Ohio Nuclear Power Plants' Contribution to the State Economy

PREPARED FOR

NUCLEAR MATTERS

and

Affiliated Construction Trades Ohio Foundation

Mechanical Contractors Association of Northwest Ohio

Ottawa County Improvement Corporation

Regional Growth Partnership (Northwest Ohio)

Team Northeast Ohio

PREPARED BY

Mark Berkman, Ph.D.

Dean Murphy, Ph.D.

April 2017

THE Brattle GROUP

This report was prepared for Nuclear Matters, the Affiliated Construction Trades Ohio Foundation, the Mechanical Contractors Association of Northwest Ohio, the Ottawa County Improvement Corporation, the Regional Growth Partnership (Northwest Ohio), and Team Northeast Ohio. FirstEnergy Nuclear Operating Company provided employment data and FirstEnergy Corp. provided access to the Regional Economic Models, Inc. (REMI) economic model of Ohio. All results and any errors are the responsibility of the authors and do not represent the opinions of The Brattle Group or its clients.

The authors would like to acknowledge the invaluable assistance of Mike Kline, Andrew O'Brien, Duncan O'Brien, Paul Organ, and David Christopher in preparing this analysis.

Table of Contents

Executive Summary

In recent years, wholesale electricity prices have declined significantly, due in large part to the shale gas revolution. Natural gas is the price-setting fuel in many U.S. electricity markets, and the dramatic reduction in its price has brought down electricity prices as well. Negligible demand growth and substantial amounts of new policy-driven renewable generation have also contributed. While lower power prices are generally a positive development for consumers, persistently low prices can threaten the economic viability of existing generators, whose premature retirement could offset much of the price reductions that have occurred. Nuclear generators in particular, because of their high fixed costs and effectively zero variable costs, tend to keep market prices low when they are operating, but are themselves financially vulnerable to sustained low power prices. Indeed, in the past few years, several nuclear plants have been retired prematurely for purely economic reasons, and a number of others are threatened. Because of the economic and environmental consequences that accompany the loss of nuclear generation, some states have implemented and others are considering policy mechanisms that would support existing nuclear power plants and prevent their premature retirement.

In this context, Nuclear Matters and several local sponsors have asked The Brattle Group to evaluate the contribution that Ohio's nuclear power plants, Davis-Besse and Perry, make to the state's economy.[1] We considered how these plants affect electricity markets and prices as well as in-state productive activity, and studied the resulting ramifications of these factors throughout the Ohio economy. We found that these plants keep electricity prices lower than they would otherwise be, and also keep productive economic activity in-state. As a result, Ohio's GDP will be higher with the plants operating than it would be without them. These plants also maintain jobs within Ohio; not only the direct employees of the plants and the indirect jobs at suppliers and contractors that support plant operations, but also additional jobs throughout the economy that result from the overall economic boost associated with lower electricity prices and more in-state production. In addition, the continued operation of these nuclear plants holds down emissions of CO_2 and other air pollutants. In their absence, correspondingly more power would be produced by fossil-fueled power plants, causing a substantial increase in emissions.

In this analysis, we have not considered the structure or cost of any potential policy mechanism that may be necessary to ensure the nuclear plants' continued operation. As a result, this analysis effectively calculates the gross economic benefits of preserving these nuclear power plants, not the net benefit of a proposed policy that would do so.[2]

---

[1] The local sponsors are the Affiliated Construction Trades Ohio Foundation, the Mechanical Contractors Association of Northwest Ohio, the Ottawa County Improvement Corporation, the Regional Growth Partnership (Northwest Ohio), and Team Northeast Ohio.

[2] A full analysis of any particular policy or proposal that would support these nuclear plants would need to incorporate the costs of that support, as well as any other aspects of the policy proposal. Further,

Continued on next page

Our analysis has determined that over the next ten years (2018–2027), the Ohio nuclear power plants:

- **Contribute approximately $510 million annually to state gross domestic product** (GDP).
- **Account for nearly 4,300 in-state jobs** (direct and secondary).
- **Help keep electricity prices low**. Ohio consumers would pay $177 million more for electricity annually, and almost $1.3 billion more in present value over the next ten years, without these two plants.
- **Are responsible for $23 million in state and local tax revenues** annually.
- **Avoid 9.3 million metric tons of CO_2 emissions annually** over the next ten years, valued at $548 million per year.
- **Avoid significant amounts of other air pollutants annually**, valued at $87 million per year over the next ten years.

These measures reflect the significance of these two nuclear power plants for the Ohio economy, and are determined by comparing the performance of Ohio's economy with these plants to its performance without them. This approach nets out the economic contribution of the alternative generation that would substitute for these two plants—both the greater utilization of existing plants, and the construction of new plants, as necessary—to determine the plants' incremental economic contribution. Absent the energy from these two nuclear power plants, Ohio and the broader region would rely more heavily on natural gas and coal-fired generating plants, many of which are outside Ohio, leading to considerably greater reliance overall on out-of-state generation. The increased reliance on fossil generation that would occur in the absence of these nuclear plants would cause higher emissions of carbon and other air pollutants, including in some current non-attainment areas of Ohio. It would also raise electricity prices; without these two nuclear power plants, wholesale power prices in Ohio and throughout the broader region would be higher. These higher prices would flow through to residential, commercial and industrial consumers as higher electricity bills. Both the effect on electricity prices and the reduction of in-state economic activity that would occur if these plants shut down prematurely contribute to their overall incremental economic impact. Note that these measures reflect only the impacts within Ohio, although the absence of the Davis-Besse and Perry nuclear power plants will have additional negative consequences in the form of higher electricity prices beyond the state's borders.

Continued from previous page

while reductions in electricity costs do benefit consumers, to determine whether they improve total social welfare the offsetting impact on producer revenues must also be considered. Our analysis of economic impacts—GDP, jobs, and tax revenues—does account for the impacts on producer revenues as well as consumer costs. Similarly, a full benefit-cost analysis of any proposed policy to support nuclear plants would need to account for both the loss of producer revenues and the consumer savings, in addition to the program's cost.

Emissions of carbon dioxide (CO_2) and "criteria pollutants" identified by the Clean Air Act, such as nitrogen oxides (NO_X) and sulfur dioxide (SO_2), would also be much higher in the absence of these two nuclear power plants, because the replacement generation would be almost entirely fossil-fired. Compliance with national ambient air quality standards (NAAQS), such as for ozone, nitrogen oxides (NO_X) and small particulate matter ($PM_{2.5}$), could become more costly for other generators, both in-state and out of state. It would likely be more difficult for Ohio to achieve targeted CO_2 reductions under any future climate policy.[3] Further, the pollutant impacts are not limited to Ohio, first because much of the replacement generation would come from outside Ohio, and second because air pollution impacts can cross state borders—they are often regional in the case of criteria pollutants, and are global in the case of carbon dioxide.

We examined the sensitivity of our results to different levels of natural gas prices, relative to current expectations, since natural gas is a key driver of electricity markets. We found that in a higher gas price environment, the beneficial impact of Ohio's nuclear plants on electricity prices would be greater, and lower gas prices would reduce their impact. Their economic impact is similarly greater at higher gas prices, and is smaller with lower gas prices. The emissions effect actually goes in the opposite direction, for reasons discussed later.

I. Background

Two nuclear power plants, each consisting of a single nuclear reactor, operate in Ohio, as illustrated in Figure 1. The Davis-Besse Nuclear Power Station is a 908 MW pressurized water reactor, licensed until 2037 and located on Lake Erie about 25 miles east of Toledo. The Perry Nuclear Generating Station is a 1,268 MW boiling water reactor, currently licensed to operate until 2026 but eligible for a 20-year license renewal, and also on Lake Erie, 40 miles northeast of Cleveland. Together, these two plants represent over 2,100 megawatts (MW) of generating capacity and over 16 million megawatt hours (MWh) of annual electricity generation, as shown in Table 1. Ohio is a part of the PJM Interconnection, the electric region operated by the PJM independent system operator.[4] PJM encompasses much more than just Ohio, both geographically and electrically; Ohio accounts for about 15% of PJM's total generation and 20% of its load. Within Ohio itself, these two nuclear power plants represent 14% of generation and 7% of capacity, as illustrated in Figure 2.

---

[3] We do not consider a national climate policy in this study. Although the Clean Power Plan (CPP), EPA's rule to limit greenhouse gas emissions from existing power plants, nominally takes effect in 2022, the new administration has taken initial steps to review and potentially rescind it, and it had previously been stayed pending resolution of legal challenges.

[4] The PJM ISO operates the power system, as well as establishing and maintaining markets for electric capacity and energy.

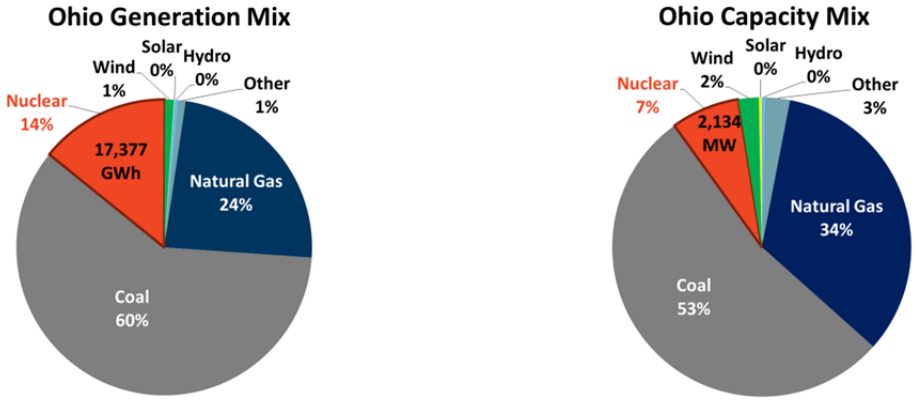
Figure 1: Locations of Ohio Nuclear Power Plants

Table 1: Summary of Ohio Nuclear Power Plants

Item	Davis-Besse	Perry	**Total Ohio Nuclear**
Number of Units	1	1	**2**
Total Net Capacity (MW)	908	1,268	**2,176**
Average Annual Generation (GWh)	7,134	9,460	**16,594**

Sources & Notes: Capacity values are net winter capacity. Average annual generation is the average of 2013–2015.

Figure 2: Ohio Electricity Generation and Capacity Shares, by Fuel



Sources & Notes: EIA Form 923, via ABB, Inc., Energy Velocity Suite. Generation is 2015 historical values; capacity is as of March 2017.

II. Ohio's Nuclear Power Plants Make a Considerable Contribution to the State's Economy and Environment

We have estimated the economic value of the Davis-Besse and Perry plants to the state of Ohio using REMI, a widely-used regional economic model.[5] Our analysis covers a ten-year period, 2018–2027. The effect of these two plants on the Ohio economy occurs through two main channels. First, electricity costs are lower for Ohio consumers with the nuclear power plants operating than they would be without them. The absence of the Davis-Besse and Perry plants would increase wholesale prices for energy and capacity in the region, since it would reduce the available supply of both (more costly plants would need to operate, setting higher energy prices; although the nuclear plants' capacity would not need to be replaced immediately, their absence would diminish the capacity surplus, raising capacity prices). Higher wholesale prices translate quite directly to higher retail prices and customer costs in a restructured state like Ohio. The second major economic effect is that with its nuclear power plants operating, Ohio will be a modest net importer of power during the study horizon, producing about 4% less power than it consumes, but without the nuclear plants, it would be a much larger net importer, importing about 12% of its power.[6] The loss of in-state power production would mean a material reduction in productive economic activity within the state. A major non-economic effect of these nuclear power plants is to hold down emissions of CO_2 and criteria pollutants. Virtually all of the replacement power that would substitute for the output of these two plants would be fossil-fired generation; these effects are discussed in Section II.F.

To characterize the electricity market effects that drive the economic effects, we utilize a proprietary power market simulation model, Xpand, which models capacity expansion/ retirement and dispatch to capture the dynamics of power system operation, power markets, and prices. We use this power sector model to characterize the effects of these two nuclear power plants on power prices, power costs to consumers, power plant revenues, and new plant construction activity. These power sector impacts then become inputs to the REMI economic model. This approach allows us to develop the most accurate picture of the plants' incremental contribution to the economy, in terms of economic output, employment, and tax revenues. Although we simulate the power system for the entire Eastern Interconnection to best capture the interstate electricity market effects, only the economic impacts that occur within Ohio are reported.

---

[5] For more details on the REMI model, see www.remi.com.

[6] Ohio has historically been a much larger importer of power than it will be in the future. In 2015, Ohio produced 18% less energy than it consumed (and this does not account for line losses; correcting for this, Ohio imported nearly 24% of its power needs). Net imports are projected to decline over the next few years, as a result of several efficient new gas-fired generators that are scheduled to come online in Ohio, and an expected increase in gas prices which will cause in-state coal plants to run more often.

We analyze the power sector and the economy both with and without the Davis-Besse and Perry plants, to determine the economic effects that are attributable to them. Our analysis indicates that keeping these two plants operating will keep electricity costs lower in Ohio, as well as in the broader PJM region, and the resulting lower electricity costs are a substantial contributor to the gross economic benefit of these plants to the Ohio economy. The other key contributor to economic impact is the productive economic activity associated with these plants. Even after netting out the economic contribution of the alternative electric generation that would substitute for them in their absence, these two nuclear power plants are responsible for a GDP impact of $510 million dollars annually, and accompanying employment and tax revenue effects (they also avoid significant environmental costs, as discussed later). Table 2 summarizes our findings for the economic impacts of these plants within Ohio. Again, these represent the gross impacts of these nuclear plants, without accounting for the cost of any policy that may be necessary to maintain their operation.

Table 2: Gross Contribution of Ohio Nuclear Plants to the State Economy (10-Year Average Annual Impacts, 2018–2027)

GDP, Direct and Secondary *(millions of nominal dollars)*	$510
Employment, Direct and Secondary *(jobs)*	4,270
Direct	1,340
Secondary	2,930
Tax Revenues, Direct and Secondary *(millions of nominal dollars)*	$135
State and Local	$23
Federal	$112

Our Base Case analysis shows that the Davis-Besse and Perry plants are responsible for $510 million in state GDP and 4,270 jobs (considerably more secondary jobs than direct jobs—the direct power sector impact is 1,340 jobs, which is the net effect of 1,420 lost nuclear jobs offset by about 80 additional jobs associated with increased in-state non-nuclear generation).[7] Much of the GDP and jobs effect is indirect, based in part on the plants' effect on electricity costs to consumers, rather than resulting from economic activity that is directly associated with the plants themselves. Because every sector of the economy depends on electricity, the power price effect is extraordinarily widespread, thus leading to a substantial overall impact. Indirect jobs are also lost as a consequence of the direct jobs losses resulting from the absences of Davis Besse and Perry.

[7] Our Base Case analysis reflects current expectations for natural gas prices, as represented by the Reference natural gas price projection from the U.S. Energy Information Administration's Annual Energy Outlook 2017.

The owners of these two nuclear power plants also pay significant state and federal taxes, as do businesses providing goods and services to the plants and their employees. In addition, the plants' incremental contributions to the state's economy account for additional tax revenues to state and local governments—considerably more than the direct taxes paid by the plants. The effect of these two nuclear power plants on the economy leads to about $23 million in additional state and local tax revenues and $112 million in federal tax revenues, beyond the tax revenues that would be available in their absence.[8]

Below, we provide further detail regarding the gross impact of the Davis-Besse and Perry plants on:

- The electricity generation mix
- The price and cost of electricity
- Economic output and GDP
- Employment
- Federal and state tax revenues
- Emissions of CO_2 and other pollutants.

A. Impact on Electric Generation Mix

As shown in Figure 3 below, with the Davis-Besse and Perry plants operating, Ohio will in future produce about 4% less power than it consumes, importing the remainder from out-of-state sources. While this is a considerable improvement relative to Ohio's historical dependence on imports, it depends on the continued operation of the nuclear plants. If they were to shut down prematurely, Ohio would return to being a significant net importer of power, importing about 12% of its own aggregate electricity needs. The missing nuclear generation would be replaced by increased reliance on natural gas and coal-fired generation. Some of this would come from in-state sources, but the large majority would be imported from other states.[9] The reduction in

---

[8] State and local tax revenues are estimated using an algorithm prepared by the Upjohn Institute for several Ohio projects. This approach results in a conservative estimate, it does not include property taxes and the two plants alone pay $24 million in state and local taxes. These payments reflect pre-impairment values of the plants. Federal tax revenues are estimated using the observed ratio of total IRS revenue from Ohio to the state's GDP in 2013 (22.1%).

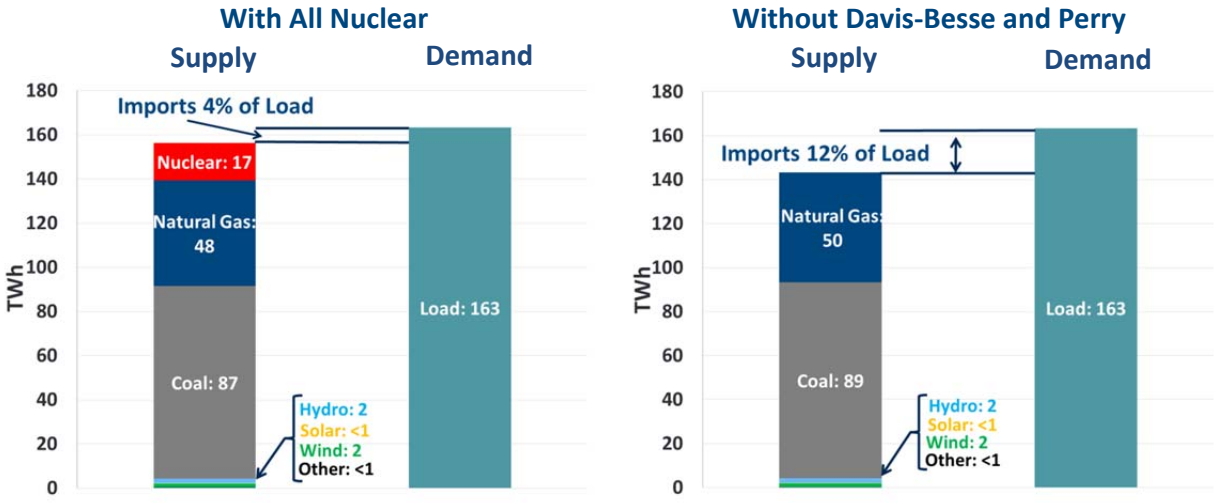
[9] Ohio is a part of the large, multi-state PJM power market, which dispatches generators to serve load without regard to state boundaries. In normal power system operation, the most economic available generation is used to meet load. If the nuclear plants are absent, the next most economical source of generation to replace their output will often be outside Ohio. The extent to which Ohio is a net importer or exporter of power can be influenced by the relative prices of natural gas and coal, which drive the relative economics of specific generators, and by generator additions and retirements (*e.g.*, several large, efficient gas-fired generators, now under construction in Ohio and due online in 2018, should increase in-state generation). But regardless how net imports may change over time due to

Continued on next page

economic activity associated with the loss of in-state generation is responsible for a significant share of the overall economic effect.

Large-scale renewable energy probably would not increase significantly in the near term, beyond additions that would occur if the nuclear plants do continue operating. Because of the significant magnitude of nuclear output relative to the small current scale of renewables and the likely pace of renewable additions, it is unlikely that enough incremental new renewable generation could or would be added to make up a significant share of the lost emission-free generation of the nuclear plants.

Figure 3: Electric Generation and Load in Ohio (2018 Projection)



B. Impact on Electricity Prices

As noted above, absent the Davis-Besse and Perry plants, electricity demand would be met by increased utilization of natural gas and coal-fired plants, some within Ohio but most from outside the state. The reduction in supply would increase wholesale energy and capacity prices, which means higher electricity prices for customers in Ohio and across PJM.[10] As shown in Table 3, average power prices in Ohio would be $1.07/MWh higher without these two nuclear power

---

Continued from previous page

such factors, the premature shutdown of Ohio's nuclear plants will cause net imports to be significantly higher than they would otherwise have been.

[10] Wholesale electricity prices can be characterized as energy and capacity price. Energy price is the cost of providing an additional small unit of electric energy over time horizons as short as an hour; it is based on the variable cost of the last unit providing power at a given time, typically in units of dollars per megawatt-hour. Since short-term energy can only be provided if there is enough generating capability installed and ready to operate, there is also value in the longer term to having sufficient available capacity for when it may be needed. This capacity value (the capacity payment that may be earned by a kilowatt of generating capacity) is often expressed in terms of dollars per kilowatt-year.

plants.[11] This price increase consists mostly of higher energy prices, with a modest contribution from higher capacity prices. (There is currently a significant surplus of capacity in PJM; the loss of these nuclear plants would reduce but not eliminate that surplus, raising capacity prices somewhat.[12]) This price effect is widespread; although the effect is somewhat stronger in Ohio and nearby regions, it is felt across PJM and beyond. The $1.07/MWh price increase represents an increase of $177 million per year in electricity costs for Ohio consumers, across residential, commercial, and industrial sectors—almost $1.3 billion in present value over ten years.[13] Again, these electricity cost impacts are the gross effects, without accounting for the cost of any nuclear support mechanism.

Table 3: Davis-Besse and Perry Plants Avoid Higher Electricity Prices (All-in Power Price and Cost Differences due to Davis-Besse and Perry Plants)

	10-Year Ohio Average, Nominal Dollars					
	Power Price with Nuclear	Power Price without Nuclear	Power Price Change without Nuclear ($/MWh)[1]	Electricity Consumption (millions of MWh)	Annual Average Electricity Cost Change (millions of nominal dollars)	Total Electricity Cost Increase 2018-2027 (millions of 2017 dollars)[2]
Base Case	$60.52	$61.59	$1.07	165	$177	$1,312
High Gas Price Case	$71.64	$72.84	$1.20	165	$198	$1,509
Low Gas Price Case	$53.93	$54.78	$0.85	165	$141	$1,012

[1]The reported Power Price Change includes only energy and capacity cost effects; does not include transmission costs, customer costs, etc. Power Price Effects are assumed to be the same, on an average per-MWh basis, for all customer classes; differences in load shape and billing determinants are not distinguished here.

[2]Present value for the 10-year period at a 3% discount rate.

11 The electricity sector model used here depicts six sub-regions within PJM. Ohio is contained entirely within one of these, PJM-ROR, which also includes West Virginia, western portions of Pennsylvania, Maryland, and Virginia, and parts of Indiana and Kentucky. The Ohio average effect is assumed to be the same as the PJM-ROR average effect (*i.e.*, we do not consider transmission congestion within the PJM-ROR sub-region). The PJM average is the load-weighted average across all six PJM sub-regions.

12 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 forces will offset a loss of one source of capacity by retaining others, or adding new capacity). Our analysis here assumed that the market response is significant and the loss of nuclear capacity would be largely offset; this mitigates the capacity price response, yielding a conservatively small overall price effect.

13 Although local and possibly regional transmission needs could differ in the absence of these nuclear power plants, this report does not consider the effects on the transmission system nor potential changes in transmission investments. Transmission upgrade costs, however, could be substantial if nuclear plants were retired prematurely, as was noted in another context by a 2014 PJM study regarding the potential closure of nuclear plants in Illinois.

Natural gas prices are a key driver of power sector economics, since gas is often the marginal fuel and plays a primary role in setting power prices in the region. Gas prices can thus alter the electricity price effect and ultimately the economic and jobs effects. If future natural gas prices are above current expectations, the cost of replacement power would be higher, tending to increase the power price impact and the economic benefits of the Ohio nuclear plants. Lower gas prices would tend to reduce the effect on power prices and the overall economic benefits of retaining these plants. To explore this, we examined the sensitivity of our results to materially higher or lower natural gas prices.[14] The lower panels of Table 3 show that a high gas price environment magnifies the electricity price impacts of the Ohio nuclear plants such that they would save Ohio consumers $198 million annually in electricity costs, 12% more than the Base Case. A low gas price mitigates the effect, reducing it to $141 million annually, 20% below the Base Case.

C. Impact on Economic Output

The Davis-Besse and Perry plants contribute an average of $510 million to annual state GDP, in part through the electricity price effects shown above, and also through the economic activity associated with in-state electricity production. This GDP effect includes both direct and secondary economic activity attributable to these plants, netting out the economic activity associated with alternative generation in their absence, to the extent this replacement generation occurs within Ohio. The largest effect is found in the utilities sector, unsurprisingly, followed by the manufacturing and construction sectors, as shown in Table 4.

In a high gas price environment, the GDP effect is about 20% greater, and is spread similarly across the sectors. In a low gas price environment, the GDP effect is considerably smaller, largely because a larger share of replacement generation comes from within Ohio. There are also more significant changes in the relative size of the effects across sectors. For instance, in the low gas price case, the manufacturing sector experiences a greater loss than the utilities sector (the reduce effect in the utility sector is due to a smaller loss of in-state generation). Note also the change in sign in the effect on the mining sector, from positive to negative: this indicates that in the low gas price case, the mining sector actually experiences an *increase* in output in the absence of the nuclear power plants, due to increased production of oil, natural gas, and coal.

[14] The High Gas Price and Low Gas Price Cases involve delivered gas prices that are, respectively, 35% higher and 25% lower than the Base Case gas prices. This range is based on Brattle's experience with the price volatility implied by financial options on natural gas, historical gas price variance and historical forecast errors.

Table 4: GDP and Gross Output Impacts by Sector in Ohio
(10-Year Average Annual Direct & Secondary Impacts in Millions of Nominal Dollars, 2018–2027)

	Output Impacts		
Sector	Base Case	High Gas Price	Low Gas Price
Utilities	$230	$279	$67
Manufacturing	$134	$159	$80
Construction	$116	$137	$38
Real Estate and Rental and Leasing	$45	$53	$25
Retail Trade	$42	$49	$19
Professional, Scientific, and Technical Services	$40	$47	$23
Health Care and Social Assistance	$29	$34	$15
Wholesale Trade	$24	$29	$12
Mining	$19	$22	-$13
Finance and Insurance	$19	$22	$10
Other (all other sectors)	$114	$136	$55
Gross Economic Output Impact, Direct and Secondary*	$811	$968	$331
GDP Impact, Direct and Secondary	$510	$608	$183

* Gross economic output is an aggregate measure of total industry sales, which includes sales to final users and intermediate sales to other industries. Summing output across sectors can lead to a form of double counting when the output of one sector is the input of another. GDP, the most widely-used measure of economic performance, reflects value added, which includes industry sales to other industries and to final users, net of the value of purchases from other industries. It removes this double counting and is thus a better measure of the aggregate economic effect.

D. IMPACT ON EMPLOYMENT

The Davis-Besse and Perry plants account for 4,270 direct and secondary jobs in the state's economy. The direct jobs effect (1,340 jobs in the power sector, the net effect of 1,420 lost nuclear jobs offset by an increase of 80 jobs due to the increase in Ohio non-nuclear generation) include those positions necessary for plant operations such as engineers and technicians as well as security and administration. Note that nuclear plants also include positions associated with refueling, maintenance and repairs, and improvements; these are often contractors or suppliers rather than plant employees who work at the plants on a regular, but partial year basis according to refueling or maintenance schedules. We have not explicitly accounted for these workers in our analysis, but they represent a substantial number of jobs. Davis Besse and Perry each require an average of 224,400 man-hours on an annual basis (about 122 full time equivalents). Combined annual man-hours for both plants have been as high as 605,000 hours (about 290 full time equivalents). These workers include a variety of Building Trades crafts.[15]

As with the economic impact, the jobs impact occurs in large part indirectly—not necessarily as employment within the nuclear and electricity sectors, but as enhanced employment in other

[15] Building Trades crafts include boilermakers, carpenters, cement masons, electricians, insulators, iron workers, laborers, millwrights, operating engineers, painters, pipefitters, and sheet metal workers.

sectors, caused largely by the economic effect of lower power prices. In addition to the occupations directly impacted by the closures of the Davis-Besse and Perry plants, the employment sectors most influenced are retail sales, construction and extraction, and general management, business, and financial services. In a high gas price environment, job losses are higher (4,820), with nearly all the additional losses in secondary employment. In a low gas price environment, the direct job loss is comparable (1,210 direct jobs lost), but the secondary loss is considerably smaller, reflecting the smaller GDP effect at low gas prices—1,130 secondary jobs lost, for a total effect of 2,340 jobs.

E. Impact on Federal and State Tax Revenues

The Davis-Besse and Perry plants and the businesses providing goods and services to these plants pay substantial state and federal taxes. In addition, since these plants keep electricity prices lower and keep productive economic activity within the state, they create incremental economic output and associated tax revenues throughout the economy. Average incremental annual state and local tax payments attributable to these plants total $23 million, and average annual federal tax payments total $112 million, as shown in Table 5. In accord with the overall economic effects, the tax effects are larger in a high gas price environment, and smaller under low gas prices.

Table 5: Annual Tax Payments Attributable to Economic Activity Related to the Davis-Besse and Perry Plants (10-Year Average Annual, in Millions of Nominal Dollars, 2018–2027)

	Base Case	High Gas Price	Low Gas Price
State and Local Tax Revenues, Direct and Secondary	$23	$27	$8
Federal Tax Revenues, Direct and Secondary	$112	$134	$40
Total Federal, State, and Local Tax Revenues	$135	$161	$48

F. Davis-Besse and Perry Plants Prevent Substantial Carbon Dioxide and Criteria Pollutant Emissions within and outside the State

The Davis-Besse and Perry plants prevent substantial emissions of CO_2, SO_2, NO_X, and particulate matter, compared to the alternative of natural gas and coal-fired generation that would replace their output. We have not included a national climate policy in our simulations. Although broad climate policy rules such as the Clean Power Plan (CPP) or alternative greenhouse gas restrictions might affect the emissions impacts of nuclear power plants, the new administration has initiated activities to review and potentially to rescind the CPP, and it had been stayed pending legal challenges even before that. We do represent existing state-level policies such as Renewable Portfolio Standards, and the Regional Greenhouse Gas Initiative (RGGI) where it applies.

To understand the potential emissions effects, it is helpful to characterize the differences in generation with and without the Davis-Besse and Perry plants. The entire Eastern Interconnection is an integrated power system, and most of the power needed to replace the output of these two plants would come from outside Ohio (simply because Ohio supply accounts for a small share of total Eastern Interconnection supply, not because Ohio's swing supply is necessarily less economic than others). Natural gas is typically the marginal electricity fuel in the region, which means that most of the replacement energy would come from gas. Table 6 shows that 84% of the replacement generation would come from outside Ohio and that 74% of the total replacement energy would be fired by natural gas. While higher gas prices increase the power price effect and the economic effect, they actually reduce the emissions effect. In a high gas price environment, the relative economics of coal and gas drive higher-emitting coal plants to generate closer to their full capacity even with the nuclear plants operating, giving them less ability to increase further to replace nuclear generation, so that most of the replacement generation must come from lower-emitting gas-fired generators. The opposite occurs at lower gas prices; cheap gas causes gas plants to be highly utilized, and coal plants make up a larger share of the swing resources.

Table 6: Changes in Generation to Replace Davis-Besse and Perry Plants (Base Case, 10-Year Average Annual GWh, 2018–2027)

	Ohio	Outside Ohio	Total
Gas	2,495	10,189	12,684
Coal	181	4,205	4,386
Wind	0	-1	-1
Solar	0	-5	-5
Other	4	-3	0
Total	2,680	14,384	17,064

The corresponding emissions offsets provided by these two nuclear power plants are summarized in Table 7. Average annual power sector CO_2 emissions would be about 9.3 million metric tons greater without these two plants.[16] To put this in perspective, this would be equivalent to adding almost 2 million cars to the road, and represents 11% of the current power sector CO_2 emissions of Ohio.[17] The magnitude of this increase reflects the fact that these two nuclear power plants account for a substantial share of Ohio's generation mix, currently about 14%. If they were absent, the overall increase in fossil-fired generation, much of it imported, would be significant relative to Ohio's historical fossil baseline. Overall power sector SO_2 emissions would increase by more than 3,400 tons; this increase is 4% of the current in-state SO_2 emissions rate, a

[16] Throughout this paper, references to tons are in metric tons; 1 metric ton = 1.10231 short tons.

[17] 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

relatively high baseline since Ohio has significant coal generation.[18] Similarly, overall NO_X emissions would increase by 7%, and PM_{10} and $PM_{2.5}$ would each increase by about 10% of current Ohio emissions levels.[19]

Table 7: Emissions and Social Cost Prevented by the Davis-Besse and Perry Plants in the Eastern Interconnection (Base Case, 10-Year Average Annual Impacts, 2018–2027)

Pollutant	Avoided Emissions (tons)	Social Cost ($/ton)	Avoided Emissions Value ($ millions)
CO_2	9,288,983	$59	$548
SO_2	3,408	$8,578	$29
NO_x	4,080	$2,366	$10
PM_{10}	4,011	$680	$3
$PM_{2.5}$	3,238	$14,050	$45
Total			$635

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. All costs are stated in 2023 dollars, the mid-point of the study time horizon, and the SCC reflects emissions in that year.

The overall social cost of these changes in emissions can be estimated using the federal government's social cost of carbon ($59/ton)[20] and the National Academy of Science's externality

[18] The effect of these nuclear power plants on SO_2 emissions is limited by the EPA's Cross-State Air Pollution Rule (CSAPR), which caps the allowed emissions of SO_2 from some units. This cap is binding even with the nuclear power plants operating, and so in their absence, additional operational changes are required. These limits partly mitigate the direct effects on SO_2 emissions, which would otherwise be larger.

[19] In comparing these emissions increases with current Ohio emission levels, note that although the emissions increase would be triggered by the absence of nuclear generation in Ohio, only part of the total emissions increase actually occurs within Ohio, since most of the replacement generation comes from outside the state.

[20] The social cost of carbon used here, $59 per ton of CO_2, is the central value (based on a 3% discount rate) determined by the Interagency Working Group on Social Cost of Greenhouse Gases, for the mid-point of the study horizon in 2023, expressed in 2023 dollars. See the EPA Fact Sheet, Social Cost of Carbon, December 2015. (For reference, in 2017 dollars, the SCC is $46/ton, and the corresponding avoided emissions value would be $427 million.) Although a recent Executive Order from the Trump administration withdraws documentation of the working group's estimate of the social cost of carbon, it does not provide an alternative value. Nonetheless, the social cost of carbon has always been associated with significant uncertainty, and is now more controversial.

cost estimates for SO_2, NO_X, PM_{10}, and $PM_{2.5}$. Evaluated at these rates, shown in, the average annual avoided social cost of CO_2 is $548 million, and the avoided costs of SO_2 and NO_X are $29 million and $10 million, respectively. The avoided costs of PM_{10} and $PM_{2.5}$ emissions are approximately $3 million and $45 million, respectively. These costs reflect environmental and human health damages and are independent of and in addition to the direct and secondary economic impacts, assessed above, that result from higher power prices and reduced in-state power production. They reflect costs incurred by society, not directly by the economy; the subsequent economic implications of these social costs are not reflected in the economic results above, but would be in addition to those values.

Because most of the replacement generation comes from outside Ohio, most of the increase in emissions also occurs outside the state. Even so, the criteria pollutants that are emitted within Ohio may have substantial local impacts. In Appendix A, we discuss some of the potential local emissions effects of criteria pollutants, including how they may impact non-attainment areas in Ohio—those areas that are currently in non-attainment for federal air quality standards for one or more of the criteria pollutants.

Appendix A. Local Environmental Impacts

Since criteria pollutants can affect local air quality, it is also important to consider the location of these emissions impacts. We have done so by mapping all of the power plants in Ohio, locating them within Ohio counties, and determining what change, if any, they would experience in generation and emissions in the absence of the Davis-Besse and Perry plants. The locations of the Ohio power plants are presented in Figure A-1, and the plants are identified in Table A-1.

Figure A-1: Ohio's Fossil Fired Power Plant Locations

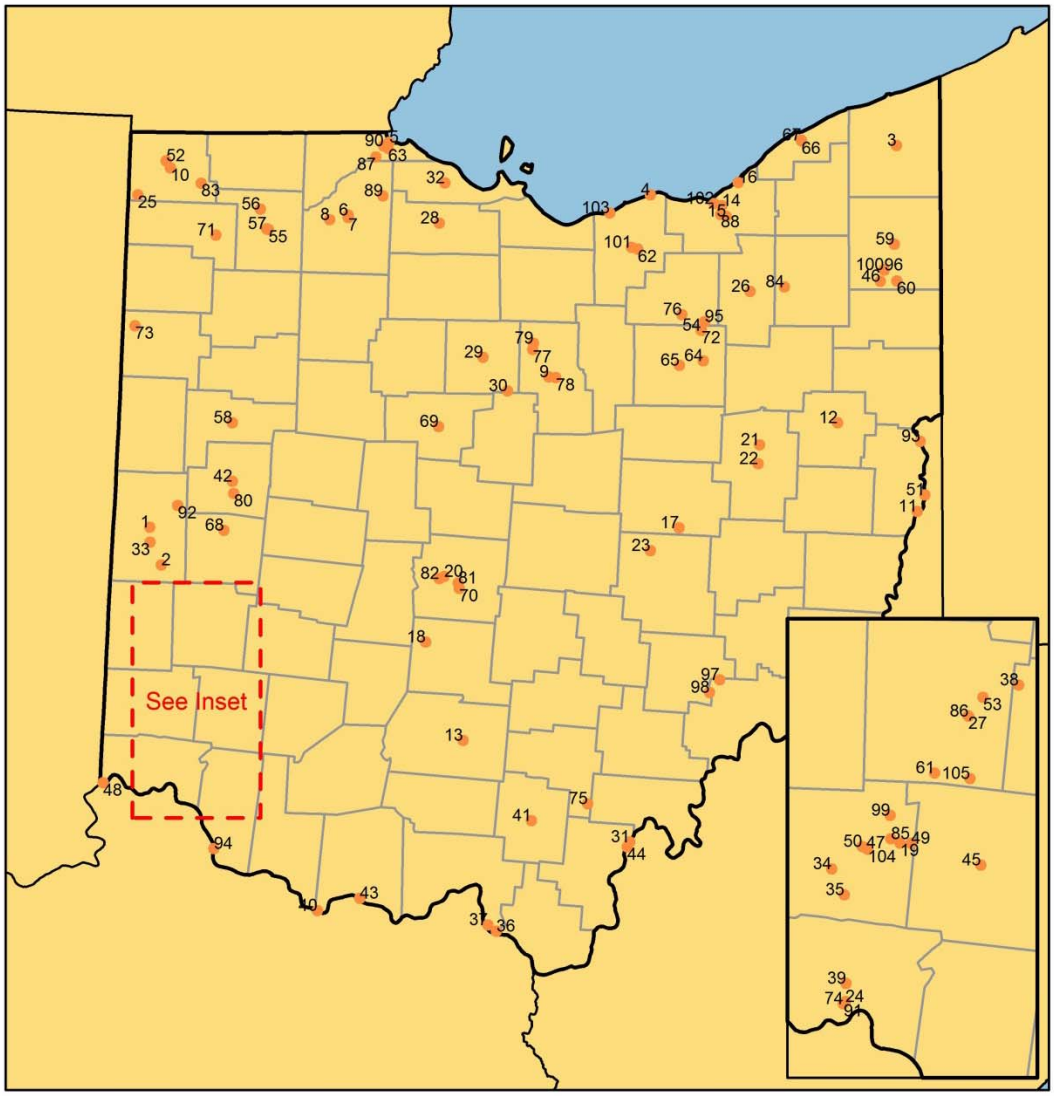


Table A-1: Ohio's Fossil Fired Power Plant Key

Item	Plant	Item	Plant
1	Arcanum	54	Morton Salt Rittman
2	Arcanum Peaking	55	Napoleon (City)
3	Ashtabula (CINERGY/TRIGEN)	56	Napoleon Peaking GT (AMP)
4	Avon Lake	57	Napoleon Peaking IC (AMP)
5	Bay Shore	58	New Knoxville
6	Bowling Green (AMP)	59	Niles (OH NILES)
7	Bowling Green Peaking	60	Niles (OH ORION)
8	Bowling Green Wind Farm Project	61	O H Hutchings
9	Broshco Fabricated Products	62	Oberlin (OH)
10	Bryan Peaking	63	Oregon Energy Center (OH)
11	Cardinal	64	Orrville
12	Carroll County Energy Project	65	Orrville Peaking
13	Chillicothe (OH)	66	Painesville
14	Cleveland (OH ISGCLVLND)	67	Painesville IC
15	Cleveland Peaking	68	Piqua
16	Collinwood	69	Prospect Municipal
17	Conesville	70	Renick Run 03 04
18	Darby Electric Generating Station	71	Richland
19	Dicks Creek	72	Rittman Paperboard
20	Dodge Park	73	Robert P Mone Plant
21	Dover (OH)	74	Rochelle Plant (OH)
22	Dover Peaking	75	Rolling Hills Generating LLC
23	Dresden Energy Facility	76	Seville
24	East Campus Utility Plant	77	Shelby Munic Light Plant
25	Edgerton	78	Shelby North
26	Engle	79	Shelby South
27	Frank M Tait	80	Sidney
28	Fremont Energy Center	81	St 1a 0006
29	Galion (OH AMP OH)	82	St 8 0005
30	Galion Generating Station	83	Stryker
31	Gavin	84	Summit Street Power Plant
32	Genoa Diesel Generating Station	85	SunCoke Energy Project
33	Greenville Electric Generating	86	Tait Electric Generating Station
34	Hamilton	87	Toledo PRT
35	Hamilton Peaking	88	Tolliver Plant
36	Hanging Rock Energy Facility	89	Troy (OH)
37	Haverhill North Cogeneration Facility	90	US Coking Cogeneration Facility
38	Heat Plant 770	91	Univ of Cincinnati
39	Ivorydale	92	Versailles Peaking
40	J M Stuart	93	W H Sammis
41	Jackson	94	W H Zimmer
42	Jackson CNTR Peaking	95	Wadsworth
43	Killen Station	96	Warren Natural Gas
44	Kyger Creek	97	Washington Energy Facility
45	Lebanon	98	Waterford Energy Facility
46	Lordstown Combined Cycle	99	Wausau Paper Middletown
47	Madison (OH)	100	Wci Steel Inc
48	Miami Fort	101	Wellington (OH)
49	Middletown Energy Center	102	West 41ST Street
50	Millercoors Trenton Brewery	103	West Lorain
51	Mingo Junction	104	Woodsdale
52	Montpelier	105	Yankee Street
53	Monument		

Note: Includes plants currently operating. Plants that have announced a shutdown date are removed from the study at that date.

We also considered whether the county is in attainment with Clean Air Act standards for criteria pollutants, and checked for instances where a plant that is located within a non-attainment area for a particular pollutant would increase its emissions of that pollutant in the absence of the Davis-Besse and Perry plants. This analysis is illustrated in a series of maps below. Each map illustrates, for a given pollutant, the Ohio generating plants, indicating whether their emissions increase (red dot), stay the same (black dot) or fall (blue dot), in the absence of the Davis-Besse and Perry plants. The size of the dot indicates the magnitude of the change in emissions. We pay particular attention to those counties that are not currently in attainment with U.S. EPA standards under the Clean Air Act for one or more of the criteria pollutants; these counties are shaded on the relevant maps.

This analysis revealed that absent the Davis-Besse and Perry plants, there are a number of instances in which fossil plant emissions of a criteria pollutant would increase in a county that is already in non-attainment for that pollutant. This can be seen where there is a red dot within a shaded county, indicating that a power plant located in a non-attainment area is increasing its emissions. In fact, because those locations are already out of compliance, additional actions may be required to mitigate these emissions increases, possibly including redispatch to utilize more costly generation sources located outside the non-attainment area, or to add costly emissions controls to the affected plants. These additional actions could increase the electricity cost effect beyond our estimates. Emissions increases in locations that are currently in compliance with federal standards could potentially push some of them into non-compliance, creating similar issues in additional locations.

Table A-2 presents the aggregate change in emissions within Ohio absent the Davis-Besse and Perry plants (this excludes incremental emissions that occur outside Ohio, in contrast with Table 7, which showed the emissions impact for the entire Eastern Interconnection). It is important to note that airborne transport could spread criteria pollutants to nearby and downwind locations; our analysis does not account for such transport and is thus only indicative of the types of problems that may arise. The table also does not present the increase in emissions at power plants that are outside of Ohio, but might affect Ohio air quality due to airborne pollutant transport. The table does show that criteria pollutant emissions within the state represent about $15 million in annual social costs (harm to health, the environment, *etc.*). Over half of this amount, $8 million, is attributable to SO_2, and another $6 million is due to $PM_{2.5}$. The location and change in emissions by type and Ohio county are discussed below.

It is worth noting that in a low gas price environment, emissions of all types within Ohio would be dramatically higher, as would the social costs. With low gas prices, gas plants run much more to begin with, and thus have less flexibility to increase their output to replace nuclear generation. This means that coal plants in general, and particularly Ohio coal plants, tend to be the swing resource in the region, so that a larger share of replacement generation comes from within Ohio to begin with, and a larger share of this comes from coal plants that typically have higher emission rates for all pollutants than gas plants.

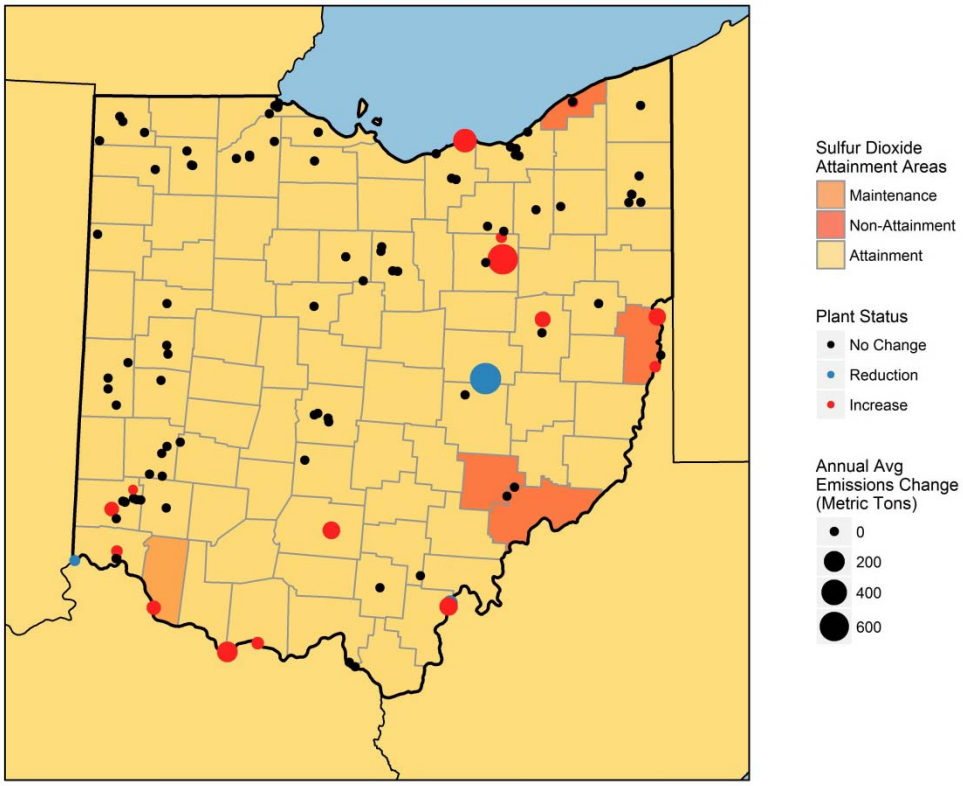
Table A-2: Emissions and Social Cost Prevented by Davis-Besse and Perry Plants within Ohio (Base Case)
(Annual Impacts, 10-Year Average, 2018–2027)

Pollutant	Avoided Emissions (tons)	Social Cost ($/ton)	Avoided Emissions Value ($ millions)
CO_2	1,182,337	$59	$69.7
SO_2	871	$8,578	$7.5
NO_x	313	$2,366	$0.7
PM_{10}	511	$680	$0.3
$PM_{2.5}$	420	$14,050	$5.9
Total			$84

SO_2

The SO_2 annual emissions increase of 871 tons presents an overall social cost of $8 million annually, the highest among the criteria pollutants, reflecting the quantity of incremental emissions in Ohio and its significant human health cost. At present, 4 Ohio counties are in non-attainment for SO_2 and one county is in maintenance. Absent the Davis-Besse and Perry plants, emissions would increase in 11 of Ohio's 88 counties, as shown in Figure A-2. This might result in non-attainment in some of those counties, though that was not analyzed here.

Figure A-2: SO_2 Emissions Increase absent Davis-Besse and Perry Plants

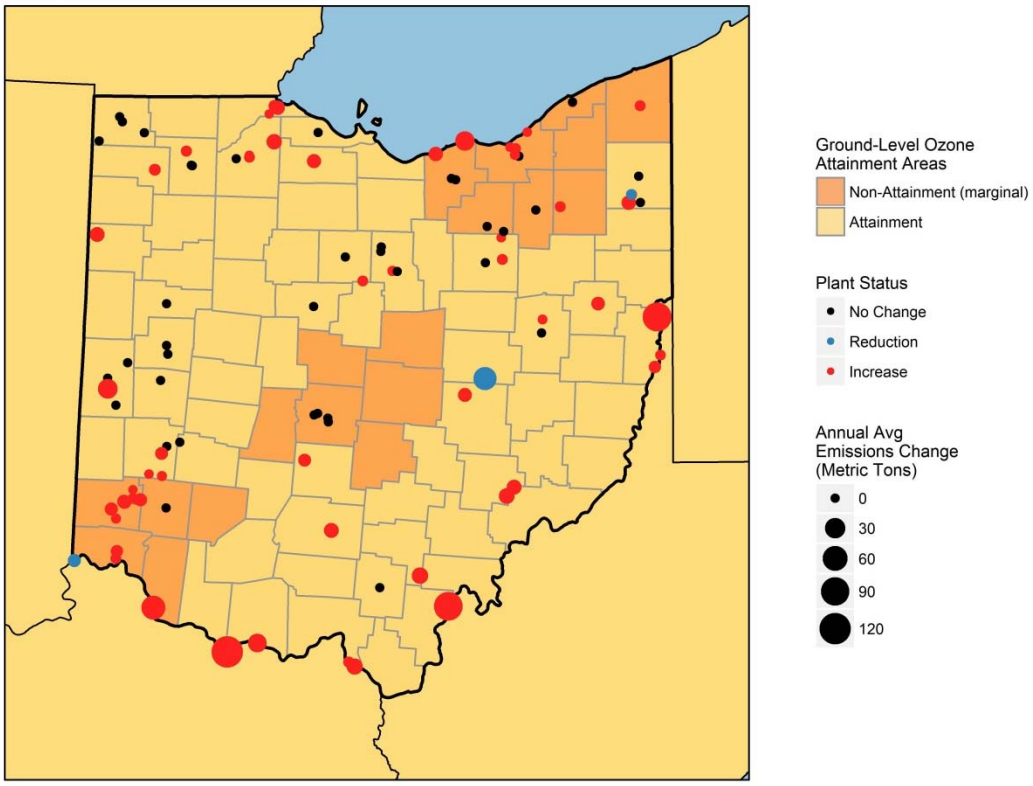


NOx

The overall social cost of the increase in NOx absent these nuclear power plants is $1 million annually, but NOx is also a precursor of ground level Ozone.[21] At present, no Ohio counties are in non-attainment for NOx, but 19 are in non-attainment for ozone. NOx emissions in Ohio are projected to increase by 313 tons per year, absent the Davis-Besse and Perry plants. This increase may raise the cost of bringing many of these counties into attainment for Ozone. The locations of NOx increases are shown alongside the non-attainment areas for Ozone in Figure A-3. To the extent that the increase in NOx emissions occurs in the more populous areas of Ohio, this could exacerbate population exposures.

[21] Ground level or tropospheric ozone occurs when nitrogen oxides (NOX), carbon monoxide (CO) and volatile organic compounds (VOCs), react in the atmosphere in the presence of sunlight. Ozone imposes social costs in the form of adverse health effects, particularly to those with pulmonary system problems including asthma. Ground level ozone has also been found to negatively affect agriculture. Reducing NOX is generally the preferred means to lower ozone levels. Determining the impact of power plant NOX emissions on ozone levels is beyond the scope of this report, but increased NOX emissions is likely to compromise efforts to reduce ozone across much of the state.

Figure A-3: NO_X Emissions Increase absent Davis-Besse and Perry Plants



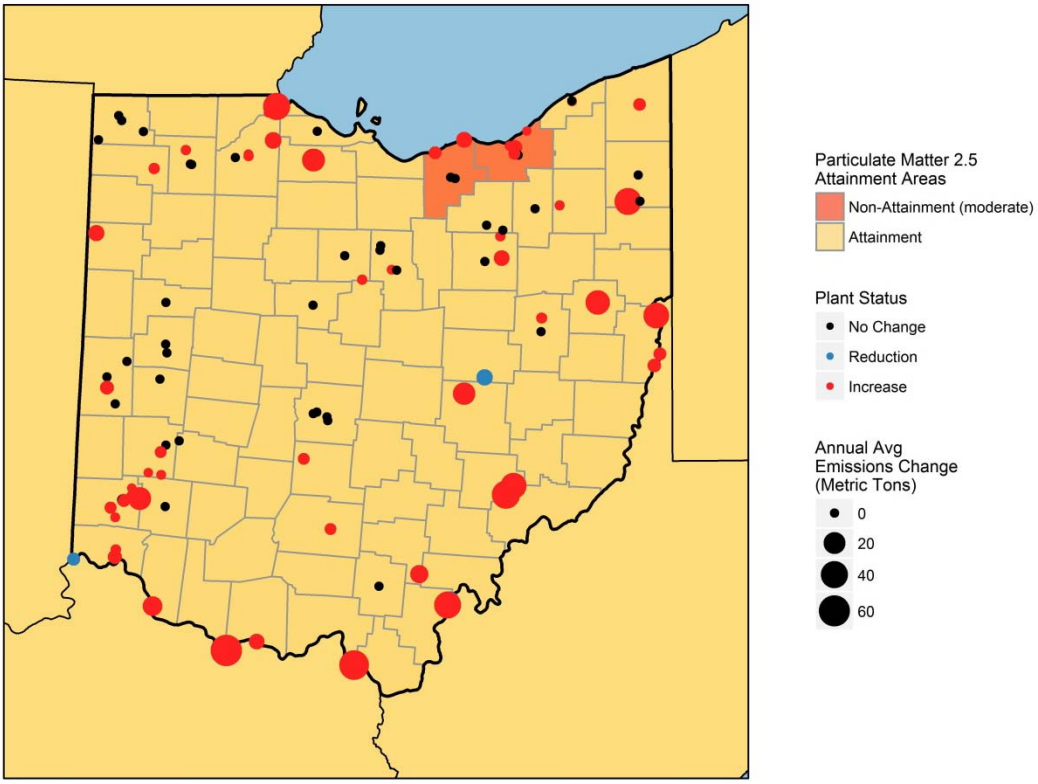
PM_{10}

The increase in PM_{10} emissions that would occur in Ohio, absent the Davis-Besse and Perry plants, is 511 tons, imposing social costs of $0.3 million annually. Two Ohio counties are in non-attainment for PM_{10}.

$PM_{2.5}$

As Table A-2 indicates, the $PM_{2.5}$ emissions increase of 420 tons annually within Ohio results in a social cost of $6 million. At present, two Ohio counties fail to meet air quality standards for $PM_{2.5}$. Without other actions, in the absence of the Davis-Besse and Perry plants, $PM_{2.5}$ emissions would increase in 32 of 88 counties statewide due to increased fossil generation, as shown in Figure A-4 (this does not account for airborne transport). These increases could place some counties into non-attainment with the Clean Air Act.

Figure A-4: $PM_{2.5}$ Emissions Increase absent Davis-Besse and Perry Plants



CAMBRIDGE
NEW YORK
SAN FRANCISCO
WASHINGTON
TORONTO
LONDON
MADRID
ROME
SYDNEY

THE Brattle GROUP