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Early nuclear retirements in deregulated U.S. markets: Causes, implications and policy options

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ABSTRACT

Electricity prices have fallen significantly since 2008, putting commercial nuclear reactors in the United States under substantial financial pressure. In this market environment driven by persistently low natural gas prices and stagnant electricity demand, we estimate that about two thirds of the 102 GW nuclear capacity are uncompetitive over the next few years under the current trajectory. Among those, 18 GW are retiring or are merchant plants at high risk of retiring prematurely.

The potential consequences of the hypothetical withdrawal of 20 GW of nuclear capacity include: 1) a ~3.2% increase in carbon emissions of the power sector if replaced by gas-fired units or 2) a significant increase in cost if replaced by renewables.

Without a carbon price, out-of-the-market payments would be needed to effectively maintain merchant nuclear capacity. Filling the revenue gap would come at a fleet-average cost of $3.5–5.5/ MWh for these plants, which is much lower than the cost of subsidizing wind power. The policy support could take the form of direct zero-emission credits, renewable portfolio standard expansion, or clean capacity market mechanisms. As a last resort, the exercise of a new mothballing status could prevent the irreversible retirement of nuclear power assets.

1. Introduction

In 2015, nuclear represented 20% of the total U.S. electricity generation and 60% of the country's carbon-free electricity (EIA, 2016a). With a total installed capacity of 104 GW, the reactor fleet reported a record high 92.5% capacity factor (NEI, 2016a, 2016b). Almost all reactors have been granted a 20-year license extension from 40 to 60 years by the Nuclear Regulatory Commission (NRC, 2016).

Despite this consistently positive performance, in the past three years five nuclear power plants, totaling 4.7 GW of installed capacity, retired from the electrical grid before the end of their operating license. Eight additional ones have officially announced their retirement in the coming years (see Table 1), and many more are at risk of retiring prematurely according to studies by Steckler (2016) and Rorke (2016). Low historical and forward electricity and capacity prices, together with relatively high long-term operating costs, make nuclear plant operation unprofitable in many locations. Even plants owned by public power utilities or rate-of-return regulated utilities have started to shut down (case of Fort Calhoun in 2016).

In this paper we first provide an updated assessment of the economic viability of the U.S. nuclear plants (Section 2). We then study the levers of profitability to explain why retirements occur (Section 3) using a wholesale electricity market model. In Section 4 the potential consequences of the closures are presented. In the last section, we discuss a set of regulatory options to the industry and policy-makers to prevent or mitigate the negative impacts identified.

This paper contributes to the existing literature in several ways. First, it provides an analysis of nuclear power plant closures. Many papers have focused on *new* nuclear and its benefits for climate policy and economics (Joskow and Parsons, 2009, 2012; Deutch et al., 2009; Linares and Conchado, 2013; Harris et al., 2013). However very few have focused on the prospects for *existing* plants, as well as on the causes and the policy consequences of nuclear power plant closures. The recent paper by Davis and Hausman (2016) is an exception. The authors quantify the consequences of the closure of the San Onofre Nuclear Generating Station in California using econometric techniques. Their analysis, though, is limited to California and to a past decision. They do not look at the nation-wide picture nor at the prospects. Other papers, mainly from the banking and financial service industry, have looked at the financial health of the U.S. nuclear reactor fleet and created forecasts on future retirements (Steckler, 2016; Rorke, 2016), but they lack long-term policy analysis and rigorous model description. More recently, the nuclear community investigated the topic of early nuclear retirements and issued policy recommendations (DOE/INL, 2016; ANS, 2016). This paper completes their profitability estimates with more precise cost and revenue data. Finally, we try to discuss

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Table 1
Executed, contingent, or planned nuclear retirements in the United States as of January 2017.

	Plant name	Year	Retirement age (yr)	Capacity (MW)	Market
Retirement executed	Crystal River	2013	36	877	South East
	San Onofre	2013	30	2150	CAISO
	Kewaunee	2013	39	574	MISO
	Vermont Yankee	2014	42	619	New England
	Fort Calhoun	2016	43	478	SPP
Retirement planned but may be overturned by policy intervention (subsidy)	Clinton	2017	30	1078	MISO
	Quad Cities	2018	46	1819	PJM
	Fitzpatrick	2017	42	853	NYISO
Retirement announced	Palisades	2018	47	820	MISO
	Oyster Creek	2019	50	637	PJM
	Pilgrim	2019	47	685	New England
	Indian Point	2020–21	45/46	2071	NYISO
	Diablo Canyon	2024	39	2240	CAISO
	Total			14,901	

policy solutions that are innovative and/ or have not been quantitatively evaluated. The reconciliation of competitive markets with environmental considerations is a common topic in the literature (IEA, 2016) but few studies have assessed the impact on the competitiveness of nuclear power specifically (OECD-NEA, 2011; Kee and Zoli, 2014a, 2014b; Kee, 2015, 2016b). Our discussion aims at filling this gap.

2. Profitability outlook for U.S. nuclear plants

What is the extent of the financial troubles of the U.S. nuclear power plants? This section provides an estimate of the past, present and future profitability of every single plant in the country. The assessment is based on public data, i.e. published prices and costs. Bilateral power purchase agreements, which are usually confidential, and unforeseen expenditures are absent from the revenue estimate. Although bilateral purchase contracts can delay the retirements of assets, we can reasonably assume that in the long run the re-negotiated price of these contracts match the price listed on the exchange market.

2.1. Methodology

The profitability of the 60 U.S. nuclear plants is defined in this section as the net pre-tax earnings of the individual facilities. For any given year, the profitability is the sum of a) the energy sales, b) the capacity market revenue, c) the policy support (subsidies if applicable) minus d) the cost of generation. Both historical (from 2013 until 2016) and future (2017–2019) earnings are estimated. The spreadsheet for the calculation can be accessed online on the MIT CEEPR website.[1]

The historical generation of each facility in MWh is obtained from EIA survey forms 923 (EIA, 2016b). For future estimates, we take the average over the 2012–2015 period (4 years, ~2.7 fuel cycles).

The power sales are approximated as the product of the yearly average of the day-ahead Locational Marginal Price[2] of wholesale electricity (LMP, in $/MWh) at the plant location, and the total generation for the time period considered. The hourly historical LMPs come from the market operator (ISO) websites when such an organization exists. The name of the nodes are extracted from the SNL mapping tool (SNL, 2016a).

For future LMPs, we summed the nearest hub forward price and the historical spread between hub and LMP at the plant location. The forward price is the "fair value price" of electricity given by Bloomberg and retrieved from a Bloomberg terminal. These forward values exist for every month in the future and for every major electricity hub of the United States. Bloomberg indicates that they are "calculated through a proprietary model that uses future prices, historical spreads, spot prices and other factors". The historical spread is the average over the last two years, which is long enough to smooth seasonal variations but short enough to incorporate recent structural changes in the locational price signals (caused by the recent large introduction of renewables and associated flow congestion in some areas for instance – see Fig. 1).

In the "cost-of-service regulated" Southeast of the country, in the absence of an ISO, the bilateral contract values of day-ahead electricity price in the Southern and Florida "hubs" are used in lieu of the LMP. These historical values are reported by Platts and SNL. The price index is therefore similar for all the nuclear plants in the zone (15 plants, 30 GW of capacity) and is less granular than in the other U.S. zones. The forecasted price is the sum of the closest hub – Indiana – forward price and the historical spread between this hub and the zones.

Capacity market revenues are known once capacity auctions have been cleared. Preliminary auctions results when they exist are used to forecast future capacity revenue (PJM, ISO-NE, NYISO and California). For MISO, where preliminary auctions do not go as far into the future, we extrapolated the latest capacity market result.

The policy support is the potential subsidy that the plants receive for their zero-carbon attribute. If confirmed, these subsidies will apply to 5 plants in the US, in the form of Zero Emission Credits (ZEC): Nine Mile Point, Fitzpatrick and Ginna in New York and Clinton and Quad Cities in Illinois starting in 2017.

Finally, the cost of generation is taken from the SNL Financial database (SNL, 2016b). SNL provides plant-specific estimates of annual generation cost, based on IEA, FERC, and RUS survey forms (which include fuel cost reporting in particular) and/or a proprietary model when the data are incomplete. The SNL model is based on a three-year regression of a "large enough sample". The regression formula is based off net generation, age of plant and operation capacity. The total cost comprises fuel, fixed operation and maintenance as well as non-fuel variable operation and maintenance. Note that the initial capital expenditure of the plant construction is a sunk cost. The fleet-average cost of generation closely matches the number disclosed by the industry (see NEI, 2016a, 2016b and Table 2). The O & M cost of future years is simply the O & M cost of the latest year augmented by the expected inflation.

2.2. Results

Results were obtained for the 60 operating U.S. nuclear plants existing as of January 2017, regardless of whether they are located in regulated or deregulated market environments. The precision of the estimates varies. In particular the 15 plants located in the Southeast are

[1] ceepr.mit.edu.

[2] Except for ERCOT where the real-time LMP is used in lieu of the day-ahead LMP, and for ISO-NE where the Zonal price is used in lieu of the LMP.