Environmental and Economic Impacts of the Calvert Cliffs Nuclear Plant

PREPARED FOR

Nuclear Powers Maryland

PREPARED BY

Dean Murphy
Mark Berkman

MARCH 2022

NOTICE

This report was prepared for Nuclear Powers Maryland and its members, including ANS, the Baltimore DC Metro Building Trades Council, the Calvert County Chamber of Commerce, the Calvert County Government, Constellation, the Center for Climate and Energy Solutions (C2ES), Centrus, Excel Services Corporation, LiUNA, the Nuclear Energy Institute, Nuclear Matters, Orano, Sensible Energy, Studsvik, The Nuclear Alternative Project, WS Corp, and X-Energy. Nuclear Powers Maryland is a statewide coalition of like-minded organizations who believe Maryland has an opportunity to become a national clean energy leader by embracing the benefits of carbon-free nuclear power. Funding was provided by Constellation.

This report is intended to be read and used as a whole and not in parts. All results and any errors are the responsibility of the author and do not represent the opinions of The Brattle Group or its clients.

The authors would like to acknowledge the invaluable assistance of Kate Peters, Shivangi Pant, Sasha Kuzura, and Xander Bartone in preparing this analysis.

TABLE OF CONTENTS

Executive Summary

Our study of the environmental and economic impacts of the Calvert Cliffs nuclear plant in Maryland shows that over a wide variety of potential futures, the plant prevents significant carbon emissions, and it also offers material economic benefits.

Absent the Calvert Cliffs plant, significantly less emission-free power would be generated, meaning correspondingly more fossil generation and emissions. Renewable generation will not fully replace lost nuclear generation; any replacement would likely be partial at best, even after accounting for Maryland's commitments to substantial increases in its renewable generation. Lost nuclear generation would only be completely replaced with clean generation if driven by a direct policy initiative—*e.g.*, by a further increase in the Renewable Portfolio Standard (RPS) sufficient to offset the lost nuclear generation from Calvert Cliffs. Even then, the replacement would lag the nuclear retirement, resulting in higher cumulative emissions. But consideration of such a policy creates a trade-off between emissions and customer costs: either 1) accept the natural increase in emissions that accompanies replacing lost nuclear generation with (mostly fossil) grid power, or 2) take policy action to require a still greater increase in clean generation than would otherwise occur to offset the loss of clean power. The latter implies greater customer costs to support building out additional clean generation, more and faster than it would be added otherwise.

In addition to the emissions impact, the shutdown of Calvert Cliffs would raise wholesale power prices in Maryland and throughout the broader region, creating moderately higher bills for Maryland's residential, commercial and industrial customers. (Here, we do not account for any potential policy cost that may be needed to keep Calvert Cliffs operating; this would need to be included to understand the full impact on customer costs, and to evaluate any proposed policy.) Further, most of the replacement generation would come from out of state, making Maryland a significantly larger importer of power than it is already, and reducing in-state economic activity. These effects, especially the loss of in-state economic activity, would cause substantial negative impacts on the Maryland economy in terms of economic output, GDP and jobs.[1]

---

[1] Price suppression itself is not a legitimate policy goal; the impact on producers must also be considered to understand the overall social welfare impacts. The economic impacts we evaluate – the output, GDP and jobs impacts – account for this producer impact.

We examined several scenarios and found that while the precise implications in terms of emissions, customer cost and economic impact do depend on the scenario, these general impacts are broadly valid across all the scenarios. Our Reference Scenario characterizes relatively aggressive decarbonization of PJM, driven by the assumed extension and expansion of federal tax credits modeled on drafts of the Build Back Better bill. These credits would make it economic to add large amounts of renewable generation, even beyond the aggregate RPS targets of PJM states. In that scenario, we find that over the period 2025-2040, Calvert Cliffs:

- Prevents about 4 million tons of CO2 emissions annually in the near term, and 56 million tons of cumulative emissions;
  - These avoided emissions have a social cost of about $2.5 billion in NPV, based on Interagency Working Group estimates of the social cost of carbon;
- Keeps Maryland customer costs lower by an average of about $47 million per year, $410 million in present value (before accounting for any cost to keep Calvert Cliffs operating);
- Keeps Maryland’s GDP higher by an average of over $600 million per year; gross output is higher by $1.2 billion (again, before accounting for any cost to keep Calvert Cliffs operating);
- Maintains about 4,760 jobs, including both direct and secondary employment effects.

Other scenarios exhibited similar results. In particular, an alternate scenario that involved no additional federal support for renewables showed about 20% greater impacts for emissions and GDP but a smaller impact on customer electricity costs. Our analysis shows that existing nuclear power and renewable energy can be viewed as complementary clean technologies, rather than competitors or substitutes. Each has a role to play in transforming and decarbonizing the grid. Maintaining existing nuclear plants can facilitate the transition to a decarbonized energy future.

I. Background

The Calvert Cliffs Nuclear Power Plant (CCNPP) is Maryland's only nuclear plant; it is located in southern Maryland on the western shore of the Chesapeake Bay, about 50 miles southeast of Washington, DC, as shown in Figure 1. The plant consists of two pressurized water reactors, totaling 1,768 MW of generating capacity. It operates at a capacity factor well over 90%, producing about 15 TWh (15 million MWh) of clean energy annually in recent years. This makes it by far the largest electricity producer in Maryland. Brattle has been asked to characterize the impacts of Calvert Cliffs on Maryland's greenhouse gas emissions and the state's economy, to understand its role in a future where Maryland (and surrounding states) are pursuing the decarbonization of their economies.

FIGURE 1: LOCATION OF THE CALVERT CLIFFS NUCLEAR POWER PLANT

Like many states, Maryland has implemented a Renewable Portfolio Standard (RPS) target to accelerate the adoption of renewable energy sources. The Clean Energy Jobs Act of 2019 stipulates that electricity suppliers must procure a minimum portion of their electricity from renewable sources, including specified amounts from solar and offshore wind facilities. Under this RPS, utilities must currently procure 33.1% of their energy from renewable sources; the renewable percentage increases to 50% by 2030. Maryland's RPS targets are part of the state's economy-wide plan to reduce greenhouse gas emissions. The state's Greenhouse Gas

Emissions Reduction Act requires a 40% GHG reduction overall (relative to a 2006 benchmark) by 2030. The Calvert Cliffs nuclear plant plays an important role in the state's transition to zero-emissions sources of energy, even though it does not qualify for the RPS targets. Indeed, Calvert Cliffs is estimated to prevent 4.3 million metrics tons of emissions annually in the near term. This represents nearly 7% of Maryland's total annual energy-related emissions.[2] Its 15 TWh of zero-emissions electricity each year is the equivalent of adding a bit more than 20% to Maryland's RPS requirements – *e.g.*, raising the 2030 requirement from 50% to just over 70%.

Maryland is a part of the PJM Interconnection, the electric region operated by the PJM Independent System Operator (PJM ISO). PJM is the largest competitive wholesale electricity market in North America, including all or parts of 13 states plus Washington DC, and stretching from New Jersey south to North Carolina, and west as far as Illinois. Maryland accounts for only about 8% of PJM's overall electric load, so the broader PJM electricity market determines the context in which the impacts of Calvert Cliffs must be understood.[3]

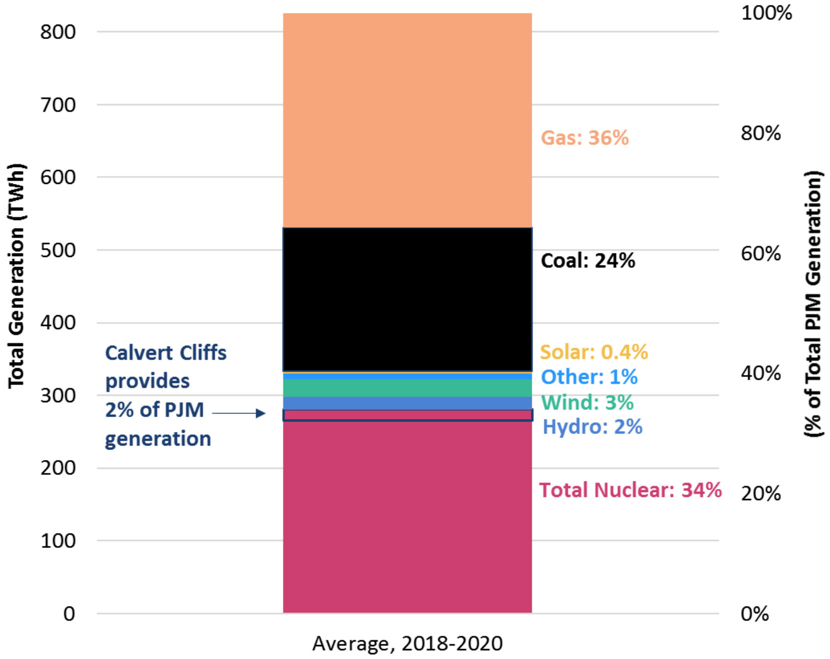
PJM is dominated by fossil gas and coal generation, which together have provided 60% of the region's energy in recent years, and by nuclear generation, which provides over one-third of PJM's total generation. The output of PJM's nuclear plants has been stable for decades, other than the recent retirement of two units; nuclear currently provides about 34% of PJM energy (Calvert Cliffs itself provides about 2%). In response to lower natural gas prices and tighter environmental requirements, a significant number of coal plants have retired recently, and those that remain have been operating less. Gas-fired generation has increased, replacing most of the loss in coal and nuclear generation. Wind and solar generation have grown quickly in relative terms, but still accounted for only 4% of PJM's energy in 2020. Even including hydro and biomass, renewables currently provide only 6% of PJM's energy. Figure 2 illustrates the recent generation mix for PJM.

---

[2] Here and throughout this report, GHG quantities are expressed in millions of metric tons of CO_2-equivalent, $MMtCO_2e$, consistent with the Maryland GHG Inventory. Maryland emits 61.7 million tons of energy related emissions, based on the most recent Maryland emissions data available (from EIA for 2018).

[3] Monitoring Analytics, "Percentage pf PJM Load by State", Accessed 2/15/2022 from https://www.monitoringanalytics.com/data/pjm_load.shtml

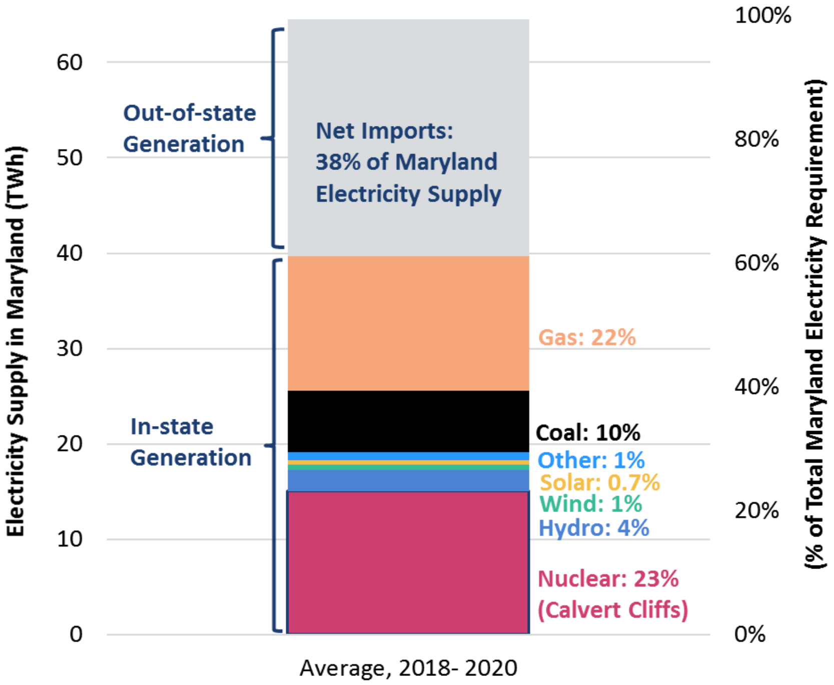
FIGURE 2: PJM GENERATION BY SOURCE



Note: "Other" includes biomass, petroleum, battery storage, and waste.
Sourced from PJM Annual State of the Market Reports.

Maryland's in-state power sources are summarized in Figure 3. Calvert Cliffs' generation currently accounts for about 23% of the state's overall electric energy usage; to the extent electricity demand may grow over the next one to two decades as a result of electrification of other sectors (such as transportation and heat), it will still provide 20% or so of the state's power needs. In addition to providing a significant share of Maryland's energy overall, Calvert Cliffs accounts for the vast majority of the state's clean generation – it has produced about 81% of Maryland's in-state clean generation recently. As Figure 3 illustrates, Maryland is a significant net importer of electricity, importing nearly 40% of its total electricity needs.

FIGURE 3: SOURCES OF MARYLAND'S ELECTRICITY



Notes: Height of column indicates total generation plus net imports, equivalent to retail sales plus losses. Data from EIA, "State Electricity Profiles," accessed 2/14/2022 from https://www.eia.gov/electricity/state/. In-state Generation accounts for power that is generated within Maryland, not necessarily power committed to Maryland. For example, Maryland utilities may purchase power from out-of-state resources through short-term purchases or longer-term contractual arrangements. Such out-of-state purchases are reflected here as Net Imports.

Calvert Cliffs will be key to Maryland's clean energy ambitions. With its goal of 50% renewable by 2030, and including Calvert Cliffs' contribution, Maryland can be about 70% clean by the end of this decade. But without Calvert Cliffs, the state would backslide to being just 50% clean by then. In addition to its significant contribution to Maryland's clean power sources, Calvert Cliffs also offers 24x7 reliability, which is increasingly valuable in the transition to decarbonized future.

II. Analytic Approach

We analyze the environmental and economic impacts of Calvert Cliffs over the period 2025 to 2040, considering the hypothetical shutdown of the plant in 2025. To do this, we simulate the PJM power system and the Maryland economy, incorporating the outputs of the power system simulation as inputs to the economic model. We perform this set of simulations twice—first with Calvert Cliffs operating through the study horizon, then a second time removing it in 2025 to simulate a hypothetical retirement in that year.[4] By comparing the results of these two simulations, in terms of power system operations, emissions, power prices and customer costs, and economic performance, we can see the impacts of Calvert Cliffs. This is an indicative analysis designed to illustrate the broad impacts of Calvert Cliffs' nuclear generation on the environment and Maryland's economy. In particular, it does not attempt to project the specific timing with which Calvert Cliffs might shut down or the precise timing and location of other generation that may be developed to replace it.

We characterize the power system using GridSIM, Brattle's proprietary power system simulation model, which portrays short-term hourly operations as well as longer-term capacity additions and retirements to capture the dynamics of plant operation, power markets, and prices over time. We simulate the entire PJM power system (accounting for power interchange with neighboring systems) to best capture the dynamics of the interstate electricity market. This power sector model allows us to simulate the effects of Calvert Cliffs on the system's generating capacity mix (via retirements and new plant development), power system operations (the utilization of each plant, which directly determines GHG emissions), and power prices and the cost of electricity to Maryland consumers. The Appendix includes a brief overview of the GridSIM model.

In addition to its environmental impacts, Calvert Cliffs also has substantial economic impacts in Maryland.[5] This occurs through two primary channels, with additional ripple effects through the economy. First, the absence of Calvert Cliffs would cause a modest increase in wholesale power prices in Maryland 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, which translate to higher customer costs. Because electricity is ubiquitous throughout the economy, higher power costs mean producers and consumers will have somewhat less to invest and spend in other ways, which acts to slow the broader economy. The second economic channel relates to the economic activity associated with electricity production at Calvert Cliffs, and the relatively high-paying nuclear jobs it supports, along with the resultant additional economic activity that those jobs sustain throughout the state's economy. Without Calvert Cliffs, Maryland would lose this in-state economic activity. We utilize REMI, a widely used regional economic model, to

---

[4] This modeling assumption, that Calvert Cliffs is removed in 2025, allows a clear comparison of the impacts of the plant, though it is not a prediction of whether or when it might actually shut down. The current license life of Calvert Cliffs runs to 2034 for Unit 1, and 2036 for Unit 2.

[5] Emissions ultimately have economic costs as well, of course, but these emissions-induced costs are not included among the economic impacts cataloged here.

study the economic impacts and interactions in Maryland, incorporating both the effects on power prices, and the in-state economic activity and jobs associated with Calvert Cliffs.[6] This allows us to estimate the plant's effects on the larger Maryland economy – on economic output, GDP, and employment.

To best reflect the impacts of Calvert Cliffs, our modeling approach explicitly includes the responses of the power system, the electricity market, and the broader economy to the plant's presence or absence. These responses can partially mitigate the emissions impacts, the effects on power prices, and the economic impact. The types of responses captured by our electric system analysis includes greater utilization of existing plants, the development of new generation, and the delayed retirement of some plants, incorporating the re-dispatch of the resulting (somewhat different) fleet of generators in order to meet load.[7] The economic modeling captures the ways in which the larger economy responds to these electricity system changes, including the positive economic contributions of alternative generation that would substitute for lost nuclear power.

We evaluate the impacts of Calvert Cliffs first in the context of a Reference Scenario that characterizes relatively aggressive decarbonization of Maryland and the PJM electricity system over the next decade and a half, using GridSIM to model the power system, and REMI to model the Maryland economy. In addition, recognizing that the future may not play out in the way specified in the Reference Scenario, we also consider several alternate scenarios designed to illuminate the sensitivity of our conclusions to potential alternate assumptions about the future. These alternate scenarios include the following; they are described in more detail below.

- Scenario B: Nuclear loss enables additional renewables
- Scenario C: No PTC extension (current federal tax credits only)
- Scenario D: Policy to increase renewables to replace lost nuclear (with no PTC extension)

---

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

[7] In each simulation, the utilization of plants, development of new generation and retirement of existing plants are based on which alternatives are most economic.

III. Characterizing the Reference Scenario Future

The Reference Scenario future involves relatively aggressive decarbonization, driven largely by the assumption of expanded and extended federal support for renewable generation. This federal support is modeled after the original Production Tax Credit (PTC) provision in the Build Back Better Bill (the ultimate form of this bill, and indeed its passage, is not assured), and amounts to around a $25/MWh subsidy for renewable production for the first ten years of project life; this significantly improves renewable economics.[8] Because of this federal subsidy, state REC prices would fall to zero as renewable additions surpass current state mandates, assisted by these federal subsidies. Power sector assumptions for the Reference Scenario (and the other scenarios), including load projections, fuel prices, generation costs, *etc.* over the study horizon are summarized in the Appendix.

Our Reference Scenario simulation shows that under these circumstances, the PJM power system would decarbonize substantially by 2040, with new renewables being added on a scale not previously seen. Many PJM states have increasing RPS requirements for Tier 1 renewables – largely wind and solar – which target an aggregate PJM-wide renewable share of over 30% by 2040.[9] Still, state renewable mandates are not the driving force behind the increase in renewables in this future; it is largely the assumed PTC subsidy, combined with continuing declines in renewable costs. These factors make new renewables very attractive economically and drives substantial new renewable development, well beyond current state RPS requirements, causing state REC prices to fall to zero. Storage is also added, to help manage the intermittence of renewable generation. Figure 4 illustrates the regional PJM implications for power production in this scenario to 2040, showing how generation changes over time (here, with Calvert Cliffs still operating). Figure 5 shows the corresponding installed capacity in PJM.

---

[8] This PTC support is proposed to be available for both wind and solar. Solar would have the option to utilize an Investment Tax Credit (ITC) structure rather than the PTC, though our analysis suggests the PTC structure is generally more advantageous and would be utilized for solar in most instances.

[9] In aggregate, PJM states are currently behind on their RPS goals, though Maryland is on track with its own goals.

FIGURE 4: REFERENCE SCENARIO—GENERATION PROJECTION

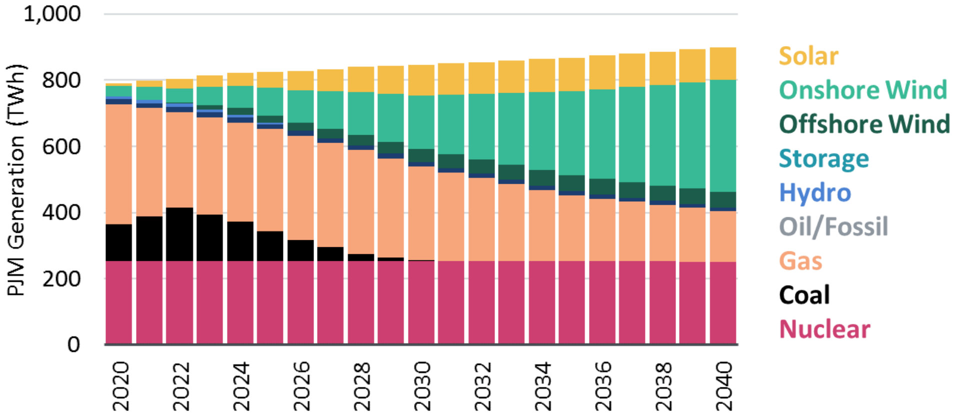
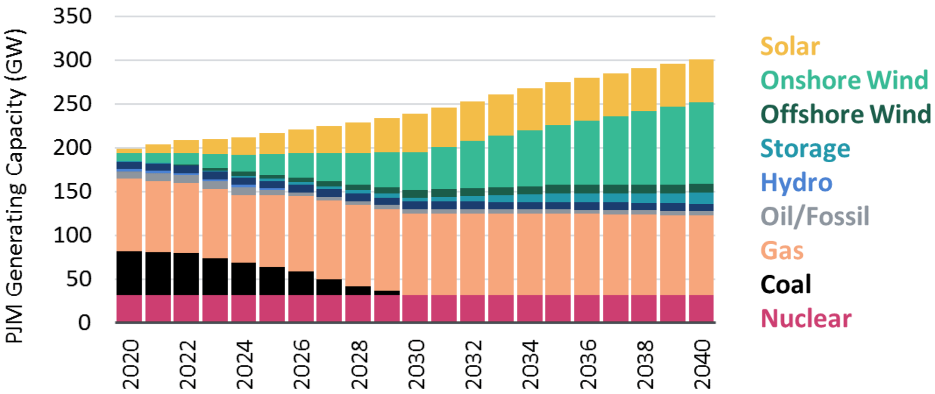
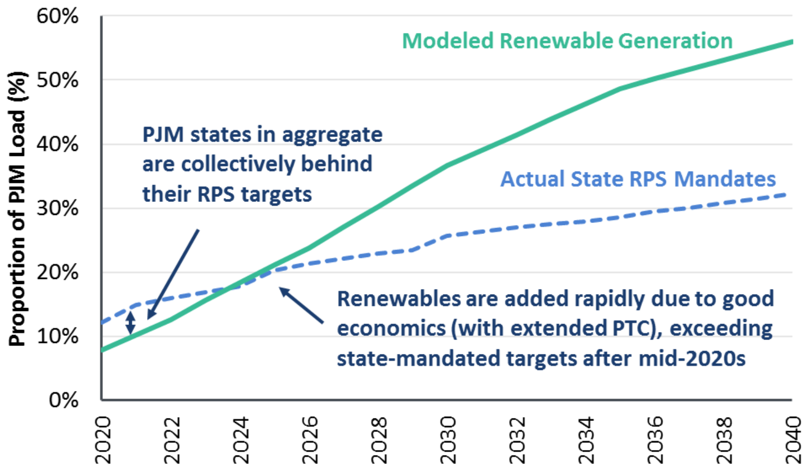


FIGURE 5: REFERENCE SCENARIO—CAPACITY PROJECTION



Aggregate PJM renewables catch up with and get ahead of state renewables mandates in the relatively near term and continue growing until they provide over 50% of total energy by 2040, as illustrated in Figure 6. But renewable additions do have some limits - ultimately constrained not by electricity market economics, which are quite attractive with the PTC, but by external factors that limit the rate at which they can be added – like supply chain and site availability. (The particular rate limits we use are an assumption, which we investigate later in sensitivity analysis.) In the near term, wind and solar capacity are added in similar amounts, but around 2030, solar additions begin to slow and wind additions continue. Large amounts of solar power depress the market price in the hours when it generates; as still more solar is added, the power price is depressed even more in mid-day hours, decreasing the value of further solar additions. Wind experiences a similar effect but less strongly (its output is spread across more hours, so it depresses its own price by less), and wind is added in greater quantities in the longer term. By 2040, wind accounts for a larger share of capacity and a much larger share of energy than solar.

FIGURE 6: REFERENCE SCENARIO—RENEWABLE GENERATION



Ultimately, large renewable additions cause fossil generation and emissions to fall significantly in the longer term. The model shows a brief near-term increase in coal usage, caused by higher near-term gas prices and peaking in 2022, followed by a rapid drop in coal generation thereafter, with most or all coal soon being retired. Ultimately, gas usage also falls, though most gas-fired capacity is retained to support reliability, even as its long-term utilization continues to decline. GHG emissions are based on generation; Figure 7 shows that coal retirements and increasing renewable generation push down overall GHG emissions significantly over time.

FIGURE 7: PROJECTED PJM ANNUAL CO_2 EMISSIONS

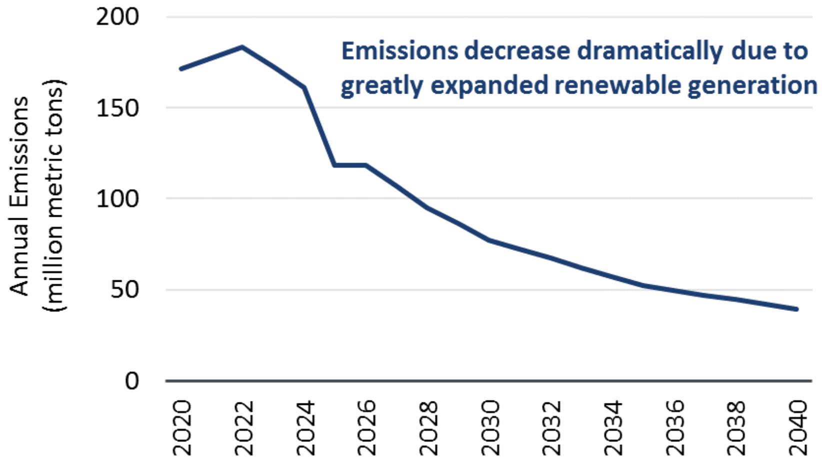
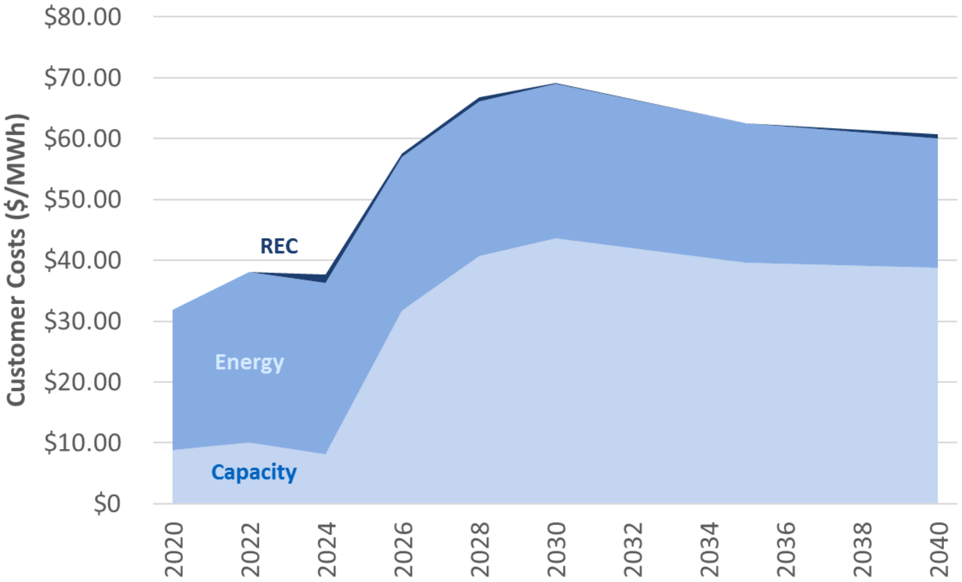


Figure 8 shows projected Maryland customer costs for wholesale generation in this Reference Scenario, illustrating the contributions from energy price, capacity price and REC price.[10]

FIGURE 8: PROJECTED MARYLAND CUSTOMER COSTS (WHOLESALE GENERATION ONLY)



Note: Reflects wholesale generation costs only, excluding transmission, distribution, and administrative costs. The presence or absence of Calvert Cliffs is not expected to affect these other costs materially.

IV. Impacts of Calvert Cliffs on the Electric System—Reference Scenario

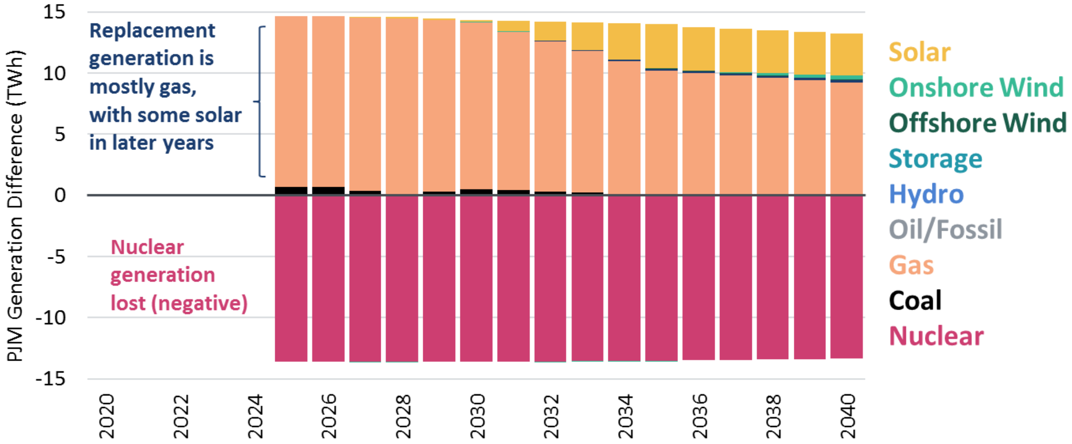
With this Reference Scenario baseline established, we estimate the impact of Calvert Cliffs by simulating the PJM system a second time, in this case removing the Calvert Cliffs plant in 2025 and allowing the system to respond according to operating requirements and natural economic forces. By comparing the results of these two simulations—with vs without Calvert Cliffs—on various dimensions, we can observe the impacts of the plant. Since even a large nuclear plant such as Calvert Cliffs is relatively small compared to the entirety of PJM, the overall generation

---

[10] The low capacity prices shown through 2024 reflect actual prices that have prevailed in the PJM capacity auctions for those delivery years. These have been well below the theoretical equilibrium capacity price based on PJM's Net CONE value (Net Cost of New Entry, the amount a generation developer would theoretically require to justify building new generating capacity). This theoretical capacity price is reflected in the modeled capacity price results for 2026 and beyond. This distinction has little impact on the results of this analysis, which looks at price differences due to the presence or absence of Calvert Cliffs, rather than absolute price levels.

picture that was illustrated in Figure 4 above would not appear dramatically different, and so in Figure 9 below we show just the differences between the cases with Calvert Cliffs vs. without Calvert Cliffs. These differences are precisely the impacts of Calvert Cliffs. We find that in this scenario, Calvert Cliffs' generation is replaced almost entirely by natural gas in the near term (its capacity, not shown here, is similarly replaced mostly by gas). New gas plants are likely to be added elsewhere in PJM, outside states like Maryland and New Jersey where it could be difficult to obtain siting authority and permits, and where they may have higher costs in any case.

FIGURE 9: IMPACT OF CALVERT CLIFFS ON PJM GENERATION – REFERENCE SCENARIO (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)



Even though renewable generation is being added at a substantial rate throughout the horizon, as was seen in Figure 4 above, this is equally true whether Calvert Cliffs continues to operate or not. Renewables would not be added significantly more or faster if Calvert Cliffs were to shut down; in fact, through much of the horizon, the rate of renewable additions is limited by external factors like supply chain and site availability. (This is in part an assumption, tested later in an alternate scenario.) Therefore, this additional renewable generation does not actually replace the lost nuclear generation; it is instead replaced primarily by gas-fired generation. In the latter part of the horizon, a moderate amount of the lost nuclear generation begins to be replaced by additional solar generation. However, there is a limit to how much intermittent renewable generation the system can utilize economically, even considering the availability of storage technologies, so additional renewable generation does not replace all or even most of Calvert Cliffs' output.

The gas-fired replacement power is provided by a very large number of generators in many small increments. In each hour, replacement power comes from the next generator(s) that would be at or near the margin (where supply meets demand in that hour), if Calvert Cliffs was operating. If Calvert Cliffs is unavailable, the next generator(s) up the supply curve must be dispatched to meet load, in each hour. Since different generators are at the margin in each hour, the replacement power is shared broadly across all the generators that are at or near the margin in any hour. Further, in most hours there are not significant transmission limitations that affect Maryland. Since there is considerably more available generation outside Maryland than within it, much of the replacement generation—the generation at or near the margin in a given hour—is outside Maryland. We find that in the near term, 90% of the replacement generation comes from out of state, pushing Maryland to be a net importer of about 60% of its energy.

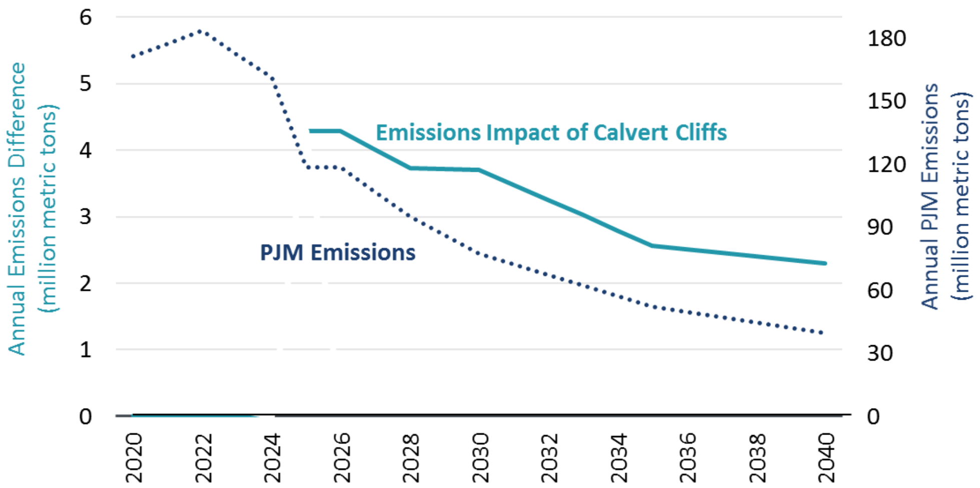
Since the replacement generation is largely gas-fired in the near term, spread across many gas generators, the emissions impact is similar to the emissions of the same amount of gas-fired generation. *I.e.*, a typical gas plant emits about 0.35 metric tons CO_2/MWh; since Calvert Cliffs produces about 13.6 million MWh annually, this corresponds to an increase of over 4 million tons of CO2 (MMtCO_2e) per year initially.[11] This would of course be a large step in the wrong direction relative to Maryland's decarbonization goals for both its electric sector and its overall economy. Figure 10 shows the change in emissions due to the loss of Calvert Cliffs—*i.e.*, the emissions that are avoided if Calvert Cliffs continues to operate. The emissions impact declines over time as renewable generation (solar) begins to substitute for a portion of the lost nuclear generation. Note that the emissions intensity of the replacement generation falls somewhat less quickly than the emissions of the system overall (total PJM emissions, from Figure 7 above, is also shown here on the right axis to illustrate this). The grid itself gets cleaner as renewables are added, with total emissions being determined by total generation, but the incremental emissions attributable to Calvert Cliffs are based on the marginal generator(s), and renewables are less often marginal.[12]

---

[11] In our modeling, we conservatively assume a Calvert Cliffs capacity factor of 92%, consistent with the national average for nuclear plants but lower than its recent history. This leads to modeled output of about 13.6 TWh, somewhat below its actual recent average of 15 TWh.

[12] There is a distinction between generation that is on the margin in hourly dispatch, vs generation that is marginal in the long term, even though it may not be marginal for short run operations. For example, the incremental new solar that may be added in response to Calvert Cliffs' retirement is marginal in the long term, even though it is never on the margin in short-run dispatch. Both contribute to the incremental emissions impact of Calvert Cliffs, and are accounted for by the structure of this analysis.

FIGURE 10: GHG EMISSIONS AVOIDED BY CALVERT CLIFFS – REFERENCE SCENARIO (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)



Over the horizon 2025–2040, this amounts to about 56 million tons of incremental emissions that will be avoided if Calvert Cliffs continues to operate through this period. This is approximately 2.5% of total PJM emissions over the study horizon, but it is all attributable to Maryland. (This approach of attributing the entire emissions change to Maryland, even though most of the replacement generation comes from out of state, is consistent with causation and with the historical emissions benchmarking approach and treatment of imports in Maryland's GHG reduction goals.[13]) The aggregate social cost of these incremental CO_2 emissions is valued at approximately $2.5 billion (net present value), using the social cost of carbon estimated by the Interagency Working Group.[14]

---

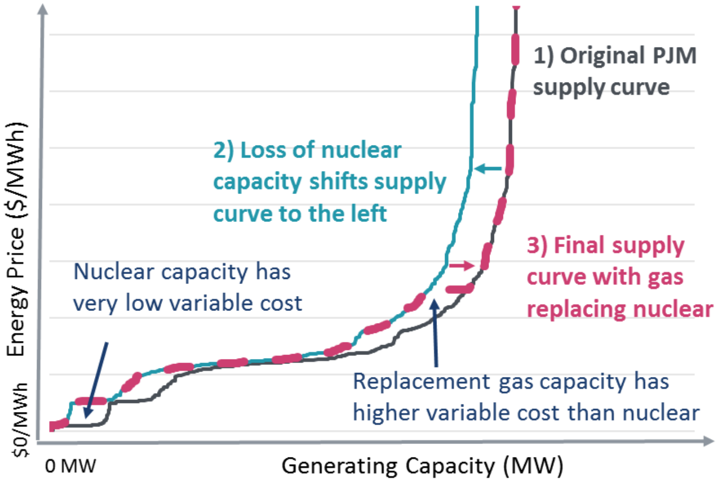
[13] See, *e.g.*, section 3.1.1 of The Greenhouse Gas Emissions Reduction Act, 203 GGRA Plan, Maryland Department of the Environment, February 19, 2021.

[14] Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide; Interagency Working Group on Social Cost of Greenhouse Gases, February 2021. The IWG social cost of carbon, evaluated at a 3% discount rate, is $56/ton in 2025, and rises to $73/ton in 2040 (in 2020 dollars). The $1.8 billion NPV is the annual incremental carbon emissions (with vs without Calvert Cliffs), valued at this social cost of carbon over time and discounted to present value at 8%.

V. Impacts on Electricity Prices and Customer Costs—Reference Scenario

In addition to the emissions impacts, the loss of Calvert Cliffs would affect electricity prices and thus customer costs. As with any market, a loss of supply will cause an increase in price. In the PJM electricity markets, the loss of a large generator with essentially zero variable cost will increase hourly energy prices. This is illustrated in stylized form in Figure 11, where the direct effect will be to shift the entire energy supply curve leftward by the plant's capacity. But since the lost nuclear capacity is largely replaced by new gas capacity, the upper portion of the supply curve (at and above the variable cost of the new gas plants) will shift back to the right about the same amount, so the upper part of the curve will be similar to the original supply curve. This leaves just the lower portion of the curve shifted leftward. The leftward shift of the lower part of the curve effectively raises the supply curve in this region. Thus, in hours when demand intersects this lower, repositioned portion of the supply curve, the resulting energy clearing price is somewhat higher; the overall average price also rises.

FIGURE 11: STYLIZED IMPACT OF THE LOSS OF NUCLEAR GENERATION ON ENERGY SUPPLY CURVE



Capacity and REC markets are linked with energy markets, since the revenue a new generator earns from energy can reduce the amount of capacity and REC revenue it needs to recover its full costs. This means that capacity and REC prices also respond to the new supply/demand balances across these markets. The capacity market also interacts with PJM's sloped capacity demand curve mechanism. All these interdependent effects on energy, capacity and REC prices are captured in our analysis, and have direct impacts on customer costs in a retail access state like Maryland. The overall effect on power prices and customer costs is modest; aggregating the impact across all price components and expressing it on a $/MWh basis, it is approximately equal to $0.71/MWh (0.071₵/kWh) on average across the relevant horizon, 2025-2040. This amounts to approximately $47 million per year, or $410 million in net present value.[15] (Note that this is before accounting for any potential costs that may be required to keep Calvert Cliffs operating; those costs would need to be incorporated to characterize the full impact on customer costs, and to evaluate any proposed policy.) For context, the total delivered retail power price in Maryland is about $110/MWh (11₵/kWh). Table 1 below summarizes the effect on power prices and direct customer costs in Maryland.

TABLE 1: PROJECTED AVERAGE WHOLESALE POWER PRICES – REFERENCE SCENARIO (ALL-IN, INCLUDING ENERGY, CAPACITY, RECS; $/MWH)

	With Calvert Cliffs	Without Calvert Cliffs	Difference
MD	$64.50	$65.21	$0.71
PJM	$55.54	$55.76	$0.22

VI. Economic Impacts—Reference Scenario

We utilized the REMI macroeconomic model to measure the economic impacts that would result from the closure of Calvert Cliffs. The REMI model is a widely recognized commercial model used by both the public and private sectors. We focus on three impact metrics: gross output, gross domestic product and employment. Gross output broadly represents economic activity and includes both final and intermediate production; it can involve a double-counting of intermediates.[16] That double-counting is avoided by the Gross Domestic Product (GDP) metric (also known as value added), which focuses on final demand and production, and is the most common measure of economic activity. The employment metric includes direct and secondary workers. Direct workers include those employed directly at the Calvert Cliffs plant. Secondary

---

[15] This NPV is the present value, to 2025, of the customer cost impacts for the period 2025–2040, using a discount rate of 8%.

[16] Gross economic output is an aggregate measure of total industry sales, which includes sales to final users and intermediate sales to other industries. It is useful in comparing relative impacts across industries. However, summing output across sectors can lead to a form of double counting when the output of one sector is an 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.

jobs include those involved in providing goods and services to the plant, and additional jobs created by changes in economic activity elsewhere in the economy (*e.g.*, by expenditures by plant workers).

Table 2 below summarizes the output, GDP and employment impact for the Reference Scenario. These results incorporate all the effects that would result from the retirement of Calvert Cliffs. That is, the effects of plant closure (which causes changes in plant revenues, and direct and secondary employment), changes in electricity prices and thus costs for Maryland consumers, new plant construction in Maryland (primarily wind and solar) and increased utilization of existing plants in Maryland (natural gas and coal). For example, impacts are higher in cases where electricity prices increase by more, and are lower where more additional generating capacity is developed in-state to replace Calvert Cliffs.

TABLE 2: ECONOMIC IMPACTS OF CALVERT CLIFFS RETIREMENT – REFERENCE SCENARIO (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)

Dimension	Impact
Output Impact (2021$ millions)	-$1,204
GDP Impact (2021$ millions)	-$634
Employment Impact (Annual Jobs)	-4,760

Total job losses under the Reference Scenario are 4,760 annually, reflecting 4,890 direct and secondary job losses related to the plant closure, and another 240 losses related to higher electricity prices. These losses are partially offset by a gain of 370 direct and secondary jobs from increased in-state economic activity at existing gas plants and developing and operating new renewable generation. Average annual GDP losses under the Reference Scenario total $634 million. This loss reflects plant closure losses of $726 million and electricity price increase related losses of $43 million. These losses are partially offset by $135 million in GDP gains from new renewable generation and increased utilization of existing plants. The annual gross output losses total $1.204 billion. These losses include $1.359 billion from plant closure and $70 million from electricity price increases, partially offset by gains of $225 million from new plant construction and increased utilization from existing plants.

These economic impacts are driven primarily by the direct effects of losing the Calvert Cliffs plant – the loss of revenue to the plant and the accompanying loss of jobs. The economic impacts of higher electricity prices and customer costs are relatively smaller. There is some partially offsetting increase in economic activity caused by increased utilization of existing in-state generators, and in the longer term, the addition of some more renewable (solar) generation within Maryland. However, since only a small share of the total replacement generation comes from in-state, this offset is small. Again, these impacts do not account for any potential policy cost that may be needed to keep Calvert Cliffs operating.

VII. Alternate Scenarios

The results corresponding to the Reference Scenario discussed above depend, at least to some extent, on the assumptions about the future that are used to characterize the Reference Scenario. In this section, we consider several alternate scenarios, to explore how different assumptions might affect the results. There are several key and related assumptions in the Reference Scenario that have the greatest effect on the results. The first is that in at least the short term, the rate of renewable additions would be limited (*e.g.*, by supply chain and siting issues), and renewables could not be added in greater quantities or faster than these limits imply. The second is that there would be substantial federal subsidies for renewables that would make it extremely economic to add them in large quantities, driving the rate of renewable additions up to these limits. Third is that nuclear retirement would not trigger a policy response that would force the replacement of lost nuclear output by other clean generation (whether such a policy response is even possible might depend on whether additions are high enough to be constrained by the rate limit of the first assumption). Together, these Reference Scenario assumptions imply that renewables are being added very quickly, but could not be added in greater quantities, or faster, if Calvert Cliffs were to shut down. They also imply that a hypothetical policy solution to force more renewables to replace lost nuclear would not be possible.

The Alternate Scenarios are designed to test the impacts of these key assumptions. They are:

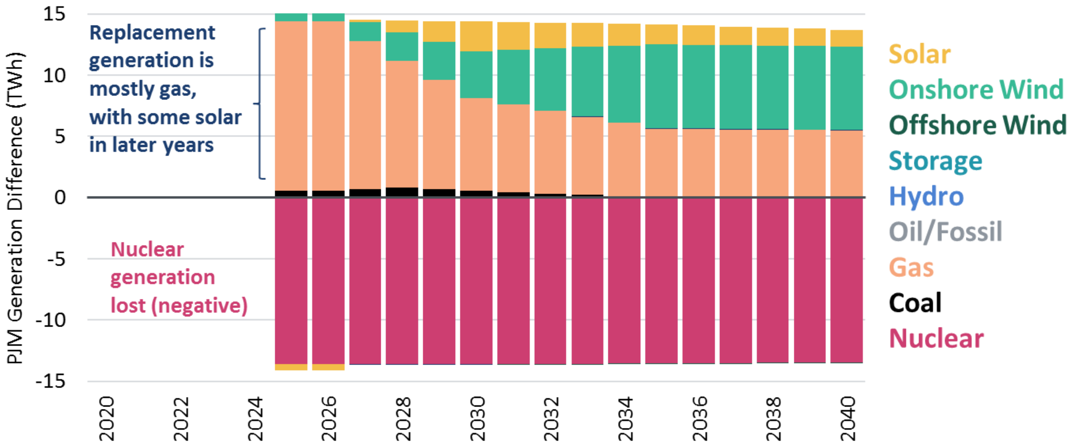
- Nuclear loss enables additional renewables, beyond the assumed limit on additions
- No expanded federal subsidies for renewables (current federal tax credits only)
- Policy to increase renewables to replace lost nuclear (combined with no expanded federal subsidies)

A. Alternate Scenario B: Nuclear loss enables additional renewables

A natural question often arises around an analysis like this: Why is it, if renewable generation is as cost-effective as assumed in the Reference Scenario, that any lost nuclear generation wouldn't be replaced by renewables? The answer is actually contained within the question itself. Since renewables are so economic to begin with, they are already being added as fast as possible, up to whatever factors are limiting the rate of additions. A range of such factors may be at work, including the supply chain for renewable development (for generator components and equipment, labor requirements, *etc.*), site availability, land use and permitting requirements, interconnection requirements, transmissions system capacity, increased balancing needs (greater storage needs to balance renewable intermittence), *etc.* While of course such limits must exist at some level, Scenario B examines, as a thought experiment, what would happen if they could be overcome. We assumed that whatever the factors are that limit the rate of renewable additions, they would be relaxed by enough to replace the lost nuclear generation. Importantly, the limit is relaxed <u>if and only if</u> the nuclear generation is lost (since relaxing the limiting factors both with and without Calvert Cliffs would constrain additions to the same, somewhat higher level in both cases, leading to essentially the same incremental impact as the Reference Scenario). To implement this, we assumed that incremental additional renewables could be added over a ten-year period (as equal parts wind and solar) to replace Calvert Cliffs, if it retired. For this scenario, the PJM future (with Calvert Cliffs) is the same as for the Reference Scenario, illustrated in Figure 4 above.

Figure 12 illustrates the replacement generation in this scenario. Results for this scenario are initially similar to the Reference Scenario, with lost nuclear generation being replaced by gas, but that result is more transient here. Because we assumed, as a part of the thought experiment, that more additional renewables <u>could</u> be added, they are in fact added, substituting for some of the gas. However, this happens only up to a point. Importantly, even though renewables are allowed to replace <u>all</u> of the lost nuclear generation, they actually replace only <u>some</u> of it. This is because the system eventually reaches a point of "saturation" with renewables – as much as the system can usefully accommodate at their (subsidized) price. The saturation point does rise somewhat with the greater need for power that follows the nuclear loss, but it rises by less than the total lost nuclear, and some replacement by gas persists essentially indefinitely.[17]

FIGURE 12: IMPACT OF CALVERT CLIFFS ON PJM GENERATION – SCENARIO B (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)



Because more renewable generation, and thus less fossil, is replacing the lost nuclear, relative to the Reference Scenario, the cumulative emissions impact is smaller—about 39 million tons over the horizon, with a corresponding social cost of $1.8 billion. The direct customer bill impact would also be somewhat lower, at about $34 million per year, because more (cheap) renewables have been made available, leading to a smaller price increase than in the Reference Scenario. The economic impacts of this scenario include an average annual decrease of $1,096 million in output, $566 million in GDP, and a loss of 4,320 jobs.

Still, it is doubtful whether the premise of this scenario, that Calvert Cliffs' retirement actually could enable more Renewables to be added, is valid. This scenario is useful not because it necessarily characterizes a realistic future, but mostly because it points out that even if somehow renewables could entirely replace the lost nuclear output, it is unlikely that they would do so fully. It also shows that the replacement would not be immediate, leading to an emissions increase in the interim, and driving up cumulative emissions.

---

[17] A somewhat different assumption for this scenario would lead to a similar result. If there were <u>no</u> limits on renewable additions at all, they would immediately be built to saturation—*I.e.*, as much as the system can usefully accommodate, given their cost—even with Calvert Cliffs operating. If Calvert Cliffs were then retired, renewables would replace some but not all of it. The saturation point would rise, but by less than the lost nuclear generation.

B. Alternate Scenario C: No expanded federal renewable subsidies

Another key assumption in the Reference Scenario is that there would be strong federal support for renewables that would make it economic to add them, well beyond RPS requirements. In contrast, Alternate Scenario C here (and also Scenario D below) assumes that expanded federal subsidies for renewables are not enacted; rather, only the current federal production tax credit (PTC) for wind, which expires over the next few years, remains in place.[18] Without the additional federal subsidies, renewables are not economic on their own against fossil gas (this is true even with our relatively aggressive assumed cost declines for renewables). They would thus be added considerably less quickly, and additions would not be constrained by the rate limiting factors of the Reference Scenario. Renewable additions would keep pace with rising state RPS requirements. REC prices would get high enough to support this lower level of additions, essentially replacing the federal subsidy with a smaller state subsidy. But an important difference between the subsidy mechanism provided by the state RPS and that of the federal PTC is that the state RPS subsidy is quantity-limited (only up to the RPS requirement), while the federal PTC subsidy is not limited by any target quantity of renewable additions. Thus, in this Scenario C, renewable additions keep pace with, but do not exceed, aggregate state RPS requirements.[19]

Figure 13 below illustrates the regional PJM implications of the current federal tax credit scenarios in terms of generation. Figure 14 shows the corresponding installed capacity. (This "With Calvert Cliffs" case applies for both Scenario C here, and also for Scenario D below.) This significantly changes the background against which the loss of Calvert Cliffs will be evaluated; relative to the Reference Scenario above, renewables are added in smaller amounts and provide considerably less energy overall – about 30% by 2040, with natural gas still supplying about 40% of PJM's total generation.

---

[18] Current legislation specifies that the PTC, only available to wind assets, expires in 2022, but the safe harbor provision allows projects coming online as late as 2026 to earn the PTC, if they began construction by 2022.

[19] If some states were to increase their RPS requirements, a similar result would be found, though at a somewhat higher level of renewables. This situation is in some ways similar to that examined in the next Scenario, Alternate Scenario D.

FIGURE 13: CURRENT FEDERAL TAX CREDITS SCENARIOS—GENERATION PROJECTION

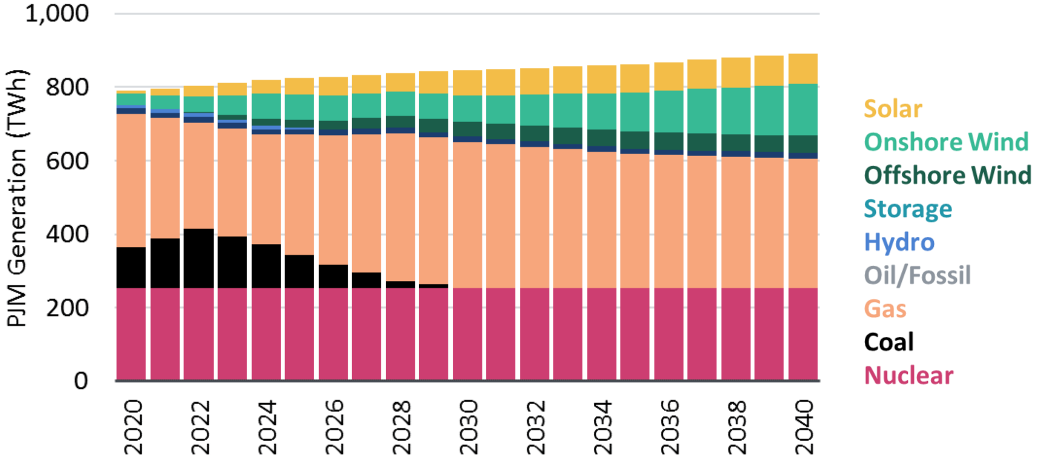
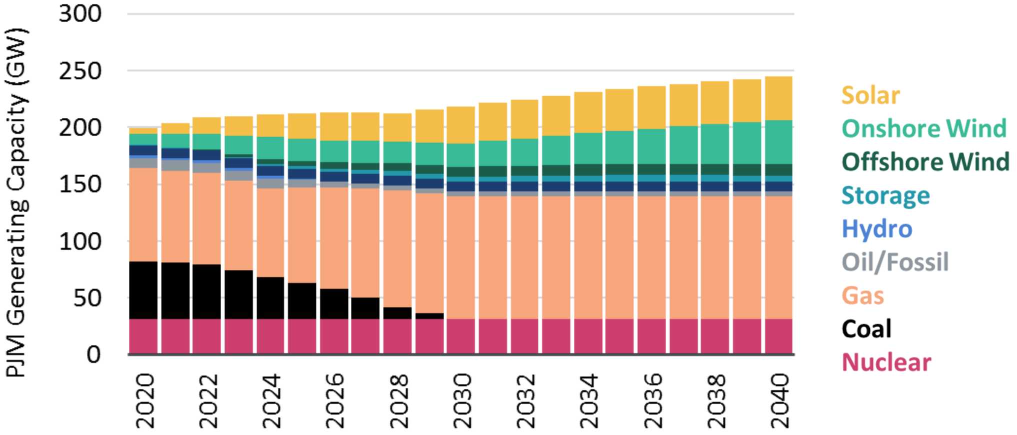
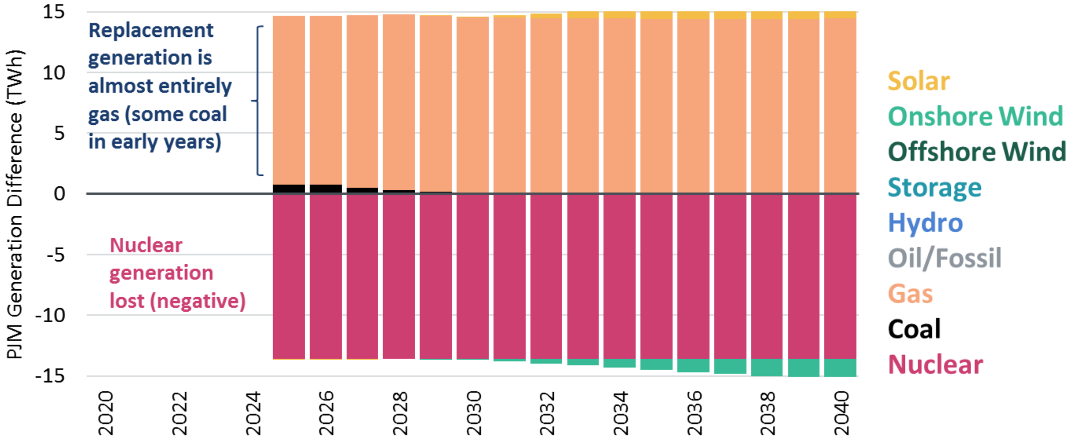


FIGURE 14: CURRENT FEDERAL TAX CREDITS SCENARIOS—CAPACITY PROJECTION



In this scenario, if Calvert Cliffs were to retire, it would be replaced virtually entirely (not just mostly) by gas generation, and the effect, illustrated in Figure 15, does not diminish over time. Renewables are added in the same quantities (*i.e.*, to meet state RPS requirements) regardless of the status of Calvert Cliffs.

FIGURE 15: IMPACT OF CALVERT CLIFFS ON PJM GENERATION—SCENARIO C (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)



The emissions impact is of course correspondingly larger – over the horizon 2025–2040, the loss of Calvert Cliffs would result in about 67 million tons of incremental emissions (vs 56 million tons in the Reference Scenario). This larger increment in emissions comes on top of the overall PJM system starting from a higher emissions baseline in this scenario. The associated social cost of this higher incremental emissions is valued at approximately $2.9 billion (net present value), based on the IWG social cost of carbon estimate. The customer cost impact would be slightly lower than in the Reference Scenario—a cost increase of approximately $32 million/year, with net present value of $240 million in higher customer costs (for comparison, the Reference Scenario involved higher customer costs of $47 million/year, NPV $410 million). The economic impacts of this scenario include an average annual decrease of $1,440 million in output, $786 million in GDP, and a loss of 5,200 jobs.

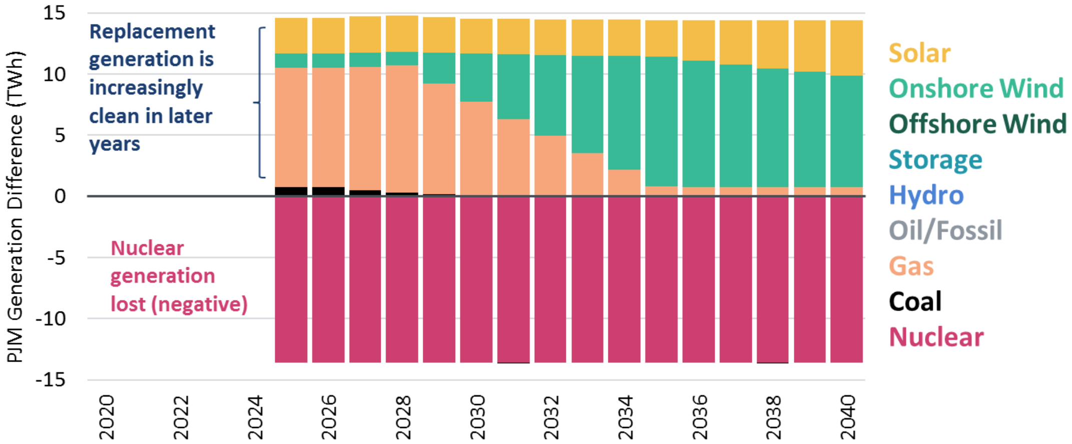
C. Alternate Scenario D: Policy to increase renewables to replace lost nuclear

The fourth and final Scenario we consider is based on the same world of current federal tax credits as the previous Scenario C. As in that case, the lack of lucrative federal incentives means that the level of renewable additions is below the external limits modeled in the Reference Scenario. This means that renewables could be added more quickly, at least up to those limits. This Alternate Scenario D considers the possibility of policy action taken, if Calvert Cliffs retires, to force the adoption of incremental, additional renewable generation to replace the lost nuclear generation. (Here, this policy action would be taken if and only if the plant retires, to regain Maryland's clean energy adoption trajectory despite the loss of clean nuclear generation.)

This policy action could take the form of an increase in the RPS requirement, or through direct state contracting for renewables beyond the RPS requirement. This could not occur immediately, of course, but might be phased in over time. We represent this hypothetical policy response as phasing in smoothly over a ten-year period, so that by 2035, Maryland would have an additional 13.6 TWh per year of renewable energy, replacing the 13.6 TWh of lost nuclear generation from Calvert Cliffs.

Figure 16 illustrates the replacement generation in this instance. At first, the replacement is still mostly gas, but over the ten-year phase-in period, the policy pushes additional new renewables to be added each year, enough to replace the full 13.6 TWh of lost nuclear generation by 2035.[20] The aggregate emissions impact is smaller, of course, and disappears by 2035, by design. But the higher emissions in the interim, after Calvert Cliffs retires but before it is fully replaced, still contribute to cumulative emissions, which of course are the key factor driving climate change. An incremental 24 million tons of CO2 is emitted (vs the Reference Scenario's 56 million tons), with associated social cost of carbon valued at $1.2 billion.

FIGURE 16: IMPACT OF CALVERT CLIFFS ON PJM GENERATION—SCENARIO D (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)



The other factor that changes here is customer cost. It increases by about $87 million annually ($650 million in NPV). This is driven primarily by the additional REC costs associated with the incremental renewables that are required by this policy. That is, the additional renewable quantity required by the policy must be supported by RECs, which have a positive price since

---

[20] If additional renewables are required in the longer term, some of them would be developed immediately, slightly ahead of the assumed policy pace, to capture the last of the expiring PTC benefits.

federal tax credits are phased out in this scenario. Maryland customers must pay this additional cost. The economic impacts of this scenario include an average annual decrease of $1,422 million in output, $773 million in GDP, and a loss of 5,090 jobs.

VIII. Discussion & Additional Issues

The analysis and scenarios examined above show that under a wide range of assumptions, the retirement of the Calvert Cliffs nuclear plant would result in replacement with gas generation, with its associated emissions. This is true at least in the short term, and in most circumstances, would continue to some extent in the longer term. This would increase cumulative GHG emissions beyond what they would be if Calvert Cliffs continues to operate – by about 56 million tons in the Reference Scenario, entailing social costs of approximately $2.5 billion in net present value.

The reasons for this vary by scenario. If renewables are economic (*e.g.*, due to expanded and extended federal tax credits as in the Reference Scenario and Scenario B), they will be added regardless of the fate of Calvert Cliffs, and to essentially the same extent. The rate of renewable addition will be limited by external factors, such as supply chain and site availability, that are unrelated to Calvert Cliffs. Here, even though renewables are being added rapidly, they would not be added more or faster in response to the nuclear retirement. So renewables would not replace the lost nuclear generation; increased fossil gas-fired generation would fill in for it. Further, Scenario B showed that even in the context of a thought experiment where renewables could be developed more and faster, this did not happen fully. In the long run, fossil generation continues to replace at least some of the lost nuclear generation.

In the alternative, if renewables are not economic by themselves (except with REC support, as in Scenario C), they would be developed up to the RPS requirement, but not beyond, again regardless of the fate of Calvert Cliffs.[21] So, despite that some new renewables are added over time, they are not replacing lost nuclear generation. In the Policy Response Scenario D where policy is assumed to require the replacement of lost nuclear with increased renewables (*e.g.*, via increasing the RPS requirement, or direct state contracting for renewables), the lost nuclear

---

[21] Voluntary demand might result in renewables beyond the RPS requirement, but the amount of voluntary demand would probably not be influenced materially by the presence or absence of Calvert Cliffs, so this conclusion holds.

generation is eventually replaced. Even here, though, emissions are higher in the interim, and in this instance, the policy increases customer costs to fund the additional renewables required. This illustrates the explicit trade-off between mitigating the emissions impact and raising customer costs.

In any of these circumstances, the loss of Calvert Cliffs would raise direct electricity costs for Maryland customers, since the decrease in regional supply causes an increase in electricity prices (accounting in our analysis for effects across the energy, capacity and REC markets). On top of this increase in direct customer costs is the social costs of the additional GHG emissions, which can amount to several billion dollars in net present value. Table 3 below summarizes the results of the scenarios analyzed, across all dimensions.

TABLE 3: SUMMARY OF CALVERT CLIFFS IMPACTS FOR SCENARIOS ANALYZED (DIFFERENCE BETWEEN WITHOUT CALVERT CLIFFS AND WITH CALVERT CLIFFS CASES)

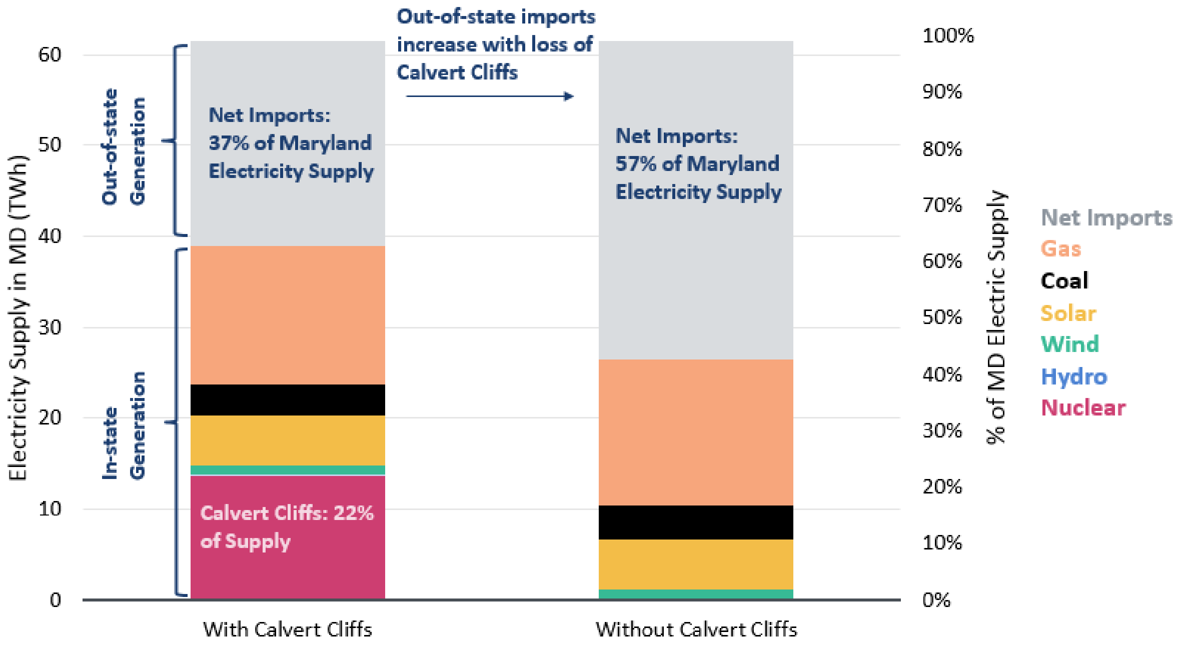
	Reference Scenario	Scenario B: Nuclear Loss Enables Renewables	Scenario C: No PTC Extension	Scenario D: Clean Energy Policy
Carbon Emissions Impact (cumulative metric tons, 2025-2040)	51 million	35 million	61 million	22 million
Carbon Emissions Social Cost (Valued at IWG SCC, 2025 NPV)	$2.5 billion	$1.8 billion	$2.9 billion	$1.2 billion
Maryland Customer Price Impact ($/MWh)	+$0.70/MWh	+$0.52/MWh	+$0.49/MWh	+$1.32/MWh
Maryland Customer Costs (2025 NPV)	$411 million	$334 million	$244 million	$646 million
Output Impact (Annual Average, 2025-2040, 2021 $)	-$1,204 million	-$1,096 million	-$1,440 million	-$1,422 million
GDP Impact (Annual Average, 2025-2040, 2021 $)	-$634 million	-$566 million	-$786 million	-$773 million
Jobs Impact (Average, 2025-2040)	-4,760	-4,320	-5,200	-5,090

Below, we discuss several additional implications that would accompany the hypothetical early retirement of Calvert Cliffs.

A. Impacts on Maryland’s Reliance on Imports

In addition to the emissions and cost implications, the loss of Calvert Cliffs would dramatically increase the amount of electricity that Maryland imports from other states. The generation that would replace Calvert Cliffs' lost nuclear output would come largely from western Pennsylvania, Ohio, West Virginia, and/or Virginia, delivered across the PJM transmission system. Maryland would import a much larger share of its total energy needs without Calvert Cliffs operating; imports would rise from their current level of 35-40%, already quite high, to approaching 60%, as illustrated in Figure 17. (In-state gas generation would also increase slightly.) This loss of in-state nuclear electricity production and the increased reliance on imports is a major factor driving the large negative impact on state output, GDP and employment. Reliance on imports can also limit state policymakers' ability to influence the state's electricity supply.

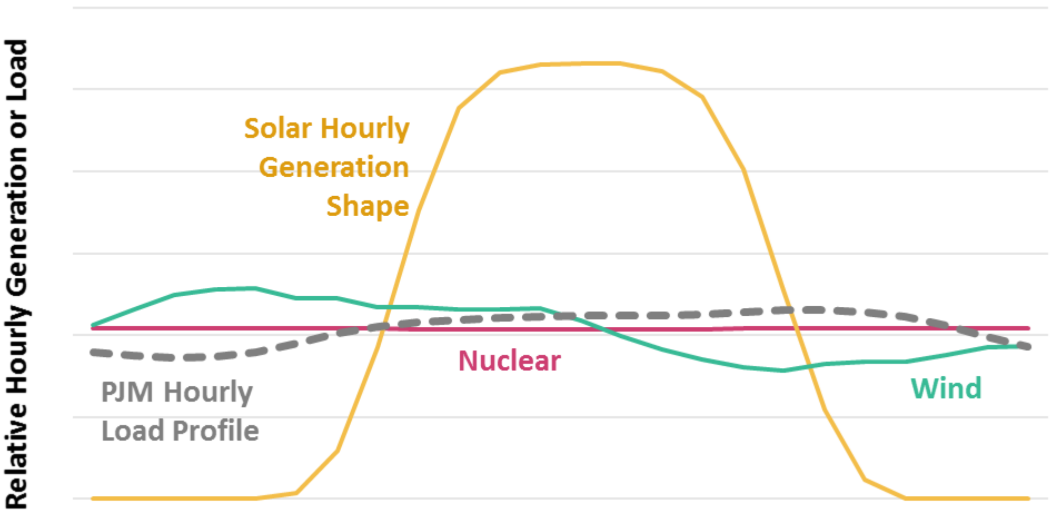
FIGURE 17: EFFECT OF CALVERT CLIFFS ON MARYLAND'S RELIANCE ON IMPORTS, 2025



B. Hourly Generation Shape vs Load Shape

The constant 24×7 output profile of a nuclear plant will become increasingly valuable as the power system decarbonizes over time. It will provide a reliability-enhancing complement to the intermittent renewable generation that will ultimately displace the majority of traditional fossil generation. One way to illustrate this is by comparing the hourly generation profile of various technologies with the load profile. Figure 18 below shows the annual average output of nuclear, wind and solar, by hour of day, comparing these with PJM's average hourly load profile (dashed grey). Each curve is scaled to show the same amount of total energy over 24 hours. These average annual profiles obscure significant hourly variability, as well as seasonal variation, for renewable generation and for load. Still, even this perspective illustrates that nuclear's flat hourly shape is generally a good match for PJM's hourly load shape. Wind is a reasonably good match on average, though its output can and does vary considerably. Solar generation is concentrated in the mid-day hours, and by itself cannot serve all load. While the system can accommodate a significant amount of renewable generation, in the long run, with high renewable penetration, it will benefit from having nuclear's consistent output profile as a part of the generation mix. These differences make nuclear and renewables complements, not substitutes or competitors, in decarbonizing the power system.

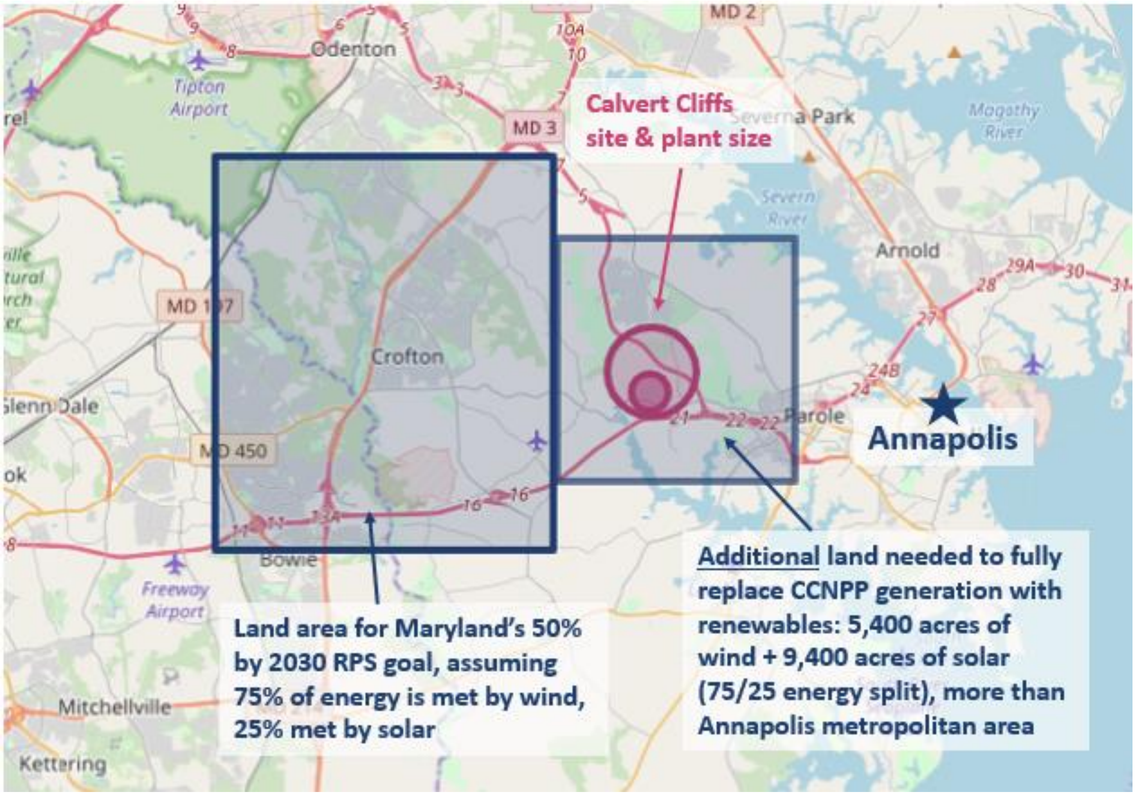
FIGURE 18: PJM GENERATION AND LOAD PROFILES (HOURLY, NORMALIZED AVERAGE ANNUAL VALUES)



C.   Land Use Impacts

Beyond the emissions and cost implications discussed above, attempting to replace lost nuclear generation with renewable generation could have material implications for land use. The Calvert Cliffs site covers approximately 1,500 acres, but the majority of this area is wildlife habitat. The nuclear plant and its associated facilities occupy much less space – only about 250 acres to generate 15 TWh annually. Generating this same amount of power with solar would require an additional 7,000 MW of solar (solar requires much more installed capacity to produce the same amount of power; while Calvert Cliffs runs at a capacity factor of over 90%, solar's capacity factor is about 25% in the Mid-Atlantic region). This amount of solar generation would occupy about 36,000 acres – 140 times the footprint of Calvert Cliffs. Alternatively, to generate 15 TWh with land-based wind would require about 4,300 MW, occupying 7,500 acres—30 times the Calvert Cliffs footprint. These potential land use requirements are not as large as what will be needed to accommodate the renewables already contemplated to meet Maryland's 50% renewable target. Still, to replace Calvert Cliffs' output with renewables would add another 45% to the overall land requirements, on top of what will be needed for Maryland's 50% renewable target. This is about three times the land area of Annapolis. The approximate areas involved are illustrated in Figure 19 below, overlaid on the portion of Maryland near Annapolis.

FIGURE 19: INCREMENTAL LAND REQUIREMENTS TO REPLACE CALVERT CLIFFS' GENERATION



Calvert Cliffs site & plant size

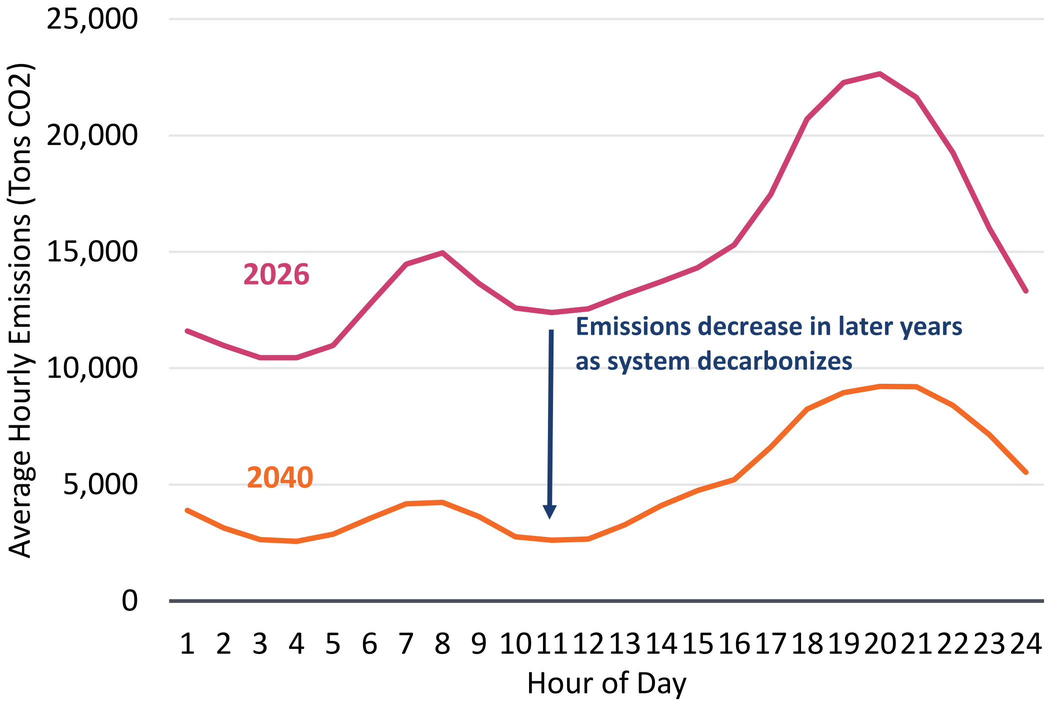
Land area for Maryland's 50% by 2030 RPS goal, assuming 75% of energy is met by wind, 25% met by solar

Additional land needed to fully replace CCNPP generation with renewables: 5,400 acres of wind + 9,400 acres of solar (75/25 energy split), more than Annapolis metropolitan area

D. Effect on Hourly Emissions

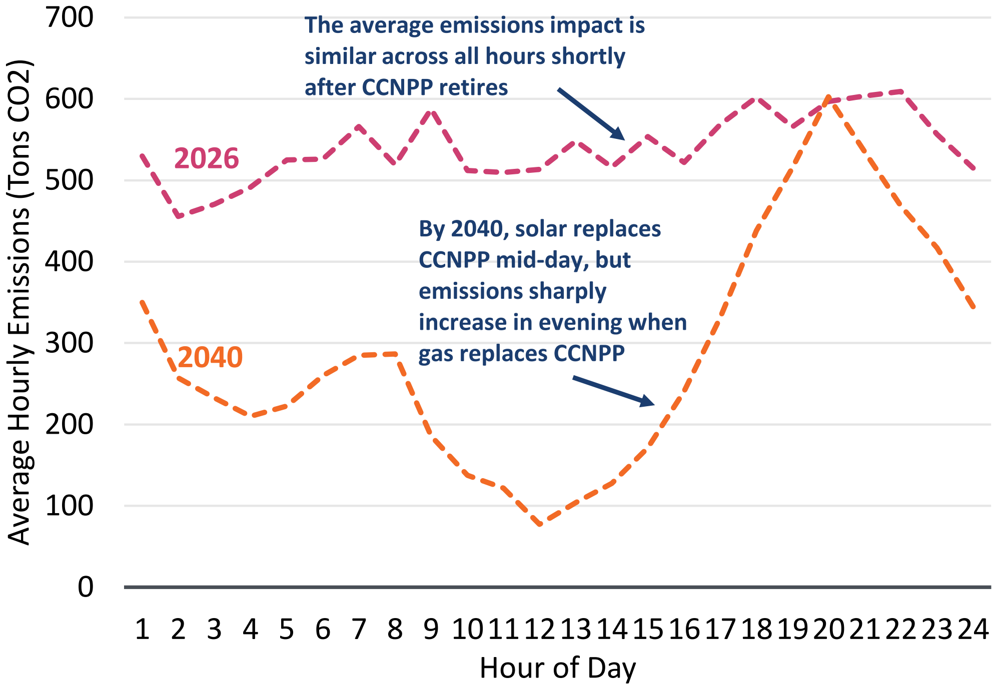
Total PJM emissions vary by hour, due primarily to the fact that load varies by hour; hours with high load also tend to have high emission, because more plants (and often somewhat less efficient plants) must operate to produce the greater output. As the PJM power system decarbonizes over time, overall emissions will fall in all hours, though to the extent solar generation increases substantially, emissions will fall to a somewhat greater extent in mid-day hours where solar is concentrated, as illustrated in Figure 20 below.

FIGURE 20: HOURLY SYSTEM EMISSIONS



However, the hourly <u>incremental</u> emissions impact of Calvert Cliffs does not behave in the same way, since Calvert Cliffs produces the same amount of power in each hour, as illustrated in Figure 21. In the near term, the incremental impact of Calvert Cliffs' retirement is roughly the same across hours, since lost nuclear is replaced almost entirely by gas in every hour. Its emissions impact is essentially the gas emissions rate (with minor hourly variability due to the efficiency of the gas plant(s) on the margin). In the longer term, the Reference Scenario shows that part of Calvert Cliffs' output is replaced by solar, but of course, essentially all the solar replacement occurs in mid-day hours, and none overnight. This causes the hourly emissions impact of Calvert Cliffs to drop during mid-day hours when much of its generation is replaced by solar. It will remain relatively high in other hours (decreasing somewhat in those other hours due to decarbonization of the rest of system generation).

FIGURE 21: INCREMENTAL IMPACT OF CALVERT CLIFFS ON HOURLY SYSTEM EMISSIONS



The average emissions impact is similar across all hours shortly after CCNPP retires

By 2040, solar replaces CCNPP mid-day, but emissions sharply increase in evening when gas replaces CCNPP

IX. Conclusion

Keeping the Calvert Cliffs nuclear plant operating will prevent significant carbon emissions. The loss of the plant would significantly reduce the amount of emission-free power generated, requiring correspondingly more fossil generation, most of it gas-fired, to replace it. Renewable generation will not naturally replace lost nuclear generation; even with direct policy intervention to ensure that replacement generation is clean (*i.e.*, requiring enough incremental new renewables to offset the lost nuclear generation), replacement could at best occur over a period of years, leading to greater emissions in the interim and higher cumulative emissions. Further, such a policy intervention would impose higher costs on customers to support the build-out of additional clean generation—more and faster than would be developed otherwise (though we have not accounted for any potential policy cost that might be necessary to keep Calvert Cliffs operating).

Beyond the emissions impact, the loss of Calvert Cliffs would increase wholesale power prices in the region, creating moderately higher bills for Maryland's customers. Since most of the replacement generation would come from out of state, Maryland would become a significantly larger power importer than it already is, reducing in-state economic activity. This combination of effects would have substantial impacts on the Maryland economy in terms of economic output, GDP and jobs.

In our Reference Scenario, which assumes significant federal support for renewables and aggressive decarbonization of the region, the impact of Calvert Cliffs over the years 2025-2040 is to:

- Prevent about 4 million tons of CO2 emissions annually in the near term, and 56 million tons of cumulative emissions, with social cost of about $2.5 billion (NPV);
- Keep Maryland customer costs lower by an average of about $47 million per year, $410 million in present value;
- Keep Maryland's GDP higher by an average of over $600 million per year;
- Maintain about 4,760 jobs, including both direct and secondary employment effects.

In an alternate scenario without federal renewable support (and which thus decarbonizes less quickly, not exceeding states' RPS requirements), effects are qualitatively similar, though differ somewhat on quantitative metrics. Other variants on these scenarios found similar implications. In particular, a direct policy intervention to require that Calvert Cliffs be replaced by incremental renewables could mitigate the emissions impact somewhat, but only by increasing customer costs to fund the additional renewable generation. Existing nuclear power and renewable energy should be viewed as complements, not competitors or substitutes, in decarbonizing the grid. As Maryland and neighboring states move to decarbonize their economies, existing nuclear plants will play a crucial role in preventing backsliding on emissions.

Appendix

A. Summary of Scenario Assumptions

Assumption	Reference Scenario	Scenario B: Nuclear Loss Enables Renewables	Scenario C: No PTC Extension	Scenario D: Clean Energy Policy
Renewable Tax Credit Policy	Build Back Better tax credits for renewables ($25/MWh PTC for wind and solar, extended through study timeline)		Current Federal Tax Credits (Wind: $25/MWh PTC step down through 2026; Solar: 30% ITC step down to 10% in 2026)	
State RPS Goals	All existing state RPS mandates (*e.g.*, MD 50% RPS by 2030)	All existing state RPS mandates (*e.g.*, MD 50% RPS by 2030)	All existing state RPS mandates (*e.g.*, MD 50% RPS by 2030)	All existing state RPS mandates, plus MD replace CCNPP with renewables in 10 yrs (~70% by 2035)
Renewable Build Limits	Annual solar and wind build constraints limited to 3-5 GW/yr, based on historical and forecasted trends	Assume CCNPP retirement increases rate at which renewables can be added, to fully replace with solar and wind over 10 years	Annual solar and wind build constraints limited to 3-5 GW/yr, based on historical and forecasted trends	Annual solar and wind build constraints limited to 3-5 GW/yr, based on historical and forecasted trends
Load Forecast	Load based on PJM Load Forecast Report prepared by PJM Resource Adequacy Planning Department. Does not include aggressive electrification.			
Gas prices	Gas price forecast based on 5 years of forwards, grown at EIA growth rates (from 2021 Annual Energy Outlook)			

B. GridSIM Overview

GridSIM is Brattle's proprietary long-term electricity simulation and capacity expansion model. We developed GridSIM to analyze how clean energy policies and technological change will affect future market outcomes, particularly in high-renewable futures. For modeling PJM's electricity future, GridSIM excels over other capacity expansion models. Like other expansion models, it incorporates the basics of supply, demand transmission, capital costs, and environmental policies, and it identifies the cost-minimizing expansion plan, given capital and fixed costs and ongoing energy and ancillary services market dynamics. Unlike other expansion models:

- GridSIM models energy and ancillary service markets chronologically so storage can be scheduled and traditional generation can be committed to balance variable wind and solar profiles. Not only is this more realistic operationally, but it is also necessary for representing the value of each technology and developing a credible investment trajectory in a high-renewable future.
- GridSIM incorporates how ICAP accreditation of each type of variable wind and solar resource is likely to decline in the future with increasing penetration. It incorporates declining Effective Load-Carrying Capability (ELCC) curves, based on an offline analysis that accounts for correlated generation profiles and their coincidence with peak net loads. This, along with the energy and ancillary service value described above, enables GridSIM to project a more realistic build mix and prices.
- GridSIM simulates PJM's capacity market, also important for developing a reasonable expansion/retirement and capacity price outlook.
- Together, these features form the foundation for our entire modeling system to produce more realistic prices for energy, capacity, and RECs.

The graphic below illustrates GridSIM's structure, inputs and outputs.

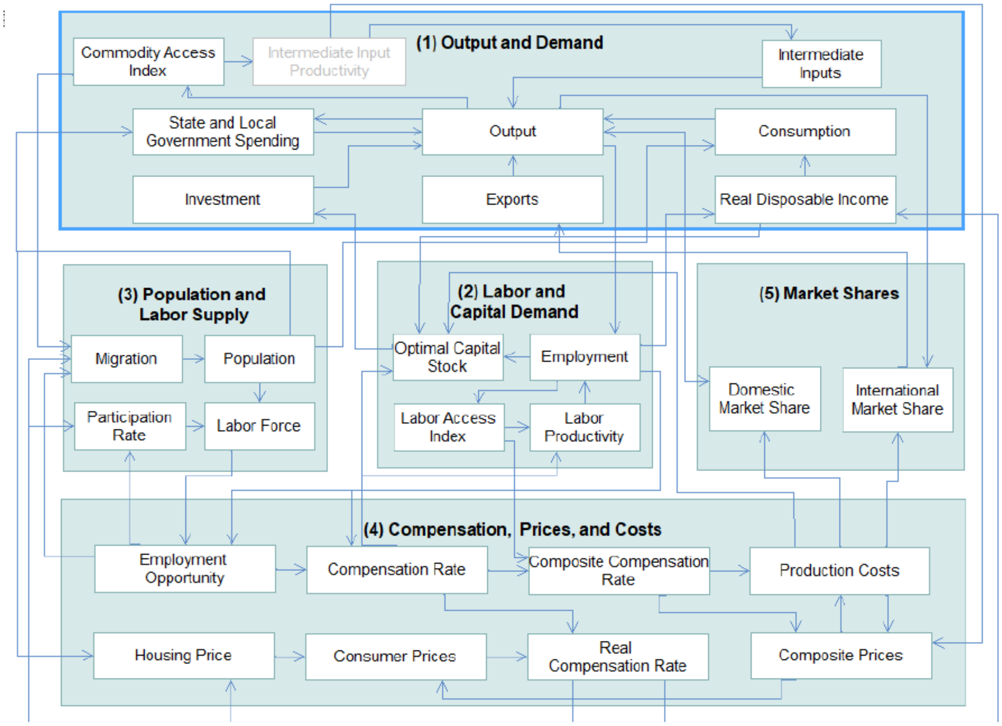
GRIDSIM MODELING FRAMEWORK

C. REMI Policy Insights Overview

We used the REMI Policy Insights (PI) model for our analysis. REMI has developed several macroeconomic models that are widely used in both public and private sectors. The summary below was provided by REMI. See www.remi.com for further information.

Policy Insight is a structural economic forecasting and policy analysis model. It integrates input-output, computable general equilibrium, econometric, and economic geography methodologies. The model is dynamic, with forecasts and simulations generated on an annual basis and behavioral responses to wage, price, and other economic factors.

The REMI model consists of thousands of simultaneous equations with a structure that is relatively straightforward. The exact number of equations used varies on the extent of the industry, demographic, demand, and other detail in the model. The overall structure of the model can be summarized in five major blocks: (1) Output and Demand, (2) Labor and Capital Demand, (3) Population and Labor Supply, (4) Compensation, Prices and Costs, and (5) Market Shares.



Block 1. Output and Demand

This block includes output, demand, consumption, investment, government spending, import, product access, and export concepts. For each industry, demand is determined by the amount of output, consumption, investment and capital demand on that industry. Consumption depends on real disposable income per capita, relative prices, differential income elasticities and population. Input productivity depends on access to inputs because the larger the choice set of inputs, the more likely that the input with specific characteristics required for the job will be formed. In the capital stock adjustment process, investment occurs to fill the difference between optimal and actual capital stock for residential, non-residential, and equipment investment. Government spending changes are determined by changes in the population.

Block 2. Labor and Capital Demand

The Labor and Capital Demand block includes the determination of labor productivity, labor intensity and the optimal capital stocks. Industry specific labor productivity depends on the availability of workers with differentiated skills for the occupations used in each industry. The occupational labor supply and commuting costs determine firms' access to a specialized labor force.

Labor intensity is determined by the cost of labor relative to the other factor inputs, capital and fuel. Demand for capital is driven by the optimal capital stock equation for both non-residential capital and equipment. Optimal capital stock for each industry depends on the relative cost of labor and capital, and the employment weighted by capital use for each industry. Employment in private industries is determined by the value added and employment per unit of value added in each industry.

Block 3. Population and Labor Supply

The Population and Labor Supply block includes detailed demographic information about the region. Population data is given for age and gender, with birth and survival rates for each group. The size and labor force participation rate of each group determines the labor supply. These participation rates respond to changes in employment relative to the potential labor force and to changes in the real after tax compensation rate. Migration includes retirement, military, international and economic migration. Economic migration is determined by the relative real after tax compensation rate, relative employment opportunity and consumer access to variety.

Block 4. Wages, Prices, and Costs

This block includes delivered prices, production costs, equipment cost, the consumption deflator, consumer prices, the price of housing, and the wage equation. Economic geography concepts account for the productivity and price effects of access to specialized labor, goods and services.

These prices measure the price of the industry output, taking into account the access to production locations. This access is important due to the specialization of production that takes place within each industry, and because transportation and transaction costs of distance are significant. Composite prices for each industry are then calculated based on the production costs of supplying regions, the effective distance to these regions, and the index of access to the variety of output in the industry relative to the access by other uses of the product.

The cost of production for each industry is determined by cost of labor, capital, fuel and intermediate inputs. Labor costs reflect a productivity adjustment to account for access to specialized labor, as well as underlying compensation rates. Capital costs include costs of non-residential structures and equipment, while fuel costs incorporate electricity, natural gas and residential fuels.

The consumption deflator converts industry prices to prices for consumption commodities. For potential migrants, the consumer price is additionally calculated to include housing prices. Housing price changes from their initial level depend on changes in income and population density.

Compensation changes are due to changes in labor demand and supply conditions and changes in the national compensation rate. Changes in employment opportunities relative to the labor force and occupational demand change determine compensation rates by industry.

Block 5. Market Shares

The Market Shares equations measure the proportion of local and export markets that are captured by each industry. These depend on relative production costs, the estimated price elasticity of demand, and effective distance between the home region and each of the other regions. The change in share of a specific area in any region depends on the changes in its delivered price and the quantity it produces compared with the same factors for competitors in that market. The share of local and external markets then drives the exports from and imports to the home economy.

The Labor and Capital Demand block includes labor intensity and productivity as well as demand for labor and capital. Labor force participation rate and migration equations are in the Population and Labor Supply block. The Wages, Prices, and Costs block includes composite prices, determinants of production costs, the consumption price deflator, housing prices, and the wage equations. The proportion of local, inter-regional and export markets captured by each region is included in the Market Shares block.