Potential Human Health Impacts Associated with Retirement of Nuclear Power Plants in Illinois

April 14, 2021

Executive Summary

On August 26, 2020, Exelon announced its intention to retire two of its nuclear power plants in Illinois (Byron and Dresden Generating Stations). In October 2019 Clean Air Task Force (CATF) released an analysis of the significant health impacts that would result from the loss of four nuclear plants. At the time, CATF also analyzed the impacts of the loss of two nuclear plants but did not report those results as their loss was encompassed within the more comprehensive analysis. Given the relevance of the two plant results, CATF has updated its 2019 report accordingly.

Using proven US EPA modeling tools CATF has determined that loss of zero emission generation from the retirement of two or four nuclear power plants in Illinois would result in the following cumulative health-related impacts and costs over a ten-year period:

Four Plants

- $10 to $24 billion ($1 to $2.4 billion per year) in monetized damages due to increased air pollution;
- Between 1,200 to almost 2,700 premature deaths;
- Almost 140,000 work loss days;
- Over 30,000 additional asthma attacks and other respiratory symptoms leading to limited daily activities.

Two Plants

- $4.4 to $10 billion ($0.4 to $1 billion per year) in monetized damages due to increased air pollution;
- Between 500 to 1,100 premature deaths;
- Almost 57,000 work loss days;
- Over 13,000 additional asthma attacks and other respiratory symptoms leading to limited daily activities.

Introduction

This study quantifies the potential health impacts and costs that would be associated with shifting power generation from zero emission nuclear plants in Illinois (Byron, Dresden, Braidwood, LaSalle)[1] to the generation that would replace them, primarily fossil fuel generation. The analysis relies on emissions data provided by The Brattle Group based on its modeling analysis of the power sector simulating these plant retirements and using the US EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool v3.1 (COBRA). COBRA estimates changes

---

[1] Plants not covered by the 2016 Future Energy Jobs Act (FEJA). More details can be found in The Brattle Group (2019), "The Impacts of Illinois Nuclear Power Plants on the Economy and the Environment".

in ambient $PM_{2.5}$ concentrations due to changes in air pollution emissions[2] and subsequently calculates and monetizes the associated health impacts. Public health impacts from ozone, nitrogen oxides, or hazardous air pollution are not considered. Over the next decade, the model predicts as many as 2,700 additional deaths and other adverse health effects could occur, resulting in monetized damages of $10 to $24 billion[3] due to increased pollution from fossil fueled power plants operating to offset the closure of four Illinois nuclear facilities. The impact of closing two of the four facilities (Bryan and Dresden) yields about half the impact, with up to 1,100 addition deaths over a decade. These results compare favorably with a similar study conducted by University of Washington researchers that analyzed air quality and health impacts of nuclear facility closures in Ohio and Pennsylvania.[4]

Fossil-fueled power plants significantly contribute to air pollution by emitting gases affecting climate (carbon dioxide) and environmental health (sulfur dioxide (SO_2) and nitrogen oxides (NOx)), along with other pollutants including fine particulate matter ($PM_{2.5}$). Meeting the environmental goals of states and the nation requires effective policies to reduce or eliminate the harmful emissions from this sector. For two decades, the Clean Air Task Force has assessed the human health impacts attributable to particle pollution from power plant emissions.

Results

COBRA uses the predicted changes in total $PM_{2.5}$ to determine changes in various human health effects. The changes are based on projected population and incidence rates for 2025 and relies on a standard set of health endpoints routinely used in EPA regulatory analyses. The endpoints include premature mortality, non-fatal heart attacks, asthma exacerbation (attacks), emergency room visits, hospital admissions (respiratory and cardiovascular), acute bronchitis, upper and lower respiratory symptoms, minor restricted activity days and work loss days.

State	Premature Mortality	Non-Fatal Heart Attacks	Asthma Exacerbation	Minor Restricted Activity Days	Work Loss Days
Pennsylvania	12-28	1-13	255	6,882	1,157
Ohio	12-27	1-14	283	7,173	1,206
Illinois	10-24	2-15	299	7,879	1,329
New York	10-24	1-11	279	7,824	1,323
New Jersey	8-17	1-9	206	5,750	968
Michigan	7-17	1-9	179	4,692	789
Indiana	6-13	1-8	167	4,090	689
Maryland	4-9	0-4	112	3,000	507
Virginia	4-9	1-5	116	3,148	531
Wisconsin	4-8	0-4	103	2,600	437
National Total	120-270	15-143	3,118	81,928	13,807

Table 1a. Four Facility Impact. Annual COBRA health results for 2020-29 for Top Ten states. Ranges shown for premature mortality are from Krewski (2009) and Lepeule (2012) and non-fatal heart attacks from a collection of four AMI studies and Peters (2001).

[2] PM2.5 is emitted directly and is also formed in the atmosphere from emissions of gaseous pollutants like SO_2 and NOx.
[3] COBRA monetized results were calculated for 2025 using the unit values as described in the appendix.
[4] Tessum and Marshall (2019) Air quality and health impacts of potential nuclear electricity generator closures in Pennsylvania and Ohio. https://depts.washington.edu/airqual/reports/Nuclear%20Replacement%20Air%20Quality.pdf

State	Premature Mortality	Non-Fatal Heart Attacks	Asthma Exacerbation	Minor Restricted Activity Days	Work Loss Days
Illinois	6 - 13	1 - 8	167	4,407	743
Ohio	4 - 10	1 - 5	103	2,604	438
Michigan	4 - 9	1 - 5	94	2,454	413
Pennsylvania	3 - 8	0 - 4	68	1,840	309
New York	3 - 8	0 - 4	89	2,499	422
Indiana	3 - 7	0 - 4	93	2,279	384
New Jersey	2 - 5	0 - 3	66	1,850	311
Wisconsin	2 - 5	0 - 2	56	1,421	239
Tennessee	2 - 4	0 - 3	51	1,314	221
Missouri	2 - 4	0 - 2	47	1,177	199
National Total	49 - 111	6 - 60	1,302	33,805	5,696

Table 1b. Two Facility Impact. Annual COBRA health results for 2020-29 for Top Ten states. Ranges shown for premature mortality are from Krewski (2009) and Lepeule (2012) and non-fatal heart attacks from a collection of four AMI studies and Peters (2001).

Primary health-related impact results are presented in Tables 1a and 1b. The tables includes the ten most impacted states for both cases along with the national totals. Note the imperfect correspondence between the states that had the greatest emission changes and the states that would have the largest increase in health effects. This reflects the combined effect of where people live and the movement of pollution downwind from sources. **Based on the analysis for four nuclear plant closures, each year hundreds of people would die prematurely due to increases in pollution from the power sector. People would also suffer thousands of additional asthma attacks, many days where daily activities would be limited and missed workdays. The results for two plant closures have impacts somewhat less than half that of the four plant case, along with some shifts in the states bearing the worst impacts.**

Discount Rate	Estimated annual economic costs (2010$ billions)	
	Two Facilities	Four Facilities
3%	$0.44 to $1.00	$1.07 to $2.40
7%	$0.39 to $ 0.90	$0.96 to $ 2.17

Table 2 COBRA estimated annual economic cost for health impacts

In addition to health effects, COBRA generates an economic cost for each health endpoint[5]. The valuation is expressed as a present value in 2010$ based on a user-specified discount rate of 3 or 7%. The potential costs associated with this study cover a range based on the discount rate and set of studies chosen for premature mortality and non-fatal heart attacks; roughly 99% of the costs are associated with premature mortality. Using the 7% discount rate, costs range from $0.96 to 2.17 Billion for the four plant case and $0.39 to 0.9 Billion for the two plant case. Using a 3% discount rate has costs from $1.07 to 2.40 or $0.44 to 1.0 Billion for the four and two plant closure cases, respectively.

[5] More details can be found in the COBRA manual Appendix F and in the appendix of this report. www.epa.gov/sites/production/files/2018-03/documents/cobra_user_manual_february_2018_508.pdf

State	Sulfur Dioxide	Nitrogen Oxides	PM2.5
Illinois	7,033 (28%)	5,830 (29%)	747 (33%)
Michigan	3,297 (13%)	2,219 (11%)	82 (4%)
Ohio	2,278 (9%)	1,399 (7%)	123 (5%)
Louisiana	2,153 (9%)	879 (4%)	40 (2%)
Indiana	2,040 (8%)	1,905 (9%)	241 (11%)
Pennsylvania	1,632 (7%)	1,392 (7%)	201 (9%)
Minnesota	1,356 (5%)	1,448 (7%)	105 (5%)
West Virginia	1,240 (5%)	1,060(5%)	142 (6%)
Wisconsin	560 (2%)	1,058 (5%)	149 (7%)
Iowa	572 (2%)	531 (3%)	93 (4%)
Net Total	24,745	20,392	2,293

Table 3a Decade average annual emissions changes for 2020-29 of top 10 states tons per year (TPY) from retirement of four Illinois nuclear plants

State	Sulfur Dioxide	Nitrogen Oxides	PM2.5
Illinois	4,555 (40%)	3,560 (33%)	437 (39%)
Louisiana	1,986 (17%)	771 (7%)	24 (2%)
Michigan	1,541 (13%)	961 (9%)	26 (2%)
Indiana	988 (9%)	1,198 (11%)	148 (13%)
Missouri	659 (6%)	290 (3%)	23 (2%)
Pennsylvania	615 (5%)	641 (6%)	80 (7%)
Minnesota	614 (5%)	579 (5%)	50 (4%)
North Dakota	396 (3%)	232 (2%)	8 (1%)
Ohio	357 (3%)	220 (2%)	20 (2%)
Wisconsin	329 (3%)	594 (6%)	98 (9%)
Net Total	11,446	10,690	1,111

Table 3b Decade average annual emissions changes for 2020-29 of top 10 states tons per year (TPY) from retirement of two Illinois nuclear plants

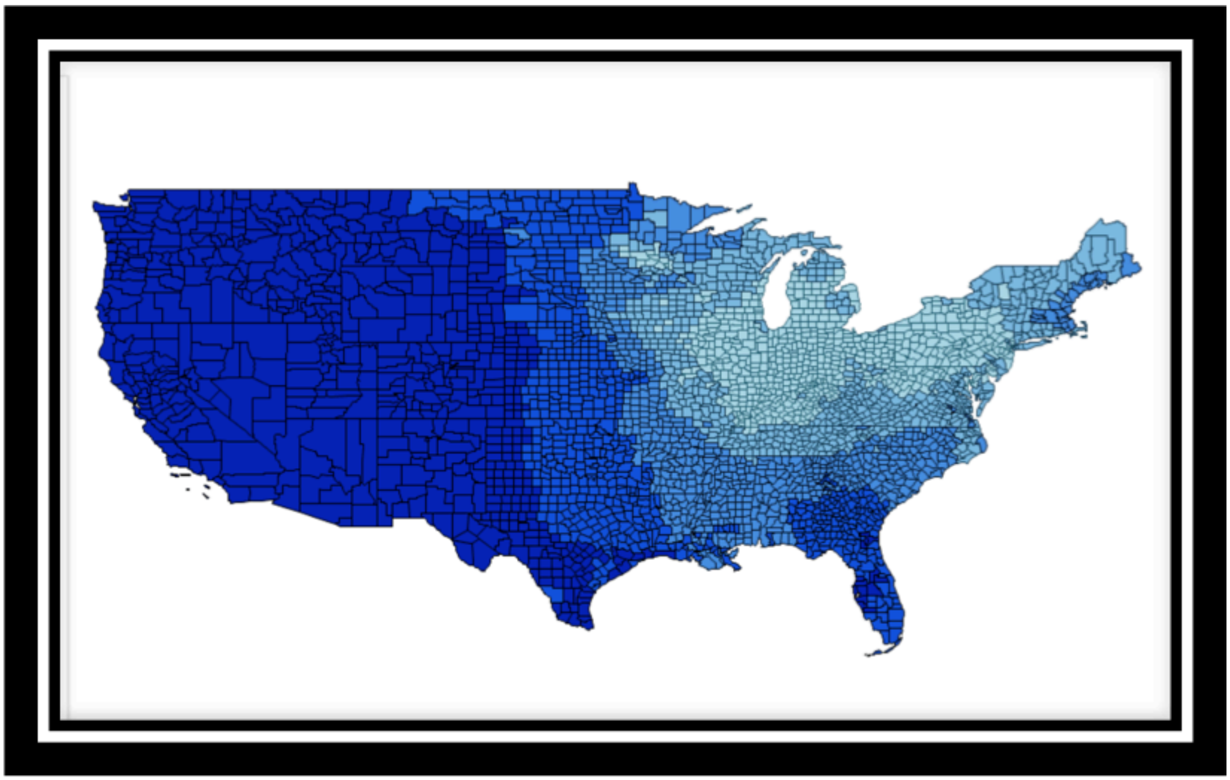
The emissions used for the COBRA analysis are based on results from The Brattle Group, who conducted an analysis of the power sector. Their study consisted of a reference scenario that included generation from four nuclear power plants in Illinois and two cases (1) no nuclear generation from the four facilities and (2) no generation from two facilities (Byron and Dresden). Over the decade 2020-29 the loss of these zero emission plants would lead to a power generation shift to other facilities, primarily fossil generators, with concomitant changes in SO_2, NO_x and $PM_{2.5}$ emissions (Tables 3a and 3b). From Table 3a, generators in ten states accounted for nearly 90% of the modeled net emission increases, with small decreases in Texas and Oklahoma. Small increases were projected for Canadian sources, but these were not modeled by CATF. A somewhat different mix of generation changes were modeled in the two plant scenario, with a modest decrease in emissions in Maryland.

CATF created input files for 2025 that included the base (reference) and two control (no nuclear generation from the four or two designated facilities) emissions as modeled by the Brattle Group for the power sector. Emissions for other sectors remained constant as projected to 2025 by US EPA from its 2011 National Emissions Inventory. Refer to the methods section for more details. The emissions were input to COBRA to determine the health impacts and monetized benefits reported above.

The increased emissions resulted in modest predicted increases in $PM_{2.5}$ across the nation (Figure 1). As expected, the largest impacts on $PM_{2.5}$ of the emissions changes were predicted to occur in the Midwest in the states outlined in Table 1.

Figure 1 COBRA estimated $PM_{2.5}$ change (four plant case). Dark to light scale from low to high change. Highest increases in $PM_{2.5}$ correspond closely to where emission increases were greatest (Midwest)

Or



Conclusion

CATF's analysis finds significant health and associated economic impact from the loss of zero emission nuclear plants in Illinois. As expected, air pollution related health effects would increase more if four nuclear facilities were to close than two. This leads to social, personal and economy-wide consequences for the citizens of Illinois and surrounding states that could be avoided if nuclear plants in Illinois continue to operate.

Appendix

Methodology

COBRA was developed by US EPA as a simple screening tool to help users understand the relative importance of different major source classes of emissions on particulate pollution and the associated health impacts. The model allows for simple adjustments of emissions of five pollutants (NOx, SO_2, $PM_{2.5}$, NH_3 and VOC) by geography and source category, providing insights into the costs and benefits associated with adjustments in emissions (control strategies).

The latest version of COBRA permits users to directly input emissions in addition to its previously available graphical user interface for emissions modification. For this project, CATF took emissions outputs from the Brattle Group for the power sector and customized the baseline and control emissions inputs for this sector for 2025. The analysis relied on default settings for the health analyses, as these represent standard procedures and functions US EPA relies on for its regulatory analyses.

The existing 2025 emissions baseline in COBRA was developed by EPA and represents a projection from the 2011 National Emission Inventory and accounts for federal and state measures promulgated by December 2014. CATF created a baseline and control emissions input file that kept emissions of all sources and pollutants constant except for the electricity generating sector. For this sector, CATF relied on a future baseline and control scenario as supplied by the Brattle Group. Input for this sector followed a two step process as described next.

First, CATF compared the ptegu_2025.xls file EPA created for its modeling inventory of the electricity generating sector with the emission inputs in the baseline 2025 COBRA file. For point sources like EGUS, COBRA identifies the location of each source and the effective stack height (low, medium, high). Generally, each high stack has its own emission line, while medium and low emission stack sources are grouped at the county level by source (Tier 2 [Coal, Natural Gas, Oil, Other]; Tier3 [Coal Type, Oil Type, Gas type]). For each emission input line, CATF recorded the details of the corresponding emission sources (e.g. ORIS ID, Unit ID, Stack ID)

Next, CATF matched the baseline and scenario emissions from the Brattle emissions file to the input lines of the COBRA emissions file. The Brattle file contained emissions of SO_2, NOx and $PM_{2.5}$ from the Eastern Interconnection. The emissions were projected averages for the period 2020-29, including projected new builds with no identifying location beyond a state. In the states fully covered by Brattle, CATF replaced the baseline and control emissions for SO_2, NOx and $PM_{2.5}$. No changes were made to NH3 or VOC as this information was not available. Since the emissions of these two pollutants from the power sector are small relative to other sources, leaving these emissions unchanged from the EPA 2025 projection should not materially impact the results of this study.

For states like Texas, Montana and New Mexico, which are not fully included in the Eastern Interconnection, CATF replaced COBRA county emissions available from the Brattle emissions file. For large emitting sources in counties not covered, CATF kept the emissions as projected by EPA. For new-build Brattle sources, CATF placed the location in the county with the greatest emission in the EPA 2025 baseline file for which no corresponding entry was available from existing sources in the Brattle file. These new sources were generally very small.

All sources with SO_2 emissions as reported by Brattle were included in the input file. However, hundreds of small sources (<100 pounds per year) of NOx and $PM_{2.5}$ were not mapped. In total, these sources summed to less than 5 and 3 TPY of emissions in the base case and their change was negligible. Since COBRA does not include Canada, changes were not modeled for those sources. They represented 0.2% and 1.1% of the overall projected changes from the Brattle emissions for NOx and $PM_{2.5}$, respectively.

CATF conducted two COBRA simulations for 2025, using a ten-year average emissions scenario (2020-2029) from the Brattle Group. Tables 1a, 1b and 2 in the report show the resulting health impacts and their valuation of these runs. Tables 3a and b summarize the average emission changes for the decade. In the executive summary, CATF reports estimates for the decade by multiplying the 2025 results by 10. This assumes that the average emissions and model results for 2025 reasonably capture results for each of the ten years. Valuation results will vary somewhat from year to year, but this change is modest and likely averaged out considering the valuation year is in the middle of the decade. From EPA's documentation, the unit valuation for mortality in 2010 dollars is $9.4 million in 2017 and $9.9 million in 2025. Premature mortality drives the total cost, and the baseline value of a statistical life will be lower than $9.9 million for the years 2020 through 2024 and greater than $9.9 million for the years 2026-2029, expressed in 2010 dollars.

The valuation procedures are outlined in the COBRA documentation. EPA describes the various methods for valuing the health functions, based on available studies. Generally, values are based on a statistical approach using relative risk reduction in a population and individual estimates of willingness to pay for a specific level of risk reduction. In some instances, the actual cost for treatment are used to estimate unit costs. EPA inflation-adjusted unit values to 2010$ using one of three indices, depending on the health endpoint: all goods index, medical cost index, or wage index.

The timing of health effects and the associated costs depend on the type of health incidence. For premature mortality, the deaths occur over twenty years beginning in the analysis year with costs discounted to present value. COBRA uses two different discount rates to bound its valuation for premature mortality, with EPA's recommended rate of 3% on one side and OMB's rate of 7% on the other. For heart attacks, the actual attacks occur in the year of analysis, but the associated costs extend into future years and are discounted accordingly. All other health effects occur in the analysis year and are valued in the same year (so no discounting is needed). The unit values used in this analysis are provided below.

Economic Values of Effects in 2025: Unit Values[6]

Health Incident Avoided	Economic Value ($2010)	
	3% discount rate	7% discount rate
Adult Mortality	$8,863,205	$7,894,316
Infant Mortality	$9,879,048	$9,879,048
Non-Fatal Heart Attacks	$33,259 - $263,795	$31,446 - $253,247
Hospital Admissions	$19,741 - $40,358	$19,741 - $40,358
Asthma ER Visits	$388 - $464	$388 - $464
Acute Bronchitis	$485	$485
Respiratory Symptoms	$21 - $34	$21 - $34
Asthma Exacerbations	$58	$58
Minor Restricted Activity Days	$69	$69
Work Loss Days	$160	$160

[6] Accessed May29, 2019 https://www.epa.gov/sites/production/files/2017-10/documents/how_cobra_works_september2017_508.pdf

	People	3% Discount Rate	7% Discount Rate
Total Health Benefits		1,074,399,000 - 2,427,331,000	958,536,000 - 2,164,838,000
Mortality	120-270	1,059,455,000 - 2,397,206,000	943,640,000 - 2,135,154,000
Infant Mortality	0.2	$ 2,047,000	
Nonfatal Heart Attacks	15-143	1,831,000 - 17,011,000	1,783,000 - 16,572,000
Acute Bronchitis	165	$ 80,000	
Asthma Exacerbation	3,118	$ 182,000	
Emergency Room Visits, Asthma	65	$ 28,000	
Hospital Admits, All Respiratory	37	$ 1,026,000	
Hospital Admits All Respiratory Direct	26		
Hospital Admits, Asthma	3		
Hospital Admits, Chronic Lung Disease	8		
Hospital Admits, Cardiovascular (except heart attacks)	45	$ 1,756,000	
Lower Respiratory Symptoms	2,106	$ 45,000	
Upper Respiratory Symptoms	3,011	$ 101,000	
Minor Restricted Activity Days	81,928	$ 5,643,000	
Work Loss Days	13,807	$ 2,205,000	

Results for all health endpoints from CATF 2025 COBRA analysis of impacts from the shutdown of four nuclear facilities.

Addendum

In August and September 2019, Vistra Energy announced that it will close five of its coal-fueled power plants in Illinois: Coffeen, Duck Creek, Havana, Hennepin and E.D. Edwards. These five facilities provide about 2,800 MW of capacity and 14 TWh of annual generation. The impact study in this report of nuclear power plants at risk is based on an emissions analysis conducted by the Brattle Group prior to the announcement of these retirements.

The Brattle study showed these five plants operating in both the baseline and nuclear closure scenarios. In the nuclear closure scenario, they were projected to modestly increase their output over baseline, accounting for a small portion of the increased emissions (about 1.4% of total incremental SO2 emissions; 5% of the incremental SO2 within Illinois). As such, the incremental health impact of these plants in our modeling is also small, accounting for less than 2% of the impact.

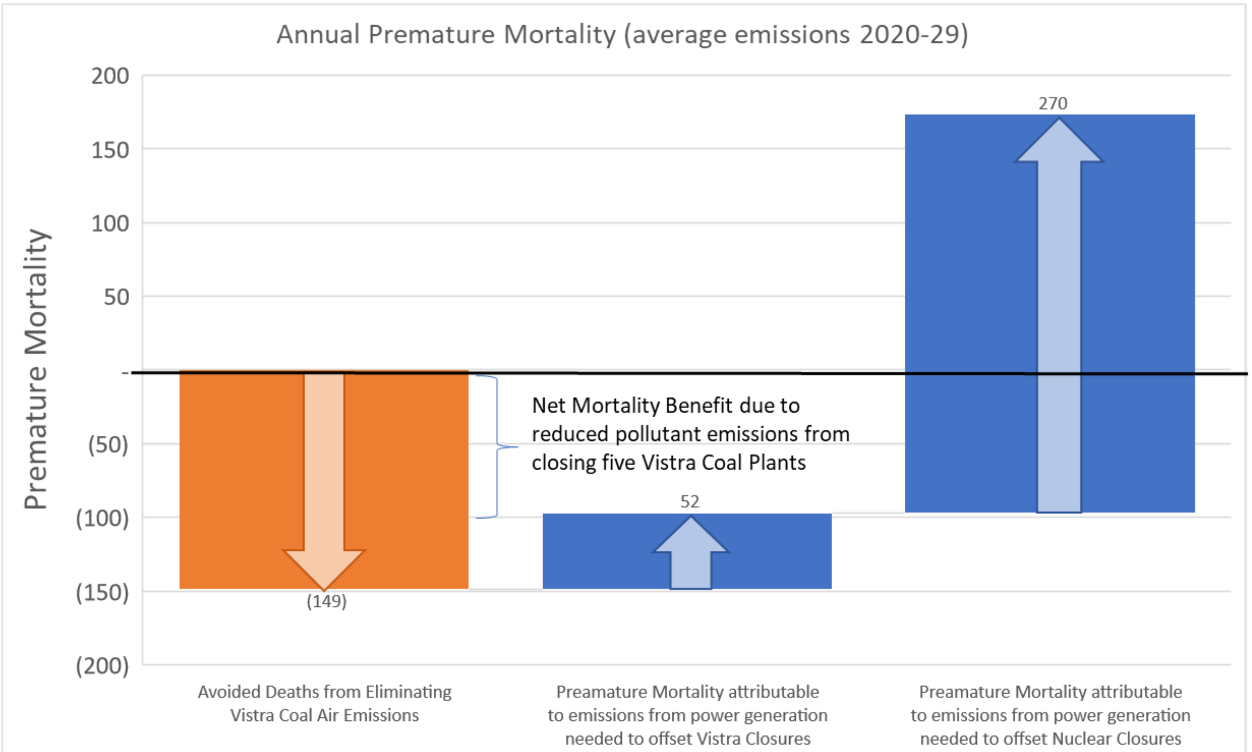
Although the emissions study will not be revised, modeling results that exclude these five coal plants would likely be very similar. The loss of coal-fired generation would be offset by a mix of renewables, gas and coal plants similar to that which was modeled to replace the much larger loss of generation from nuclear plants (74 TWh). However, this additional generation, wherever it occurs, would be present in both the baseline and no nuclear scenarios. The only differences between the existing analysis and one without the five Vistra Coal plants would be to offset the marginal increased generation from the Vistra plants in the original modeling.

CATF conducted two additional COBRA runs to assess the impact of baseline and marginal emissions from the Vistra facilities: (1) Impact of future baseline emissions of five Vistra plants and (2) impact of incremental emissions from five Vistra. The results of the first run are shown in the orange bar in the figure below. The direct impact of removing the emissions from the five coal plants avoids 149 premature mortalities.

To estimate the premature mortalities for replacement generation of the five coal plants, CATF determined the premature mortalities per MWh based on the loss of nuclear run and multiplied by the MWh lost from the five Vistra facilities. Since the average emissions per MWh is lower than that for the baseline emission rate per MWh from the Vistra facilities, the health impact of that generation is less than what it replaces and contributes 52 premature mortalities, as shown in the middle bar of the figure.

Finally, to estimate the total health impact of the loss of nuclear power generation of the five Vistra plants retired, CATF first ran COBRA with the same incremental changes as in the original modeling, except for the five Vistra plants whose emissions were zero in both baseline and future cases. Next, the average premature mortality per MWh calculated from the additional generation needed to replace the loss of nuclear generation was multiplied by the marginal generation from the Vistra plants that was lost. The net result was virtually no change from the original modeling, since the marginal Vistra emissions impact was very similar to the impact from all additional generation modeled to replace the loss of nuclear power.

In summary, closing four nuclear plants would require additional fossil fuel generated power, that would lead to an additional 270 premature mortalities; regardless of whether or not the Vistra plants operate. In the future baseline, emissions from the five Vistra coal plants would cause 149 premature mortalities, with four addition mortalities due to incremental emissions modeled as part of the offset of lost nuclear power. Emissions from replacement power for the coal plants would contribute 52 premature mortalities. With Vistra coal and without nuclear, 270 additional lives would be lost each year. The case with both Vistra coal and nuclear retirement would yield 173 additional premature mortalities.


Annual Premature Mortality (average emissions 2020-29)
Premature Mortality
200
150
100
50
-
(50)
(100)
(150)
(200)
270
Net Mortality Benefit due to reduced pollutant emissions from closing five Vistra Coal Plants
52
(149)
Avoided Deaths from Eliminating Vistra Coal Air Emissions
Preamature Mortality attributable to emissions from power generation needed to offset Vistra Closures
Preamature Mortality attributable to emissions from power generation needed to offset Nuclear Closures