Salem and Hope Creek Nuclear Power Plants' Contribution to the New Jersey Economy

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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, The Brattle Group has evaluated the contribution that the Salem and Hope Creek nuclear power plants in New Jersey make to the state's economy. 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 New Jersey 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, New Jersey's GDP will be higher with these plants operating than it would be without them. These plants also maintain jobs within New Jersey; 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 both within and outside New Jersey. 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 continued operation of these nuclear plants. As a result, this analysis effectively calculates the gross economic benefits of preserving these plants, not the net benefit of a proposed policy that would do so.[1]

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[1] 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. Also, while reductions in electricity costs do benefit consumers, the offsetting impact on producer revenues must

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Our analysis has determined that over the next ten years (2018–2027), the Salem and Hope Creek plants operating in New Jersey:

- **Contribute approximately $809 million annually to state gross domestic product** (GDP).
- **Account for 5,800 in-state jobs** (direct and secondary).
- **Help keep electricity prices low**. New Jersey consumers would pay $400 million more for electricity annually, about $3.3 billion more in present value over the next ten years, without these two plants.
- **Are responsible for $37 million in state tax revenues** annually.
- **Avoid 13.8 million metric tons of CO_2 emissions annually** over the next ten years, valued at $585 million per year.
- **Avoid significant amounts of other air pollutants annually**, valued at $148 million per year over the next ten years.

These measures reflect the significance of these two nuclear power plants for the New Jersey economy, and are determined by comparing the performance of New Jersey's economy with these plants operating 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 nuclear power plants, New Jersey and the broader region would rely more heavily on natural gas and coal-fired generating plants, many of which are outside New Jersey, leading to considerably greater reliance overall on out-of-state generation, and transforming New Jersey from being a modest importer, producing almost as much electricity as it consumes, to being a substantial net importer, procuring over a third of its electricity requirements from out of state. 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 New Jersey. It would also raise power prices; without these two nuclear power plants, wholesale electricity prices in New Jersey and throughout the broader region would be higher. Higher prices would flow through to residential, commercial and industrial consumers as higher electricity bills. It is this effect on electricity prices that accounts for about half of the overall incremental economic impact; the reduction of in-state generation and associated economic activity is also important. Note that these measures reflect only the impacts within New Jersey, although the absence of these two New Jersey nuclear power plants will have significant additional negative consequences in the form of higher power prices beyond the state's borders.

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

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also be considered to determine whether they improve total social welfare. Our analysis of economic impacts—GDP, jobs, and tax revenues—does account for the producer revenue impacts.

the Salem and Hope Creek plants, because the replacement generation would be almost entirely fossil-fired. Compliance with national ambient air quality standards (NAAQS), such as for ozone season 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 New Jersey to achieve targeted CO_2 reductions under any future climate policy.[2] Further, the pollutant impacts are not limited to New Jersey, first because much of the replacement generation would come from outside New Jersey, 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.

I. Background

Three nuclear power plants, comprising 4 nuclear reactors, operate in New Jersey; see Figure 1. The Oyster Creek Nuclear Generating Station, a single-unit boiling water reactor plant located about 75 miles south of New York City, is scheduled to be shut down permanently at the end of 2019. The Salem Nuclear Power Plant consists of two pressurized water reactors and is located 30 miles south of Wilmington, Delaware; Units 1 and 2 are licensed to operate until 2036 and 2040, respectively. The Hope Creek Nuclear Generating Station, a single-unit boiling water reactor adjacent to the Salem plant, is licensed to operate until 2046. Together, these four reactors represent 4,100 megawatts (MW) of generating capacity and almost 32 million megawatt hours (MWh) of annual electricity generation, as shown in Table 1. After the closure of Oyster Creek, the remaining two plants will account for 3,500 MW of capacity and almost 27 million MWh of annual generation.

New Jersey is a part of the PJM Interconnection, the electric region operated by the PJM independent system operator.[3] PJM encompasses much more than just New Jersey, both geographically and electrically; New Jersey accounts for about 10% of PJM's total generation and load. Within New Jersey itself, these three nuclear power plants represent a very large share of generation and capacity at 43% and 26%, respectively, as illustrated in Figure 2.

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[2] We do not consider a national climate policy in this study. Although the Clean Power Plan, EPA's rule to limit greenhouse gas emissions from existing power plants, nominally would take effect in 2022, the Trump administration has announced its intention to reverse it.

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

Figure 1: Locations of New Jersey Nuclear Power Plants

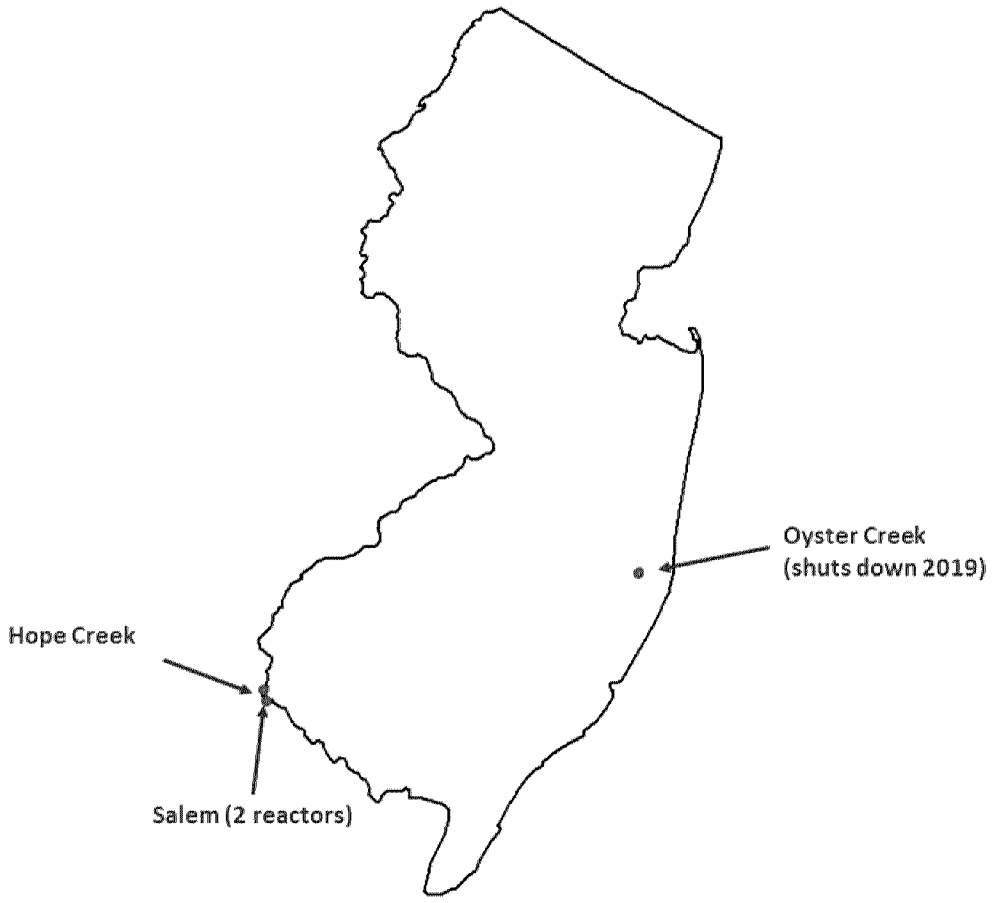


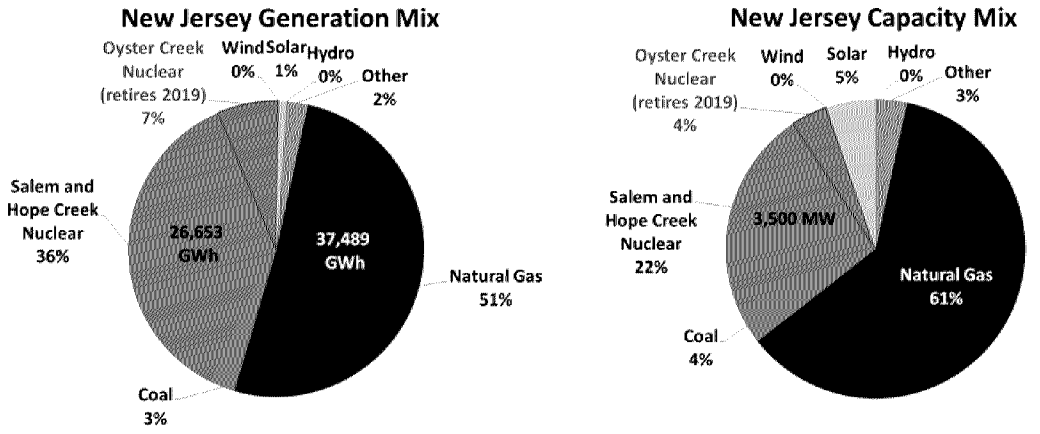
Table 1: Summary of New Jersey Nuclear Power Plants

Item	Oyster Creek	Salem	Hope Creek	**Total New Jersey Nuclear through 2019***	**Total New Jersey Nuclear after 2019***
Number of Units	1	2	1	**4**	**3**
Total Net Summer Capacity (MW)	608	2,328	1,172	**4,108**	**3,500**
Average Annual Generation (GWh)	4,898	16,858	9,796	**31,551**	**26,653**

Sources & Notes: Data from ABB, Inc., Energy Velocity Suite. Average annual generation is the average of 2014–2016.

*Oyster Creek is scheduled to shut down permanently at the end of 2019; only Salem and Hope Creek remain beyond 2019.

Figure 2: New Jersey Electricity Generation and Capacity Shares, by Fuel



Sources & Notes: EIA Form 923, via ABB, Inc., Energy Velocity Suite. Generation is average 2014-2016 historical values; capacity is as of September 2017.

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

We have estimated the economic value of the Salem and Hope Creek plants to the state of New Jersey using REMI, a widely-used regional economic model.[4] Our analysis covers a ten year period, 2018-2027. The effect of these two plants on the New Jersey economy occurs through two main channels. First, electricity costs are lower for New Jersey consumers with the nuclear power plants operating than they would be without them. The absence of the Salem and Hope Creek 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 current capacity surplus, raising capacity prices). Higher wholesale prices translate directly to higher retail prices and customer costs in a restructured state like New Jersey. The second major economic effect is that with its nuclear power plants operating, New Jersey produces almost as much power as it consumes, but it would become a significant net importer without them. The loss of in-state power production would mean a material reduction in 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 and retirement as well as dispatch to capture the dynamics of power system operation, power

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

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 New Jersey are reported.

We analyze the power sector and the economy both with and without the Salem and Hope Creek plants, to determine the economic effects attributable to them (the Oyster Creek plant is modeled as operating through 2019 in both cases). Our analysis indicates that keeping these two plants operating will keep electricity costs lower in New Jersey, 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 New Jersey 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 $809 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 New Jersey. 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 Salem and Hope Creek Plants to the New Jersey Economy (10-Year Average Annual Impacts, 2018–2027)

Direct and Secondary GDP *(2017 dollars)*	$809 million
Direct and Secondary Employment *(jobs)*	5,800
Direct	1,400
Secondary	4,400
State and Federal Taxes *(2017 dollars)*	
Direct and Secondary State Tax Revenues	$37 million
Direct and Secondary Federal Tax Revenues	$204 million

Our analysis shows that the Salem and Hope Creek plants are responsible for $809 million in state GDP and 5,800 jobs (considerably more secondary jobs than direct jobs, as discussed below). 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 contributing to a substantial overall impact.[5]

The owners of these two nuclear power plants also pay significant federal and state 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 $37 million in incremental state tax revenues and $204 million in federal tax revenues, beyond the tax revenues that would be available in their absence.

Below, we provide further detail regarding the impact of the Salem and Hope Creek 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

With the Salem and Hope Creek plants operating, New Jersey is a modest net importer of power, producing slightly less than it consumes, as shown in the left panel of Figure 3 below. The right panel shows the situation in New Jersey without these nuclear plants; the state would become a significant net importer of power, relying on out-of-state sources for over a third of its 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.[6] The reduction in economic activity that

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[5] Our 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. We also examined the sensitivity of our results to materially higher or lower natural gas prices, since natural gas is a key factor in regional electricity markets. We found that in a higher gas price environment, these nuclear power plants would have a somewhat larger effect on GDP, and lower gas prices would slightly decrease their economic impact. The plants' effects on electricity price and emissions go in the other direction, being somewhat smaller at high gas prices, and larger at low gas prices.

[6] New Jersey is 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

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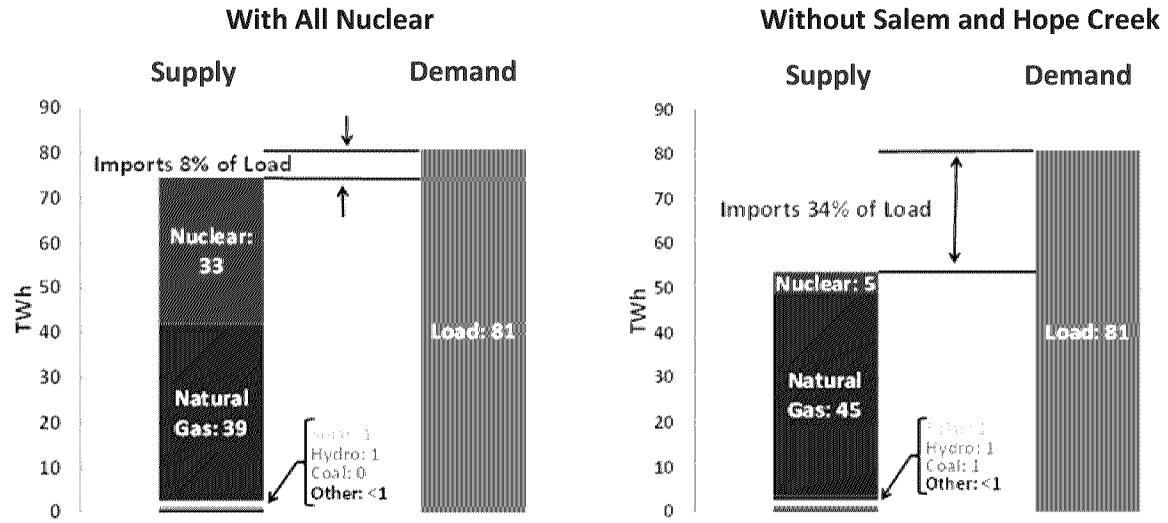
accompanies the loss of in-state generation is responsible for a significant share of the overall economic effect.

Large-scale renewable energy probably would not increase significantly in the near term beyond the 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 offset a significant share of the lost emission-free generation of the nuclear plants.

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



Note: This characterization precedes Oyster Creek's 2019 shutdown, after which its 5 TWh of generation will be removed from both panels, replaced by a mix of mostly imports and some in-state gas generation.

B. IMPACT ON ELECTRICITY PRICES

As noted above, absent the Salem and Hope Creek plants, electricity demand would be met by increased utilization of natural gas and coal-fired plants, some within New Jersey 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 New Jersey and across PJM.[7] As shown in

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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 New Jersey.

7 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

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Table 3, average power prices in New Jersey would be $4.99/MWh higher without these two nuclear power plants.[8] Because the PJM-East region that includes New Jersey needs its own local generating capacity, the loss of the large amount of capacity from these plants causes a notable increase in capacity prices within this region. (There is currently a modest capacity surplus in PJM-East; the loss of these two plants would eliminate much of that surplus in the near term, raising capacity prices.[9]) In fact, the capacity price effect accounts for over half of the total electricity price effect in PJM-East. The overall average price effect in PJM as a whole is considerably smaller at $1.30/MWh; outside PJM-East, the energy price effect is smaller, and the capacity price effect is slightly negative.

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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.

8 The electricity sector model used here depicts six sub-regions within PJM. New Jersey is contained entirely within one of these, PJM-East, which also includes the Philadelphia metro area in south-eastern Pennsylvania, and the Delmarva Peninsula (Delaware, the Eastern Shore of Maryland and the Eastern Shore of Virginia). The New Jersey average effect is assumed to be the same as the PJM-East average effect (*i.e.*, we do not consider transmission congestion within the PJM-East sub-region). The PJM average is the load-weighted average across all six PJM sub-regions.

9 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 finds 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.

Table 3: Salem and Hope Creek Plants Avoid Higher Electricity Prices (All-in Power Price and Cost Differences due to Salem and Hope Creek Plants)

	% of Utility Load[1]	Power Price Change without Nuclear ($/MWh)[2]	Wholesale Electric Demand (millions of MWh)	Annual Electricity Cost Change (2017 $millions)	Total Electricity Cost Increase Over 10 Years (2017 $millions)[3]
New Jersey Average		**$4.99**	**80**	**$400**	**$3,311**
Residential	39%		31	$155	$1,283
Commercial/Industrial	61%		49	$245	$2,028
PJM Average		**$1.30**	**823**	**$1,073**	**$8,949**
Residential	37%		306	$399	$3,324
Commercial/Industrial	63%		518	$674	$5,626

[1]Load share by customer class is based on data from 2015, EIA Form 861.

[2]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.

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

This $4.99/MWh price increase in New Jersey translates to about $3.64 per month for a typical residential ratepayer; across all New Jersey consumers, this represents an increase of $400 million per year in electricity costs, or about $3.3 billion in present value over ten years.[10] Across the state, about 39% of these increased costs would fall on residential customers, and 61% on commercial and industrial customers. Preventing higher electricity prices is a major means by which these nuclear power plants benefit New Jersey's economy. By keeping electricity prices lower, these plants leave residential, commercial, and industrial consumers with more money to spend and invest in other ways; this boosts jobs, output, and the overall economy (though again, these are the gross impacts, without accounting for the cost of any nuclear support mechanism).

C. Impact on Economic Output

The Salem and Hope Creek plants contribute an average of $809 million to annual state GDP ($1.29 billion in gross output), in part through the electricity price effects shown above, and also

[10] Electricity transmission requirements might affect the level and the geographic distribution of electricity costs. 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 costs could, however, be substantial if a premature transition from nuclear to natural gas were to occur, as noted by a PJM study regarding the closure of nuclear plants in Illinois. See PJM Response to Illinois Commerce Commission (ICC) Request to Analyze the Impact of Various Illinois Nuclear Power Plant Retirements, 10/21/2014. PJM found that premature retirement would require "substantial time to correct"; "would require substantial construction activity and could significantly inconvenience Illinois citizens"; and "[transmission] costs would be significant—in the hundreds of millions of dollars or more" (page 7).

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 New Jersey. The largest effect is found in the utilities sector, as expected, followed by the construction and manufacturing sectors, as shown in Table 4.

Table 4: GDP and Gross Output Impacts by Sector in New Jersey (10-Year Average Annual Direct and Secondary Impacts in Millions of 2017 Dollars, 2018–2027)

Sector	Output Impact
Utilities	$411
Construction	$184
Manufacturing	$154
Retail Trade	$69
Professional, Scientific, and Technical Services	$68
Real Estate and Rental and Leasing	$62
Health Care and Social Assistance	$45
Wholesale Trade	$39
Accommodation and Food Services	$30
Information	$29
Other	$201
Gross Economic Output Impact, Direct and Secondary*	$1,292
GDP Impact, Direct and Secondary	$809

* 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 Salem and Hope Creek plants account for 5,800 direct and secondary jobs in the state's economy, as shown in Table 5. Direct jobs include those positions necessary for plant operations such as engineers and technicians as well as security and administration. We find a net loss of about 1,400 jobs in the power sector.[11] As with the economic impact, the overall jobs impact

[11] There are roughly 1,600 direct employees at the plants, not including contractors and suppliers such as the 1,000 temporary jobs associated with twice-annual refueling and maintenance outages. If the plants close, the lost direct jobs are partly offset by an increase of about 200 jobs associated with the increase in in-state non-nuclear generation that partly offsets the loss of the nuclear output.

occurs in large part indirectly; not necessarily as employment within the nuclear and electricity sectors, but as enhanced secondary employment in other sectors, caused largely by the economic effect of lower power prices. As shown in Table 5, in addition to the occupations directly impacted by the nuclear plants, the employment sectors most influenced are sales, construction, and business and financial occupations.

Table 5: Net Employment Impacts by Category in New Jersey
(Direct and Secondary Impacts, Number of Jobs, 10-Year Average, 2018–2027)

Category	Employment Impact
Sales and related, office and administrative support occupations	1,220
Construction and extraction occupations	780
Management, business, and financial occupations	510
Installation, maintenance, and repair occupations	350
Food preparation and serving related occupations	330
Building and grounds cleaning and maintenance, personal care and service occupations	280
Transportation and material moving occupations	270
Production occupations	260
Healthcare occupations	250
Computer, mathematical, architecture, and engineering occupations	240
Other	1,310
Total	5,800

Note: Numbers may not sum due to independent rounding.

E. IMPACT ON FEDERAL AND STATE TAX REVENUES

The Salem and Hope Creek 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 activity within the state, they create incremental economic output and associated tax revenues throughout the economy. We used the recent historical relationship between New Jersey GDP and tax payments at both the state and federal levels to estimate the tax revenue impact of the plants. Using this approach, average incremental annual state tax payments attributable to these plants are estimated at $37 million, and average annual federal tax payments at $204 million, as shown in Table 6.

Table 6: Annual Federal and State Tax Payments Attributable to Economic Activity Related to the Salem and Hope Creek Plants (10-Year Average Annual Impacts, in 2017 Dollars, 2018-2027)

Direct and Secondary State Tax Revenues	$37 million
Direct and Secondary Federal Tax Revenues	$204 million
Total Federal and State Tax Revenues	$241 million

F. Salem and Hope Creek Plants Prevent Substantial Carbon Dioxide and Criteria Pollutant Emissions within and outside the State

The Salem and Hope Creek plants prevent substantial emissions of CO_2, SO_2, NO_X, and particulate matter ($PM_{2.5}$ and PM_{10}), 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 Trump administration has initiated activities to review and potentially reverse the CPP, which 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 they apply.

To understand the potential emissions effects, it is helpful to characterize the differences in generation with and without the Salem and Hope Creek 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 New Jersey (simply because New Jersey supply accounts for a small share of total Eastern Interconnection supply, not because New Jersey's swing supply is necessarily less economic). Natural gas is typically the marginal electricity fuel in the region, which means that most of the replacement energy would come from gas. Table 7 shows that 79% of the replacement generation would come from outside New Jersey, and that 85% of the total replacement energy would be fired by natural gas.

Table 7: Changes in Generation to Replace Salem and Hope Creek Plants (10-Year Average Annual GWh, 2018-2027)

	New Jersey	Outside New Jersey	Total
Gas	4,328	19,070	23,398
Coal	1,529	2,616	4,145
Wind	0	18	18
Solar	0	77	77
Other	2	31	33
Total	5,858	21,813	27,671

The corresponding emissions offsets provided by these two nuclear power plants are summarized in Table 8. Average annual power sector CO_2 emissions would be about 13.8 million metric tons greater absent these two plants.[12] To put this in perspective, this would be equivalent to adding about 3 million cars to the road – which would about double the total number of automobiles in New Jersey.[13] Alternatively, this would represent a 69% increase relative to New Jersey's current power sector CO_2 emissions. The magnitude of this increase reflects the fact that these two nuclear power plants account for a large initial share (36%) of New Jersey's generation mix. If they were absent, fossil-fired power, much of it imported, would increase by a very large amount relative to the historical New Jersey fossil baseline. Overall power sector SO_2 emissions would increase by more than 4,000 tons; this increase is 88% of the current in-state SO_2 emissions, which are relatively low since New Jersey has little coal.[14] Similarly, overall NO_X, PM_{10}, and $PM_{2.5}$ would all increase by more than current New Jersey emissions levels.[15]

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[12] Throughout this paper, references to tons are in metric tons; 1 metric ton = 1.10231 short tons. Emissions of CO_2 and criteria pollutants will already experience an increase when the Oyster Creek nuclear power plant retires at the end of 2019. The Oyster Creek effect does not contribute to the differences shown here, however, since it is modeled as retiring at the same time regardless of the status of the Salem and Hope Creek plants.

[13] 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. In 2015, 2.92 million automobiles were registered in New Jersey; Federal Highway Administration, Highway Statistics 2015.

[14] 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 changes partly mitigate the direct effects on SO_2 emissions, which would otherwise be larger.

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

Table 8: Emissions and Social Cost Prevented by the Salem and Hope Creek Plants in the Eastern Interconnection (10-Year Average Annual Impacts, 2018–2027)

Pollutant	Avoided Emissions (tons)	Social Cost ($/ton)	Avoided Emissions Value (2017 $millions)
CO_2	13,779,652	$42	$585
SO_2	4,331	$7,546	$33
NO_x	6,367	$2,082	$13
PM_{10}	9,537	$598	$6
$PM_{2.5}$	7,778	$12,360	$96
Total			$733

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.

The overall social cost of these incremental emissions can be estimated using the federal government's social cost of carbon ($42/ton)[16] and the National Academy of Science's externality cost estimates for SO_2, NO_X, PM_{10}, and $PM_{2.5}$. Evaluated at these rates, which are shown in Table 8, the average annual avoided social cost of CO_2 is $585 million, and the avoided costs of SO_2 and NO_X are $33 million and $13 million, respectively. The avoided costs of PM_{10} and $PM_{2.5}$ emissions are approximately $6 million and $96 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 New Jersey, most of the increase in emissions also occurs outside the state. Even so, the incremental criteria pollutants that are emitted within New Jersey 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-

[16] The social cost of carbon used here, $42 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 2015, converted to 2017 dollars. See the EPA Fact Sheet, Social Cost of Carbon, December 2015. Although President Trump issued an Executive Order that withdrew documentation of the working group's social cost of carbon estimate, 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.

attainment areas in New Jersey—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 New Jersey, locating them within New Jersey counties, and determining what change, if any, they would experience in generation and emissions in the absence of the Salem and Hope Creek plants. The locations of the New Jersey power plants are presented in Figure A-1, and the plants are identified in Table A-1.

Figure A-1: New Jersey's Power Plant Locations

Table A-1: New Jersey's Power Plant Key

Item	Plant	Item	Plant
1	Asbury Park Press Inc	35	Marina Energy
2	Aventis Pharmaceuticals	36	Masterfoods USA
3	B L England	37	Merck Rahway Power Plant
4	Bayonne Cogeneration Plant	38	Midtown Thermal Control Center
5	Bayonne Energy Center	39	Montclair Cogeneration
6	Bayville Central Facility	40	NRG Energy Center Princeton Hospital
7	Bayway Refinery	41	National Gypsum CHP
8	Bergen	42	Newark Bay Cogeneration Project
9	Bristol Myers Squibb	43	Newark Energy Center (NJ)
10	Bristol Myers Squibb Lawrenceville	44	Ocean Peaking Power LP
11	CPV Woodbridge Energy Center	45	Oyster Creek Nuclear Generating Station
12	Camden Cogeneration	46	PSEG Burlington Generating Station
13	Carneys Point Generating Plant	47	PSEG Linden Generating Station
14	Clayville Switch GT	48	PSEG Salem Generating Station
15	College of New Jersey	49	Parlin
16	Cumberland (NJ)	50	Paulsboro Refinery
17	Eagle Point Cogeneration	51	Pedricktown Cogeneration Plant
18	Elmwood Park	52	Princeton University West Windsor Solar
19	Essex (NJ PSEG)	53	Red Oak
20	Essex County Correctional Facility	54	Repauno Products
21	Forked River	55	Roche Vitamins Inc
22	Freehold Ashbury Park Press	56	Rowan University
23	Gilbert	57	Rutgers University Busch Cogeneration
24	Hoffmann Laroche Inc	58	Salem Nuclear Power Plant
25	Hope Creek Nuclear Power Plant	59	Sayreville
26	Howard M Down	60	Sayreville Cogeneration Facility
27	Hunterdon Cogeneration	61	Schering Cogen Facility
28	Inlet District Energy Center	62	Seaside Heights Power Plant
29	Kearny Generating Station	63	Sewaren
30	Kenilworth Energy	64	Trigen Trenton
31	Linden Cogen Plant	65	United Water
32	Logan Generating Plant	66	Univ Medicine Dentistry
33	MTF Combined Heat & Power Facility	67	West Deptford Power Project
34	Mannington Mills Cogen	68	West Station

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 Salem and Hope Creek plants. This analysis is illustrated in a series of maps below. Each map illustrates, for a given pollutant, the New Jersey generating plants, indicating whether their emissions increase (red dot), stay the same (black dot) or fall (blue dot), in the absence of the Salem and Hope Creek 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 reveals that absent the Salem and Hope Creek 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 New Jersey absent the Salem and Hope Creek plants (this excludes incremental emissions that occur outside New Jersey, in contrast with Table 8, 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 New Jersey, but might affect New Jersey air quality due to airborne pollutant transport. The table does show that criteria pollutant emissions within the state represent about $30 million in annual social costs (harm to health, the environment, *etc.*). Almost half of this ($14 million) is attributed to $PM_{2.5}$. The location and change in emissions by type and New Jersey county are discussed below.

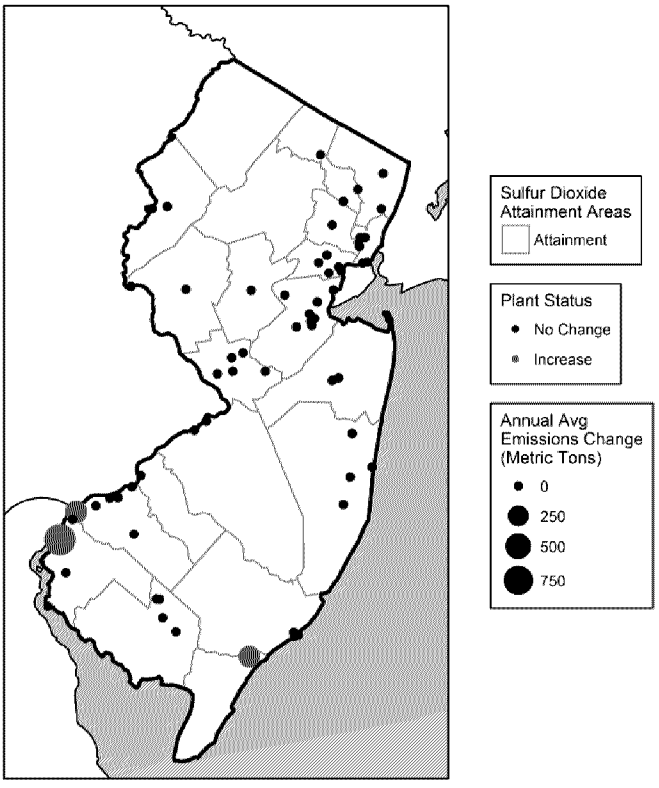
Table A-2: Emissions and Social Cost Prevented by Salem and Hope Creek Plants within New Jersey (10-Year Average Annual Impacts, 2018–2027)

Pollutant	Avoided Emissions (tons)	Social Cost ($/ton)	Avoided Emissions Value (2017 $millions)
CO_2	3,323,263	$42	$141
SO_2	1,529	$7,546	$12
NO_x	1,637	$2,082	$3
PM_{10}	1,382	$598	$1
$PM_{2.5}$	1,115	$12,360	$14
Total			$171

SO_2

The SO_2 annual emissions increase of 1,529 tons within New Jersey incurs an overall social cost of $12 million annually. At present, no New Jersey counties are in non-attainment for SO_2. Absent the Salem and Hope Creek plants, net emissions would increase in three of New Jersey's 21 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 Salem and Hope Creek Plants



NO_X

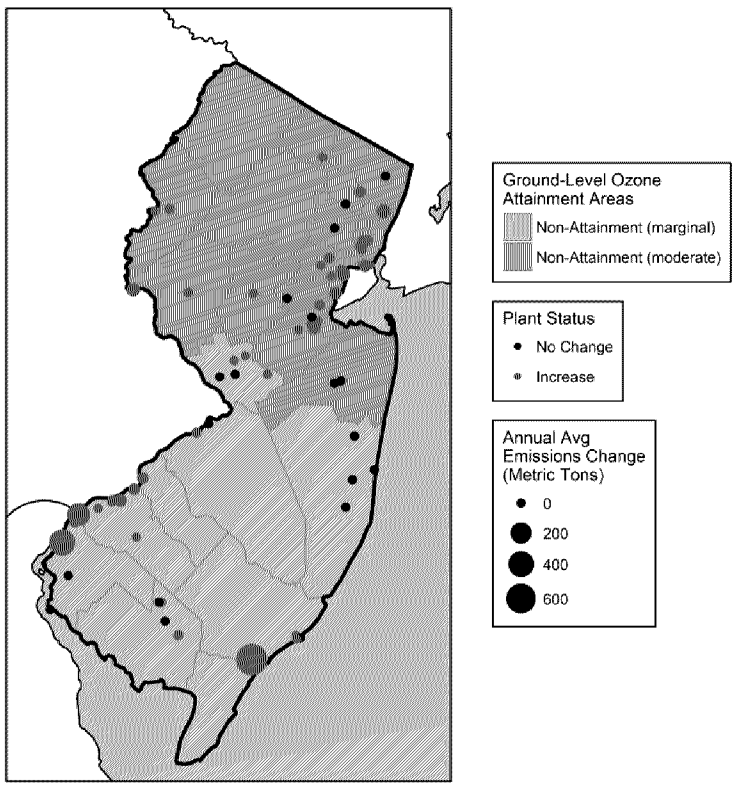
The overall social cost of the increase in New Jersey NO_X emissions absent these nuclear power plants is $3 million annually, but NO_X is also a precursor of ground level ozone.[17] At present, no

[17] Ground level or tropospheric ozone occurs when nitrogen oxides (NO_X), 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 NO_X is generally the preferred means to lower ozone levels. Determining the impact of

Continued on next page

New Jersey counties are in non-attainment for NOx, but 12 are in non-attainment for ozone. NOx emissions in New Jersey are projected to increase by 1,637 tons per year, absent the Salem and Hope Creek plants. This increase may raise the cost of bringing many of these counties into attainment for ozone. The locations of NOx increases are overlaid on the non-attainment areas for ozone in Figure A-3. Much of the increase in NOx emissions occurs in the more populous areas of New Jersey, which would exacerbate population exposures.

Figure A-3: NO_X Emissions Increase absent Salem and Hope Creek Plants



PM_{10}

The increase in PM_{10} emissions that would occur in New Jersey, absent the Salem and Hope Creek plants, is 1,382 tons, imposing social costs of $1 million annually. No counties are in non-attainment for PM_{10}.

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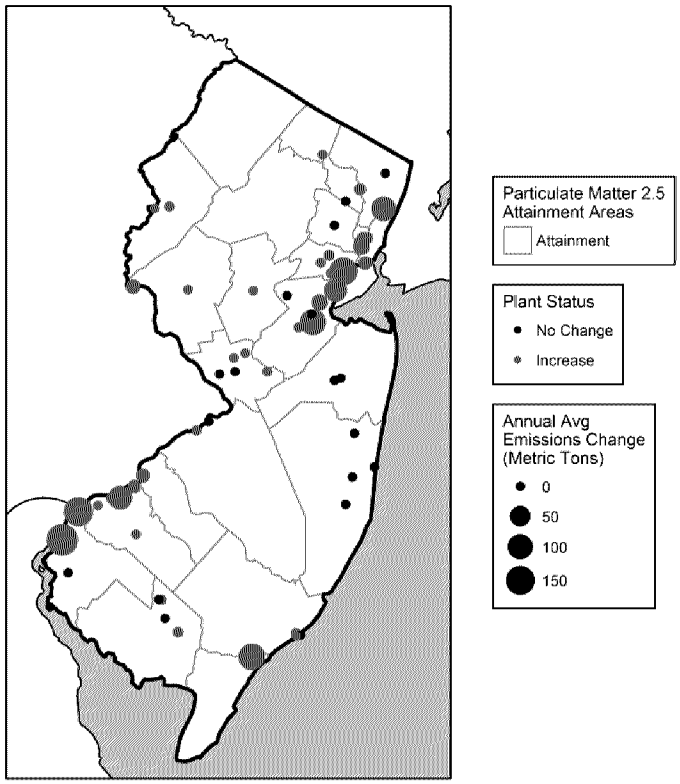
power plant NOx emissions on ozone levels is beyond the scope of this report, but increased NOx emissions is likely to compromise efforts to reduce ozone across much of the state.

$PM_{2.5}$

As Table A-2 indicates, the $PM_{2.5}$ emissions increase of over 1,000 tons annually within New Jersey results in a social cost of $14 million, the highest among the criteria pollutants, reflecting its significant impacts on human health. At present, no New Jersey counties fail to meet air quality standards for $PM_{2.5}$. Without other actions, in the absence of the Salem and Hope Creek plants, $PM_{2.5}$ emissions would increase in 17 of 21 counties statewide due to increased fossil generation, as shown in Figure A-4 (again, 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 Salem and Hope Creek Plants



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