The Impacts of Illinois Nuclear Power Plants on the Economy and the Environment

PREPARED FOR

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Executive Summary

At the request of the Illinois IBEW State Council and the Illinois AFL-CIO, The Brattle Group has estimated the impact of four Illinois nuclear plants (Braidwood, Byron, Dresden, and LaSalle—the plants not supported by the Future Energy Jobs Act of 2016) on the state's economy and on emissions of carbon dioxide (CO_2) and other pollutants.

Our analysis has determined that over the next ten years (2020–2029), the Braidwood, Byron, Dresden, and LaSalle nuclear plants:

- **Help avoid an increase in electricity prices that would occur if the plants retired prematurely as a result of failure to compensate them for their environmental benefits**. Illinois consumers and businesses would pay about $483 million more annually for electricity without these four nuclear plants, (about $4.2 billion in present value over ten years).
- **Contribute about $3.5 billion annually to state gross domestic product** (GDP), primarily by preventing higher power prices and retaining in-state productive activity.
- **Account for over 28,000 in-state jobs** (direct and secondary).
- **Maintain an estimated $149 million in annual Illinois state tax revenues** ($1.3 billion over ten years on a present value basis).
- **Avoid 45 million metric tons of CO_2 emissions (estimated social cost $2.6 billion) each year**, equivalent to almost 10 million cars, or 70% of current state CO_2 emissions.[1] Over the next ten years, this is 450 million tons of CO_2, and $22 billion in social costs.
- **Also avoid tens of thousands of tons of other air pollutants annually**, and the human health impacts that would be associated with these.

We determined these impacts by modeling the performance of the regional power system and the Illinois economy with these four plants operating, and then again without these plants, comparing the two. If these nuclear plants were lost, electricity costs for consumers would increase, and productive activity in the state would be lower, with impacts on Illinois GDP, jobs, and tax revenues. The replacement for the lost nuclear generation would be primarily fossil-fired. (Although Illinois has recently implemented policies to increase renewable generation, we find that renewables are not likely to increase by more or faster if these nuclear plants shut down, so the additional renewables cannot be considered a replacement for lost nuclear generation.) The loss of nuclear generation will cause Illinois and the broader region to rely more heavily on natural gas and coal-fired generating plants, increasing CO_2 emissions. This would make it much more

[1] All monetary values are in 2020 dollars.

difficult for Illinois to achieve its targeted CO_2 reductions as a member of the U.S. Climate Alliance, a group of states committed to reducing GHG emissions consistent with the United Nations Paris Agreement.[2]

In this analysis, we have not considered the structure or cost of any potential policy mechanism that may be necessary to ensure the continued operation of these nuclear plants. As a result, this analysis effectively estimates the gross economic impacts of preserving these plants, not the net impacts of a proposed policy that would do so.[3]

In recent years, wholesale electricity prices have declined significantly, due in large part to the shale gas revolution. Natural gas is the price-setting fuel in many U.S. electricity markets, and the reduction in its price has brought down wholesale electricity prices as well. Negligible demand growth and substantial additions of new policy-driven renewable generation have also played a role. While lower power prices are generally positive for consumers, persistently low prices can threaten the economic viability of existing generators. Nuclear generators, because their costs are largely fixed, are particularly vulnerable to sustained low power prices; these financial challenges are exacerbated by the fact that competitive power markets do not compensate them for displacing carbon emissions. Indeed, in the past few years, low prices and lack of compensation for environmental benefits have pushed several otherwise well-operating nuclear plants to retire prematurely, and a number of others are threatened. This is a particular concern at a time when many states and localities, including Illinois, are attempting to increase clean energy generation in order to limit carbon emissions. Nuclear generation is the country's largest source of clean energy and its loss can set back decarbonization efforts considerably.

Because of the environmental consequences that accompany the loss of nuclear generation, several states, including Illinois, New York, Connecticut and New Jersey, have implemented policy mechanisms that provide economic support for existing nuclear power plants, to compensate them for their environmental impact and prevent their premature economic retirement. Two of the six operating Illinois nuclear plants already receive such state support for their environmental attributes, under the Future Energy Jobs Act of 2016 (FEJA). FEJA is a broad package of clean energy measures that expands the Renewable Portfolio Standard and supports energy efficiency.

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[2] On January 23, 2019, Governor Pritzker signed Executive Order 2019-06 entering Illinois in the U.S. Climate Alliance (Alliance), a group of states committed to reducing greenhouse gas (GHG) emissions consistent with the United Nations Paris Agreement - For further information on Illinois climate policies, *see* "Climate Change in Illinois," Illinois Environmental Protection Agency, https://www2.illinois.gov/epa/topics/climate/Pages/default.aspx.

[3] A full analysis of any particular policy or proposal intended to support these nuclear plants would need to incorporate the costs of that support, as well as any other aspects of the policy proposal. Also, while reductions in electricity costs do provide a benefit to consumers, the offsetting impact on producer revenues must also be considered to determine whether they improve total social welfare. Our analysis of overall economic impacts—GDP, jobs, and estimated tax revenues—accounts for producer revenue impacts, though again does not consider the costs or other aspects of any particular policy proposal.

It also establishes a Zero-Emission Standard (ZES) program to create and purchase approximately 20 million Zero Emission Credits (ZECs) annually from zero-emission nuclear plants, compensating selected plants for their environmental attributes through May 2027. The Quad Cities and Clinton plants were selected to receive ZECs under this program, which will prevent their premature retirement and retain their zero-emission generation.[4] Exelon, the owner and operator of all six of the Illinois nuclear plants, has recently announced that three of the remaining four Illinois nuclear plants—Braidwood, Byron, and Dresden—are now facing similar financial challenges that could lead to their premature retirement.[5] In this context, The Brattle Group has been asked to evaluate the economic and environmental impact that would accompany the loss of the remaining four Illinois nuclear plants not covered by FEJA.

In addition to increasing CO_2 emissions, the loss of these nuclear plants would also increase other air pollutants, including "criteria pollutants" identified by the Clean Air Act, such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), and particulate matter, which would have human health impacts (we have not modeled the air transport, atmospheric chemistry, exposures, and ultimate health effects that would result from these increased pollutant emissions).

It is important to understand up front how potential policy support for nuclear plants may affect the economy and economic efficiency. The presence of these nuclear plants affects electricity markets, keeping prices lower than they would otherwise be, and keeping economic activity within the state. If competitive power markets incorporated all relevant attributes of power generation, then the prospect of lower electricity prices and the corresponding economic benefits alone would not justify providing support for uneconomic nuclear plants. Doing so could harm economic efficiency and competitive markets and could increase customer costs in the long run. But there is a gap in the market—a significant environmental externality that means the market does not compensate nuclear plants for displacing carbon-emitting generation. If indeed the failure to correct this environmental externality is threatening the economic viability of the largest sources of zero-emission generation in Illinois, at a time when reducing emissions is a major policy goal, then a policy that would keep the nuclear plants operating could improve economic efficiency, to the benefit of the environment, consumers and the economy.[6] That is, a properly designed policy to support these plants would not be distorting an otherwise economically efficient market outcome, but rather would be working to counter an existing market distortion. Compared with an uncorrected environmental externality, the resulting resource allocation would be a better reflection of the efficient market outcome—*i.e.*, the outcome that would result from internalizing the environmental externality. At the same time, the fact that nuclear plants keep power prices lower than they would otherwise be may help to offset the direct customer costs of supporting them.

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[4] Illinois Commerce Commission, "Public Notice of Successful Bidders and Average Prices: Illinois Power Agency January 2018 Procurement of Zero Emission Credits from Facilities Fueled by Nuclear Power," January 25, 2018.

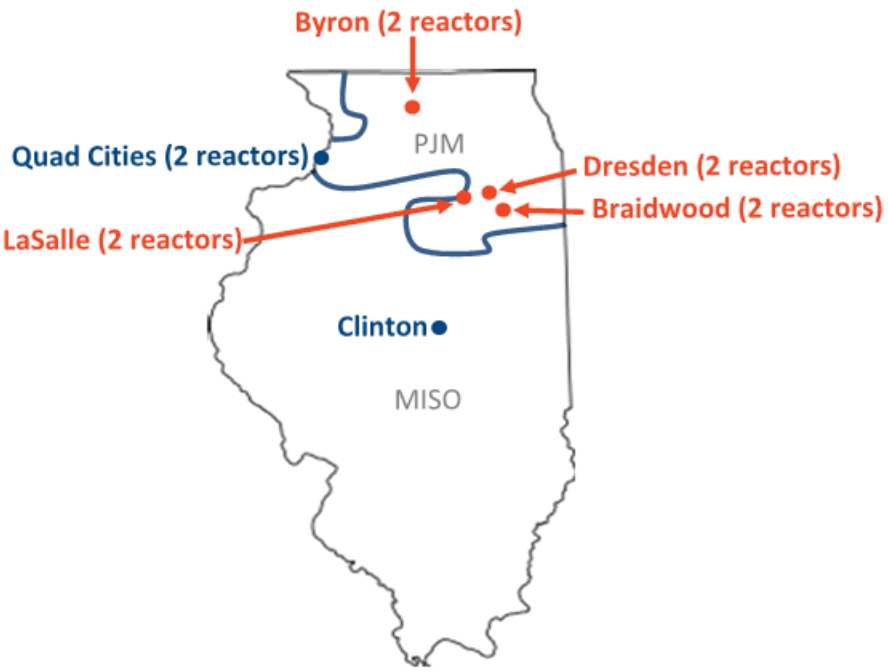
[5] Exelon shares ownership of the Quad Cities plant with MidAmerican Energy, which owns 25%.

[6] This can be true even if the policy does not price the externality directly, as a carbon price would.

I. Background

Six nuclear plants, comprising a total of 11 reactors, currently operate in Illinois, as illustrated below in Figure 1. Two of these plants, Quad Cities and Clinton, are supported by the Illinois Zero-Emission Standard (ZES) program, the component of FEJA that compensates them for their environmental attributes in order to prevent their premature economic retirement and preserve their zero-emission generation. Of the other four nuclear plants in the state—Braidwood, Byron, Dresden, and LaSalle—several are now facing similar financial challenges and could thus face premature economic retirement themselves.[7] It is in this context that Brattle is examining the economic and environmental impact that would accompany the loss of these plants. Together, the four nuclear plants not covered by FEJA represent almost 8,700 megawatts (MW) of generating capacity and approximately 74 million megawatt hours (MWh) of annual electricity generation, as shown in Table 1.

Figure 1: Locations of Illinois Nuclear Power Plants, and PJM/MISO RTO Boundary (Plants analyzed in this report, those not covered by FEJA, in Red)



[7] Exelon Corporation, Form 10-K for the Fiscal Year Ended December 31, 2018, pages 82 and 319.

Table 1: Summary of Illinois Nuclear Power Plants

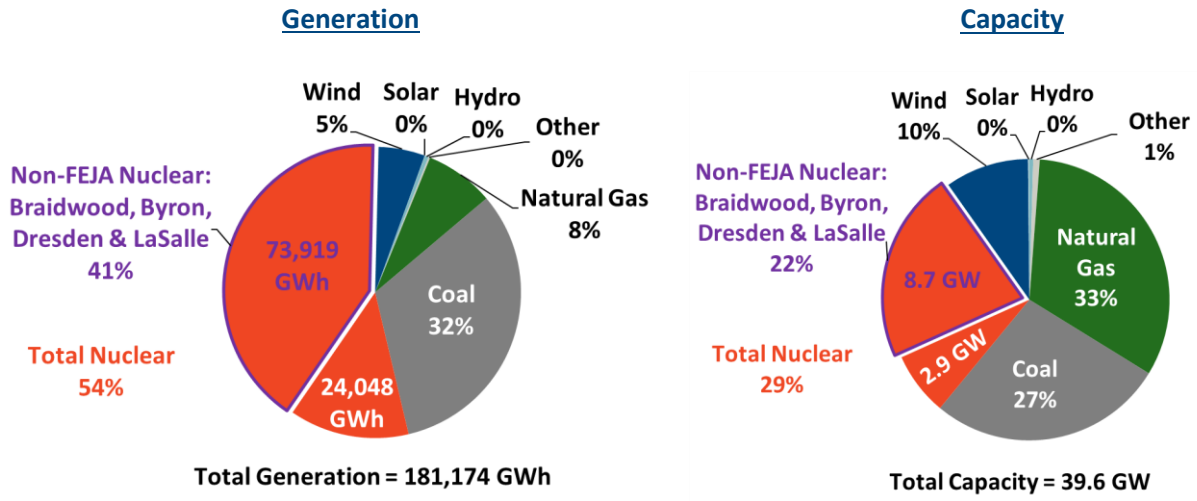
	Number of Units	Total Net Summer Capacity (MW)	Average Annual Generation (GWh)
Braidwood	2	2,330	19,712
Byron	2	2,300	19,598
Dresden	2	1,779	15,476
LaSalle	2	2,272	19,133
Subtotal Non-FEJA Nuclear	**8**	**8,680**	**73,919**
Clinton and Quad Cities	3	2,884	24,048
Total Illinois Nuclear	**11**	**11,564**	**97,967**

Sources and Notes:
Data from Velocity Suite, ABB Inc. Capacity as of May 2019. Average annual generation is the average of 2016–2018. Clinton has one unit and Quad Cities has 2 units.

Illinois straddles two large electricity markets. The Commonwealth Edison (ComEd) service territory in the northern portion of the state, which includes Chicago and surrounding areas, is a part of the PJM Interconnection, the electric region operated by the PJM Independent System Operator. This region contains all four of the reactors not covered by FEJA. PJM encompasses much more than this portion of Illinois, both geographically and electrically, extending eastward through the Mid-Atlantic states; ComEd accounts for only about 15% of PJM. The remaining southern portion of Illinois is part of the Midcontinent Independent System Operator, MISO, which covers a broad swath of the Midwest, from Michigan and Indiana in the east through the Dakotas in the west, southward to the Gulf of Mexico, and including parts of a number of nearby states.[8] The southern MISO portion of Illinois represents less than 10% of MISO. In aggregate, Illinois makes up a relatively small share of these two large electricity markets—about 10% of MISO and PJM combined. These broader electricity markets (and markets beyond them) interact with the Illinois electricity system and must be taken into account in order to accurately characterize the impact of the Illinois nuclear plants. Within Illinois, its six nuclear plants make up about 54% of the state's generation and 29% of its generating capacity, as illustrated in Figure 2.

[8] PJM operates the power system in its region, as well as establishing and operating centralized markets for electric capacity and energy. MISO operates the power system in its region, and runs a centrally-dispatched energy market and a short-term capacity balancing market. A map showing the footprints of these ISOs is available at https://www.misoenergy.org/planning/interregional-coodination/.

Figure 2: Illinois Generation and Capacity Shares, by Fuel



Sources and Notes:
Velocity Suite, ABB Inc. Capacity mix as of May 2019. Generation mix reflects average annual generation from 2016–2018.

II. Overview of Analyses

We analyze the economic and environmental impacts of these four Illinois nuclear plants over a ten-year period, 2020–2029. To do this, we simulate the regional power system and the economy of Illinois and surrounding states, incorporating the outputs of the power system simulation as inputs to the economic model. We perform these sets of simulations twice—first with, then again without these nuclear plants operating.[9] We compare the results of the simulations with nuclear plants operating to those without, looking at the differences in power prices, economic performance and emissions between the two, to determine the impacts of these plants. This is an indicative analysis designed to illustrate the broad impacts of nuclear generation on the economy and the environment. In particular, it does not examine the specific timing with which these nuclear plants might shut down or the timing of potential replacement generation, nor does it characterize short-term market impacts, like price spikes, that could occur if several nuclear plants were to shut down with little advance notice and create a temporary shortage.

We characterize the power system using a proprietary power market simulation model, Xpand, which models plant dispatch as well as capacity expansion and retirement to capture the dynamics

[9] In the with-nuclear case, we assume all these nuclear units would operate at least through 2029, despite that the current license lives of several units expire before then, implicitly assuming that these units would extend their license lives. In the without-nuclear case, all plants are assumed to be retired

of power system operation, power markets, and prices. We simulate the power system for the entire Eastern Interconnection, to best capture the interstate electricity market effects. This power sector model allows us to simulate the effects of these four nuclear power plants on power system operations (which determines emissions), power prices and costs to consumers, power plant revenues and operating costs, and new plant construction activity.

We find that substantial economic impacts would accompany the loss of these nuclear plants. These would occur through two primary direct channels, with additional ripple effects through the economy. First, the absence of the nuclear plants would cause wholesale power prices to be higher in Illinois and beyond—a result of the law of supply and demand which says that, other things equal, a reduction in supply generally leads to higher prices. Higher wholesale prices translate directly to higher retail prices and customer costs, particularly in a state like Illinois which has restructured and has retail access. Because electricity is ubiquitous throughout the economy, higher power costs will mean virtually all producers and consumers will have less to invest and spend in other ways, which slows the broader economy. Second, without these nuclear plants operating, Illinois produces considerably less power in-state, which implies a material reduction in economic activity within the state. We utilize REMI,[10] a widely-used regional economic model, to study these economic impacts, looking at the state of Illinois and also at surrounding states to capture the primary interstate effects.[11]

In all of our analyses, we explicitly include the responses of the power system, the electricity market, and the broader economy to the loss of these nuclear plants. These responses partially mitigate the effects on power prices and the economic impact. Power system and electricity market responses captured by our analyses include adding new generation that would not be added if the nuclear plants continued operating, potentially delaying or preventing the retirement of some other generators, and re-dispatching the resulting (somewhat different) fleet of generators to meet load.[12] After accounting for these power system and market responses, we find that the loss of these four nuclear plants would raise wholesale electricity prices in Illinois and throughout the broader region, flowing through to residential, commercial, and industrial consumers as higher electricity bills. Similarly, our economic impact analysis accounts for the loss of the economic activity associated with the nuclear plants, and also the positive economic contributions of the alternative generation that would substitute—the greater utilization of existing plants, the

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immediately in 2020; this assumption allows a clear comparison of the impacts of these nuclear plants, though it may not characterize a likely timeline of retirements.

[10] For information on the REMI model, *see* www.remi.com.

[11] The surrounding states economic region considered here consists of the Midwest portion of MISO in the U.S. and outside Illinois, excluding the physically and electrically more distant southerly portion of MISO that corresponds to the Entergy service territory in Arkansas, Louisiana, Mississippi, and Texas.

[12] We find that new generation is gas-fired because that is most economic; additional new renewable generation beyond current requirements would not be economic. Both additions and retirements are reflected to the extent they are economic.

construction of new generators, and continued operation of plants whose retirement would be delayed.

We find that emissions of CO_2 and criteria pollutants increase, because lost nuclear generation is replaced primarily by fossil-fired generation—about two-thirds gas and one-third coal. This is true even after accounting for recent commitments to increasing renewable generation in Illinois. Losing nuclear generation means less emission-free power than there would otherwise be, and correspondingly more fossil generation and emissions. Since renewable generation is unlikely to increase more or faster if these nuclear plants are lost, any new Illinois renewables that will be developed in any case would not actually replace lost nuclear generation.

In addition to determining the impact on emissions of CO_2, which is a global pollutant, we also assess the increase in emissions of several criteria pollutants, including SO_2, NO_X, and particulate matter (PM_{10} and $PM_{2.5}$). The regional pollutant impacts are not limited to Illinois, first because much of the replacement generation would come from outside Illinois, and second because air pollution impacts can cross state borders. We do not model air transport, exposures, and the health impacts of criteria air pollutants in this paper.

Below, we describe the impact of these four nuclear plants on:

- The price and cost of electricity;
- Economic measures: GDP, employment, estimated state and federal tax revenues;
- The electricity generation mix;
- Emissions of CO_2, SO_2, NO_X, and particulate matter.

III. Impact on Electricity Price and Cost

Absent the four nuclear plants considered here, electricity demand would be met by increased utilization of natural gas and coal-fired plants, some within Illinois but most from outside the state (see Section V below). The reduction in supply would increase wholesale electricity prices according to the law of supply and demand: other things equal, a reduction in supply generally leads to higher prices. Higher prices mean higher electricity costs for customers in Illinois and across the region. As shown in Table 2 below, we find that average power prices in Illinois would be about $3.27/MWh higher without these four nuclear power plants. The price impact is significantly larger in the ComEd service territory in northern Illinois (part of PJM) where the four nuclear plants are located, and smaller in the Ameren Illinois service territory, which is part of MISO. In surrounding states (defined here as the Midwest portion of MISO), the price impact is slightly less than in the Ameren Illinois service territory.

Table 2: Impact of Non-FEJA Nuclear Plants on All-In Electricity Prices and Costs to Customers

	% of Utility Load[1]	10-Year Average, 2020-2029 Power Price with Nuclear (2020$/MWh)	Power Price without Nuclear (2020$/MWh)	Power Price Change without Nuclear (2020$/MWh)[2]	Electricity Consumption (TWh)	Annual Electricity Cost Change (2020$ millions)
Illinois Average		**$47.03**	**$50.29**	**$3.27**	**148**	**$483**
Commonwealth Edison (PJM)[3]		$48.91	$53.17	$4.26	103	$438
Residential	30%				31	$133
Commercial	37%				38	$164
Industrial	32%				33	$141
Ameren Illinois (MISO)[3]		$42.72	$43.72	$1.00	45	$45
Residential	35%				16	$16
Commercial	35%				16	$16
Industrial	30%				13	$13
Surrounding States Average[4]		**$44.66**	**$45.56**	**$0.90**	**474**	**$427**

Sources and Notes:

[1] Load share by customer class is based on data from EIA Form 861 for 2017.

[2] The Illinois average price impact is the load-weighted average price paid by customers across the ComEd zone in northern Illinois (which accounts for about two-thirds of Illinois electric load), and the remainder of the state which is in MISO. Similarly, the impact for the surrounding states is the load-weighted average across that region. All-In Electricity Price includes both energy and capacity price effects; though not transmission costs, customer costs, *etc.* In estimating approximate Residential, Commercial and Industrial costs, power price effects are assumed to be the same for all customer classes, without distinguishing differences in load shape and billing determinants. Note that the average price earned by a nuclear generator is lower than the average price paid by customers, since customer price is load-weighted (customer load is higher in higher-priced hours). For comparison, in the ComEd territory, the equivalent average all-in price earned by a nuclear plant is $38.09/MWh, vs. average customer cost of $48.91/MWh.

[3] Each of the regions within Illinois is identified by its largest utility. As used here, "Commonwealth Edison" and "Ameren Illinois" represent the entire PJM and MISO portions of Illinois, respectively, including smaller utilities within each region.

[4] "Surrounding States" is the Midwest portion of MISO (*i.e.*, excluding the Entergy territory in Arkansas, Louisiana, Mississippi, and Texas), and is used for the economic impact analysis. Parts of some of these surrounding states are not in MISO and are not included in this Surrounding States region.

The price impact identified here is driven by an increase in the short-term wholesale energy price, and not by an increase in the capacity price (see below).[13] The energy price is based on very short-term (hourly) markets, which accept lowest offers first and clear just enough generation to meet current-hour load, setting energy price equal to the highest-cost offer accepted in that hour. Generators' offers are based on their short-run variable cost of producing energy, which is primarily fuel cost for fossil plants. But nuclear generators have essentially zero short-run costs; they bid into the market at $0/MWh and run in all hours, accepting whatever price the market offers, as long as they operate. This means that when they are operating, they hold down the

[13] Wholesale electricity markets are composed primarily of energy and capacity markets, which operate on different time frames to set prices for energy and capacity products. Energy price is the unit cost of electric energy over time horizons as short as an hour, typically in dollars per megawatt-hour. Capacity price reflects the value of having sufficient generating capacity available for when it may be needed. Capacity is a longer-term product, typically a season to a year, and often transacted for multiple years; its value is typically expressed in dollars per kilowatt-year or dollars per megawatt-day.

market price because fewer fossil megawatts must be accepted to meet load. If a nuclear generator is lost, more and thus higher-priced fossil megawatts must be accepted, setting the market clearing price higher. This effect can be pronounced if the amount of nuclear generation lost is large relative to the electric region where it is located, as is the case here. Much of the energy price impact occurs in the PJM ComEd zone in northern Illinois, where these four nuclear plants are located. Energy prices also increase, though by smaller amounts, in the rest of Illinois and beyond the state, through much of MISO and PJM.

The capacity price impact that might accompany the loss of these four nuclear plants is less clear; capacity price effects can be difficult to project with confidence, because the market response can be hard to predict (*i.e.*, the timing and extent to which the market will offset a loss of capacity by adding new capacity, and the resulting impact on capacity price). The ComEd region has a local generating capacity requirement in PJM and there is currently a moderate capacity surplus, so the loss of a large amount of capacity in this area might in principle be expected to increase the local capacity price. However, if the capacity price is already at or near its long-term equilibrium value (*i.e.*, the price that would support new capacity additions) when the nuclear plants are operating, the loss of nuclear capacity might simply prompt further market entry, without causing a persistent increase in the value and price of capacity.[14]

By some measures, capacity prices may already be high enough to support new gas-fired generation in the ComEd territory and in the larger PJM market, as well as MISO. Reserve margins have been persistently above target levels for a number of years across the PJM RTO as well as in the ComEd region, and MISO has also had a modest capacity surplus relative to its resource adequacy targets. Capacity clearing prices have been on the order of $100-150/MW-day across the PJM RTO for the past several years, and some new gas-fired capacity has been entering the market at these prices. (It has been several years since new gas-fired capacity has been added in ComEd, though ComEd capacity prices have been somewhat higher, most recently at $196/MW-day.) If energy prices rise in response to the loss of nuclear plants, as discussed above, a new combined cycle plant would earn still more energy revenue and might require a correspondingly lower capacity price. Thus, while the loss of several nuclear plants in the ComEd region would likely require replacement of at least some of their capacity with new gas capacity, it would not necessarily cause a persistent increase in capacity prices. The All-In electricity price impacts reported in Table 2 are driven primarily by higher energy prices, but reflect both energy and capacity price impacts.

The overall $3.27/MWh electricity price increase in Illinois seen in Table 2 translates to an average of about $2.42 per month for a typical residential ratepayer in the state. Across all consumers, this represents an increase of $483 million per year in electricity costs (about $4.2 billion in present

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[14] A temporary capacity shortage and short-term increase in capacity price might occur if nuclear capacity were to shut down with little advance notice, more quickly than the market is able to respond in full. While we do find that some of the lost nuclear capacity would need to be replaced to maintain the local capacity requirement, we have not attempted to project the timing dynamics of retirements and replacement that might affect a potential price spike, to perform a reliability analysis, nor to establish whether the transmission system might require modification in the absence of these nuclear plants.

value over ten years, using a 3% discount rate). Across the state of Illinois, about 31% of these increased costs would fall on residential customers, 37% on commercial customers, and 32% on industrial customers. That amounts to an annual electricity cost increase of $149 million for residential customers, $179 million for commercial customers, and $155 million for industrial customers.

Preventing higher electricity prices is a major mechanism by which these nuclear power plants benefit the Illinois economy, as discussed below. If competitive power markets incorporated all relevant attributes of power generation, then the fact that nuclear plants keep electricity prices lower and help the economy would not in itself justify supporting them, and doing so could distort competitive markets and increase customer costs in the long run. But given the gap in power markets—their failure to account for environmental externalities—a properly designed policy that addresses this gap can counter an existing market distortion, leading to a more efficient market outcome. The fact that nuclear plants keep prices lower than they would otherwise be would also help to offset the direct customer costs of a policy to support the plants.

IV. Economic Impacts

The economic impacts of the four Illinois nuclear plants within the state of Illinois are measured by comparing economic conditions (measured in terms of state level GDP, gross output, employment, and tax revenues) with and without these plants. As discussed above, Illinois would face substantially higher electricity prices without these plants, and would produce less electricity and import more from the surrounding region. These changes would have negative impacts on the state's economy, which would be partially offset by the positive economic impacts of new gas power plant construction and operations within Illinois that partially replace the lost nuclear plant generation.

Making this comparison, we find that these four Illinois nuclear plants account for:

- $3.46 billion in annual state GDP ($4.90 billion in gross output);
- 28,030 annual jobs;
- $149 million in estimated annual Illinois state tax revenues.

These impacts occur primarily because the nuclear plants:

- Keep electricity prices and costs lower, leaving residential, commercial, and industrial consumers with more money to invest and spend in other ways, which boosts GDP, jobs, and the overall economy.[15]

[15] Note that these impacts do not account for the cost of any nuclear support mechanism.

- Support in-state economic activity—electricity production—much of which would otherwise take place outside the state as more electricity is imported.

The economic impact in surrounding states is considerably smaller in comparison. The electricity price increase is smaller than within Illinois, and rather than experiencing a reduction in electricity production, the surrounding states see an increase as power generation rises to make up for the lost Illinois nuclear output. Employment in some sectors, including manufacturing, wholesale trade and information, would be lower, but would be higher in the utility, construction, and mining sectors.

A. Impact on Economic Output and GDP

The Braidwood, Byron, Dresden, and LaSalle plants contribute an average of $3.46 billion to annual Illinois state GDP ($4.90 billion in gross output), in part through the electricity price effects discussed above, and also through the economic activity associated with in-state electricity production. This GDP effect includes both direct and secondary economic activity attributable to these plants, netting out the economic activity associated with alternative generation in their absence, to the extent this replacement generation occurs within Illinois. The largest effect is found in the utilities sector, as expected, followed by the construction and manufacturing sectors, shown in Table 3.

In the states surrounding Illinois, the aggregate impact on GDP and output is much smaller, in part because the nuclear plants have a smaller impact on electricity prices outside Illinois, and in part because the impact on the utility sector in the surrounding states is positive (shown as a negative reduction on the right in Table 3 below), which partially offsets the negative impact on other sectors.

Table 3: Annual GDP and Gross Output Impacts by Sector, Illinois and Surrounding States (10-Year Average Direct and Secondary Impacts of Non-FEJA Nuclear Plants, 2020–2029, Millions of 2020 Dollars)

Sector	Illinois Output Impact	Surrounding States Output Impact
Utilities	$1,246	-$602
Manufacturing	$566	$438
Real estate and rental and leasing	$479	$167
Professional, scientific, and technical services	$441	$31
Retail trade	$342	$94
Health care and social assistance	$248	$97
Administrative, support, waste management, and remediation services	$232	$26
Wholesale trade	$214	$56
Information	$199	$56
Finance and insurance	$193	$46
Other	$745	$109
Gross Economic Output Impact (All Sectors), Direct and Secondary*	**$4,904**	**$518**
GDP Impact, Direct and Secondary	**$3,464**	**$606**

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

B. Impact on Employment

The Braidwood, Byron, Dresden, and LaSalle plants account for 4,240 direct and secondary jobs in the utilities sector (3,273 are direct jobs), as shown in Table 4. Direct jobs include those positions necessary for plant operations such as engineers and technicians as well as security and administration. As with the economic impact, the overall employment impact, 28,030 jobs, occurs in large part indirectly; not necessarily as employment within the nuclear and utilities sectors, but as enhanced secondary employment throughout the economy, caused largely by the economic effect of lower power prices. As shown in Table 4, in addition to the occupations directly impacted by the nuclear plants, the employment sectors most influenced are the construction, retail trade, professional services, and administrative sectors. Note that these employment impacts are net of increased construction and utility operating jobs attributed to developing and operating replacement generation.

Table 4: Annual Net Employment Impacts by Category, Illinois and Surrounding States (10-Year Average Direct and Secondary Impacts of Non-FEJA Nuclear Plants, 2020–2029, Jobs)

Category	Illinois Employment Impact	Surrounding States Employment Impact
Construction	6,330	540
Utilities	4,240	-290
Retail trade	3,320	910
Professional, scientific, and technical services	2,670	180
Administrative, support, waste management, and remediat	2,580	250
Health care and social assistance	2,280	890
Accommodation and food services	1,620	440
Real estate and rental and leasing	930	340
Finance and insurance	790	210
Wholesale trade	720	210
Other	2,550	1,060
Total	**28,030**	**4,740**

C. Impact on Federal and State Tax Revenues

The Braidwood, Byron, Dresden, and LaSalle plants and the businesses providing goods and services to these plants pay substantial state and federal taxes. In addition, since these plants keep electricity prices lower and keep productive activity within the state, they create incremental economic output and associated tax revenues throughout the economy. We used the recent historical relationship between Illinois GDP and tax payments at both the state and federal levels to estimate the tax revenue impact of the plants. Using this approach, average incremental annual Illinois state tax payments attributable to these plants are estimated at $149 million, and average annual federal tax payments from Illinois at $579 million, as shown in Table 5. This state tax impact totals $1.3 billion on a present value basis over the period 2020-2029.

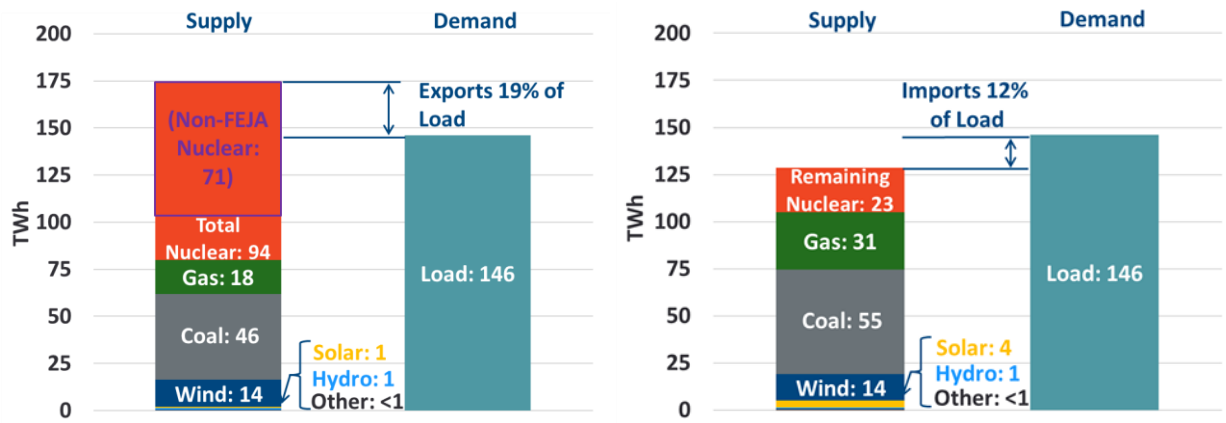
Table 5: Annual Federal and State Tax Impacts (10-Year Average Impacts of Non-FEJA Nuclear Plants, 2020–2029, Millions of 2020 Dollars)

	Illinois Output Impact	Surrounding States Output Impact
Direct and Secondary State Tax Revenues	$149	$34
Direct and Secondary Federal Tax Revenues	$579	$101
Total Federal and State Tax Revenues	$728	$135

V. Impact on the Electric Generation Mix

With these four nuclear plants operating, Illinois is a significant exporter of power, producing about 19% more power than it consumes in 2020, as shown in the first panel of Figure 3 below.[16] The second panel shows the situation without these four plants. The missing nuclear generation would be replaced by increased reliance on fossil generation fired by natural gas and coal.[17] Despite significant increases in generation from Illinois gas and coal plants, the majority (about 55%) of the replacement energy would come from outside the state, causing Illinois to become a net electricity importer and to rely on out-of-state power sources for 12% of its aggregate electricity needs. This occurs because the entire Eastern Interconnection is operated as an integrated power system that is dispatched (within technical and operational constraints) based on economics, without regard to state borders. The most economic replacement generation is often outside Illinois. This is simply because there is far more potential supply outside the state than within it, not because the swing supply in Illinois is necessarily less economic.

Figure 3: Electric Generation and Load in Illinois (2020 Projection)



16 Our projections include new renewable generation and energy efficiency required by FEJA, both with and without the nuclear plants.

17 We do not include a national climate policy in our simulations; we do represent state-level policies such as Renewable Portfolio Standards and the Regional Greenhouse Gas Initiative (RGGI) where they apply, as well as FEJA requirements for additional renewables for Illinois. Large-scale renewable generation will likely increase over time, driven in large part by policies such as these which have been adopted by many states in the region. *See* the N.C. Clean Energy Technology Center's Database of State Incentives for Renewables and Efficiency. However, we find that renewable generation is not likely to increase significantly more or faster in the absence of these nuclear plants than it would if they continued to operate, and so the increase in renewable generation over time would not actually replace lost nuclear generation.

Both natural gas and coal are often the marginal electricity fuel in Illinois and the surrounding region, which means that both of these sources would provide replacement energy. About 65% of the total replacement energy would come from natural gas (the majority of this from increased utilization of existing gas capacity), and 35% from coal. Table 6 summarizes the fuel source and location of the replacement generation that would substitute for lost nuclear generation, on average over the study horizon. Although a large share of the fossil generation used to replace the lost nuclear output would come from outside Illinois, a CO_2 emissions inventory would need to account for the reduced exports and increased imports. This would show a significant increase in Illinois carbon emissions regardless of the physical location of the source of electricity.

Our analysis suggests that the shutdown of the four nuclear plants could cause significantly more new renewables (especially solar) to be located in Illinois rather than in other states, based on FEJA and to take advantage of higher Illinois energy prices, but that across PJM and MISO, there would not be a material impact on the total amount of new renewable generation.[18]

Table 6: Changes in Annual Generation to Replace Non-FEJA Nuclear Plants (10-Year Average, 2020–2029, TWh)

	Without Braidwood, Byron, Dresden & LaSalle			
	Illinois	Outside Illinois	**Total**	%
Gas	13	33	**46**	65%
Coal	9	16	**25**	35%
Wind	2	-2	**1**	1%
Solar	8	-9	**-1**	-1%
Other	0	0	**0**	0%
Total	**32**	**39**	**71**	
%	45%	55%		

Note: Table 6 here shows the average over the study's 10-year horizon, whereas Figure 2 above illustrates only the first year of the horizon. The distinction is most apparent for renewables; since they increase significantly over the horizon, the average impact is significantly larger than the first year.

[18] Other factors not modeled, such as siting requirements, might limit this relocation effect somewhat; this could cause a slightly higher Illinois price impact, and it would have very little impact on overall emissions.

VI. Impact on Emissions

The four Illinois nuclear plants considered here, Braidwood, Byron, Dresden, and LaSalle, prevent substantial emissions of a number of pollutants, including CO_2, SO_2, NO_x, and particulate matter (both $PM_{2.5}$ and PM_{10}), by avoiding the natural gas and coal-fired generation that would replace their output if they were shut down prematurely. The effect of losing nuclear plants on the generation mix, presented above, translates directly into emissions impacts, as summarized in Table 7. Average annual power sector CO_2 emissions would be about 45 million metric tons greater in the absence of these four plants. To put this in perspective, this would be equivalent to adding almost 10 million cars to the road—more than twice the total number of automobiles currently registered in Illinois.[19] Alternatively, this represents about a 70% increase relative to current Illinois power sector CO_2 emissions. The magnitude of this increase reflects the fact that these four nuclear power plants currently account for a very large share (41%) of the Illinois generation mix—about the same as total current Illinois fossil generation (40%) as was seen in Figure 2 above (though the replacement generation would consist of relatively less coal and more gas than the current Illinois fossil mix). The social cost of these incremental CO_2 emissions can be approximated using the federal government's estimated social cost of carbon, $58 per metric ton.[20] Applied to the 45 million metric tons of annual incremental CO_2 emissions, this is a social cost of about $2.6 billion per year, about $22 billion in present value over the 10-year horizon.

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[19] The EPA estimates that a typical automobile emits 4.6 metric tons CO_2 annually. *See* Environmental Protection Agency, "Greenhouse Gas Emissions from a Typical Passenger Vehicle," March 2018, EPA-420-F-18-008. In 2017, 4.66 million automobiles were registered in Illinois. *See* Federal Highway Administration, "Highway Statistics 2017: Table MV-1, State Motor-Vehicle Registrations," January 2019.

[20] The social cost of carbon estimate applied here is determined by the Interagency Working Group on Social Cost of Greenhouse Gases. The central value (based on a 3% discount rate) for 2025, the midpoint of the study horizon, is $46 per metric ton CO_2 in 2007 dollars. Converted to 2020 dollars, this is $58 per ton. *See* Environmental Protection Agency, "EPA Fact Sheet: Social Cost of Carbon," December 2016. This value is utilized by statute and order in Illinois, New Jersey, and New York. The true social cost of carbon has always been associated with significant uncertainty.

Table 7: Annual Emissions Prevented by Non-FEJA Nuclear Plants (10-Year Average, 2020–2029, Metric Tons)

Pollutant	Emissions Increase Without Braidwood, Byron, Dresden & LaSalle
CO_2	45,208,804
SO_2	22,448
NO_x	18,512
$PM_{2.5}$	2,095
PM_{10}	2,737

Note: PM_{10} includes particles that are 10 micrometers or less in diameter. $PM_{2.5}$ is the subset of PM_{10} particles that are 2.5 micrometers or less in diameter.

Emissions of other pollutants would increase as well. Table 7 also shows the overall increase in several other pollutants, within Illinois and beyond the state. These increases in CO_2 and criteria pollutants would have human health effects and additional economic impacts. These emissions-related impacts are not included in the estimated economic impacts of the loss of the nuclear plants, presented in Section IV above.

VII. Conclusion

Two of the six nuclear plants in Illinois are supported by the 2016 Future Energy Jobs Act, which compensates them for their environmental attributes. The remaining four nuclear plants, Braidwood, Byron, Dresden, and LaSalle, do not receive such support, and Exelon, their owner, recently announced that three of these four are facing financial challenges that could lead to their premature retirement for purely economic reasons. In this context, we have studied the impacts of these four Illinois nuclear plants, considering their effect on electricity prices, and their impact on the Illinois economy in terms of GDP, jobs, and estimated tax revenues. We also considered the generation that would replace them if they were to shut down and the associated impact on air emission of CO_2 and several criteria pollutants.

These nuclear plants keep electricity prices lower than they would otherwise be, by $3.27/MWh on average across Illinois; more in the northern Illinois region where the plants are located, and less in the rest of the state. This price difference amounts to nearly $500 million per year in customer costs across the state of Illinois (this does not include the policy cost that might be necessary to support these plants). Losing the nuclear plants would also result in a loss of productive activity within the state. These effects—an increase in consumer costs, and a loss of

productive activity—would have broader impacts across the Illinois economy, causing a $3.5 billion reduction in annual state GDP, 28,000 fewer jobs, and the loss of $149 million in annual Illinois state tax revenues, if the nuclear plants were to shut down.

If competitive power markets incorporated all relevant attributes of power generation, then lower electricity prices and economic benefits alone would not justify supporting uneconomic nuclear plants. Doing so could harm competitive markets, increasing customer costs in the long run. But there is a gap in the market—a substantial environmental externality that means the market does not compensate nuclear plants for displacing carbon-emitting generation. The loss of these nuclear plants would dramatically increase emissions at a time when reducing emissions is a major Illinois policy goal, and would likely represent an inefficient outcome from this perspective. The financial challenges facing these nuclear plants are related to this gap in competitive markets. Given this, a properly designed policy to support these plants may counter the effects of an existing market distortion—the environmental externality—rather than being a distortion imposed on a market that is currently efficient. The lower electricity prices and corresponding economic effects would better reflect an efficient market outcome, improving on the inefficient outcome that results from an uncorrected environmental externality, even if the support policy does not price the externality directly. And the lower electricity prices, relative to what would prevail if the nuclear plants were to shut down, may help to offset any direct policy costs to customers.

We found that these four nuclear plants prevent about 71 million MWh of fossil generation each year. The fossil generation that would replace these plants if they shut down would be about two-thirds gas-fired, and one-third coal, and would come mostly from outside Illinois, with about 45% coming from within the state. This replacement fossil generation would be accompanied by a 45 million metric ton annual increase in CO_2 emissions, causing an estimated $2.6 billion in additional social costs each year, based on the EPA's social cost of carbon estimate of $58/ton CO_2. These four nuclear plants also prevent tens of thousands of tons of other air pollutants annually.

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