WORKING PAPER

Retirements and Funerals: The Emission, Mortality, and Coal-Mine Employment Effects of a Two-Year Delay in Coal and Nuclear Power Plant Retirements

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RESOURCES
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Abstract

We employ a detailed electric sector simulation model and an air pollution dispersion model to estimate several effects of a policy that prevents the retirement of coal-fired and nuclear generators in the US for the next two years, as proposed in a draft US government memo leaked on May 31, 2018. Specifically, we estimate the effects on generation, emissions, mortality from those emissions, coal-mine employment, and more, assuming that the policy is in effect in 2019 and 2020. We project that, by delaying the retirement of an average of 7,800 MW (3%) of US coal-fired capacity and 1,100 MW (1%) of US nuclear capacity, the policy would cause an estimated 353 to 815 additional premature deaths in the United States from power plant sulfur dioxide and nitrogen oxide emissions, and would increase carbon dioxide emissions by 22 million short tons, over the two-year period. This amount of carbon dioxide is the amount emitted by 4.3 million average US cars each year. The total estimated welfare loss from these deaths and carbon dioxide emissions is between $4 billion and $9 billion, with deaths from SO_2 emissions constituting the majority. Additionally, the policy would support 1,580 coal mine job-years, though it might reduce economy-wide employment due to its effects in other sectors. These results indicate that each year, one American would die from air pollution for every two to 4.5 coal-mine jobs supported by the policy. Applying the policy only to the nuclear generators would prevent an estimated 24 to 53 premature deaths, and an estimated 9 million tons of carbon dioxide emissions.

Key Words: Electric power plants, retirement, emissions, health, mortality, markets, simulation, air pollution modeling

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Daniel Shawhan and Paul Picciano*

Introduction

Several US national policy proposals in 2018 and 2017 have aimed to support the use of coal for power generation in the US, and some of them have also aimed to support nuclear generation. A number of these have been tailored to the task of preventing the retirement of pre-existing generators, invoking the resilience of the electricity generation supply as motivation. One such policy is a bill proposed by US Senator Joe Manchin, the Energy Reliability Act of 2018 (Senate Bill 2681), which would offer a tax credit to coal generators (Senate, 2018). Another is a policy proposed by FirstEnergy Solutions to use section 202(c) of the Federal Power Act (FirstEnergy, 2018), and a third is a Notice of Proposed Rulemaking (NOPR) on "Grid Resiliency Pricing" issued by the U.S. Department of Energy (DOE) and later unanimously rejected by the Federal Energy Regulatory Commission (FERC, 2018). We projected and analyzed the impacts of that NOPR in depth in Shawhan and Picciano (2017), estimating that it would have delayed the retirement of about 25 GW of coal and 20 GW of nuclear, and that over 25 years it would have caused 27,000 premature deaths, $217 billion in environmental costs, and $46 billion in non-environmental costs.

In this paper, we examine a fourth proposed policy, one of preventing the retirement of most US coal and nuclear power plants that would otherwise retire, for two years. This, in turn, is based on an order from President Trump and on a leaked Trump Administration internal memo. The order, announced June 1, 2018, instructed Secretary of Energy Rick Perry to

"prepare immediate steps to stop the loss" of coal and nuclear power generation units. The leaked 40-page draft memo (DOE, 2018) contains the following language:[1]

> The Department [of Energy] is exercising its [Defense Production Act] and [Federal Power Act] authority by directing System Operators (as defined in the [Order]), for a period of twenty-four (24) months, to purchase or arrange the purchase of electric energy or electric generation capacity from a designated list of Subject Generation Facilities (SGFs) sufficient to forestall any further actions toward retirement, decommissioning, or deactivation of such facilities during the pendency of DOE's Order. DOE also is directing SGFs outside of the RTO/ISO territories to continue generation and delivery of electric energy according to their existing or recent contractual arrangements with Load-Serving Entities…. This prudent stop-gap measure will allow the Department further to address the Nation's grid security challenges while the Order remains in force.

In this paper, we estimate effects of this two-year "stop-gap" policy on emissions, mortality from those emissions, generation, coal mine employment, and more, assuming that it is in effect in 2019 and 2020. To do so, we employ a detailed electric sector simulation model and an air pollution dispersion model. We represent the policy as one of delaying, until at least 2021, the retirement of all but two US utility-scale coal-fired and nuclear electric generation units that had announced that they would retire during this two-year period. The two exceptions are the Oyster Creek and Indian Point 2 nuclear units, which are retiring for non-economic reasons and seem very unlikely to be saved by federal government action such as that described above (DOE, 2017). We intend for our analysis to serve as a case study of some of the effects that such a policy might have, particularly due to lack of detail regarding the policy in the leaked memo. The after-effects of the proposed two-year retirement stoppage are important too, but in this study we focus on the effects during the two years. Shawhan and Picciano (2017), mentioned above, provides an indication of possible after-effects, since it examines a longer-lasting policy of a type that could follow the two-year "stop-gap" policy examined in this paper.

Policy Representation, Methods and Assumptions

We simulate a business-as-usual (BAU) case, and three policy cases: (1) "the Policy," in which both the identified coal and nuclear generators do not retire; (2) "the Coal-Only Policy," in which only coal generators do not retire; and (3) "the Nuclear-Only Policy" in which only nuclear generators do not retire.

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[1] Bracketed words and phrases in this quote are clarifications by us.

As a result of the Policy, we assume that most US utility-scale coal-fired and nuclear generators that had previously announced they would retire between July 2018 and the end of 2020 do not retire until after 2020. On average over the two-year period, there is 7,825 MW more coal-fired generation capacity and 1,079 MW more nuclear generation capacity in the Policy scenario than in the BAU (no-Policy) scenario we simulate. Those are the average amounts of capacity that are being prevented from retiring over the two years, accounting for approximately 3% of the US coal fleet and 1% of the US nuclear fleet, respectively. These assumed paces of retirements match the recent retirement rates of coal and nuclear generation capacity in the US, which are approximately 8 GW of coal per year and 1 GW of nuclear per year (Geman, 2018).

Appendix A contains a table of the specific generators that we assume are prevented from retiring by the Policy. If our assumptions were correct, the Policy would result in there being about 6,100 MW more coal capacity in 2019 and 9,500 MW more in 2020; and about 700 MW more nuclear capacity in 2019 and 1,500 MW more in 2020. Over the two years, these average to 7,825 MW of coal-fired capacity and 1,079 MW of nuclear, as mentioned above. We intend these to serve as a roughly representative selection of the generators that might be saved by such a Policy, rather than as an exact prediction of which generators would be saved if such a Policy were implemented; the list of Subject Generation Facilities mentioned in the draft memo has yet to be released. The generators listed in Appendix A are all but three of those with expected retirement dates between the start of July 2018 and the end of June 2020, per a combined list we constructed by merging the most recently available EIA-860 Monthly dataset and the S&P Global Market Intelligence (SNL) database of generators (EIA, 2018a; SNL, 2018).[2] The two main exceptions are Indian Point unit 2 in New York and Oyster Creek unit 1 in New Jersey, nuclear generators that are retiring for reasons other than market conditions and lack of profitability, and seem very unlikely to be saved by such a policy (DOE, 2017).[3]

The set of generators prevented by the Policy from retiring could be larger or smaller than the set we have assumed. In the past, some generators have retired without having announced their retirement more than a few months in advance, so the set of generators, particularly coal generators, that will actually retire without the Policy may be larger than that on the list of expected retirements that we are using. On the other hand, the policy may not prevent all of the coal unit retirements.

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[2] EIA Electric Power Monthly as of April 2018, and SNL database as of June 22, 2018.

[3] The third exception is Herbert A. Wagner unit 2, a small coal unit omitted accidentally.

We used the methods and data described in Shawhan and Picciano (2017), with some exceptions. In this paper, we assume that the only retirements that occur are those of generators with planned retirements dates during the simulation horizon. In the Policy case, coal and nuclear generators that have announced retirement reverse their decision; otherwise, the retirement of generators is unaffected by the Policy. As a result, there are no endogenous retirements decisions; we assume that because the Policy duration is short, and there is uncertainty beyond the two-year period, existing generators that are not currently planning to retire but might as a result of the Policy, would delay a retirement decision until more information is available. We allow the simulation to determine the amount of generation capacity built in 2019 and 2020, as preserving coal and nuclear capacity could offset new investments. The rationale is similar: investors might wait until the policy future beyond the two years is more certain.

The power system simulation model we use is the Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST), a detailed model of the electric power system and markets in the US and Canada. The engineering component of E4ST includes a grid model that contains all of the high-voltage transmission lines, and the power flows over the lines are determined by Kirchoff's Laws of physics, based on the quantity injected at each node and the quantity demanded at each node. It is a linear optimization program that, like a system operator, identifies the lowest-cost combination of generators to use at each moment, given millions of constraints including line and generator constraints. Along with operation across the year, E4ST simultaneously optimizes generator investment and retirement, with only private costs in the objective function, to predict investor and owner behavior. The model replicates actual market and system outcomes well. For example, to test this, we simulated one past year, 2016, with the same model used for this paper, except with the generation fleet adjusted to match 2016. In the model's results, the amounts of net generation from the two fuels that are the subjects of the Policy and this paper, coal and nuclear, differed from the actual historical amounts by 1.1% and 3.1%, respectively. In our prior test (Mao et al. 2016), which focused on locational electricity prices in 2013, the model closely approximated the observed state average prices, with close match of the average and a correlation coefficient of 0.97 between the simulated and actual prices across the states. Shawhan and Picciano (2017), E4ST.org, Shawhan et. al (2014), and Mao et al. (2016) describe the model in greater detail.

We estimate the mortality effects of the policies using two different estimated relationships between air pollution (specifically, fine airborne particulate matter, in this case formed from SO_2 and NO_X emissions) and number of premature deaths. These relationships are known as exposure-response functions. The weaker estimated relationship comes from Krewski

et al. (2009) and the stronger from Lepeule et al. (2012). These are the two most commonly used estimates of the exposure-response relationship between fine airborne particulate matter from outdoor sources and mortality for public health analyses, and are both based on rigorous, repeated statistical analyses. The results of a massive newer study, Di et al. (2017), which are based on 460 million person-years of US Medicare data, support the use of the stronger relationship, that of Lepeule et al. (2012), at the air pollution concentrations that prevail where most Americans live. However, we report both. For simplicity, in some places including our charts, we just report the results based on the weaker relationship, that estimated by Krewski et al. (2009), in keeping with our conservative approach. However, the Di et al. (2017) study indicates that the stronger relationship is at least as appropriate. To calculate a close approximation of the results of using the stronger relationship, multiply the deaths or mortality damage values from the weaker relationship by 2.2.

The air pollution transport-and-fate model we use is an exact replica of the Co-Benefits Risk Assessment (COBRA) Model. The replica is built into E4ST for air pollution dispersion and health-risk assessment in the United States. COBRA is described in detail in EPA (2018). We use this model with the Krewski et al. (2009) exposure-response function.

We also use another method, which involves using national average deaths per ton estimates that were calculated by Neil Fann, Kirk Baker, and Charles Fulcher using a different air pollution transport-and-fate model than the COBRA model mentioned above. This method is described in EPA (2013) and Fann et al. (2012). Using the Fann, Baker, and Fulcher method with Krewski et al.'s (2009) estimate of the exposure-response relationship, we obtain premature death estimates very similar to those from the COBRA method, given in the Results section below. (Specifically, we obtain 365 from the Policy, 389 from the Coal-Only Policy, and -24 from the Nuclear-Only Policy). As a result, for our mortality estimates that are based on Lepeule et al.'s (2012) estimate of the exposure-response relationship, we use the Fann, Baker, and Fulcher method.

Results

We compare the results of the simulations with and without the Policy to produce estimates of several effects of the Policy. These include its effects on generation, power plant emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x), premature deaths from SO_2 and NO_x emissions, coal-mine jobs, and some non-environmental costs. We also simulate cases in which the Policy applies only to the coal generators, and only to the nuclear generators. The effects of these Coal-Only and Nuclear-Only simulations almost exactly sum to

the effects of the Policy applying to both coal and nuclear generators, and therefore indicate the contributions of each generation type to the combined effects of the Policy. All monetary values reported are in year 2013 dollars and are discounted with a 3% discount rate, from the perspective of the end of 2019.

The assumptions described above and embodied in our simulation model produce conservative estimates of the mortality effects of the Policy. A later section, entitled A Conservative Approach, lists some of these assumptions.

Generation

The Policy increases the two-year total coal generation by 38 TWh and the two-year total nuclear generation by 17 TWh, relative to the business-as-usual scenario. These represent 1.7% of US coal generation and 1.1% of US nuclear generation in the BAU over the two years. The effect on coal generation is the net effect of a 55 TWh increase in the generation of the saved coal generators and a 17 TWh decrease in the generation of other coal generators. The other Policy effects reported in this paper, such as the SO_2 and mortality effects, are net effects.

Figure 1. Annual Effects of Policy on Coal, Nuclear, and Natural Gas Generation
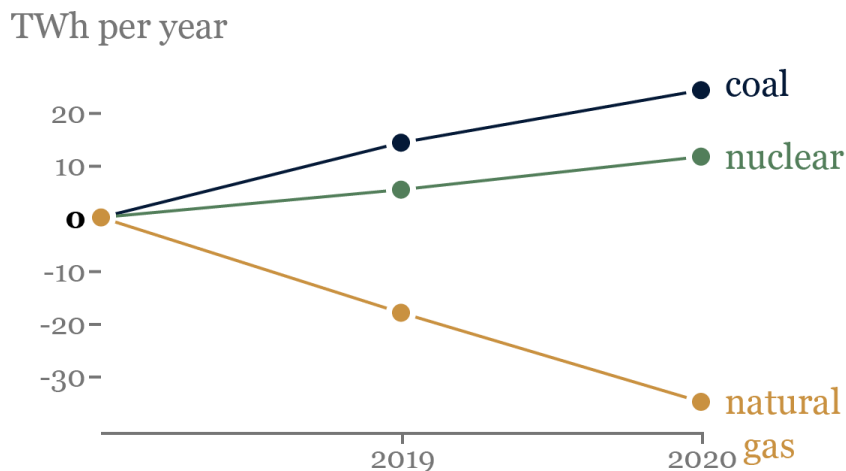
As shown in Figure 1, the Policy's main other effect on generation is to reduce the two-year total natural gas-fueled generation by 53 TWh, or 1.8%. The Policy has little effect on generation from other primary energy types such as wind, solar, and oil.

Sulfur Dioxide and Nitrogen Oxide Emissions and Resulting Premature Deaths

In the monetized environmental damage estimates for the Policy, the largest estimated damage is not from carbon dioxide emissions but from the US mortality caused by sulfur dioxide

and nitrogen oxide emissions. This estimated SO_2 and NO_x mortality damage has an estimated total value of $3.1 billion over the two years. This is based on the simulation result that the Policy causes an estimated 353 premature deaths in the US, using the weaker estimated relationship between particulate matter and mortality. We assume, like EPA (2018), that those premature deaths have an estimated average value of $9.1 million each.

The Coal-Only and Nuclear-Only simulations indicate that preventing the retirement of the coal generators causes approximately 380 premature deaths and preventing the retirement of the nuclear generators prevents approximately 27 premature deaths. This suggests that a policy such as that considered in this paper would need to prevent approximately twice as much nuclear generation capacity as coal-fired generation capacity from retiring, in order to avoid increasing premature deaths from power plant emissions.

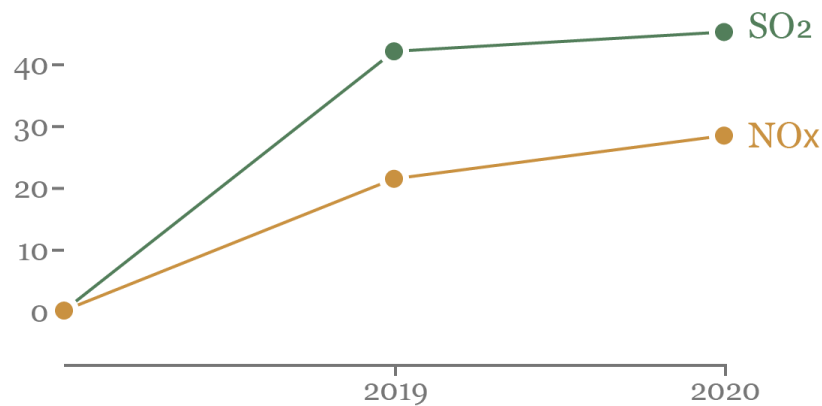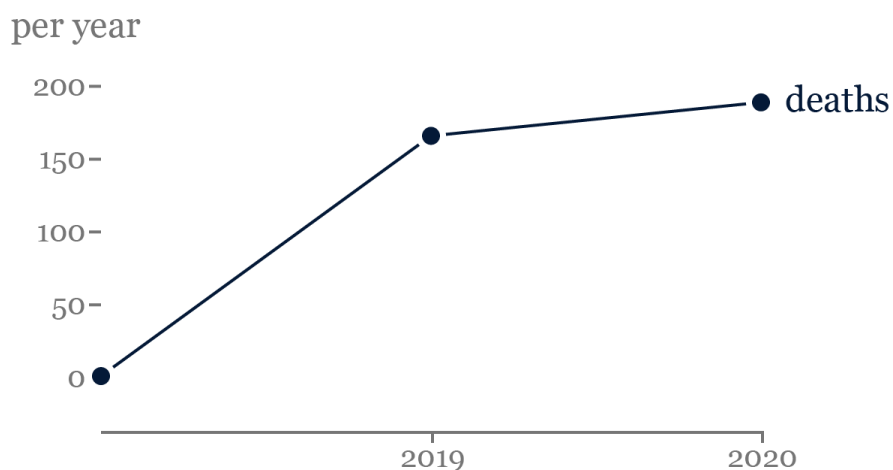**Figure 2. Annual Effects of Policy on SO_2 and NO_X Emissions**

thousand short tons per year

Figure 3. Annual Effects of Policy on Premature Deaths from SO$_2$ and NO$_X$ Emissions, Using Weaker Exposure-Response Function

per year

Using the stronger of the two estimated air pollution-mortality relationships, we obtain premature death estimates approximately 2.2 times as large: 815 from the Policy, 868 from the Coal-Only Policy, and -53 from the Nuclear-Only Policy.

There is heterogeneity in the effects of retiring different coal units. The Navajo units in Arizona have an SO$_2$ emission rate only approximately 20% that of the US average. Furthermore, saving the Navajo units decreases the generation of higher-emitting coal units in the western US, and does so enough to produce a net reduction in SO$_2$ emissions in the western US.

Carbon Dioxide

Over the two years, the simulations indicate that the Policy would increase CO$_2$ emissions by 22 million short tons, equivalent to the amount of CO$_2$ emitted by 4.3 million average US cars in a year. Using the social cost of CO$_2$ estimate of the Inter-Agency Working Group on the Social Cost of Carbon, the damage from this CO$_2$ is $0.9 billion.

The results of applying the Policy to coal and nuclear generators separately indicate that applying it to the coal generators increases CO$_2$ emissions by 31 million tons and applying it to the nuclear generators decreases CO$_2$ emissions by 9 million tons, over the two years. These amount to approximately 4,000 tons of additional CO$_2$ emissions per MW of coal generators prevented from retiring and 8,000 tons less of CO$_2$ emissions per MW of nuclear generators prevented from retiring. This implies that an otherwise similar policy that prevented half as much nuclear generation capacity as coal-fired generation capacity from retiring might have approximately zero effect on national CO$_2$ emissions. Shawhan and Picciano (2017), with a

larger sample of saved nuclear generators than this paper, found that a policy would need to save almost as much nuclear capacity as coal capacity in order to avoid increasing CO_2 emissions. However, if it did so, the preceding section indicates that a policy that prevented even 100% as much nuclear generation capacity as coal-fired generation capacity from retiring would be likely to still substantially increase premature deaths from power plant emissions. The difference results from the fact that nuclear generation mostly offsets natural gas-fired generation that has substantial CO_2 emissions (approximately 40% of those of coal-fired generation) but has near-zero SO_2 emissions and low NO_x emissions, per MWh.

Figure 4. Effects of Policy on Carbon Dioxide Emissions

million short tons per year
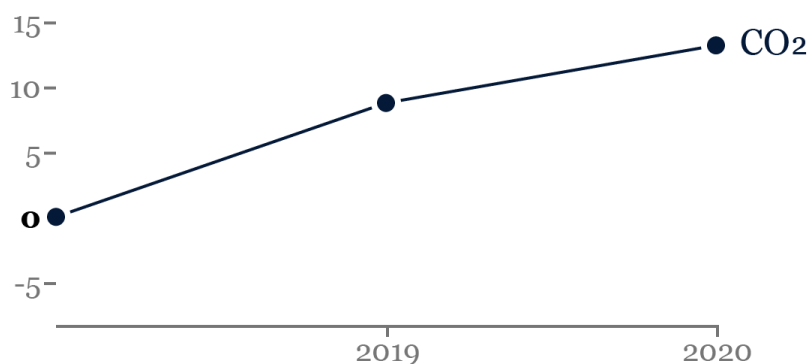
The Policy increases net coal generation by 1.7% and coal-unit CO_2 emissions by a similar 1.8%, but increases coal-unit SO_2 emissions by 3.6% and coal-unit NO_X emissions by 2.9%. One reason is that the coal units saved by the Policy have a generation-weighted average emission rate per MWh that is approximately 80% higher than that of the coal units that continue to operate without the Policy. This is exacerbated by the other reason, which is that the other coal generation displaced by saving the coal units that were going to retire has a lower-than-average SO_2 emission rate. Similar reasons apply for NO_x.

One of the two nuclear generators saved by the Policy is the Pilgrim Nuclear Power Station, which is within the geographic area of the CO_2 cap-and-trade program under the Regional Greenhouse Gas Initiative in the northeastern United States. A nuclear generator's effectiveness at reducing emissions depends greatly on the extent to which it substitutes for generation that is subject to the cap-and-trade program instead of for generation that is not. To the extent that it substitutes for generation that is subject to the cap-and-trade program, it has less effect on emissions, because the total emissions from generators subject to the cap-and-trade

program are subject to an emission constraint policy that, while not simply a perfectly inelastic emission allowance supply curve, is still likely to reduce the emissions-reduction effectiveness of preserving or building zero-emission generators in the RGGI region. Pilgrim is in eastern Massachusetts, which is the part of the RGGI region that is farthest from non-RGGI states and provinces. However, in spite of that, the simulations indicate that approximately 80% of the generation it offsets is outside of the RGGI cap-and-trade program, so it is quite effective at reducing emissions. This may be related to the fact that the RGGI region imports a large share of its electric energy, so there is congestion for power flowing from non-RGGI states and provinces toward Pilgrim more than there is congestion in the opposite direction.

Total Environmental Damage

The estimated damages from the SO_2, NO_x, and CO_2 emission effects of the Policy sum to $4 billion over two years, estimated using the weaker exposure-response function. The coal-only simulations suggest that each MW of coal prevented from retiring results in $607 thousand of emission damages. The nuclear-only simulations suggest that each MW of nuclear generators prevented form retiring results in a $570 thousand reduction in emission damages. These coal and nuclear damage per MW values in turn suggest that in order for the Policy to produce a net environmental benefit, it would need to save 1.07 times as much nuclear generation capacity as coal-fueled generation capacity. Using the stronger exposure-response function, it would need to save a 1.35 times as much nuclear capacity as coal-fueled capacity.

Figure 5. Annual Effects of Policy on Estimated Environmental Damages, Using Weaker Exposure-Response Function
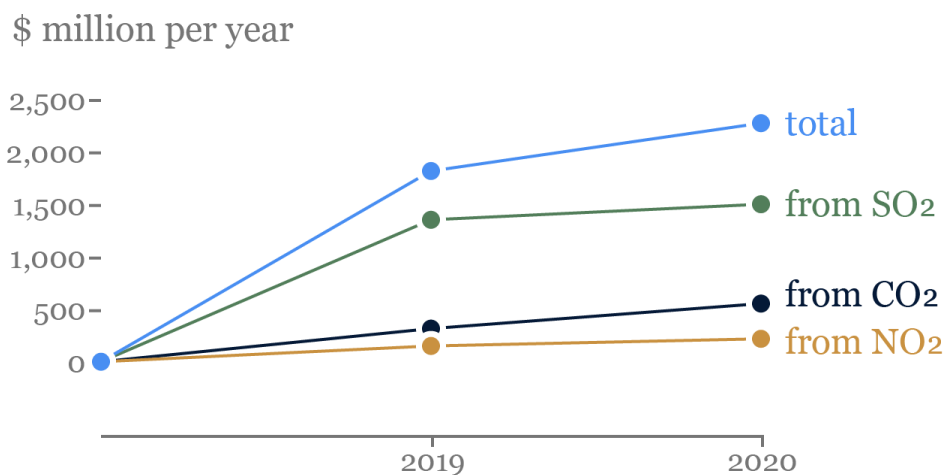
The capacity factors of the saved nuclear generators, at approximately 89% on average, are higher than those of the saved coal generators, at approximately 42% on average. The

emission damage per MWh of generation by saved coal generators is $113 while the emission damage reduction per MWh of generation by saved nuclear generators is $37, using the weaker exposure-response function. These values indicate that for the Policy to produce a net environmental benefit, the nuclear generators it saves would need to generate approximately 3 times as much electrical energy as the coal generators it saves.

Non-Environmental Cost

The prices that a wholesale generator receives in each hour represent the marginal internal costs of substituting for that generator's output in that hour. Except when retirement is for non-economic reasons, planning to retire is an indication that the internal costs of continuing to operate the unit are higher than the internal costs of replacing its generation, which in turn implies that the total internal cost of its continued operation is greater than zero. For some of the generators that are planning to retire, it may be much greater than zero; typically, some generators that are planning to retire are doing so because they would need to make some larger-than-usual capital expenditures, such as for a major component replacement or environmental control upgrade, in order to continue operation. For example, at least three of the four nuclear power plants planning to retire between the middle of 2018 and the middle of 2020 would need to make large new investments to continue operating (Pratt, 2015; World Nuclear News, 2017; World Nuclear News, 2018). Other than for those three, we do not know the which of the generators that would be saved by the Policy are facing abnormally high costs, and how high those costs are. As a result, we cannot calculate the total internal or non-environmental cost of keeping them in operation.

However, we can calculate how large the estimated non-environmental cost of preventing the units from retiring would be as a function of how high their going-forward fixed costs are relative to the national averages for coal and nuclear units. The resulting formula is that the estimated non-environmental cost of preventing the units from retiring is -$2.6 billion + $1.5 billion times the ratio of the going-forward fixed cost per MW of saved generators over the national average going-forward fixed cost per MW for a set of generators with the same ratio of coal to nuclear capacity. For example, if the going-forward fixed costs of the saved units are, on average, twice as high as the national averages for their fuel types, then the estimated non-environmental cost of the Policy is $0.4 billion. How much of this cost would be borne by electricity customers versus taxpayers versus generation unit owners would depend on how it would be paid for and how large the subsidies to generation owners would be. The Policy could potentially subsidize a much larger set of units than the set that would otherwise retire in the next

two years, which would raise the cost to customers. The set we assume does not include any units owned by FirstEnergy, and the Administration may wish to support units owned by FirstEnergy in light of factors including FirstEnergy's request for relief from low market prices. Secretary Perry stated in June of 2018 that approximately 50 GW of coal and nuclear generation capacity is planning to retire of over the following two years (Northey, 2018). That is nearly three times as large as the recent rate of coal and nuclear retirements, which are 8 and 1 GW per year respectively. It is similarly larger than the announced retirements over the next two years, which are similar to the recent historical rate.

The fact that the units are planning to retire, combined with our simulation results for those units, indicates that their average going-forward fixed costs per MW are greater than 1.7 times the national average going-forward fixed cost per MW for a set of generators with the same ratio of coal to nuclear capacity, potentially much greater. Otherwise, they would not be retiring.

Total Cost

Figure 6 shows the estimated total cost of the Policy, as a function of the going-forward fixed costs of the generators that would be saved by the Policy. For example, if their going-forward fixed costs are twice the national average, the estimated total cost of the Policy is $4.4 billion. The figure uses the weaker estimated effect of SO_2 and NO_X on emissions. Using the stronger estimated effect, the line would be higher by $5.1 billion. For example, if the going-forward fixed costs of the saved generators are twice the national average, the estimated total cost of the Policy is $9.5 billion.

Figure 6. Estimated Total Cost of Operating the Saved Units, Using Weaker Exposure-Response Function
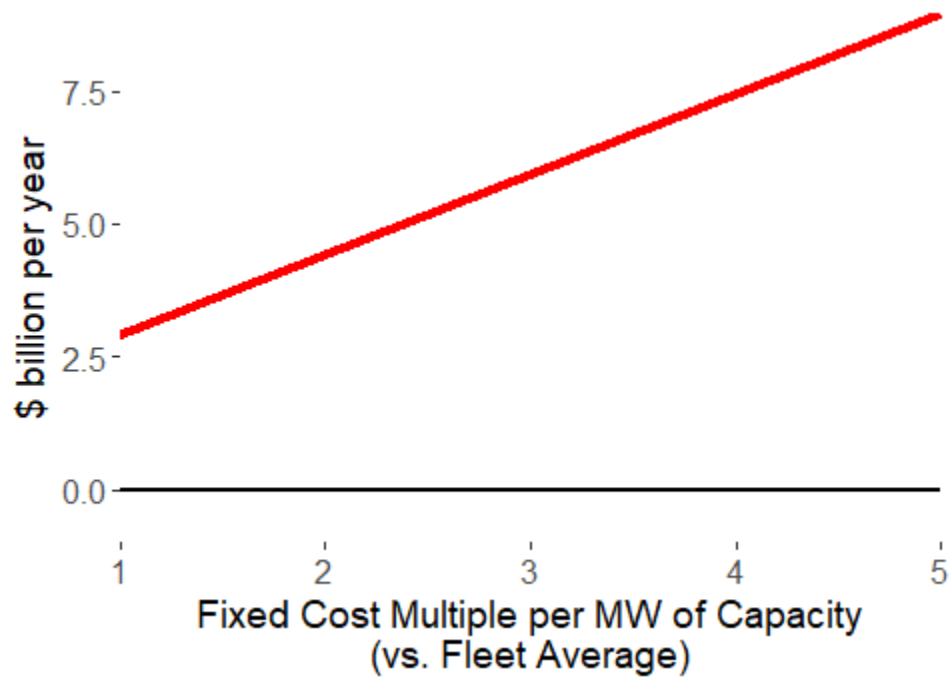
Coal-Mine Jobs and Other Jobs

In 2016, the US coal industry produced 14,062 short tons of coal per mine employee (EIA, 2018b; EIA, 2018c). Assuming that each 14,062 tons of coal consumed supports one coal-mine job, the Policy would support an estimated average of 595 coal-mine jobs in the first year and 985 in the second, for a total of 1,580 coal-mine job-years. Coal mines employ more than just miners, so the numbers of coal *miner* jobs supported would be smaller than these numbers.

Figure 7. Estimated Number of Annual Coal-Mine Jobs Supported by the Policy
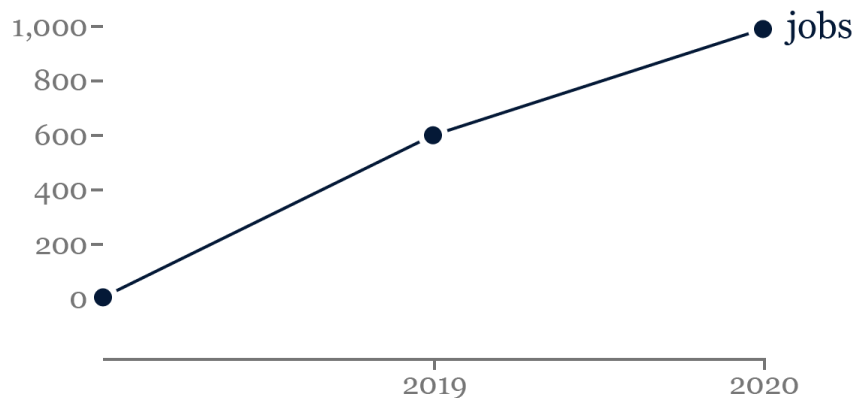
In contrast, the Nuclear-Only Policy would cause the electric power industry to support fewer coal-mine jobs, by an average of 62 in 2019 and 112 in 2020. In light of that, it is unsurprising that the Coal-Only Policy would support more coal-mine jobs than the coal-and-nuclear Policy would: 655 in 2019 and 1,080 in 2020.

The policies would also be likely to reduce the number of jobs in other sectors by raising the cost of electricity generation. Effects on jobs outside the energy industry could be larger than effects inside the energy industry (Deschenes 2012).

Coal-Mine Jobs per Air Pollution Death

According to these results in the preceding sub-sections, the Policy would cause one premature US death from power plant emissions, for every two to 4.5 coal-mine job-years supported. Expressed differently, increased emissions from the policy would kill someone in the US each year for every two to 4.5 coal-mine jobs supported by the policy. If just miners were counted instead of all coal mine employees, the job numbers in these ratios would be even lower. Some of these coal-mine jobs could be expected to still exist in the absence of the Policy, with the number depending on the coal supply and demand functions and the miner supply and demand functions.

For the Coal-Only Policy, the ratio of coal-mine job-years to premature deaths is two to 4.6, similar to those for the coal-and-nuclear Policy. Auffhammer and Fischer (2017) found a ratio of between 1 and 2.

A Conservative Approach

Our assumptions are designed to produce a conservative estimate of the mortality effects of the potential Policy per MW of capacity it saves, in several respects.

1. We assume that the Policy does not increase the use of coal or nuclear power plants other than by preventing the retirement of some such units. Expressed differently, we assume that the Policy does not subsidize the *operation* of coal or nuclear power plants, or otherwise favor them in the procurement and dispatch processes of system operators, even though the leaked memo does discuss that possibility.

2. We represent RGGI as a perfectly inelastic emission quantity limit rather than as the step function that it really is. This understates the effect of the Policy on emissions since there is a saved nuclear generator, but no saved coal generators, in RGGI.

3. It is also possible to estimate the effects of the Policy on non-fatal health problems such as hospital admissions and days of work and school missed (EPA, 2013), but we have not done that.

4. We omit some some of the other pollution types that are caused by power plants and estimated to cause deaths, such as directly emitted fine particulate matter and ground-level ozone.

5. Deaths in downwind countries, chiefly Canada and the European countries, are not counted.

6. We assume that the Three Mile Island and Pilgrim nuclear units scheduled to retire soon could be saved by the Policy, even though it may be too late to prevent one or both of them from retiring and the Three Mile Island unit might be saved by the Pennsylvania state government if it is not saved by the federal government.

In addition, with respect to the non-environmental cost impacts of the Policy, all of the simulations presented in this paper assume that, before the end of 2020, the policy does not make generators less thrifty, does not increase the risk premium that power plant investors must expect to earn in order to be willing to build power plants, does not cause the affected Independent System Operator (ISO)/Regional Transmission Operator (RTO) markets to shrink, and does not "blow up the markets" in the words of one former and two current FERC commissioners (Bade, 2017).

Conclusion

We examine a policy, consistent with a recent US government memo and an order from President Trump to the Secretary of Energy, that would delay the retirement of coal-fired and nuclear generators in the US for two years. The order is the latest in a series of recent policy proposals aimed at protecting coal and nuclear generators in the US. Most notably, it follows a Notice of Proposed Rulemaking (NOPR) on "Grid Resiliency Pricing," which was issued by the U.S. Department of Energy in Fall of 2017 and later unanimously rejected by FERC in January of 2018 (FERC, 2018), and which we analyzed in-depth in Shawhan and Picciano (2017).

In this paper, we employ E4ST, a detailed electric sector simulation model, and a replica of COBRA, an air pollution dispersion model, to project the effects of the two-year "stop-loss" policy in 2019 and 2020 on generation, emissions, mortality from those emissions, coal-mine employment, and more. These results are presented in the Results section of this paper and summarized in the abstract. In addition to estimating the effects of a policy consistent with the recent US government memo, this paper is also another case study of the effects of policies that aim to keep coal and nuclear generators online.

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Appendix A. Eligible Coal and Nuclear Generators

Power Plant	Generator ID	Type	Capacity (MW)	State	Market	Retirement Year in BAU Simulation
B.L. England	2	Coal	150	NJ	PJM	2019
Clay Boswell	1	Coal	67	MN	MISO	2019
Clay Boswell	2	Coal	67	MN	MISO	2019
Crystal River	1	Coal	324	FL	N/A	2019
Crystal River	2	Coal	442	FL	N/A	2019
E.W. Brown	1	Coal	106	KY	N/A	2019
E.W. Brown	2	Coal	166	KY	N/A	2019
Edgewater	4	Coal	294	WI	MISO	2019
Elmer Smith	1	Coal	137	KY	N/A	2019
Gibbons Creek	1	Coal	470	TX	ERCOT	2019
J.T. Deely	1	Coal	420	TX	ERCOT	2019
J.T. Deely	2	Coal	420	TX	ERCOT	2019
Montrose	2	Coal	164	MO	SPP	2019
Montrose	3	Coal	170	MO	SPP	2019
North Valmy Station	1	Coal	254	NV	N/A	2019
Pilgrim Nuclear Power Station	1	Nuclear	677.2	MA	ISO-NE	2019
Pleasants	1	Coal	644	WV	PJM	2019
Pleasants	2	Coal	644	WV	PJM	2019
Presque Isle	5	Coal	55	MI	MISO	2019
Presque Isle	6	Coal	55	MI	MISO	2019
Presque Isle	7	Coal	83	MI	MISO	2019
Presque Isle	8	Coal	83	MI	MISO	2019
Presque Isle	9	Coal	83	MI	MISO	2019
Sibley	2	Coal	42.1	MO	SPP	2019
Sibley	3	Coal	364.1	MO	SPP	2019
Yorktown	1	Coal	159	VA	PJM	2019
Yorktown	2	Coal	164	VA	PJM	2019
Asheville	1	Coal	189	NC	N/A	2020
Asheville	2	Coal	189	NC	N/A	2020
James River Genco	GEN1	Coal	46	VA	PJM	2020
James River Genco	GEN2	Coal	46	VA	PJM	2020
Navajo	NAV1	Coal	750	AZ	N/A	2020
Navajo	NAV2	Coal	750	AZ	N/A	2020
Navajo	NAV3	Coal	750	AZ	N/A	2020
TES Filer City Station	GEN1	Coal	60	MI	MISO	2020
Three Mile Island	1	Nuclear	802.8	PA	PJM	2020
W.H. Sammis	1	Coal	180	OH	PJM	2020
W.H. Sammis	2	Coal	180	OH	PJM	2020
W.H. Sammis	3	Coal	180	OH	PJM	2020
W.H. Sammis	4	Coal	180	OH	PJM	2020

Note: "Retirement Year in BAU Simulation" is the first year in which that generator is out of service, unless the policy prevents its retirement.

Appendix B. Figures Comparing Effects of Policies

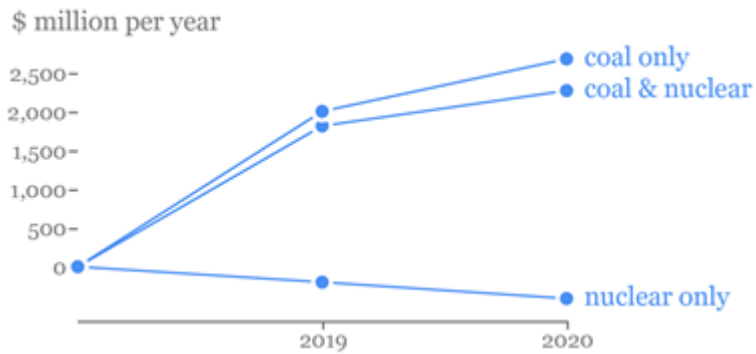**Figure 8: Annual Effects of Policies on Total Estimated Environmental Damage**

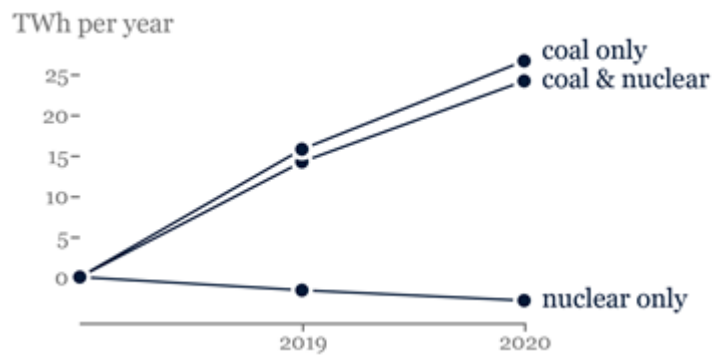

Figure 9: Annual Effects of Policies on Coal Generation

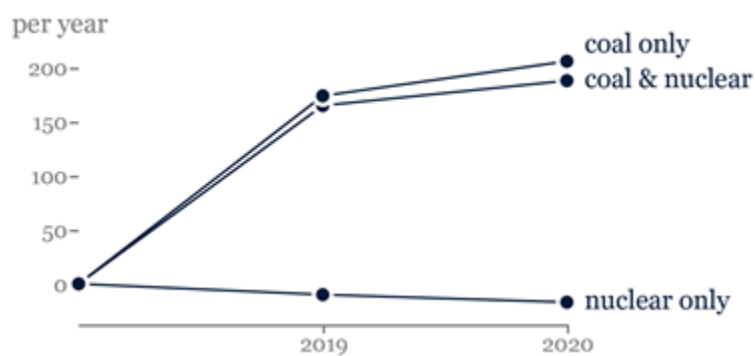**Figure 10: Annual Effects of Policies on Premature Deaths from SO₂ and NOₓ Emissions**

Figure 11: Annual Effects of Policies on CO₂ Emissions
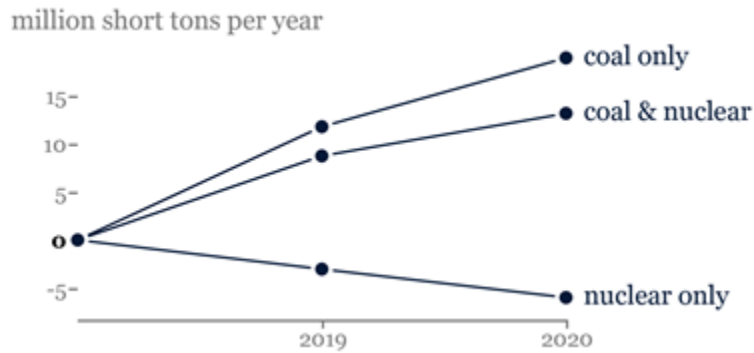
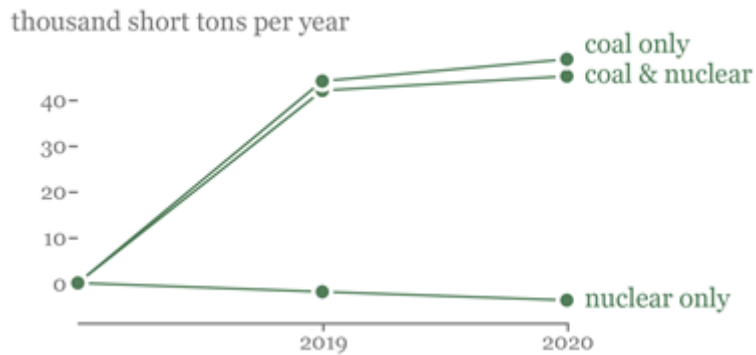

Figure 12: Annual Effects of Policies on SO₂ Emissions

Figure 13: Annual Effects of Policies on Coal-Mine Jobs