Impacts of Indian Point Nuclear Plant Closure:
Human Health, Climate Change, and Ecosystem Damages

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Executive Summary

New York State did not conduct a comprehensive impact analysis of closing the Indian Point nuclear power plant. We compare the impacts on human health, climate change, and ecosystem damages from the electricity generation mix shift under two scenarios – with and without Indian Point. We use the ReCiPe life-cycle impact analysis tool and the ‘social cost of carbon’ frameworks to determine the net societal burden of the plant’s closure to be $1.26 billion to $3.78 billion per annum. The resultant increase in particulate pollution costs 325 human lives per annum.

Plant closure can be postponed by attracting a willing operator by rewarding the enterprise for its environmental characteristics, as the state does with all other low-carbon resources. We determine that such a policy has a societal benefit-to-cost ratio between 3.8 to 11.6. Our research aims to further evidence-based policymaking, including the proposed Clean Energy Standard rule making proceeding Case 15-E-0302. Policy decisions that are based on holistic, evidence-based analyses benefit society greatly. Those that do not have severe inadvertent consequences.

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1. Introduction

It is difficult to make science-based decisions on energy shifts related to nuclear power due to stakeholder perceptions of high risk. Often policymakers do not evaluate the real-world impacts of switching from nuclear energy to other technologies, even fossil fuel ones. We evaluate the human health, greenhouse gas (GHG) emission, and ecological impacts caused by the decision to close Indian Point nuclear power plant (IP) in Westchester County, New York.

Adler et al. (2020) used an event-study framework of all U.S. nuclear power plant (NPP) openings from 1970 to 1995 to find that each opening reduced coal-fired generation by ~200 gigawatt-hours (GWh) per month. Conversely, forced plant outages from 1999 to 2014 increased coal use by a similar amount. Despite "natural" methane gas generation becoming cheaper with the shale revolution, they found no statistically significant increase in gas-fired generation with one-month nuclear plant outages 2008-2014.

In New York, all the coal plants are already closed and methane gas prices for electric power consumers in plummeted 49% from the 2008-2014 average to 2019 (Figure 1). Methane gas combustion generates the marginal unit of electricity, setting the price; all other producers are price-takers. New York City wholesale electricity prices have followed gas down, with 2019 level 51% below 2008-2014.

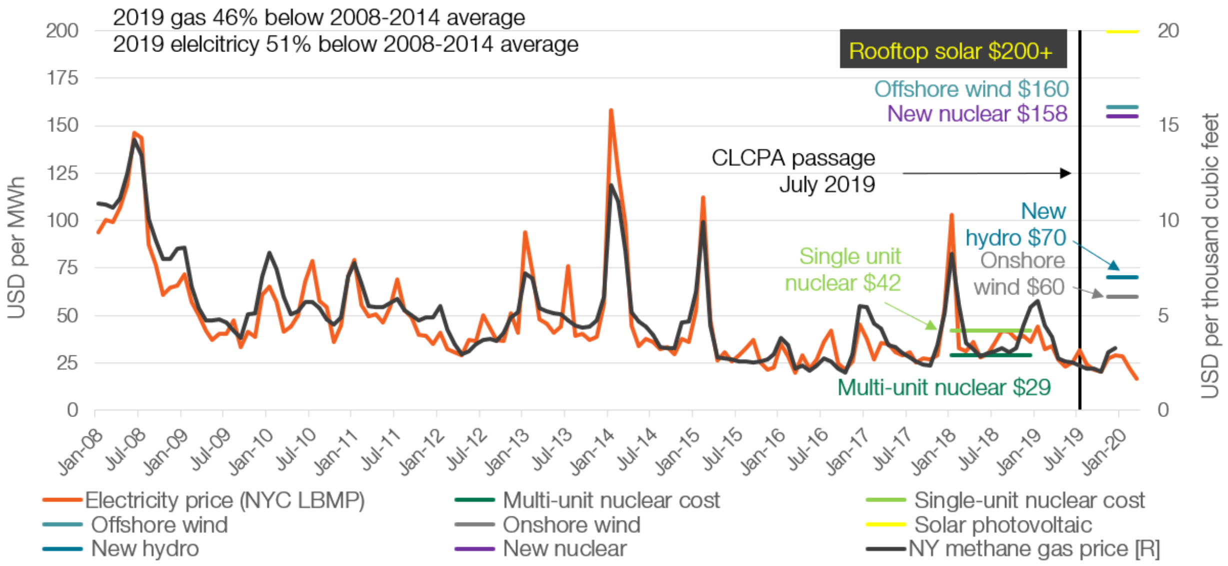

Figure 1. NY Methane gas price, gas-driven NYC electric price, and unsubsidized cost of other generation sources (Beiter et al., 2018; J. Besha, personal communication, March 2020; EIA, n.d.-c; Hunter & Jackson, 2019; Lazard, 2019; NEI, 2019; NYISO, n.d.-a; NYSERDA, 2018)

New York State did not conduct a comprehensive evaluation of the impacts of IP's early retirement. Westchester County challenged the Supplemental Final Environmental Impact

Assessment on IP's water permits, arguing that it "does not consider the economic and social impacts of Indian Point's early retirement" (NYSDEC, 2017a). New York State Department of Environmental Conservation (NYSDEC) responded that there is "no reasonable basis for comparing the environmental, economic and social factors resulting from early retirement to those that hypothetically would exist if Entergy had not limited its own project." While many state agencies scrutinized IP's environmental impacts, they have ignored the consequences of incremental fossil-fired generation due to its closure.

New York City's Department of Environmental Protection retained Charles River Associates to comprehensively analyze the economic, reliability, and environmental effects of the proposed retirement of the IP (Charles River Associates, 2014). The report found that the development of a combined cycle gas turbine (CCGT) power plant is "the only market-based response to IP's retirement."

Most analyses that claim that energy efficiency (EE) and Variable Renewable Energy (VRE) sources wind and solar will "replace" or has already "replaced" Indian Point (Congdon, 2019; Dillon, 2020; Kennedy, 2020) misunderstand or mischaracterize the role of both. Since all industrial activities have negative externalities (Harris et al., 2017), using less energy to achieve the same output (EE) is the most ecologically beneficial path. However, EE does not help identify the source for the remaining electricity demand. The role of VRE should be to reduce polluting fossil fuel use. Ascribing decades of (past and future) VRE and EE to justify displacing nuclear generation has no rational basis.

Critics of nuclear power argue that replacing IP with VRE will be cheaper than maintaining operational NPPs (Cebulla & Jacobson, 2018). The authors acknowledge that they ignore the systems cost of operating and maintaining VRE, e.g. vastly expanded energy storage and transmission infrastructure. When arguing against the operational Indian Point plant, the authors conflate the cost overruns and delays of building new NPPs with that of maintaining operational NPPs.

MIT Center for Energy and Environmental Policy Research showed that extending the lifespan of Spain's existing nuclear plants (built in the 1980s) is the least-cost path to reduce GHG emissions (Fratto-Oyler & Parsons, 2018). High penetration of VRE (post 2030) significantly increases overall system cost. Park et al. (2016) evaluated the feasibility of South Korean replacing nuclear generation with renewables within 10 years. Based on customers' willingness to pay, it was economically feasible to replace only 55% of nuclear generation with renewables (Park et al., 2016). Thus, the premature closure of nuclear generation would lead to a large increase in fossil fueled generation.

Germany's decision to phase out nuclear power by 2022 may offer the starkest warning on the outcome of nuclear closures. After the Fukushima nuclear reactor accident in Japan, Germany shut down 8.8 gigawatts (GW) of nuclear capacity in March 2011 and is on-track to close the remaining 12.7 GW of capacity by 2022 (Nestle, 2012). In all scenarios, the deficit is largely filled by coal- and lignite-based generation, increasing the CO_2-intensity of the German electricity sector and electricity prices, regardless of the ramp-up of renewable generation (Bruninx et al., 2013; Knopf et al., 2014).

New York legislated nation-leading climate goals in its Climate Leadership and Community Protection Act (CLCPA) in 2019 (NRDC, 2019; NY Governor, 2019). Two key goals are ensuring 100% of the state's electricity is emissions free by 2040 and reducing economy-wide emissions 85% below 1990 levels by 2050.

Until the externalities of global warming, human health damages from pollution, and ecological impacts of electricity generation are incorporated into the cost of generation, deregulated power markets will shift towards lowest cost generation sources. With the collapse of gas prices, methane-fired generation has become the most economic form of electricity in New York (Figure 1), and its contribution to the state grid grew from 29% in 2006 to 38% in 2019 (Appendix A).

In order to meet the CLCPA goals, New York is inducing offshore wind development at a cost of $160 per megawatt-hour (MWh) (Beiter et al., 2018; NYSERDA, 2018), a level far above the 2019 New York City wholesale electricity price of $28/MWh in (Figure 1). New York has also instituted Zero Emission Credits (ZECs) to reward NPPs for their beneficial climate attribute (NYSERDA, 2016). However, IP was not afforded this compensation by the New York Public Service Commission (McDermott Will & Emery, 2016). Expanding the lowest-cost methods of avoiding GHG emissions ensures that ratepayer and taxpayer funds generate the most benefit.

We evaluate the unpriced externalities of New York's electricity mix shift due to the IP closure and conduct a societal cost-benefit calculation of keeping IP operational. Our contribution is a science-based framework to make energy policy decisions.

2. Background

2.1 Past

Indian Point NPP units IP2 and IP3 have been in operation since 1974 and 1976, respectively (NRC, 2020). In 2007, the plant owner Entergy applied for 20-year federal operating license extensions for both units, which were to expire in 2013 and 2015 (NYSDEC, 2017b). In 2009, Entergy filed for Water Quality Certification ("WQC") under the federal Clean Water Act ("CWA"). The CWA is a federal statute that NYSDEC oversees on behalf of the U.S. EPA (NYSDEC, 2017b). In 2010, NYSDEC rejected this application.

In January 2017, New York State, Entergy, and Riverkeeper (a local antinuclear group) signed a Closure Agreement for IP's Early Retirement (NYS et al., 2017). IP2 shut down in April 2020, and IP3 is to follow in April 2021.

State regulators, who had been withholding water discharge permits, promptly granted them in February 2017, conditional on Early Retirement (NYSDEC, 2017a). In December 2017, the New York wholesale grid operator (NYISO) conducted a deactivation assessment (NYISO, 2017). The report identified three major generation facilities – all powered by fossil fuels – as being key to grid stability after IP's deactivation. No comprehensive effort was taken to assess or publicize the impacts of this switch. In response to Westchester County raising the need for a fulsome evaluation, NYSDEC waived further investigation citing 58 hearing days and evidence collection during water discharge permit proceedings in 2003 (NYSDEC, 2017).

While the NYSDEC evaluated the discharge from the one plant – Indian Point – it did not consider whether its closure would create a much larger social and environmental impact from multiple sources. Rather than conduct a holistic cost-benefit analysis before making this fundamental shift in New York's energy landscape, NYSDEC postulated "potential replacement sources of energy… in New York include many renewables (primarily wind)" (NYSDEC, 2017).

2.2 Present

New York's electricity is a tale of two grids: the low-carbon upstate grid (81% powered by hydro and nuclear), and the fossil-dependent downstate one (69% powered by oil and gas) (NYISO, 2020b). The 2,083 MW Indian Point plant generated 16.7 TWh of electricity in 2019 (NYISO, 2020a). This amounts to 81% of all downstate fossil-free electricity generation, including behind-the-meter "rooftop solar" (Appendix A). Despite decades of subsidies from federal, state, and local jurisdictions, VRE sources contributed 1.9% of downstate electricity generation (grid plus rooftop solar) in 2019 (Appendix A). There is a growing opposition from local jurisdictions to land-intensive solar and wind projects (New York League of Conservation Voters Education Fund, 2019). Based on the projections for 2030 in the U.S. National Climate Assessment (U.S. Global Change Research Program, 2014), to numerically replace IP's output with wind would require a 30x the land area, or 1.5x that of New York City. For solar photovoltaic replacement, the total land requirement is 0.8x that of the City.

IP sits within the grid-constrained subregion called 'Lower Hudson Valley,' which includes New York City (NYISO, 2019b). Since transmission constraints limit power flow into this region, the grid operator requires a minimum 92.3% of generative capacity to be procured within the area to reliably serve load (NYISO, 2019b).

The Nuclear Regulatory Commission has permitted IP2 to operate until April 2024 (NRC, n.d.-b), and IP3 until April 2025 (NRC, n.d.-c) without further plant upgrades. Thus, there is no federal permitting barrier to New York reversing its current closure trajectory.

3. Methodology

We evaluate the impacts of the shift in electricity sources using the ReCiPe2016 method for Life Cycle Impact Assessment over 100-year and 20-year timeframes (National Institute for Public Health and the Environment, 2016).

3.1 Future Generation Mix

We evaluate the change in electricity generation in Lower Hudson Valley (LHV) from January 2020 to December 2022 under two scenarios: (A) Indian Point is closed, (B) Indian Point remains operational (Table 1). For both scenarios, we model electricity demand for 2022 by subtracting EE and behind-the-meter generation (BTM) savings estimates (excluding rooftop solar) from NYISO's Load and Capacity Data report (Gold Book) (NYISO, 2020a). Released in April 2020, this report incorporates demand destruction from the ongoing COVID-19 pandemic. In both cases, we tabulate all LHV rooftop solar projects from the Gold Book, and all grid-connected projects in NYISO's interconnection queue (as of March 2020) slated to come online during the evaluation period (NYISO, n.d.-b). Further, we include all projects not subject to the NYISO process (NYS Public Service Commission, 2019) from utility interconnection queues of Consolidated Edison, Orange & Rockland Utilities, and Central Hudson Gas & Electric with 'verification testing or final acceptance dates' after 30 June 2019 (NY State, 2020). We assume the annual deployment of such utility-level solar to increase by 20% per annum.

Since VRE generation has zero marginal cost, electricity produced from such sources enters the generation mix irrespective of the electricity price.[1] Methane gas plants generate the marginal unit of electricity (Figure 1), and therefore expands and contracts to balance net demand. Since the flexible gas portion of LHV generation is so high, we assume each unit of VRE will displace a unit of fossil fuel generation.

Under Scenario A, the bulk of incremental generation will come from fossil fuel plants (Table 1). Of the two new massive CCGT projects identified by NYISO, Cricket Valley (1,020 MW) in Dover (Dutchess County), is ramping up since January 2020. However, CPV Valley (678 MW) in Wawayanda (Orange County) which began generation in October 2018 (McKenna, 2017) operated with a 69% capacity factor in 2019 (NYISO, 2020a). North Bergen Liberty Generating station in NJ (1,200 MW) is explicitly pursuing the market opening created by IP's retirement (Liberty Generating, n.d.). Beyond these CCGT plants, residual demand is balanced

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[1] However, upstate wind generation is starting to be curtailed due to transmission limitations (NYISO, 2020b).

by ramping up existing fossil fuel plants in Metro NYC (5 boroughs of New York City plus Linden, and Bayonne in New Jersey). Gas/oil “dual fuel” plants in this region operated at capacity factor of 23% in 2019 (NYISO, 2020a), leaving ample room to burn more hydrocarbons with rising demand.

Under Scenario B, growing VRE displaces generation from fossil fuel plants. Nuclear generation does not compete with VRE, since solar and wind expansion is due to State and federal subsidies (Figure 1). Not only would Scenario B negate the need for new fossil fuel plant development, it would also allow the state to retire aging fossil fuel plants situated in environmental justice communities (Bryer, 2020; Strategen Consulting, 2017). This option is consistent with the ‘community protection’ aspects of CLCPA.

Scenario A **Current trajectory without Indian Point**		**Gigawatt-hours per year**	**% of Indian Point generation**
p	- Indian Point	(16,695)	-100%
q	+ EE and BTM savings (vs. 2018)	4,152	25%
$r = p + q$	2022 supply shortfall	(14,268)	-85%
s	+ Solar	3,154	19%
$t = -(r + s)$	+ Fossil Fuels (marginal supply)	9,388	56%
Scenario B **Alternate possibility with Indian Point**			
u	+ EE and BTM savings (vs. 2018)	4,152	25%
v	+ Solar	3,154	19%
$w = -(u + v)$	- Fossil Fuels (marginal supply)	(7,306)	-44%

Table 1. Lower Hudson Valley electricity shifts over 2018-2022 with and without Indian Point

While dual fuel plants can generate electricity from oil or gas, we make the simplifying assumption that all fossil fuel plants burn only gas. The average gas share of combustion at the duel-fuel plants Ravenswood and Astoria was - respectively - 97% (EIA, n.d.-b) and 98% (EIA, n.d.-a, n.d.-b) during the last 5 years. However, as gas pipeline expansions are curtailed (Balaraman, 2019), the Public Service Commission is contemplating increased oil burning at some plants (Rhodes, 2019).

Since congestion on the current transmission system limits the amount of upstate electricity that can reach the densely populated downstate region, a large part of IP’s replacement generation must be met by local resources (NYISO, 2017). NYISO has selected two transmission lines “increasing delivery of environmentally desirable power to meet state energy goals, relieving congestion, and replacing aging infrastructure to bolster system reliability and resilience” (NYISO, 2019c). These projects, slated to transmit at least 900 MW to LHV by December 2023 (NYISO, 2019b), are beyond the scope of our study. However, NYISO warns "[e]ven with the Transmission projects selected... congestion will persist. The inability of the transmission system to deliver increasing amounts of renewables from upstate to downstate jeopardizes achieving the state’s public policy goals."

Major wind projects in federal waters offshore Long Island are expected to be a key contribution to New York's CLCPA (NY Governor, 2019). Of the announced projects, Empire Wind (816 MW) was expected to start servicing LHV (through Gowanus substation in Brooklyn) from December 2024, but recent federal actions have delayed development by more than a year (NYSDPS, 2020; Stromsta, 2020).

To accurately project how wind and solar impact the grid, we would need to analyze the hourly and yearly fluctuations in VRE generation vs. electricity demand. VRE sources add significant generation in some hours, and less in others (Fratto-Oyler & Parsons, 2018). At large-scale deployment, VRE generation may need to be curtailed at certain periods. Though not considered in present research, the near absence of grid-scale storage and difficulties with expanding congested transmission will likely reduce potential VRE capacity utilization factors.

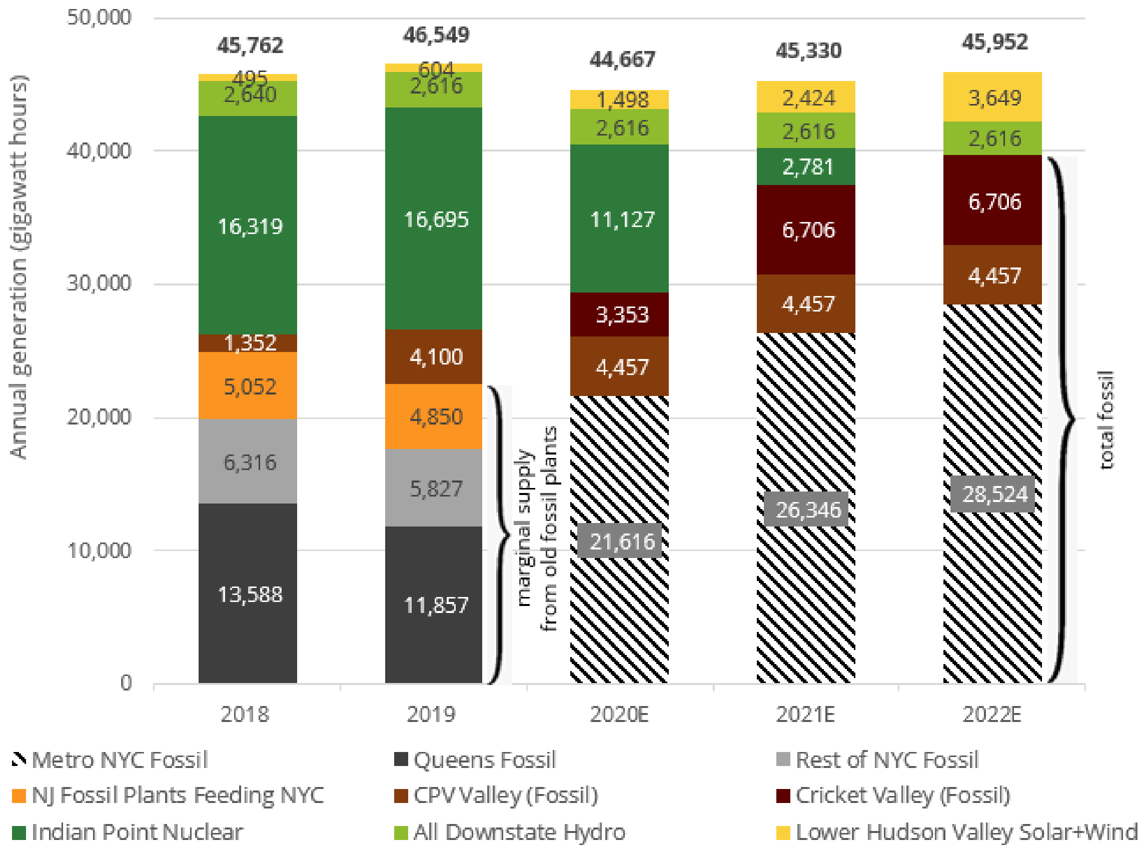

Figure 2. Electricity Generation Feeding New York City by Source (including on-grid sources plus behind-the-meter solar) (NYISO 2017, 2019a, 2010b, 2020a, 2020b, n.d.-b; NY State, 2020)

New York City (NYCA Zone J) consumed 52,003 GWh in 2019, a third of statewide demand (NYISO 2020a). Nearly all of the roughly 22,500 GWh of electricity generated within NYC was from fossil fuel-fired generation (NYSDPS, 2020). We conducted a plant-by-plant analysis of all electricity sources that feed New York City in Figure 2. This included all downstate hydro and excluded imports from New Jersey and upstate New York. Given the aforementioned transmission limits, Metro NYC fossil generation through to 2022 should be accurate. As seen in Figure 2, existing fossil fuel plants in Metro NYC need to ramp up by 27% between 2019 and 2022 to make up for lost nuclear generation.

3.2 Human Health

Disability Adjusted Life Years

The burden on human health is measured in Disability-Adjusted Life Years (DALY). WHO defines each DALY to be equivalent to losing one year of full health, either from disability or premature death (WHO, n.d.). The impact categories evaluated dame from particulate pollution, tropospheric ozone formation, ionizing radiation, stratospheric ozone depletion, human toxicity, global warming, and water to human health via increases in respiratory disease, cancer, other disease/causes, and malnutrition (National Institute for Public Health and the Environment, 2016).

Particulate Pollution

Air pollution from particulate matter finer than 2.5 µm ($PM_{2.5}$) causes human health problems by reaching the upper part of the airways and lungs when inhaled (National Institute for Public Health and the Environment, 2016). Secondary $PM_{2.5}$ aerosols are formed in air from emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), including from fossil fuel combustion (WHO, 2003). Most epidemiological studies on large populations have found no ambient $PM_{2.5}$ concentration threshold below which there is no effect on mortality and morbidity (Lepeule et al., 2012). The $PM_{2.5}$ impact factor for human health (Figure 3) is the same over 20- and 100-year time frames (National Institute for Public Health and the Environment, 2016).

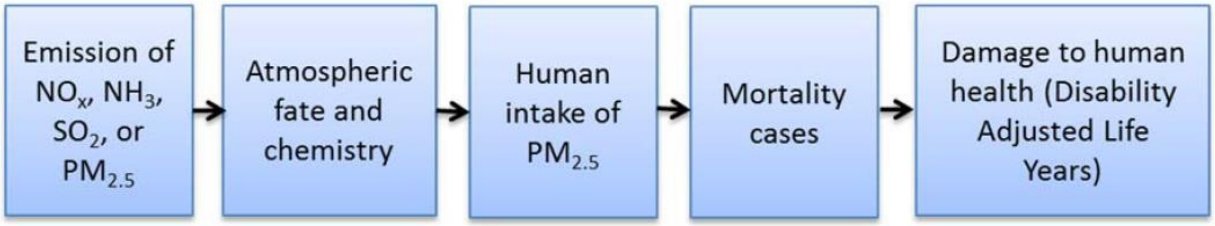

Figure 3. Cause-and-effect chain, from fine dust formatting emissions to damage on human health (National Institute for Public Health and the Environment, 2016)

Apte et al. (2015) found that of the 3.2 million annual deaths globally attributed to ambient $PM_{2.5}$ pollution, mortality risks increase with concentration. They concluded that modest improvements in $PM_{2.5}$ in relatively clean regions like North America would lead to a surprisingly large decrease in mortality.

Cardiovascular Disease-Related Mortality

Furthermore, we investigated the impact on air pollution-induced mortality based on the findings from the ‘Harvard Six Cities’ study (Dockery, 1993) and its extended follow-up (Lepeule, 2012). We modeled the cardiovascular disease-related increase at 0.9% per unit of air pollution (1 $\mu g/m^3$) and excluded lung cancer-related deaths in this analysis. We extracted background particulate matter concentration data from Brauer, et al. (2012), and the fraction that is inhaled by humans (intraurban intake fraction, iF) from Apte, et al (2012). We used the iF of Poughkeepsie to evaluate Hudson Valley fossil plants, and that of New York-Northern New Jersey-Long Island for Metro NYC plants. We determined the population within a 25-mile radius of each fossil generating region (CPV Valley, Cricket Valley, and Metro NYC) and prorated the background cardiovascular disease-related deaths to this population (NYC Dept of Planning, n.d.). The population for Metro NYC is the average for each borough/town weighted by 2019 fossil generation. We determined the number of annual deaths based on the changes in particulate pollution from the ReCiPe model.

Radionuclide Exposure

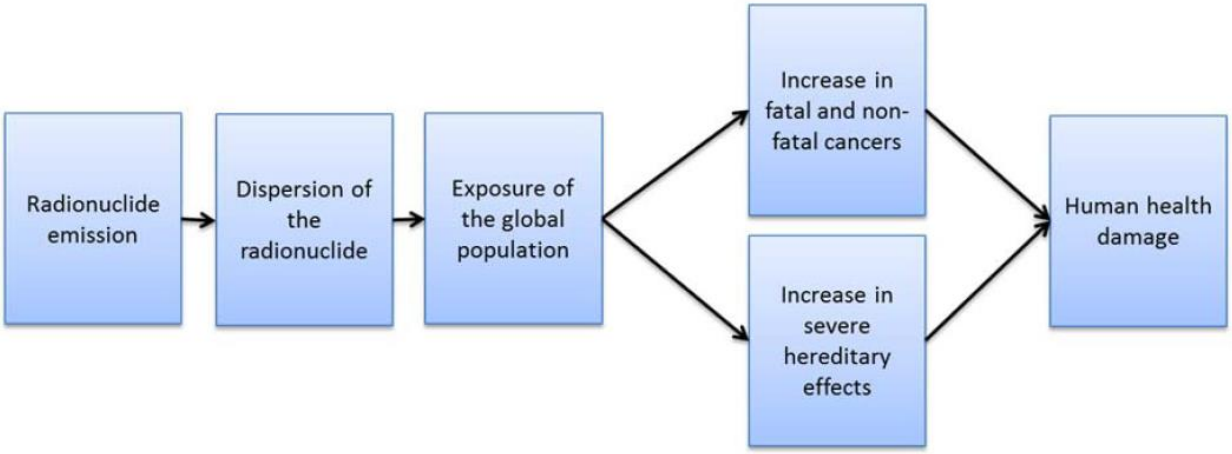

Figure 4. Cause-and-effect chain, from an airborne or waterborne emission of a radionuclide to damage to human health (National Institute for Public Health and the Environment, 2016)

Anthropogenic emissions of radionuclides are generated in the nuclear fuel cycle (mining, processing, and waste disposal), as well as during other human activities, such as the burning of coal and the extraction of phosphate rock (National Institute for Public Health and the Environment, 2016). Ionizing radiation impacts human health via increased incidence of cancers and severe hereditary effects (Figure 4, De Schryver et al., 2011; Frischknecht et al., 2000). However, the commonly applied “linear non threshold” theory for health impacts of radiation is contested (Sacks et al., 2016). Unlike with particulate pollution, due to life evolving with much higher background radiation levels, exposure needs to be acute to trigger a human health impact. Due to in-built cell repair mechanisms, radionuclide exposure impacts are not cumulative, and linear extrapolation may be flawed. We have not corrected for these possible distortions.

3.3 Climate Change

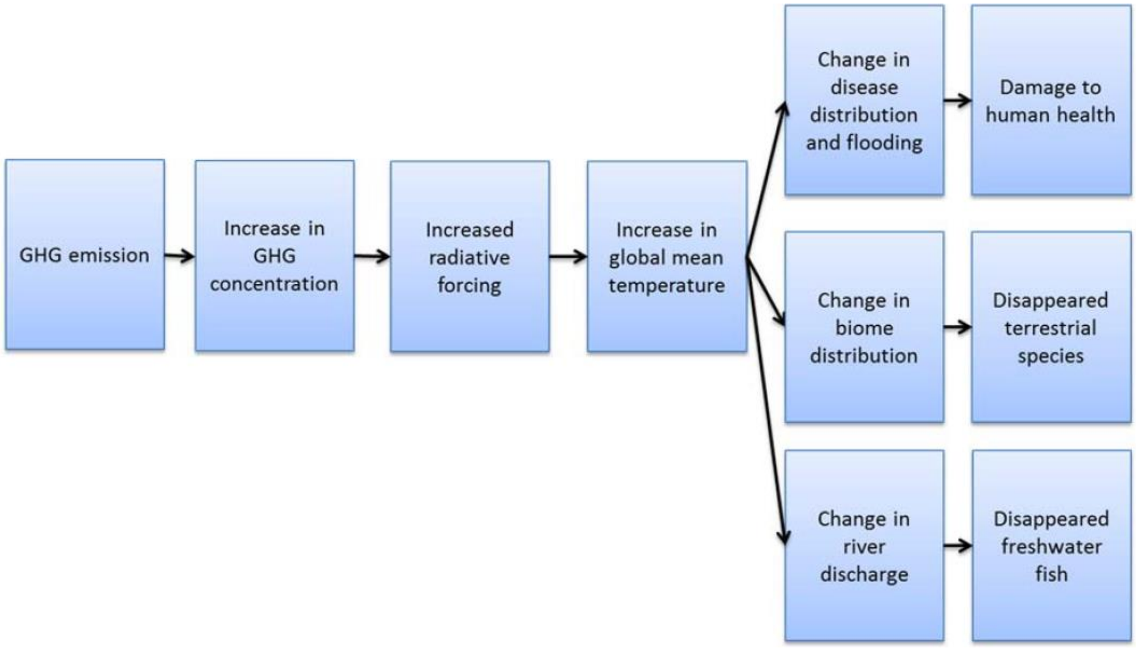

Figure 5. Cause-and-effect chain from greenhouse gas emissions to human health damage and relative loss of species in terrestrial and freshwater ecosystems (National Institute for Public Health and the Environment, 2016)

The climate change impact of each greenhouse gas is based on its global warming potential via infrared radiative forcing (Figure 5). The ReCiPe method assesses the cumulative impact over a 100-year timeframe (GWP_{100}). Further, we conduct sensitivity analysis of the 20-year impact (GWP_{20}), as envisioned by New York's CLCPA (Friedlander, 2019) using the methodology from Appendix B.

Damages to human health from global warming are quantified along increased disease and malnutrition (National Institute for Public Health and the Environment, 2016).

3.4 Ecosystem Impact

The unit for ecosystem quality impact is the loss of species over a certain area, during a certain time (species year) (National Institute for Public Health and the Environment, 2016). We do not place a monetary value on this impact here, since life-cycle impact assessments rarely do so (Winter et al., 2017).

3.5 Estimate of Impact to Human Health

We use the ‘value of a life year’ (VOLY) method to estimate the human health damage (Desaigues et al., 2011). A survey of nine comparable European countries demonstrated citizens’ willingness to pay €40,000 to extend life expectancy by one year (sensitivities €25,000 and €100,000). We multiply this ‘contingent valuation’ by DALY, along with a 1.1 EUR:USD exchange rate.

We also provide an alternate estimation of the damage to human life from cardiovascular mortality adjusting EPA’s Statistical Value of Life for inflation (EPA, n.d.).

3.6 Estimate of Impact due to Climate Change

We use the ‘social cost of carbon’ (SCC) method to quantify the damage of climate change (Interagency Working Group on Social Cost of Greenhouse Gases, 2016; Keck, 2015), consistent with NYISO’s carbon pricing proposal (NYISO, 2018b). SCC models measure changes in economic activity due to climate change. Most damage functions, largely constructed without public health research input, do not directly estimate any specific type of health impacts (Scovronick et al., 2019). Given the minimal overlap between SCC and human health burden of climate change (Diaz & Moore, 2017), we treat impacts outlined in §3.2 and §3.5 as distinct from §3.6.

New York is part of the ten-state ‘Regional Greenhouse Gas Initiative,’ an electricity sector cap-and-trade system, which already prices carbon. To calculate the unpriced social cost of carbon, we subtract the latest auction price of $5.65 per U.S. ton (Regional Greenhouse Gas Initiative, n.d.) from NYISO proposal’s average price of $47.80 per U.S. ton over 2020 and 2021.

We do not include the other main area of protection considered in the ReCiPe life-cycle impact analysis, resource scarcity. The depletion of finite fossil fuels, high-grade uranium deposits, iron ore for wind turbines and other resources does have a long-term impact on sustainability. However, such impacts are beyond the scope of this analysis.

4. Results

4.1 Climate Change Impact Due to the Switch

Table 2 shows the GHG emission changes associated with the electricity sector shifts in Table 1 under the two scenarios from §3.1.

Change in annual GHG emission from Lower Hudson Valley electricity mix shift 2018-2022			**million (metric) tonnes CO_2e per year**		
(Scenario A) Current trajectory without Indian Point		Gigawatt-hours	ReCiPe GWP_{100}	GWP_{20} 2.3% leak rate	GWP_{20} 3.5% leak rate
p	- Indian Point	(16,695)	(0.2)	(0.2)	(0.2)
s	+ Solar	3,154	0.1	0.1	0.1
t	+ Fossil Fuels	9,388	6.4	7.1	8.7
$a = p + s + t$	**Scenario A Total**		**6.4**	**7.1**	**8.7**
(Scenario B) Alternate possibility with Indian Point					
v	+ Solar	3,154	0.1	0.1	0.1
w	- Fossil Fuels	(7,306)	(5.0)	(5.5)	(6.8)
$b = v + w$	**Scenario B Total**		**(4.8)**	**(5.4)**	**(6.7)**
$a - b$	**Scenario A – Scenario B**		**11.2**	**12.5**	**15.4**
	+ Fossil Fuels	16,695			

Table 2. Climate change sensitivity to evaluation timeframes and methane leak rates

4.2 Human Health and Environmental Impacts Due to the Switch

	Human Health Annual Change in DALY		**Ecosystem Damages** Annual Change in Species Years	
	100-years	20-years	100-years	20-years
Scenario A	23,028	15,840	41.6	22.3
Scenario B	(3,797)	(1,467)	(12.4)	(7.1)
Scenario A - Scenario B	**26,826**	**17,307**	**54.0**	**29.5**

Table 3. Human health impact comparison

Over a 100-year timeframe, Scenario A has a 26,826 worse DALY than Scenario B (Table 3). The highest impact category is particulate matter pollution (46%), followed by climate change (39%), offset by a minor benefit from ionizing radiation (-1%). Over a 20-year timeframe, closing IP increases DALY by 17,304, with particulate pollution responsible for most (71%).

Over a 100-year timeframe, Scenario A has a higher ecosystem damage of 54.0 species years vs. Scenario B (Table 3). The biggest impact is from climate change (58%), followed by terrestrial acidification (38%), offset by a minor improvement in water depletion (-1%). In a 20-year timeframe, closing IP induces the regional species extinction to increase by 29.5 species years, with terrestrial acidification being the main cause (71%).

The annual human cost of air-pollution from electricity generation shift (from IP to fossil plants) is outlined in Table 4. New York could be closing fossil plants that cause air pollution, especially in population-dense Metro NYC areas. Instead, by expanding fossil generation, 325 more lives will be annually lost to cardiovascular diseases.

4.3 Cardiovascular Mortality Impacts Due to the Switch

Change	GWh per year	Population within 25mi^2 (000s)	Back-ground CVD deaths/a	PM$_{2.5}$ change (ug/m^3)	CVD mortality change per annum	Economic value lost due to CVD mortality ($m/a)
- Indian Point	(16,695)	2,087				
+ CPV Valley	3,106	551	1,337	+4.0	+47.7	452
+ Cricket Valley	6,706	592	1,437	+8.6	+110.8	1,049
+ Metro NYC Plants	6,883	13,131	31,860	+0.6	+166.9	1,580
Total	**16,695**		**34,634**		**+325.4**	**3,081**

Table 4. Annual cardiovascular disease (CVD)-related deaths

5. Discussion

On a unit of electricity basis, air pollution-related mortality rates (of switching from nuclear to gas) derived in this study are higher than estimated by others (Kharecha & Hansen, 2013; Kharecha & Sato, 2019; Markandya & Wilkinson, 2007). Unlike these country-level studies, our bottom-up analysis accounts for the population density, background air pollution levels, and cardiovascular disease burden. The extraordinarily high population density within Metro NYC exposes many residents around fossil electricity plants to air pollution (Table 5).

	CVD mortality per megawatt hour	Population exposed (000s)	Population density (people per m^2)	Note on density
CPV Valley	15.4	551	281	(calculated)
Orange County		*382*	*471*	
Cricket Valley	16.5	592	302	(calculated)
Dutchess County		*294*	*369*	
Litchfield County, CT		*181*	*369*	
Metro NYC Plants	24.2	13,131	6,688	(calculated)
Queens County		*2,299*	*21,000*	
Union County, NJ		*553*	*5,425*	
New York County		*1,632*	*71,900*	
Kings County		*2,601*	*37,000*	
Richmond County		*474*	*8,185*	
New York			420	(reference)
U.S.			87	(reference)

Table 5. Population density & mortality from methane electricity generation (NYC Dept of Planning, n.d.)

The background air pollution in North America has been decreasing with over time (Harvard University, n.d.), which likely decreased the background CVD deaths presented in §4.3. However, particulate pollution also exacerbates COVID-19 mortality to the tune of 8% per unit of $PM_{2.5}$ air pollution (1 $\mu g/m^3$) (Xiao, et. al., 2020). We have not treated for these complications.

We apply the VOLY from Europe to all DALY damages. A systematic review of 120 studies on the value of statistical life year found the median VOLY to be €165,000, or 6.4 times GDP/capita (Schwarz et al., 2017). This survey found the North American median VOLY to be €272,000. However, DALY damages due to climate change are spread throughout the world. Lancet Commission on Investing in Health found the value of increased life expectancy to be 2.3 times GDP per capita for low- and middle-income countries (Jamison et al., 2013).

5.1 Nuclear Safety

Most perceived threats of IP (earthquakes, terrorism, explosion of a nearby gas pipeline) stem from the notion that “20 million people within a 50-mile radius of the plant will be threatened / need to be evacuated in case of an accident” (Cuomo, 2017; Kennedy, 2020; NRDC, 2011). There is little rational or scientific merit to this claim (NRC, n.d.-a; Specter, 2019). In the unlikely event of a nuclear meltdown at IP, only a 2-mile to 5-mile evacuation zone would be required – not 50 (NRC, n.d.). Food within a 50-mile radius needs to be sampled for safety.

As in Kharecha & Hansen (2013), we do not weigh probabilities of nuclear power related that cannot meaningfully be quantified due to very large uncertainties. Risks of an extremely low-probability nuclear accident (UNSCEAR, 2013, p. 19) need to be balanced against documented health effects associated with outdoor air pollution.

5.2 The Cost of Fear

Area of Protection		**Low** 100-year	**Mid** 20y, 2.3% leak rate	**High** 20y, 3.5% leak rate	**High Leaks, Human Mortality**
Human Health (HH)	Value of Life Year (VOLY)	€25,000	€40,000	€100,000	$9.47 million per life
	Cost (billion USD)	0.74	0.76	1.90	3.08
	HH Cost (USD/MWh)	$44	$46	$114	$185
Climate Change (CC)	GWP of gas-based electricity (grams CO_2e per kWh)	684	758	932	932
	Emissions increase (Mt CO_2e)	11.2	12.5	15.4	15.4
	Cost @ $46/tonne CO_2e (billion USD)	0.52	0.58	0.70	0.70
	CC Cost (USD/MWh)	$31	$35	$42	$42
Total	Cost (billion USD)	1.26	1.34	2.60	3.78
	HH+CC Cost (USD/MWh)	$75	$80	$156	$226
	Cost (billion USD)	0.74	0.76	1.90	3.08

Table 6. Human health and climate change cost sensitivities (total and per-unit)

5.3. A Brighter Future

Nuclear power has the highest energy density and the lowest ecological footprint per unit of power generation (McDonald et al., 2009; U.S. Dept of Energy, 2017). Out of all sources of reliable electricity, nuclear is the lowest-carbon (Appendix B) and the safest (Markandya & Wilkinson, 2007; Sovacool et al., 2016) option. By preventing fossil fuel electricity generation from 1971 to 2009, nuclear power has prevented 1.8 million premature deaths worldwide (Kharecha & Hansen, 2013).

While we do not know the revenue threshold that makes IP profitable, maintaining existing U.S. NPPs is one of the lowest-cost means to prevent GHG emissions (Figure 1). Just as NYS is contracting offshore wind far above the marginal cost of electricity (Figure 1), it can decide to reward IP for its societal benefits.

Keeping IP operational would generate a ‘societal benefit’ ranging from $75/MWh to $226/MWh, far above wholesale electricity prices ($28/MWh NYC in 2019, Figure 1). Plant closure can be postponed by attracting a willing operator by rewarding the enterprise for its environmental characteristics, as the state does with all other low-carbon resources, including upstate NPPs (Knauss, 2016). The price of Zero Emission Credits for upstate NPPs in 2019 was $20/MWh (NYSERDA, n.d.). Similarly, incentivizing IP has a societal benefit-to-cost ratio ranging from 3.8 to 11.6 (Table 7).

Benefit-Cost Calculator	Low	Mid	High	High+Mortality
Societal Benefit (Benefit) $/MWh	75	80	156	226
Zero Emission Credit (Cost) $/MWh	20	20	20	20
Benefit/Cost Ratio	3.8	4.1	8.0	11.6

Table 7. Benefit-Cost Calculator

Fossil-fired generators in the densely populated metro NYC region are mostly located in environmental justice areas (*Comments of Rachel Spector, Director of the Environmental Justice Program, New York Lawyers for the Public Interest before the New York City Council Committee on Environmental Protection February 11, 2019 Regarding Intro 1318*, 2019; Strategen Consulting, 2017; NYSDEC, n.d.). Curtailment of generation from these plants has social justice benefits beyond those outlined above.

Policy decisions that are based on holistic, evidence-based analyses benefit society greatly. Those that do not have severe inadvertent consequences.

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Appendix A: New York's Electricity Grid and Indian Point

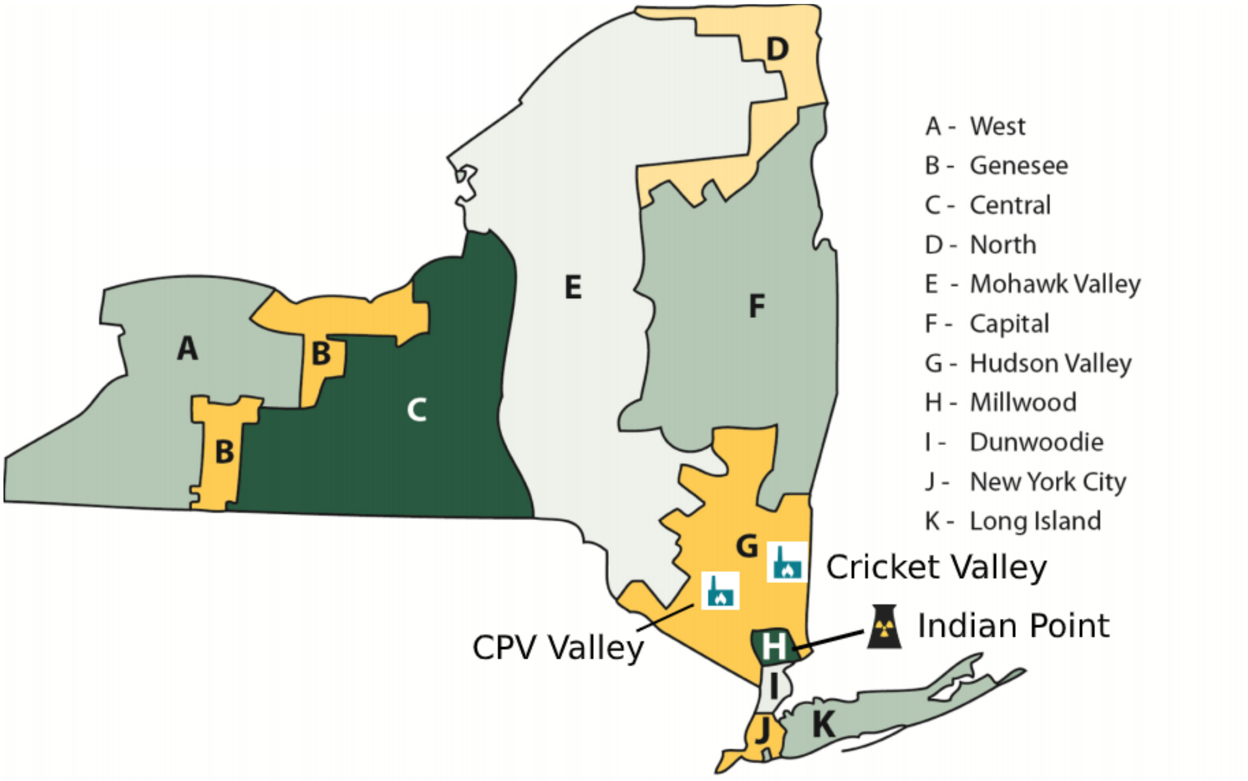

Figure 6. NYCA Load Zones and Power Plants of Interest (NYS Energy Planning Board, 2012)

Upstate A-E. Downstate F-K. Lower Hudson Valley G-J.

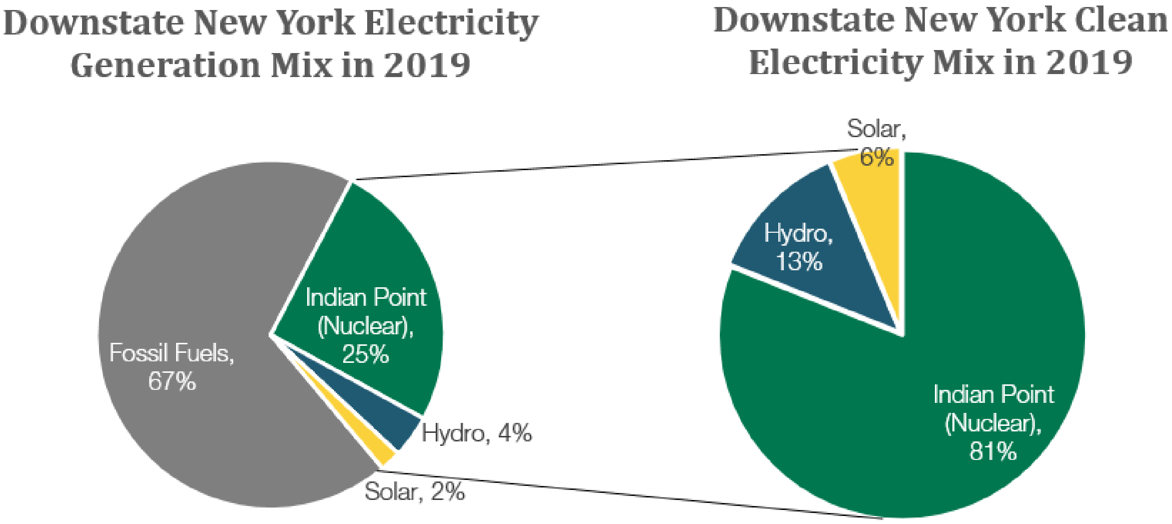

Figure 7. IP's significance to electricity in downstate New York, including behind-the-meter solar (NYISO, 2020a, 2020b)

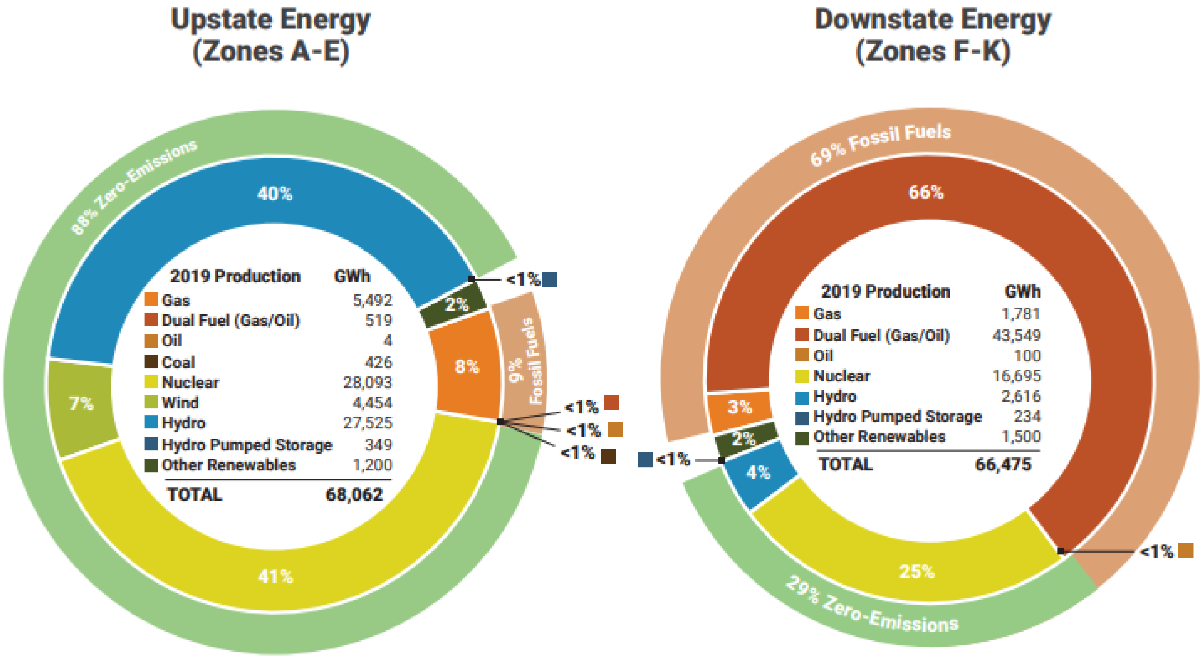

Figure 8. Electricity generation by type - upstate vs. downstate (NYISO, 2020b)

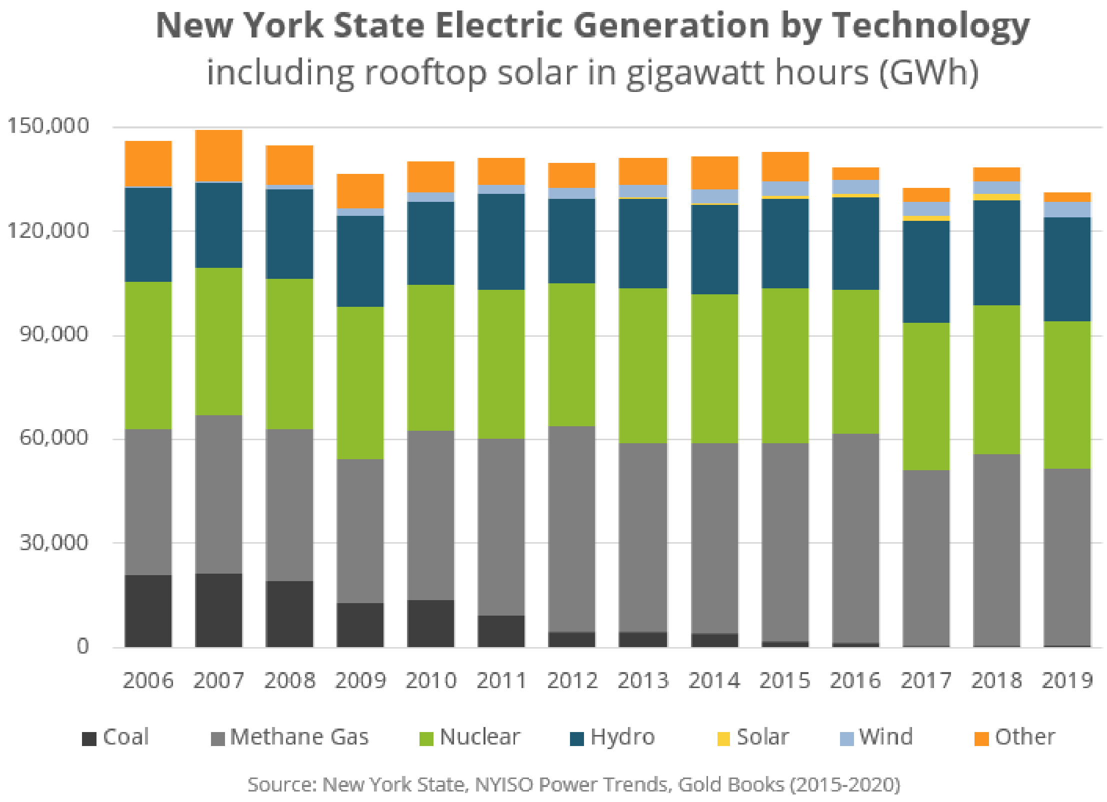

Figure 9. New York electricity generation evolution (Open Data NY, 2020; NYISO 2018a, 2019a, 2020a)

Between 2006 and 2019, the share of New York VRE (wind and solar) went from 0.5% to 4.8% (Figure 9). Methane gas-based generation grew from 29% to 38%. Total in-state consumption (including imports) remained steady through this period due to efficiency improvements.

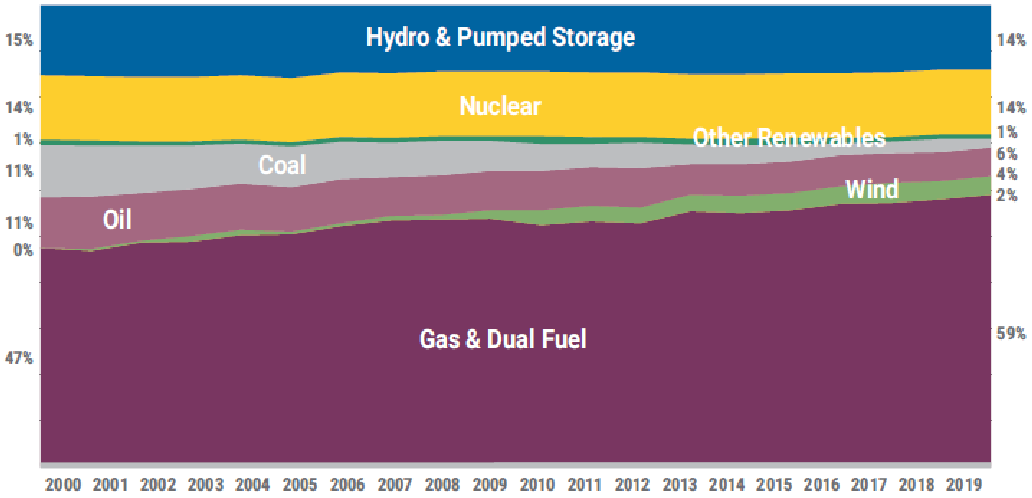

Figure 10. New York bulk electricity capacity mix evolution (NYISO, 2019b)

The portion of New York's generating capability from methane gas and dual-fuel facilities grew from 47% in 2000 to 62% in 2019, as coal declined from 11% to 1%. Wind capacity – virtually non-existent in 2000 – grew to nearly 4.5% by 2019 (NYISO, 2019a, 2020b).

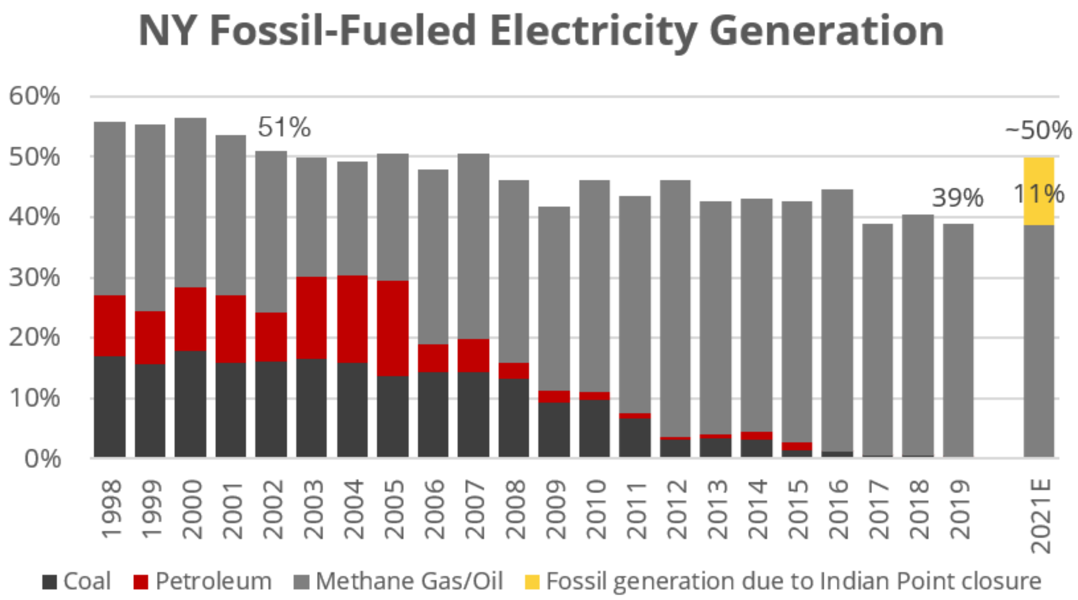

Figure 11. Fossil share of New York electricity generation

New York's fossil share of electricity generation is to revert to 2002 levels with IP's closure.

Appendix B: Greenhouse Gas Emissions

			Emissions (grams per kWh)			
		Methane Leak Rate	**CO_2**	**CH_4**	**CO_2e 100y**	**CO_2e 20y**
CH_4 Global Warming Potential (vs. CO_2)[1]			1		34	86
U.S. Methane Gas (Combined Cycle Gas Turbine)	EPA	1.4% [2]	436 [3]	2.3	513	630
	EDF	2.3% [4]	436	3.7	563	758
	Shale	3.5% [5]	436	5.8	632	932
ReCiPe						
Methane Gas					684	
Solar Photovoltaic		*variable (requires grid storage/gas backup)*			*47*	*47*
Nuclear					13	13
Wind		*variable (requires grid storage/gas backup)*			*11*	*11*
Hydro					4	4

Table 8: CO_2+CH_4 emissions per unit of electricity

GWP$_{100}$ (in grams CO_2e per kWh) from ReCiPe (National Institute for Public Health and the Environment, 2016) are deemed similar for Solar Photovoltaic, Hydro, Nuclear, and Wind. In Table 8, we calculate what global warming potential these technologies have over a 20-year time-frame at various methane leak rates.

Notes:

1. On a gram-for-gram basis, methane's global warming potential is 34x that of carbon-dioxide over a 100-year timeframe, rising to 84x in a 20-year time horizon (IPCC, 2018). New York's CLCPA defines the CO_2-equivalency of other GHGs on a 20-year timeframe (Friedlander, 2019).
2. U.S. methane leakage estimates exceed EPA's 1.4% in EDF survey's 2.3% average (EDF, 2018).
3. Combined-cycle gas turbine (CCGT) plants emit 436 g CO_2 per kWh (de Gouw et al., 2014).
4. (See note 2)
5. Fracture stimulated gas from shale fields leak/vent/flare 3.5% of extracted resources (Howarth, 2019). Most gas used in New York fossil fuel plants come from Marcellus/Utica fields in Pennsylvania.