# Clean Energy in New York State:

## The Role and Economic Impacts of a Carbon Price in NYISO's Wholesale Electricity Markets

## TECHNICAL APPENDIX

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## Table of Contents
## Technical Appendix

# I. Clean energy resource additions needed to comply with New York State policies (re: Section III of the Final Report)

## A. Analytic approach and data

The purpose of this analysis was to quantify the amount of additional zero-carbon and renewable resources needed in different time periods to achieve the targets established in the New York State Climate Leadership and Community Protection Act (the Act or CLCPA).[1]

For this purpose, we explored the implications for new resource additions of two outlooks for demand: a baseline scenario in which the demand forecast is the one used in NYISO transmission planning processes; and a second, high-electrification scenario, in which residential electric vehicles and electric heating systems are assumed to be added, and at a much faster pace, than in the baseline scenario in order to replicate electrification expectations directionally consistent with the carbon reduction requirements of the Act.

### 1. Baseline scenario

This scenario relies on NYISO's 2019 forecast of "baseline" demand for electricity in various years through 2040.[2] According to NYISO, its baseline forecasts reflects the impact of "energy efficiency programs, building codes and standards, distributed energy resources, behind-the-meter energy storage, and behind-the-meter solar photovoltaic power," as well as the expected impacts of a modest increase in electric vehicle usage.[3] The NYISO forecast was developed prior to the passage of the Act, and does not attempt to reflect potential scenarios for electrification to meet the Act's requirements for all sectors of the economy.

We used this baseline scenario as the foundation for identifying the amount of renewable and zero-carbon resources in megawatt-hours (MWh) that will need to be added to the New York system as of 2030 and 2040 to meet the CLCPA's target percentages for renewables or for zero-carbon supply in the electric sector. By 2030, for example, renewable generation will need to equal 70 percent of baseline demand; by 2040, baseline demand would need to be fully met by zero-carbon-emitting resources.

As a simplifying assumption, we adjusted the supply outlook so that it would reflect percentages of such resources consistent with a smooth transitions toward these goals in the years between 2018 and those target years.

As the starting point for current electricity supply from different types of generating technologies and fuels, we relied on NYISO data for 2018 generation (in gigawatt-hours, or GWh) and 2019 summer installed capacity (in megawatts, or MW) for the NYISO system.[4] We then determined the quantity of capacity (MW) available in future years for each resource type—natural gas, oil, coal, nuclear, onshore wind, offshore wind, solar, hydro, pumped storage, and distributed solar and storage—based on the information, assumptions and sources described below. From such capacity numbers, we also estimated the quantity of energy (GWh) available in these years for each type of renewable and zero-carbon resource.

[1] Text of New York State Senate bill S. 6599 and Assembly bill A. 8429 (CLCPA), available at https://legislation.nysenate.gov/pdf/bills/2019/s6599, (hereafter "CLCPA"). The targets aim for 70-percent renewable electricity by 2030 and 100-percent carbon-free power by 2040.

[2] NYISO, "2019 Load & Capacity Data Report," April 2019 (hereafter "2019 NYISO Gold Book").

[3] 2019 NYISO Gold Book, page 1.

[4] 2017, 2018, and 2019 NYISO Gold Books.

We assumed that hydro, onshore and offshore wind, and solar would qualify as renewables, and that zero-carbon supply includes nuclear, hydro, onshore and offshore wind, and solar.

We assumed that nuclear installed capacity would remain constant, based on the 2019 summer capacity and 2016-2018 average annual generation, until nuclear units are assumed to retire at the end of their operating licenses or as scheduled according to agreements. We assumed the following dates for nuclear unit retirements in New York:

| Nuclear Unit | Retirement | Source |
|---|---|---|
| Indian Point Energy Center Unit 2 | 4/30/2020 | NYISO 2019 Gold Book, Table IV-5. |
| Indian Point Energy Center Unit 3 | 4/30/2021 | NYISO 2019 Gold Book, Table IV-5. |
| R.E. Ginna | 9/18/2029 | License expiration date. https://www.nrc.gov/info-finder/reactors/ginn.html. |
| Nine Mile Point Unit 1 | 8/22/2029 | License expiration date. https://www.nrc.gov/info-finder/reactors/nmp1.html. |
| Nine Mile Point Unit 2 | 10/31/2046 | License expiration date. https://www.nrc.gov/info-finder/reactors/nmp2.html. |
| James A. FitzPatrick | 10/17/2034 | License expiration date. https://www.nrc.gov/info-finder/reactors/fitz.html. |

For renewable energy capacity available in future years, we started by accounting for certain known or 'committed' resources, which we assumed to include:

- existing renewables as of 2018 (which we assumed will remain in place through 2040)
- renewables that are not yet in operation but that have been procured by NYSERDA in recent years (2017, 2018, and with an assumed amount of new projects awarded in 2019) through long-term Renewable Energy Credit (REC) contracts
- any new incremental renewable resources that have been specifically called out as planned additions under the Act[5]

We relied upon various sources of information (as described below) about capacity factors associated with each type of resource in order to convert capacity estimates into generation estimates (again, for the purpose of estimating generation that would count toward meeting renewable-generation shares to support the Act's goals).

Regarding wind resources, we assumed that onshore wind capacity would double by 2025 to 3,478 MW (from 1,739 MW in 2019) based on Governor Cuomo' s Green New Deal targets.[6] Onshore wind generation was calculated using a 36-percent average capacity factor for the Northeastern U.S., based on historical New

[5] Section 13.e of the Act specifies certain capacity additions: 6,000 MW of distributed solar energy capacity installed in the state by 2025, 9,000 MW of offshore wind capacity installed by 2035, statewide energy efficiency goal of 185 trillion Btus of energy reduction from the 2025 forecast, and 3,000 MW of statewide energy storage capacity by 2030. See CLCPA.

[6] New York State, "Governor Cuomo Announces Green New Deal Included in 2019 Executive Budget," January 17, 2019, available at https://www.governor.ny.gov/news/governor-cuomo-announces-green-new-deal-included-2019-executive-budget (hereafter Cuomo Green New Deal Targets).

York State onshore wind capacity factors from S&P Global Intelligence. Offshore wind capacity was assumed to be in line with Governor Cuomo's Green New Deal targets (2,400 MW by 2030 and 9,000 MW by 2035), with the latter specified in the Act, in part reflecting the Empire and Sunrise offshore wind contract awards announced and executed in July 2019.[7] We assumed that half of the 2030 capacity would be added by 2025.[8] Offshore wind generation was calculated using a 44-percent capacity factor, based on the 2019 National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB).[9] (This capacity-factor assumption is likely conservative in light of the New York State Energy Research and Development Authority's (NYSERDA's) default assumption that the two new offshore-wind awards would have a capacity factor of 38 percent.)

Solar capacity was assumed to include all existing installed capacity as well as New York Clean Energy Standard (CES) procurements through 2019. For the 2019 CES procurement, we assume that NYSERDA would award an amount equivalent to the average of the 2017 and 2018 CES procurements.[10] Solar generation was calculated using an 18-percent average capacity factor, based on the 2019 National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB).[11] Distributed solar is based on the amount forecasted in NYISO's 2019 Gold Book, with distributed solar assumed to have a 14-percent average capacity factor, based on the 2019 NREL ATB.[12]

Existing hydro was assumed to remain constant through 2040 based on 2018 generation and 2019 capacity. We also assumed that imports would remain constant at 26,000 GWh, the approximate NYISO average for 2016 through 2018.[13] The sole addition we made to hydro resources was to assume that the Champlain Hudson Power Express will come online by 2025 and provide an additional 1,000 MW of capacity from Hydro Quebec at a capacity factor of 95 percent.[14] (This is likely to be conservative, in light of the potential for curtailment in a situation where both the new Canadian hydro as well if much if not all of the new offshore wind were delivered into and/or need to pass through New York City area.) For the purposes of the analysis (and in terms of counting whether imports are renewable and/or zero-carbon for the purpose of meeting the Act's targets), we also assumed that imports from Hydro Quebec and Independent Electricity System Operator (Ontario) are zero-carbon but not counted as qualified renewable resources.

We did not count storage or pumped storage as providing incremental clean energy resources. Nor did we forecast changes in the fossil fleet, due to our focus in this analysis on the share of renewables and zero-carbon resources that would need to be added to satisfy targets as of 2030 and 2040.

Based on these assumed changes in the amount of existing/planned/specified resources entering the system as described above, we compared these resources to the 70-percent renewables target by 2030, and the 100-percent zero-carbon electricity goal by 2040, with assumed need for New York to make gradual progress

[7] New York, "Governor Cuomo Executes the Nation's Largest Offshore Wind Agreement and Signs Historic Climate Leadership and Community Protection Act," July 18, 2019, available at https://www.governor.ny.gov/news/governor-cuomo-executes-nations-largest-offshore-wind-agreement-and-signs-historic-climate.

[8] Cuomo Green New Deal Targets.

[9] NREL, 2019 Annual Technology Baseline (ATB), available at https://atb.nrel.gov/.

[10] NYSERDA, "Fact Sheet: 2017 Renewable Energy Standard Solicitation," 2017; NYSERDA, "Fact Sheet: 2018 Renewable Energy Standard Solicitation," 2018; NYSERDA, 2019 Purchase of New York Tier 1 Eligible Renewable Energy Certificates, Request for Proposals (RFP) No. RESRFP19-1, April 23, 2019 (hereafter NYSERDA CES Procurement Fact Sheets).

[11] NREL, 2019 ATB.

[12] NREL, 2019 ATB.

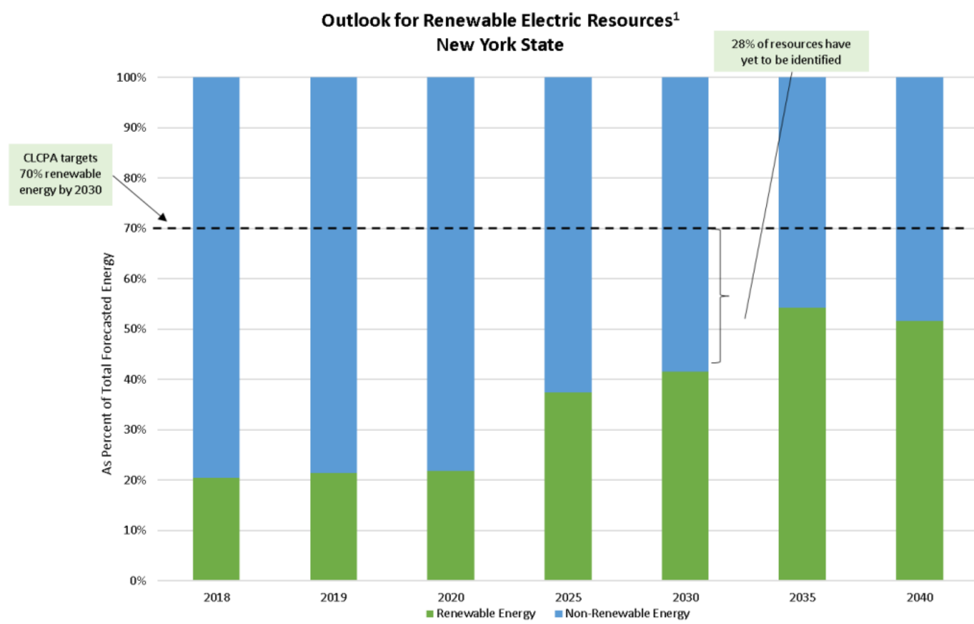
[13] 2016, 2017, and 2018 NYISO Gold Books, Table III-3d.

[14] Transmission Developers Inc., Champlain Hudson Power Express website, available at http://www.chpexpress.com/.

toward them over time.[15] Any difference between existing/planned/specified renewable and zero-carbon resources and the MWh generation needed to meet the Act's goals was assumed to be the amount of additional renewable or zero-carbon resources—that is, beyond what is already "in the pipeline" in one form or another—that will need to enter operation to satisfy the Act's requirements.

Figures A.1 to A.4 and Tables A.1 to A.2 below provide detailed results.[16]

**Figure A.1**




Notes:
[1] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[2] Energy forecast based on the 2019 Gold Book projected baseline demand.
[3] Renewable resources include hydro, wind and solar.

[15] For the 70-percent renewable electricity goal, we assumed 30 percent in 2020, 50 percent in 2025, and 70 percent in 2030. For the 100-percent carbon-free electricity goal, we assumed 30 percent in 2020, 50 percent in 2025, 70 percent in 2030, 85 percent in 2035, and 100 percent in 2040.

[16] Sources for these tables and figures are: 2017, 2018, and 2019 NYISO Gold Books; NYSERDA Procurement Fact Sheets; CLCPA; and Cuomo Green New Deal Targets.

**Figure A.2**

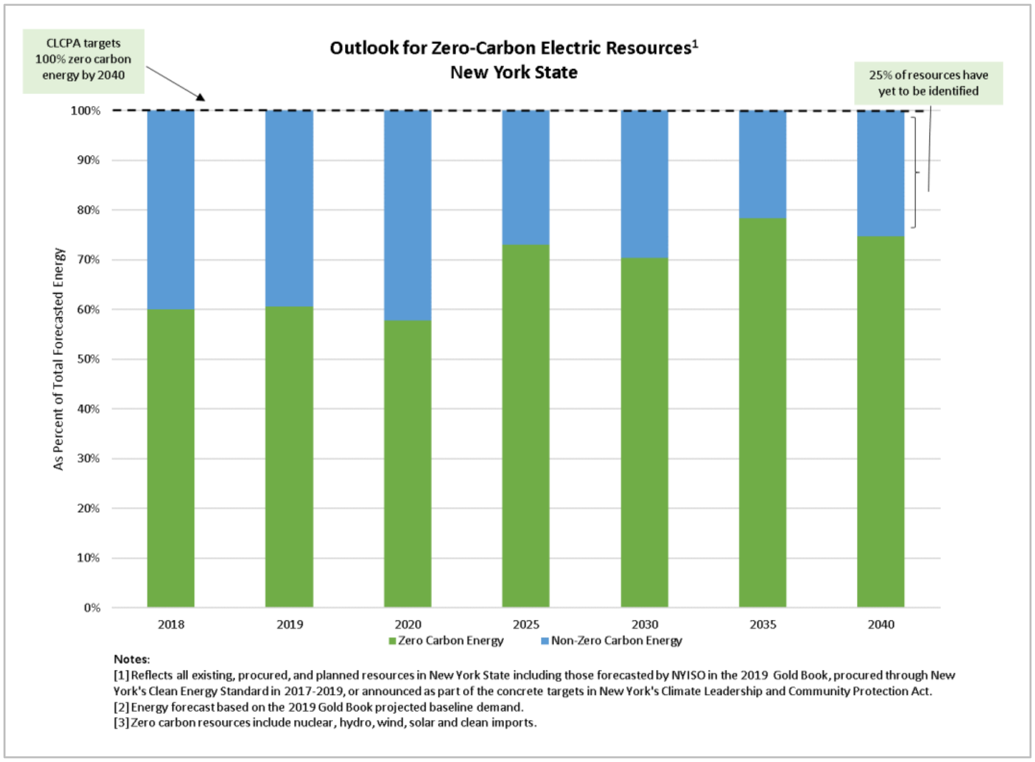



**Figure A.3**

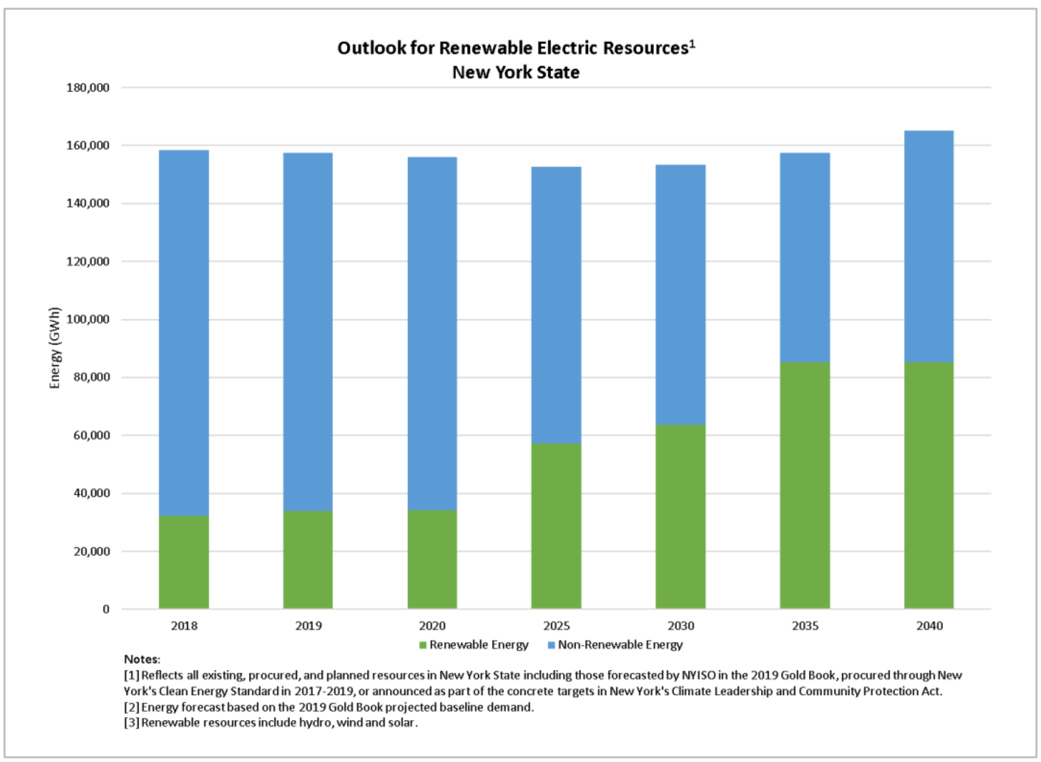
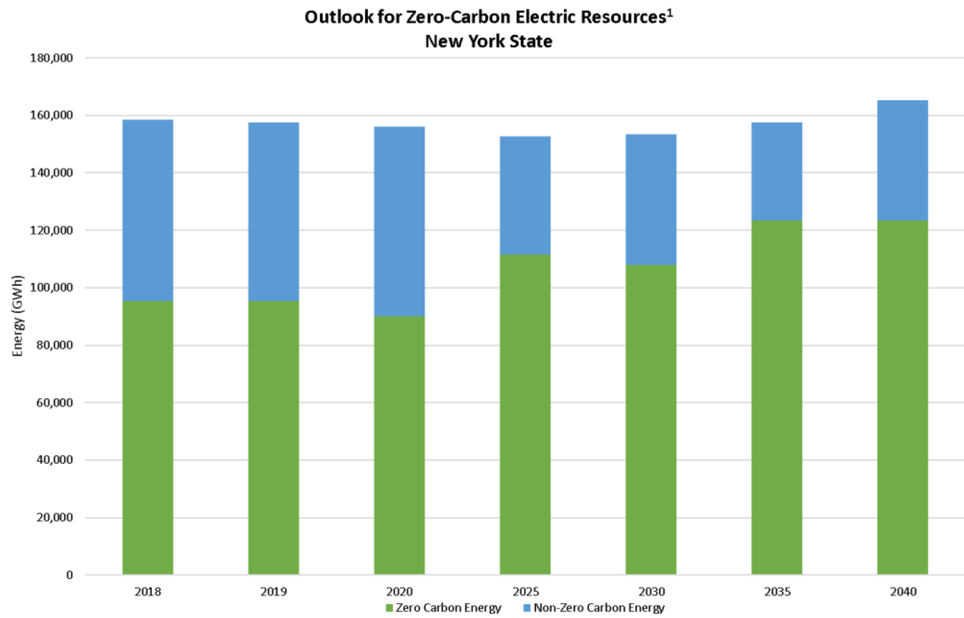


**Figure A.4**




Notes:
[1] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[2] Energy forecast based on the 2019 Gold Book projected baseline demand.
[3] Zero carbon resources include nuclear, hydro, wind, solar and clean imports.

**Table A.1**
**Clean Energy Resources in NYISO System vs. New York State Targets (GWh)**
**Electricity Sector**

| | 2018 | 2019 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| **Forecasted Energy Demand (GWh)**[1] | 158,445 | 157,500 | 156,000 | 152,600 | 153,400 | 157,500 | 165,200 |
| **Zero-Carbon Resources: Known/Planned (GWh)**[2] | | | | | | | |
| In-State | 75,341 | 76,100 | 70,800 | 83,900 | 80,400 | 95,700 | 95,700 |
| Imports | 19,916 | 19,400 | 19,400 | 27,700 | 27,700 | 27,700 | 27,700 |
| Total | 95,257 | 95,500 | 90,200 | 111,600 | 108,100 | 123,400 | 123,400 |
| As percent of total supply needs | 60% | 61% | 58% | 73% | 70% | 78% | 75% |
| CLCPA target (%) | | | 30% | 50% | 70% | 85% | 100% |
| Total zero-carbon resources needed to meet target | | | 46,800 | 76,300 | 107,380 | 133,875 | 165,200 |
| Additional zero-carbon resources yet to enter the market or to be identified | | | - | - | - | 10,475 | 41,800 |
| **Renewable Resources: Known/Planned (GWh)**[2] | | | | | | | |
| Total | 32,338 | 33,800 | 34,100 | 57,200 | 63,700 | 85,300 | 85,300 |
| As percent of total supply needs | 20% | 21% | 22% | 37% | 42% | 54% | 52% |
| CLCPA target (%) | | | 30% | 50% | 70% | 70% | 70% |
| Total renewable resources needed to meet target | | | 46,800 | 76,300 | 107,380 | 110,250 | 115,640 |
| Additional renewable resources yet to enter the market or be identified | | | 12,700 | 19,100 | 43,680 | 24,950 | 30,340 |

**Notes:**
[1] Forecasted Energy Demand is based on NYISO forecast of Baseline Demand in 2019 Gold Book.
[2] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[3] The CLCPA targets seek 70% renewable energy by 2030 and 100% carbon free energy by 2040. A smooth transition to renewable and carbon free energy targets is assumed between 2018 and the target years.
[4] Assumes nuclear plants retire when their license expires.
[5] Renewable resources include hydro, wind and solar.
[6] Zero-carbon resources include nuclear, hydro, wind, solar and clean imports.
[7] All forecasted values are rounded to the nearest hundred.

**Table A.2**
**Resource Capacity vs. Forecasted Peak Summer Demand (MW)**
**Electricity Sector**

| | 2018 | 2019 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| **Forecasted Capacity Needs (MW)**[1] | | | | | | | |
| Peak Summer Demand | 32,512 | 32,400 | 32,200 | 31,400 | 31,100 | 31,700 | 33,000 |
| Installed Reserve Margin | 5,852 | 5,800 | 5,800 | 5,700 | 5,600 | 5,700 | 5,900 |
| Total Capacity Requirement | 38,364 | 38,200 | 38,000 | 37,100 | 36,700 | 37,400 | 38,900 |
| **Known/Planned Resources (MW)**[2] | | | | | | | |
| In-State | 39,066 | 39,300 | 37,500 | 41,000 | 49,600 | 54,300 | 54,300 |
| Imports | 1,625 | 1,500 | 1,800 | 2,900 | 2,900 | 2,900 | 2,900 |
| Total | 40,691 | 40,800 | 39,300 | 43,900 | 52,500 | 57,200 | 57,200 |
| Surplus or gap in capacity resources (MW) | 2,327 | 2,600 | 1,300 | 6,800 | 15,800 | 19,800 | 18,300 |

**Notes:**
[1] Forecasted Capacity Needs are based on NYISO forecast of Summer Peak Demand in 2019 Gold Book.
[2] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[3] Assumes no retirement of fossil and non-fossil resources with the exception of coal plants which are scheduled to retire by 2020 and nuclear plants which are assumed to retire when their license expires.
[4] Assumes an installed reserve margin of 18% of peak summer demand.
[5] All forecasted values are rounded to the nearest hundred.

## 2. High-electrification scenario

The Act has changed—potentially in fundamental ways—the outlook for demand in the power sector, through an outsized reliance on electrification (in combination with the renewable/zero-carbon goals discussed above) to achieve the Act's carbon reductions in other sectors of the economy. Thus we also considered a high-electrification scenario in which we assess the amount of renewable and zero-carbon resources that would need to enter the market if electricity demand were significantly higher than in the baseline forecast, due to more aggressive electrification of building energy use or transportation. Such a scenario is at least implied by the economy-wide decarbonization targets set forth in the Act. In addition, we estimated the net impact on carbon dioxide-equivalent ($CO_2e$) emissions that would result from increased electrification of certain building and transportation end uses over time.

### *Magnitude of electrification*

For the high-electrification scenario, we focused illustratively on increased shifting of residential buildings' heating systems and vehicles to electricity. We assumed increasing levels of such electrification in 5-year intervals to estimate what could potentially be required to meet the requirements of the Act: Specifically, we assumed electrification levels of 10 percent in 2025, 35 percent in 2030, 60 percent in 2035, and 85 percent in 2040. These shares apply to households converting from gas- or oil-fired heating to electric heating, and to vehicle owners transitioning from gasoline engines to electric vehicles (EVs). As a starting point for this analysis, there were 5,891,167 households in New York that heated their homes (e.g., single family, apartments) with gas or oil,[17] and 9,983,711 light-duty vehicles (LDVs) registered in New York in 2017.[18]

### *Electrification of home heating*

To estimate the increase in electricity demand from electrification of home heating, we multiplied the number of households switching from gas- or oil-fired heating to electric heating by the average amount of electricity used to heat a standard dwelling unit in New York. In each time period, the number of households estimated to switch to electric heating is based on our assumed level of electrification. For example, in 2030 we assumed 35 percent of households will have switched (with an additional 2,061,907 households heating with electricity).

To estimate the incremental electricity demand from this fuel switching, we used the Source Energy and Emissions Analysis Tool (SEEAT) to estimate the amount of electricity needed to heat a standard dwelling unit with an efficient electric heat pump.[19] The average amount of electricity used varies across the state. We represent all households switching in New York City (Bronx, Kings, New York, Queens, and Richmond counties) by an average NYC household using 7,267 kWh annually. For households in other parts of the state, we used a proxy of the average household in Albany that uses 10,962 kWh annually. We calculated the total incremental increase in electricity demand by multiplying the total number of switching households in each geographic region times the average electricity used to heat a home in that region. Our results are shown in the table below.

**Table A.3**
**Calculation of Incremental Electricity Demand Resulting From**
**Illustrative Increased Fuel-Switching of Residential Heating Systems in New York State**

| | New York City | | | |
|---|---|---|---|---|
| **Year** | **2025** | **2030** | **2035** | **2040** |
| **Level of Electrification** | 0.10 | 0.35 | 0.60 | 0.85 |
| **Count of Households Switching to Electricity** | 261,591 | 915,570 | 1,569,549 | 2,223,528 |
| **Electricity Used in Average Home (kWh)** | 7,267 | 7,267 | 7,267 | 7,267 |
| **Total Increase in Electricity (MWh)** | 1,900,982 | 6,653,447 | 11,405,913 | 16,158,378 |

| | All Other NY | | | |
|---|---|---|---|---|
| **Year** | **2025** | **2030** | **2035** | **2040** |
| **Level of Electrification** | 0.10 | 0.35 | 0.60 | 0.85 |
| **Count of Households Switching to Electricity** | 327,525 | 1,146,337 | 1,965,150 | 2,783,963 |
| **Electricity Used in Average Home (kWh)** | 10,962 | 10,962 | 10,962 | 10,962 |
| **Total Increase in Electricity (MWh)** | 3,590,329 | 12,566,146 | 21,541,974 | 30,517,802 |
| | | | | |
| ***Aggregated Increase in Electricity (MWh)*** | ***5,491,311*** | ***19,219,593*** | ***32,947,887*** | ***46,676,180*** |

[17] U.S. Census Bureau, 2017 American Community Survey (hereafter American Community Survey), available at https://factfinder.census.gov.

[18] The total number of LDVs in New York was estimated using publicly available data from the Federal Highway Administration (FHWA). The FHWA reports data on the number of LDVs in the U.S. (250,533,248) and the total number of motor vehicles in the U.S. (272,480,899) in 2017. See "Annual Vehicle Distance Traveled in Miles and Related Data by Highway Category and Vehicle Type - 2017,"available at https://www.fhwa.dot.gov/policyinformation/statistics/2017/vm1.cfm. The FHWA reports data on the total number of motor vehicles in New York (10,857,455) but not on the number of LDVs. To estimate the number of LDVs in New York, we applied the national share of LDVs to all motor vehicles (92 percent) to all motor vehicles in New York to calculate an estimate of 9,983,711 light duty-vehicles in New York. See "State Motor-Vehicle Registrations - 2017," available at https://www.fhwa.dot.gov/policyinformation/statistics/2017/mv1.cfm.

[19] We assumed the standard household to be a 3-person, 2,300 square foot, residential detached 2-story household. We assumed an 18 SEER/9.2 HSPF heat pump. Additional information available at http://seeatcalc.gastechnology.org/ .

### *Electrification of vehicles*

To estimate the total increase in electricity demand from our illustrative example of more aggressive electrification of vehicles, we translated the number of vehicle owners switching from gasoline-vehicles to electric vehicles into a total amount of electricity needed to power the new EVs. In 2030, for example, we assumed that 35 percent of gasoline-vehicles would be replaced by EVs, which results in nearly 3.5 million additional electric vehicles on the roads in New York. We multiplied the number of new EVs in each forecasted year by the average number of miles driven by a LDV in NY to obtain the total number of miles driven by the new EV fleet.[20] We then converted this increase in miles to an amount of electricity using the standard efficiency of an EV.[21] In 2030, for example, this results in a total increase in electricity demand of more than 11 million MWh.

**Table A.4**
**Calculation of Incremental Electricity Demand Resulting From Illustrative Increased Adoption of EVs by Households in New York State**

| | New York | | | |
|---|---|---|---|---|
| **Year** | **2025** | **2030** | **2035** | **2040** |
| **Level of Electrification** | 0.10 | 0.35 | 0.60 | 0.85 |
| **Count of Vehicles Switching to EV** | 998,371 | 3,494,298 | 5,990,226 | 8,486,154 |
| **Average Vehicle Miles Per Year (FHWA)** | 11,101 | 11,101 | 11,101 | 11,101 |
| **Average EV Efficiency (kWh/Mile)** | 0.3 | 0.3 | 0.3 | 0.3 |
| ***Total Increase in Electricity (MWh)*** | ***3,324,893*** | ***11,637,125*** | ***19,949,359*** | ***28,261,594*** |

### *Emissions impact*

In our scenarios, electrification leads to net reductions in total $CO_2$e emissions as a result of the decrease in emissions from fuel-switching of residential end uses outweighing the increase in emissions from more generation to satisfy incremental increased electricity demand. With home heating electrification, there is a large decrease in emissions as fewer households use gas or oil-fired heating, but this is partially offset by a small increase in emissions resulting from electrical generation to serve these homes that switch to electric heating. With transportation electrification, there is a large decrease in emissions from fewer gasoline vehicles, but this is partially offset by a small increase in emissions from the electric sector to meet the demand from more EVs.

For home heating electrification, we calculated the total reduction in $CO_2$e emissions by determining the number of households switching from gas or oil to electricity, translating the number of households into a reduction in gas and oil used for home heating, and converting that total quantity into a $CO_2$e emissions

[20] The total vehicle miles traveled (VMT) for LDVs in New York was estimated using publicly available data from the FHWA. FHWA provides data on VMT for LDVs in the U.S. (2.9 trillion) and for all U.S. motor vehicles (3.2 trillion). See "Annual Vehicle Distance Traveled in Miles and Related Data by Highway Category and Vehicle Type - 2017," available at https://www.fhwa.dot.gov/policyinformation/statistics/2017/vm1.cfm. The FHWA reports data on total VMT by all motor vehicles in New York (123,732 million). See "Functional System Travel - 2017, Annual Vehicle - Miles," available at https://www.fhwa.dot.gov/policyinformation/statistics/2017/vm2.cfm. To estimate total VMT by LDVs in New York, we applied the national share of LDV VMT to all motor vehicles (89.6 percent) to produce an estimate of 110,830 million VMT by LDVs in New York. The average VMT per vehicle for LDVs in New York was calculated as total LDV VMT divided by the total number of LDVs, which resulted in an estimate of 11,101 VMT for an LDV in New York.

[21] The U.S. Department of Energy estimates light-duty EVs can drive 100 miles consuming between 25–40 kWh. We used the middle of that distribution to assume a standard EV efficiency of 0.3 kWh per mile. See US DOE, "Electric Vehicle Benefits and Considerations," available at https://afdc.energy.gov/fuels/electricity_benefits.html.

decrease. We used the current count and share of households heating with gas and oil to determine the proportion of households switching from gas or from oil in each of the relevant years.[22] Using the SEEAT tool, we estimated the average consumption of gas or oil used to heat a typical household in New York City or other parts of the state (using Albany as the proxy) over the course of a year.[23] We sourced downstream combustion emissions factors for carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_20$) from the Environmental Protection Agency (EPA), and upstream extraction, processing, and transportation emission factors for the same pollutants from the SEEAT tool.[24] The total reduction in gas and oil heating consumption was then converted into a total emissions impact (i.e., decrease) using the composite emissions factors.

For transportation electrification, the total reduction in emissions was calculated by determining the number of vehicle owners switching from gasoline to electric, and then calculating the average annual emissions associated with a gasoline vehicle. As described above, we calculated the number of vehicle switches in each of the relevant years. The annual emissions for gasoline consumed in a LDV were sourced from the FHWA, EIA, and EPA. The annual metric tons of $CO_2e$ for a LDV in New York were calculated to be 6.32.[25] The reduction in gasoline-vehicle emissions was calculated as the total number of vehicles switching to electricity multiplied by the annual emissions for a gasoline LDV.

To convert an increase in electricity demand (from the fuel switching described above) to an increase in $CO_2e$ emissions, we projected the electric-generation fuel mix in each of the relevant years based on the requirements of the Act (taking into account both the increased supply of renewables that would be needed to meet targets associated with incremental demand, as well as increased generation from fossil-fuel facilities), and tracked the emissions associated with the net increase in gas-fired generation needed to satisfy total demand. To be conservative, we assumed that emissions from future gas-fired generating units will be relatively efficient (and therefore have lower emissions/MWh than at present).[26] Because under the CLCPA, all renewable and nuclear generation in these years will reduce emissions in New York's electric system, we calculate the fuel mix to include 29 percent natural gas in 2025, 21 percent in 2030, 12 percent in 2035, and 0 percent in 2040.

We then separately converted the estimated increase in electricity demand (MWh) from this electrification scenario into a total amount of electricity generation that will be needed from gas. Using a weighted-average heat rate (MMBtu / MWh) for large, efficient gas-fired units in New York, we calculated the $CO_2e$ emissions from the incremental gas-fired generation needed to fulfill the increase in electricity demand d from the illustrative high-electrification scenario.[27] Actual emission impacts associated with an increase in electricity

[22] 2017 American Community Survey.

[23] For a standard, 3-person, 2,300-square-foot, residential, detached building, average gas consumption was 728 therms in New York City and 883 therms in Albany. Average oil consumption was 512 gallons in New York City and 621 gallons in Albany. We assumed households switching would currently be using inefficient heating units (annual fuel-use efficiency (AFUE) of 80 percent for natural gas and 82 percent for oil). See the Source Energy Emissions and Analysis tool, available at http://seeatcalc.gastechnology.org/

[24] For downstream emissions factors, see EPA, "Emission Factors for Greenhouse Gas Inventories - Table 1: Stationary Combustion," 2018, available at https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf. For upstream emissions factors, see the SEEAT tool, available at http://seeatcalc.gastechnology.org/.

[25] Using data from the FHWA on average VMT per LDV and average fuel economy (MPG) per LDV, the average annual gallons consumed by a LDV is 505. The emissions factor for baseline gasoline is equal to 98.2 kg $CO_2e$ per MMBtu. See EPA, "Lifecycle Greenhouse Gas Results," available at https://www.epa.gov/fuels-registration-reporting-and-compliance-help/lifecycle-greenhouse-gas-results.

[26] In 2017, the share of renewables in New York's fuel mix was 28 percent and the Act requires 70 percent renewable generation by 2030. This was interpolated to estimate that 50 percent of New York's fuel mix in 2025 would be renewables. See NYISO, "Power Trends 2018," page 25, available at https://www.nyiso.com/documents/20142/2223020/2018-Power-Trends.pdf/4cd3a2a6-838a-bb54-f631-8982a7bdfa7a.

[27] We assumed an average heat rate of 8.9 MMBtu/MWh to represent an efficient natural gas unit in New York. See S&P Global Market Intelligence.

demand would depend on how the demand increase affects emissions from units on the margin hour to hour. Developing this estimate would benefit from production cost modeling assuming the changing fuel mix, which was not conducted for this analysis. Instead, and as a first-order approximation, we simply based these illustrative calculations on the annual average assumed fuel mix, which may understate the impact on electric sector emissions at least in early years, when natural gas would likely be on the margin more often than implied by our average fuel mix calculations.

We sourced downstream combustion emissions factors for carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_20$) from EPA and upstream extraction, processing, and transportation emission factors for the same pollutants from the SEEAT tool.[28] Finally, we converted the total increase in gas demand into a total increase in $CO_2$e emissions.

These countervailing impacts on net $CO_2$e emissions are shown in Table A.5, below.

**Table A.5**
**Calculation of Net Impact on $CO_2$e Emissions in New York State as a Result of Illustrative Electrification of Household Heating Systems and Households' Adoption of EVs**

| **Year** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|
| Level of Electrification | 10% | 35% | 60% | 85% |
| **Net Emissions Reduction from Electrification of Home Heating (MT $CO_2$e)** | **2,434,674** | **9,960,285** | **18,481,027** | **29,199,781** |
| *Decrease in Emissions from Fewer Homes Heated by Gas and Oil* | *3,435,265* | *12,023,433* | *20,611,607* | *29,199,781* |
| *Increase in Emissions from Greater Electricity Demand* | *1,000,591* | *2,063,148* | *2,130,581* | *0* |
| **Net Emissions Reduction from Electrification of Vehicles (MT $CO_2$e)** | **5,698,904** | **20,817,402** | **36,538,438** | **53,590,330** |
| *Decrease in Emissions from Fewer Gasoline Vehicles* | *6,304,744* | *22,066,602* | *37,828,466* | *53,590,330* |
| *Increase in Emissions from Greater Electricity Demand* | *605,840* | *1,249,200* | *1,290,029* | *0* |
| **Net Emissions Reduction (MT $CO_2$e)** | **8,133,578** | **30,777,687** | **55,019,464** | **82,790,112** |

### *Renewable and zero-carbon resource requirements under an illustrative high-electrification scenario*

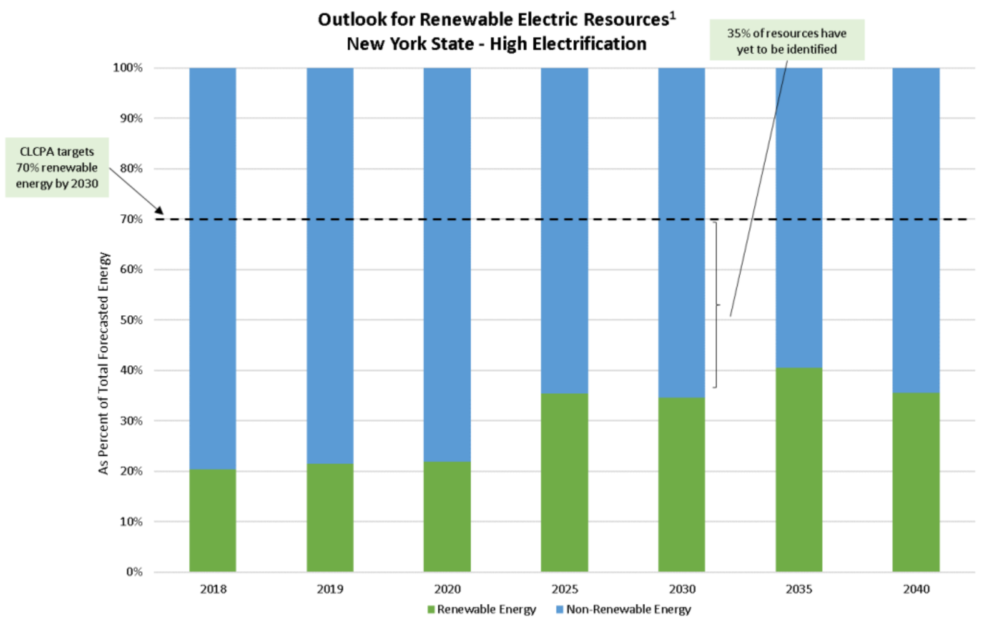
Using the higher level of electricity demand, we calculated the amount of clean generation that would be needed to satisfy the 2030 and 2040 targets in the Act. Using the same logic described above (i.e., comparing existing/planned/specified resources to the clean-resource requirement), we identified the amount of additional renewable or zero-carbon resources that would be needed if New York is to meet its objective of reducing GHG emissions in other sectors of the economy besides power generation, and does so in ways that also satisfy the Act's electric-sector clean energy targets.

Figures A.5 to A.8 and Table A.6 below provide detailed results.[29]

[28] For downstream emissions factors, see EPA, "Emission Factors for Greenhouse Gas Inventories - Table 1: Stationary Combustion," 2018, available at https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf. For upstream emissions factors, see the SEEAT tool, available at http://seeatcalc.gastechnology.org/.

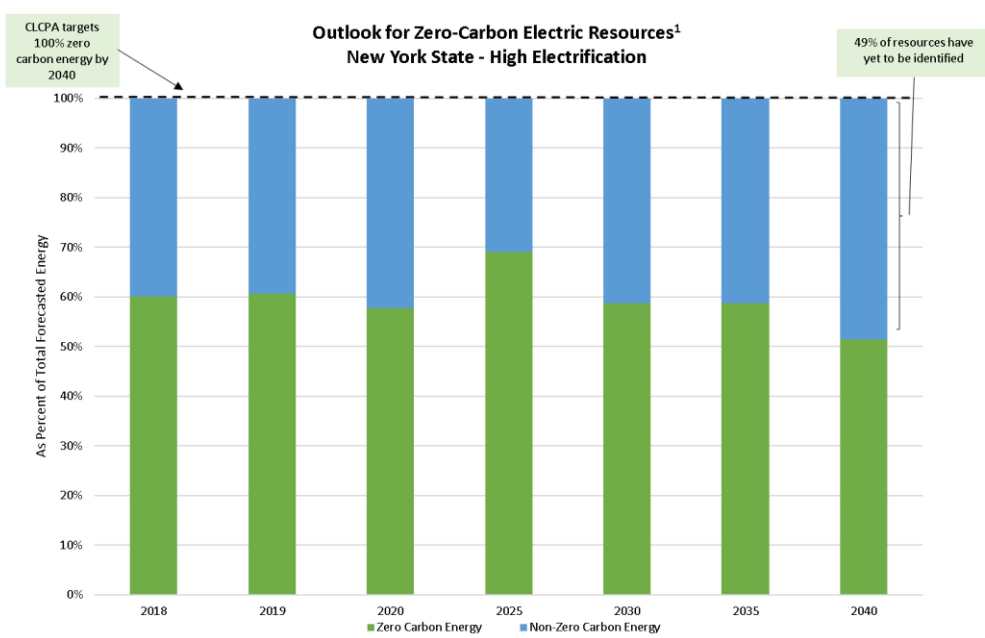
[29] Sources for these figures are as follows: [1] 2017, 2018, and 2019 NYISO Gold Books; [2] 2017, 2018, and 2019 CES procurements; [3] CLCPA; [4] Cuomo Green New Deal targets.

**Figure A.5**



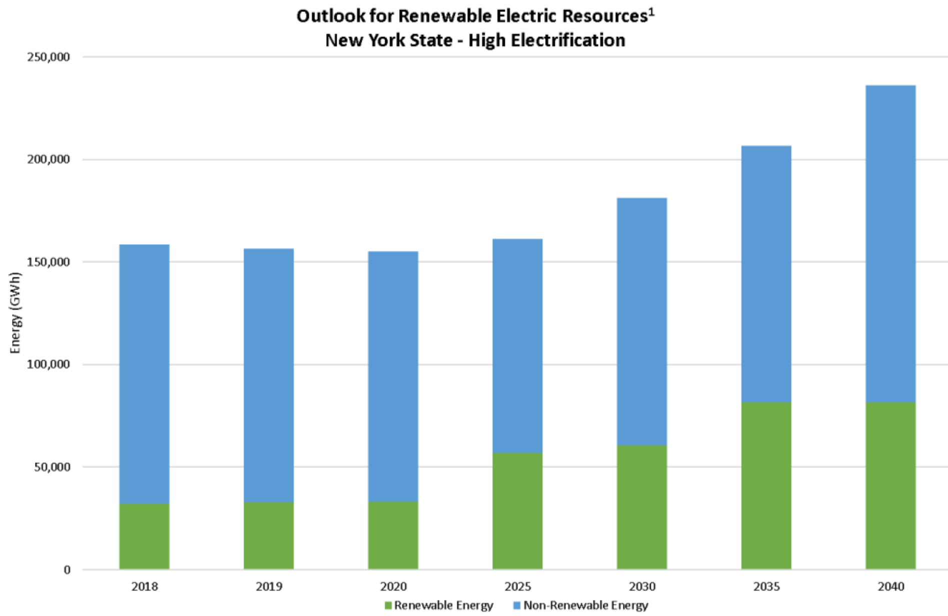

Notes:
[1] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[2] Energy forecast based on the 2019 Gold Book projected baseline demand.
[3] Renewable resources include hydro, wind and solar.

**Figure A.6**



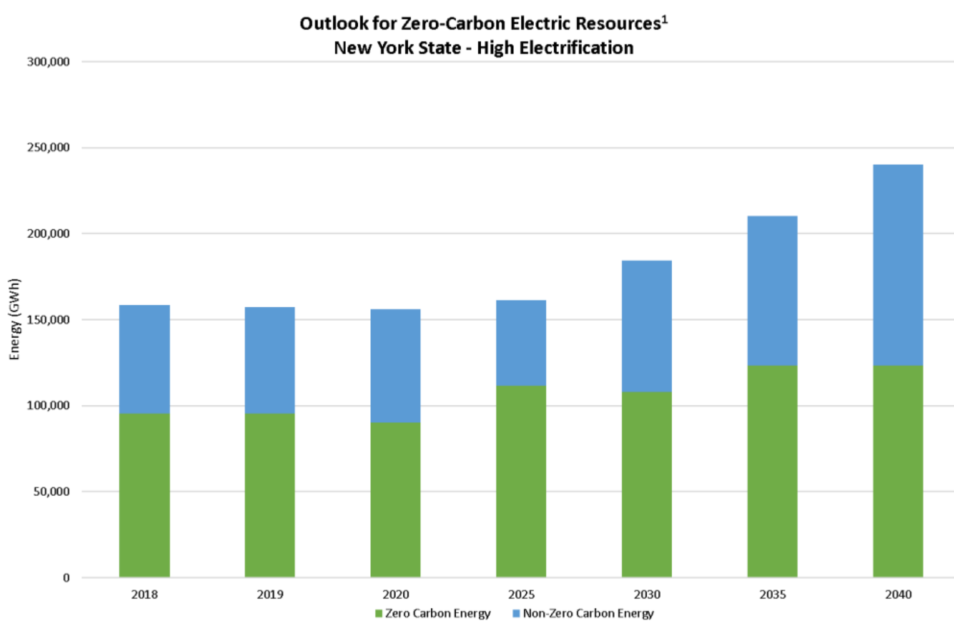

Notes:
[1] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[2] Energy forecast based on the 2019 Gold Book projected baseline demand.
[3] Zero carbon resources include nuclear, hydro, wind, solar and clean imports.

**Figure A.7**




Notes:
[1] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[2] Energy forecast based on the 2019 Gold Book projected baseline demand.
[3] Renewable resources include hydro, wind and solar.

**Figure A.8**




Notes:
[1] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of the concrete targets in New York's Climate Leadership and Community Protection Act.
[2] Energy forecast based on the 2019 Gold Book projected baseline demand.
[3] Zero carbon resources include nuclear, hydro, wind, solar and clean imports.

**Table A.6**
**Clean Energy Resources in NYISO System vs. New York State Targets**
**Electricity Sector - High Electrification**

| | 2018 | 2019 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| **Forecasted Energy Demand (GWh)[1]** | 158,400 | 157,500 | 156,000 | 161,500 | 184,300 | 210,400 | 240,100 |
| **Zero-Carbon Resources: Known/Planned (GWh)[2]** | | | | | | | |
| In-State | 75,341 | 76,100 | 70,800 | 83,900 | 80,400 | 95,700 | 95,700 |
| Imports | 19,916 | 19,400 | 19,400 | 27,700 | 27,700 | 27,700 | 27,700 |
| Total | 95,257 | 95,500 | 90,200 | 111,600 | 108,100 | 123,400 | 123,400 |
| As percent of total supply needs | 60% | 61% | 58% | 69% | 59% | 59% | 51% |
| Green New Deal target (%) | | | 30% | 50% | 70% | 85% | 100% |
| Total zero-carbon resources needed to meet target | | | 46,800 | 80,750 | 129,010 | 178,840 | 240,100 |
| Additional zero-carbon resources yet to enter the market or to be identified | | | - | - | 20,910 | 55,440 | 116,700 |
| **Renewable Resources: Known/Planned (GWh)[2]** | | | | | | | |
| Total | 32,338 | 33,800 | 34,100 | 57,200 | 63,700 | 85,300 | 85,300 |
| As percent of total supply needs | 20% | 21% | 22% | 35% | 35% | 41% | 36% |
| Green New Deal target (%) | | | 30% | 50% | 70% | 70% | 70% |
| Total renewable resources needed to meet target | | | 46,800 | 80,750 | 129,010 | 147,280 | 168,070 |
| Additional renewable resources yet to enter the market or be identified | | | 12,700 | 23,550 | 65,310 | 61,980 | 82,770 |

**Notes:**
[1] Forecasted Energy Demand is based on NYISO forecast of Baseline Demand in 2019 Gold Book adjusted upwards based on estimates from NREL's Electrification Future Study.
[2] Reflects all existing, procured, and planned resources in New York State including those forecasted by NYISO in the 2019 Gold Book, procured through New York's Clean Energy Standard in 2017-2019, or announced as part of concrete targets in New York's Climate Leadership and Community Protection Act.
[3] The CLCPA targets seek 70% renewable energy by 2030 and 100% carbon free energy by 2040. A smooth transition to renewable and carbon free energy targets is assumed between 2018 and the target years.
[4] Assumes nuclear plants retire when their license expires.
[5] Renewable resources include hydro, wind and solar.
[6] Zero-carbon resources include nuclear, hydro, wind, solar and clean imports.
[7] All forecasted values are rounded to the nearest hundred.

## B. Market-efficiency savings from a carbon price: Literature review

To estimate cost savings for meeting the Act's renewable resource goals that can reasonably be expected to result from introducing a carbon price to NYISO markets, we reviewed literature on economic efficiency savings in U.S. organized wholesale electricity markets. Specifically, we examined literature presenting quantitative estimates of cost savings realized in these markets as a result of the introduction of market mechanisms.[30] We focused in particular on estimates of retrospective cost savings based on actual instances of industry restructuring, and supplemented them with forward-looking analyses where available and appropriate. We sourced articles for review using existing literature reviews and bibliographies of papers identified therein,[31] keyword searches on Google and Google Scholar, and citation searches on Google Scholar.

The literature on cost savings through market mechanisms in U.S. wholesale electricity markets is still evolving, and we were unable to identify any retrospective studies that offer all-encompassing estimates of cost savings brought about market mechanisms. Instead, existing studies provide estimates of specific types of savings; we have grouped these into three buckets, which we discuss below. Our overall conclusion to use an estimated range of savings, from 1 percent to 3 percent, from market efficiencies is based on our

[30] We looked for percentage-based estimates where available, as these could be adopted more naturally as scaling factors for our analysis than estimates of gross savings that did not provide information about their corresponding cost baselines. For an example of the latter, see, for instance, Western Energy Imbalance Market, "Benefits," available at https://www.westerneim.com/Pages/About/QuarterlyBenefits.aspx.

[31] James Bushnell, Erin T. Mansur, and Kevin Novan, "Review of the Economics Literature on US Electricity Restructuring," working paper, February 23, 2017 (hereafter Bushnell et al.), available at http://bushnell.ucdavis.edu/uploads/7/6/9/5/76951361/economics-literature.pdf; Severin Borenstein and James Bushnell, "The US Electricity Industry After 20 Years of Restructuring," *Annual Review of Economics*, August 2015, Volume 7, pages 437-463. Most of the empirical articles cited below contained literature reviews themselves that were used as additional points of comparison.

judgment after reviewing the evidence from each of these buckets, which show modest benefits from market mechanisms in unit performance and system operations.

### 1. System efficiencies

A number of studies provide quantitative cost impacts of what Bushnell *et al*. describe in their 2017 literature review as improvements to "system efficiency" from actual instances of market restructuring, with efficiencies resulting from such things as lowered transaction costs for trade or more efficient resource dispatch.[32] Most recent and most comprehensive is Cicala, who estimated 5-percent savings on fuel costs from the introduction of ISO-administered centralized markets based on larger gains from trade and reduced out-of-merit dispatch. He produced his estimates from a nationwide hourly-level panel dataset covering both demand and supply across the entire U.S. from 1999 to 2012.[33]

Focusing on Texas, Zhang identified a 0.5-percent reduction in production costs in Texas from reduced out-of-merit dispatch after the introduction of a centralized market in 2010.[34] Wolak's study of the 2009 introduction of nodal pricing in place of centrally mediated bilateral scheduling in California's electricity market finds a 2.1-percent reduction in total variable costs.[35] Mansur and White's study found that PJM Interconnection's 2004 expansion generated $160 million in savings from increased trade across power control areas, equivalent to 0.7 percent of PJM-wide forward and spot market revenues in 2004.[36]

### 2. Within-unit efficiencies

Another set of studies uses input and output data from individual generator units to quantify the cost impacts of market restructuring at the unit level.[37] These efficiencies are conceptually distinct from system efficiencies: the latter come from improved coordination of dispatch between a given set of units, whereas the former reflect improvements in operations of those units themselves. However, in practice, studies that present evidence for system-level efficiencies may be also capturing unit-level operations improvements. As Bushnell *et al*. note, the establishment of centralized markets partially coincided with other reforms such as utility divestiture that exposed units to greater competitive pressures.[38]

Nonetheless, there is a range of articles that focus specifically on unit-level operational improvements. Fabrizio *et al*. found that investor-owned utilities in states that had launched market restructuring hearings during the 1990s saw a 3-5-percent reduction in labor and nonfuel expenses against their

32 Bushnell et al., pages 25–26.

33 Steve Cicala, "Imperfect Markets versus Imperfect Regulation in U.S. Electricity Generation," working paper, May 9, 2019, available at http://home.uchicago.edu/~scicala/papers/elec_gov_v_mkt/elec_gov_v_mkt_draft_2.pdf.

34 Yiyuan Zhang, "The Efficiency and Environmental Impacts of Market Organization: Evidence from the Texas Electricity Market," in *Three Essays on the Impacts of Energy and Environmental Policies*, PhD thesis at the University of Michigan, 2017, pages 1–32.

35 Frank A. Wolak, "Measuring the Benefits of Greater Spatial Granularity in Short-Term Pricing in Wholesale Electricity Markets," *The American Economic Review*, May 2011, Vol. 101:3, pages 247–252.

36 Erin T. Mansur and Matthew W. White, "Market Organization and Efficiency in Electricity Markets," working paper, January 13, 2012, available at http://www.dartmouth.edu/~mansur/papers/mansur_white_pjmaep.pdf.

37 Excluded from this discussion are papers that estimate efficiency improvements for coal-fired generating resources, in light of the small role that such generators play in NYISO. See NYISO, "2019-2028 Comprehensive Reliability Plan," July 16, 2019, available at https://www.nyiso.com/documents/20142/2248481/2019-2028CRP-FinalReportJuly-2019.pdf/51b573b7-9edb-bbb9-8a87-742e9e7c3b7f?t=1564421089120, page 14.

38 Bushnell et al., pages 28–29.

counterparts in states that had not.[39] They found no impact on heat rate, a more significant driver of costs for fossil-fuel units.[40] Bushnell and Wolfram did find modest, 2 percent improvements in heat rates at units divested by regulated utilities between 1998 and 2002, but these gains were matched by non-divested units in states that adopted incentive-based regulation.[41]

The literature suggests efficiency gains from market restructuring for nuclear plants may be particularly large. Focusing on nuclear generators, Davis and Wolfram identified a 10-percent jump in capacity factor for plants divested by utilities, while Zhang found a 9-percent increase in capacity factor for plants in states that underwent restructuring during the 1990s.[42]

### 3. Investment and capital costs

Economists have posited savings in investment and capital costs from the introduction of market efficiencies by transferring investment risks from consumers to generators and transmission operators, the actual investment decision-makers in the system.[43]

However, the literature to date provides little retrospective evidence on the size of efficiency gains (or losses) in investment activity under market restructuring.[44] Some of the only exceptions are analyses conducted by the RTOs themselves, though these figures often come in terms of gross benefits that are difficult to convert to scaling factors. For instance, MISO's 2017 review cited prospective savings from deferred generation investment and other capital benefits totaling $1.8 billion over a 20-year period.[45] A 2016 study by PJM compared returns on equity required by 31 regulated utilities and merchant generators using company financial data from 2000 to 2015. PJM found that regulated firms have lower

[39] Those savings reached 6–12 percent in comparison to government-owned plants or cooperatives. Kira R. Fabrizio et al., "Do Markets Reduce Costs? Assessing the Impact of Regulatory Restructuring on U.S. Electric Generation Efficiency," *The American Economic Review*, September 2007, Vol. 97:4, pages 1250–1277.

[40] Regarding fuel costs as a share of overall power-plant costs, see, e.g., James B. Bushnell and Catherine Wolfram, "Ownership Change, Incentives, and Plant Efficiency: The Divestiture of U.S. Electric Generation," University of California Energy Institute Center for the Study of Energy Markets Working Paper Series, March 2005, available at http://faculty.haas.berkeley.edu/wolfram/Papers/Divest_0331.pdf, page 2 ("fuel expenses account for about 75% of operating expenses at power plants").

[41] James B. Bushnell and Catherine Wolfram, "Ownership Change, Incentives, and Plant Efficiency: The Divestiture of U.S. Electric Generation," University of California Energy Institute Center for the Study of Energy Markets Working Paper Series, March 2005, available at http://faculty.haas.berkeley.edu/wolfram/Papers/Divest_0331.pdf.

[42] Lucas W. Davis and Catherine Wolfram, "Deregulation, Consolidation, and Efficiency: Evidence from US Nuclear Power," *American Economic Journal: Applied Economics*, October 2012, Vol. 4:4, pages 194–225; Fan Zhang, "Does Electricity Restructuring Work? Evidence from the U.S. Nuclear Energy Industry," *The Journal of Industrial Economics*, September 2007, Vol. 55:3, pages 397–418.

[43] See, e.g., Severin Borenstein and James Bushnell, "Electricity Restructuring: Deregulation or Reregulation?" *Regulation*, 2000, Vol. 23:2, page 48 ("Since the bulk of the rate disparities in this country are due to investment decisions that turned out badly, it stands to reason that what is 'broke' in this industry is the process that produced those poor investment decisions. Firms that do not have the security of a guaranteed rate of return on their investments will be more prudent in their capital expenditures and the way they manage risk."); Paul L. Joskow, "Restructuring, Competition and Regulatory Reform in the U.S. Electricity Sector," *Journal of Economic Perspectives*, Summer 1997, Vol. 11:3, page 125 ("The most important opportunities for cost savings are associated with long-run investments in generating capacity….Traditional regulatory pricing principles, based on the prudent investment standard and recovery of investment costs, implicitly allocates most of the market risks associated with investments in generating capacity to consumers rather than producers.").

[44] See, e.g., Bushnell et al., pages 3 and 24, fn7 ("The economics literature has yet to identify the causal effects of restructuring on either the levels or types of investment"; "we are unaware of any empirical study that convincingly demonstrates the impact of restructuring on the efficiency (rather than magnitudes) of investment in the power sector").

[45] *See* Midcontinent Independent System Operator, "MTEP17 MVP Triennial Review," September 2017, page 6, available at https://cdn.misoenergy.org/MTEP17%20MVP%20Triennial%20Review%20Report117065.pdf.

costs of equity than merchant firms by around 1.8-2.7 percent, but also that returns from a more recent sample of rate cases suggest they may not necessarily pass those savings on to loads (consumers).[46]

Forward-looking studies of several RTOs have estimated gross savings in investment and capital costs from market restructuring. For instance, a 2008 report by Charles River Associates and Resero International projected a net present value of $180 million in benefits from improved generation siting between 2009 and 2020, as a result of the introduction of nodal pricing in Texas.[47] There is also evidence, from Zhen *et al.*'s 2017 study of 1990s and 2000s nuclear uprates, that deregulation incentivizes nuclear plants to make profitable investments in increased capacity that align with their technology needs.[48]

### C. Market-efficiency savings from a carbon price: Estimating the dollar savings

In order to calculate an estimate of the dollar savings that would be expected to result from incorporating a carbon price in the NYISO energy market and, in so doing, leveraging the competitive pressures of the wholesale power market, we applied the 1 percent to 3 percent range of expected market efficiencies (as described above) to a rough estimate of potential above-market costs of renewable and zero-carbon resources needed to satisfy the CLCPA's goals.

The resources included in this rough calculation of above-market costs are: the 2017-2019 CES contracts; the resource additions specified in the Act;[49] and the estimated incremental resource additions needed to meet demand under the goals of the Act (above and beyond existing, CES, and these known/planned resources). We examined four alternative illustrative portfolios for the incremental resource additions to capture four different possible ways in which New York might meet its 2030 and 2040 targets: (1) exclusively by land-based wind; (2) exclusively by off-shore wind; (3) exclusively by utility-scale solar; and (4) 60 percent by utility-scale solar and 40 percent by off-shore wind.

We took into account the dollar amounts associated with NYSERDA's 2017 and 2018 CES REC contracts as reflecting above-market costs. NYSERDA has published a total payment amount for each of these two procurements (2017 and 2018), along with the MW capacity of the projects receiving REC contracts. To convert these into a $/MWh of above-market costs, we applied technology-specific capacity factors as described in Section I.A to estimate the MWh anticipated to be supplied from each procurement, and then applied a NYISO published weighted average price per REC (in $/MWh) for each procurement: $21.71/MWh in the 2017 procurement, and $18.52 in the 2018 procurement.[50] (Although these contracts are included in the estimate of above-market costs to comply with the Act, we did not include these 2017-2018 CES contract

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[46] PJM Interconnection, "Resource Investment in Competitive Markets," May 5, 2016, available at https://www.pjm.com/~/media/library/reports-notices/special-reports/20160505-resource-investment-in-competitive-markets-paper.ashx.

[47] CRA International, "Update on the ERCOT Nodal Market Cost-Benefit Analysis," report prepared for the Public Utility Commission of Texas, December 18, 2008, available at http://www.puc.texas.gov/industry/electric/reports/31600/puct_cba_report_final.pdf.

[48] Zhen Lei, Chen-Hao Tsai, and Andrew N. Kleit, "Deregulation and Investment in Generation Capacity: Evidence from Nuclear Power Uprates in the United States," *The Energy Journal*, Vol. 38:3, pages 113–139.

[49] Note that as discussed above, we do not count the storage additions specified in the Act as providing incremental clean energy resources. However, we do include these storage resources in the above-market-cost calculations, because they are part of the Act's requirements and will support integration of renewables.

[50] NYSERDA, Clean Energy Standard, 2017 Solicitation, available at https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Standard/Renewable-Generators-and-Developers/RES-Tier-One-Eligibility/Solicitations-for-Long-term-Contracts/2017-Solicitation; NYSERDA, Clean Energy Standard, 2018 Solicitation, available at https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Standard/Renewable-Generators-and-Developers/RES-Tier-One-Eligibility/Solicitations-for-Long-term-Contracts/RFP-Resources.

resources in our subsequent calculation of market-efficiency savings that could result from introduction of a carbon pricing mechanism in NYISO markets because these contracts have already been priced and would not benefit from any efficiencies associated with application of a carbon price in wholesale markets.)

For the known/planned resources and incremental resources, we used the following calculation to estimate above-market costs:

Annual Cost to Producers minus Annual Market-Based Revenue to Producers = Above-Market Costs

For these renewable resources, we first calculated an annual cost to producers using the following levelized cost of energy (LCOE) inputs from the 2019 NREL ATB[51]: $32/MWh for land-based wind; $96/MWh for off-shore wind; and $63/MWh for hydro. For the remaining technologies, we used the following LCOE estimates from Lazard[52]: $41/MWh for utility-scale solar, $73/MWh for community distributed solar, and $297/MWh for wholesale storage.

For the energy revenues, we used 2030 LBMPs from the Brattle/IPPTF study.[53] We used an upstate-specific LBMP for hydro and land-based wind resources, a downstate-specific LBMP for off-shore wind, and a NYCA-wide LBMP for solar and storage, based on our assumption about the likely locations of these future resources. For the capacity revenues, we used 2030 capacity prices from the Brattle/IPPTF study,[54] including a 50/50 split of a Zone J and Zone K capacity prices for off-shore wind and a NYCA-wide capacity price for the rest of the resource types. The amount of capacity credited with capacity revenues was based on the UCAP percentages for land-based wind, off-shore wind, and solar according to the NYISO installed capacity manual.[55] We held the 2030 energy and capacity prices constant in both the 2030 and 2040 calculations.[56]

After estimating the above-market costs for each of the four alternative resource portfolios described above, we used the simple average of costs of the four illustrative portfolios as of the years 2030 and 2040. This was added to the costs of the CES contracts to yield a total amount of above-market costs for those years. For the years 2022 through 2029 and 2031 through 20039, we assumed that total above-market payments would rise in a linear fashion, between the 2019 and 2030 and between 2030 and 2040, reflecting the increased amount of resources combined with the changing technology-specific price outlooks.

For market efficiency savings for each year, we applied a 1-percent and a 3-percent savings estimate for each year (2022 through 2040) and then discounted those savings estimates to derive a net present value estimate in 2019$, using a 3-percent and 7-percent discount rate.

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[51] NREL, 2019 ATB.

[52] Lazard, "Levelized Cost of Energy Analysis - Version 12.0," November 2018; Lazard, "Levelized Cost of Storage Analysis - Version 4.0," November 2018.

[53] Sam Newell, Bruce Tsuchida, Michael Hagerty, Roger Lueken, and Tony Lee, "Analysis of a New York Carbon Charge (Updated)," The Brattle Group, presented to IPPTF, updated December 21, 2018 (hereafter Brattle/IPPTF).

[54] Brattle/IPPTF Study.

[55] NYISO, Manual 4, Installed Capacity Manual, March 2019, available at https://www.nyiso.com/documents/20142/2923301/icap_mnl.pdf/234db95c-9a91-66fe-7306-2900ef905338, pages 52-55.

[56] Given the magnitude of changes in the power system and markets implied by meeting the Act's requirements, it is at best very difficult to anticipate how—or even in what direction—energy and capacity prices may change in the coming decades. Recognizing this level of uncertainty, we considered it appropriate to base these first-order, illustrative approximations of out-of-market costs using the Brattle/IPPTF estimates, which represent the most recent effort to estimate these prices going forward.

# II. Buyer-side mitigation calculation (re: Section IV of the Final Report)

## A. Analytic approach and data

The goal of this particular discussion in the report was to examine the impact of a potential carbon price on reducing the risk of and/or avoiding costs associated with Buyer-Side Mitigation (BSM) that, in theory, could be assessed if the Federal Energy Regulatory Commission (FERC) were to decide that New York's procurement of clean energy resources (such as long-term contracts for renewable energy credits (RECs) or for zero-emission credits (ZECs)) were out-of-market resources warranting mitigation.

The analysis does not express an opinion about whether FERC will or will not take steps in future decisions on NYISO market rules with regard to changes in the BSM penalties (or whether the New York Public Service Commission (PSC) might take steps to avoid such action by FERC). Rather, the analysis frames the discussion by addressing the question of what costs might arise, in terms of BSM penalties, if FERC were to modify its BSM policies in light of a growing level of resources entering the market through out-of-market contracts.

Examination of this "what-if" question was prompted by (a) the potential for New York State officials to decide to procure most, if not all, future renewables and clean energy resources through long-term contracts, rather than through NYISO markets alone, and (b) the increasing share of new entry from clean resources that will be required in the next two decades to satisfy the Act's requirements.

Although we do not report our calculation of the cost implications of potential BSM, we did perform an analysis of a hypothetical application of BSM considered three possible scenarios over two zonal groupings. This was to provide us with insights into the order of magnitude of potential BSM costs.

The two zonal groupings we analyzed are the Current Mitigation Zones (Zones G – J), and all currently unmitigated Zones (Zones A - F and K, sometimes referred to as "rest of state" in the context of BSM). We analyze three scenarios to develop "first-order" impacts associated with potentially expanded application of BSM:

- Scenario 1: Retroactive Mitigation,
- Scenario 2: Proactive Mitigation with Current 1,000 MW Renewable Exemption, and
- Scenario 3: Proactive Mitigation without Current 1,000 MW Renewable Exemption.

As stated in our Report, the first order effects do not account for changes in capacity prices that would occur in response to the dynamics of a highly mitigated capacity market.

Across this range of scenarios, we estimated that the first-order cost impact of expanded BSM could be quite sizeable in terms of additional costs to consumers, with the amount dependent upon whether mitigation were applied retroactively (i.e., to resources anywhere in the state and applied to all existing ZEC and REC contracts with NYSERDA, which sets the lower amount in the range) or only prospectively (to all new CES contracts anywhere in the state, which accounts for higher-cost impacts in the range).

# III. Production cost modeling data used from the Brattle/IPPTF Study and the Potomac Economics analyses (re: Sections V, VI, VII, and VIII of the Final Report)

## A. Brattle/IPPTF Study

Many of the separate analyses in this report were based on data from the production cost modeling (GE MAPS, or MAPS) conducted as part of the IPPTF study, which was performed by The Brattle Group and which resulted in a report presented to NYISO and its stakeholders in December 2018.[57] This modeling, described in an October 12, 2018 memorandum by the IPPTF study team, simulated NYCA power system operations in three individual years (i.e., 2022, 2025, and 2030) and in 15-minute intervals under a series of different scenarios.[58] The study resulted in power plant unit-level projections for a variety of power system operations metrics, including unit-level dispatch, fuel consumption, and emissions.

Our analyses used outputs provided by the IPPTF study team for six runs of MAPS: for each of three years (2022, 2025, and 2030), a case with no carbon price (a "baseline case") and another run with a carbon price (a "carbon case"). The impacts of the carbon charge were estimated by comparing metrics generated in each year from these outputs for the "baseline case" and the "carbon case." This method was used to inform estimates of air emissions and public-health impacts, fuel-use impacts, and customer-bill impacts (as described in subsequent sections of this Appendix). The scenarios used in our analysis are described in the table below.[59]

Of the six scenarios, five were used in the original Brattle/IPPTF Study, and the sixth is a modified combination of dynamic effects, as shown in Table A.7, below.

[57] Brattle/IPPTF Study.

[58] "Summary of GE MAPS Cases Used in Issue Track 5 Analysis," Memorandum from Sam Newell et al., The Brattle Group, to Mike DeSocio and Nicole Bouchez, NYISO, October 12, 2018 (hereafter Brattle Memo). The analysis presented in this memorandum was conducted for 2020, 2025, and 2030; the 2020 analysis was replaced with a 2022 analysis for the final report. See Brattle/IPPTF.

[59] Brattle Memo, pages 1–2; Timothy Duffy, "Consumer Impact Analyses: Proposed Assumption Framework," NYISO, May 21, 2018, pages 2–5.

**Table A.7**
**Modeling Scenarios Examined by Analysis Group, Based on Brattle/IPPTF Modeling Runs**

| Analysis Group Case | Name of Brattle/IPPTF Modeling Run | Scenario Description |
|---|---|---|
| Baseline (No-Carbon) Case for 2022 | CARIS-Based 2022: Status Quo | This scenario was based on NYCA's 2018 Congestion Assessment and Resource Integration Studies (CARIS) Phase 2 base case, used in NYISO's economic planning process. The scenario incorporates updates for procured and targeted renewable build-outs and transmission system upgrades. It assumes the retirement of Indian Point Nuclear Station and all coal units. |
| Carbon Case for 2022 | CARIS-Based 2022: Simple Change | This scenario was identical to the CARIS-Based 2022 Status Quo scenario except for the addition of a carbon charge. |
| Baseline (No-Carbon) Case for 2025 | Reference Scenario 2025: Status Quo (D2) | This scenario was based on projections for NYCA's 2018 CARIS Phase 2 base case, with adjusted natural gas prices for Zones F-I. |
| Carbon Case for 2025 | Reference Scenario 2025: Simple Change (D3) | This scenario was identical to the D2 scenario except for the addition of a carbon charge. |
| Baseline (No-Carbon) Case for 2030 | Reference Scenario 2030: Status Quo (D5) | This scenario was based upon NYCA's 2018 CARIS Phase 2 base case, with adjusted natural gas prices for Zones F-I. |
| Carbon Case for 20300.76 | NYISO Updated 2030 Carbon Case | This scenario—not used in the original Brattle/IPPTF Study—combines all of the Study's dynamic-effect assumptions that affect the generation mix within NYCA into one scenario. This scenario modifies the D5 scenario by: adding a carbon charge; retaining FitzPatrick; shifting 2.9 TWh of renewables from upstate to downstate; and adding 116 MW of solar PV in Zone G. |

## B. Potomac Economics analyses

Potomac Economics conducted a similar set of enhanced supplemental analyses to examine the impacts of a carbon price on the performance of NYISO markets.

In a base-case analysis, Potomac made several adjustments to the Brattle/IPPTF Study's modeling runs to account for several technical enhancements that Potomac thought were relevant and important. These adjustments included: assuring that any local-area reliability requirements (LRRs) were appropriately reflected in the dispatch of plants in the New York City area; and accounting for capacity-price effect interactions with changes in energy-market prices arising from a carbon price; and estimating effects of modeling New York City reserve markets on LBMPs and reserve clearing prices.

With these technical changes, Potomac modified the production cost modeling from the Brattle/IPPTF Study. Potomac's analyses included two sets of production cost modeling runs, each set representing base and carbon cases in the three model years (2022, 2025, and 2030). One set ("No Repowering") modifies modeling of local reliability requirements, and the second set ("Repowering") both modifies LRRs and repowers two 360 MW steam turbines as fast start units. Effects from the capacity-price and reserve-market enhancements were estimated post-modeling for both sets of modeling runs.

A more detailed discussion of the specifications for these scenarios can be found in Potomac's May 9, 2019 presentation to the Market Issues/ICAP Working Group.[60]

[60] Pallas LeeVanSchaik, "MMU Evaluation of Impacts of Carbon Pricing," Potomac Economics, presentation at Market Issues/ICAP Working Group, May 9, 2019.

# IV. Emissions and public health impact analyses (re: Section VI of the Final Report)

## A. Analytic approach

These analyses use MAPS outputs from both the Brattle/IPPTF Study and Potomac, as described above. MAPS provides unit-specific $NO_x$, $SO_2$ and $CO_2$ emissions for each scenario.

We translated $NO_x$ and $SO_2$ emissions reductions into public health impacts using several EPA health-impact modeling tools. First, we used EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) to convert changes in $NO_x$ and $SO_2$ emissions into changes in concentrations of particulate matter ($PM_{2.5}$). Second, we used EPA's Benefits Mapping and Analysis Program - Community Edition (BenMap-CE) tool to translate the changes in $PM_{2.5}$ concentration into public health impacts. Public health impacts are measured both in terms of health endpoint incidence (e.g., the number of avoided work loss days), and health endpoint valuation (e.g., the economic value of work loss days). The details of the analysis are described further below.

In addition to evaluating the public health impacts of emissions reductions, we also evaluated additional potential impacts of emissions reductions on areas that have been designated as environmental justice (EJ) areas by the New York State Department of Environmental Conservation (DEC), and that occur during the high ozone season. The details of these analyses are also discussed further below.

## B. COBRA (EPA Co-Benefits Risk Assessment health impacts screening and mapping tool)

COBRA is a free, publically available screening tool that estimates the effect of emissions changes on air quality (specifically ambient PM concentration). The tool can calculate air quality impacts from changes in $PM_{2.5}$, $SO_2$, $NO_x$, $NH_3$, and VOCs. COBRA also translates changes in air quality into health impacts (in incidents and dollars). COBRA has several limitations, including that it only accounts for emissions benefits related to $PM_{2.5}$, and therefore may be conservative in the exclusion of other pollutants, such as ozone ($O_3$), in estimating health impacts.[61]

COBRA contains baseline emissions inventories for 2017 and 2025, forecasted from EPA's 2011 Version 6.2 Air Emissions Modeling Platform.[62] For the purpose of this analysis, we imported a baseline versus carbon case scenario for each year of modeling from the Brattle/IPPTF and the Potomac analyses. We aggregated emissions data annually, by county and emitting fuel group.[63] The relevant emitting fuel groups are oil, natural gas and other (biomass and refuse plants).

In order to translate the user-specified emissions changes to changes in $PM_{2.5}$ concentrations, COBRA uses a Source Receptor (S-R) Matrix air quality model.[64] The translation of $NO_x$ and $SO_2$ emissions into $PM_{2.5}$ concentrations served as the input to BenMap-CE. While COBRA can estimate health impact incidence and

[61] EPA describes COBRA as a "screening tool" and suggests that the use of more-sophisticated air-quality monitoring tools would provide more refined results. EPA, "Estimating the Co-Benefits of Clean Energy Policies, Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool: How COBRA Works," September 2017, pages 3, 9.

[62] COBRA, "User's Manual, Version 3.2," May 2018, page A-5.

[63] Counties were matched to plants in the IPPTF Study and Potomac analyses GE Maps data using S&P Global Intelligence data.

[64] See COBRA, "User's Manual, Version 3.2," May 2018, Appendix A for more detail on the development of the Source-Receptor Matrix.

valuation based on 2017 and 2025 health impact datasets, we instead use BenMap-CE to quantify health impacts specific to each model year of data: 2022, 2025, and 2030.

## C. BenMAP-CE (EPA Benefits Mapping and Analysis Program)

BenMap-CE is a free, publically available tool that estimates the health incidence and economic impacts of changes in air emissions. To use it in our analysis of public-health impacts associated with a price on carbon, we imported county-level $PM_{2.5}$ concentrations from COBRA into BenMap-CE. The tool then translates changes in the concentration of $PM_{2.5}$ into health-incidence effects using health impact functions based on a series of epidemiological studies. The health endpoints measured are shown in the table below.

The tool then monetizes the health incidence effects for each health endpoint to quantify the economic value of each the effect (e.g., the dollar value of a day of work not lost, direct medical costs of an illness, or the willingness to pay to avoid illness).[65] For both the set-up and selection of the health impact and valuation functions in BenMap-CE, we used the configuration files in the "U.S. EPA approach for quantifying and valuing PM effects," available on EPA's website.[66]

Dollar values are reported by BenMap-CE in 2015$, using a 3-percent discount rate for any benefit incurred beyond the year of exposure. We converted the dollar units from 2015$ to 2018$ assuming annual inflation of 2 percent. The public health benefits quantified captures the impact of $PM_{2.5}$. Ozone impacts, which could be expected from a change in $NO_x$ emissions, are not quantified. While both $NO_x$ and $SO_2$ are precursors to $PM_{2.5}$,[67] $SO_2$ emissions changes between baseline and carbon cases have more of an impact on the resulting public-health impact values. Tables A.8 to A.10 below provide detailed results by study.

**Table A.8**
**New York State Health Benefits from Carbon Price $NO_x$ and $SO_2$ Emissions Changes[68]**
**Brattle/IPPTF Study**

| | 2022 | | 2025 | | 2030 | |
|---|---|---|---|---|---|---|
| | Incidence | Valuation | Incidence | Valuation | Incidence | Valuation |
| Hospital Admits, Asthma | 0.000 | -$1 | 0.001 | $22 | 0.000 | $7 |
| Hospital Admits, All Respiratory | -0.001 | -$23 | 0.011 | $357 | 0.004 | $126 |
| Hospital Admits, Chronic Lung Disease | 0.000 | -$4 | 0.003 | $65 | 0.001 | $19 |
| Hospital Admits, All Cardiovascular | -0.001 | -$41 | 0.015 | $595 | 0.005 | $200 |
| Acute Bronchitis | -0.004 | -$2 | 0.076 | $38 | 0.025 | $13 |
| ER Visits, Asthma | -0.001 | $0 | 0.032 | $14 | 0.010 | $4 |
| Mortality (low estimate) | -0.006 | -$56,708 | 0.070 | $688,954 | 0.024 | $240,255 |
| Mortality (high estimate) | -0.013 | -$128,260 | 0.158 | $1,558,525 | 0.055 | $543,044 |
| Infant Mortality | 0.000 | -$252 | 0.000 | $3,000 | 0.000 | $927 |
| Asthma Exacerbation | -0.111 | -$7 | 1.912 | $116 | 0.619 | $38 |
| Work Loss Days | -0.428 | -$59 | 6.977 | $1,220 | 2.139 | $378 |
| Minor Restricted Activity Days | -2.572 | -$185 | 41.329 | $2,967 | 12.643 | $908 |
| Upper Respiratory Symptoms | -0.079 | -$3 | 1.370 | $48 | 0.453 | $16 |
| Lower Respiratory Symptoms | -0.056 | -$1 | 0.963 | $21 | 0.317 | $7 |
| Acute Myocardial Infarction, Nonfatal (low estimate | -0.001 | -$75 | 0.006 | $792 | 0.002 | $259 |
| Acute Myocardial Infarction, Nonfatal (high estimate | -0.005 | -$694 | 0.057 | $7,360 | 0.019 | $2,402 |
| **Total (low estimate)** | **-3.260** | **-$57,360** | **52.764** | **$698,209** | **16.242** | **$243,156** |
| **Total (high estimate)** | **-3.272** | **-$129,531** | **52.903** | **$1,574,348** | **16.290** | **$548,089** |

65 EPA, "BenMap-CE User Manual," July 2018, page 1–3 and Appendices E, H, I.

66 EPA, "BenMap Community Edition 1.5, U.S. EPA Approach for quantifying and valuing PM effects," available at https://www.epa.gov/benmap/benmap-community-edition.

67 EPA, Office of Air Quality Planning and Standards, "$PM_{2.5}$ Precursor Demonstration Guidance," EPA-454/R-16-001, May 2019, available at https://www.epa.gov/sites/production/files/2019-05/documents/transmittal_memo_and_pm25_precursor_demo_guidance_5_30_19.pdf.

68 Notes: [1] Results for 2022 reflect changes in emissions between the simple baseline case and the simple carbon case. Results for 2025 reflect changes between the simple baseline case (D2) and simple carbon case (D3). Results for 2030 reflect changes between the simple baseline case (D5) and a carbon case, including all dynamic adjustments. Emissions changes were analyzed on an annual basis at the county level. The above aggregates results across all counties in New York State; [2] Dollar values are reported in 2018$, using a 3-percent discount rate for any benefit incurred beyond the year of exposure;

**Table A.9**
**New York State Health Benefits from Carbon Price $NO_x$ and $SO_2$ Emissions Changes[69]**
**Potomac LRR Scenario**

| | 2022 | | 2025 | | 2030 | |
|---|---|---|---|---|---|---|
| **Health Endpoint** | **Incidence** | **Valuation** | **Incidence** | **Valuation** | **Incidence** | **Valuation** |
| Hospital Admits, Asthma | 0.000 | $1 | 0.000 | $2 | 0.000 | $2 |
| Hospital Admits, All Respiratory | -0.001 | -$17 | 0.001 | $17 | 0.001 | $35 |
| Hospital Admits, Chronic Lung Disease | 0.000 | -$2 | 0.000 | $4 | 0.000 | $6 |
| Hospital Admits, All Cardiovascular | -0.001 | -$24 | 0.001 | $33 | 0.001 | $60 |
| Acute Bronchitis | -0.002 | -$1 | 0.004 | $2 | 0.007 | $4 |
| ER Visits, Asthma | 0.001 | $0 | 0.002 | $1 | 0.003 | $2 |
| Mortality (low estimate) | -0.004 | -$44,246 | 0.004 | $35,073 | 0.007 | $70,103 |
| Mortality (high estimate) | -0.010 | -$100,038 | 0.008 | $79,369 | 0.016 | $158,473 |
| Infant Mortality | 0.000 | -$189 | 0.000 | $156 | 0.000 | $272 |
| Asthma Exacerbation | -0.060 | -$4 | 0.102 | $6 | 0.181 | $11 |
| Work Loss Days | -0.222 | -$21 | 0.390 | $78 | 0.649 | $123 |
| Minor Restricted Activity Days | -1.358 | -$98 | 2.303 | $165 | 3.829 | $275 |
| Upper Respiratory Symptoms | -0.040 | -$1 | 0.073 | $3 | 0.133 | $5 |
| Lower Respiratory Symptoms | -0.028 | -$1 | 0.051 | $1 | 0.093 | $2 |
| Acute Myocardial Infarction, Nonfatal (low estimate | 0.000 | -$59 | 0.000 | $41 | 0.001 | $78 |
| Acute Myocardial Infarction, Nonfatal (high estimate | -0.004 | -$545 | 0.003 | $383 | 0.006 | $721 |
| **Total (low estimate)** | **-1.716** | **-$44,662** | **2.931** | **$35,583** | **4.907** | **$70,978** |
| **Total (high estimate)** | **-1.726** | **-$100,940** | **2.938** | **$80,221** | **4.921** | **$159,991** |

**Table A.10**
**New York State Health Benefits from Carbon Price $NO_x$ and $SO_2$ Emissions Changes[70]**
**Potomac LRR/Repowering Scenario**

| | 2022 | | 2025 | | 2030 | |
|---|---|---|---|---|---|---|
| **Health Endpoint** | **Incidence** | **Valuation** | **Incidence** | **Valuation** | **Incidence** | **Valuation** |
| Hospital Admits, Asthma | 0.001 | $11 | 0.001 | $9 | 0.000 | $6 |
| Hospital Admits, All Respiratory | 0.001 | $50 | 0.002 | $68 | 0.002 | $60 |
| Hospital Admits, Chronic Lung Disease | 0.001 | $15 | 0.001 | $16 | 0.001 | $12 |
| Hospital Admits, All Cardiovascular | 0.003 | $141 | 0.004 | $155 | 0.003 | $119 |
| Acute Bronchitis | 0.018 | $9 | 0.019 | $10 | 0.014 | $7 |
| ER Visits, Asthma | 0.013 | $6 | 0.012 | $5 | 0.008 | $4 |
| Mortality (low estimate) | 0.010 | $98,198 | 0.014 | $140,118 | 0.012 | $120,625 |
| Mortality (high estimate) | 0.023 | $222,524 | 0.032 | $317,100 | 0.028 | $272,743 |
| Infant Mortality | 0.000 | $470 | 0.000 | $619 | 0.000 | $479 |
| Asthma Exacerbation | 0.439 | $27 | 0.466 | $28 | 0.355 | $22 |
| Work Loss Days | 1.856 | $369 | 1.876 | $361 | 1.348 | $256 |
| Minor Restricted Activity Days | 10.861 | $780 | 11.022 | $791 | 7.932 | $569 |
| Upper Respiratory Symptoms | 0.327 | $11 | 0.345 | $12 | 0.261 | $9 |
| Lower Respiratory Symptoms | 0.230 | $5 | 0.242 | $5 | 0.183 | $4 |
| Acute Myocardial Infarction, Nonfatal (low estimate | 0.001 | $123 | 0.001 | $172 | 0.001 | $137 |
| Acute Myocardial Infarction, Nonfatal (high estimate | 0.009 | $1,139 | 0.012 | $1,596 | 0.010 | $1,274 |
| **Total (low estimate)** | **13.761** | **$100,215** | **14.005** | **$142,370** | **10.120** | **$122,309** |
| **Total (high estimate)** | **13.781** | **$225,556** | **14.034** | **$320,776** | **10.145** | **$275,564** |

[3] The public health cost/benefit quantified in this table captures the impact of PM2.5. Ozone impacts are not quantified.

Sources: IPPTF Study GE Maps Outputs, received March 5, 2019, April 2, 2019, and May 6, 2019; EPA, Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool, version v3.542; EPA, Benefits Mapping and Analysis Tool (BenMap), Community Edition v1.5.

[69] Notes: [1] Emissions changes were analyzed on an annual basis at the county level. The above aggregates results across all counties in New York State; [2] Dollar values are reported in 2018$, using a 3-percent discount rate for any benefit incurred beyond the year of exposure; [3] The public health cost/benefit quantified in this table captures the impact of PM2.5. Ozone impacts are not quantified.

Sources: Potomac LRR Scenario GE Maps Output, received April 22, 2019; EPA, Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool, version v3.542; EPA, Benefits Mapping and Analysis Tool (BenMap), Community Edition v1.5.

[70] See prior footnote for notes. Sources: Potomac LRR/Repowering Scenario GE Maps Output, received May 13, 2019; EPA, Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool, version v3.542; EPA, Benefits Mapping and Analysis Tool (BenMap), Community Edition v1.5.

### D. Impacts in Environmental justice areas

In October 1999, the New York State Department of Environmental Conservation (DEC) established an environmental justice (EJ) program.[71, 72] Under the umbrella of the EJ program, Commissioner Policy 29 Environmental Justice and Permitting defines statistical thresholds that qualify certain census blocks as potential environmental justice areas. These thresholds are:

1. At least 15.1 percent of the population in an urban area reported themselves to be members of a minority group; or
2. At least 33.8 percent of the population in rural areas reported themselves to be members of minority groups; or
3. At least 23.95 percent of the population in an urban or rural area had household incomes below the federal poverty level.[73]

In order to analyze changes in power-plant emissions in EJ areas, we first matched the geographic coordinates of the emitting power plants in New York State to the emitting power plants in the Brattle/IPPTF Study and Potomac analyses data.[74] We then used the geographic coordinates of emitting power plants in conjunction with geospatial files of the EJ areas[75] to determine the proportion of emissions reductions occurring within EJ areas. Tables A.11 to A.13 below provide detailed results by study.

### E. Emissions during months with history of non-attainment

The federal Clean Air Act requires EPA to establish and set National Ambient Air Quality Standards (NAAQS), and then determine whether areas in the U.S. are in attainment or not in attainment with respect to these standards. Certain counties in New York State are currently not in attainment for the 2015 8-hour ozone NAAQS threshold requirement.[76] The standards cover six "criteria" pollutants, including carbon monoxide (CO), lead (Pb), nitrogen dioxide ($NO_2$), ozone ($O_3$), particle pollution (PM), and sulfur dioxide ($SO_2$).[77] The current 8-hour standard for ozone in order to be considered in attainment is 0.070 ppm.[78] The standard threshold is based off of the "annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years."[79]

[71] "Today, DEC's Office of Environmental Justice (OEJ) continues to serve as a vehicle to address environmental justice concerns in the environmental permit review process and across other DEC operations." The policies and regulations of the EJ program include Commissioner Policy 29 / Environmental Justice and Permitting, Commissioner Policy 42 / Contact, Cooperation, and Consultation with Indian Nations, and Regulation-Part 487: Analyzing Environmental Justice Issues in Siting of Major Electric Generating Facilities Pursuant to Public Service Law Article 10. New York State Department of Conservation, Environmental Justice, Office of Environmental Justice, available at https://www.dec.ny.gov/public/333.html.

[72] New York DEC, CP-29 Environmental Justice and Permitting, Issuing Authority: Commissioner Erin M. Crotty, Date Issued: March 19, 2003, Latest Date Revised: March 19, 2003, available at https://www.dec.ny.gov/docs/permits_ej_operations_pdf/cp29a.pdf.

[73] New York DEC, Environmental Justice, Maps & Geospatial Information System (GIS) Tools for Environmental Justice (hereafter "DEC EJ Mapping Tools"), available at https://www.dec.ny.gov/public/911.html.

[74] Geographic coordinates are from S&P Global Intelligence.

[75] DEC EJ Mapping Tools.

[76] EPA, "Additional Air Quality Designations for the 2015 Ozone National Ambient Air Quality Standards," Final Rule. Published June 4, 2018. 83 FR 25776.

[77] EPA, NAAQs Table, available at https://www.epa.gov/criteria-air-pollutants/naaqs-table.

[78] The EPA sets both primary and secondary standards: "Primary standards provide public health protection, including protecting the health of 'sensitive' populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings." EPA, NAAQs Table, available at https://www.epa.gov/criteria-air-pollutants/naaqs-table. The primary and secondary standards for ozone are the same.

[79] EPA, NAAQs Table, available at https://www.epa.gov/criteria-air-pollutants/naaqs-table.

In order to determine whether emissions reductions identified in the Brattle/IPPTF Study and Potomac analyses occur during high ozone months—when their impacts would be more acute in terms of contributing to public-health concerns—we first aggregated the hourly emissions reductions from each scenario by month. Next, using daily air quality monitoring data from EPA for 2018,[80] we identified months that had at least one day during which any New York State air quality monitor recorded a daily maximum 8-hour ozone concentration greater than or equal to the 0.070 ppm threshold. We used the months where New York State recorded non-attainment levels of ozone concentration to determine whether the Brattle/IPPTF Study showed emissions reductions in those same high ozone months. Table A.14 below provides detailed results.

[80] EPA, AirNow Daily Air Quality Data, New York State, Ozone, 2018, https://www.epa.gov/outdoor-air-quality-data/download-daily-data.

## Table A.11
## Impact of Carbon Price on Emissions in Environmental Justice Areas[81]
## Brattle/IPPTF Study

**Total New York State Emissions Changes [1]**

| | | $NO_x$ 2022 (Tons) | $NO_x$ 2025 (Tons) | $NO_x$ 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 108 | -31 | -39 |
| GENESEE | B | 44 | 12 | 0 |
| CENTRAL | C | 84 | -6 | -43 |
| NORTH | D | -2 | -2 | -2 |
| MOHAWKVA | E | 1 | 0 | 0 |
| CAPITAL | F | 26 | -7 | -14 |
| HUDSONVA | G | -131 | -121 | 8 |
| MILLWOOD | H | 0 | 0 | -4 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -518 | -333 | -335 |
| LONGISLA | K | -52 | 10 | 18 |
| | **Total** | **-439** | **-479** | **-410** |

| | | $SO_2$ 2022 (Tons) | $SO_2$ 2025 (Tons) | $SO_2$ 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 6 | 0 | 0 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | -67 | -19 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 2 | -1 | -3 |
| HUDSONVA | G | -1 | 2 | 0 |
| MILLWOOD | H | 0 | 0 | -1 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -5 | -2 | -5 |
| LONGISLA | K | -1 | 0 | -1 |
| | **Total** | **2** | **-69** | **-28** |

**Emissions Changes for Plants within Environmental Justice Areas**

| | | $NO_x$ 2022 (Tons) | $NO_x$ 2025 (Tons) | $NO_x$ 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 58 | 0 | -1 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | -8 | -4 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 0 | 0 | 0 |
| HUDSONVA | G | 0 | 0 | 0 |
| MILLWOOD | H | 0 | 0 | 0 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -266 | -137 | -179 |
| LONGISLA | K | -14 | -18 | -2 |
| Total Zone J Adjacent [2] | | -124 | -85 | -163 |
| | **Total** | **-346** | **-248** | **-349** |

| | | $SO_2$ 2022 (Tons) | $SO_2$ 2025 (Tons) | $SO_2$ 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 6 | 0 | 0 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | -66 | -17 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 0 | 0 | 0 |
| HUDSONVA | G | 0 | 0 | 0 |
| MILLWOOD | H | 0 | 0 | 0 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | 0 | 0 | 0 |
| LONGISLA | K | 0 | 0 | 0 |
| Total Zone J Adjacent [2] | | -4 | -3 | -5 |
| | **Total** | **2** | **-68** | **-22** |

**Notes:**

[1] Results for 2022 reflect changes in emissions between the simple baseline case and the simple carbon case. Results for 2025 reflect changes between the simple baseline case (D2) and simple carbon case (D3). Results for 2030 reflect changes between the simple baseline case (D5) and a carbon case, including all dynamic adjustments.

[2] The plants included in "Zone J Adjacent" include Linden and Bayonne. These plants are physically located in New Jersey, but their generation is fully integrated into NYISO.

[3] Generic emitting units in the GE Maps output are excluded from the Environmental Justice area totals since they could not be geo-located. These generic units account for the following emissions deltas in tons statewide: $NO_x$ (+1.5 in 2022, +1.23 in 2025, +0.6 in 2030) and $SO_2$ (-0.02 in 2022, 0 in 2025 and -0.02 in 2030).

[4] The following plants result in environmental justice area positive emissions deltas: Zone A, 2022, 58 tons NOx and 6 tons SO2 (American Refuse Fuel); Zone J, 2030, 1 ton from a combination of small increases at the following plants: Astoria East Energy, East River, Astoria (Poletti), Gowanus, Kent Avenue, Vernon Boulevard, East River, and Ravenswood.

[81] Sources: IPPTF Study GE Maps Output, received March 5, 2019, April 2, 2019, and May 6, 2019; S&P Global Markets Data for geographical coordinates of power plants; [C] NY DEC, Potential Environmental Justice Areas, https://www.dec.ny.gov/public/911.html.

## Table A.12
## Impact of Carbon Price on Emissions in Environmental Justice Areas[82]
## Potomac LRR Scenario

**Total New York State Emissions Changes**

$NO_x$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 91 | -40 | -57 |
| GENESEE | B | 41 | 10 | -8 |
| CENTRAL | C | 80 | 9 | -73 |
| NORTH | D | 0 | -1 | -4 |
| MOHAWKVA | E | 2 | 1 | -4 |
| CAPITAL | F | 32 | -2 | -17 |
| HUDSONVA | G | -125 | -95 | 1 |
| MILLWOOD | H | 0 | 0 | -4 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -513 | -249 | -259 |
| LONGISLA | K | -54 | -2 | 24 |
| | **Total** | **-448** | **-368** | **-402** |

$SO_2$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 7 | 0 | -1 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | -1 | -2 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 2 | -1 | -3 |
| HUDSONVA | G | 1 | 2 | 0 |
| MILLWOOD | H | 0 | 0 | -1 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -5 | -3 | -5 |
| LONGISLA | K | -1 | -1 | 0 |
| | **Total** | **3** | **-3** | **-11** |

**Emissions Changes for Plants within Environmental Justice Areas**

$NO_x$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 61 | 0 | -4 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | 0 | 0 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 0 | 0 | 0 |
| HUDSONVA | G | 0 | 0 | 0 |
| MILLWOOD | H | 0 | 0 | 0 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -160 | -80 | -105 |
| LONGISLA | K | -15 | -14 | -3 |
| Total Zone J Adjacent [1] | | -120 | -78 | -144 |
| | **Total** | **-234** | **-172** | **-255** |

$SO_2$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 7 | 0 | 0 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | 0 | 0 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 0 | 0 | 0 |
| HUDSONVA | G | 0 | 0 | 0 |
| MILLWOOD | H | 0 | 0 | 0 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | 0 | 0 | 0 |
| LONGISLA | K | 0 | 0 | 0 |
| Total Zone J Adjacent [1] | | -4 | -3 | -5 |
| | **Total** | **2** | **-3** | **-5** |

**Notes:**

[1] The plants included in "Zone J Adjacent" include Linden and Bayonne. These plants are physically located in New Jersey, but their generation is fully integrated into NYISO.

[2] Generic emitting units in the GE Maps output are excluded from the Environmental Justice area totals since they could not be geo-located. These generic units account for the following emissions changes in tons statewide: $NO_x$ (+1.33 in 2022, +1 in 2025, -0.14 in 2030) and $SO_2$ (-0.01 in 2022, -0.03 in 2025 and -0.01 in 2030).

[3] The following plant results in Environmental Justice area positive emissions changes: Zone A, 2022, 61 tons NOx and 7 tons SO2 (American Refuse Fuel).

[82] Sources: Potomac LRR Scenario GE Maps Output, received April 22, 2019; S&P Global Markets Data for geographical coordinates of power plants; NY DEC, Potential Environmental Justice Areas, https://www.dec.ny.gov/public/911.html.

## Table A.13
## Impact of Carbon Price on Emissions in Environmental Justice Areas[83]
## Potomac LRR/Repowering Scenario

**Total New York State Emissions Changes**

$NO_x$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 107 | -42 | -80 |
| GENESEE | B | 43 | 8 | -11 |
| CENTRAL | C | 53 | -12 | -85 |
| NORTH | D | -1 | -1 | -8 |
| MOHAWKVA | E | 0 | -3 | -4 |
| CAPITAL | F | 16 | -9 | -22 |
| HUDSONVA | G | -138 | -93 | -10 |
| MILLWOOD | H | 0 | 3 | 4 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -615 | -364 | -334 |
| LONGISLA | K | -85 | -11 | 20 |
| | **Total** | **-620** | **-525** | **-530** |

$SO_2$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 7 | 0 | 0 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | -1 | -2 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 1 | -1 | -3 |
| HUDSONVA | G | 0 | 1 | 0 |
| MILLWOOD | H | 0 | 1 | 1 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -6 | -3 | -4 |
| LONGISLA | K | -1 | -1 | 0 |
| | **Total** | **0** | **-4** | **-9** |

**Emissions Changes for Plants within Environmental Justice Areas**

$NO_x$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 61 | 0 | 0 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | 0 | 0 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 0 | 0 | 0 |
| HUDSONVA | G | 0 | 0 | 0 |
| MILLWOOD | H | 0 | 0 | 0 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -234 | -156 | -188 |
| LONGISLA | K | -14 | -13 | -3 |
| Total Zone J Adjacent [1] | | -135 | -101 | -160 |
| Repowered Generics [3] | | 70 | 67 | 58 |
| | **Total** | **-252** | **-203** | **-293** |

$SO_2$

| | | 2022 (Tons) | 2025 (Tons) | 2030 (Tons) |
|---|---|---|---|---|
| WEST | A | 7 | 0 | 0 |
| GENESEE | B | 0 | 0 | 0 |
| CENTRAL | C | 0 | 0 | 0 |
| NORTH | D | 0 | 0 | 0 |
| MOHAWKVA | E | 0 | 0 | 0 |
| CAPITAL | F | 0 | 0 | 0 |
| HUDSONVA | G | 0 | 0 | 0 |
| MILLWOOD | H | 0 | 0 | 0 |
| DUNWOODI | I | 0 | 0 | 0 |
| NYCITY | J | -1 | -1 | -1 |
| LONGISLA | K | 0 | 0 | 0 |
| Total Zone J Adjacent [3] | | -5 | -3 | -5 |
| Repowered Generics [4] | | 1 | 2 | 3 |
| | **Total** | **2** | **-2** | **-4** |

**Notes:**

[1] The plants included in "Zone J Adjacent" include Linden and Bayonne. These plants are physically located in New Jersey, but their generation is fully integrated into NYISO.

[2] Generic emitting units in the GE Maps output are excluded from the Environmental Justice area totals since they could not be geo-located. These generic units account for the following emissions changes in tons statewide: $NO_x$ (+1.45 in 2022, +1.09 in 2025, -0.29 in 2030) and $SO_2$ (+0.03 in 2022, 0 in 2025 and -0.01 in 2030).

[3] Repowered generic units include Ravenswood 1 Generic CC-FAST and Ravenswood 2 Generic CC-FAST.

[4] The following plant results in Environmental Justice Zone positive emissions deltas: Zone A, 2022, 61 tons NOx and 7 tons SO2 (American Refuse Fuel).

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[83] Sources: Potomac LRR/Repowering Scenario GE Maps Output, received May 13, 2019; S&P Global Markets Data for geographical coordinates of power plants; NY Department of Environmental Conservation, Potential Environmental Justice Areas, https://www.dec.ny.gov/public/911.html.

**Table A.14**
**Emissions Changes in Months with History of Ozone Non-Attainment Days[84]**
**Brattle/IPPTF Study**

| | | $NO_x$ | | |
|---|---|---|---|---|
| Month | Nonattainment Days Occur in the Month? | 2022 Change (Tons) | 2025 Change (Tons) | 2030 Change (Tons) |
| 1 | | -1.72 | -3.02 | -91.22 |
| 2 | | -28.16 | -13.67 | 15.53 |
| 3 | | -23.79 | -6.33 | 66.33 |
| 4 | | -26.82 | -32.96 | 55.40 |
| 5 | Yes | -24.40 | -75.30 | -25.19 |
| 6 | Yes | -39.58 | -72.97 | -54.93 |
| 7 | Yes | -82.68 | -53.42 | -80.56 |
| 8 | Yes | -90.08 | -53.08 | -61.08 |
| 9 | Yes | -70.99 | -69.32 | -65.87 |
| 10 | | -57.71 | -68.37 | -145.07 |
| 11 | | 15.09 | -8.77 | 14.76 |
| 12 | | -8.11 | -21.87 | -37.80 |
| **Total** | | **-439** | **-479** | **-410** |

## F. Changes in $CO_2$ emissions

In addition to reductions in $NO_x$ and $SO_2$ emissions, the MAPS outputs from both the Brattle/IPPTF Study and Potomac study show decreases in $CO_2$ emissions in aggregate. Decreases in CO2 emissions are key to addressing climate change concerns. Tables A.15 to A.17 below provide detailed results for the 2030 model year.

**Table A.15**
**2030 New York State $CO_2$ Emissions Changes[85]**
**Brattle/IPPTF Study**

| $CO_2$ - Change Reference Case Minus Carbon Case | | | | |
|---|---|---|---|---|
| | | Base (Tons) | Carbon (Tons) | Change (Tons) |
| WEST | A | 111,109 | 91,889 | -19,220 |
| GENESEE | B | 9,541 | 11,327 | 1,786 |
| CENTRAL | C | 1,109,612 | 848,527 | -261,085 |
| NORTH | D | 24,582 | 21,451 | -3,131 |
| MOHAWKVA | E | 19,365 | 24,243 | 4,878 |
| CAPITAL | F | 3,750,317 | 3,556,451 | -193,866 |
| HUDSONVA | G | 3,640,822 | 3,715,738 | 74,916 |
| MILLWOOD | H | 1,519 | 1,612 | 93 |
| DUNWOODI | I | 1,573 | 1,572 | -1 |
| NYCITY | J | 10,263,243 | 9,246,561 | -1,016,682 |
| LONGISLA | K | 2,444,922 | 2,380,241 | -64,681 |
| | **Total** | **21,376,605** | **19,899,612** | **-1,476,993** |

[84] Notes: [1] A day is considered in non-attainment if the daily maximum 8-hour ozone concentration is greater than 0.070 ppm in 2018 EPA daily air quality air monitoring data. [2] Results for 2022 reflect changes in emissions between the simple baseline case and the simple carbon case. Results for 2025 reflect changes between the simple baseline case (D2) and simple carbon case (D3). Results for 2030 reflect changes between the simple baseline case (D5) and a carbon case, including all dynamic adjustments. Sources: IPPTF Study GE Maps Outputs, received March 5, 2019, April 2, 2019, and May 6, 2019; EPA, AirNow Daily Air Quality Data, New York State, Ozone, 2018, https://www.epa.gov/outdoor-air-quality-data/download-daily-data; EPA, NAAQs Table, https://www.epa.gov/criteria-air-pollutants/naaqs-table.

[85] Changes for 2030 reflect changes between the simple baseline case (D5) and a carbon case reflective of all dynamic cases. Source: Brattle/IPPTF Study GE Maps Output, received May 9, 2019 and May 22, 2019.

## Table A.16
## 2030 New York State $CO_2$ Emissions Changes[86]
## Potomac LRR Scenario

**$CO_2$ - Change Reference Case Minus Carbon Case**

| | | Base (Tons) | Carbon (Tons) | Change (Tons) |
|---|---|---|---|---|
| WEST | A | 71,569 | 45,443 | -26,126 |
| GENESEE | B | 2,008 | 1,032 | -975 |
| CENTRAL | C | 864,514 | 516,987 | -347,527 |
| NORTH | D | 4,257 | 2,626 | -1,630 |
| MOHAWKVA | E | 1,244 | 866 | -378 |
| CAPITAL | F | 3,505,639 | 3,173,854 | -331,786 |
| HUDSONVA | G | 3,415,221 | 3,505,779 | 90,559 |
| MILLWOOD | H | 1,276 | 1,300 | 24 |
| DUNWOODI | I | 1,304 | 1,249 | -55 |
| NYCITY | J | 10,497,914 | 9,562,620 | -935,293 |
| LONGISLA | K | 2,356,803 | 2,287,292 | -69,511 |
| | **Total** | **20,721,748** | **19,099,049** | **-1,622,699** |

## Table A.17
## 2030 New York State $CO_2$ Emissions Changes[87]
## Potomac LRR/Repowering Scenario

**$CO_2$ - Change Reference Case Minus Carbon Case**

| | | Base (Tons) | Carbon (Tons) | Change (Tons) |
|---|---|---|---|---|
| WEST | A | 75,422 | 38,415 | -37,007 |
| GENESEE | B | 2,303 | 1,147 | -1,157 |
| CENTRAL | C | 855,145 | 478,081 | -377,063 |
| NORTH | D | 10,788 | 3,665 | -7,123 |
| MOHAWKVA | E | 2,746 | 1,786 | -960 |
| CAPITAL | F | 3,474,705 | 3,123,260 | -351,445 |
| HUDSONVA | G | 3,411,436 | 3,378,959 | -32,477 |
| MILLWOOD | H | 1,152 | 1,301 | 149 |
| DUNWOODI | I | 1,331 | 1,240 | -91 |
| NYCITY | J | 10,139,722 | 9,466,551 | -673,171 |
| LONGISLA | K | 2,361,059 | 2,302,311 | -58,748 |
| | **Total** | **20,335,810** | **18,796,716** | **-1,539,094** |

[86] Source: Potomac LRR Scenario GE Maps Output, received April 22, 2019.

[87] Source: Potomac LRR/Repowering Scenario GE Maps Output, received May 13, 2019.

# V. Fuel use impact analyses (re: Section VII of the Final Report)

This analysis uses MAPS outputs from both the Brattle/IPPTF Study and Potomac study, as described above. The analysis quantifies the change in natural gas consumption in New York's electric power sector as a result of the proposed carbon charge. MAPS provides fuel consumed (in MMBtu) on an hourly, power plant unit-specific level.

We identified two types of units as consuming natural gas: units that only consume natural gas, and natural gas dual-fuel units. We assumed dual fuel units operate economically on gas (that is, they consume natural gas only in hours when the price of natural gas is below the price of oil relevant for the unit). We aggregated the hourly, power plant unit-level fuel consumption for each scenario, for each year of analysis, and for each of the capacity Zones (A-K). We calculated the difference between the total natural gas consumed in the baseline scenario and the corresponding carbon case. Tables A.18 to A.20 below provide detailed results by study.

**Table A.18**
**Impact of a Carbon Price on Gas Consumption by Zone (Thousands of MMBtu)[88]**
**Brattle/IPPTF Study**

| | 2022 | | | | 2025 | | | | 2030 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [A] | [B] | [C] = [A] - [B] | [C] / [B] | [D] | [E] | [F] = [D] - [E] | [F] / E | [G] | [H] | [I] = [G] - [H] | [I] / [H] |
| Zone | Carbon | Base | Change | % of Base | Carbon | Base | Change | % of Base | Carbon | Base | Change | % of Base |
| Zone A | 1,454 | 1,745 | -291 | *-16.7%* | 1,770 | 2,320 | -550 | *-23.7%* | 1,283 | 1,608 | -325 | *-20.2%* |
| Zone B | 100 | 103 | -3 | *-3.0%* | 152 | 171 | -18 | *-10.8%* | 143 | 124 | 19 | *15.5%* |
| Zone C | 13,719 | 14,251 | -532 | *-3.7%* | 15,283 | 18,116 | -2,832 | *-15.6%* | 12,053 | 16,850 | -4,797 | *-28.5%* |
| Zone D | 376 | 548 | -171 | *-31.3%* | 433 | 571 | -138 | *-24.2%* | 274 | 323 | -50 | *-15.4%* |
| Zone E | 190 | 225 | -35 | *-15.4%* | 290 | 309 | -18 | *-6.0%* | 295 | 238 | 57 | *24.0%* |
| Zone F | 97,462 | 91,462 | 6,000 | *6.6%* | 78,485 | 81,335 | -2,850 | *-3.5%* | 55,679 | 59,673 | -3,994 | *-6.7%* |
| Zone G | 92,379 | 93,435 | -1,056 | *-1.1%* | 82,122 | 76,754 | 5,368 | *7.0%* | 58,881 | 58,439 | 441 | *0.8%* |
| Zone H | 36 | 33 | 3 | *10.4%* | 32 | 26 | 6 | *22.1%* | 24 | 23 | 1 | *2.7%* |
| Zone I | 37 | 34 | 3 | *9.7%* | 33 | 28 | 5 | *17.2%* | 23 | 24 | -1 | *-4.4%* |
| Zone J | 202,236 | 217,400 | -15,164 | *-7.0%* | 178,838 | 186,886 | -8,047 | *-4.3%* | 151,508 | 167,869 | -16,361 | *-9.7%* |
| Zone K | 59,607 | 61,792 | -2,186 | *-3.5%* | 49,887 | 51,460 | -1,572 | *-3.1%* | 38,743 | 39,986 | -1,243 | *-3.1%* |
| Total | *467,598* | *481,028* | *-13,430* | *-2.8%* | *407,327* | *417,976* | *-10,648* | *-2.5%* | *318,906* | *345,158* | *-26,253* | *-7.6%* |

**Table A.19**
**Impact of a Carbon Price on Gas Consumption by Zone (Thousands of MMBtu)[89]**
**Potomac LRR Scenario**

| | 2022 | | | | 2025 | | | | 2030 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [A] | [B] | [C] = [A] - [B] | [C] / [B] | [D] | [E] | [F] = [D] - [E] | [F] / E | [G] | [H] | [I] = [G] - [H] | [I] / [H] |
| Zone | Carbon | Base | Delta | % of Base | Carbon | Base | Delta | % of Base | Carbon | Base | Delta | % of Base |
| Zone A | 1,136 | 1,635 | -499 | *-30.5%* | 1,280 | 1,939 | -660 | *-34.0%* | 764 | 1,203 | -439 | *-36.5%* |
| Zone B | 30 | 65 | -35 | *-53.2%* | 44 | 75 | -31 | *-40.8%* | 17 | 34 | -16 | *-48.6%* |
| Zone C | 11,254 | 12,428 | -1,174 | *-9.4%* | 11,660 | 13,898 | -2,239 | *-16.1%* | 8,689 | 14,530 | -5,841 | *-40.2%* |
| Zone D | 197 | 290 | -93 | *-32.2%* | 166 | 232 | -66 | *-28.6%* | 44 | 72 | -27 | *-38.3%* |
| Zone E | 53 | 61 | -8 | *-13.5%* | 31 | 24 | 6 | *26.4%* | 15 | 21 | -6 | *-30.4%* |
| Zone F | 97,520 | 89,469 | 8,052 | *9.0%* | 78,928 | 80,664 | -1,735 | *-2.2%* | 53,342 | 58,918 | -5,576 | *-9.5%* |
| Zone G | 89,388 | 87,967 | 1,421 | *1.6%* | 77,690 | 71,795 | 5,896 | *8.2%* | 58,921 | 57,399 | 1,522 | *2.7%* |
| Zone H | 34 | 31 | 2 | *7.7%* | 30 | 25 | 4 | *17.8%* | 22 | 21 | 0 | *1.9%* |
| Zone I | 34 | 33 | 2 | *5.4%* | 30 | 27 | 3 | *9.9%* | 21 | 22 | -1 | *-4.2%* |
| Zone J | 208,052 | 226,040 | -17,988 | *-8.0%* | 182,795 | 191,565 | -8,770 | *-4.6%* | 160,715 | 176,434 | -15,719 | *-8.9%* |
| Zone K | 58,561 | 61,522 | -2,961 | *-4.8%* | 49,385 | 51,626 | -2,241 | *-4.3%* | 38,442 | 39,610 | -1,168 | *-2.9%* |
| Total | *466,259* | *479,540* | *-13,281* | *-2.8%* | *402,039* | *411,870* | *-9,832* | *-2.4%* | *320,991* | *348,263* | *-27,271* | *-7.8%* |

[88] Notes: [1] Assumes dual fuel units are dispatched economically. [2] Changes for 2022 reflect changes in emissions between the simple baseline case and the simple carbon case. Changes for 2025 reflect changes between the simple baseline case (D2) and simple carbon case (D3). Changes for 2030 reflect changes between the simple baseline case (D5) and a carbon case, including all dynamic adjustments. Source: IPPTF Study GE Maps Outputs, received March 5, 2019, April 2, 2019, and May 6, 2019.

[89] Note: Assumes dual fuel units are dispatched economically. Source: Potomac LRR Scenario GE Maps Output, received April 22, 2019.

**Table A.20**
**Impact of a Carbon Price on Gas Consumption by Zone (Thousands of MMBtu)[90]**
**Potomac LRR/Repowering Scenario**

| | 2022 | | | | 2025 | | | | 2030 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [A] | [B] | [C] = [A] - [B] | [C] / [B] | [D] | [E] | [F] = [D] - [E] | [F] / E | [G] | [H] | [I] = [G] - [H] | [I] / [H] |
| **Zone** | **Carbon** | **Base** | **Delta** | **% of Base** | **Carbon** | **Base** | **Delta** | **% of Base** | **Carbon** | **Base** | **Delta** | **% of Base** |
| **Zone A** | 1,161 | 1,447 | -287 | ***-19.8%*** | 1,272 | 1,841 | -569 | ***-30.9%*** | 646 | 1,268 | -622 | ***-49.1%*** |
| **Zone B** | 27 | 40 | -13 | ***-31.7%*** | 47 | 74 | -27 | ***-36.6%*** | 19 | 39 | -19 | ***-50.2%*** |
| **Zone C** | 10,635 | 12,114 | -1,479 | ***-12.2%*** | 11,005 | 14,178 | -3,173 | ***-22.4%*** | 8,035 | 14,372 | -6,337 | ***-44.1%*** |
| **Zone D** | 233 | 351 | -118 | ***-33.6%*** | 193 | 278 | -85 | ***-30.6%*** | 62 | 181 | -120 | ***-66.0%*** |
| **Zone E** | 54 | 48 | 6 | ***12.2%*** | 48 | 29 | 18 | ***63.3%*** | 30 | 46 | -16 | ***-35.0%*** |
| **Zone F** | 95,552 | 91,574 | 3,977 | ***4.3%*** | 77,287 | 80,255 | -2,969 | ***-3.7%*** | 52,492 | 58,398 | -5,906 | ***-10.1%*** |
| **Zone G** | 89,324 | 90,538 | -1,214 | ***-1.3%*** | 75,077 | 71,433 | 3,645 | ***5.1%*** | 56,789 | 57,335 | -546 | ***-1.0%*** |
| **Zone H** | 32 | 28 | 4 | ***13.7%*** | 29 | 24 | 5 | ***22.3%*** | 22 | 19 | 3 | ***12.9%*** |
| **Zone I** | 34 | 28 | 6 | ***21.9%*** | 30 | 24 | 6 | ***22.7%*** | 21 | 22 | -2 | ***-6.8%*** |
| **Zone J** | 208,822 | 219,860 | -11,037 | ***-5.0%*** | 183,423 | 187,840 | -4,417 | ***-2.4%*** | 159,100 | 170,414 | -11,314 | ***-6.6%*** |
| **Zone K** | 57,705 | 61,756 | -4,050 | ***-6.6%*** | 49,415 | 52,017 | -2,603 | ***-5.0%*** | 38,694 | 39,682 | -987 | ***-2.5%*** |
| **Total** | ***463,579*** | ***477,785*** | ***-14,206*** | ***-3.0%*** | ***397,824*** | ***407,993*** | ***-10,169*** | ***-2.5%*** | ***315,910*** | ***341,777*** | ***-25,867*** | ***-7.6%*** |

[90] Note: Assumes dual fuel units are dispatched economically. Source: Potomac LRR/Repowering Scenario GE Maps Output, received May 14, 2019.

# VI. Analysis of customer bill and social welfare impacts (re: Section VIII of the Final Report)

For customer-bill impacts, we converted information from consumer bill impacts, as reported by Brattle/IPPTF and Potomac, into a net present value (NPV) for the period from 2022 through 2036, stated in 2019$. Both Brattle and Potomac generated both a retail price impact (in $/kWh) and a total dollar value of nominal-dollar impacts on consumers' electricity bills for the years 2022, 2025, and 2030. In order to calculate the NPV of such impacts, we needed account for annual impacts for those and other years in the analyses.

In generating estimates for other years, we followed the method used in the Brattle/IPPTF analysis, which used linear interpolation to estimate impacts for the years 2023, 2024, and 2026-2029.[91] For the years after 2030 and up through 2036, we applied an inflation factor (2 percent/year) to the estimated impact amount in 2030. We used the same inflation factor to express those NPV amounts in 2019$.

We calculated NPVs based on two different discount factors: a 3-percent social discount rate and a 7-percent private discount rate. We chose to use two discount rates, as recommended in situations where an analysis involves money flows to various entities in society over different periods of time, especially when there is a significant difference in the timing of costs and benefits. Our analysis inherently involves the assessment of costs (e.g., expenditures and investments, increase and decreases in prices, revenues and other dollar flows depending upon the year) and benefits (e.g., lower electricity bills for consumers) that occur in different periods of time.

There is a deep literature on the proper discount rate to use in analyzing certain public policies: On the one hand, a private discount rate is used when analyzing the investment options of private enterprises. The appropriate private discount rate varies, depending upon whether the economic analysis focuses on a single company (where that company's weighted average cost of capital would be appropriate) versus a group of companies (where the appropriate discount rate would reflect their collective opportunity costs). On the other hand, a different discount rate may be appropriate for use by government agencies when they analyze investments, when consumers look at their economic options, or when evaluating the rate at which society as a whole is willing to trade off present for future benefits.

Given the character of a proposed policy to adopt a carbon price in NYISO markets, in order to assist New York State in accomplishing its statutory carbon-reduction goals, we have opted to present the results using both the social and private discount rates. We note that the federal Office of Management and Budget's Circular No. A-94 ("Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs"[92]) as well as the U.S. EPA[93] have established guidance for discount rates used in benefit-cost and other types of economic analysis by federal agencies.

[91] Brattle/IPPTF Report, page 11.

[92] Office of Management and Budget Circular No. A-94 (1992), "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." http://www.whitehouse.gov/omb/circulars_a094/.

[93] U.S. Environmental Protection Agency (National Center for Environmental Economics, Office of Policy), "Guidelines for Preparing Economic Analyses," EPA 240-R-10-001, December 2010, page 6–19.

Finally, we present estimates of global social welfare from the 2019 RFF Study.[94] The authors of that study report their estimates of annual social welfare as of 2025 (the year modeled), and estimate them for two cases (one with assumptions of high renewable technology costs, and another assuming low renewable technology costs and high gas prices). The results, ranging from $108 million for the high-cost case to $691 million in the low-cost case), are reported in 2013$. We converted these amount to 2019$, using the Bureau of Labor Statistics' CPI calculator,[95] which yielded a range of $118 million to $755 per year in 2019$.

[94] Daniel Shawhan, Paul Picciano, and Karen Palmer, "Benefits and Costs of Power Plant Carbon Emissions Pricing in New York: A Dynamic, Simulation-Based Analysis," Resources for the Future, July 18, 2019 (hereafter RFF 2019 Study), available at https://www.rff.org/publications/reports/benefits-and-costs-of-the-new-york-independent-system-operators-carbon-pricing-initiative/.

[95] As of August 27, 2019, Bureau of Labor Statistics, CPI Inflation Calculator, available at https://data.bls.gov/cgi-bin/cpicalc.pl.