources (DOER). It includes input from the GWSA Study Group, which includes Massachusetts Department of Environmental Protection (MassDEP), consultants to the Massachusetts Energy Efficiency Advisory Council (EEAC), and members of the Massachusetts energy efficiency program administrators. The GWSA Study Group helped to develop and review methodological approaches, compliance strategies, and other issues related to the development of the avoided cost of GWSA compliance.

This supplemental analysis finds that the incremental 15-year levelized avoided cost of GWSA compliance is 2.09 cents per kWh, expressed in 2018 dollars.[3] This represents an 18 percent increase over the 11.69 cents per kWh avoided cost as currently calculated on Table ES-1 of the 2018 AESC study.

Table 1. Illustration of avoided retail summer on-peak electricity cost components, AESC 2018 and GWSA Supplement (2018 cents/kWh, 15-year levelized values from 2018 through 2032)

Total avoided costs in 2018 AESC Study Table ES-1	16.05	(a)
"CO_2 non-embedded" component (not used in MA)	4.36	(b)
Total avoided costs, less "CO_2 non-embedded" component[4]	11.69	(c) = (a) – (b)
Estimated incremental avoided cost of GWSA compliance	2.09	(d)
Total avoided cost with incremental avoided GWSA compliance cost	13.78	(e) = (c) + (d)
Percent difference	18%	(f) = (e)/(c) - 1

Because the Massachusetts energy efficiency program administrators do not use 2018 in their three-year energy efficiency plan for 2019 through 2021, we also calculate the 15-year levelized cost for 2019 through 2033. Under this timeframe, the 15-year levelized avoided cost of GWSA compliance is 1.79

[1] Chapter 298 of the Acts of 2008.

[2] See http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf.

[3] This cost is inclusive of an adjustment for distribution losses (8 percent), consistent with the non-embedded environmental cost methodology applied in the 2018 AESC study in Table ES-1.

[4] Includes embedded Massachusetts regulations 310 CMR 7.70, 7.74, and 7.75 (see page 5 for details).

cents per kWh. This is a 16 percent increase over the avoided cost in the 2018 AESC Study, were it calculated on a 15-year levelized basis between 2019 and 2033 (see Table 2).

Table 2. Illustration of avoided retail summer on-peak electricity cost components, AESC 2018 and GWSA Supplement (2018 cents/kWh, 15-year levelized values from 2019 through 2033)

Total avoided costs in 2018 AESC Study	15.53	(a)
"CO_2 non-embedded" component (not used in MA)	4.31	(b)
Total avoided costs, less "CO_2 non-embedded" component[5]	11.22	(c) = (a) – (b)
Estimated incremental avoided cost of GWSA compliance	1.79	(d)
Total avoided cost with incremental avoided GWSA compliance cost	13.01	(e) = (c) + (d)
Percent difference	16%	(f) = (e)/(c) - 1

We calculated the avoided cost of GWSA compliance using a weighted average of anticipated costs and greenhouse gas (GHG) emission reduction potential for seven strategies. All seven strategies are currently being deployed by the Commonwealth of Massachusetts (Commonwealth) in the near to medium term under already promulgated legislation and regulations, or as part of the *Massachusetts Clean Energy and Climate Plan for 2020 (CECP)* in order to comply with the GWSA.[6] These strategies include: (1) onshore wind, (2) offshore wind, (3) large solar, (4) medium solar, (5) small solar, (6) clean energy imports, and (7) light-duty vehicle electrification infrastructure.

In the counterfactual AESC case that presumes no incremental energy efficiency in 2018 and all later years, the Commonwealth would not achieve the GWSA limit for 2020 and later years without implementing additional non-efficiency strategies. While the Commonwealth does not develop two CECPs (one with and one without energy efficiency), for this analysis, we have assumed that the counter-factual AESC case of no incremental energy efficiency would rely on an expansion of the above-listed electric-related strategies already in the CECP.

As a result, these incremental avoided costs of GWSA compliance may be applied to any measure in the 2019–2021 three-year plan for energy efficiency. Said another way, any measure in the 2019–2021 three-year plan for energy efficiency (which may include but is not limited to LEDs, heat pumps, insulation, weatherization, energy efficiency appliances, demand response, storage, etc.) will reduce GHG emissions and avoid the cost of GWSA compliance. This may improve the cost-effectiveness of measures in each program administrator's three-year energy efficiency plan.

Because the "main" AESC case represents a theoretical future in which no new energy efficiency measures are put into place, the 2018 AESC Study and results from this Supplement should not be used to infer information about actual future market conditions, energy prices, or resource builds in New England. Furthermore, actual prices in the future will be different than the long-term prices calculated in

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[5] Includes embedded Massachusetts regulations 310 CMR 7.70, 7.74, and 7.75 (see page 5 for details).

[6] See https://www.mass.gov/files/documents/2017/12/06/Clean%20Energy%20and%20Climate%20Plan%20for%202020.pdf.

this study as actual future prices will be subject to short-term variations in energy markets that are unknowable at this point in time.

The following sections provide detailed findings and a description of the methodology used to derive an avoided cost of compliance with GWSA.

1. BACKGROUND

The Global Warming Solutions Act (GWSA) requires the Commonwealth to reduce greenhouse gas (GHG) emissions by 25 percent in 2020, relative to 1990 levels, and by at least 80 percent in 2050, relative to 1990 levels.[7] GWSA tasks state agencies with developing regulations that require reporting of GHG emissions by different sources in the Commonwealth, establishing target emission reductions that must be achieved by 2020, and developing a plan for achieving these targets. To this end, Massachusetts agencies published a *Massachusetts Clean Energy and Climate Plan for 2020* in 2010 and an updated version in 2015. These two documents outline the measures or strategies that the Commonwealth is using to achieve the emissions reduction requirements.[8]

In May 2016, the Massachusetts Supreme Judicial Court ruled in *Kain et al.* that the Commonwealth must also promulgate regulations establishing declining annual emissions limits for sources or categories of sources that emit GHGs, enabling the state to comply with the 2020 limit set by the Secretary of Energy and Environmental Affairs.[9] In response to this decision, MassDEP and EEA issued a set of regulations that would result in compliance with the 2020 emissions limit.[10] As noted in the 2018 AESC Study report, three specific regulations—one pre-*Kain* regulation (310 CMR 7.70) and two post-*Kain* regulations (310 CMR 7.74 and 310 CMR 7.75) as discussed further on page 6—were modeled in the current 2018 AESC Study. Therefore, the costs associated with complying with these regulations are already included in the 2018 AESC avoided energy costs.

However, the 2018 AESC Study does not necessarily represent a future in which compliance with the GWSA emissions reduction requirement is achieved. The 2018 AESC Study models a future in which no energy efficiency is installed in 2018 through 2050. This hypothetical "but-for" case is then used to estimate the costs avoidable by any unit of energy efficiency (or other demand-side measure). Because electric generating resources that emit GHGs are commonly on the margin in New England, the 2018 AESC Study—with its lack of new energy efficiency—represents a future in which emissions in Massachusetts and the rest of New England are higher than they would be in a future that does account for the impact of incremental energy efficiency.

For this reason, the avoided cost of complying with the GWSA is not fully accounted for in the 2018 AESC Study.[11] To estimate the avoided cost of compliance under the AESC counter-factual, this supplement assumes that in the absence of energy efficiency, the Commonwealth would pursue an expansion of the strategies outlined in the CECP.

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[7] See https://www.mass.gov/service-details/global-warming-solutions-act-background.

[8] All the measures or strategies in the CECP have GHG benefits. Some may also achieve additional goals such as public health, economic development, or avoiding costs of capacity, transmission, and distribution.

[9] See http://masscases.com/cases/sjc/474/474mass278.html.

[10] See https://www.mass.gov/guides/reducing-ghg-emissions-under-section-3d-of-the-global-warming-solutions-act.

[11] Note the calculation of the avoided cost of GWSA is not the primary focus of the AESC study. The objective of the AESC study is to calculate a wide range of categories of avoided costs of demand-side measures for the different New England states. Historically, analyses on state-specific avoided costs have been conducted separately from the main AESC study.

2. METHODOLOGY

This section describes the general methodology used to calculate a non-embedded avoided cost of GWSA compliance. Unless otherwise noted, all dollar terms in this analysis are in 2018 dollars.

2.1. Calculating the Avoided Cost of GWSA Compliance

The approach used to calculate preliminary findings involves assembling costs and emission-reducing potentials for seven compliance strategies: onshore wind, offshore wind, large solar, medium solar, small solar, clean energy imports, and light-duty vehicle electrification infrastructure (see Table 3). While this set of strategies may not include all possible strategies eventually employed to reduce GHG emissions, it is our understanding that it represents the strategies that are most likely to produce sizeable GHG emission reductions through the study period.[12]

Six of the seven strategies listed in Table 3 are electric-sector technologies and are calculated first in $-per-MWh terms and MWh potentials. The expected cost of energy (per the 2018 AESC Study) is then subtracted from these $-per-MWh terms to estimate the incremental avoided cost of employing a particular strategy, as opposed to an "all-in" cost.[13] Using a set of seasonal- and temporal-specific emissions rates calculated in the EnCompass electric-sector dispatch model from the 2018 AESC Study, the incremental costs and incremental potentials are then converted into $-per-short-ton and short-ton values. Because the light-duty vehicle electrification strategy involves switching from fossil fuels to electricity for light-duty vehicles, it increases load on the grid rather than generating electricity.[14] Therefore, the avoided cost of compliance for this strategy is not directly calculated from a $/MWh cost and GWh potential. Instead, it is converted natively into $-per-short-ton and short tons.

All incremental avoided costs are averaged and weighted using each strategy's potential for emission reductions separately for 2018, 2019, 2020, and 2030 (see an example of this calculation in Equation 1).[15] Incremental avoided GWSA costs between 2020 and 2030 are interpolated, with the implied

[12] Again, note that this list specifically does not include energy efficiency or other demand-side measures. This analysis focuses on strategies that could be done in place of demand-side measures. Demand-side measures (as they are installed) would avoid or reduce the cost of compliance, i.e., the deployment of these strategies.

[13] This step is performed for all strategies except light-duty vehicle electrification infrastructure, which is unaffected by energy prices.

[14] As such, the electric sector will be involved to a significant extent in implementing this strategy.

[15] Although 2018 and 2019 do not have specific emissions reductions requirements, energy efficiency measures installed in these years and which persist through 2020 and later years are able to contribute to future-year emissions reductions and avoid some portion of the cost of GWSA compliance. The load forecast in the 2018 AESC Study is created by using ISO New England's gross load projections from CELT 2017, which accounts for a future without new energy efficiency beginning in 2018. Note that avoided costs for 2018 are not used by the energy efficiency program administrators in their development of the 2019–2021 three-year plan for energy efficiency, but are calculated as part of this analysis for consistency with the main 2018 AESC Study. See Appendix A for additional detail on calculations for avoided costs in 2018 and 2019.

increase in costs extrapolated through 2031 and all later years.[16] Our analysis indicates that the incremental weighted average avoided costs for 2020 and 2030 are $41 per short ton and $28 per short ton, respectively (see Table 3 and Table 4).[17]

This methodology results in a single potential avoided cost for each of the analyzed years. This weighted average approach means that no single strategy dominates the calculated compliance value. This is important for two reasons: first, the costs and potentials for each of these values are inherently uncertain. While they represent our best estimate as of August 2018, it is possible that these values may increase or decrease as technologies improve, materials and labor costs change, or as other, different technologies become available.

Second, this approach considers that many different strategies are likely and reasonably foreseeable to be employed to meet the state's emission reduction requirements. Each of the seven strategies is already present in Massachusetts today. Further, each strategy is being employed in the near to medium term under already promulgated legislation and regulations, or as part of the *Massachusetts Clean Energy and Climate Plan for 2020* (CECP).[18] For example, onshore wind, offshore wind, and solar installations are eligible to fulfill Massachusetts' Renewable Portfolio Standard (RPS) requirements, and clean energy imports are regulated under Section 83D of Chapter 169 of the Acts of 2008, as amended by the 2016 Energy Diversity Act ("83D").[19]

The 2018 AESC Study already accounts for three strategies or regulations currently in place that steer Massachusetts towards GWSA compliance: (1) 310 CMR 7.70 *Massachusetts CO_2 Budget Trading Program* (also known as Regional Greenhouse Gas Initiative or RGGI); (2) 310 CMR 7.74 *Reducing CO_2 Emissions from Electricity Generating Facilities* (cap on CO_2 emissions from power generators inside Massachusetts); and (3) 310 CMR 7.75 *Clean Energy Standard* (CES) for Massachusetts load-serving entities. These electric-sector regulations (and other regulations that address emissions from other parts of the economy) were designed to yield 2020 GHG emissions at or below the specified annual requirement. In the counterfactual AESC case that presumes no incremental energy efficiency for 2018, 2019, 2020, and all later years through 2050, non-efficiency measures would be needed to replace the emissions reductions from energy efficiency in order to still achieve GWSA-required 2020, 2030, 2040, and 2050 GHG emissions limits. To evaluate the incremental portion of GWSA avoided costs, these

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16 This is similar to the methodology applied in other parts of the 2018 AESC Study. For example, avoided energy costs are calculated for 2018 through 2035, then extrapolated at a specified rate of change for 2036 to 2050. Importantly, because avoided costs in these later years are discounted heavily in the 30-year levelization (and not used at all in the 10- and 15-year levelizations), avoided costs after 2030 have less of an impact on the levelized value than do avoided costs in the nearer term.

17 Note that the 2018 AESC Study calculates a total environmental avoided cost for CO_2 abatement of $100 per short ton. Avoided costs in this supplemental analysis generally decline over time as the different strategies become less expensive relative to the energy prices modeled in the 2018 AESC study.

18 See the following section describing the costs and potentials for each strategy for additional information on specific existing and proposed legislation and regulations associated with each strategy.

19 Requests for proposals for both 83C and 83D were defined in Chapter 188 of the Acts of 2016 "An Act to Promote Energy Diversity," available at https://malegislature.gov/Laws/SessionLaws/Acts/2016/Chapter188. For more information, see https://macleanenergy.com/83d/ https://macleanenergy.com/83c/.

already modeled GWSA avoided costs must be removed from the total avoided cost of GWSA compliance. Because these avoided costs are embedded in the modeled avoided energy cost in the 2018 AESC Study, removing the already modeled avoided energy cost from the total "all-in cost" of compliance functionally removes this double-counting of the already modeled avoided GWSA costs.[20]

The resulting 15-year levelized avoided cost (over 2018–2032) is about $41 per short ton, or $19 per MWh, as shown in Table 5.[21] Over 2019–2033, the resulting 15-year levelized avoided cost is about $35 per short ton, or $17 per MWh. See Appendix B. Avoided GWSA Compliance Costs for 10- and 30-year levelized avoided costs.

[20] Note that the 2018 AESC Study is different. It instead calculates a $100/ton non-embedded avoided cost of environmental compliance, which is based on the incremental cost to install carbon capture and sequestration technology on existing emitting facilities. In the 2018 AESC Study, the already modeled avoided cost of compliance with environmental regulations —e.g., 310 CMR 7.70 (RGGI), 310 CMR 7.74, and 310 CMR 7.75—are subtracted from the $100/ton value to determine the incremental avoided cost of reducing CO_2 emissions in a future with no additional energy efficiency.

[21] Note that in some years, a strategy's potential is estimated to be 0 GWh. This occurs in situations where more energy is assumed to be deployed from this strategy in the existing 2018 AESC Study, in the specified year. This occurs as a result of the 2018 AESC Study being a hypothetical future with no energy efficiency; in this future, energy prices are higher, and total MWh requirements under RPS policies are higher, changing the economic potential of various resources. Also note that in certain years, the estimated "all-in" cost for a particular strategy is less than the projected avoided energy price; in these years, we assume a "floor" price of $0 per MWh.

Table 3. Calculating the avoided cost of GWSA compliance in 2020

	All-In Costs	Incremental Costs		Incremental Potential		Notes
	2018 $/MWh	*2018 $/MWh*	*2018 $/short ton*	*GWh*	*million short tons*	
	a	*b*	*c*	*d*	*e*	*f*
Onshore wind	$68	$30	$64	0	0.0	
Offshore wind	-	-	-	-	-	*Assumed none in 2020*
Large solar	$40	$3	$5	6,013	2.9	*Utility*
Medium solar	$82	$44	$93	1,632	0.8	*Commercial*
Small solar	$105	$68	$142	1,348	0.6	*Residential*
Clean Energy Imports	-	-	-	-	-	*Assumed none in 2020*
Light-duty vehicle electrification	-	-	$0	-	0.1	*Public charging infrastructure costs only*
2020 Weighted Avg Avoided Cost	**-**	**-**	**$41**	**-**	**-**	

Notes: The weighted average avoided cost is calculated by calculating the average of $-per-ton values in column "c" using the weights in column "e". Potentials are incremental to the quantity of the strategy that is already modeled within the main 2018 AESC study. This $-per-ton value is then converted into an incremental $-per-MWh value (see Table 5) using the summer on-peak emission rate identified in Table 150 of the 2018 AESC Study (June 1 release). This note applies to this table, as well as Table 4.

Table 4. Calculating the avoided cost of GWSA compliance in 2030

	All-In Costs	Incremental Costs		Incremental Potential		Notes
	2018 $/MWh	*2018 $/MWh*	*2018 $/short ton*	*GWh*	*million short tons*	
	a	*b*	*c*	*d*	*e*	*f*
Onshore wind	$69	$18	$38	2,279	1.1	
Offshore wind	$66	$16	$33	79,845	38.0	
Large solar	$35	$0	$0	8,883	4.2	*Utility*
Medium solar	$58	$8	$17	2,143	1.0	*Commercial*
Small solar	$73	$23	$48	1,788	0.9	*Residential*
Clean Energy Imports	$60	$10	$20	58,100	27.7	
Light-duty vehicle electrification	-	-	$151	-	1.2	*Public charging infrastructure costs only*
2030 Weighted Avg Avoided Cost	**-**	**-**	**$28**	**-**	**-**	

Equation 1. Example of calculating the weighted average avoided cost

$A = \frac{\sum_{i=1}^{n} w_i c_i}{\sum_{i=1}^{n} w_i}$, where A is the weighted average avoided cost for 2030, w is the weight (measured in million short tons), and c is the cost (measured in 2018 \$/short ton)

$$A = \frac{(\$38)(1.1)+(\$33)(38)+(\$0)(4.2)+(\$17)(1.0)+(\$48)(0.9)+(\$20)(27.7)+(\$151)(1.2)}{1.1+38+4.2+1.0+0.9+27.7+1.2}$$

$$A = \$28 \text{ / short ton}$$

Table 5. Incremental avoided cost of GWSA compliance

Year	Incremental Avoided MA GWSA Cost (2018 $/ton) *a*	Incremental Avoided MA GWSA Cost (2018$/MWh) *b=a*emissions rate*
2018	$104.77	$49.87
2019	$58.24	$27.72
2020	$40.99	$19.51
2021	$39.72	$18.91
2022	$38.46	$18.31
2023	$37.19	$17.70
2024	$35.93	$17.10
2025	$34.67	$16.50
2026	$33.40	$15.90
2027	$32.14	$15.30
2028	$30.88	$14.70
2029	$29.61	$14.10
2030	$28.35	$13.49
2031	$27.08	$12.89
2032	$25.82	$12.29
2033	$24.69	$11.75
15-Year Levelized Avoided Cost (2018-2032)	**$40.61**	**$19.33**
15-Year Levelized Avoided Cost (2019-2033)	**$34.89**	**$16.61**

Note: Real discount rate of 1.34 percent. Values are converted from $-per-short-ton to $-per-MWh using the summer on-peak emissions rate identified in Table 150 of the 2018 AESC Study (June 1 Release). Avoided costs in this table have not been adjusted for distribution losses (assumed to be 8 percent).

These avoided costs may then be calculated in terms of $-per-MMBtu for non-electric fuels. Table 6 converts the 15-year levelized avoided cost values from column (a) in Table 5 into $-per-MMBtu values using the CO_2 emissions rates developed in the 2018 AESC Study. Compared to the avoided costs calculated in the 2018 AESC Study, these represent a 15 percent increase in the avoided cost of residential distillate fuel oil and a 36 percent increase in the avoided cost of residential natural gas.[22] See Appendix B for additional detail on non-electric avoided fuel costs.

Table 6. Incremental avoided costs of GWSA compliance for non-electric fuels

Fuel	Sector	Incremental avoided GWSA compliance cost 2018–2032 (2018 $ per MMBtu)	Incremental avoided GWSA compliance cost 2019–2033 (2018 $ per MMBtu)
Natural Gas	Residential	$2.38	$2.04
	Commercial	$2.38	$2.04
	Industrial	$2.38	$2.04
Distillate fuel oil	Residential	$3.27	$2.81
	Commercial	$3.27	$2.81
	Industrial	$3.27	$2.81
B5 Biofuel	All	$3.11	$2.67
B20 Biofuel	All	$2.62	$2.25
Kerosene	All	$3.23	$2.77
LPG	All	$2.82	$2.43
RFO	All	$3.51	$3.02
Wood	All	zero	zero
Wood & Waste	All	zero	zero

Notes: CO_2 emissions rates for wood and wood & waste are assumed to be zero (see 2018 AESC Study, June 1 Release, Table 149), resulting in a non-embedded CO_2 avoided cost of zero. As in the 2018 AESC Study, as the emission rates of non-electric fuels do not vary by time of day or season, there is only one set of annual compliance avoided cost values.

2.2. Costs and Potentials of Compliance Strategies

For each of the seven strategies (onshore and offshore wind, large [utility] solar, medium [commercial] solar, small [residential] solar, light-duty vehicle electrification, and clean energy imports), Synapse has conducted a literature review assessing the likely unit cost (in 2018 $/MWh or $/short ton) and emissions-reducing potential of each of the compliance strategies.[23] This section describes the specific approaches and sources used to calculate these values for each strategy. Note that some strategies

[22] See 2018 AESC Study, June 1 release, Table 117 and Table 130. Comparisons are shown relative to residential avoided costs only for the sake of simplicity. Natural gas percent changes are calculated using an example value of "All" residential natural gas avoided costs with some avoidable retail margin in Southern New England. Distillate fuel oil (DFO) percent changes are calculated using an example value of residential DFO avoided costs.

[23] Note that Synapse originally evaluated an eighth strategy: electrification of commuter rail equipment. However, because recent documentation from the MBTA's Focus 40 project (see https://static1.squarespace.com/static/57757a3cff7c50f318d8aae0/t/5b5f2ebef950b7feeb9eaf9a/1532964586865/FOCUS40_PRINT_DRAFT_07-30-2018.pdf) does not cite commuter rail electrification as an action it is pursuing before 2040, it was not included in this analysis. Note that the MBTA is launching a separate commuter rail study, which may eventually yield specific information about commuter rail electrification plans and costs (see https://www.mbta.com/news/2017-06-15/mbta-launching-study-future-needs-commuter-rail and https://www.mbta.com/projects/commuter-rail-vision).

(onshore and offshore wind; large, medium, and small solar) feature similar methodologies or sources, resulting in those strategies being discussed in combination below. This section also includes discussion of existing and proposed legislation and regulation linked with each strategy.

Wind (Onshore and Offshore)

Both onshore and offshore wind are eligible resources under the Massachusetts Class I RPS and the CES.[24] In addition to the Class I RPS and CES, both onshore and offshore wind are eligible resources under the Section 83D Clean Energy request for proposals. Offshore wind is the sole resource identified under the Section 83C Clean Energy request for proposals. In addition, both onshore and offshore wind were identified as strategies for meeting compliance with the Massachusetts GWSA in the 2015 update to the *Massachusetts Clean Energy and Climate Plan for 2020*.[25] For these reasons, deployment of onshore wind and offshore wind is assumed to be a reasonably foreseeable strategy for reducing GHG emissions in a future lacking incremental energy efficiency in 2018 and later years.

Much of the wind energy literature cites the U.S. Department of Energy's 2015 *Wind Vision* report, which analyzed future scenarios of onshore and offshore wind energy development through 2050.[26] However, authors of the *Wind Vision* report did not directly assess the economic potential of wind energy. Instead, they developed future plausible scenarios grounded in wind energy growth projections from the U.S. Energy Information Administration's Annual Energy Outlook and expanded with several sensitivities for future fuel costs and wind costs. As a result, Synapse relied on alternate resources that directly calculate the economic potential of wind energy in the northeastern United States. Synapse used different approaches to calculate the potential economic onshore and offshore wind energy resources, described in detail below.

Onshore wind energy potentials for 2018, 2019, 2020, and 2030 were calculated using results from NREL's 2017 Annual Technology Baseline (ATB) Cost and Performance Summary.[27] The annual generation values for the northeastern states reported in the NREL study were reduced by the onshore wind energy quantities already present in the 2018 AESC Study for each year analyzed, yielding an annual incremental amount of potential generation of 1 TWh in 2018, 0 TWh in 2019, 0 TWh in 2020,

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[24] See 225 CMR 14.00 (RPS) and 310 CMR 7.75 (CES)

[25] See www.mass.gov/eea/docs/eea/energy/cecp-for-2020.pdf.

[26] U.S. Department of Energy. Wind Vision: A New Era for Wind Power in the United States. March 2015. See https://openei.org/apps/wv_viewer/# for data visualization and download.

[27] See https://atb.nrel.gov/electricity/2017/summary.html and https://openei.org/apps/reeds/ for more detail. Economic potential data from the 2018 version of this study is not yet available. Economic potentials were aggregated from the 2017 study based on the scenarios that featured onshore wind costs most analogous to the "Mid" case modeled in the 2018 version of this study (available at https://atb.nrel.gov/electricity/2018/summary.html).

and 2.3 TWh in 2030.[28] Translating this to reduced CO_2 emissions using the 2018 AESC summer on-peak emissions rate yields an incremental reduction of 1.1 million short tons of CO_2 in 2030.[29]

For onshore wind, Synapse included potential generation data from all six New England states. Any wind energy generation in the region can be utilized as part of the MA Class I RPS, therefore the total wind energy potential in those six states is included in this analysis—less the amount already modeled in the 2018 AESC Study as part of Massachusetts' RPS and renewable policies in other states.

Onshore wind energy costs for 2018 were adopted using NREL's latest 2018 ATB Cost and Performance Summary. This approach yields all-in costs for onshore wind between $65 and $68 per MWh and $38 and $70 per short ton of CO_2 (see Table 7).[30]

Synapse estimated offshore wind energy generation potential using data derived from NREL's study "An Assessment of the Economic Potential of Offshore Wind in the United States from 2015 to 2030."[31] The original data was screened to only include offshore areas between 12–50 nautical miles offshore in Massachusetts and Rhode Island where it is possible to install fixed turbines.[32] These additional filters, after subtracting the quantity of offshore wind energy already modeled in the 2018 AESC Study, yield an offshore potential of about 80 TWh in 2030. Synapse did not calculate potentials for 2018 through 2020 because we assumed large-scale offshore wind deployment in Massachusetts would not be achievable until the early 2020s. Translating this to reduced CO_2 emissions using the AESC summer on-peak emissions rate yields an incremental reduction of 38 million short tons of CO_2.

Offshore energy costs were derived from the MA DOER 83C filing to the Department of Public Utilities, which states the levelized long-term generation cost of the offshore wind energy projects is 6.5 cents

[28] The 2018 AESC Study models a total of 5.9 TWh of onshore wind in 2020 (for example), versus the total economic potential of 4.9 TWh cited in the 2017 NREL ATB study. The 2018 AESC Study features a higher quantity of potential generation in this year due to a variety of reasons, including likely differences in assumptions relating to technology costs and differences in terms of market prices for energy (i.e., the 2018 AESC Study features higher-than-otherwise-expected avoided energy costs since it models a future without incremental energy efficiency). This same logic was applied to 2019.

[29] During the summer on-peak period, this value is approximately 952 lbs per MWh (see 2018 AESC Study, June 1 Release, Table 150). Note that this value does not vary substantially throughout the year.

[30] These cost ranges reflect the changing costs of wind technology based on technological improvements and the phase-out of the production tax credit (PTC), as well as the changing price of energy as calculated in the 2018 AESC Study.

[31] See https://www.nrel.gov/docs/fy15osti/64503.pdf. This data source was chosen as it is a recent analysis that contains a particularly high level of resolution on wind deployment in New England.

[32] The range of 12–50 nautical miles offshore was determined to be the economic region by Sustainable Energy Advantage (SEA. Northeast Offshore Wind Regional Market Characterization. 2017). Available at https://www.cesa.org/assets/Uploads/Northeast-Offshore-Wind-Regional-Market-Characterization.pdf). While offshore wind resources throughout New England are theoretically eligible to receive credit under the Massachusetts Class I RPS and CES, this analysis focuses on the regions currently associated with offshore wind energy leases: Massachusetts and Rhode Island. This report also deems floating turbines to not yet be a commercial technology; therefore, this assessment further filtered the economic regions to only include areas where fixed turbines can be installed. Note that this "filtering" methodology was used instead of relying on a previous study's analysis of economic potential because of the rapid changes taking place in the likely costs of offshore wind installed in New England.

per kWh in 2017 dollars.[33] This equates to $66 per MWh in 2018 dollars in 2030 (see Table 7). Subtracting the estimated cost of energy and converting this value into units of dollars-per-short-ton yields an offshore wind cost of approximately $33 per short ton of CO_2 in 2030.

Table 7. Onshore and offshore wind energy costs and potentials

Year	Onshore Wind		Offshore Wind	
	All-In Cost (2018 $/MWh)	*Incremental Potential (TWh)*	*All-In Cost (2018 $/MWh)*	*Incremental Potential (TWh)*
2018	$65	1.0	-	-
2019	$65	0.0	-	-
2020	$68	0.0	-	-
⋮				
2030	$69	2.3	$66	79.8

Note: Only offshore zones in Massachusetts and Rhode Island are considered economic in this study due to the location of offshore wind energy leases.

Solar (Large, Medium, and Small)

This analysis includes large, medium, and small solar categories across all six New England states. For the purposes of this analysis, we define "large" solar as being utility-scale, "medium" solar as being distributed solar at commercial and industrial sites, and "small" solar as being distributed solar at residential sites. As with wind energy, any solar energy generation in the region can be utilized as part of the Massachusetts Class 1 RPS, therefore solar from all six states was included. All solar resources are eligible resources under both Massachusetts' Class I RPS and CES. Solar was also identified as an eligible resource under the Section 83D Clean Energy request for proposals. In addition, specific types of solar programs are eligible under other programs promulgated by the Commonwealth, including the Class I solar carve-out, and the Solar Massachusetts Renewable Target (SMART) Program.[34] Solar resources were also identified as a strategy for meeting compliance with the Massachusetts GWSA in the 2015 update to the *Massachusetts Clean Energy and Climate Plan for 2020*. For these reasons, deployment of large, medium, and small solar is assumed to be a reasonably foreseeable strategy for reducing GHG emissions in a future without incremental energy efficiency in 2018 and later years.

[33] See https://macleanenergy.files.wordpress.com/2018/08/doer-83c-filing-letter-dpu-18-76-18-77-18-78august-1-2018.pdf. Note that this cost assumes that the proposed projects under 83C will be eligible for the federal tax credit, which is phasing out. We did not consider the impact of this tax credit phase-out, or the impacts of any potential cost improvements for offshore wind.

[34] See https://www.mass.gov/service-details/development-of-the-solar-massachusetts-renewable-target-smart-program.

Synapse first calculated the economic potential for all three sizes of solar. As with onshore wind, we relied on NREL's 2017 ATB Cost and Performance Summary.[35] To estimate distributed solar independently for both the residential and commercial sectors, we relied on NREL's 2016 study "Rooftop Solar Photovoltaic Technical Potential in the United States."[36] This study provides technical potential for all three categories of solar. We calculated the relationship between the technical and economic potential of distributed and utility solar in the two NREL studies and applied this ratio to the technical potential for both commercial and residential solar. We then subtracted the quantity of solar capacity already estimated to be in place in each analyzed year in the 2018 AESC Study from the total economic potential values to determine "residual" values for solar potential.[37] This results in the potential generation described in Table 8. When converted into avoided emissions, these resources are estimated to together incrementally avoid 6.1 million short tons in 2030.

We next calculated the levelized cost of solar resources. NREL's 2018 ATB Cost and Performance Summary provides national levelized costs of energy (LCOE) for large, medium, and small solar resources in 2030.[38] In 2018, 2019, 2020, and 2030, we estimate a range of "all-in" LCOEs from $35 to $115 per MWh; when these costs are converted to dollar-per-short-ton values, and the 2018 cost of energy is subtracted, they yield a range of $0 to $175 per short ton of CO_2 (see Table 8).[39]

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[35] See https://atb.nrel.gov/electricity/2017/summary.html and https://openei.org/apps/reeds/ for more detail. Economic potential data from the 2018 version of this study is not yet available. Economic potentials were aggregated from the 2017 study based on the scenarios that featured large, medium, and small solar costs most analogous to the "Mid" case modeled in the 2018 version of this study (available at https://atb.nrel.gov/electricity/2018/summary.html).

[36] Available at https://www.nrel.gov/docs/fy16osti/65298.pdf.

[37] Note that ISO New England also conducts a solar forecast, the most recent of which is the "2018 PV Forecast" (available at https://www.iso-ne.com/static-assets/documents/2018/03/a03-2018-pv-forecast.pdf). Note that the quantities of solar projected by ISO New England's solar forecast are smaller than the solar resources already modeled in the existing 2018 AESC study and therefore are not used in this analysis.

[38] Available at https://atb.nrel.gov/electricity/2018/summary.html. NREL's ATB study provides levelized costs for a selected number of regions around the United States. While New England is not one such region, we applied the cost values associated with Chicago given that it has the most comparable capacity factors to New England. Note that we also reviewed other studies, such as Lazard's Levelized Cost of Energy Analysis – Version 11.0 (available at https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf); this study and others were used by NREL in its ATB analysis to develop a projection of future costs, making it most appropriate to rely on the NREL ATB study.

[39] These costs reflect technological improvements, as well as the phase-out of the investment tax credit (ITC) and the changing price of energy as calculated in the 2018 AESC Study. In 2030, the expected cost of large solar is below the avoided cost of energy modeled in the 2018 AESC Study. As a result, we assume that the incremental cost of pursuing this specific measure is capped at $0 per MWh, and $0 per short ton.

Table 8. Estimated solar energy costs and potentials

Year	Large Solar		Medium Solar		Small Solar	
	All-In Cost (2018 $/MWh)	*Incremental Potential (TWh)*	*All-In Cost (2018 $/MWh)*	*Incremental Potential (TWh)*	*All-In Cost (2018 $/MWh)*	*Incremental Potential (TWh)*
2018	$42	1.1	$86	1.2	$114	1.7
2019	$43	5.6	$86	1.3	$115	1.1
2020	$40	6.0	$82	1.6	$105	1.3
⋮						
2030	$35	8.9	$58	2.1	$73	1.8

Clean Energy Imports

Clean Energy Imports (defined in this document as energy purchased from large hydroelectric facilities via newly built transmission lines) are an eligible resource under Massachusetts' CES. Clean Energy Imports were also identified as an eligible resource under the Section 83D Clean Energy request for proposals, and as a strategy for meeting compliance with the Massachusetts GWSA in the 2015 update to the *Massachusetts Clean Energy and Climate Plan for 2020*. For these reasons, deployment of Clean Energy Imports is assumed to be a reasonably foreseeable strategy for reducing GHG emissions in a future lacking incremental energy efficiency in 2018 and later years.

In this analysis, the cost associated with Clean Energy Imports comes directly from the Massachusetts DOER 83D filing to the Department of Public Utilities, which states the levelized long-term generation cost of the New England Clean Energy Connect (NECEC) project is 5.9 cents per kWh in 2017 dollars.[40] This equates to $60 per MWh in 2018 dollars.

To estimate energy potential for Clean Energy Imports, we first relied on the annual Clean Energy Import generation modeled in the 2018 AESC Study (8.3 TWh). This value is assumed to represent the potential added generation from a single transmission line carrying clean energy imports from Canada.[41] We assume that the maximum possible annual incremental generation from Clean Energy Imports is limited to one transmission line per year.[42] Given that 2023 is the first full year Clean Energy Imports are assumed to be operational (Table 9), we calculated the maximum generation potential in 2030 by multiplying the transmission line potential (8.3 TWh) by eight years (2023 to 2030). That value was then reduced by the Clean Energy Imports generation modeled in the 2018 AESC Study, yielding a potential of 58.1 TWh in 2030, or an avoided potential of 27.7 million short tons. Because the first Clean Energy

[40] See https://macleanenergy.files.wordpress.com/2018/07/doer-83d-filing-letter-dpu-18-64-18-65-18-66july-23-2018.pdf.

[41] The majority of the 2018 AESC Study was completed before the winning proposal under 83D was announced. The project ultimately selected under 83D, the New England Clean Energy Connect (NECEC), is proposed to provide 9.55 TWh of energy to Massachusetts beginning in 2023.

[42] Note that this analysis does not make any assumptions as to the siting or feasibility of any particular CEI project.

Imports line will not be producing electricity until 2023, we do not model any potentials or costs for 2020.

Table 9. Clean Energy Import timeline and potential annual generation in years 2023 to 2030

Clean Energy Import name	Online date	Year fully energized	Generation (TWh)
83D Modeled in AESC 2018	31 Dec 2022	2023	8.3
CEI A	31 Dec 2023	2024	8.3
CEI B	31 Dec 2024	2025	8.3
CEI C	31 Dec 2025	2026	8.3
CEI D	31 Dec 2026	2027	8.3
CEI E	31 Dec 2027	2028	8.3
CEI F	31 Dec 2028	2029	8.3
CEI G	31 Dec 2029	2030	8.3
Total CEI in 2030 (TWh)			**66.4**
Incremental CEI in 2030, relative to AESC 2018 (TWh)			**58.1**
Cost of CEI in 2030 (2018 $/MWh)			**$60**

Light-Duty Vehicle Electrification

Light-duty vehicle electrification is identified as a strategy for meeting compliance with the Massachusetts GWSA in the 2015 update to the *Massachusetts Clean Energy and Climate Plan for 2020*. Massachusetts is also a signatory to the zero-emission vehicle memorandum of understanding (i.e., the "ZEV MOU"), a document signed by nine states that commits these states to having at least 3.3 million electric vehicles (EV) operating on their roadways by 2025.[43] When this 3.3 million vehicle number is apportioned using vehicle stock or vehicle miles traveled values, it results in approximately 300,000 EVs for Massachusetts in 2025.[44] In addition, as of August 2018, one Massachusetts electric distribution company (EDC) has already received approval from the Massachusetts Department of Public Utilities to install charging infrastructure to incent the adoption of EVs. The approval creates a precedent wherein electric ratepayers pay for the cost of building publicly sited EV charging infrastructure.[45] For these reasons, deployment of light-duty vehicle electrification infrastructure is assumed to be a reasonably

[43] See https://www.mass.gov/news/massachusetts-joins-nine-state-coalition-in-releasing-new-zero-emission-vehicle-action-plan.

[44] Note that because Massachusetts follows California's emission standards under Section 177 of the Clean Air Act, the Commonwealth is projected to have 160,000 EVs on the road in 2025 (this is in line with the California Air Resources Board's (CARB) 2017 report *California's Advanced Clean Cars Midterm Review*, available at https://www.arb.ca.gov/msprog/acc/mtr/acc_mtr_finalreport_full.pdf). The main scenario modeled in the 2018 AESC Study did not model any incremental EVs in place in Massachusetts or other states.

[45] See D.P.U. 12-95, D.P.U. 13-182, D.P.U. 17-05, and D.P.U. 17-13.

foreseeable strategy for reducing GHG emissions in a future lacking incremental energy efficiency in 2018 and later years.

This analysis assumes a potential for emissions reductions in Massachusetts linked to its ZEV MOU commitment (300,000 EVs by 2025). Synapse used an in-house EV adoption model to project how many EVs would be on the road in Massachusetts in 2030, given the interim target of 300,000 EVs by 2025. The EV model uses a Bass Diffusion growth curve and projects that approximately 1.2 million EVs will be on the road by 2030.[46] Additional outputs taken from this model include: annual wholesale electricity usage by EVs, avoided gasoline emissions, and annual EV sales.

For this analysis, Synapse considered only the cost of installing publicly sited, non-residential EV supply equipment (EVSE), or charging stations, to reach the potential EV penetration in 2030.[47] This analysis includes equipment and installation costs associated with Level 1 chargers, Level 2 chargers, and Direct Current Fast Chargers (DCFC).[48] NREL's January 2017 study "Infrastructure for Plug-In Electric Vehicles: A Case Study of Massachusetts" estimates the number of charging plugs—Level 1 (L1), Level 2 (L2), and DCFC—required for Massachusetts to reach its 2025 EV goal (see Table 10).[49]

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46 For this analysis, EVs include battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). The model assumes that 40 percent of EVs on the road are BEV and 60 percent are PHEVs, based on 2017 sales data from the Auto Alliance. For original EV sales data see: https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/ . This model also assumes that 50 percent of light-duty vehicles in Massachusetts are cars, with the rest being light trucks, based on 2016 fleet composition data. Massachusetts fleet composition data comes from the Federal Highway Administration's Highway Statistics: https://www.fhwa.dot.gov/policyinformation/statistics.cfm. Finally, the model assumes that 50 percent of the vehicle miles traveled by PHEVs is run on electricity, based on the central scenario of the NREL study "National Plug-In Electric Vehicle Infrastructure Analysis" (September 2017).

47 The cost of publicly sited, non-residential EVSE is the cost component most likely to be addressed through state-level policymaking or utility incentives, and therefore borne by ratepayers. This is in line with programs like Eversource's "Make Ready" program (described above) wherein MA D.P.U. has approved that electric ratepayers may bear the cost of installing publicly sited electric vehicle charging infrastructure. As a result, the cost of the electric vehicles and home chargers were not included in this analysis. This analysis also does not make any assumptions regarding the economics of EVs relative to conventional vehicles in 2030, which may vary a great deal depending on the assumptions used for upfront cost, fuel savings, and maintenance savings.

48 Only non-residential (workplace and public) EV charging stations were considered in this analysis. Generally speaking, workplace chargers are those which are accessible to employees of the company where the charger is sited, whereas public charging stations are available to any EV driver. Level 1 (L1) chargers provide electricity at 1 kW; these chargers may require 8–15 hours for a full charge. Level 2 (L2) chargers provide faster electricity than L1 chargers, at about 6 kW; a full charge may require 3–8 hours. Direct current fast chargers (DCFC) provide electricity at 50 kW and require 20 minutes to an hour for a full charge.

49 See https://www.nrel.gov/docs/fy17osti/67436.pdf.

Table 10. Number of plugs required to meet the Massachusetts goal of 300,000 EVs on the road by 2025, by charger type

Charger Type	Plugs Required for 2025 EV Goal				
	Low Estimate Total Plugs	*High Estimate Total Plugs*	*Average Total Plugs*	*Average Plugs per 1,000 EV*	*Average Total Plugs*
Work L1	33,700	40,800	37,250	124	148,985
Public L1	1,000	2,400	1,700	6	6,799
Work L2	3,700	4,500	4,100	14	16,398
Public L2	3,700	40,700	22,200	74	88,791
DCFC	220	1,600	910	3	3,640
Total	**42,320**	**90,000**	**66,160**	**221**	**264,613**

Source: NREL. Infrastructure for Plug-In Electric Vehicles: A Case Study of Massachusetts. January 2017.

The ratio of plugs per EV was applied to the projected number of EVs on the road in 2030 from the EV model to calculate the total number of plugs required in 2030. That value was then converted from plugs to charging stations, as stations commonly have multiple plugs.[50] Using EVSE equipment and installation costs from the Department of Energy's 2015 report "Costs Associated with Non-Residential Electric Vehicle Supply Equipment" (see Table 11), we calculated a total EVSE cost for 2030.[51]

Table 11. Equipment and installation costs associated with each type of EV charging station

Charger Type	Equipment Costs			Installation Costs		
	Low 2011 $	*High 2011 $*	*Average 2011 $*	*Low 2011 $*	*High 2011 $*	*Average 2011 $*
Level 1	$300	$1,500	**$900**	$0	$3,000	$1,500
Level 2	$400	$6,500	**$3,450**	$600	$12,700	$6,650
DCFC	$10,000	$40,000	**$25,000**	$4,000	$51,000	$27,500
Total	**$10,700**	**$48,000**	**$29,350**	**$4,600**	**$66,700**	**$35,650**

Source: U.S. DOE. Costs Associated with Non-Residential Electric Vehicle Supply Equipment. November 2015.

Because the EVSE costs associated with the 2030 EV goal will be spent incrementally between 2018 and 2030, the total cost was spread over the period of 2018 through 2030, scaled to the number of EV sales

[50] We assume an average of one plug per station for L1, two plugs per station for L2 (per requirements of MassDEP's MassEVIP [Electric Vehicle Incentive Program] grant application for Fleets, available at https://www.mass.gov/files/documents/2017/11/08/massevipap_6.pdf), and four plugs per station for DCFC (NREL Sept. 2017, available at https://www.nrel.gov/docs/fy17osti/69031.pdf).

[51] These costs are for single-plug charging stations, but they were applied for all chargers due to a lack of data on how cost scales with additional ports. See https://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf for more information.

estimated for each year. Furthermore, because EVSE funds have already been committed via the Volkswagen Settlement Funds[52] and the Eversource Make-Ready Program[53] and are therefore not paid by ratepayers (VW) or are unavoidable (Eversource), those annual investments were subtracted from 2019 to 2022, yielding the net annual EVSE cost needed to achieve the Massachusetts EV goal in those years. The incremental 2030 costs were used to calculate the all-in costs for EVs in 2030. In 2020, the estimated incremental cost of EVSE deployment is $0 million. In 2030, the estimated incremental cost of EVSE deployment is $185 million (see Table 12). Note that reliance on public EVSE decreases as vehicle range improves, meaning that cost estimates may be lower if electric vehicle technological advancements continue.

Synapse calculated emissions impacts by taking the avoided gasoline emissions from the EV model and subtracting the additional emissions from grid electricity usage by EVs. Additional emissions were calculated for each year by multiplying the annual EV grid electricity usage (TWh) from the EV model by the 2018 AESC average summer electricity emissions rate. This yields a potential of 1.2 million short tons of avoided CO_2 emissions in 2030, implying a cost per short ton of $151 (see Table 12).

Table 12. Incremental costs and avoided emissions from electrification of light-duty vehicles in 2020 and 2030

		2018	2019	2020	2030
Total Incremental EVSE Expenditures	*2018 $ million*	$6	$9	$12	$185
VW Settlement Investment	*2018 $ million*	$0	-$5	-$3	$0
Eversource Makeready Investment	*2018 $ million*	$0	$0	-$9	$0
Net Incremental EVSE Expenditures	*2018 $ million*	$6	$4	$0	$185
Net Avoided Emissions	*million short tons*	0.05	0.06	0.08	1.22
Incremental EVSE Cost	*2018 $ million / short ton*	$117	$55	$0	$151

Note: In 2020, the net incremental EVSE expenditures is $0 million because the Volkswagen Funds and the Eversource Make-Ready program together fulfill the required EVSE investment for that year. The same is true for 2021 and 2022 (not shown).

[52] Massachusetts plans to spend $5 million (of the $11.25 million available for EVSE) in 2019, the first year of the program. We assume that remaining available funds are spent equally in the two subsequent years (2020 and 2021). See https://www.mass.gov/files/documents/2018/07/19/vw-draftbmp_0.pdf for more information.

[53] Eversource is committing $45 million from 2020 through 2022 for "make-ready" electric vehicle charging infrastructure, which includes all prep and site work for everything up to, but not including, the charging station (i.e., the Eversource program covers the installation portion of total EVSE costs, but not the equipment costs). In 2022, 100 percent of the required EVSE investment for that year is fulfilled by Eversource Make Ready program; the implicit assumption is that Eversource's three-year investment front-loads make-ready infrastructure, allowing investments in later years to be directed more towards the accompanying charging stations. See https://www.eversource.com/content/docs/default-source/investors/d-p-u-17-05-final-order-(revenue-requirement)-11-30-17.pdf for more information.

APPENDIX A. AVOIDED COST OF GWSA COMPLIANCE DETAIL

This section provides additional detail on the derivation of avoided costs for 2018 and 2019 in Table 13 and Table 14. The detail in these tables correspond to the detail presented for 2020 and 2030 (see Table 3 and Table 4).

Table 13. Calculating the avoided cost of GWSA compliance in 2018

	All-In Costs	Incremental Costs		Incremental Potential		Notes
	2018 $/MWh	*2018 $/MWh*	*2018 $/short ton*	*GWh*	*million short tons*	
	a	*b*	*c*	*d*	*e*	*f*
Onshore wind	$65	$33	$69	1,011	0.5	
Offshore wind	-	-	-	-	-	*Assumed none in 2018*
Large solar	$42	$10	$21	1,128	0.5	*Utility*
Medium solar	$86	$54	$114	1,152	0.5	*Commercial*
Small solar	$114	$82	$172	1,738	0.8	*Residential*
Clean Energy Imports	-	-	-	-	-	*Assumed none in 2018*
Light-duty vehicle electrification	-	-	$117	-	0.1	*Public charging infrastructure costs only*
2018 Weighted Avg Avoided Cost	**-**	**-**	**$105**	**-**	**-**	

Notes: The weighted average avoided cost is calculated by calculating the average of $-per-ton values in column "c" using the weights in column "e". Potentials are incremental to the quantity of the strategy that is already modeled within the main 2018 AESC study. This $-per-ton value is then converted into an incremental $-per-MWh value (see Table 5) using the summer on-peak emission rate identified in Table 150 of the 2018 AESC Study (June 1 release). This note applies to this table, as well as Table 14.

Table 14. Calculating the avoided cost of GWSA compliance in 2019

	All-In Costs	Incremental Costs		Incremental Potential		Notes
	2018 $/MWh	*2018 $/MWh*	*2018 $/short ton*	*GWh*	*million short tons*	
	a	*b*	*c*	*d*	*e*	*f*
Onshore wind	$65	$33	$70	0	0.0	
Offshore wind	-	-	-	-	-	*Assumed none in 2019*
Large solar	$43	$11	$23	5,614	2.7	*Utility*
Medium solar	$86	$55	$115	1,303	0.6	*Commercial*
Small solar	$115	$83	$175	1,073	0.5	*Residential*
Clean Energy Imports	-	-	-	-	-	*Assumed none in 2019*
Light-duty vehicle electrification	-	-	$55	-	0.1	*Public charging infrastructure costs only*
2019 Weighted Avg Avoided Cost	**-**	**-**	**$58**	**-**	**-**	

APPENDIX B. AVOIDED GWSA COMPLIANCE COSTS

The following tables contain detailed annual information on the avoided costs of Massachusetts GWSA compliance. Table 15 provides information on avoided costs for electric measures in a similar format to Appendix B of the 2018 AESC Study. Table 16 provides information for avoided costs for non-electric measures in a similar format to Table 130 of the 2018 AESC Study.

Table 15. Massachusetts GWSA avoided cost of compliance for electric measures

	Wholesale Incremental GWSA Cost of Compliance				Retail Incremental GWSA Cost of Compliance[1]			
	Winter Peak	Winter Off-Peak	Summer Peak	Summer Off-Peak	Winter Peak	Winter Off-Peak	Summer Peak	Summer Off-Peak
Units:	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh
Period:	i	ii	iii	iv	v = i*(1+DL)	vi = ii*(1+DL)	vii = iii*(1+DL)	viii = iv*(1+DL)
2018	0.0512	0.0523	0.0499	0.0502	0.0553	0.0565	0.0539	0.0543
2019	0.0285	0.0291	0.0277	0.0279	0.0308	0.0314	0.0299	0.0302
2020	0.0200	0.0205	0.0195	0.0197	0.0216	0.0221	0.0211	0.0212
2021	0.0194	0.0198	0.0189	0.0190	0.0210	0.0214	0.0204	0.0206
2022	0.0188	0.0192	0.0183	0.0184	0.0203	0.0207	0.0198	0.0199
2023	0.0182	0.0186	0.0177	0.0178	0.0196	0.0201	0.0191	0.0193
2024	0.0176	0.0179	0.0171	0.0172	0.0190	0.0194	0.0185	0.0186
2025	0.0170	0.0173	0.0165	0.0166	0.0183	0.0187	0.0178	0.0180
2026	0.0163	0.0167	0.0159	0.0160	0.0176	0.0180	0.0172	0.0173
2027	0.0157	0.0161	0.0153	0.0154	0.0170	0.0173	0.0165	0.0166
2028	0.0151	0.0154	0.0147	0.0148	0.0163	0.0167	0.0159	0.0160
2029	0.0145	0.0148	0.0141	0.0142	0.0156	0.0160	0.0152	0.0153
2030	0.0139	0.0142	0.0135	0.0136	0.0150	0.0153	0.0146	0.0147
2031	0.0132	0.0135	0.0129	0.0130	0.0143	0.0146	0.0139	0.0140
2032	0.0126	0.0129	0.0123	0.0124	0.0136	0.0139	0.0133	0.0134
2033	0.0121	0.0123	0.0118	0.0118	0.0130	0.0133	0.0127	0.0128
2034	0.0115	0.0118	0.0112	0.0113	0.0125	0.0127	0.0121	0.0122
2035	0.0110	0.0113	0.0107	0.0108	0.0119	0.0122	0.0116	0.0117
2036	0.0106	0.0108	0.0103	0.0104	0.0114	0.0116	0.0111	0.0112
2037	0.0101	0.0103	0.0098	0.0099	0.0109	0.0111	0.0106	0.0107
2038	0.0097	0.0099	0.0094	0.0095	0.0104	0.0107	0.0102	0.0102
2039	0.0092	0.0094	0.0090	0.0091	0.0100	0.0102	0.0097	0.0098
2040	0.0088	0.0090	0.0086	0.0087	0.0095	0.0097	0.0093	0.0094
2041	0.0084	0.0086	0.0082	0.0083	0.0091	0.0093	0.0089	0.0089
2042	0.0081	0.0082	0.0079	0.0079	0.0087	0.0089	0.0085	0.0086
2043	0.0077	0.0079	0.0075	0.0076	0.0083	0.0085	0.0081	0.0082
2044	0.0074	0.0075	0.0072	0.0072	0.0080	0.0081	0.0078	0.0078
2045	0.0071	0.0072	0.0069	0.0069	0.0076	0.0078	0.0074	0.0075
2046	0.0068	0.0069	0.0066	0.0066	0.0073	0.0074	0.0071	0.0072
2047	0.0065	0.0066	0.0063	0.0063	0.0070	0.0071	0.0068	0.0068
2048	0.0062	0.0063	0.0060	0.0061	0.0067	0.0068	0.0065	0.0065
2049	0.0059	0.0060	0.0057	0.0058	0.0064	0.0065	0.0062	0.0063
2050	0.0056	0.0058	0.0055	0.0055	0.0061	0.0062	0.0059	0.0060

Levelized Costs								
10 years (2018-2027)	0.0226	0.0230	0.0220	0.0221	0.0244	0.0249	0.0237	0.0239
15 years (2018-2032)	0.0199	0.0203	0.0193	0.0195	0.0214	0.0219	0.0209	0.0210
30 years (2018-2047)	0.0150	0.0153	0.0146	0.0147	0.0162	0.0166	0.0158	0.0159

Levelized Costs								
10 years (2019-2028)	0.0188	0.0192	0.0183	0.0184	0.0203	0.0207	0.0197	0.0199
15 years (2019-2033)	0.0171	0.0174	0.0166	0.0167	0.0184	0.0188	0.0179	0.0181
30 years (2019-2048)	0.0133	0.0136	0.0129	0.0130	0.0144	0.0147	0.0140	0.0141

*Notes: All avoided costs are in 2018 Dollars. ISO New England periods are: Summer is June through September; winter is all other months. Peak hours are Monday through Friday 7 AM–11 PM; Off-Peak Hours are all other hours. Avoided retail cost of GWSA compliance = (wholesale avoided cost) * (1 + Distribution Losses), e.g., v = i * (1 + 8.0%).*

Table 16. Avoided costs of Massachusetts GWSA compliance for natural gas, petroleum fuels, and other fuels by sector

Year	Natural Gas			Fuel Oils							Other Fuels				
				Residential	Commercial			Industrial			Residential				Industrial
	Residential	Commercial	Industrial	Distillate Fuel Oil	Distillate Fuel Oil	Residual Fuel Oil	Weighted Average	Distillate Fuel Oil	Residual Fuel Oil	Weighted Average	Cord Wood	Pellets	Kerosene	Propane	Kerosene
	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu	$/MMBtu
2018	$6.13	$6.13	$6.13	$8.43	$8.43	$9.06	$8.45	$8.43	$9.06	$8.48	$0.00	$0.00	$8.33	$7.28	$8.33
2019	$3.41	$3.41	$3.41	$4.69	$4.69	$5.04	$4.70	$4.69	$5.04	$4.72	$0.00	$0.00	$4.63	$4.05	$4.63
2020	$2.40	$2.40	$2.40	$3.30	$3.30	$3.55	$3.31	$3.30	$3.55	$3.32	$0.00	$0.00	$3.26	$2.85	$3.26
2021	$2.32	$2.32	$2.32	$3.20	$3.20	$3.44	$3.21	$3.20	$3.44	$3.22	$0.00	$0.00	$3.16	$2.76	$3.16
2022	$2.25	$2.25	$2.25	$3.10	$3.10	$3.33	$3.10	$3.10	$3.33	$3.11	$0.00	$0.00	$3.06	$2.67	$3.06
2023	$2.18	$2.18	$2.18	$2.99	$2.99	$3.22	$3.00	$2.99	$3.22	$3.01	$0.00	$0.00	$2.96	$2.59	$2.96
2024	$2.10	$2.10	$2.10	$2.89	$2.89	$3.11	$2.90	$2.89	$3.11	$2.91	$0.00	$0.00	$2.86	$2.50	$2.86
2025	$2.03	$2.03	$2.03	$2.79	$2.79	$3.00	$2.80	$2.79	$3.00	$2.81	$0.00	$0.00	$2.76	$2.41	$2.76
2026	$1.95	$1.95	$1.95	$2.69	$2.69	$2.89	$2.70	$2.69	$2.89	$2.70	$0.00	$0.00	$2.66	$2.32	$2.66
2027	$1.88	$1.88	$1.88	$2.59	$2.59	$2.78	$2.59	$2.59	$2.78	$2.60	$0.00	$0.00	$2.56	$2.23	$2.56
2028	$1.81	$1.81	$1.81	$2.49	$2.49	$2.67	$2.49	$2.49	$2.67	$2.50	$0.00	$0.00	$2.45	$2.15	$2.45
2029	$1.73	$1.73	$1.73	$2.38	$2.38	$2.56	$2.39	$2.38	$2.56	$2.40	$0.00	$0.00	$2.35	$2.06	$2.35
2030	$1.66	$1.66	$1.66	$2.28	$2.28	$2.45	$2.29	$2.28	$2.45	$2.30	$0.00	$0.00	$2.25	$1.97	$2.25
2031	$1.58	$1.58	$1.58	$2.18	$2.18	$2.34	$2.19	$2.18	$2.34	$2.19	$0.00	$0.00	$2.15	$1.88	$2.15
2032	$1.51	$1.51	$1.51	$2.08	$2.08	$2.23	$2.08	$2.08	$2.23	$2.09	$0.00	$0.00	$2.05	$1.79	$2.05
2033	$1.44	$1.44	$1.44	$1.99	$1.99	$2.14	$1.99	$1.99	$2.14	$2.00	$0.00	$0.00	$1.96	$1.72	$1.96
2034	$1.38	$1.38	$1.38	$1.90	$1.90	$2.04	$1.91	$1.90	$2.04	$1.91	$0.00	$0.00	$1.88	$1.64	$1.88
2035	$1.32	$1.32	$1.32	$1.82	$1.82	$1.95	$1.82	$1.82	$1.95	$1.83	$0.00	$0.00	$1.80	$1.57	$1.80
2036	$1.26	$1.26	$1.26	$1.74	$1.74	$1.87	$1.74	$1.74	$1.87	$1.75	$0.00	$0.00	$1.72	$1.50	$1.72
2037	$1.21	$1.21	$1.21	$1.66	$1.66	$1.79	$1.67	$1.66	$1.79	$1.67	$0.00	$0.00	$1.64	$1.44	$1.64
2038	$1.16	$1.16	$1.16	$1.59	$1.59	$1.71	$1.59	$1.59	$1.71	$1.60	$0.00	$0.00	$1.57	$1.37	$1.57
2039	$1.10	$1.10	$1.10	$1.52	$1.52	$1.63	$1.52	$1.52	$1.63	$1.53	$0.00	$0.00	$1.50	$1.31	$1.50
2040	$1.06	$1.06	$1.06	$1.45	$1.45	$1.56	$1.46	$1.45	$1.56	$1.46	$0.00	$0.00	$1.44	$1.25	$1.44
2041	$1.01	$1.01	$1.01	$1.39	$1.39	$1.49	$1.39	$1.39	$1.49	$1.40	$0.00	$0.00	$1.37	$1.20	$1.37
2042	$0.97	$0.97	$0.97	$1.33	$1.33	$1.43	$1.33	$1.33	$1.43	$1.34	$0.00	$0.00	$1.31	$1.15	$1.31
2043	$0.92	$0.92	$0.92	$1.27	$1.27	$1.37	$1.27	$1.27	$1.37	$1.28	$0.00	$0.00	$1.26	$1.10	$1.26
2044	$0.88	$0.88	$0.88	$1.22	$1.22	$1.31	$1.22	$1.22	$1.31	$1.22	$0.00	$0.00	$1.20	$1.05	$1.20
2045	$0.84	$0.84	$0.84	$1.16	$1.16	$1.25	$1.17	$1.16	$1.25	$1.17	$0.00	$0.00	$1.15	$1.00	$1.15
2046	$0.81	$0.81	$0.81	$1.11	$1.11	$1.19	$1.11	$1.11	$1.19	$1.12	$0.00	$0.00	$1.10	$0.96	$1.10
2047	$0.77	$0.77	$0.77	$1.06	$1.06	$1.14	$1.07	$1.06	$1.14	$1.07	$0.00	$0.00	$1.05	$0.92	$1.05
2048	$0.74	$0.74	$0.74	$1.02	$1.02	$1.09	$1.02	$1.02	$1.09	$1.02	$0.00	$0.00	$1.00	$0.88	$1.00
2049	$0.71	$0.71	$0.71	$0.97	$0.97	$1.04	$0.97	$0.97	$1.04	$0.98	$0.00	$0.00	$0.96	$0.84	$0.96
2050	$0.68	$0.68	$0.68	$0.93	$0.93	$1.00	$0.93	$0.93	$1.00	$0.94	$0.00	$0.00	$0.92	$0.80	$0.92
Levelized Costs															
10 years (2018-2027)	$2.70	$2.70	$2.70	$3.71	$3.71	$3.99	$3.72	$3.71	$3.99	$3.74	$0.00	$0.00	$3.67	$3.21	$3.67
15 years (2018-2032)	$2.38	$2.38	$2.38	$3.27	$3.27	$3.51	$3.28	$3.27	$3.51	$3.29	$0.00	$0.00	$3.23	$2.82	$3.23
30 years (2018-2047)	$1.80	$1.80	$1.80	$2.47	$2.47	$2.66	$2.48	$2.47	$2.66	$2.49	$0.00	$0.00	$2.44	$2.13	$2.44
Levelized Costs															
10 years (2019-2028)	$2.25	$2.25	$2.25	$3.09	$3.09	$3.32	$3.10	$3.09	$3.32	$3.11	$0.00	$0.00	$3.05	$2.67	$3.05
15 years (2019-2033)	$2.04	$2.04	$2.04	$2.81	$2.81	$3.02	$2.82	$2.81	$3.02	$2.83	$0.00	$0.00	$2.77	$2.43	$2.77
30 years (2019-2048)	$1.59	$1.59	$1.59	$2.19	$2.19	$2.35	$2.19	$2.19	$2.35	$2.20	$0.00	$0.00	$2.16	$1.89	$2.16

Notes: All avoided costs are in 2018 dollars per MMBtu. Emission rates for wood products are assumed to be zero.