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Impacts of Announced Nuclear Retirements in Ohio and Pennsylvania

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The owners of four nuclear plants in Ohio and Pennsylvania have announced that these plants will be retired over the next several years because of challenges in wholesale power markets that do not value the environmental attributes provided by these plants. FirstEnergy Solutions, which owns the Davis-Besse and Perry plants in Ohio, and the twin-reactor Beaver Valley plant in western Pennsylvania, announced recently that absent state or federal relief, it will retire these plants over the next three years. Exelon Generation, the owner of Three Mile Island, had previously announced it would retire that plant in 2019.

We have developed an estimate of the environmental and electricity price impacts of these announced nuclear plant retirements, drawing from prior work that examined the impacts of the Ohio and Pennsylvania nuclear plants.[1] We found that the retirement of these four plants would cause substantially higher emissions of CO_2 and other pollutants, and that there would be a significant increase in electricity prices in Ohio and Pennsylvania, as well as throughout PJM.

This new analysis estimates that if the four Ohio and Pennsylvania nuclear plants now scheduled for retirement were to continue operating, their output would offset substantial fossil generation from gas and coal plants and thus would:

- **Avoid over 21 million metric tons of CO_2 emissions annually**, equivalent to 4.5 million cars on the roads and potential social costs of $921 million per year.
- **Avoid tens of thousands of tons of criteria pollutants annually** and potential social costs of $170 million per year.

The total zero-emission generation of these four nuclear plants, and thus the fossil emissions avoided by them, is considerably greater than all solar and wind generation in PJM.

- These four nuclear plants provide 39 million MWh of zero-emission energy each year, while wind and solar generation across PJM provided about 26 million MWh in 2017.
- **Retiring these plants would more than reverse the emissions benefits of all the renewable generation in PJM installed over the past 25 years**, and the billions of dollars of historical investments that have supported it.

[1] This report was prepared at the request of Nuclear Matters. It reflects the views of the authors and does not necessarily represent the opinions of The Brattle Group or its clients.

- At the current rate of renewable additions, total zero-emission generation in PJM would not return to 2017 levels until 2032.
- Even if the development rate of new renewables was doubled, it would take until 2034 to restore the level of zero-emission generation that would result from maintaining the nuclear plants and continuing renewable growth at the current rate. Emissions would be higher in the intervening years, leading to higher cumulative atmospheric CO_2 levels.
- Replacing the zero-emission output of these four nuclear plants with zero-emission renewable generation could cost around $2 billion annually, based on EIA's national average renewable cost estimates, and would not offset any incremental fossil generation.

Maintaining these nuclear plants would also keep gross electricity costs lower, raise state GDP and tax revenues, and provide more direct and indirect jobs. These plants would:

- **Help keep electricity prices lower.** With these plants operating, customers' annual gross electricity costs could be as much as $400 million lower in Ohio and $285 million in Pennsylvania. Across all of PJM, electricity costs could be as much as $1.5 billion lower.
- The plants currently provide over 3,000 direct jobs as well as other non-employee contractor jobs, most of which would be lost by the plants' retirement. The plants' economic impact supports thousands of additional secondary jobs, increases state GDP by hundreds of millions of dollars, and supports state and local tax revenues.

This paper leverages the results of our prior analyses examining the environmental and economic impacts of the nuclear plants in Ohio, and separately, Pennsylvania.[2] Table 1 summarizes the capacity and recent energy output of these four nuclear plants. Although the prior studies did not examine these four plants as a group, each of the prior studies modeled the impact of nuclear retirements on the power markets in the entire Eastern Interconnection. We can use the results of those studies, which included these four plants among others, to approximate the impact that the retirement of this particular set of plants would have on emissions and electricity prices. The current analysis does not update the prior analyses since they were published in December 2016 and April 2017 for changed market conditions (such as generator additions and retirements, fuel prices, *etc.*), so the estimates presented here are less precise than what would be provided by a new, updated study that examined this set of four nuclear plants with fully updated market information. Nevertheless, comparing these results with several of the sensitivity cases we

[2] "Ohio Nuclear Power Plants' Contribution to the State Economy," April 2017; and "Pennsylvania Nuclear Power Plants' Contribution to the State Economy," December 2016. The aggregate impacts shown in the Ohio study were generally smaller than those cited here, and those in the Pennsylvania study were larger. This is primarily because the Ohio study considered the retirement of about half as much total nuclear generation as this composite study, and the Pennsylvania study considered the retirement of over twice as much. The magnitudes of impacts seen in any of these studies must be viewed in the context of the amount of nuclear generation being considered.

studied in the prior studies gives us confidence that these approximations still offer a reasonable measure of the impacts under current conditions.

Table 1: Ohio and Pennsylvania Nuclear Plants with Announced Retirement

Plant	Units	Operating Company	Summer Net Capacity (MW)	Energy (million MWh)
Beaver Valley	2	FirstEnergy NOC	1,808	14.9
Davis-Besse	1	FirstEnergy NOC	894	7.1
Perry	1	FirstEnergy NOC	1,240	9.7
Three Mile Island	1	Exelon Nuclear	803	6.9
		Total:	**4,745**	**38.7**

Sources and Notes: EIA Form 906/923, data compiled by ABB Velocity Suite. Energy production is the annual average for 2013–2017.

Emissions and Electricity Price Effects

The retirement of these four plants would lead to a substantial increase in emissions of CO_2 and criteria pollutants including SO_2, NO_X, PM_{10}, and $PM_{2.5}$, since the non-emitting nuclear generation would be replaced by increased fossil generation. We estimate that about 72% of the replacement would come from gas-fired generation and 28% from coal. Table 2 summarizes the total estimated emissions increase across all regions (most occurs within PJM, with some minor increases beyond it due to increased imports and reduced exports with neighboring regions). Average annual power sector CO_2 emissions would be about 21 million metric tons greater without these four nuclear plants. This is equivalent to adding around 4.5 million cars to the road—which would be a nearly 50% increase in the number of automobiles in both Ohio and Pennsylvania.[3] The total social cost of this increase in CO_2 and criteria pollutants is estimated at almost $1.1 billion per year.

[3] This is based on EPA's estimate of 4.7 tons CO_2 annually per automobile. EPA, "Greenhouse Gas Emissions from Passenger Vehicles," May 2014, EPA 420-F-14-040a, p.2. There are 4.7 million automobiles registered in Ohio and another 4.7 million in Pennsylvania, totaling 9.4 million; Federal Highway Administration, Highway Statistics 2015.

Table 2: Emissions and Social Cost Impacts of Ohio and Pennsylvania Nuclear Plants with Announced Retirements (Annual Impacts, 10-Year Average)

Pollutant	Avoided Emissions (Metric Tons)	Social Cost ($/ton)	Avoided Emissions Value (2018 $Millions)
CO_2	21,080,268	$44	$921
SO_2	6,775	$7,761	$53
NO_x	8,277	$2,141	$18
PM_{10}	9,135	$616	$6
$PM_{2.5}$	7,363	$12,712	$94
Total			$1,091

Sources: Social cost of carbon is from the Interagency Working Group on the Social Cost of Carbon, United States Government. Social costs of other pollutants are from "Hidden Cost of Energy: Unpriced Consequences of Energy Production and Use," National Research Council, 2010.

Similarly, using power price impacts from the prior studies, we found that the retirement of these four nuclear plants is likely to cause a material increase in wholesale electricity prices, with roughly half the impact coming from the energy market and half from the capacity market. Table 3 summarizes the average wholesale impacts for Ohio, for Pennsylvania, and for PJM as a whole. It combines the capacity and energy price components into an all-in dollars per MWh figure, and also shows the overall estimated electricity cost impact for customers, assuming the wholesale price increase is passed on to retail customers.[4] These electricity cost impacts do not consider the cost of any potential policy mechanism that may be associated with ensuring the nuclear plants' continued operation, and thus effectively show the gross impact of keeping these nuclear power plants, not the net benefit of a proposed policy that would do so.

[4] Capacity price effects can be difficult to ascertain with confidence, because the market response can be hard to predict (*e.g.*, the extent to which market participants will offset a loss of one source of capacity by retaining others, or adding new capacity). Recent PJM capacity market performance, with continuing new generation additions in the face of persistent low capacity prices, may suggest that capacity markets have changed in ways that could mitigate the capacity price effect found in our prior results. Also, while reductions in electricity costs do benefit consumers, the offsetting impact on producer revenues must also be considered to determine the total social welfare impact.

Table 3: Electricity Cost Impact of Ohio and Pennsylvania Nuclear Plants with Announced Retirements

	Power Price Change without Nuclear ($/MWh)	Electricity Consumption (millions of MWh)	Annual Electricity Cost Change (2018 $Millions)
Ohio	2.43	165	401
Pennsylvania	1.77	162	285
PJM	1.84	825	1,519

Note: The Power Price Change is the load-weighted average of the price effect within each PJM sub-region, for PJM as a whole and for the sub-regions that comprise Ohio and Pennsylvania. This includes only energy and capacity cost effects; it does not include transmission costs, customer costs, *etc.*

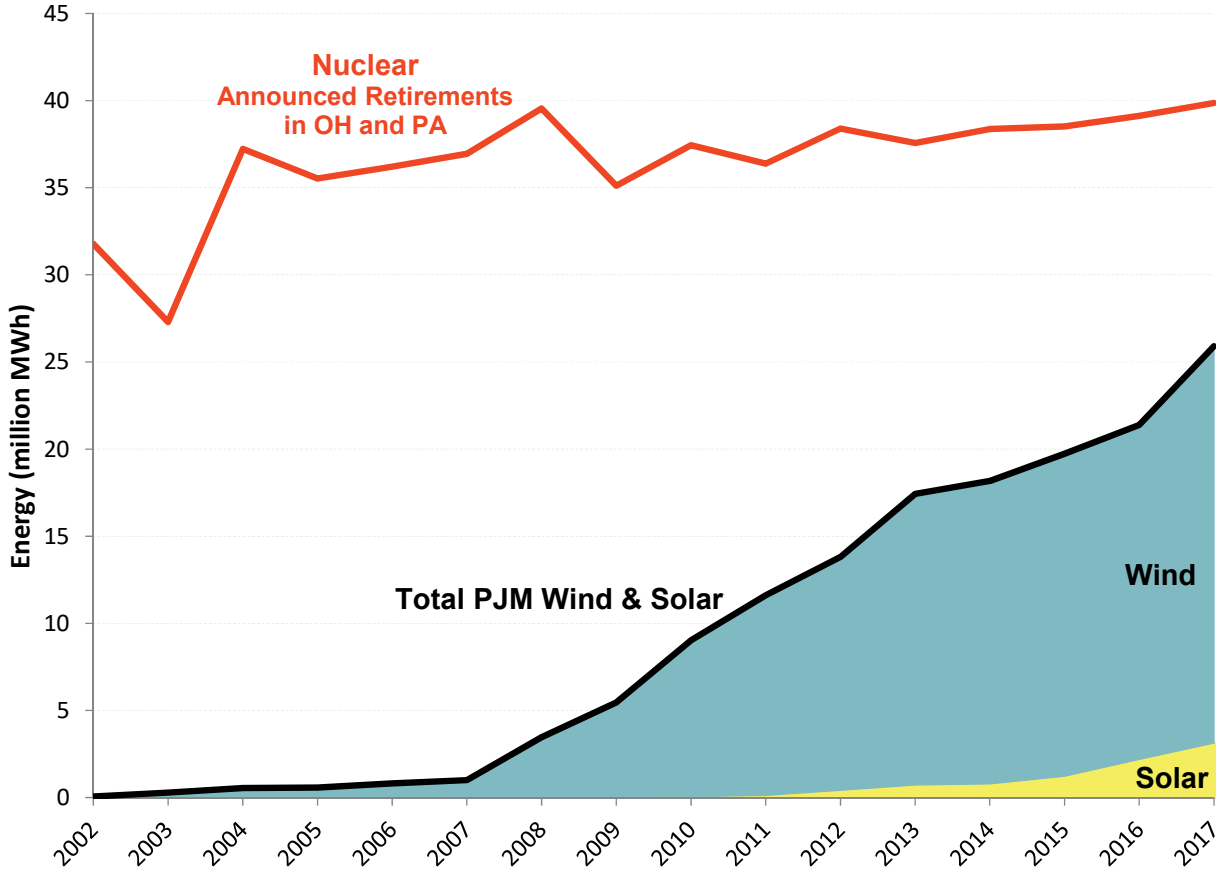
Relating Announced Nuclear Retirements to PJM Renewable Generation

To illustrate the magnitude of the emissions impact of retiring these four nuclear plants, we relate it to the zero-emission renewable generation that has been developed over the last 25 years in the PJM region. Many PJM states have had renewable portfolio standards for ten years or more that require that a growing share of load be supplied from renewable generation such as solar and wind. These RPS requirements have traditionally been supported by state renewable energy credits (RECs), paid for by customers to help finance new renewable resources. Federal tax credits, which are now being phased out over the next several years, have provided further encouragement for renewables and helped to offset direct REC costs to customers. These state RPS mandates and federal tax credits are motivated in large part by the fact that renewables do not emit pollutants, an attribute they share with nuclear power.

These four nuclear plants together have recently generated 39 million MWh of zero-emission electricity annually. As shown in Figure 1, this is 50% more than the entire 26 million MWh of zero-emission power produced by all wind and solar generation operating in PJM in 2017.[5] This means that the retirement of these four nuclear generators would more than undo the entire emissions benefits of all renewable generation investments made to date throughout the PJM region. The retirement of these nuclear plants would mean zero-emissions generation would fall to a level *below* where it would have been if no renewables had ever been built in PJM. It would take less than 4 years to reverse the entire 149 million MWh of zero-emissions electricity cumulatively produced over the last two decades by solar and wind in PJM, negating billions of dollars of historical customer and taxpayer investment.

[5] Even if hydro is included as well, the total amount of zero-emissions generation from non-nuclear sources in PJM is only 35 million MWh in 2017—still below the output of these four nuclear plants.

Figure 1: Generation of Ohio and Pennsylvania Nuclear Plants with Announced Retirements vs. Total PJM Renewable Generation

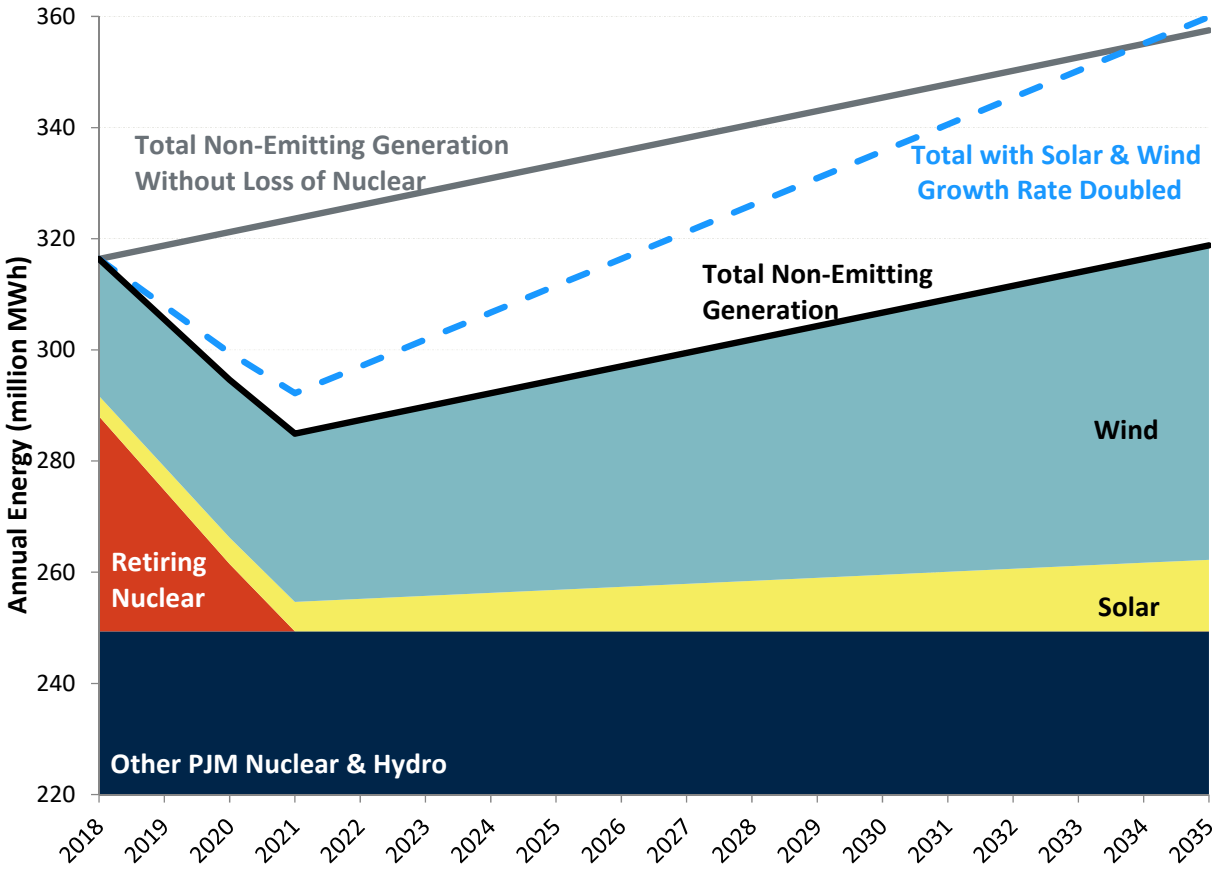


Sources and Notes: Data compiled by ABB Velocity Suite from EIA Form 906/923, reporting generation from electric plants located in the PJM physical footprint (not accounting for imports and exports). EIA data is not yet available for 2017; the 2017 value here is estimated based on renewable generation information from the 2017 PJM Annual State of the Market Report, with an adjustment based on the historical differences between these data sources. Hydro generation (not shown) adds about 8 million MWh of additional zero-emission generation.

If new solar and wind continue to be added at the pace of the past 5 years (increasing combined wind and solar generation by 2.4 million MWh each year), it will take 14 years, until 2032, to get back to 2017 levels of zero-emissions generation. And of course, having enough total renewables to get back to where we are now would not replace the retiring nuclear generation, since if the nuclear plants continue operating, zero-emissions generation would continue to grow. To actually replace the retiring nuclear plants' output would require adding enough *additional* renewable generation to produce an incremental 39 million MWh each year, beyond the renewable growth that would otherwise take place. That would require a greatly increased pace of new renewable additions, sustained over many years. To illustrate this, Figure 2 shows that if the current renewable addition rate were to double to 4.8 million MWh annually (an additional 2.4 million MWh annual growth, on top of extrapolating the 2.4 million MWh recent growth), it would take until about 2034 to get to the level of zero-emissions generation that would have been achieved by maintaining the nuclear plants and continuing renewable growth at the current rate (assuming no other nuclear retirements in the meantime). It would also involve

higher cumulative emissions in the intervening years, contributing to higher CO_2 concentrations in the atmosphere.

Figure 2: Potential Future Total PJM Non-Emitting Generation with Ohio and Pennsylvania Announced Nuclear Retirements



Note: Other PJM Nuclear and Hydro are shown as the average output over the past 5 years, 2013–2017. The four announced plants plan to retire fully within three years, and are represented here with output declining smoothly to 2021. Solar and wind generation are grown at 2.4 million MWh per year, the average rate for 2012–2017, or alternatively at double that rate (dashed blue line).

The cost of replacing retiring nuclear generation with additional renewable investments would be substantial, even considering that renewable generation costs have declined materially in recent years. Recent cost estimates by the U.S. Energy Information Agency find that levelized costs in the U.S. are currently about $48.1/MWh for wind and $57.7/MWh for solar, excluding the value of federal tax credits.[6] At these rates, replacing the 39 million MWh output of these

[6] U.S. Energy Information Administration, *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook, 2018*. The cost estimates used here are only roughly indicative. They are national cost averages, and since capacity factors in PJM are lower than national averages for both technologies, PJM costs would be higher than this. On the other hand, technological improvement may push renewable costs lower over time.

four nuclear plants would cost between $1.9 billion and $2.2 billion annually, depending on the mix of wind and solar. Since the amount of nuclear generation that would need to be replaced is more than 15 times the current annual rate of renewable additions in PJM, it would not be possible to actually replace this nuclear generation immediately upon retirement, which means cumulative emissions will be higher.

Economic and Employment Impacts of the Announced Nuclear Retirements

Our prior Ohio and Pennsylvania analyses can provide some sense of the potential magnitude of the impact on gross domestic product (GDP) and employment that would arise following the recently announced nuclear plant retirements, but we are not able to provide specific estimates of these impacts. This is because our prior Ohio and Pennsylvania studies assessed economic impacts only for the state of interest, and did not model the impact of a nuclear closure in one state on the economy of neighboring states. When using these prior studies to understand the potential impacts of the four plants considered here, it is important to keep in mind that the Ohio study considered the retirement of only about half as much nuclear generation, and the Pennsylvania study about twice as much.

Our prior Ohio study looked at the economic contributions of two of these four plants, Davis-Besse and Perry, and found that the gross electricity price increase associated with just these two plants retiring would result in substantial losses in state gross domestic product and employment. These two nuclear retirements would reduce Ohio GDP by $510 million (2017 dollars), and cost 4,200 jobs.[7] Retiring two additional nearby plants—Beaver Valley and Three Mile Island in Pennsylvania—would further increase the gross electricity cost and economic impacts in Ohio.

Our prior Pennsylvania study addressed the economic contributions of all five Pennsylvania nuclear plants, including Beaver Valley and Three Mile Island, though not the two Ohio plants.[8] Using the same methodology as the Ohio study, we determined that the retirement of all five Pennsylvania nuclear plants would result in a Pennsylvania GDP loss of $2 billion annually, with employment (direct and indirect) declining by 15,900 jobs.

The four plants considered here employ over 3,000 people directly, as well as other non-employee contractors. Most of these jobs would be lost with the plants' retirement and, based on our previous work, thousands of additional secondary jobs would be lost. In addition, state GDP

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[7] Our methodology compared the state of the economy with and without the nuclear plants, netting out the offsetting impacts of the expected replacement generation. Again, the electricity cost and economic impacts are gross figures in that they do not consider any cost associated with keeping the nuclear plants operating.

[8] The five plants considered in the Pennsylvania study are Beaver Valley, Limerick, Peach Bottom, Susquehanna, and Three Mile Island.

for Ohio and Pennsylvania would be lower by hundreds of millions of dollars, and state and local tax revenues would fall by tens of millions of dollars.

Conclusion

Based on the results of two prior studies, we estimate that the retirement of these four Ohio and Pennsylvania nuclear plants would lead to an additional 21 million metric tons of CO_2 emissions annually, as well as substantially more criteria pollutants (SO_2, NO_X, and particulates). These four nuclear plants produce considerably more zero-emission generation, and thus avoid considerably more fossil emissions, than all solar and wind generation in the entire PJM region combined. The retirement of these plants would also raise gross electricity costs for customers—by approximately $400 million for Ohio, $285 million for Pennsylvania, and $1.5 billion in all of PJM. This would cause a substantial reduction in state GDP and jobs in Ohio and Pennsylvania, as well as surrounding states.