November 2017 ■ RFF WP 17-22

WORKING PAPER

Costs and Benefits of Saving Unprofitable Generators

A Simulation Case Study for US Coal and Nuclear Power Plants

Daniel Shawhan and Paul Picciano

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES
FOR THE FUTURE

Costs and Benefits of Saving Unprofitable Generators: A Simulation Case Study for US Coal and Nuclear Power Plants

Daniel Shawhan and Paul Picciano

Abstract

In this paper, we use a detailed power sector model, E4ST, to project effects of preventing a set of unprofitable generators from retiring. We simulate the “Grid Resiliency Pricing Rule” proposed by the US Department of Energy in the fall of 2017, and several variations. In the proposed policy, eligible coal and nuclear generators would be guaranteed revenues sufficient to make them profitable. Our analysis is an examination of that potential policy and an illustrative case study for similar national, regional, or state policies in the United States or elsewhere. The results highlight the importance of estimating environmental net benefits, as they dominate the cost–benefit analysis of all of the policy variations considered. In the simulation results, the total subsidy amount required to guarantee profits for coal and nuclear generators in 2025 is $7.6 billion. If the policy is in effect from 2020 through 2045, it prevents the retirement of approximately 25 GW of coal-fueled capacity, delays the retirement of 20 GW of nuclear capacity, causes 27,000 premature deaths in the United States, and has an estimated total net cost of $263 billion during those 25 years. Of that, $217 billion is environmental damages and $45 billion is non-environmental net costs. We find that the policy’s net non-environmental cost for electricity end-users is $72 billion and its net benefit for generation owners is $28 billion. In an alternative scenario, we find that guaranteeing only recovery of costs necessary for continued operation, instead of guaranteeing profits, shifts costs from end-users to generators enough to nullify the policy’s effect on electric bills and make it detrimental to generator profits, but has little effect on the other outcomes. Preventing the retirement of just nuclear capacity is the only simulated policy that produces positive net benefits. Our analysis assumes that the policies do not otherwise affect the efficiency of the electricity markets, and it does not estimate effects on reliability or resilience, but it could be considered in combination with analyses of such effects.

An interactive results viewer is available at the bottom of the blog post at http://www.rff.org/blog/2018/projecting-impacts-doe-s-grid-resiliency-pricing-proposal.

Contents

Costs and Benefits of Saving Unprofitable Generators: A Simulation Case Study for US Coal and Nuclear Power Plants

Daniel Shawhan and Paul Picciano*

1. Introduction

Policymakers, regulators, system operators, or publicly owned utilities in any part of the world may wish to prevent unprofitable generators from retiring for any number of reasons. They may wish to preserve the jobs of coal miners or plant workers, they may prefer not to make the capital investment necessary for replacement capacity, or they may consider the plants to be important for reliability, for resilience, or for limiting harmful emissions. Alternatively, more stringent environmental restrictions on new generators may make it difficult to replace old ones with new ones. In the US, the states of Illinois and New York have each made plans to provide subsidies to prevent nuclear power plants from shutting down (Pyper, 2017) and the Illinois legislation originally included coal-fueled plants (Sweeney, 2016). The projected continuation of low natural gas prices in the US, Canada, and Mexico (CME Group, 2017) may cause the consideration of subsidies for existing generators to become widespread at least in those countries (Steckler, 2017).

This paper presents a simulation-based, cost-benefit analysis of the "Grid Resiliency Pricing Rule" proposed by the US Department of Energy (DOE) in the Fall of 2017 to ensure the profitability of a set of coal- and nuclear-fueled generators in parts of the US, in order to prevent them from retiring. In addition to being a study of that particular policy, we hope that this paper may serve as an illustrative case study of some of the effects of policies that aim to achieve similar outcomes, whether in individual US states or control areas, or in other countries.

To date, several studies have estimated the total dollar amount of subsidies that would have to be paid to unprofitable generators under the proposed policy, presumably by electricity end-users. Their estimates differ substantially, largely depending on the interpretation of the policy and what costs are covered. For example, one study estimates total subsidy payments ranging from $300 million to $700 million[1] based on 2015 historical data, if the rule had applied

---

* Shawhan: RFF Visitng Fellow, shawhan@rff.org; Picciano: RFF Research Assistant, picciano@rff.org. The authors thank Karen Palmer, Anthony Paul, Ray Kopp, and Devin Hartman for input, Adrienne Young for editing, and Kate Petersen for production.

[1] In these estimates, the policy only covers generator costs that exceed total revenues earned. Orvis et al. provide additional estimates in which full costs of eligible generators are recovered, resulting in larger subsidy amounts.

in 2015 (Orvis et al., 2017). Another estimates total subsidy payments of $3.7 to $11.2 billion based on 2016 historical data if the rule had applied in 2016 (Celebi et al., 2017). The independent PJM Market Monitor estimates costs of $18 billion to $288 billion over ten years in its region (Monitoring Analytics, 2017).

In addition to estimating the required subsidy payments, as in previous studies, this study has several other intended contributions. First, it is a multi-decade simulation study that incorporates interactions and projects both short- and long-run effects, including after-effects, of the policy. Second, it estimates and incorporates environmental effects and their costs. Third, it estimates end-user welfare, including the effect of the policy on electricity prices. Fourth, it also estimates the effects of the policies on generator profits, government revenues, and total net benefits. Fifth, it simulates policies that apply only to coal-fueled or only to nuclear-fueled generators, as well as policies that apply to both types. Sixth, it examines and explains the effects of guaranteeing only costs needed for continued operation, rather than guaranteeing profit. Seventh, it estimates of the effects of higher natural gas prices on the results of the potential policy. Eighth, it examines of the interaction of the policies with an emission cap-and-trade program. Finally, it explains a few phenomena that affect the results and their relevance to other situations.

2. Policy Representation

In a Notice of Proposed Rulemaking (NOPR) for a “Grid Resiliency Pricing Rule,” the DOE proposed to the US Federal Energy Regulatory Commission (FERC) that it “ensure that...each eligible resource recovers its fully allocated costs and a fair return on equity.”[2] The eligibility requirements in the version published in the *Federal Register* (2017) include that the resources must be “physically located within the Commission-approved organized markets” that have “energy and capacity markets,” must “have a 90-day fuel supply on site,” must be “not subject to cost-of-service rate regulation,” must “be able to provide essential energy and ancillary reliability services” and “must be compliant with all applicable environmental regulations.” The NOPR says little more than this about its recommended design of the rule. The FERC acting chair indicated on November 9, 2017 that he hoped for the FERC to consider interim measures in response to the DOE NOPR by December 11, and for the FERC to follow that with a longer-term response (Traywick and Kern, 2017).

---

[2] DOE issued the NOPR on September 28. The *Federal Register* published a revised version with the addition of the capacity market requirement on October 10.

For the simulations that we report in this paper, we assume that currently existing merchant coal- and nuclear-fueled generators in the PJM (mid-Atlantic), New England (ISO-NE), New York (NYISO), and Midcontinent (MISO) system operator territories would be able to satisfy the criteria for eligibility. We represent the proposed rule as a profit guarantee for such generators. More specifically, we assume that, for each eligible generator, the policy guarantees coverage of its variable and fixed operating and maintenance (O&M) costs, routine capital expenditures and life extension expenditures, plus a normal rate of recovery of construction costs and other past capital expenditures and a fair rate of return on equity, while the policy remains in force. Eligible units with market revenues insufficient to cover those costs receive subsidies, raised via an uplift charge on electricity customers in their state, that make their revenues exactly cover them.

The policy just described guarantees recovery of a larger amount than is necessary to prevent the units' retirement. To prevent retirement, it is sufficient to cover only "going-forward" costs, which we define as variable and fixed O&M costs, routine capital expenditures, and life extension expenditures. Consequently, we also simulate a policy that guarantees recovery only of going-forward costs.

For each of these two policies, we simulate versions that apply to both coal- and nuclear-fueled generators, to coal-fueled generators only, and to nuclear-fueled generators only. The modeling horizon extends through 2045 in all simulations. Our simulations project the effects that the policy would have on outcomes such as online capacity by type of power plant, electricity generation by fuel type, emissions, mortality and illness from those emissions, and the four components of social welfare as measured by social surplus to allow a cost-benefit analysis.

Importantly, all of the simulations presented in this paper assume that the policy 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 make generators less thrifty, 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). These phenomena could be described as further affecting the efficient functioning of the electricity markets. Our analysis also does not address the question of whether implementing the proposed policy would increase or decrease reliability and resilience. Such additional effects, and their consequences, could be estimated separately or could be integrated with an approach such as the one used in this study.

3. Methods and Key Assumptions

3.1. Model Description

We employ the Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST), a set of software packages used for power system planning and policy analysis that is well suited for the present analysis. E4ST is built to simulate in detail how the power sector will respond to changes in environmental and non-environmental policies and regulations, input costs, transmission investments, conventional and renewable generation investments, energy efficiency, demand response, and other changes in conditions. It models successive multi-year periods, predicting hourly system operation for a set of representative hours throughout the year, along with generator construction and retirement, emissions, emission health effects, prices (including capacity prices), and all of the elements of social surplus, among other outcomes. Another E4ST feature important for the present analysis is that electricity consumption at each node responds to electricity price changes, and those prices can include geographically differentiated uplift charges.

We utilize E4ST's validated models of the Eastern Interconnection (EI), Western Interconnection (WECC), and Texas Interconnection (ERCOT) to capture both detailed sub-national and national impacts of the DOE-proposed policy[3]. The three models collectively contain the 19,000 existing grid-scale generators with their detailed individual characteristics[4], tens of thousands of buildable generators including location- and hour-specific wind and solar availability, and approximately 20,000 transmission line segments, including all of the high-voltage (>200 kV) segments as well as selected lower-voltage transmission segments in areas of chronic congestion. The models include detailed generator emission rates to enable E4ST to calculate emissions and estimated health effects. As a result, E4ST includes high spatial detail, realistic representation of power flows, and uniquely comprehensive benefit-cost analysis capabilities. E4ST is open-source and transparent, and has been developed by researchers at Resources for the Future, Cornell University, and Arizona State University, with funding, input, and review by DOE, NSF, and industry (the NYISO and the Power Systems Engineering

---

[3] We simulate all three interconnections in order to calculate national totals, but by our interpretation of the policy, there are no eligible generators outside of the EI. Consequently, the WECC and ERCOT results are identical in the policy and no-policy simulations.

[4] Presently, when there are very similar units at the same transmission node, they are aggregated to help enable the model to solve quickly and solve in spite of complexity.

Research Center). More information is available at e4st.org and in research journal papers including Shawhan et al. (2014) and Mao et al. (2016).

3.2. Scenario Descriptions

We simulate three versions of each of the following five scenarios: one business-as-usual (BAU) scenario and four cost recovery scenarios reflecting potential variants of the policy. Each scenario is simulated in ten-year time steps over the time horizon 2015-2045. Simulating with a policy not in effect in 2015, then in effect in 2025, represents that policy coming into effect at the beginning of 2020. Similarly, simulating with a policy in effect in 2025, then not in effect in 2035, represents that policy ending at the beginning of 2030. In scenarios 3, 4, and 5, the policy is applied in the near-term, from 2020-2030, while in scenario 2, it is extended through 2045.

In scenarios 2 and 3, we assume that currently existing merchant coal- and nuclear-fueled generators operating in the ISO/RTO territories of ISO-NE, NYISO, PJM, and MISO are eligible for the policy. In scenarios 4 and 5, only one of the two types is eligible. By these criteria, approximately 54 GW, or 20 percent, of total US coal capacity and 38 GW, or 38 percent, of nuclear capacity are eligible. Eligible coal-fueled generators span 23 states, while eligible nuclear-fueled generators span 12. In all scenarios, no new generators that are endogenously built in the simulations are eligible, and no generators that retired before July, 2017 are eligible.

Table 1. Scenario Descriptions

Scenario	Coal Eligible	Nuclear Eligible	Policy in Effect 2020-2030	Policy in Effect 2020-2045
1. Business-As-Usual (BAU)				
2. Coal & Nuclear (10-Years)	X	X	X	
3. Coal & Nuclear (25 Years)	X	X		X
4. Coal-Only (10 Years)	X		X	
5. Nuclear-Only (10 Years)		X	X	

In the first version of these five scenarios, the “Profit Guarantee” version, eligible generators are guaranteed recovery of the costs necessary for continued operation, plus a normal rate of recovery of any unrecovered past costs and a normal rate of return on equity. The second version of the scenarios, the “Going-Forward Guarantee” version, eligible generators are guaranteed recovery only of costs necessary for continued operation (going-forward costs). Lastly, the third version is a sensitivity version, with the Profit Guarantee but with a higher path of natural gas prices than in the former two versions.

3.3. Costs Subject to Guaranteed Recovery

The NOPR asks FERC to "ensure that each eligible resource...recovers its fully allocated costs and a fair return on equity." We interpret "fully allocated costs and a fair return on equity" as having four parts: (1) variable O&M (VOM) costs; (2) fixed O&M (FOM) costs (including the expected post-construction capital expenditure needs of the unit); (3) a normal rate of recovery of past, previously unrecovered, expenditures; and (4) a normal rate of return on equity. Parts 1 and 2 are the going-forward costs.

In our input data, part 2, annual FOM costs including post-construction capital expenditures average $66/kW for existing coal-fueled generators, $212/kW for existing nuclear, and $27/kW for existing natural gas in 2015, plus a life extension expenditure to operate past age 40. Parts 3 and 4 are guaranteed recovery under the Profit Guarantee but not under the Going-Forward Guarantee. We assume that parts 3 and 4 together equal the estimated construction cost of the unit, levelized over 60 years at a real cost of capital of 5.4 percent. Based on our assumptions and input data, parts 3 and 4 together for coal-fueled generators are $57/kW, or an average of approximately 46 percent of total non-variable costs subject to guaranteed recovery under the Profit Guarantee. For nuclear generators, they are $115/kW, or an average of approximately 35 percent of total non-variable costs subject to guaranteed recovery under the Profit Guarantee.

3.4. Calculation of Subsidies and Uplift Charges

In the policy scenarios, generators that, in a particular simulated year, would not otherwise receive the guaranteed revenues receive a subsidy sufficient to bring their revenues up to that level. The uplift charge in each state is the per-MWh charge necessary to pay for the subsidies to generators in that state. The "Uplift Charge Calculation" section in Appendix B provides more details about this.

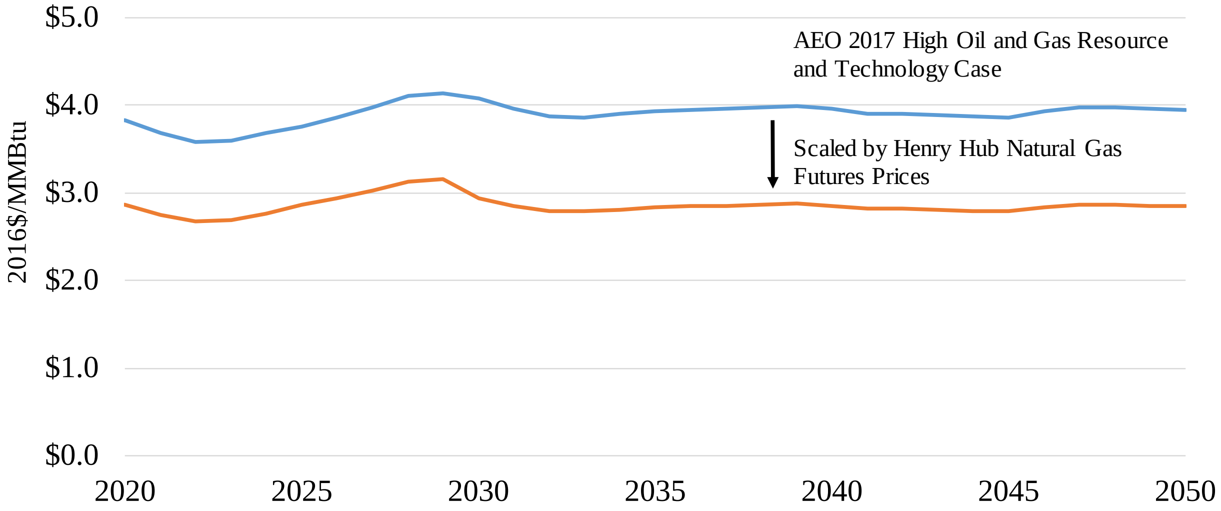
3.5. Dispatch of Generators

We assume that the policies affect only units that continue to be operable, and that, with or without the policies, dispatch minimizes the sum of short-run variable costs subject to the many constraints of the generators and the transmission system and subject to which generators are operable.

3.6. Fuel Prices

We assume the average coal, oil, and uranium fuel prices in each E4ST region in the future to be the prices from the US Energy Information Administration’s (EIA) *Annual Energy Outlook* (AEO) 2017 High Oil and Gas Resource and Technology Case, which is the EIA case with the lowest fuel prices. Coal prices remain relatively flat throughout the time horizon at an average of $2.19/MMBtu across the US. Oil prices rise from around $15/MMBtu in 2020 to around $20/MMBtu by 2045. Uranium prices for nuclear-fueled generators rise from $0.62/MMBtu in 2020 to $1.24/MMBtu by 2045. We adjust average natural gas prices from the same AEO case using Henry Hub Natural Gas Futures quotes (CME Group, October 22, 2017), scaling by the ratio of these to the AEO’s Henry Hub forecasts, as shown in Figure 1. We believe these prices to be a better indication of future natural gas prices; the Henry Hub natural gas prices in AEO’s set of prices are on average about 34 percent higher than the 2020 to 2029 CME natural gas price futures as of October 22, 2017. As the futures prices are available only through 2029, we maintain the 2029 scaling through the end of the time horizon. In Appendix A we provide sensitivity results using the AEO natural gas prices (blue path in Figure 1).

Figure 1. Assumed Future Paths of Average US Natural Gas Prices to Electric Generators



3.7. Welfare Analysis

We estimate all components of social surplus in order to conduct a cost-benefit analysis. The total net benefit of a policy is its total social surplus, which is the sum of its effects on End-User Net Benefits, Generator Profit, Environmental Net Benefits, and Government Revenue. Each component is defined below.

- End-User Net Benefits - The direct effect of the policy on end-user surplus as well as the effect on transmission payments (known as "merchandising surplus."). We include transmission payments in end-user net benefits because they change little and because in the regions where the policy would apply, changes in transmission payments are usually passed through to electricity users.
- Generator Profit - Revenues earned from electric energy and capacity markets, less costs including fixed and variable costs and capital expenditures. In this calculation, they are valued on a cash flow basis, i.e. revenues and costs are counted fully in the year that they occur.
- Environmental Net Benefits - This has two parts: the estimated net value of damage and benefits caused by power plant CO_2 emissions, and the estimated value of the mortality and morbidity due to emissions of power plant SO_2 and NO_X emissions. These damages are calculated from estimated emissions from each generator during a simulation. See Appendix B for more detailed assumptions.
- Government Revenue - Revenues collected by the government through emission taxes or cap-and-trade allowance sales, plus revenues from property taxes and other non-income taxes paid by generators, less costs of the Production Tax Credit for wind generation and Investment Tax Credit for solar investments.

3.8. Other Methods and Key Assumptions

Appendix B describes additional methods and key assumptions used in this study. They are important, but not necessary for a basic understanding of the study.

4. Results

This section describes the effects of the policy and its variations on the simulation results. We first present the results of simulating the proposed policy, as we interpret it. We then present the results of applying it only to coal-fueled generators and only to nuclear-fueled generators. After that, we present the results of simulating a policy that is the same except that the only costs subject to the cost recovery guarantee are those necessary for continued operation (going-forward costs). In each table, the effects of each policy are the differences between the outcomes under that policy and the outcomes in the BAU scenario.

4.1. Profit Guarantee Policy Outcomes

Table 2 presents the projected results of the policy as we interpret it, first with a duration of 25 years (left), then with a duration of ten years (right). We will first discuss the results in 2025, which are the same in these two scenarios. Of the four columns for each policy, the first three show the annual effects of the policy in the specified year, and the fourth shows the net present value (NPV) of the welfare effects of the policy, as well as total deaths, through 2045.

The amounts of coal and nuclear capacity that the policy prevents from retiring by 2025 are approximately equal.[5] This increases the amount of nuclear-fueled generation by approximately twice as much as it increases the amount of coal-fueled generation because the coal-fueled generators have higher variable operating costs and so have lower capacity factors. Additionally, preventing some capacity from retiring reduces the average capacity factor of eligible coal-fueled generators in general.

---

[5] The simulation result that a large portion of nuclear capacity may not be able to cover its going-forward costs is consistent with Steckler's (2017) finding that 34 of the 60 US nuclear power plants were losing money.

Table 2. Key US Results: Effects of Profit Guarantee for Coal & Nuclear Generators

	Coal & Nuclear (2020-2045)				Coal & Nuclear (2020-2030)			
	2025	2035	2045	Total/NPV*	2025	2035	2045	Total/NPV*
Online Coal Capacity (GW)	+22	+25	+25		+22	+6	+5	
Eligible Generators	+24	+25	+26		+24	+6	+6	
Non-Eligible Generators	-2	-0	-1		-2	-1	-1	
Online Nuclear Capacity (GW)	+21	+19	+4		+21	+11	-2	
Eligible Generators	+21	+20	+6		+21	+13	-0	
Non-Eligible Generators	-0	-1	-1		-0	-1	-1	
Coal Generation (TWh)	+88	+110	+104		+88	+30	+31	
Nuclear Generation (TWh)	+164	+148	+33		+164	+89	-12	
Natural Gas Generation (TWh)	-254	-259	-139		-254	-122	-21	
CO_2 Emissions (million short tons)	-4	+17	+53		-4	-19	+23	
SO_2 Emissions (thousand short tons)	+194	+247	+268		+194	+40	+43	
NO_x Emissions (thousand short tons)	+99	+117	+117		+99	+24	+32	
Deaths	+840	+1,139	+1,291	+26,896	+840	+188	+214	+11,461
EI-Wide Average LMP ($/MWh)	-$0.79	-$0.63	-$0.30		-$0.79	-$0.23	$0.07	
EI-Wide Average Uplift ($/MWh)	$2.45	$1.48	$0.73		$2.45	$0.00	$0.00	
Total Uplift Borne by End-Users ($ billions)	$7.6	$5.0	$2.6		$7.6	$0	$0	
Total Net Benefits ($ billions)	-$10	-$19	-$24	-$263	-$10	-$4	-$6	-$127
End-User Net Benefits	-$5	-$4	-$2	-$72	-$5	+$0	-$0	-$44
Environmental Net Benefits	-$9	-$15	-$20	-$217	-$9	-$1	-$4	-$93
Generator Profit	+$4	-$0	-$2	+$28	+$4	-$3	-$1	+$14
Gov't Revenue	-$0	-$0	+$0	-$2	-$0	-$0	-$0	-$3

*Calculated for 2015-2045 by applying linear interpolation between the years 2015, 2025, 2035 and 2045. Total Net Benefits and each of its components are net present values (NPV), assuming 3% continuous discounting from the perspective of 2018. Deaths are simple totals.

The generation displaced by the increased coal- and nuclear-fueled generation is almost entirely natural gas-fueled generation, in all scenarios including this one. As a result, the policy in 2025 decreases gas-fueled generation by 2.9 times as much as it increases coal-fueled generation. This decreases CO_2 emissions slightly, but increases SO_2 and NO_X emissions, since the incremental coal-fueled generation has average per-MWh SO_2 and NO_X emission rates more than three times as high as those of the displaced gas-fueled generation. The result is that the policy increases premature deaths from SO_2 and NO_X emissions by approximately 840 in 2025. This mortality effect combined with the morbidity effect of the same emissions increases environmental damage by $9 billion in 2025, meaning its environmental net benefits in that year are -$9 billion.

Also in 2025, the policy produces negative end-user net benefits (i.e. negative end-user surplus) because of the $7.6 billion in uplift charges. However, the negative end-user net benefits are only $5.4 billion because the Profit Guarantee reduces the average underlying wholesale electricity price (before adding the uplift charges) by an amount that offsets 29 percent of the uplift charge. Similar offsets occur in the other Profit Guarantee scenarios as well. This same effect is visible in the ratio of the average uplift per MWh to the average effect of the policy on the average underlying locational marginal price (LMP): Across all scenarios, when a Profit Guarantee policy is in effect, there is a reduction in average underlying wholesale electricity price (before counting the uplift) that offsets approximately 29 percent of the average uplift.

The uplift varies widely across states in which eligible generators are located. It is highest in Pennsylvania, at $17 per MWh consumed, and second-highest in Maryland, at $9 per MWh. The average per MWh across the states with eligible generators is $3.53. The average per MWh across the Eastern Interconnection is lower at $2.11 because not all states in the Eastern Interconnection have eligible generators, and none of the Canadian provinces do.

For generators, the policy increases the profits of some and decreases the profits of others. The effect on their aggregate profits is positive in 2025. The effect on government revenues is very small by comparison.

4.1.1. Effects in 2035 and 2045 if the Policy Remains in Force

In 2035 and 2045, if the policy remains in force (as shown in the left pane of Figure 2), its positive effect on coal capacity and generation increases as a larger set of coal-fueled generators remains online than would without the policy extension. However, the policy's positive effect on nuclear-fueled generation decreases as nuclear-fueled generators reach age 60, at which age we assume that they retire because they are unable to renew their operating licenses. As a result of this growing coal effect and shrinking nuclear effect, the policy's impact on emissions and associated damages grows. Its effect on premature deaths from SO_2 and NO_X emissions, from 2020 to 2045, is approximately 27,000.

The total annual dollar amount of subsidies, which is also the total annual dollar amount of uplift charges, decreases over time because fewer nuclear-fueled units remain to be subsidized and because the average electricity price increases modestly. Consequently, the annual policy-induced loss of end-user benefits decreases over time.

In spite of the subsidies and the modest decade-to-decade increase in average electricity prices, the effect of the policy on the aggregate profit of generators is negative in 2035 and 2045 because the policy reduces the amount of lower-cost capacity built in earlier years and reduces the average wholesale electricity prices (before adding the uplift charges) compared to those in the BAU scenario.

4.1.2. Effects in 2035 and 2045 if the Policy Ends in 2030

If the policy ends in 2030, some of the capacity prevented from retiring through 2030 does not retire until after 2035 or 2045 because of modestly higher electricity prices after 2030.

Largely as a result of that, the policy continues to have effects in 2035 and 2045, though most of them are considerably smaller than the effects it would have if it remained in force. Its effect on premature deaths from SO_2 and NO_X emissions, from 2020 to 2045, is approximately 11,000.

4.1.3. Effects of the Policy if Natural Gas Prices Are Higher

In Appendix A, we provide results of a simulation set with somewhat higher natural gas prices. This set repeats all five simulations that are listed in Table 1 and represented in Tables 2-5, but this set uses the upper rather than lower path of average natural gas prices in Figure 1. Many of the impacts of the policy have the same sign but are reduced because of fewer coal and nuclear retirements in the BAU scenario that uses these higher gas prices. One exception is that the coal-fueled generation and emissions in the aftermath of the 2020-2030 coal-and-nuclear Profit Guarantee are higher. The reason is that the higher natural gas prices cause the coal capacity preserved after 2025 to have a higher capacity factor.

With the higher natural gas prices, the ratio of the 2020-2030 policy's effect on coal-fueled generation to its effect on nuclear-fueled generation is larger. As a result, the environmental damage resulting from the policy is 86 percent as large even though the policy's effect on end-user net benefits is only 52 percent as large.

4.1.4. Effects of the Policy if Applied Only to Coal-Fueled Generators

The left pane of Table 3 shows some of the effects of applying the policy only to coal-fueled generators, compared to the BAU (no-policy) scenario. In the case of this policy, it is interesting to also compare its effects with those of applying the policy to both coal- and nuclear-fueled generators (right pane of Table 2). Applying it only to coal-fueled generators instead of to both coal- and nuclear-fueled generators causes a larger increase in coal-fueled generation because there are fewer nuclear-fueled generators to lower electricity prices during lower-load hours. The greater coal-fueled generation, and less displacement of natural gas-fueled generation by continued nuclear-fueled generation, cause a larger increase in emissions. Those additional emissions produce approximately 2,900 additional premature deaths and total additional environmental damage with a net present value (NPV) of $69 billion, between 2020 and 2045. Partially offsetting that, less subsidies and uplift charges are needed, which increases the NPV of end-user net benefits by $31 billion but decreases the NPV of generator profits by $15 billion. It slightly increases government revenue because it increases the prices of RGGI emission allowances that will be auctioned by state governments in the future. In total, the net present

Table 3. Key US Results: Effects of Coal-Only and Nuclear-Only Profit Guarantees

	Coal-Only (2020-2030)				Nuclear-Only (2020-2030)			
	2025	2035	2045	Total/NPV*	2025	2035	2045	Total/NPV*
Online Coal Capacity (GW)	+22	+8	+7		-1	+0	+0	
Eligible Generators	+24	+8	+8		NA	NA	NA	
Non-Eligible Generators	-1	-0	-1		-1	+0	+0	
Online Nuclear Capacity (GW)	+1	-1	-2		+20	+12	-0	
Eligible Generators	NA	NA	NA		+21	+13	-0	
Non-Eligible Generators	+1	-1	-2		-1	-1	-0	
Coal Generation (TWh)	+100	+48	+40		-14	-0	+6	
Nuclear Generation (TWh)	+10	-5	-12		+158	+92	-3	
Natural Gas Generation (TWh)	-110	-45	-30		-140	-96	-4	
CO_2 Emissions (million short tons)	+65	+30	+28		-70	-40	+3	
SO_2 Emissions (thousand short tons)	+229	+61	+53		-36	-4	+23	
NO_x Emissions (thousand short tons)	+122	+51	+45		-25	-10	+5	
Deaths	+995	+294	+268	+14,370	-159	-24	+110	-1,222
EI-Wide Average LMP ($/MWh)	-$0.29	-$0.17	-$0.05		-$0.39	-$0.07	$0.10	
EI-Wide Average Uplift ($/MWh)	$0.85	$0.00	$0.00		$1.53	$0.00	$0.00	
Uplift Borne by End-Users ($ billions)	$2.6	$0	$0		$4.7	$0	$0	
Total Net Benefits ($ billions)	-$14	-$7	-$6	-$175	+$4	+$1	-$3	+$33
End-User Net Benefits	-$2	+$0	-$0	-$14	-$4	-$0	-$0	-$31
Environmental Net Benefits	-$14	-$5	-$5	-$162	+$5	+$3	-$2	+$53
Generator Profit	+$1	-$2	-$0	-$2	+$3	-$1	-$1	+$15
Gov't Revenue	+$0	-$0	-$0	+$2	-$0	-$0	+$0	-$5

*Calculated for 2015-2045 by applying linear interpolation between the years 2015, 2025, 2035 and 2045. Total Net Benefits and each of its components are net present values (NPV), assuming 3% continuous discounting from the perspective of 2018. Deaths are simple totals.

value of total net benefits is $48 billion lower if the Profit Guarantee is applied only to coal-fueled generators than if it is applied to both coal- and nuclear-fueled generators.

4.1.5. Effects of the Policy if Applied Only to Nuclear-Fueled Generators

All three of the policy variations considered so far have produced negative total net benefits with NPVs of between -$127 billion and -$263 billion. However, much of that has been because of environmental damage. The non-environmental net benefits effects of those policies have NPVs of between -$13 billion and -$46 billion. If a version of the policy had positive environmental net benefits and they were large enough, it could produce a positive total net benefits effect.

Applying the policy only to nuclear-fueled generators has such an effect. Compared to business-as-usual (no policy), it reduces natural gas- and coal-fueled generation by an amount that reduces health and environmental damage by $53 billion. The reduction in premature deaths between 2020 and 2045 is approximately 1,200. The policy reduces end-user net benefits by $31 billion and increases aggregate generator profits by $15 billion. It reduces government revenue by $5 billion because it reduces the prices of future RGGI emission allowances. Its total net benefits effect is positive $33 billion.[6] These are all NPVs.

4.1.6. Comparison with Prior Studies

The estimated out-of-market payments in Celebi et al. (2017), based on 2016 historical data, range from $3.7 to $11.2 billion in 2016, depending on assumed plant depreciation and capital costs. The assumed fleet of eligible generators closely resembles those used in the present study, and the average natural gas price is similar to the ones we use in 2025, 2035, and 2045 in Tables 2-5. Our estimates of total annual uplift payments fall within this predicted range. In the most comparable scenario in Orvis et al (2017), the estimated total annual uplift is $700 million. This estimate is based on 2015 historical data. In this year, the average natural gas price is between the one we use for Tables 2-5 and the one we use for Tables 6-7. While both going-forward costs and capital costs are covered, only units with negative cash flow are eligible, according to the report. Other factors that could explain why this estimate is lower than ours include the assumption that underlying wholesale electricity prices are not suppressed by the policy, the assumption that each generator is dispatched during the highest-price hours, and different cost data or assumptions.

4.2. Going-Forward Guarantee Policy Outcomes

To prevent the owners of existing generators from choosing to retire them, it is only necessary to guarantee recovery of going-forward costs. As a result, a policy that does only that is a logical alternative to the policy in the DOE NOPR.

The only difference between this alternative and the policy in the NOPR, as we interpret it, is that this alternative does not include recovery of past expenditures and a fair return on equity in the amounts that are subject to guaranteed recovery. As mentioned previously, we assume that these amounts are $57/kW/year for coal-fueled generators and $115/kW/year for nuclear-fueled generators. These are, on average, 35 percent of total non-variable costs for nuclear-fueled generators and 46 percent for coal-fueled generators in 2015, as calculated in the Methods and Key Assumptions section.

---

[6] The negative total welfare effect in 2045 results from higher coal-fueled generation in 2045 in the nuclear-only Profit Guarantee scenario than in the BAU scenario. This in turn results from conditions being favorable for coal-fueled generation to substitute for nuclear-fueled generators that, in that scenario, retire between 2036 and 2045 rather than earlier as in the BAU scenario. In addition, the 2045 coal-fueled generation has a slightly higher average per-MWh emission rate in the nuclear-only Profit Guarantee scenario than in the BAU scenario.

Since the alternative policy and the rule in the NOPR prevent the same capacity from retiring, most of the simulation outcomes will be nearly identical. The only differences in capacity, generation, emissions, environmental net benefits, government revenue, and total net benefits will be those that result from electricity end-users facing lower uplift charges and hence consuming slightly more electricity. Those differences will consequently be very small. The only outcomes that will be substantially different are total uplift payments (which always equal total subsidy payments), end-user net benefits, and generator profit. The uplift payments are transfers from end-users to generators, so the alternative policy will increase end-user net benefits and reduce generator profits by the same amount, relative to the rule in the NOPR. In 2025 in the 2020-2030 coal-and-nuclear guarantee scenario, the total uplift payments are $1.7 billion under the alternative policy and $7.6 billion under the NOPR policy. This is a reduction of 78 percent relative to the outcome under NOPR policy, and the reduction percentages in the other scenarios are similar.

The reduction is this large for two reasons. First, under the NOPR policy, some generators that do not need any subsidy to cover just their going-forward costs receive subsidies. Second, those generators that do need some amount of subsidy to cover just their going-forward costs cover some portion of those costs from market revenues, so that eliminating the subsidy for past expenditures and return on equity reduces their subsidy by more than the percentage share of those costs in total non-variable costs.

The reduction in wholesale electricity prices that results from preventing the retirement of eligible coal-fueled and nuclear-fueled generators almost exactly counteracts the end-user impact of the uplift payments, so that the end-user net benefits effects of the four going-forward cost recovery guarantee policies are close to zero.

Table 4. Key US Results: Effects of Going-Forward Cost Recovery Guarantee for Coal & Nuclear Generators

	Coal & Nuclear (2020-2045)				Coal & Nuclear (2020-2030)			
	2025	2035	2045	Total/NPV*	2025	2035	2045	Total/NPV*
Online Coal Capacity (GW)	+22	+25	+25		+22	+6	+5	
Eligible Generators	+24	+25	+26		+24	+6	+6	
Non-Eligible Generators	-2	-1	-1		-2	-1	-1	
Online Nuclear Capacity (GW)	+21	+19	+4		+21	+11	-2	
Eligible Generators	+21	+20	+6		+21	+13	-0	
Non-Eligible Generators	-0	-1	-1		-0	-1	-1	
Coal Generation (TWh)	+90	+108	+104		+90	+30	+31	
Nuclear Generation (TWh)	+164	+148	+33		+164	+89	-12	
Natural Gas Generation (TWh)	-250	-256	-138		-250	-122	-21	
CO_2 Emissions (million short tons)	-1	+15	+53		-1	-19	+23	
SO_2 Emissions (thousand short tons)	+197	+245	+267		+197	+39	+44	
NO_x Emissions (thousand short tons)	+101	+116	+117		+101	+24	+33	
Deaths	+856	+1,130	+1,289	+26,953	+856	+183	+219	+11,592
EI-Wide Average LMP ($/MWh)	-$0.81	-$0.63	-$0.29		-$0.81	-$0.22	$0.08	
EI-Wide Average Uplift ($/MWh)	$0.56	$0.34	$0.15		$0.56	$0.00	$0.00	
Uplift Borne by End-Users ($ billions)	$1.7	$1.1	$0.5		$1.7	$0	$0	
Total Net Benefits ($ billions)	-$11	-$18	-$24	-$263	-$11	-$4	-$6	-$129
End-User Net Benefits	+$0	+$0	-$0	+$5	+$0	+$0	-$0	+$3
Environmental Net Benefits	-$9	-$14	-$20	-$219	-$9	-$1	-$4	-$96
Generator Profit	-$2	-$4	-$4	-$48	-$2	-$3	-$1	-$34
Gov't Revenue	-$0	-$0	+$0	-$2	-$0	-$0	-$0	-$3

*Calculated for 2015-2045 by applying linear interpolation between the years 2015, 2025, 2035 and 2045. Total Net Benefits and each of its components are net present values (NPV), assuming 3% continuous discounting from the perspective of 2018. Deaths are simple totals.

As previously mentioned, the improvement in end-user net benefits relative to the NOPR policy is matched by an equal reduction in generator profit impacts. Consequently, the pattern of total net benefits effects is the same as under the NOPR policy: Applying the policy only to coal-fueled generators produces the largest welfare reduction, while applying it only to nuclear-fueled generators produces a welfare gain.

Table 5. Key US Results: Effects of Coal-Only & Nuclear-Only Going-Forward Cost Recovery Guarantees

	Coal-Only (2020-2030)				Nuclear-Only (2020-2030)			
	2025	2035	2045	Total/NPV*	2025	2035	2045	Total/NPV*
Online Coal Capacity (GW)	+22	+8	+7		-1	+0	+1	
Eligible Generators	+24	+8	+8		NA	NA	NA	
Non-Eligible Generators	-1	-0	-1		-1	+0	+1	
Online Nuclear Capacity (GW)	+1	-1	-2		+20	+12	-0	
Eligible Generators	NA	NA	NA		+21	+13	-0	
Non-Eligible Generators	+1	-1	-2		-1	-1	-0	
Coal Generation (TWh)	+100	+47	+40		-13	-0	+6	
Nuclear Generation (TWh)	+10	-5	-12		+158	+92	-3	
Natural Gas Generation (TWh)	-109	-44	-30		-139	-96	-5	
CO_2 Emissions (million short tons)	+65	+30	+28		-69	-40	+3	
SO_2 Emissions (thousand short tons)	+229	+61	+53		-34	-4	+24	
NO_x Emissions (thousand short tons)	+123	+51	+45		-24	-10	+5	
Deaths	+997	+294	+269	+14,394	-151	-22	+112	-1,112
EI-Wide Average LMP ($/MWh)	-$0.30	-$0.17	-$0.05		-$0.39	-$0.07	$0.10	
EI-Wide Average Uplift ($/MWh)	$0.24	$0.00	$0.00		$0.28	$0.00	$0.00	
Uplift Borne by End-Users ($ billions)	$0.7	$0	$0		$0.9	$0	$0	
Total Net Benefits ($ billions)	-$15	-$7	-$6	-$175	+$4	+$1	-$3	+$32
End-User Net Benefits	+$0	+$0	-$0	+$2	+$0	-$0	-$0	+$0
Environmental Net Benefits	-$14	-$5	-$5	-$162	+$5	+$3	-$2	+$52
Generator Profit	-$1	-$2	-$0	-$18	-$1	-$1	-$1	-$16
Gov't Revenue	+$0	-$0	-$0	+$2	-$0	-$0	+$0	-$5

*Calculated for 2015-2045 by applying linear interpolation between the years 2015, 2025, 2035 and 2045. Total Net Benefits and each of its components are net present values (NPV), assuming 3% continuous discounting from the perspective of 2018. Deaths are simple totals.

The policy can reduce profits in part because the generators that are prevented from retiring earn zero profits. If they retired, they would be replaced by generators that would be expected to earn positive profits. In addition, the policy reduces the average wholesale electricity price (before adding the uplift charges), which can reduce the profits of generators that do not receive subsidies under the policy.

4.3. General Additional Observations

Expanding the set of generators eligible for a Profit Guarantee will increase the subsidy required for the initial set. This is because expanding the set will suppress the average electricity price (before counting uplift charges), reducing the market revenues of the initial set. A comparison of Tables 2 and 3 illustrates this phenomenon: the sum of the 2025 total uplift payments under the coal-only and nuclear-only Profit Guarantees is $7.3 billion, which is less than the $7.6 billion in the coal-and-nuclear scenario.

In the presence of a CO_2 emission cap-and-trade program, preserving capacity (i.e. preventing it from retiring) only if it is coal-fueled can preserve nuclear capacity, and can even preserve more nuclear capacity than it displaces. This can occur because the coal-fueled capacity has high per-MWh emission rates, so preserving it raises the demand for emission allowances and consequently raises the emission allowance price. That in turn favors nuclear capacity, which is non-emitting, over natural gas-fueled capacity, which is moderately emitting. This occurs in the coal-only Profit Guarantee scenario in 2025 because a portion of the regions that are subject to the Profit Guarantee are also subject to a power sector CO_2 emission cap-and-trade program, the Regional Greenhouse Gas Initiative (RGGI).

The obverse also occurs: By reducing the emission allowance price, the nuclear-only Profit Guarantee preserves coal capacity and increases coal-fueled generation and SO_2 emissions in the RGGI region in 2025, though not enough to fully offset decreases induced by the nuclear-only guarantee outside of the RGGI region.

Preventing some capacity from retiring can displace other capacity not just of other types but also of the same type, partially offsetting the preservation of capacity of that type. Table 2 through 5 each show this: preventing eligible coal- or nuclear-fueled generators from retiring causes some non-eligible coal- and nuclear-fueled generators to retire, as indicated by the negative numbers in the “Non-Eligible Generators” rows. The generators prevented from retiring displace other generation by reducing wholesale electricity prices (before adding the uplift charges) that other generators receive if they exist and generate. This causes some other generators to no longer be able to cover their going-forward costs.

5. Conclusions

Using the E4ST model of the US and Canadian power sectors, we project effects of ensuring cost recovery to a set of coal- and nuclear-fueled generators in the US electric power system in order to prevent their retirement, as outlined in the Fall 2017 DOE Notice of Proposed Rulemaking. Our analysis assumes that the policy does not otherwise affect the efficient functioning of the market, and it does not attempt to simulate resilience or resilience effects of the policies; thus, it encompasses some of the potential effects of the policy, and it could be combined with, or considered along with, analysis of other potential effects. We offer these results as a study of the particular DOE policy proposal and variations, and also as an illustrative case study for national, regional, or state policies that aim to achieve similar outcomes, whether in the US or internationally.

We simulate versions lasting ten and 25 years, versions applied to both coal- and nuclear-fueled generators, versions applied to only one of these two fuel types, and versions guaranteeing recovery of different cost components. In the simulation results, all versions of the policy reduce non-environmental welfare. All but two also reduce environmental welfare, the exceptions being the versions in which the guarantee is applied only to nuclear generators. Those nuclear-only versions are also consequently the only ones that produce positive net benefits. In contrast, a version that applies only to coal-fueled generators produces higher emissions and a greater reduction in net benefits than does a policy that applies to both coal- and nuclear-fueled generators.

In all scenarios, the environmental welfare effect is at least 2.6 times as large as the net non-environmental effect, and in some cases it has the opposite sign. As a result, the environmental damage effects would need to be overestimated by at least a multiple of 2.6 in order to change the sign of the total estimated net benefit of any of the policy versions simulated.

The estimated environmental effects consist of climate change damages from CO_2 emissions and premature mortality and illness from SO_2 and NO_X emissions. For example, if the policy prevents both coal- and nuclear-fueled generators from retiring, it increases premature deaths by approximately 840 in 2025, and its estimated environmental damage is approximately $9 billion in that year, using natural gas prices based on futures prices as of October 2017. The annual environmental damage of that policy more than doubles by 2045 if it remains in force, but decreases over time after 2030 if instead the policy ends in 2030.

The Profit Guarantee described in the DOE NOPR, as we interpret it, involves $7.6 billion of subsidies to unprofitable generators in 2025, funded by collecting that amount from customers in the form of uplift charges which we assume to vary from state to state. However, preventing retirements decreases the underlying wholesale electricity prices, so the policy’s net cost to electricity users in 2025 is $5.4 billion. The net increase in generator aggregate profits would be $4.3 billion. These effects decrease after 2025, whether the policy remains in force or not.

If the policy instead guarantees recovery only of the costs necessary for continued operation (going-forward costs), the only large difference in the results is that the transfers from electricity users to generation owners are greatly reduced. This is because only the units that need subsidies to continue operating receive them, and they receive only enough to keep them operating. In 2025, the total subsidy amount is $1.7 billion, so the transfer from electricity users to generation owners is smaller by $5.9 billion. Consequently, there is a positive user benefit (end-user surplus) of $0.2 billion, while the effect on generator aggregate profits becomes a reduction of $0.7 billion. The environmental effects of policy are nearly the same as under the corresponding full Profit Guarantee policy, at 856 additional premature deaths and $9 billion in damages in 2025.

Most of our simulations use future natural gas prices based on October 2017 futures prices. In a Profit Guarantee simulation with prices that are approximately 34 percent higher, the policy has smaller effects than with the lower natural gas prices, because the higher natural gas prices cause fewer nuclear and coal-fueled generators to retire without the policy. The Results section explains these results and others in greater detail.

References

Bade, Gavin. “Chatterjee: FERC may boost coal, won't 'blow up the market'.” Utility Dive. Oct. 13, 2017. https://www.utilitydive.com/news/chatterjee-ferc-may-boost-coal-wont-blow-up-the-market/507266/.

CME Group, 2017. Henry Hub Natural Gas Futures Quotes. 4 pm US eastern time, October 22, 2017. http://www.cmegroup.com/trading/energy/natural-gas/natural-gas.html

Federal Register. Vol. 82, No. 194 (October 10, 2017), p. 46940.

Fann, N., Baker, K.R. & Fulcher, C.M., 2012. Characterizing the $PM_{2.5}$-related health benefits of emission reductions for 17 industrial, area and mobile emission sectors across the US Environment international, 49, pp.141–51. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23022875

Carolyn Fischer, Biao Mao, and Daniel Shawhan. “Trade between Mass- and Rate-Based Regulatory Regimes: Bad for Emissions?” Resources for the Future working paper, forthcoming December 2017.

Celebi et al. “Evaluation of the DOE’s Proposed Grid Resiliency Pricing Rule.” The Brattle Group. October 23, 2017. http://www.brattle.com/system/publications/pdfs/000/005/530/original/Evaluation_of_the_DOE%27s_Proposed_Grid_Resiliency_Pricing_Rule.pdf?1509064658

Huntoon, Steve. “Cash for Clunkers Redux.” *RTO Insider*, pp. 3-4, October 3, 2017.

Interagency Working Group on Social Cost of Carbon. 2015. Technical support document: Technical update of the social cost of carbon for regulatory impact analysis under Executive Order 12866. Washington, DC: US Government.

Mao, Biao, Daniel Shawhan, Ray Zimmerman, Jubo Yan, Yujia Zhu, William Schulze, Richard Schuler, and Daniel Tylavsky. 2016. The Engineering, Economic and Environmental Electricity Simulation Tool (E4ST): Description and an illustration of its capability and use as a planning/policy analysis tool. *Proceedings of the 49th Annual Hawaii International Conference on System Sciences*, Computer Society Press, 2317–25.

Monitoring Analytics, LLC. “Comments of the Independent Market Monitor for PJM.” Grid Reliability and Resilience Pricing FERC Docket No. RM18-1-000, October 23, 2017.

Orvis et al. “The Department of Energy’s Grid Resilience Pricing Proposal: A Cost Analysis.” Energy

Innovation Policy and Technology LLC and Climate Policy Initiative, October, 2017. http://energyinnovation.org/wp-content/uploads/2017/10/20171021_Resilience-NOPR-Cost-Research-Note-FINAL.pdf

P. Jaramillo and N.Z. Muller. Air pollution emissions and damages from energy production in the US: 2002–2011. Energy Policy 90: 202 - 211, 2016.

Krewski et al. Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. 2009.

Nicholas Steckler, “Half of US Nuclear Power Plants are Underwater,” *Bloomberg New Energy Finance*, June 13, 2017

Rory D. Sweeney. “Bill to Save Coal, Nuclear Plants Introduced in Illinois.” *RTO Insider*. November 16, 2016. https://www.rtoinsider.com/illinois-bill-save-coal-nuclear-plants-34304/.

Shawhan, Daniel L., John T. Taber, Di Shi, Ray D. Zimmerman, Jubo Yan, Charles M. Marquet, Yingying Qi, Biao Mao, Richard E. Schuler, William D. Schulze, and Daniel J. Tylavsky, 2014. Does a detailed model of the electricity grid matter? Estimating the impacts of the Regional Greenhouse Gas Initiative. *Resource and Energy Economics* 36(1) (January): 191–207. http://dx.doi.org/10.1016/j.reseneeco.2013.11.015.

Traywick, Catherine and Rebecca Kern. “US Energy Regulator Lays Out Plan to Keep At-Risk Coal.” *Bloomberg Online*. November 9, 2017. Accessed November 26, 2017 at https://www.bloomberg.com/news/articles/2017-11-09/u-s-energy-regulator-lays-out-plan-to-keep-at-risk-coal-online.

US Census, "Annual Estimates of the Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2015." United States Census Bureau, Population Division, December 2015.

US Energy Information Administration (USEIA). 2015 Form EIA-860 detailed data, released 2016.

USEIA. Preliminary Monthly Electric Generator Inventory, July 2017.

US Environmental Protection Agency (USEPA). Air Markets Program Data, 2017.

USEPA. Power Sector Modeling Platform v5.15, 2015. https://www.epa.gov/airmarkets/power-sector-modeling-platform-v515

USEPA. Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors, January 2013. https://www.epa.gov/sites/production/files/2014-10/documents/sourceapportionmentbpttsd.pdf

Appendix A. Natural Gas Price Sensitivity Results

Tables 6 and 7 present key nation-wide impacts of a Profit Guarantee policy covering the variable and fixed O&M costs, plus a normal rate of return on all capital expenditures including levelized construction costs, assuming natural gas prices from AEO 2017's High Oil and Gas Resource and Technology case.

Table 6. Key US Results: Effects of Profit Guarantee for Coal & Nuclear Generators, Natural Gas Price Sensitivity

	Coal & Nuclear (2020-2045)				**Coal & Nuclear (2020-2030)**			
	2025	2035	2045	Total/NPV*	2025	2035	2045	Total/NPV*
Online Coal Capacity (GW)	+13	+14	+13		+13	+6	+5	
Eligible Generators	+14	+16	+14		+14	+7	+6	
Non-Eligible Generators	-1	-1	-1		-1	-1	-1	
Online Nuclear Capacity (GW)	+9	+6	+1		+9	+2	-1	
Eligible Generators	+9	+6	+1		+9	+3	-1	
Non-Eligible Generators	-1	-1	-0		-1	-1	+0	
Coal Generation (TWh)	+47	+60	+49		+47	+41	+33	
Nuclear Generation (TWh)	+66	+44	+8		+66	+16	-5	
Natural Gas Generation (TWh)	-111	-106	-56		-111	-56	-28	
CO_2 Emissions (million short tons)	+6	+27	+33		+6	+23	+25	
SO_2 Emissions (thousand short tons)	+74	+139	+127		+74	+71	+63	
NO_x Emissions (thousand short tons)	+45	+75	+60		+45	+48	+38	
Deaths	+325	+646	+617	+13,102	+325	+338	+312	+8,350
EI-Wide Average LMP ($/MWh)	-$0.65	-$0.06	$0.08		-$0.65	$0.00	-$0.02	
EI-Wide Average Uplift ($/MWh)	$1.70	$0.80	$0.39		$1.70	$0.00	$0.00	
Uplift Borne by End-Users ($ billions)	$5.2	$2.7	$1.4		$5.2	$0	$0	
Total Net Benefits ($ billions)	-$4	-$11	-$12	-$130	-$4	-$6	-$6	-$89
End-User Net Benefits	-$3	-$2	-$1	-$41	-$3	-$0	+$0	-$23
Environmental Net Benefits	-$4	-$9	-$10	-$115	-$4	-$5	-$6	-$80
Generator Profit	+$3	+$1	-$1	+$22	+$3	-$1	-$1	+$14
Gov't Revenue	+$0	+$0	+$0	+$3	+$0	-$0	-$0	+$0

*Calculated for 2015-2045 by applying linear interpolation between the years 2015, 2025, 2035 and 2045. Total Net Benefits and each of its components are net present values (NPV), assuming 3% continuous discounting from the perspective of 2018. Deaths are simple totals.

Table 7. Key US Results: Effects of Coal-Only and Nuclear-Only Profit Guarantees, Natural Gas Price Sensitivity

	Coal-Only (2020-2030)				**Nuclear-Only (2020-2030)**			
	2025	2035	2045	Total/NPV*	2025	2035	2045	Total/NPV*
Online Coal Capacity (GW)	+13	+6	+8		-2	-2	+1	
Eligible Generators	+14	+7	+8		NA	NA	NA	
Non-Eligible Generators	-1	-1	+0		-2	-2	+1	
Online Nuclear Capacity (GW)	-0	-0	+3		+8	+2	+3	
Eligible Generators	NA	NA	NA		+9	+3	+1	
Non-Eligible Generators	-0	-0	+3		-1	-1	+2	
Coal Generation (TWh)	+53	+41	+33		-18	-12	-13	
Nuclear Generation (TWh)	-1	-1	+0		+64	+19	+0	
Natural Gas Generation (TWh)	-52	-38	-32		-43	-7	+13	
CO_2 Emissions (million short tons)	+37	+30	+23		-36	-14	-8	
SO_2 Emissions (thousand short tons)	+97	+74	+67		-29	-8	-5	
NO_x Emissions (thousand short tons)	+59	+47	+37		-22	-8	-10	
Deaths	+425	+350	+330	+9,569	-131	-39	-30	-1,870
EI-Wide Average LMP ($/MWh)	-$0.22	-$0.07	$0.00		-$0.29	$0.29	$0.10	
EI-Wide Average Uplift ($/MWh)	$0.53	$0.00	$0.00		$1.10	$0.00	$0.00	
Uplift Borne by End-Users ($ billions)	$1.6	$0	$0		$3.4	$0	$0	
Total Net Benefits ($ billions)	-$7	-$6	-$6	-$109	+$3	+$1	+$1	+$31
End-User Net Benefits	-$1	+$0	+$0	-$6	-$2	-$1	-$0	-$23
Environmental Net Benefits	-$7	-$6	-$6	-$104	+$3	+$1	+$1	+$36
Generator Profit	+$1	-$1	-$0	+$0	+$2	+$0	-$0	+$19
Gov't Revenue	+$0	-$0	-$0	+$2	-$0	+$0	+$0	-$1

*Calculated for 2015-2045 by applying linear interpolation between the years 2015, 2025, 2035 and 2045. Total Net Benefits and each of its components are net present values (NPV), assuming 3% continuous discounting from the perspective of 2018. Deaths are simple totals.

Appendix B. Additional Methods and Key Assumptions

Generator Data & Policy Eligibility

The starting generator dataset includes all units online as of the beginning of 2016 (USEIA 2016). This dataset includes detailed generator-level characteristics, such as the 2015 average heat rate and average CO_2, SO_2 and NO_X emission rates, based on data reported to the USEPA (USEPA 2017). The pre-existing generators in our simulations have the emission rates that they reported in 2015. To the extent that some existing generators have improved their emission controls since 2015, or will do so by 2045, our emission estimates are overestimates.

In the simulations for this study, we allowed new generators of the following types to be built: natural gas combined cycle (NGCC), natural gas turbines (NGT), NGCC with carbon capture and storage (NGCC-CCS), nuclear, solar, and wind. No new coal-fueled capacity is allowed to be built because of current US regulations on allowable CO_2 emission rates of new generators, pursuant to Clean Air Act Section 111(b). Assumptions for new generators primarily source from AEO 2017.

We assume that currently existing merchant coal- and nuclear-fueled generators operating in the ISO/RTO territories of ISO-NE, NYISO, PJM, and MISO are eligible for the policy. In order to determine eligibility, we use plant-level data on regulatory status and ISO/RTO territories provided by the S&P Global Market Intelligence Platform (SNL).

Generator Retirement

In all scenarios, we exogenously retire the generators that have retired as of July 2017, per the most recently available EIA-860 Monthly dataset (USEIA 2017).[7] We also assume that nuclear-fueled generators must retire by age 60, based on the assumption that each will receive Nuclear Regulatory Commission licenses that allow it to operate to that age but not beyond. This assumption requires that approximately 75 GW of nuclear capacity, constituting approximately 75 percent of 2017 US nuclear capacity, retire nation-wide by 2045, although generators may retire earlier than required if continued operation is uneconomical.

---

[7] This is a conservative assumption, as the policy could incentivize recently retired generators to re-open (Huntoon 2017).

In the BAU, we exogenously retire generators that have announced planned retire dates by the middle of 2021 (USEIA 2016, USEIA 2017). Generators also endogenously retire if revenues expected from continuing operation would not cover going-forward costs.

In the policy scenarios, the eligible generators that had announced retirement effective August 2017 or later reverse this decision. Additionally, eligible generators do not retire in the years the policy is in force due to the ability of these generators to receive at least break-even revenues.

Average Variable Costs

VOM costs per MWh average $7.1/MWh plus fuel costs for existing coal-fueled generators, $0.2/MWh plus fuel for existing nuclear-fueled generators, and $4.7/MWh plus fuel costs for existing natural gas-fueled generators.

Uplift Charge Calculation

For each state, we calculate and apply the “uplift” charge per MWh that will recover the total amount of subsidies to generators in that state. In reality, uplift charges might instead differ from one utility territory to another. We determine the uplift applied in a given policy-year through an iterative simulation process. This is because we must calculate the resulting uplift after a simulation year, and this approach allows us to apply an accurate uplift during that same year. After the first simulation of a policy-year, we calculate the total amount of subsidy paid in each state and divide it equally across all MWh sold in that state to determine the per-MWh uplift that would have been necessary in that state to fund the subsidy. We then run the same simulation year again with that set of uplift charges, and then simulate the year a third time with the uplift charges from the second iteration. We find that the uplift values from the third iteration are very close to those from the second iteration, indicating sufficient convergence and that we do not need more than three iterations. We keep the results of the third iteration, and continue to the next simulated year.

Net Present Value Calculations

We report the net present value (NPV) of each component of total net benefits from 2015 through 2045. To calculate NPV, we linearly interpolate between 2015, 2025, 2035, and 2045, and assume 3 percent continuous discounting from the perspective of 2018.

Years Simulated

We simulate the years 2015, 2025, 2035, and 2045. We do not show the 2015 results because they are the same in every scenario and they closely match the actual outcomes in 2015. The entry and retirement of generators that occurs in the 2025, 2035, and 2045 simulations represents ten years of entry and retirement, and we assume for the purpose of the producer profit and total surplus calculations that the total construction expenditures in that year are one tenth of the total construction expenditures in those ten years.

Environmental Damages

For CO_2, we use the damage values from the Inter-Agency Working Group on the Social Cost of Carbon (2015). For SO_2 and NO_X, we use the lower of two sets of national average damage- and mortality-per-ton values that are reported in EPA (2013) and Fan, Baker and Fulcher (2012). These national average values are calculated using exposure-response relationships estimated in Krewski et al. (2009). They are conservative in the sense that using the exposure-response relationship for mortality estimated by Lepeule et al. (2012) would have resulted in approximately 2.2 times as many estimated deaths and approximately 2.2 times as much SO_2 and NO_X damage (EPA 2013). The national average of the mortality- and damage-per-ton values for SO_2 and NO_X in Jaramillo and Muller (2016) are slightly larger than those we use. Our use of national average damage-per-ton values may underestimate damages because the regions in which the policy would apply have higher population density (US Census, 2015) and approximately 35 percent higher damage-per-ton than other parts of the Eastern Interconnection (Fischer et al 2017), and because the eastern US has double the population density of the western US (US Census, 2015).

Table 8. Assumed National Average Environmental Damages

Pollutant	2015	2025	2035	2045
CO_2 ($/ton)	37.5	47.9	57.3	66.7
SO_2 ($/lb)	18.9	22.4	25.9	29.0
NO_X ($/lb)	2.8	3.3	3.8	4.3

EI Renewable Portfolio Standard

In all scenarios, we assume that a single renewable portfolio standard (RPS) applies to generation in the states that are located primarily in PJM, NYISO, or ISO-NE (Ohio, Kentucky, North Carolina, and the twelve states northeast of them, plus Illinois). There are not RPS policies in all of those states, but generation in all of those states can qualify for meeting the RPS policies that exist. For simplicity, we apply the RPS only to wind and solar capacity built after 2015. The wind and solar generation in those states, from capacity built after 2015, must equal or exceed a percentage of the load in those states, increasing from 2.2 percent in 2020 to 14.5 percent in 2045. This is based on extrapolation of the growth rate of state RPS percentages from 2016 to 2020.

Regional Greenhouse Gas Initiative

In all scenarios, we assume that the Regional Greenhouse Gas Initiative is in force for all utility-scale generators in the same nine northeastern US states as in 2016. We use a RGGI CO_2 emission constraint of 71 million short tons in 2020 and calculate it in later years based on the assumption that it decreases by 3 percent per year, compounded annually.