Renewable Electricity: Potential Economic Effects of Increased Commitments in Massachusetts

Model Release

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This model accompanies the USITC report, *Renewable Electricity: Potential Economic Effects of Increased Commitments in Massachusetts*, Inv. 332-574. The quantitative analysis focuses on potential economic effects of two commitments in Massachusetts: an increase in Massachusetts's Renewable Portfolio Standard (RPS) in 2018, and the creation of a Clean Energy Standard (CES) in 2017. The analysis compares projections for electricity rates and carbon dioxide emissions with and without these increased commitments in place. The model simulates the effects on residential and commercial ratepayers in Massachusetts, ratepayers in New England, and greenhouse gas emissions in Massachusetts from Massachusetts reaching its recent renewable and clean energy commitments. The model estimates the effects of the commitments on (1) the costs to Massachusetts residential and commercial electricity consumers, (2) the cost to the rest of New England, and (3) the greenhouse gas (GHG) emissions associated with Massachusetts's electricity supply. These effects are estimated in five-year increments from 2030 to 2050.

The model is a partial equilibrium model of New England's electricity sector. The model uses forecasts from the 2020 edition of the Annual Energy Outlook (AEO) produced by the U.S. Energy Information Administration (EIA) as inputs for estimating the future profitability and expansion of renewable generation resources to meet Massachusetts's commitments. The model makes use of the AEO's Reference case ("Ref," the EIA's best estimate of conditions through 2050, including projected technological improvements in the energy sector and current laws and regulations) as well as four alternative scenarios also from the AEO: the High Renewables Cost case (equations and variables denoted with "HRC" in the name), the Low Renewables Cost case ("LRC"), the High Oil and Gas Supply case ("HOGS"), and the Low Oil and Gas Supply case ("LOGS"). The model also includes calculations for three sets of alternative assumptions: (1) where wind (instead of solar) is the marginal resource meeting the increased demand for renewables ("Wind"); (2) where Massachusetts's access to imports is varied ("30pct," "20pct," and "NoImports"); and (3) for alternative assumptions for residential and commercial customer growth. More information on the AEO scenarios and alternative assumptions is in table 3.2 in Chapter 3 of the report.

The data inputs of the USITC's model are largely from the AEO's 2020 projections, including estimates of the average revenue per megawatt-hour (MWh) available to new generation over the life cycle of the investment (LACE) and the average cost of building and operating the generation over this life cycle (LCOE). The model also uses AEO calculations of international imports, interregional imports, net load, generation by source, residential and commercial prices, and carbon dioxide emissions. The projection values are calculated by EIA for New England for each year to 2050 based on the general equilibrium framework that underlies the 2020 AEO. The USITC's model uses the AEO's projections to assess the profitability of new generation from different renewable plant types in 2030, 2035, 2040, 2045, and 2050. The USITC's model also uses the time profiles for Massachusetts's RPS and CES, as set out in Massachusetts state law.

Data inputs in the simulation are in the BLUE-shaded cells (with sources for the input data listed in the cell below). Outputs are in the GREEN-shaded cells. The white cells are intermediate calculations. Table numbers reference the accompanying report.

This PDF is a printout of the Mathematica file "Renewable Electricity - Potential Economic Effects of Increased Commitments in Massachusetts - Model Release.nb."

Table of Contents:

1. Definitions and Calculations Applicable to All Cases, All Assumptions

1.1. Years

In[1]:=
```
CalcYears = {2030, 2035, 2040, 2045, 2050};
```

In[2]:=
```
Years = Table[CalcYears[[j]], {j, 1, 5}];
```

1.2. Massachusetts's Renewable and Clean Energy Commitment Shares

Table E.1: Renewable and clean energy requirements (as a percentage of total load; reported for {2030,2035,2040,2045,2050}):

Initial RPS, Class I only (pre-2018): 15 percent of electricity sales from Class I renewable sources by 2020, with a 1 percentage point increase each year thereafter, reaching 45 percent in 2050.

In[3]:=
```
So = {0.25, 0.30, 0.35, 0.40, 0.45};
```

Source: Government of Massachusetts, "Program Summaries: Summaries of all the Renewable and Alternative Energy Portfolio Standard Programs," https://www.mass.gov/service-details/program-summaries (accessed September 16, 2020).

Updated RPS, Class I only (2018): Act to Advance Clean Energy increased the requirement for sales coming from Class I renewable sources to 16 percent of electricity sales in 2020, with a further increase of 2 percentage points per year until reaching 34 percent in 2029, then growing 1 percentage point per year from 2030 until reaching 55 percent in 2050.

In[4]:=
```
Su = {0.35, 0.40, 0.45, 0.50, 0.55};
```

Source: "Renewable Energy Portfolio Standard for Retail Electricity Suppliers," Mass. Gen. Laws ch. 25A, § 11 F, https://malegislature.gov/Laws/GeneralLaws/PartI/TitleII/Chapter25A/Section11F.

CES (2017, includes large-scale hydropower): Massachusetts's CES requires sourcing 16 percent of electricity sales from clean energy sources by 2018 and increases by 2 percentage points per year until reaching 80 percent in 2050.

In[5]:=
```
Sc = {0.40, 0.50, 0.60, 0.70, 0.80};
```

Source: "Clean Energy Standard," 310 CMR 7.75 (2017), 509, 513-14, https://www.mass.gov/doc/310-cmr-700-air-pollution-control-regulations/download; "Act to Advance Clean Energy (H4857)," 2018, https://malegislature.gov/Bills/190/H4857.

In[6]:=
```
CESoverUpRPS = Table[Sc[[j]] - Su[[j]], {j, 1, 5}]
```

Out[6]=
```
{0.05, 0.1, 0.15, 0.2, 0.25}
```

2. Reference Case

2.1. Reference Case, Definitions and Calculations Applicable to All Assumptions

Estimated Load for Massachusetts

Projected Massachusetts load not from municipal providers (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[7]:=
```
MALoad = {47.34659, 48.73428, 50.30960, 52.25038, 54.76449};
```

Source:
(1) Projected load for New England: EIA, Annual Energy Outlook 2020, Table 54.7, (accessed August 26, 2020). https://www.eia.gov/outlooks/aeo/supplement/excel/suptab_54.7.xlsx

(2) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load," n.d. https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); U.S. Energy Information Administration; "State Electricity Profiles," n.d. (accessed March 24, 2020). https://www.eia.gov/electricity/state/

(3) Massachusetts load from non-municipal sources: EIA, Table 9: Retail Electricity Sales Statistics, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed Sept 16, 2020).

2.2. Reference Case, Baseline Assumptions

Hydroelectricity Imports Share of Total Load

In[8]:=
```
Sh = {0.145850427211624, 0.139888235404149,
    0.143092750503851, 0.14217089550185, 0.14160298497264};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, table 54.7 (Excel file, accessed August 26, 2020). https://www.eia.gov/outlooks/aeo/supplement/excel/suptab_54.7.xlsx
Note: Retail electricity prices do not include renewable or clean energy credit costs.

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/myModule/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

(3) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load by Source" https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); EIA, "State Electricity Profiles" (accessed March 24, 2020). https://www.eia.gov/electricity/state/

Calculations from Shares

Table E.6: Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load; reported for {2030,2035,2040,2045,2050}):

In[9]:=
```
Sx = Table[Max[Sc[[j]] - Su[[j]] - Sh[[j]], 0], {j, 1, 5}]
```

Out[9]=
```
{0, 0, 0.00690725, 0.0578291, 0.108397}
```

Effects on the Price of Wholesale Generation

Pro-rated wholesale price effect: PriceEffect = $(P_{Ref} - P_{Sunset}) \frac{(S_u - S_o) + I_h ((S_c - S_u) - S_h)}{(S_u - 0)} (S_{NE})$ (equation (E6))

Table 3.1: AEO 2020 Reference case projections for the New England region: Retail electricity price, all-sector average (2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[10]:=
```
PRef = {18.17822, 18.01433, 18.33042, 18.28688, 18.0705};
```

Source: EIA, Annual Energy Outlook 2020, table 54.7 : Reference Case, (accessed August 26, 2020), https://www.eia.gov/outlooks/aeo/supplement/excel/suptab_ 54.7.xlsx.

AEO 2020 RPS Sunset case projections for the New England region: Retail electricity price, all-sector average (2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[11]:=
```
PSunset = {18.27931, 18.40043, 18.52642, 18.59083, 18.25166};
```

Source: EIA, Annual Energy Outlook 2020, Table 54 : Renewable Portfolio Standard Sunset (accessed August 26, 2020), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=norps&start=2018&end=2050&f=A&linechart=&sourcekey=0.

Share of Massachusetts in New England's total load:

In[12]:=
```
Sne = 0.456;
```

Source: ISO New England, "Net Energy and Peak Load by Source" https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); EIA, "State Electricity Profiles" (accessed March 24, 2020). https://www.eia.gov/electricity/state/.

Effects on the price of wholesale generation (included in **table E.8**) in 2019 dollars per MWh:

In[13]:=
```
PriceEffect = Table[(PRef[[j]] - PSunset[[j]])
    ((1/(Su[[j]] - 0)) ((Su[[j]] - So[[j]]) + If[((Sc[[j]] - Su[[j]]) > Sh[[j]]), ((Sc[[j]] - Su[[j]]) - Sh[[j]]), 0]))
    (Sne), {j, 1, 5}]
```

Out[13]=
```
{-0.0131706, -0.0440154, -0.0212332, -0.0437506, -0.0313008}
```

Average Revenue, Average Cost, and Value of Credits

Table E.5: Average revenue of the marginal solar generation plant, Reference case (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[14]:=
```
SolarAR = {33.69569, 33.108585, 35.330486, 34.785381, 33.686523};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Table E.5: Average cost of the marginal solar generation plant, Reference case (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[15]:=
```
SolarAC = {37.562761, 35.338593, 33.395058, 31.751778, 30.478415};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.5: Average revenue minus average cost of the marginal solar generation plant, Reference case (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
(Defined in report as "$\pi(S_u)$")

In[16]:=
```
PROFREF = Table[SolarAR[[j]] - SolarAC[[j]], {j, 1, 5}]
```

Out[16]=
```
{-3.86707, -2.23001, 1.93543, 3.0336, 3.20811}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[17]:=
```
VOC = Table[Max[0, -(PROFREF[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - Sx[[j]])))], {j, 1, 5}]
```

Out[17]=
```
{3.86707, 2.23001, 0, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_0 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[18]:=
```
VOC0 = Table[Max[0, -(PROFREF[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[18]= {3.73374, 2.08715, 0, 0, 0}

Estimated Effects on Costs to Massachusetts Consumers

Table 3.5: Estimated increase in per-unit cost to Massachusetts consumers in different cases (in 2019 cents per kWh; reported for {2030, 2035, 2040, 2045, 2050})

In[19]:=
```
dCCave = Table[
  Round[(If[VOC[[j]] > 0, 1, 0] ((VOC[[j]] - VOC0[[j]]) So[[j]] + VOC[[j]] (Su[[j]] - So[[j]])) + If[Sh[[j]] <
        Sc[[j]] - Su[[j]], 1, 0] VOC[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOC[[j]] > 0, 1, 0] ×
      If[Sh[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - Sh[[j]]))]) / 10, .000001], {j, 1, 5}]
```

Out[19]= {0.041148, 0.023945, 0., 0., 0.}

Table 3.6: Estimated increase in total cost to Massachusetts consumers in different cases (in millions of 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050})

In[20]:=
```
dCCtot =
 Table[MALoad[[j]] (If[VOC[[j]] > 0, 1, 0] ((VOC[[j]] - VOC0[[j]]) So[[j]] + VOC[[j]] (Su[[j]] - So[[j]])) +
    If[Sh[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOC[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOC[[j]] > 0,
      1, 0] × If[Sh[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - Sh[[j]]))]), {j, 1, 5}]
```

Out[20]= {19.4822, 11.6694, 0., 0., 0.}

Massachusetts' s total residential and commercial customers (based on 2018 data):

In[21]:=
```
ResidCust = {2 784 243, 2 784 243, 2 784 243, 2 784 243, 2 784 243};
CommCust = {408 972, 408 972, 408 972, 408 972, 408 972};
```

Source: EIA, Table 8: Retail Sales, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed September 15, 2020).

Residential and commercial electricity use projections for New England Region:

In[23]:=
```
ResidElecUseTot = {0.160173, 0.16594, 0.17168, 0.178003, 0.186351};
CommElecUseTot = {0.169090, 0.171978, 0.175600, 0.182044, 0.191692};
```

Source:
(1) Residential: EIA, Table 2: Energy Consumption by Sector and Source: Residential Electricity (Reference case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=ref2020&start=2018&end=2050&f=A&linechart=ref2020-d112119a.9-2-AEO2020.1-1&map=ref2020-d112119a.5-2-AEO2020.1-1&ctype=linechart&sourcekey=0 (accessed August 26, 2020);

(2) Commercial: EIA, Table 2: Energy Consumption by Sector and Source: Commercial Electricity (Reference case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=ref2020&start=2018&end=2050&f=A&linechart=~ref2020-d112119a.24-2-AEO2020.1-1&map=ref2020-d112119a.5-2-AEO2020.1-1&ctype=linechart&sourcekey=0 (accessed August 26, 2020).

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[25]:=
```
ResidElecUse =
  Table[((ResidElecUseTot[[j]] * (293.07107017222) * (Sne)) / ResidCust[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUse = Table[(CommElecUseTot[[j]] * (293.07107017222) *
      (Sne) / CommCust[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table 3.7: Estimated increase in the cost to Massachusetts residential consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[27]:=
```
Table[Round[dCCave[[j]] * (ResidElecUse[[j]]), 0.0001], {j, 1, 5}]
```

Out[27]=
```
{0.2636, 0.1589, 0., 0., 0.}
```

Table 3.8: Estimated increase in the cost to Massachusetts commercial consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[28]:=
```
Table[Round[dCCave[[j]] * (CommElecUse[[j]]), 0.0001], {j, 1, 5}]
```

Out[28]=
```
{1.8947, 1.1214, 0., 0., 0.}
```

Estimated Effects on Costs to New England Consumers

Projected New England load (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[29]:=
```
NELoad = {120.8734, 124.4161, 128.4378, 133.3925, 139.8109};
```

Source: EIA, Annual Energy Outlook 2020, table 54.7 (Excel file, accessed August 26, 2020). https://www.eia.gov/outlooks/aeo/supplement/excel/supt-ab_54.7.xlsx

Table 3.9: Estimated savings for New England, excluding Massachusetts, due to Massachusetts's commitments (in 2019 cents per kWh; reported for {2030, 2035, 2040, 2045, 2050})

In[30]:=
```
Table[If[VOC[[j]] > 0, 1, 0] PriceEffect[[j]] / 10, {j, 1, 5}]
```

Out[30]=
```
{-0.00131706, -0.00440154, 0., 0., 0.}
```

Table 3.9: Estimated total annual savings for New England, excluding Massachusetts, due to Massachusetts's commitments (in 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050})

In[31]:=
```
Table[If[VOC[[j]] > 0, 1, 0] PriceEffect[[j]] * (-NELoad[[j]] (1 - Sne)), {j, 1, 5}]
```

Out[31]=
```
{0.866033, 2.97907, 0., 0., 0.}
```

Estimated Effects on Massachusetts's Greenhouse Gas Emissions

Table E.7: Carbon dioxide (CO2) emissions rate of natural gas generation in New England, Reference case (in million metric tons per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[32]:=
```
erng = {0.4107072, 0.3917429, 0.4292624, 0.4368336, 0.4469854};
```

Source: EIA, Annual Energy Outlook 2020 : Carbon Dioxide : Electric Power : Natural Gas, New England. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.REF2020.EMI_CO2_ELEP_NA_NG_NA_NEENGL_MILLMETNCO2.A (accessed August 10, 2020);
EIA, Annual Energy Outlook 2020 : Electricity Generation : Northeast Power / New England : Natural Gas. https://www.eia.gov/opendata/qb.php?catego-

ry=3604506&sdid=AEO.2020.REF2020.GEN_NA_ELEP_NA_NG_NA_NPCCNE_BLNKWH.A (accessed August 10, 2020).

Table 3.10: Estimated effect of commitments on carbon dioxide emissions under the Reference case: Change in emissions per MWh (in million metric tons per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[33]:=
```
dEMave =
 Table[If[VOC[[j]] > 0, 1, 0] * (-1) * erng[[j]] (Max[Su[[j]], Sc[[j]] - Sh[[j]]] - So[[j]]), {j, 1, 5}]
```

Out[33]=
```
{-0.0410707, -0.0391743, 0., 0., 0.}
```

Table 3.10: Estimated effect of commitments on carbon dioxide emissions under the Reference case: Change in total emissions (in million metric tons; reported for {2030,2035,2040,2045,2050}):

In[34]:=
```
dEMtot = Table[
   MALoad[[j]] (If[VOC[[j]] > 0, 1, 0] (-1) erng[[j]] (Max[Su[[j]], Sc[[j]] - Sh[[j]]] - So[[j]])), {j, 1, 5}]
```

Out[34]=
```
{-1.94456, -1.90913, 0., 0., 0.}
```

2.3. Reference Case, Alternative Assumption #1: Marginal Resource

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[35]:=
```
WindAR = {34.409359, 34.701832, 37.315632, 37.063381, 36.012241};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[36]:=
```
WindAC = {41.381124, 39.57092, 37.912683, 36.535092, 34.459348};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.14: Profitability (average revenue minus average cost) of onshore wind in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
(Defined in report as "$\pi(S_u)$")

In[37]:=
```
PROFREFWind = Table[WindAR[[j]] - WindAC[[j]], {j, 1, 5}]
```

Out[37]=
```
{-6.97176, -4.86909, -0.597051, 0.528289, 1.55289}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $\text{VOC}_1 = \text{MAX}\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[38]:=
```
VOCWind = Table[Max[0, -(PROFREFWind[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - Sx[[j]])))], {j, 1, 5}]
```

Out[38]=
```
{6.97176, 4.86909, 0.609769, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $\text{VOC}_0 = \text{MAX}\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[39]:=
```
VOC0Wind = Table[Max[0, -(PROFREFWind[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[39]=
```
{6.83843, 4.72623, 0.443205, 0, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.11: Estimated increase in per-unit cost to Massachusetts consumers with onshore wind as the marginal resource (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[40]:=
```
dCCaveWind = Table[Round[
   (If[VOCWind[[j]] > 0, 1, 0] ((VOCWind[[j]] - VOC0Wind[[j]]) So[[j]] + VOCWind[[j]] (Su[[j]] - So[[j]])) +
      If[Sh[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCWind[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCWind[[j]] > 0, 1, 0] ×
       If[Sh[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - Sh[[j]]))]]) / 10, .000001], {j, 1, 5}]
```

Out[40]=
```
{0.072195, 0.050336, 0.019921, 0., 0.}
```

Table E.12: Estimated increase in total cost to Massachusetts consumers with onshore wind as the marginal resource (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[41]:=
```
dCCtotWind = Table[MALoad[[j]]
   (If[VOCWind[[j]] > 0, 1, 0] ((VOCWind[[j]] - VOC0Wind[[j]]) So[[j]] + VOCWind[[j]] (Su[[j]] - So[[j]])) +
     If[Sh[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCWind[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffect[[j]] If[VOCWind[[j]] > 0, 1, 0] ×
      If[Sh[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - Sh[[j]]))]), {j, 1, 5}]
```

Out[41]=
```
{34.1818, 24.5307, 10.0221, 0., 0.}
```

2.4. Reference Case, Alternative Assumption #2: Access to Imports

Hydroelectricity Imports Share of Total Load

Hydroelectricity Imports Share of Total Load when Massachusetts has access to 30 percent of New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[42]:=
```
Sh30pct = {0.095954228, 0.092031734, 0.094139967, 0.093533484, 0.093159859};
```

Hydroelectricity Imports Share of Total Load when Massachusetts has access to 20 percent of New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[43]:=
```
Sh20pct = {0.063969486, 0.061354489, 0.062759978, 0.062355656, 0.062106572};
```

Hydroelectricity Imports share of total load when Massachusetts has no access to New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[44]:=
```
ShNoImports = {0, 0, 0, 0, 0};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, table 54.7 (Excel file, accessed August 26, 2020). https://www.eia.gov/outlooks/aeo/supplement/excel/suptab_54.7.xlsx

Note: Retail electricity prices do not include renewable or clean energy credit costs.

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/my-Module/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load)

In[45]:=
```
SxNoImports = Table[Max[Sc[[j]] - Su[[j]] - ShNoImports[[j]], 0], {j, 1, 5}];
```

Effects on the Price of Wholesale Generation

Pro-rated effect on the price of wholesale generation: PriceEffect = $(P_{Ref} - P_{Sunset}) \frac{(S_u - S_o) + I_h ((S_c - S_u) - S_h)}{(S_u - 0)} (S_{NE})$ (equation (E6))

In[46]:=
```
PriceEffect30pct = Table[
  (PRef[[j]] - PSunset[[j]]) (1/(Su[[j]] - 0) ((Su[[j]] - So[[j]]) + If[((Sc[[j]] - Su[[j]]) > Sh30pct[[j]]),
      ((Sc[[j]] - Su[[j]]) - Sh30pct[[j]]), 0])) (Sne), {j, 1, 5}];
PriceEffect20pct = Table[(PRef[[j]] - PSunset[[j]]) (1/(Su[[j]] - 0)
    ((Su[[j]] - So[[j]]) + If[((Sc[[j]] - Su[[j]]) > Sh20pct[[j]]), ((Sc[[j]] - Su[[j]]) - Sh20pct[[j]]), 0]))
  (Sne), {j, 1, 5}];
PriceEffectNoImports = Table[(PRef[[j]] - PSunset[[j]])
  (1/(Su[[j]] - 0) ((Su[[j]] - So[[j]]) + If[((Sc[[j]] - Su[[j]]) > ShNoImports[[j]]),
      ((Sc[[j]] - Su[[j]]) - ShNoImports[[j]]), 0])) (Sne), {j, 1, 5}];
```

Average Revenue, Average Cost, and Value of Credits

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[49]:=
```
VOCNoImports = Table[Max[0, -(PROFREF[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxNoImports[[j]])))], {j, 1, 5}];
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.17: Estimated increase in per-unit cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in 2019 cents per kWh; reported for {2030, 2035, 2040, 2045, 2050})

In[50]:=
```
dCCaveNoImports =
 Table[Round[ (If[VOCNoImports[[j]] > 0, 1, 0] ((VOCNoImports[[j]] - VOC0[[j]]) So[[j]] +
          VOCNoImports[[j]] (Su[[j]] - So[[j]])) + If[ShNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0]
       VOCNoImports[[j]] (Sc[[j]] - Su[[j]]) + PriceEffectNoImports[[j]]
       If[VOCNoImports[[j]] > 0, 1, 0] × If[ShNoImports[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], (1 - (Sc[[j]] - ShNoImports[[j]]))]) / 10, .000001], {j, 1, 5}]
```

Out[50]=
```
{0.063487, 0.054484, 0., 0., 0.}
```

Table E.18: Estimated increase in total cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in millions of 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050})

In[51]:=
```
dCCtotNoImports = Table[MALoad[[j]] (If[VOCNoImports[[j]] > 0, 1, 0]
      ((VOCNoImports[[j]] - VOC0[[j]]) So[[j]] + VOCNoImports[[j]] (Su[[j]] - So[[j]])) +
     If[ShNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCNoImports[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffectNoImports[[j]] If[VOCNoImports[[j]] > 0, 1, 0] ×
      If[ShNoImports[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - ShNoImports[[j]]))]), {j, 1, 5}]
```

Out[51]=
```
{30.0591, 26.5525, 0., 0., 0.}
```

2.5. Reference Case, Alternative Assumption #3: Residential and Commercial Customer Growth

Massachusetts' s total residential and commercial customers (linear growth based on 1990-2018 trend; reported for {2030, 2035, 2040, 2045, 2050}):

In[52]:=
```
ResidCustTrend = {3 008 260.659, 3 092 805.753, 3 177 350.846, 3 261 895.94, 3 346 441.033};
CommCustTrend = {483 821.4571, 509 671.9695, 535 522.4818, 561 372.9941, 587 223.5064};
```

Source: EIA, Table 8: Retail Sales, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed September 15, 2020).

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[54]:=
```
ResidElecUseTrend = Table[
    ((ResidElecUseTot[[j]] * (293.07107017222) * (Sne)) / ResidCustTrend[[j]] * 10 000 000 / 12),
    {j, 1, 5}];
CommElecUseTrend = Table[ (CommElecUseTot[[j]] * (293.07107017222) *
      (Sne) / CommCustTrend[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table E.19: Estimated increase in the cost to residential consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[56]:=
```
Table[Round[dCCave[[j]] * (ResidElecUseTrend[[j]]), 0.0001], {j, 1, 5}]
```

Out[56]=
```
{0.244, 0.1431, 0., 0., 0.}
```

Table E.20: Estimated increase in the cost to commercial consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[57]:=
```
Table[Round[dCCave[[j]] * (CommElecUseTrend[[j]]), 0.0001], {j, 1, 5}]
```

Out[57]=
```
{1.6015, 0.8998, 0., 0., 0.}
```

3. High Renewables Cost Case

3.1. High Renewables Cost Case, Definitions and Calculations Applicable to Assumptions

Estimated Load for Massachusetts

Projected Massachusetts net energy load not from municipal providers (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[58]:=
```
MALoadHRC = {47.63167644, 49.09508259, 50.8998196, 52.9157634, 55.39450549};
```

Source:
(1) Projected load for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region: Total Net Energy for Load (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~high-ogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load," n.d. https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); U.S. Energy Information Administration; "State Electricity Profiles," n.d. (accessed March 24, 2020). https://www.eia.gov/electricity/state/

(3) Massachusetts load from non-municipal sources: EIA, Table 9: Retail Electricity Sales Statistics, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed Sept 16, 2020).

3.2. High Renewables Cost Case, Baseline Assumptions

Hydroelectricity Imports Share of Total Load

In[59]:=
```
ShHRC = {0.15017827642237, 0.14965206480279,
   0.14588789894571, 0.14858205576412, 0.14128301779505};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/myModule/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

(3) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load by Source" https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); EIA, "State Electricity Profiles" (accessed March 24, 2020). https://www.eia.gov/electricity/state/

Calculations from Shares

Table E.6: Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load; reported for {2030, 2035, 2040, 2045, 2050})

In[60]:=
```
SxHRC = Table[Max[Sc[[j]] - Su[[j]] - ShHRC[[j]], 0], {j, 1, 5}]
```

Out[60]=
```
{0, 0, 0.0041121, 0.0514179, 0.108717}
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[61]:=
```
SolarARHRC = {37.958618, 38.458946, 39.830532, 40.307243, 42.967808};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[62]:=
```
SolarACHRC = {49.580048, 49.501502, 49.589095, 49.81906, 50.592887};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.13: Profitability (average revenue minus average cost) of solar (photovoltaic) in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): *(Defined in report as "$\pi(S_u)$")*

In[63]:=
```
PROFHRC = Table[SolarARHRC[[j]] - SolarACHRC[[j]], {j, 1, 5}]
```

Out[63]=
```
{-11.6214, -11.0426, -9.75856, -9.51182, -7.62508}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[64]:=
```
VOCHRC = Table[Max[0, -(PROFHRC[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHRC[[j]])))], {j, 1, 5}]
```

Out[64]=
```
{11.6214, 11.0426, 9.7661, 9.62644, 7.94363}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_0 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[65]:=
```
VOC0HRC = Table[Max[0, -(PROFHRC[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[65]=
```
{11.4881, 10.8997, 9.60472, 9.34515, 7.44326}
```

Estimated Effects on Costs to Massachusetts Consumers

Table 3.5: Estimated increase in per-unit cost to Massachusetts consumers in different cases (in 2019 cents per kWh; reported for

{2030, 2035, 2040, 2045, 2050}):

In[66]:=
```
dCCaveHRC = Table[
  Round[ (If[VOCHRC[[j]] > 0, 1, 0] ((VOCHRC[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRC[[j]] (Su[[j]] - So[[j]])) +
      If[ShHRC[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRC[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCHRC[[j]] > 0, 1, 0] × If[ShHRC[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], (1 - (Sc[[j]] - ShHRC[[j]]))]) / 10, .000001], {j, 1, 5}]
```

Out[66]=
```
{0.118692, 0.11207, 0.248642, 0.298082, 0.299476}
```

Table 3.6: Estimated increase in total cost to Massachusetts consumers in different cases (in millions of 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050}):

In[67]:=
```
dCCtotHRC = Table[MALoadHRC[[j]]
   (If[VOCHRC[[j]] > 0, 1, 0] ((VOCHRC[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRC[[j]] (Su[[j]] - So[[j]])) +
     If[ShHRC[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRC[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffect[[j]] If[VOCHRC[[j]] > 0, 1, 0] ×
      If[ShHRC[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - ShHRC[[j]]))]), {j, 1, 5}]
```

Out[67]=
```
{56.5348, 55.021, 126.558, 157.732, 165.893}
```

Residential and commercial electricity use projections for New England Region:

In[68]:=
```
ResidElecUseTotHRC = {0.160396, 0.165735, 0.172151, 0.178423, 0.185939};
CommElecUseTotHRC = {0.172247, 0.175371, 0.180648, 0.188027, 0.198143};
```

Source:
(1) Residential: EIA, Table 2: Energy Consumption by Sector and Source: Residential Electricity (High Renewables Cost case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=hirencst&start=2018&end=2050&f=A&linechart=hirencst-d112619a.9-2-AEO2020.1-1~hirencst-d112619a.24-2-AEO2020.1-1&map=hirencst-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020);

(2) Commercial: EIA, Table 2: Energy Consumption by Sector and Source: Commercial Electricity (High Renewables Cost case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=hirencst&start=2018&end=2050&f=A&linechart=hirencst-d112619a.9-2-AEO2020.1-1~hirencst-d112619a.24-2-AEO2020.1-1&map=hirencst-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020).

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[70]:=
```
ResidElecUseHRC =
  Table[ ((ResidElecUseTotHRC[[j]] * (293.07107017222) * (Sne)) / ResidCust[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseHRC = Table[ (CommElecUseTotHRC[[j]] * (293.07107017222) *
     (Sne) / CommCust[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table 3.7: Estimated increase in the cost to Massachusetts residential consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[72]:=
```
Table[Round[dCCaveHRC[[j]] * (ResidElecUseHRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[72]=
```
{0.7615, 0.7429, 1.7121, 2.1273, 2.2273}
```

Table 3.8: Estimated increase in the cost to Massachusetts commercial consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[73]:=
```
Table[Round[dCCaveHRC[[j]] * (CommElecUseHRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[73]=
```
{5.5672, 5.3519, 12.2312, 15.2623, 16.1586}
```

Estimated Effects on Costs to New England Consumers

Projected New England net energy for load, High Renewables Cost case (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[74]:=
```
NELoadHRC = {121.6012, 125.3372, 129.9446, 135.0912, 141.4193};
```

Source: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 26, 2020).

Table E.8: Estimated total annual savings for New England, excluding Massachusetts, due to Massachusetts's commitments (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[75]:=
```
Table[If[VOCHRC[[j]] > 0, 1, 0] PriceEffect[[j]] * (-NELoadHRC[[j]] (1 - Sne)), {j, 1, 5}]
```

Out[75]=
```
{0.871248, 3.00112, 1.50097, 3.21522, 2.40804}
```

Estimated Effects on Massachusetts's Greenhouse Gas Emissions

Carbon dioxide (CO2) emissions rate of natural gas generation in New England, Reference case (in million metric tons per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[76]:=
```
erngHRC = {0.409999084, 0.419689019, 0.42173688, 0.427312788, 0.426815426};
```

Source: EIA, Annual Energy Outlook 2020 : Carbon Dioxide : Electric Power : Natural Gas, New England. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.HIRENCST.EMI_CO2_ELEP_NA_NG_NA_NEENGL_MILLMETNCO2.A (accessed August 26, 2020);
EIA, Annual Energy Outlook 2020 : Electricity Generation : Northeast Power / New England : Natural Gas. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.HIRENCST.GEN_NA_ELEP_NA_NG_NA_NPCCNE_BLNKWH.A (accessed August 26, 2020).

Table E.9: Estimated effect of commitments on carbon dioxide emissions per MWh in Massachusetts, alternative scenarios (in million metric tons, Mmt, per MWh; reported for {2030,2035,2040,2045,2050}):

In[77]:=
```
dEMaveHRC = Table[
  If[VOCHRC[[j]] > 0, 1, 0] * (-1) * erngHRC[[j]] (Max[Su[[j]], Sc[[j]] - ShHRC[[j]]] - So[[j]]), {j, 1, 5}]
```

Out[77]=
```
{-0.0409999, -0.0419689, -0.0439079, -0.0647028, -0.0890836}
```

Table E.10: Estimated effect of commitments on total carbon dioxide emissions in Massachusetts, alternative scenarios (in million metric tons, Mmt; reported for {2030,2035,2040,2045,2050}):

In[78]:=
```
dEMtotHRC = Table[MALoadHRC[[j]]
   (If[VOCHRC[[j]] > 0, 1, 0] (-1) erngHRC[[j]] (Max[Su[[j]], Sc[[j]] - ShHRC[[j]]] - So[[j]])), {j, 1, 5}]
```

Out[78]=
```
{-1.95289, -2.06047, -2.2349, -3.4238, -4.93474}
```

3.3. High Renewables Cost Case, Alternative Assumption #1: Marginal Resource

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[79]:=
```
WindARHRC = {36.558872, 37.033638, 37.691223, 37.975586, 41.638493};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[80]:=
```
WindACHRC = {45.208262, 45.113931, 45.199777, 45.390301, 45.970205};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.14: Profitability (average revenue minus average cost) of onshore wind in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
(Defined in report as "$\pi(S_u)$")

In[81]:=
```
PROFHRCWind = Table[WindARHRC[[j]] - WindACHRC[[j]], {j, 1, 5}]
```

Out[81]=
```
{-8.64939, -8.08029, -7.50855, -7.41472, -4.33171}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[82]:=
```
VOCHRCWind = Table[Max[0, -(PROFHRCWind[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHRC[[j]])))], {j, 1, 5}]
```

Out[82]=
```
{8.64939, 8.08029, 7.51609, 7.52934, 4.65027}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_0 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[83]:=
```
VOC0HRCWind = Table[Max[0, -(PROFHRCWind[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[83]=
```
{8.51606, 7.93744, 7.35471, 7.24805, 4.14989}
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.11: Estimated increase in per-unit cost to Massachusetts consumers with onshore wind as the marginal resource (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[84]:=
```
dCCaveWindHRC =
 Table[Round[ (If[VOCHRCWind[[j]] > 0, 1, 0] ((VOCHRCWind[[j]] - VOC0HRCWind[[j]]) So[[j]] +
          VOCHRCWind[[j]] (Su[[j]] - So[[j]])) + If[ShHRC[[j]] < Sc[[j]] - Su[[j]], 1, 0]
        VOCHRCWind[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOCHRCWind[[j]] > 0, 1, 0] × If[
         ShHRC[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShHRC[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[84]=
```
{0.088971, 0.082448, 0.192391, 0.235169, 0.184208}
```

Table E.12: Estimated increase in total cost to Massachusetts consumers with onshore wind as the marginal resource (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[85]:=
```
dCCtotWindHRC =
 Table[MALoadHRC[[j]] (If[VOCHRCWind[[j]] > 0, 1, 0] ((VOCHRCWind[[j]] - VOC0HRCWind[[j]]) So[[j]] +
          VOCHRCWind[[j]] (Su[[j]] - So[[j]])) + If[ShHRC[[j]] < Sc[[j]] - Su[[j]], 1, 0]
        VOCHRCWind[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOCHRCWind[[j]] > 0, 1, 0] ×
        If[ShHRC[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShHRC[[j]])]), {j, 1, 5}]
```

Out[85]=
```
{42.3784, 40.4778, 97.9268, 124.442, 102.041}
```

3.4. High Renewables Cost Case, Alternative Assumption #2: Access to Imports

Hydroelectricity Imports Share of Total Load

Hydroelectricity Imports Share of Total Load when Massachusetts has access to 30 percent of New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[86]:=
```
ShHRC30pct = {0.098801498, 0.098455306, 0.095978881, 0.097751352, 0.092949354};
```

Hydroelectricity Imports Share of Total Load when Massachusetts has access to 20 percent of New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[87]:=
```
ShHRC20pct = {0.065867665, 0.065636871, 0.063985921, 0.065167568, 0.061966236};
```

Hydroelectricity Imports share of total load when Massachusetts has no access to New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[88]:=
```
ShHRCNoImports = {0, 0, 0, 0, 0};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 26, 2020).

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/myModule/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load)

In[89]:=
```
SxHRC30pct = Table[Max[Sc[[j]] - Su[[j]] - ShHRC30pct[[j]], 0], {j, 1, 5}];
SxHRC20pct = Table[Max[Sc[[j]] - Su[[j]] - ShHRC20pct[[j]], 0], {j, 1, 5}];
SxHRCNoImports = Table[Max[Sc[[j]] - Su[[j]] - ShHRCNoImports[[j]], 0], {j, 1, 5}];
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[92]:=
```
VOCHRC30pct = Table[Max[0, -(PROFHRC[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHRC30pct[[j]])))], {j, 1, 5}];
VOCHRC20pct = Table[Max[0, -(PROFHRC[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHRC20pct[[j]])))], {j, 1, 5}];
VOCHRCNoImports =
  Table[Max[0, -(PROFHRC[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHRCNoImports[[j]])))], {j, 1, 5}];
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.15: Estimated increase in per-unit cost to consumers of Massachusetts's increased commitments, varying levels of access to imports, High Renewables Cost Case (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050})

In[95]:=
```
dCCaveHRC30pct = Table[Round[(If[VOCHRC30pct[[j]] > 0, 1, 0]
      ((VOCHRC30pct[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRC30pct[[j]] (Su[[j]] - So[[j]])) +
    If[ShHRC30pct[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRC30pct[[j]] (Sc[[j]] - Su[[j]]) +
    PriceEffect30pct[[j]] If[VOCHRC30pct[[j]] > 0, 1, 0] × If[ShHRC30pct[[j]] > Sc[[j]] - Su[[j]],
      1 - Su[[j]], 1 - (Sc[[j]] - ShHRC30pct[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[95]=
```
{0.118692, 0.222422, 0.254348, 0.307739, 0.316818}
```

In[96]:=
```
dCCaveHRC20pct = Table[Round[(If[VOCHRC20pct[[j]] > 0, 1, 0]
      ((VOCHRC20pct[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRC20pct[[j]] (Su[[j]] - So[[j]])) +
    If[ShHRC20pct[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRC20pct[[j]] (Sc[[j]] - Su[[j]]) +
    PriceEffect20pct[[j]] If[VOCHRC20pct[[j]] > 0, 1, 0] × If[ShHRC20pct[[j]] > Sc[[j]] - Su[[j]],
      1 - Su[[j]], 1 - (Sc[[j]] - ShHRC20pct[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[96]=
```
{0.118692, 0.224723, 0.258746, 0.315462, 0.331349}
```

Table E.17: Estimated increase in per-unit cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[97]:=
```
dCCaveHRCNoImports =
 Table[Round[ (If[VOCHRCNoImports[[j]] > 0, 1, 0] ((VOCHRCNoImports[[j]] - VOC0HRC[[j]]) So[[j]] +
          VOCHRCNoImports[[j]] (Su[[j]] - So[[j]])) + If[ShHRCNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0]
        VOCHRCNoImports[[j]] (Sc[[j]] - Su[[j]]) + PriceEffectNoImports[[j]]
        If[VOCHRCNoImports[[j]] > 0, 1, 0] × If[ShHRCNoImports[[j]] > Sc[[j]] - Su[[j]],
         1 - Su[[j]], 1 - (Sc[[j]] - ShHRCNoImports[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[97]=
```
{0.179803, 0.230735, 0.269863, 0.336193, 0.374008}
```

Table E.16: Estimated increase in total cost to consumers of Massachusetts's increased commitments, varying levels of access to imports, High Renewables Cost Case (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[98]:=
```
dCCtotHRC30pct = Table[MALoadHRC[[j]] (If[VOCHRC30pct[[j]] > 0, 1, 0]
       ((VOCHRC30pct[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRC30pct[[j]] (Su[[j]] - So[[j]])) +
      If[ShHRC30pct[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRC30pct[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect30pct[[j]] If[VOCHRC30pct[[j]] > 0, 1, 0] ×
       If[ShHRC30pct[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShHRC30pct[[j]])]), {j, 1, 5}]
```

Out[98]=
```
{56.5348, 109.198, 129.463, 162.843, 175.5}
```

In[99]:=
```
dCCtotHRC20pct = Table[MALoadHRC[[j]] (If[VOCHRC20pct[[j]] > 0, 1, 0]
       ((VOCHRC20pct[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRC20pct[[j]] (Su[[j]] - So[[j]])) +
      If[ShHRC20pct[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRC20pct[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect20pct[[j]] If[VOCHRC20pct[[j]] > 0, 1, 0] ×
       If[ShHRC20pct[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShHRC20pct[[j]])]), {j, 1, 5}]
```

Out[99]=
```
{56.5348, 110.328, 131.701, 166.929, 183.549}
```

Table E.18: Estimated increase in total cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[100]:=
```
dCCtotHRCNoImports = Table[MALoadHRC[[j]] (If[VOCHRCNoImports[[j]] > 0, 1, 0]
       ((VOCHRCNoImports[[j]] - VOC0HRC[[j]]) So[[j]] + VOCHRCNoImports[[j]] (Su[[j]] - So[[j]])) +
      If[ShHRCNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHRCNoImports[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffectNoImports[[j]] If[VOCHRCNoImports[[j]] > 0, 1, 0] ×
       If[ShHRCNoImports[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - Sc[[j]]]), {j, 1, 5}]
```

Out[100]=
```
{85.6431, 113.28, 137.36, 177.899, 207.18}
```

3.5. High Renewables Cost Case, Alternative Assumption #3: Residential and Commercial Customer Growth

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[101]:=
```
ResidElecUseTrendHRC = Table[
   ((ResidElecUseTotHRC[[j]] * (293.07107017222) * (Sne)) / ResidCustTrend[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseTrendHRC = Table[ (CommElecUseTotHRC[[j]] * (293.07107017222) *
     (Sne) / CommCustTrend[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table E.19: Estimated increase in the cost to residential consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[103]:=
```
Table[Round[dCCaveHRC[[j]] * (ResidElecUseTrendHRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[103]=
```
{0.7048, 0.6688, 1.5003, 1.8158, 1.8531}
```

Table E.20: Estimated increase in the cost to commercial consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[104]:=
```
Table[Round[dCCaveHRC[[j]] * (CommElecUseTrendHRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[104]=
```
{4.7059, 4.2945, 9.3409, 11.1189, 11.2537}
```

4. Low Renewables Cost Case

4.1. Low Renewables Cost Case, Definitions and Calculations Applicable to Assumptions

Estimated Load for Massachusetts

Projected Massachusetts load not from municipal providers (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[105]:=
```
MALoadLRC = {47.30366352, 48.37246705, 49.72071222, 51.40703711, 53.70716217};
```

Source:
(1) Projected load for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region: Total Net Energy for Load (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~high-ogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load," n.d. https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); U.S. Energy Information Administration; "State Electricity Profiles," n.d. (accessed March 24, 2020). https://www.eia.gov/electricity/state/

(3) Massachusetts load from non-municipal sources: EIA, Table 9: Retail Electricity Sales Statistics, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed Sept 16, 2020).

4.2. Low Renewables Cost Case, Baseline Assumptions

Hydroelectricity Imports Share of Total Load

In[106]:=
```
ShLRC = {0.14173258284843, 0.13726490373231,
   0.14918909749865, 0.14909651251351, 0.14837199421835};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirenc

st~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/my-Module/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

(3) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load by Source" https://www.iso-ne.com/isoex-press/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); EIA, "State Electricity Profiles" (accessed March 24, 2020). https://www.eia.gov/electricity/state/

Calculations from Shares

Table E.6: Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load; reported for {2030,2035,2040,2045,2050}):

In[107]:=
```
SxLRC = Table[Max[Sc[[j]] - Su[[j]] - ShLRC[[j]], 0], {j, 1, 5}]
```

Out[107]=
```
{0, 0, 0.000810903, 0.0509035, 0.101628}
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[108]:=
```
SolarARLRC = {33.222332, 32.430424, 31.717731, 29.78805, 27.653578};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[109]:=
```
SolarACLRC = {35.656716, 31.344569, 27.399198, 23.84435, 20.707879};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.13: Profitability (average revenue minus average cost) of solar (photovoltaic) in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): *(Defined in report as "$\pi(S_u)$")*

In[110]:=
```
PROFLRC = Table[SolarARLRC[[j]] - SolarACLRC[[j]], {j, 1, 5}]
```

Out[110]=
```
{-2.43438, 1.08586, 4.31853, 5.9437, 6.9457}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[111]:=
```
VOCLRC = Table[Max[0, -(PROFLRC[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxLRC[[j]])))], {j, 1, 5}]
```

Out[111]=
```
{2.43438, 0, 0, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
$VOC_0 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[112]:=
```
VOC0LRC = Table[Max[0, -(PROFLRC[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[112]=
```
{2.30105, 0, 0, 0, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table 3.5: Estimated increase in per-unit cost to Massachusetts consumers in different cases (in 2019 cents per kWh; reported for {2030, 2035, 2040, 2045, 2050})

In[113]:=
```
dCCaveLRC = Table[
  Round[(If[VOCLRC[[j]] > 0, 1, 0] ((VOCLRC[[j]] - VOC0LRC[[j]]) So[[j]] + VOCLRC[[j]] (Su[[j]] - So[[j]])) +
      If[ShLRC[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLRC[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCLRC[[j]] > 0, 1, 0] × If[ShLRC[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], (1 - (Sc[[j]] - ShLRC[[j]]))]) / 10, .000001], {j, 1, 5}]
```

Out[113]=
```
{0.026821, 0., 0., 0., 0.}
```

Table 3.6: Estimated increase in total cost to Massachusetts consumers in different cases (in millions of 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050})

In[114]:=
```
dCCtotLRC = Table[MALoadLRC[[j]]
    (If[VOCLRC[[j]] > 0, 1, 0] ((VOCLRC[[j]] - VOC0LRC[[j]]) So[[j]] + VOCLRC[[j]] (Su[[j]] - So[[j]])) +
      If[ShLRC[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLRC[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCLRC[[j]] > 0, 1, 0] ×
       If[ShLRC[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - ShLRC[[j]]))]), {j, 1, 5}]
```

Out[114]=
```
{12.6874, 0., 0., 0., 0.}
```

Residential and commercial electricity use projections for New England Region:

In[115]:=
```
ResidElecUseTotLRC = {0.161296, 0.165893, 0.171695, 0.177539, 0.18557};
CommElecUseTotLRC = {0.168445, 0.168598, 0.170348, 0.17425, 0.181657};
```

Source:
(1) Residential: EIA, Table 2: Energy Consumption by Sector and Source: Residential Electricity (Low Renewables Cost case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=hirencst&start=2018&end=2050&f=A&linechart=hirencst-d112619a.9-2-AEO2020.1-1~hirencst-d112619a.24-2-AEO2020.1-1&map=hirencst-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020);

(2) Commercial: EIA, Table 2: Energy Consumption by Sector and Source: Commercial Electricity (Low Renewables Cost case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=hirencst&start=2018&end=2050&f=A&linechart=hirencst-d112619a.9-2-AEO2020.1-1~hirencst-d112619a.24-2-AEO2020.1-1&map=hirencst-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020).

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[117]:=
```
ResidElecUseLRC =
  Table[((ResidElecUseTotLRC[[j]] * (293.07107017222) * (Sne)) / ResidCust[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseLRC = Table[(CommElecUseTotLRC[[j]] * (293.07107017222) *
     (Sne) / CommCust[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table 3.7: Estimated increase in the cost to Massachusetts residential consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[119]:=
```
Table[Round[dCCaveLRC[[j]] * (ResidElecUseLRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[119]=
```
{0.173, 0., 0., 0., 0.}
```

Table 3.8: Estimated increase in the cost to Massachusetts commercial consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[120]:=
```
Table[Round[dCCaveLRC[[j]] * (CommElecUseLRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[120]=
```
{1.2303, 0., 0., 0., 0.}
```

Estimated Effects on Costs to New England Consumers

Projected New England net energy for load, Low Renewables Cost case (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[121]:=
```
NELoadLRC = {120.7638, 123.4924, 126.9344, 131.2395, 137.1116};
```

Source: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 26, 2020).

Table E.8: Estimated total annual savings for New England, excluding Massachusetts, due to Massachusetts's commitments (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[122]:=
```
Table[If[VOCLRC[[j]] > 0, 1, 0] PriceEffect[[j]] * (-NELoadLRC[[j]] (1 - Sne)), {j, 1, 5}]
```

Out[122]=
```
{0.865248, 0., 0., 0., 0.}
```

Estimated Effects on Massachusetts's Greenhouse Gas Emissions

Carbon dioxide (CO2) emissions rate of natural gas generation in New England (in million metric tons per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[123]:=
```
erngLRC = {0.410105329, 0.418539702, 0.420998452, 0.427421137, 0.436292499};
```

Source: EIA, Annual Energy Outlook 2020 : Carbon Dioxide : Electric Power : Natural Gas, New England. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.LORENCST.EMI_CO2_ELEP_NA_NG_NA_NEENGL_MILLMETNCO2.A (accessed August 26, 2020);
EIA, Annual Energy Outlook 2020 : Electricity Generation : Northeast Power / New England : Natural Gas. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.LORENCST.GEN_NA_ELEP_NA_NG_NA_NPCCNE_BLNKWH.A (accessed August 26, 2020).

Table E.9: Estimated effect of commitments on carbon dioxide emissions per MWh in Massachusetts, alternative scenarios (in million metric tons, Mmt, per MWh; reported for {2030,2035,2040,2045,2050}):

In[124]:=
```
dEMaveLRC = Table[
  If[VOCLRC[[j]] > 0, 1, 0] * (-1) * erngLRC[[j]] (Max[Su[[j]], Sc[[j]] - ShLRC[[j]]] - So[[j]]), {j, 1, 5}]
```

Out[124]=
```
{-0.0410105, 0., 0., 0., 0.}
```

Table E.10: Estimated effect of commitments on total carbon dioxide emissions in Massachusetts, alternative scenarios (in million metric tons, Mmt; reported for {2030,2035,2040,2045,2050}):

In[125]:=
```
dEMtotLRC = Table[MALoadLRC[[j]]
    (If[VOCLRC[[j]] > 0, 1, 0] (-1) erngLRC[[j]] (Max[Su[[j]], Sc[[j]] - ShLRC[[j]]] - So[[j]])), {j, 1, 5}]
```

Out[125]=
```
{-1.93995, 0., 0., 0., 0.}
```

4.3. Low Renewables Cost Case, Alternative Assumption #1: Marginal Resource

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[126]:=
```
WindARLRC = {32.826469, 32.756584, 31.08073, 30.555973, 28.951326};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[127]:=
```
WindACLRC = {33.804586, 30.232261, 26.141041, 24.822761, 22.872077};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.14: Profitability (average revenue minus average cost) of onshore wind in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
(Defined in report as "$\pi(S_u)$")

In[128]:=
```
PROFLRCWind = Table[WindARLRC[[j]] - WindACLRC[[j]], {j, 1, 5}]
```

Out[128]=
```
{-0.978117, 2.52432, 4.93969, 5.73321, 6.07925}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $\text{VOC}_1 = \text{MAX}\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[129]:=
```
VOCLRCWind = Table[Max[0, -(PROFLRCWind[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxLRC[[j]])))], {j, 1, 5}]
```

Out[129]=
```
{0.978117, 0, 0, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $\text{VOC}_0 = \text{MAX}\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[130]:=
```
VOC0LRCWind = Table[Max[0, -(PROFLRCWind[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[130]=
```
{0.844784, 0, 0, 0, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.11: Estimated increase in per-unit cost to Massachusetts consumers with onshore wind as the marginal resource (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[131]:=
```
dCCaveWindLRC =
 Table[Round[ (If[VOCLRCWind[[j]] > 0, 1, 0] ((VOCLRCWind[[j]] - VOC0LRCWind[[j]]) So[[j]] +
          VOCLRCWind[[j]] (Su[[j]] - So[[j]])) + If[ShLRC[[j]] < Sc[[j]] - Su[[j]], 1, 0]
        VOCLRCWind[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOCLRCWind[[j]] > 0, 1, 0] × If[
         ShLRC[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShLRC[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[131]=
```
{0.012258, 0., 0., 0., 0.}
```

Table E.12: Estimated increase in total cost to Massachusetts consumers with onshore wind as the marginal resource (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[132]:=
```
dCCtotWindLRC =
 Table[MALoadLRC[[j]] (If[VOCLRCWind[[j]] > 0, 1, 0] ((VOCLRCWind[[j]] - VOC0LRCWind[[j]]) So[[j]] +
          VOCLRCWind[[j]] (Su[[j]] - So[[j]])) + If[ShLRC[[j]] < Sc[[j]] - Su[[j]], 1, 0]
        VOCLRCWind[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOCLRCWind[[j]] > 0, 1, 0] ×
        If[ShLRC[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShLRC[[j]])]), {j, 1, 5}]
```

Out[132]=
```
{5.79868, 0., 0., 0., 0.}
```

4.4. Low Renewables Cost Case, Alternative Assumption #2: Access to Imports

Hydroelectricity Imports Share of Total Load

Hydroelectricity Imports share of total load when Massachusetts has no access to New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[133]:=
```
ShLRCNoImports = {0, 0, 0, 0, 0};
```

Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load)

In[134]:=
```
SxLRCNoImports = Table[Max[Sc[[j]] - Su[[j]] - ShLRCNoImports[[j]], 0], {j, 1, 5}];
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[135]:=
```
VOCLRCNoImports =
 Table[Max[0, -(PROFLRC[[j]] + (1 - (1 - Su[[j]]) / (1 - Su[[j]] - SxLRCNoImports[[j]])))], {j, 1, 5}];
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.17: Estimated increase in per-unit cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[136]:=
```
dCCaveLRCNoImports =
 Table[Round[ (If[VOCLRCNoImports[[j]] > 0, 1, 0] ((VOCLRCNoImports[[j]] - VOC0LRC[[j]]) So[[j]] +
          VOCLRCNoImports[[j]] (Su[[j]] - So[[j]])) + If[ShLRCNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0]
        VOCLRCNoImports[[j]] (Sc[[j]] - Su[[j]]) + PriceEffectNoImports[[j]]
        If[VOCLRCNoImports[[j]] > 0, 1, 0] × If[ShLRCNoImports[[j]] > Sc[[j]] - Su[[j]],
         1 - Su[[j]], 1 - (Sc[[j]] - ShLRCNoImports[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[136]=
```
{0.041997, 0., 0., 0., 0.}
```

Table E.18: Estimated increase in total cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[137]:=
```
dCCtotLRCNoImports = Table[MALoadLRC[[j]] (If[VOCLRCNoImports[[j]] > 0, 1, 0]
      ((VOCLRCNoImports[[j]] - VOC0LRC[[j]]) So[[j]] + VOCLRCNoImports[[j]] (Su[[j]] - So[[j]])) +
     If[ShLRCNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLRCNoImports[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffectNoImports[[j]] If[VOCLRCNoImports[[j]] > 0, 1, 0] ×
      If[ShLRCNoImports[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - Sc[[j]]]), {j, 1, 5}]
```

Out[137]=
```
{19.8662, 0., 0., 0., 0.}
```

4.5. Low Renewables Cost Case, Alternative Assumption #3: Residential and Commercial Customer Growth

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[138]:=
```
ResidElecUseTrendLRC = Table[
   ((ResidElecUseTotLRC[[j]] * (293.07107017222) * (Sne)) / ResidCustTrend[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseTrendLRC = Table[ (CommElecUseTotLRC[[j]] * (293.07107017222) *
     (Sne) / CommCustTrend[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table E.19: Estimated increase in the cost to residential consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[140]:=
```
Table[Round[dCCaveLRC[[j]] * (ResidElecUseTrendLRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[140]=
```
{0.1602, 0., 0., 0., 0.}
```

Table E.20: Estimated increase in the cost to commercial consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[141]:=
```
Table[Round[dCCaveLRC[[j]] * (CommElecUseTrendLRC[[j]]), 0.0001], {j, 1, 5}]
```

Out[141]=
```
{1.0399, 0., 0., 0., 0.}
```

5. High Oil and Gas Supply Case

5.1. High Oil and Gas Supply Case, Definitions and Calculations Applicable to All Assumptions

Estimated Load for Massachusetts

Projected Massachusetts load not from municipal providers (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[142]:=
```
MALoadHOGS = {47.75564254, 49.15751002, 50.66872599, 52.58748725, 55.50482618};
```

Source:
(1) Projected load for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region: Total Net Energy for Load (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~high-ogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load," n.d. https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); U.S. Energy Information Administration; "State Electricity Profiles," n.d. (accessed March 24, 2020). https://www.eia.gov/electricity/state/

(3) Massachusetts load from non-municipal sources: EIA, Table 9: Retail Electricity Sales Statistics, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed Sept 16, 2020).

5.2. High Oil and Gas Supply Case, Baseline Assumptions

Hydroelectricity Imports Share of Total Load

In[143]:=
```
ShHOGS = {0.17568409232763, 0.17506774214444,
   0.17174317242798, 0.16894444260285, 0.15532890786941};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/myModule/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

(3) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load by Source" https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); EIA, "State Electricity Profiles" (accessed March 24, 2020). https://www.eia.gov/electricity/state/

Calculations from Shares

Table E.6: Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load; reported for {2030,2035,2040,2045,2050}):

In[144]:=
```
SxHOGS = Table[Max[Sc[[j]] - Su[[j]] - ShHOGS[[j]], 0], {j, 1, 5}]
```

Out[144]=
```
{0, 0, 0, 0.0310556, 0.0946711}
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[145]:=
```
SolarARHOGS = {33.131718, 33.798374, 33.486668, 32.22411, 33.289124};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[146]:=
```
SolarACHOGS = {37.282577, 35.530369, 33.541851, 31.612036, 30.100948};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.13: Profitability (average revenue minus average cost) of solar (photovoltaic) in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): *(Defined in report as "$\pi(S_u)$")*

In[147]:=
```
PROFHOGS = Table[SolarARHOGS[[j]] - SolarACHOGS[[j]], {j, 1, 5}]
```

Out[147]=
```
{-4.15086, -1.73199, -0.055183, 0.612074, 3.18818}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[148]:=
```
VOCHOGS = Table[Max[0, -(PROFHOGS[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHOGS[[j]])))], {j, 1, 5}]
```

Out[148]=
```
{4.15086, 1.73199, 0.055183, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_0 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[149]:=
```
VOC0HOGS = Table[Max[0, -(PROFHOGS[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[149]=
```
{4.01753, 1.58914, 0, 0, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table 3.5: Estimated increase in per-unit cost to Massachusetts consumers in different cases (in 2019 cents per kWh; reported for {2030, 2035, 2040, 2045, 2050})

In[150]:=
```
dCCaveHOGS = Table[Round[
   (If[VOCHOGS[[j]] > 0, 1, 0] ((VOCHOGS[[j]] - VOC0HOGS[[j]]) So[[j]] + VOCHOGS[[j]] (Su[[j]] - So[[j]])) +
      If[ShHOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHOGS[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCHOGS[[j]] > 0, 1, 0] × If[ShHOGS[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], (1 - (Sc[[j]] - ShHOGS[[j]]))]) / 10, .000001], {j, 1, 5}]
```

Out[150]=
```
{0.043986, 0.018965, 0.001315, 0., 0.}
```

Table 3.6: Estimated increase in total cost to Massachusetts consumers in different cases (in millions of 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050})

In[151]:=
```
dCCtotHOGS = Table[MALoadHOGS[[j]]
   (If[VOCHOGS[[j]] > 0, 1, 0] ((VOCHOGS[[j]] - VOC0HOGS[[j]]) So[[j]] + VOCHOGS[[j]] (Su[[j]] - So[[j]])) +
     If[ShHOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHOGS[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffect[[j]] If[VOCHOGS[[j]] > 0, 1, 0] ×
      If[ShHOGS[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - ShHOGS[[j]]))]), {j, 1, 5}]
```

Out[151]=
```
{21.0057, 9.32259, 0.666501, 0., 0.}
```

Residential and commercial electricity use projections for New England Region:

In[152]:=
```
ResidElecUseTotHOGS = {0.162178, 0.168001, 0.174011, 0.180152, 0.189528};
CommElecUseTotHOGS = {0.170518, 0.173693, 0.177355, 0.183812, 0.194041};
```

Source:
(1) Residential: EIA, Table 2: Energy Consumption by Sector and Source: Residential Electricity (High Oil and Gas Supply case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=highogs&start=2018&end=2050&f=A&linechart=highogs-d112619a.9-2-AEO2020.1-1~highogs-d112619a.24-2-AEO2020.1-1&map=highogs-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020);

(2) Commercial: EIA, Table 2: Energy Consumption by Sector and Source: Commercial Electricity (High Oil and Gas Supply case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=highogs&start=2018&end=2050&f=A&linechart=highogs-d112619a.9-2-AEO2020.1-1~highogs-d112619a.24-2-AEO2020.1-1&map=highogs-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020).

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[154]:=
```
ResidElecUseHOGS =
  Table[((ResidElecUseTotHOGS[[j]] * (293.07107017222) * (Sne)) / ResidCust[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseHOGS = Table[(CommElecUseTotHOGS[[j]] * (293.07107017222) *
     (Sne) / CommCust[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table 3.7: Estimated increase in the cost to Massachusetts residential consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[156]:=
```
Table[Round[dCCaveHOGS[[j]] * (ResidElecUseHOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[156]=
```
{0.2853, 0.1274, 0.0092, 0., 0.}
```

Table 3.8: Estimated increase in the cost to Massachusetts commercial consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[157]:=
```
Table[Round[dCCaveHOGS[[j]] * (CommElecUseHOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[157]=
```
{2.0424, 0.897, 0.0635, 0., 0.}
```

Estimated Effects on Costs to New England Consumers

Projected New England net energy for load, High Oil and Gas Supply case (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[158]:=
```
NELoadHOGS = {121.917679, 125.496574, 129.35463, 134.253128, 141.700943};
```

Source: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 26, 2020).

Table E.8: Estimated total annual savings for New England, excluding Massachusetts, due to Massachusetts's commitments (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[159]:=
```
Table[If[VOCHOGS[[j]] > 0, 1, 0] PriceEffect[[j]] * (-NELoadHOGS[[j]] (1 - Sne)), {j, 1, 5}]
```

Out[159]=
```
{0.873515, 3.00494, 1.49416, 0., 0.}
```

Estimated Effects on Massachusetts's Greenhouse Gas Emissions

Carbon dioxide (CO2) emissions rate of natural gas generation in New England (in million metric tons per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[160]:=
```
erngHOGS = {0.417199506, 0.427057372, 0.433008274, 0.440518738, 0.443658469};
```

Source: EIA, Annual Energy Outlook 2020 : Carbon Dioxide : Electric Power : Natural Gas, New England. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.HIGHOGS.EMI_CO2_ELEP_NA_NG_NA_NEENGL_MILLMETNCO2.A (accessed August 26, 2020);
EIA, Annual Energy Outlook 2020 : Electricity Generation : Northeast Power / New England : Natural Gas. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.HIGHOGS.GEN_NA_ELEP_NA_NG_NA_NPCCNE_BLNKWH.A (accessed August 26, 2020).

Table E.9: Estimated effect of commitments on carbon dioxide emissions per MWh in Massachusetts, alternative scenarios (in million metric tons, Mmt, per MWh; reported for {2030,2035,2040,2045,2050}):

In[161]:=
```
dEMaveHOGS = Table[If[VOCHOGS[[j]] > 0, 1, 0] * (-1) *
    erngHOGS[[j]] (Max[Su[[j]], Sc[[j]] - ShHOGS[[j]]] - So[[j]]), {j, 1, 5}]
```

Out[161]=
```
{-0.04172, -0.0427057, -0.0433008, 0., 0.}
```

Table E.10: Estimated effect of commitments on total carbon dioxide emissions in Massachusetts, alternative scenarios (in million metric tons, Mmt; reported for {2030,2035,2040,2045,2050}):

In[162]:=
```
dEMtotHOGS = Table[MALoadHOGS[[j]] (If[VOCHOGS[[j]] > 0, 1, 0]
      (-1) erngHOGS[[j]] (Max[Su[[j]], Sc[[j]] - ShHOGS[[j]]] - So[[j]])), {j, 1, 5}]
```

Out[162]=
```
{-1.99236, -2.09931, -2.194, 0., 0.}
```

5.3. High Oil and Gas Supply Case, Alternative Assumption #1: Marginal Resource

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[163]:=
```
WindARHOGS = {33.223064, 33.912388, 33.895752, 34.438114, 35.653671};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[164]:=
```
WindACHOGS = {41.133046, 39.875838, 38.201277, 36.468647, 35.120646};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.14: Profitability (average revenue minus average cost) of onshore wind in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
(Defined in report as "$\pi(S_u)$")

In[165]:=
```
PROFHOGSWind = Table[WindARHOGS[[j]] - WindACHOGS[[j]], {j, 1, 5}]
```

Out[165]=
```
{-7.90998, -5.96345, -4.30552, -2.03053, 0.533025}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[166]:=
```
VOCHOGSWind = Table[Max[0, -(PROFHOGSWind[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxHOGS[[j]])))], {j, 1, 5}]
```

Out[166]=
```
{7.90998, 5.96345, 4.30552, 2.09676, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_0 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[167]:=
```
VOC0HOGSWind = Table[Max[0, -(PROFHOGSWind[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[167]=
```
{7.77665, 5.82059, 4.15168, 1.86387, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.11: Estimated increase in per-unit cost to Massachusetts consumers with onshore wind as the marginal resource (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[168]:=
```
dCCaveWindHOGS = Table[Round[ (If[VOCHOGSWind[[j]] > 0, 1, 0]
        ((VOCHOGSWind[[j]] - VOC0HOGSWind[[j]]) So[[j]] + VOCHOGSWind[[j]] (Su[[j]] - So[[j]])) +
      If[ShHOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHOGSWind[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCHOGSWind[[j]] > 0, 1, 0] × If[ShHOGS[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], 1 - (Sc[[j]] - ShHOGS[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[168]=
```
{0.081577, 0.061279, 0.047272, 0.070167, 0.}
```

Table E.12: Estimated increase in total cost to Massachusetts consumers with onshore wind as the marginal resource (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[169]:=
```
dCCtotWindHOGS =
  Table[MALoadHOGS[[j]] (If[VOCHOGSWind[[j]] > 0, 1, 0] ((VOCHOGSWind[[j]] - VOC0HOGSWind[[j]]) So[[j]] +
        VOCHOGSWind[[j]] (Su[[j]] - So[[j]])) + If[ShHOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0]
      VOCHOGSWind[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOCHOGSWind[[j]] > 0, 1, 0] ×
      If[ShHOGS[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShHOGS[[j]])]), {j, 1, 5}]
```

Out[169]=
```
{38.9577, 30.1234, 23.9521, 36.8989, 0.}
```

5.4. High Oil and Gas Supply Case, Alternative Assumption #2: Access to Imports

Hydroelectricity Imports Share of Total Load

Hydroelectricity Imports share of total load when Massachusetts has no access to New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[170]:=
```
ShHOGSNoImports = {0, 0, 0, 0, 0};
```

Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load)

In[171]:=
```
SxHOGSNoImports = Table[Max[Sc[[j]] - Su[[j]] - ShHOGSNoImports[[j]], 0], {j, 1, 5}];
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[172]:=
```
VOCHOGSNoImports =
  Table[Max[0, -(PROFHOGS[[j]] + (1 - (1 - Su[[j]]) / (1 - Su[[j]] - SxHOGSNoImports[[j]])))], {j, 1, 5}];
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.17: Estimated increase in per-unit cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[173]:=
```
dCCaveHOGSNoImports =
 Table[Round[ (If[VOCHOGSNoImports[[j]] > 0, 1, 0] ((VOCHOGSNoImports[[j]] - VOC0HOGS[[j]]) So[[j]] +
          VOCHOGSNoImports[[j]] (Su[[j]] - So[[j]])) + If[ShHOGSNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0]
       VOCHOGSNoImports[[j]] (Sc[[j]] - Su[[j]]) + PriceEffectNoImports[[j]]
       If[VOCHOGSNoImports[[j]] > 0, 1, 0] × If[ShHOGSNoImports[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], 1 - (Sc[[j]] - ShHOGSNoImports[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[173]=
```
{0.067744, 0.044524, 0.023825, 0.001327, 0.}
```

Table E.18: Estimated increase in total cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[174]:=
```
dCCtotHOGSNoImports = Table[MALoadHOGS[[j]] (If[VOCHOGSNoImports[[j]] > 0, 1, 0]
      ((VOCHOGSNoImports[[j]] - VOC0HOGS[[j]]) So[[j]] + VOCHOGSNoImports[[j]] (Su[[j]] - So[[j]])) +
     If[ShHOGSNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCHOGSNoImports[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffectNoImports[[j]] If[VOCHOGSNoImports[[j]] > 0, 1, 0] ×
      If[ShHOGSNoImports[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - Sc[[j]]]), {j, 1, 5}]
```

Out[174]=
```
{32.3517, 21.8869, 12.0717, 0.69766, 0.}
```

5.5. High Oil and Gas Supply Case, Alternative Assumption #3: Residential and Commercial Customer Growth

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[175]:=
```
ResidElecUseTrendHOGS = Table[
   ((ResidElecUseTotHOGS[[j]] * (293.07107017222) * (Sne)) / ResidCustTrend[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseTrendHOGS = Table[ (CommElecUseTotHOGS[[j]] * (293.07107017222) *
     (Sne) / CommCustTrend[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table E.19: Estimated increase in the cost to residential consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[177]:=
```
Table[Round[dCCaveHOGS[[j]] * (ResidElecUseTrendHOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[177]=
```
{0.2641, 0.1147, 0.008, 0., 0.}
```

Table E.20: Estimated increase in the cost to commercial consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[178]:=
```
Table[Round[dCCaveHOGS[[j]] * (CommElecUseTrendHOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[178]=
```
{1.7265, 0.7198, 0.0485, 0., 0.}
```

6. Low Oil and Gas Supply Case

6.1. Low Oil and Gas Supply Case, Definitions and Calculations Applicable to Assumptions

Estimated Load for Massachusetts

Projected Massachusetts load not from municipal providers (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[179]:=
```
MALoadLOGS = {46.5759523, 47.41048394, 49.32346874, 51.2197031, 54.01888413};
```

Source:
(1) Projected load for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region: Total Net Energy for Load (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load," n.d. https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); U.S. Energy Information Administration; "State Electricity Profiles," n.d. (accessed March 24, 2020). https://www.eia.gov/electricity/state/

(3) Massachusetts load from non-municipal sources: EIA, Table 9: Retail Electricity Sales Statistics, https://www.eia.gov/electricity/state/massachusetts/state_tables.php (accessed Sept 16, 2020).

6.2. Low Oil and Gas Supply Case, Baseline Assumptions

Hydroelectricity Imports Share of Total Load

In[180]:=
```
ShLOGS = {0.15701765751438, 0.16191747081912,
   0.16051739148010, 0.16037082865121, 0.14969670953713};
```

Source:
(1) Projected load and imports for New England: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region (Multiple cases, New England region). https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 25, 2020).

(2) Share of imports coming from hydropower: NEPOOL General Information System, System Mix, (accessed November 3, 2020) https://www1.nepoolgis.com/myModule/rpt/ssrs.asp?rn=107&r=%2FPROD%2FNEPOOLGIS%2FPublic%2FNEPOOL_ImportSystemMix&apxReportTitle=Import%20System%20Mix.

(3) Massachusetts share of New England load (based on 2018 data): ISO New England, "Net Energy and Peak Load by Source" https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load (accessed March 24, 2020); EIA, "State Electricity Profiles" (accessed March 24, 2020). https://www.eia.gov/electricity/state/

Calculations from Shares

Table E.6: Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load; reported for {2030,2035,2040,2045,2050}):

In[181]:=
```
SxLOGS = Table[Max[Sc[[j]] - Su[[j]] - ShLOGS[[j]], 0], {j, 1, 5}]
```

Out[181]=
```
{0, 0, 0, 0.0396292, 0.100303}
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[182]:=
```
SolarARLOGS = {38.924355, 40.539337, 41.559181, 40.711468, 40.006027};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal solar generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[183]:=
```
SolarACLOGS = {38.622712, 35.945833, 33.761977, 32.005928, 30.992094};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.13: Profitability (average revenue minus average cost) of solar (photovoltaic) in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): *(Defined in report as "$\pi(S_u)$")*

In[184]:=
```
PROFLOGS = Table[SolarARLOGS[[j]] - SolarACLOGS[[j]], {j, 1, 5}]
```

Out[184]=
```
{0.301643, 4.5935, 7.7972, 8.70554, 9.01393}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $\text{VOC}_1 = \text{MAX}\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[185]:=
```
VOCLOGS = Table[Max[0, -(PROFLOGS[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxLOGS[[j]])))], {j, 1, 5}]
```

Out[185]=
```
{0, 0, 0, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $\text{VOC}_0 = \text{MAX}\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[186]:=
```
VOC0LOGS = Table[Max[0, -(PROFLOGS[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[186]=
```
{0, 0, 0, 0, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table 3.5: Estimated increase in per-unit cost to Massachusetts consumers in different cases (in 2019 cents per kWh; reported for {2030, 2035, 2040, 2045, 2050})

In[187]:=
```
dCCaveLOGS = Table[Round[
    (If[VOCLOGS[[j]] > 0, 1, 0] ((VOCLOGS[[j]] - VOC0LOGS[[j]]) So[[j]] + VOCLOGS[[j]] (Su[[j]] - So[[j]])) +
       If[ShLOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLOGS[[j]] (Sc[[j]] - Su[[j]]) +
       PriceEffect[[j]] If[VOCLOGS[[j]] > 0, 1, 0] × If[ShLOGS[[j]] > Sc[[j]] - Su[[j]],
         1 - Su[[j]], (1 - (Sc[[j]] - ShLOGS[[j]]))]) / 10, .000001], {j, 1, 5}]
```

Out[187]=
```
{0., 0., 0., 0., 0.}
```

Table 3.6: Estimated increase in total cost to Massachusetts consumers in different cases (in millions of 2019 dollars; reported for {2030, 2035, 2040, 2045, 2050})

In[188]:=
```
dCCtotLOGS = Table[MALoadLOGS[[j]]
    (If[VOCLOGS[[j]] > 0, 1, 0] ((VOCLOGS[[j]] - VOC0LOGS[[j]]) So[[j]] + VOCLOGS[[j]] (Su[[j]] - So[[j]])) +
      If[ShLOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLOGS[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCLOGS[[j]] > 0, 1, 0] ×
       If[ShLOGS[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], (1 - (Sc[[j]] - ShLOGS[[j]]))]), {j, 1, 5}]
```

Out[188]=
```
{0., 0., 0., 0., 0.}
```

Residential and commercial electricity use projections for New England Region:

In[189]:=
```
ResidElecUseTotLOGS = {0.157855, 0.161046, 0.167407, 0.172839, 0.181107};
CommElecUseTotLOGS = {0.167429, 0.167908, 0.172187, 0.178225, 0.187495};
```

Source:
(1) Residential: EIA, Table 2: Energy Consumption by Sector and Source: Residential Electricity (Low Oil and Gas Supply case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=hirencst&start=2018&end=2050&f=A&linechart=hirencst-d112619a.9-2-AEO2020.1-1~hirencst-d112619a.24-2-AEO2020.1-1&map=hirencst-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020);

(2) Commercial: EIA, Table 2: Energy Consumption by Sector and Source: Commercial Electricity (Low Oil and Gas Supply case, New England region), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2020&region=1-1&cases=hirencst&start=2018&end=2050&f=A&linechart=hirencst-d112619a.9-2-AEO2020.1-1~hirencst-d112619a.24-2-AEO2020.1-1&map=hirencst-d112619a.5-2-AEO2020.1-1&ctype=linechart&sid=&sourcekey=0 (accessed August 26, 2020).

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[191]:=
```
ResidElecUseLOGS =
  Table[((ResidElecUseTotLOGS[[j]] * (293.07107017222) * (Sne)) / ResidCust[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseLOGS = Table[(CommElecUseTotLOGS[[j]] * (293.07107017222) *
      (Sne) / CommCust[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table 3.7: Estimated increase in the cost to Massachusetts residential consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[193]:=
```
Table[Round[dCCaveLOGS[[j]] * (ResidElecUseLOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[193]=
```
{0., 0., 0., 0., 0.}
```

Table 3.8: Estimated increase in the cost to Massachusetts commercial consumers, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[194]:=
```
Table[Round[dCCaveLOGS[[j]] * (CommElecUseLOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[194]=
```
{0., 0., 0., 0., 0.}
```

Estimated Effects on Costs to New England Consumers

Projected New England net energy for load, Low Oil and Gas Supply case (in terawatt-hours; reported for {2030,2035,2040,2045,2050}):

In[195]:=
```
NELoadLOGS = {118.905991, 121.036507, 125.920258, 130.761246, 137.90741};
```

Source: EIA, Annual Energy Outlook 2020, Table 54: Electric Power Projections by Electricity Market Module Region. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-7&cases=ref2020~highogs~lowogs~hirencst~lorencst&start=2018&end=2050&f=A&linechart=ref2020-d112119a.5-62-AEO2020.5-7~highogs-d112619a.5-62-AEO2020.5-7~lowogs-d112619a.5-62-AEO2020.5-7~hirencst-d112619a.5-62-AEO2020.5-7~lorencst-d120119a.5-62-AEO2020.5-7~ref2020-d112119a.80-62-AEO2020.5-7~highogs-d112619a.80-62-AEO2020.5-7~lowogs-d112619a.80-62-AEO2020.5-7~hirencst-d112619a.80-62-AEO2020.5-7~lorencst-d120119a.80-62-AEO2020.5-7&sourcekey=0 (accessed August 26, 2020).

Table E.8: Estimated total annual savings for New England, excluding Massachusetts, due to Massachusetts's commitments (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[196]:=
```
Table[If[VOCLOGS[[j]] > 0, 1, 0] PriceEffect[[j]] * (-NELoadLOGS[[j]] (1 - Sne)), {j, 1, 5}]
```

Out[196]=
```
{0., 0., 0., 0., 0.}
```

Estimated Effects on Massachusetts's Greenhouse Gas Emissions

Carbon dioxide (CO2) emissions rate of natural gas generation in New England (in million metric tons per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[197]:=
```
erngLOGS = {0.400794475, 0.412211171, 0.4224153, 0.418881286, 0.423411947};
```

Source: EIA, Annual Energy Outlook 2020 : Carbon Dioxide : Electric Power : Natural Gas, New England. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.LOWOGS.EMI_CO2_ELEP_NA_NG_NA_NEENGL_MILLMETNCO2.A (accessed August 26, 2020);
EIA, Annual Energy Outlook 2020 : Electricity Generation : Northeast Power / New England : Natural Gas. https://www.eia.gov/opendata/qb.php?category=3604506&sdid=AEO.2020.LOWOGS.GEN_NA_ELEP_NA_NG_NA_NPCCNE_BLNKWH.A (accessed August 26, 2020).

Table E.9: Estimated effect of commitments on carbon dioxide emissions per MWh in Massachusetts, alternative scenarios (in million metric tons, Mmt, per MWh; reported for {2030,2035,2040,2045,2050}):

In[198]:=
```
dEMaveLOGS = Table[If[VOCLOGS[[j]] > 0, 1, 0] * (-1) *
    erngLOGS[[j]] (Max[Su[[j]], Sc[[j]] - ShLOGS[[j]]] - So[[j]]), {j, 1, 5}]
```

Out[198]=
```
{0., 0., 0., 0., 0.}
```

Table E.10: Estimated effect of commitments on total carbon dioxide emissions in Massachusetts, alternative scenarios (in million metric tons, Mmt; reported for {2030,2035,2040,2045,2050}):

In[199]:=
```
dEMtotLOGS = Table[MALoadLOGS[[j]] (If[VOCLOGS[[j]] > 0, 1, 0]
      (-1) erngLOGS[[j]] (Max[Su[[j]], Sc[[j]] - ShLOGS[[j]]] - So[[j]])), {j, 1, 5}]
```

Out[199]=
```
{0., 0., 0., 0., 0.}
```

6.3. Low Oil and Gas Supply Case, Alternative Assumption #1: Marginal Resource

Average Revenue, Average Cost, and Value of Credits

Average revenue of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[200]:=
```
WindARLOGS = {42.073563, 41.744576, 43.210724, 42.729176, 44.209011};
```

Source: EIA, Annual Energy Outlook 2020 : LACE (available from EIA on request; accessed October 2, 2020).

Average cost of the marginal wind generation plant (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):

In[201]:=
```
WindACLOGS = {42.751542, 40.369646, 38.346979, 36.671382, 38.120421};
```

Source: EIA, Annual Energy Outlook 2020 : LCOE, (available from EIA on request; accessed October 2, 2020).

Table E.14: Profitability (average revenue minus average cost) of onshore wind in New England for all scenarios (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}):
(Defined in report as "$\pi(S_u)$")

In[202]:=
```
PROFLOGSWind = Table[WindARLOGS[[j]] - WindACLOGS[[j]], {j, 1, 5}]
```

Out[202]=
```
{-0.677979, 1.37493, 4.86375, 6.05779, 6.08859}
```

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[203]:=
```
VOCLOGSWind = Table[Max[0, -(PROFLOGSWind[[j]] + (1 - (1 - Su[[j]])/(1 - Su[[j]] - SxLOGS[[j]])))], {j, 1, 5}]
```

Out[203]=
```
{0.677979, 0, 0, 0, 0}
```

Value of the credit for the initial RPS commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_0 = MAX\left[-\left(\pi(S_u)+1-\left(\frac{1-S_u}{1-S_o}\right)\right), 0\right]$ (equation (E5))

In[204]:=
```
VOC0LOGSWind = Table[Max[0, -(PROFLOGSWind[[j]] + (1 - (1 - Su[[j]])/(1 - So[[j]])))], {j, 1, 5}]
```

Out[204]=
```
{0.544646, 0, 0, 0, 0}
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.11: Estimated increase in per-unit cost to Massachusetts consumers with onshore wind as the marginal resource (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[205]:=
```
dCCaveWindLOGS = Table[Round[ (If[VOCLOGSWind[[j]] > 0, 1, 0]
        ((VOCLOGSWind[[j]] - VOC0LOGSWind[[j]]) So[[j]] + VOCLOGSWind[[j]] (Su[[j]] - So[[j]])) +
      If[ShLOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLOGSWind[[j]] (Sc[[j]] - Su[[j]]) +
      PriceEffect[[j]] If[VOCLOGSWind[[j]] > 0, 1, 0] × If[ShLOGS[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], 1 - (Sc[[j]] - ShLOGS[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[205]=
```
{0.009257, 0., 0., 0., 0.}
```

Table E.12: Estimated increase in total cost to Massachusetts consumers with onshore wind as the marginal resource (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[206]:=
```
dCCtotWindLOGS =
  Table[MALoadLOGS[[j]] (If[VOCLOGSWind[[j]] > 0, 1, 0] ((VOCLOGSWind[[j]] - VOC0LOGSWind[[j]]) So[[j]] +
        VOCLOGSWind[[j]] (Su[[j]] - So[[j]])) + If[ShLOGS[[j]] < Sc[[j]] - Su[[j]], 1, 0]
      VOCLOGSWind[[j]] (Sc[[j]] - Su[[j]]) + PriceEffect[[j]] If[VOCLOGSWind[[j]] > 0, 1, 0] ×
      If[ShLOGS[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - (Sc[[j]] - ShLOGS[[j]])]), {j, 1, 5}]
```

Out[206]=
```
{4.31155, 0., 0., 0., 0.}
```

6.4. Low Oil and Gas Supply Case, Alternative Assumption #2: Access to Imports

Hydroelectricity Imports Share of Total Load

Hydroelectricity Imports share of total load when Massachusetts has no access to New England's total imports (reported for {2030,2035,2040,2045,2050}):

In[207]:=
```
ShLOGSNoImports = {0, 0, 0, 0, 0};
```

Additional renewable generation necessary to meet CES commitment (as a share of total Massachusetts load)

In[208]:=
```
SxLOGSNoImports = Table[Max[Sc[[j]] - Su[[j]] - ShLOGSNoImports[[j]], 0], {j, 1, 5}];
```

Effects on the Price of Wholesale Generation

Note: See discussion in report appendix E for more information as to why the Price Effect does not vary across scenarios.

Average Revenue, Average Cost, and Value of Credits

Value of the credit for the updated RPS and CES commitments (in 2019 dollars per megawatt-hour; reported for {2030,2035,2040,2045,2050}): $VOC_1 = MAX\left[-\left(\pi(S_u) + 1 - \left(\frac{1-S_u}{1-S_u-S_x}\right)\right), 0\right]$ (equation (E4))

In[209]:=
```
VOCLOGSNoImports =
  Table[Max[0, -(PROFLOGS[[j]] + (1 - (1 - Su[[j]]) / (1 - Su[[j]] - SxLOGSNoImports[[j]])))], {j, 1, 5}];
```

Estimated Effects on Costs to Massachusetts Consumers

Table E.17: Estimated increase in per-unit cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in 2019 cents per kWh; reported for {2030,2035,2040,2045,2050}):

In[210]:=
```
dCCaveLOGSNoImports =
 Table[Round[ (If[VOCLOGSNoImports[[j]] > 0, 1, 0] ((VOCLOGSNoImports[[j]] - VOC0LOGS[[j]]) So[[j]] +
          VOCLOGSNoImports[[j]] (Su[[j]] - So[[j]])) + If[ShLOGSNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0]
       VOCLOGSNoImports[[j]] (Sc[[j]] - Su[[j]]) + PriceEffectNoImports[[j]]
       If[VOCLOGSNoImports[[j]] > 0, 1, 0] × If[ShLOGSNoImports[[j]] > Sc[[j]] - Su[[j]],
        1 - Su[[j]], 1 - (Sc[[j]] - ShLOGSNoImports[[j]])]) / 10, .000001], {j, 1, 5}]
```

Out[210]=
```
{0., 0., 0., 0., 0.}
```

Table E.18: Estimated increase in total cost to consumers of Massachusetts's increased commitments if Massachusetts has no access to imported hydroelectricity (in millions of 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[211]:=
```
dCCtotLOGSNoImports = Table[MALoadLOGS[[j]] (If[VOCLOGSNoImports[[j]] > 0, 1, 0]
      ((VOCLOGSNoImports[[j]] - VOC0LOGS[[j]]) So[[j]] + VOCLOGSNoImports[[j]] (Su[[j]] - So[[j]])) +
     If[ShLOGSNoImports[[j]] < Sc[[j]] - Su[[j]], 1, 0] VOCLOGSNoImports[[j]] (Sc[[j]] - Su[[j]]) +
     PriceEffectNoImports[[j]] If[VOCLOGSNoImports[[j]] > 0, 1, 0] ×
      If[ShLOGSNoImports[[j]] > Sc[[j]] - Su[[j]], 1 - Su[[j]], 1 - Sc[[j]]]), {j, 1, 5}]
```

Out[211]=
```
{0., 0., 0., 0., 0.}
```

6.5. Low Oil and Gas Supply Case, Alternative Assumption #3: Residential and Commercial Customer Growth

Estimated total annual electricity use per residence or commercial establishment (in megawatt-hours per month):

In[212]:=
```
ResidElecUseTrendLOGS = Table[
   ((ResidElecUseTotLOGS[[j]] * (293.07107017222) * (Sne)) / ResidCustTrend[[j]] * 10 000 000 / 12),
   {j, 1, 5}];
CommElecUseTrendLOGS = Table[ (CommElecUseTotLOGS[[j]] * (293.07107017222) *
     (Sne) / CommCustTrend[[j]] * 10 000 000 / 12), {j, 1, 5}];
```

Note: 293.07107017222 constant converts electricity use from quads to terawatt hours.

Table E.19: Estimated increase in the cost to residential consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[214]:=
```
Table[Round[dCCaveLOGS[[j]] * (ResidElecUseTrendLOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[214]=
```
{0., 0., 0., 0., 0.}
```

Table E.20: Estimated increase in the cost to commercial consumers for high population growth, monthly cost per customer (in 2019 dollars; reported for {2030,2035,2040,2045,2050}):

In[215]:=
```
Table[Round[dCCaveLOGS[[j]] * (CommElecUseTrendLOGS[[j]]), 0.0001], {j, 1, 5}]
```

Out[215]=
```
{0., 0., 0., 0., 0.}
```