Clean Portfolio Replacement at Tennessee Valley Authority

Economic and Emissions Benefits for TVA Customers

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EXECUTIVE SUMMARY

The Tennessee Valley Authority (TVA), once one of the largest owners and operators of coal-fired capacity in the United States, announced last year its commitment to achieving net-zero emissions of carbon dioxide (CO_2) by 2050. With more than 33 gigawatts (GW) of capacity, TVA is the sixth largest owner of electric generating capacity in the country and is one of many to have publicly committed to greenhouse gas emission reductions.[1] TVA has also set interim targets of 70 percent emission reductions by 2030 and 80 percent reductions by 2035, and it has stated that these targets are attainable using technologies that exist today. To bolster utility commitments, President Biden has set a more ambitious target date of 2035 for full electric sector decarbonization, underscoring the need for TVA to begin making tangible and near-term progress towards net-zero. While TVA's public support for decarbonization is an important step, our modeling demonstrates that achieving these targets will require a steep departure from the utility's "business-as-usual" approach.

TVA's strategy for meeting these interim goals would retire existing coal-fired capacity and replace it, at least in part, with new gas-fired generation. In the context of TVA's net-zero emissions goal—and given declining costs for solar, wind, and storage resources—this strategy is risky. Any new gas-fired capacity constructed in the next decade is likely to result in stranded assets, in which a generator with remaining depreciable life has been rendered uneconomic to customers.

Sierra Club retained Synapse Energy Economics, Inc. (Synapse) to model TVA's system and examine the resource options available to TVA for replacing retiring coal-fired generators. Synapse used state-of-the-art electric simulation software to determine the cost to ratepayers of replacing coal generators with new gas-fired resources relative to scenarios that eschew new gas builds in favor of resource portfolios with increased volumes of renewables, storage, and energy efficiency. We modeled three resource portfolios: (1) *Business-As-Usual (BAU),* in which retiring coal is replaced largely with new gas-fired capacity; (2) *Solar/Storage Replacement*, in which retiring coal is replaced with new solar and battery storage resources; and (3) *Clean Portfolio Replacement*, in which retiring coal is replaced with a portfolio of energy efficiency, wind, solar, and storage resources.

The Synapse modeling resulted in the following overarching findings:

- Replacement portfolios that rely exclusively on renewables and storage will achieve the same level of reliability as a replacement portfolio that consists largely of gas-fired combined cycle and combustion turbine replacement capacity.

[1] IHS Markit. May 19, 2021. "Net-zero pledges by US utilities spotlight different timelines, benchmarks." *Clean Energy News*. Available at: https://cleanenergynews.ihsmarkit.com/research-analysis/netzero-pledges-by-us-utilities-spotlight-different-timelines-.html.

- Both replacement portfolios result in customer savings relative to the *BAU* scenario. The *Solar/Storage Replacement* scenario saves an estimated $6.4 billion from 2022 to 2042 compared to the *BAU* scenario, while the *Clean Portfolio Replacement* scenario saves $9.4 billion.
- A resource portfolio that avoids investments in new gas capacity results in greater emissions reductions over the next 20 years and puts TVA on a more linear path toward net-zero CO_2 emissions in 2050.

The following two tables present a summary of the Synapse modeling results, first through 2030 and then through 2042. Table 1 (through 2030) and Table 2 (through 2042) each include various key metrics associated with our three scenarios, including annual emissions, capacity by resource type, and net present value of revenue requirements of each portfolio.

Table 1. Summary of Synapse modeling results (2022–2030)

Results (2022–2030)	Business-As-Usual	Solar/Storage Replacement	Clean Portfolio Replacement
2030 NPV With EE ($B)	$43.8	$41.3	$41.0
Annual CO2 Emissions (million tons)	35.0	19.8	17.2
Cumulative CO2 Emissions (million tons)	383.5	339.8	323.0
Utility Solar (MW)	2,158	14,018	8,118
Distributed Solar (MW)	1,232	1,712	2,152
Onshore Wind (MW)	1,318	1,318	3,718
Utility-scale Storage (MW)	799	6,686	3,643
Distributed Storage (MW)	2	28	184
Gas (MW)	14,500	10,981	10,981
Coal (MW)	2,808	854	854

Table 2. Summary of Synapse Modeling Results (2022–2042)

Results (2022–2042)	Business-As-Usual	Solar/Storage Replacement	Clean Portfolio Replacement
2042 NPV with Energy Efficiency ($B)	$78.2	$71.7	$68.7
Annual CO_2 Emissions (million tons)	26.2	5.0	6.1
Cumulative CO_2 Emissions (million tons)	742.9	465.7	441.2
Utility Solar (MW)	3,933	29,873	8,573
Distributed Solar (MW)	2,119	3,221	4,462
Onshore Wind (MW)	2	2	5,402
Utility-Scale Storage (MW)	1,721	31,906	3,565
Distributed Storage (MW)	2	134	641
Gas (MW)	18,207	10,981	10,981
Coal (MW)	0	0	0

As the Synapse modeling shows, replacing fossil generation with zero-carbon generation leads to dramatic emission reductions on TVA's system. At the same time, clean energy portfolios cost less than the business-as-usual approach that leans on fossil fuels. One of the most important findings of this modeling exercise is that there is no single resource that on its own will help TVA achieve decarbonization. Rather, an "all-of-the-above" clean energy approach that harnesses the full slate of available demand-side and supply-side zero-carbon resources is the cheapest and most reliable way to reach TVA's emission reduction targets. In addition, as the separate results through 2030 and 2042 show, our modeling demonstrates that clean energy resources offer cost savings both mid-term and long-term. This finding supports resource planning that procures solar, wind, storage, and energy efficiency as early as possible in the 2020s.

TVA has a viable pathway to steep emission reductions, but it requires TVA to move decisively to retire existing coal, minimize reliance on new gas, and commit to increased volumes of renewables, storage, and demand-side resources. TVA serves "the people of the Tennessee Valley through its work in three areas: Energy, the Environment and Economic Development." Our modeling results demonstrate that TVA can pursue a portfolio of clean energy resources that maintains reliability, reduces costs, benefits the environment, and supports job creation and new investment across TVA's footprint.

1. INTRODUCTION

The Tennessee Valley Authority (TVA) is a federally owned electric utility and the largest provider of public power in the United States. It produces electricity for 10 million customers in nearly all of Tennessee, as well as smaller portions of several surrounding states.[2] TVA was founded in 1933 and has a stated mission of (1) delivering low-cost, reliable, and clean energy, (2) protecting and preserving public lands, (3) maintaining air and water quality, and (4) delivering jobs and capital investment across the region.[3]

Phasing out fossil fuels in its generating portfolio is perhaps the most important way for TVA to meet these stated goals. The utility targeted carbon dioxide emissions (CO_2) reductions of 70 percent by 2030 relative to 2005 levels, 80 percent by 2035,[4] and net zero by 2050.[5] To date, TVA has achieved a 63 percent reduction in carbon emissions relative to a 2005 base-year,[6] largely via the retirement of more than half its coal fleet.[7] TVA's Board of Directors has also approved the retirement of an additional 865 MW of coal capacity at the Bull Run unit no later than December 2023.[8]

Continued progress toward TVA's emission reduction goals requires the retirement of the utility's remaining coal capacity at Cumberland, Shawnee, Gallatin, and Kingston; however, retirement of these units leaves TVA with a capacity and energy deficit that must be met with other resources.[9] TVA's decisions around its future mix of replacement resources will not only determine its path toward net-zero CO_2 emissions, but also its ability to achieve the various components of its stated mission. The utility is currently preparing Environmental Impact Statements (EIS) that evaluate the retirement and replacement of the Cumberland and Kingston plants. TVA is considering three alternatives, each of which would replace the plants with 1,450 MW of new generation: Option A constructs a new combined cycle plant at the existing sites; Option B constructs combustion turbines at the existing sites; and Option C constructs solar and storage facilities primarily at alternate locations.

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[2] Tennessee Valley Authority. 2022. *About TVA*. Available at: https://www.tva.com/about-tva.

[3] Tennessee Valley Authority. 2021. *Leadership & Innovation on a Path to Net-Zero*. Available at: https://www.tva.com/environment/environmental-stewardship/sustainability/carbon-report.

[4] Note that the Biden administration's climate goal is decarbonization of the electric sector by 2035; thus, TVA's targeted reductions are inconsistent with that goal.

[5] Id.

[6] Id.

[7] Retiring units include John Sevier (2012 and 2014), Johnsonville (2013), Widows Creek (2015), Colbert (2016), Allen (2018), and Paradise (2020).

[8] Tennessee Valley Authority. 2022. *Bull Run Plant*. Available at: https://www.tva.com/energy/our-power-system/coal/bull-run-fossil-plant.

[9] The magnitude of that deficit depends directly on TVA's projected electric demand. If one or more member power company customers were to leave the TVA system, fewer megawatts of replacement capacity would be needed to replace retiring plants.

Put simply, TVA's first two options, which would entail the construction of almost 3,000 MW of new gas-fired capacity, are inconsistent with TVA's mission to provide low-cost clean energy while minimizing impacts to land, air, and water. As the utility moves toward deeper CO_2 emissions reductions, it will rely less and less on its gas-fired generators. These assets are typically constructed with a projected operating life of 30 to 40 years; thus, gas units constructed in the next decade and retired in or before 2050 would be considered "stranded assets," which provide no economic benefit and yet are not fully depreciated.

Sierra Club retained Synapse to model three scenarios that examined different sets of replacement resource portfolios. Synapse then assessed whether the resources considered by TVA as part of its Environmental Impact Statements are consistent with the utility's own carbon reduction goals and also reflect the most cost-effective portfolios from the view of TVA customers. By accounting for the rapid decline in both current and projected renewable costs, our analysis updates the modeling done by TVA in its 2019 Integrated Resource Plan (IRP) and presents a more current view of resource options available as replacements for retiring coal.

Modeling new gas assets in Colorado

In its most recent Electric Resource Plan filed with the Colorado Public Utilities Commission, Tri-State Generation and Transmission Association, Inc. restricted its capacity optimization model from adding new gas capacity prior to 2030. The intent of this constraint was to avoid investments in assets that might potentially be stranded, while giving nascent zero-carbon, dispatchable resources time to mature.

In this study, Synapse used the EnCompass capacity optimization and production cost model to model alternative resource portfolios to replace retiring coal. Synapse modeled three scenarios: a *Business-As-Usual* (*BAU)* scenario that attempts to mirror the *Current Outlook* scenario/*Base Case* strategy presented in the 2019 TVA IRP and relies largely on new gas capacity to replace retiring coal,[10] a *Solar/Storage Replacement* scenario that avoids new gas and offers only solar and storage replacement resources, and a *Clean Portfolio Replacement* scenario that includes higher energy efficiency, higher distributed generation, and onshore wind alongside solar and storage.

We describe the modeled scenarios in more detail in the next sections, along with the input assumptions that differentiate those scenarios. For each scenario, we present capacity additions, generation, and CO_2 emissions, along with a comparison of the revenue requirements associated with each scenario. Finally, Appendix A provides additional detail on input assumptions.

[10] The *Current Outlook* scenario represents TVA's current forecasts for key uncertainties and reflects modest economic growth. The *Base Case* strategy represents current assumptions for resource costs.

2. Scenario Analysis

Synapse used the EnCompass capacity expansion and production cost model, licensed from Anchor Power Solutions, to examine three scenarios over a 20-year analysis period from 2022 to 2042.[11] The EnCompass model uses information about forecasted peak and energy demand along with the capital and operating costs of existing and new resources to produce an optimal, least-cost resource portfolio and generation mix. Specifically, the model does the following: (1) builds new resources when necessary to meet peak demand, plus a required reserve margin; (2) simulates economic dispatch of the various generating resources; and (3) calculates the total cost (capital and operating) of the respective resource portfolio options.

Synapse modeled three different scenarios, which vary the type of generating resource offered to the EnCompass model to replace TVA's retiring coal units. The *BAU* scenario attempts to mirror TVA's 2019 IRP, in which the bulk of the resource additions over the analysis period come from new gas-fired capacity in the form of new combined cycle units and combustion turbines. The *Solar/Storage Replacement* scenario adds new utility-scale solar and battery storage resources to replace retiring coal generators. In the *Clean Portfolio Replacement* scenario, a portfolio of increased energy efficiency, distributed resources, solar, wind, and battery storage is added to TVA's system over the duration of the analysis period.

Business-As-Usual

The Synapse modeled scenarios include input assumptions that come directly from TVA and various publicly available data sources. Specifically, the *BAU* scenario assumes the following:

- **Demand:** Reference peak load and annual energy from TVA's 2019 IRP.
- **Reserve margin:** A summer reserve margin of 17 percent and a winter reserve margin of 25 percent.
- **Coal retirements:** Retirement of Kingston and Cumberland no later than December 31, 2028. Retirement of Shawnee and Gallatin no later than December 31, 2035.
- **Coal unit costs:** Annual capital expenditures were added for each of the coal units based on a regression equation developed by Sargent & Lundy for the U.S. Energy Information Administration's (EIA) *2019 Annual Energy Outlook*.
- **New gas resources:** Resource capital and operating costs for new combined cycle and combustion turbines from the U.S. EIA's *Annual Energy Outlook*.

[11] Capacity and production cost models like EnCompass are used to simulate future utility operations under different scenarios to help determine the best strategy for minimizing costs and risks while meeting specific reliability and transmission constraints.

- **Existing gas resources:** Existing gas resources are scheduled to retire according to TVA's projections in the 2019 IRP and are allowed to be selected for endogenous retirement by the EnCompass model.

- **Biomass resources:** New biomass resources in this analysis follow projections from the U.S. EIA's projections for Municipal Solid Waste from the *Annual Energy Outlook*.

- **New renewable resources**: Standalone solar and standalone battery storage costs from the National Renewable Energy Laboratory's *Annual Technology Baseline 2021*, with solar modeled as a power purchase agreement (PPA) and storage modeled as a utility-owned asset.[12] Integration costs for new resources match the 2019 IRP. New solar and storage resources are capped at limits based on the cumulative total of new solar and storage additions in TVA's 2019 IRP.

- **Fuel prices:** Coal price forecast from TVA's 2019 IRP. A gas price forecast that consists of NYMEX futures (short-term) and prices from the *Annual Energy Outlook* 2021 Reference case (long-term).[13]

- **Firm capacity values:** Unless otherwise noted, firm capacity values for new renewables and storage match those used in TVA's 2019 IRP:
    - Solar: 68 percent for 1-axis solar and 50 percent for fixed solar in the summer, 1 percent for each in the winter.[14]
    - Wind: 14 percent in the summer, 38 percent in the winter.
    - Storage: A year-round value of 95 percent.

- **Imports:** Synapse modeled TVA's service territory on a standalone basis.

- **CO_2 price:** A price on CO_2 emissions of $5/ton (nominal) starting in 2025 and escalating by inflation. This emissions price matches the CO_2 price used in the TVA IRP's Growth scenario.[15]

- **Behind-the-meter (BTM) resources:** Synapse used three distributed solar/storage trajectories, each sourced from TVA's 2019 IRP.[16] The *BAU* uses TVA's base BTM forecast, resulting in 2,119 MW of BTM solar by 2042.

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[12] National Renewable Energy Laboratory. *2021 Annual Technology Baseline*. Available at: https://atb.nrel.gov/electricity/2021/data.

[13] As described in Appendix A, the resulting long-term Synapse gas price forecast is lower than TVA's 2019 IRP forecast.

[14] The summer firm capacity values for solar match TVA's 2019 IRP exactly. Solar resources are given a firm capacity value of 0 percent in the winter in the IRP, but this was adjusted to 1 percent in our modeling to match the value used in recent IRPs by Duke Energy Carolinas and Duke Energy Progress.

[15] TVA IRP, Figure 6-6.

[16] TVA IRP, Figures C-8 and C-9.

Solar/Storage Replacement

The *Solar/Storage Replacement* scenario includes the input assumptions listed above for the BAU, with the following changes:

- **Coal retirements:** Instead of hardcoded retirement dates, the model is allowed to select early retirement of coal units.
- **No new gas:** The model is prevented from selecting new gas resources.
- **New renewable resources**: While standalone solar and standalone battery storage costs are the same as in the BAU, the annual limits on new solar and new storage are removed.
- **BTM resources:** We used the moderate BTM solar and storage forecast in TVA's IRP, leading to 3,221 MW of BTM solar and 132 MW of BTM storage by 2042.

Clean Portfolio Replacement

The *Clean Portfolio Replacement* scenario includes the input assumptions listed above for the *BAU* and *Solar/Storage Replacement* scenarios, with the following adjustments:

- **Energy efficiency:** Additional energy efficiency savings that increase by 0.10 percent per year until they reach 1.0 percent in 2035, and then are held constant. This results in peak demand savings of 2,882 MW and annual energy savings of 17,653 GWh by 2042.
- **New renewable resources**: The model is allowed to select new wind resources, available via PPA from within TVA, and from the Southwest Power Pool (SPP) and Midcontinent Independent System Operator (MISO). These wind PPA costs are based on the National Renewable Energy Laboratory's Annual Technology Baseline and include integration costs and, in the case of wind from SPP and MISO, wheeling costs.
- **BTM resources:** The highest BTM solar and storage forecast in TVA's IRP, leading to 4,462 MW of BTM solar and 640 MW of BTM storage by 2042.

We provide additional details on input assumptions and modeling methodology in Appendix A.

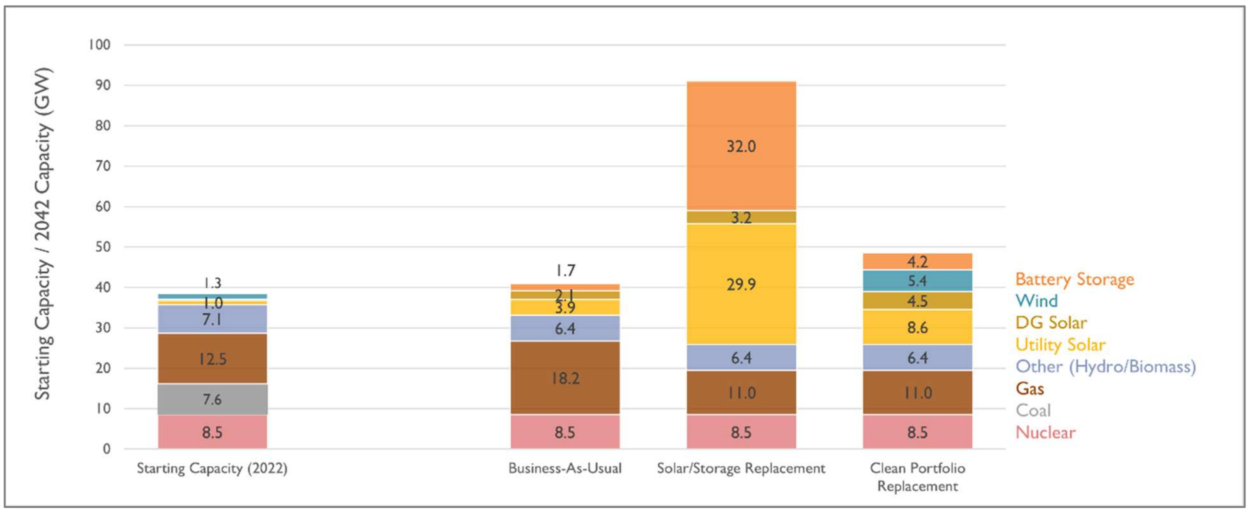
3. ELECTRIC SECTOR MODELING RESULTS

Synapse used the EnCompass model to produce optimal, least-cost resource portfolios under different scenarios based on the detailed capacity expansion and electric system dispatch modeling of TVA's service territory. This section describes the results of that modeling with respect to the changing capacity mix and resulting electricity generation in the three modeled scenarios.

3.1. Capacity Results

TVA's capacity mix in 2022 is heavily dependent on fossil-fueled generating units—coal and gas make up over 52 percent of the resource portfolio. Nuclear makes up an additional 22 percent, and a combination of hydro and biomass makes up another 18 percent. This means that TVA starts each of the scenarios with just under 8 percent of nameplate capacity coming from utility solar, distributed solar, or onshore wind resources. Renewable capacity grows over the duration of the analysis period in all scenarios, including the *BAU*. Figure 1 illustrates the nameplate capacity for each scenario by 2042. Note that *BAU* and *Solar/Storage Replacement* are from scenarios with the same load forecast, while the *Clean Portfolio Replacement* scenario is based on a lower load forecast as a result of increased energy efficiency savings.

Figure 1. Nameplate capacity in 2042



The large amount of new capacity built in the *Solar/Storage Replacement* scenario demonstrates the importance of taking a full "all-of-the-above" approach to clean energy procurement. The *Solar/Storage Replacement* scenario prohibits new gas while only allowing solar and storage to be selected as new resources. Due to the low winter capacity value of solar used for the purposes of this analysis (1 percent compared to between 50 and 68 percent in the summer) and the lack of supply-side candidate resources in this scenario, the model is forced to build large amounts of solar and storage to meet the winter reserve margin. In contrast, the *Clean Portfolio Replacement* scenario allows the model to benefit from a lower load forecast due to energy efficiency and also includes a full portfolio of clean energy candidate resources (wind, solar, and storage). This allows the model to build less new capacity when compared to the *Solar/Storage Replacement* scenario while still meeting summer and winter reserve margins.

A second noticeable difference between the *BAU* and the Synapse alternative scenarios is the volume of gas on the system in 2042. All scenarios include some planned gas retirements but keep the bulk of the existing gas units on the system. The *BAU* scenario builds 7 GW of new gas, leading to an additional 7.2 GW of gas in 2042 in comparison with the *Solar/Storage Replacement* and *Clean Portfolio Replacement* scenarios.

Compared to the BAU scenario, the Synapse alternative scenarios avoid new gas while maintaining reliability due to additional solar and storage builds in the *Solar/Storage Replacement* scenario and additional solar, wind, storage, and energy efficiency measures in the *Clean Portfolio Replacement* scenario. In the alternative *Solar/Storage Replacement* scenario, TVA's system adds 28.9 GW of new utility solar, 3.2 GW of distributed solar, 31.9 GW of utility-scale storage, and 0.1 GW of BTM storage. In the *Clean Portfolio Replacement* scenario, TVA adds 7.6 GW of utility solar, 4.5 GW of distributed solar, 3.5 GW of utility-scale storage, 0.6 GW of BTM storage, and 5.4 GW of onshore wind.[17] All scenarios include planned retirements for existing units (gas, wind, coal, etc.) that are consistent with the 2019 IRP.

Figure 2 shows annual capacity additions in the *BAU* scenario. Approximately 3.5 GW of new gas is added in 2029 to replace retiring the retiring coal units at Cumberland and Kingston. Additional new gas is added to the system in 2036, 2037, and 2038, with new gas builds totaling 7.0 GW by 2042. To compare the cost delta between new gas resources in the *BAU* scenario and renewable alternatives in the other scenarios, we capped new utility solar procurements in the BAU scenario at 160 MW per year. The model selected the full amount of new utility solar in every single year, showing the importance and affordability of solar as a future resource option. Battery storage was similarly capped at 90 MW per year, with the model selecting the full amount of available storage in almost every year as well. In total, the BAU scenario adds 1.8 GW of utility-scale storage.

[17] In Figure 1, utility-scale storage and distributed (or BTM) storage are combined into a single category given the low amount of distributed storage included. Distributed solar, by contrast, is displayed as a stand-alone category separate from the utility-scale solar category. All distributed solar and storage forecasts match the low, medium, and high BTM scenarios developed by TVA in the 2019 IRP.

Figure 2. Nameplate capacity by year, *BAU* scenario

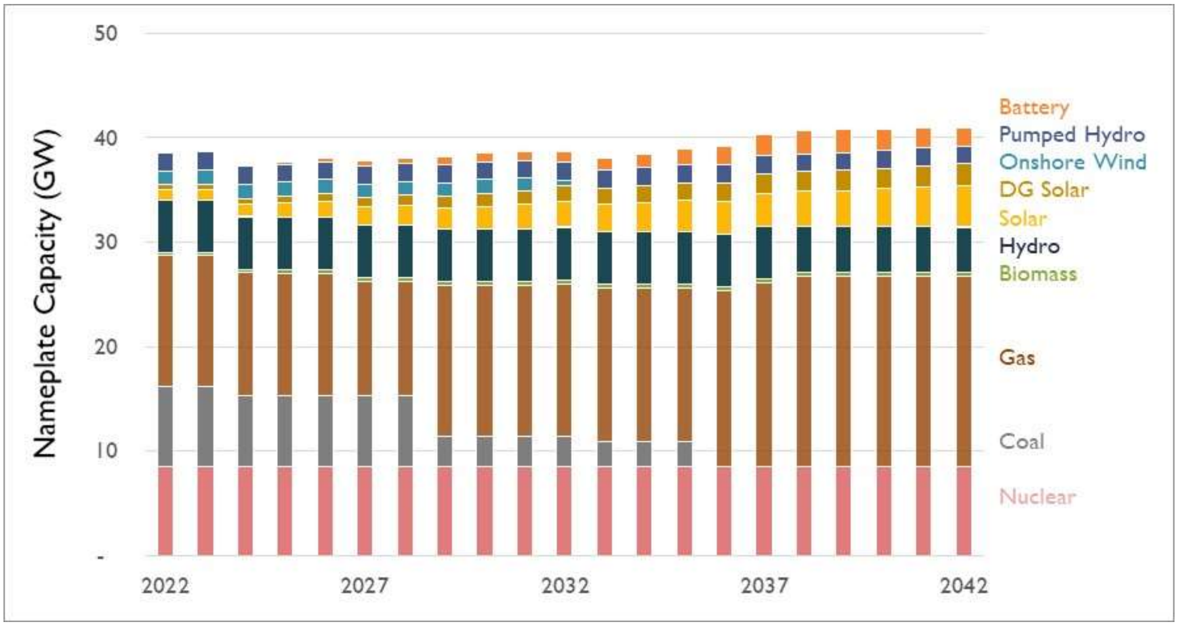


Figure 3 shows capacity by year in the *Solar/Storage Replacement* scenario. Note the difference in scale on the y-axis between this figure and Figure 2. In this scenario, the model is allowed to select unlimited amounts of solar and storage but is prevented from selecting new onshore wind. Given the higher winter reserve margin and the extremely low seasonal capacity value given to solar resources, there is a substantial amount of new solar and storage resources needed to maintain reliability following the retirements of TVA's coal units. Specifically, maintaining the 25 percent winter reserve margin in the month of January necessitates the dramatic overbuild of 4-hour duration storage resources in the later years of the analysis period.

Endogenous coal unit retirements occur in the following years: two units from Gallatin (456 MW) and six units from Shawnee (828 MW) in 2023 and then an additional two Gallatin units (532 MW) and one Shawnee unit (138 MW) in 2024, before the planned retirements of Kingston and Cumberland in 2028. In this scenario, all coal retires by 2028 with the exception of the Red Hills PPA (440 MW) and three units at the Shawnee plant (414 MW). The Red Hills PPA expires in 2032 and the remaining Shawnee units are retired in 2035.

Figure 3. Nameplate capacity by year, *Solar/Storage Replacement*

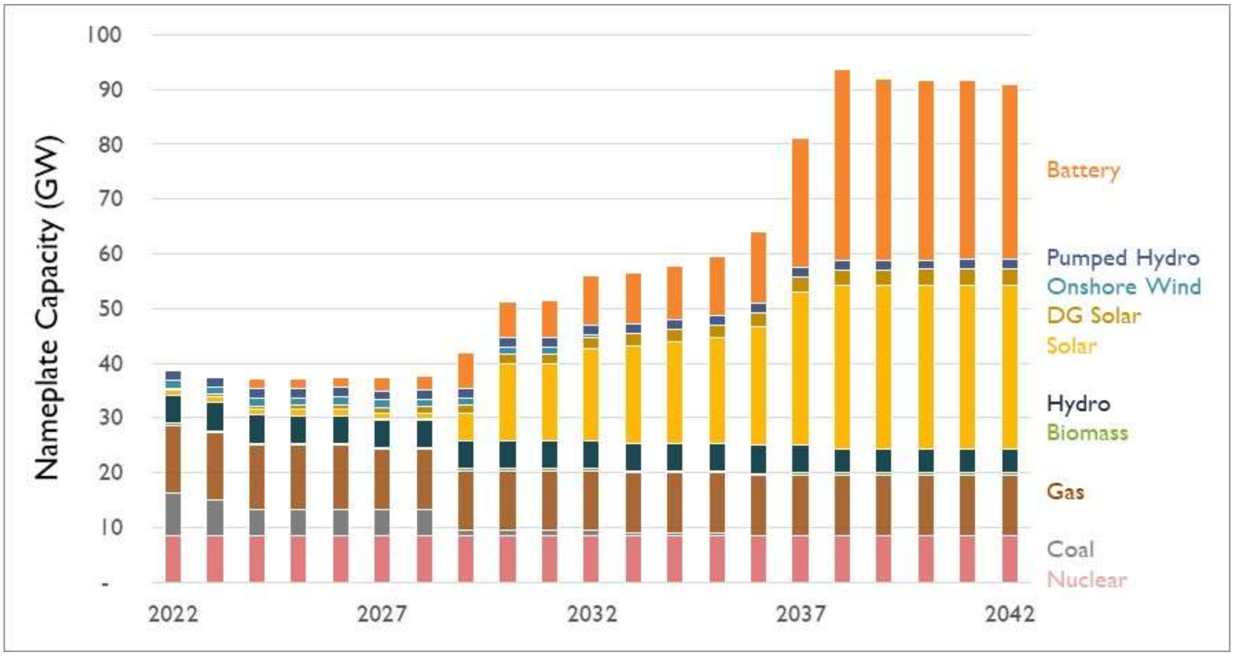
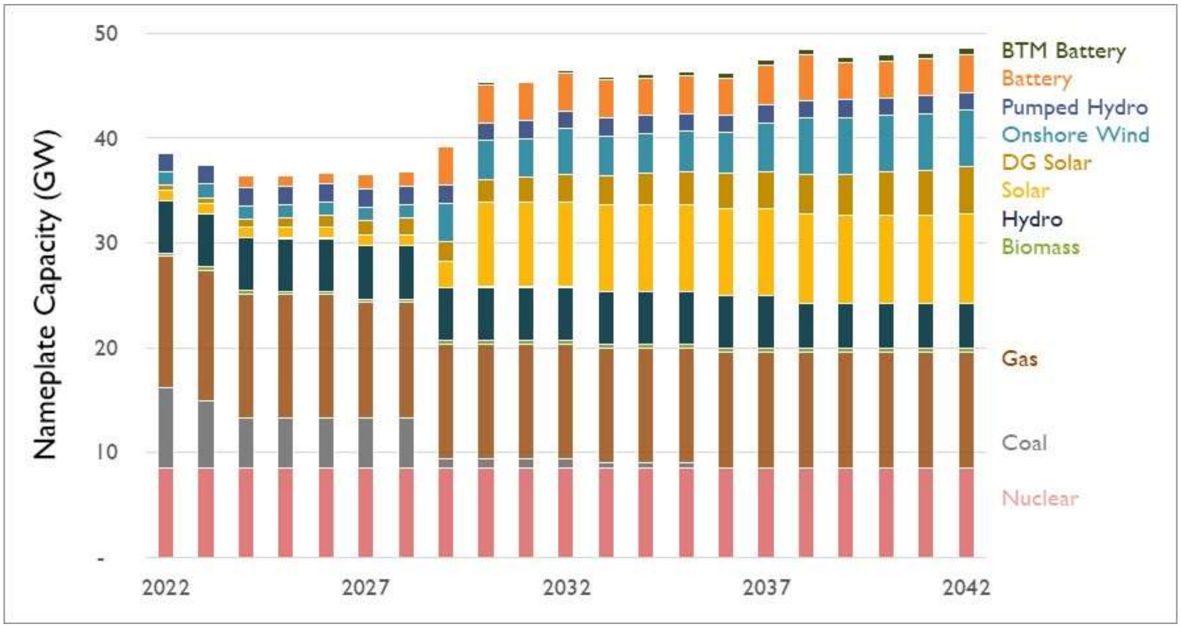


Figure 4 below shows capacity by year in the *Clean Portfolio Replacement* scenario, which includes additional energy efficiency and allows the model to select new wind resources. The increased energy efficiency included in this scenario reduces peak load by 2,882 MW in 2042, meaning that TVA needs less firm capacity to meet system peak load than in the other two scenarios. This is particularly important given the relative capacity contributions of different resources. Coal- and gas-fired generators are fully dispatchable in a given hour, subject to their specific operating constraints, and are typically assumed to contribute 90 to 100 percent of their capacity toward the utility's required reserve margin. Renewable generators operate intermittently and thus a smaller percentage of their nameplate capacity is counted as firm capacity and contributes to reserves. This firm capacity rating often decreases as penetrations increase.[18] The 2,882 MW decrease in peak load that is attributable to increased energy efficiency measures would allow TVA to avoid investment in nearly 3 GW of replacement gas resources or would allow it to avoid investment in 6 GW of replacement solar (assuming a 50 percent firm capacity rating). Given that these supply-side resources are often more expensive than energy efficiency programs, this results in savings to TVA customers. More information on the firm capacity values and energy efficiency assumptions used in our modeling is available in Appendix A.

[18] Because the Synapse assumptions attempt to align with the TVA 2019 IRP as much as possible, we model a constant capacity contribution for wind, solar, and battery storage resources. At high levels of renewable penetrations, modeling will shift toward a methodology that determines capacity credit using an Effective Load Carrying Capability (ELCC) methodology, in which the firm capacity value of a resource declines as its penetrations increase.

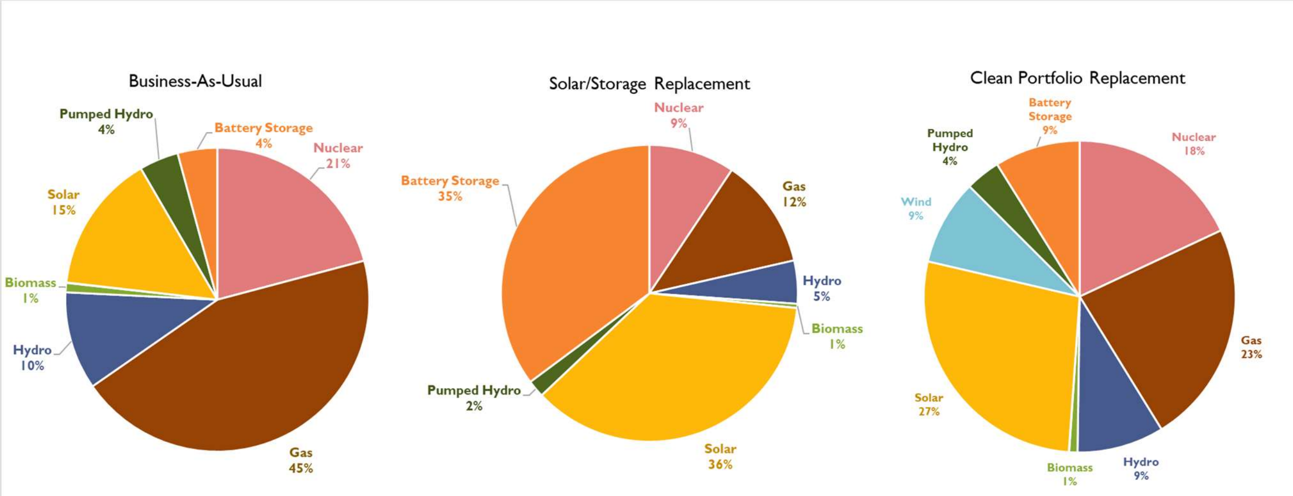
Figure 4. Nameplate capacity by year, *Clean Portfolio Replacement* scenario



As shown in Figure 4, the *Clean Portfolio Replacement* scenario does not include coal units as economic resources and removes them from the system ahead of schedule. In fact, the *Clean Portfolio Replacement* scenario retires the same coal units in the same years as the *Solar/Storage Replacement* scenario: a total of 1,284 MW from units at Gallatin and Shawnee in 2023, and an additional 670 MW from those same plants in 2024. Kingston and Cumberland retire as planned in 2028, and TVA is completely coal-free in both scenarios by 2035 with the retirement of the final 414 MW at Shawnee. The results of the *Clean Portfolio Replacement* scenario demonstrate that TVA can meet system demand with a portfolio of new solar, wind, and storage resources.

Figure 5 compares capacity by fuel type for each of the three scenarios, as a percent of total capacity, in the final year of the analysis period.

Figure 5. Capacity mix by resource type, as a percent of total, 2042



3.2. Generation Results

Annual generation for specific scenarios is shown in Figure 6 through Figure 8. From a generation perspective, the three scenarios modeled by Synapse portray strikingly different energy futures for TVA's system.

In the *BAU* scenario, shown in Figure 6, generation from coal declines based on TVA's current schedule for coal retirements. New gas capacity is the primary replacement resource, and as a result, gas generation increases from approximately 26 percent of total generation to nearly 38 percent in the BAU between 2022 and 2042.

Figure 6. Generation by year, *BAU* scenario

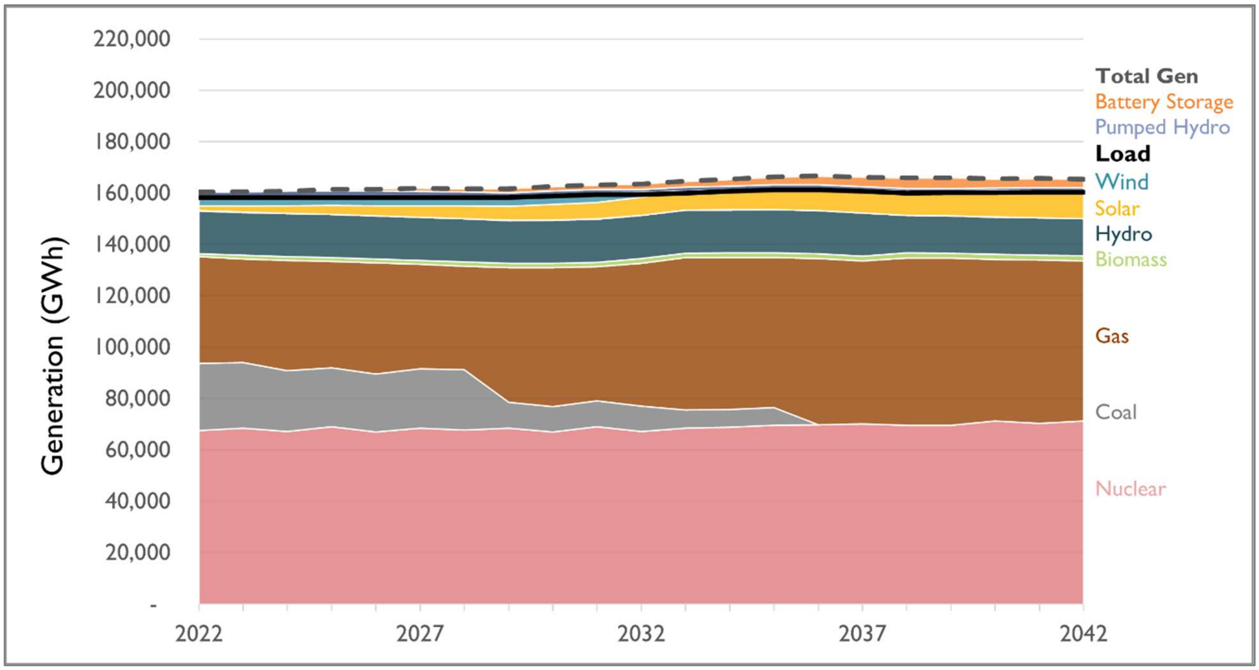
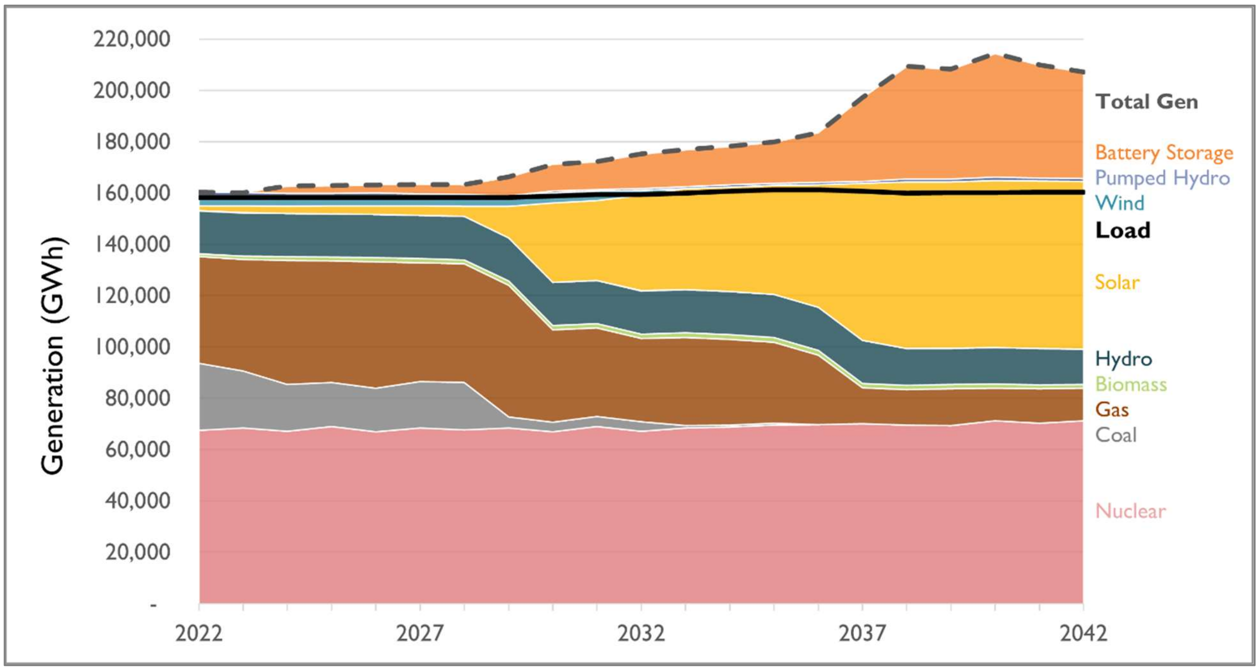


Figure 7 shows annual generation under the *Solar/Storage Replacement* scenario. Unlike the *BAU* scenario, the model is allowed to endogenously retire coal units as more economic resources join the system. This means that coal generation decreases in the late 2020s when compared to the BAU scenario and is replaced with solar PPAs and sizable battery storage builds. The *Solar/Storage Replacement* scenario is thus notable for the increase in battery storage dispatch, which plays an important role in integrating renewables and meeting demand throughout the study period. The release of energy from battery storage is shown above the load line, as the batteries store energy in hours in which there is a surplus and discharges that energy in hours in which it is needed. A portion of the generation below the load line is not used to meet demand in the hour in which it is generated, but rather it is stored in the batteries and dispatched in subsequent hours. In this way, the battery storage "firms" the solar resource.

Figure 7. Generation by year, *Solar/Storage Replacement* scenario

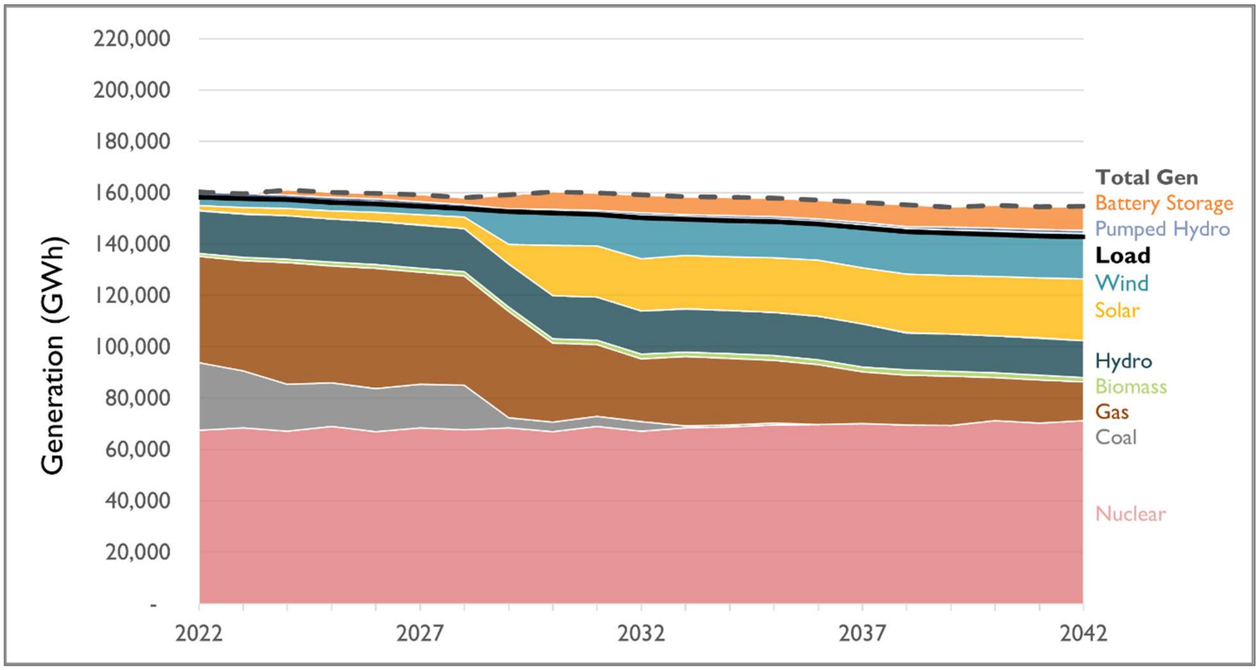


The *Clean Portfolio Replacement* scenario differs from the *Solar/Storage Replacement* scenario in two important ways. First, *Clean Portfolio Replacement* is the only scenario in which the model is allowed to select wind PPAs as a resource option, resulting in onshore wind making up 11.5 percent of TVA's generation mix by 2042. The *Clean Portfolio Replacement* scenario also has more ambitious energy efficiency targets. This effect can be seen when we compare Figure 6 and Figure 7 with Figure 8.

In the *BAU* and *Solar/Storage Replacement* scenarios, the annual energy demand, shown as the black line labeled "Load," remains relatively flat at approximately 160,000 GWh throughout the modeling period. By contrast, early and sustained investment in energy efficiency means that load is reduced to just over 142,000 GWh by 2042 in the *Clean Portfolio Replacement* scenario. Avoidance of the need for additional energy generation through more cost-effective energy efficiency saves money for TVA customers. Our energy efficiency assumptions are described in more detail in Appendix A.

In the *Clean Portfolio Replacement* scenario, both solar PPAs and wind PPAs emerge as preferred resource options for the model and increase from a combined 3.6 percent of generation in 2022 to a combined 27 percent in 2042.

Figure 8. Generation by year, *Clean Portfolio Replacement* scenario



While transmission planning is beyond the scope of this report, the success of the *Clean Portfolio Replacement* scenario in reducing costs and emissions while maintaining reliability stems in large part from the availability of wind resources from projects located in the SPP and MISO regions. Accessing these resources will require proactive transmission planning that connects wind-rich resource areas with TVA's load centers. A series of recent studies from the Energy Systems Integration Group (ESIG), Grid Strategies, the Brattle Group, and National Renewable Energy Laboratories have emphasized the need to build transmission in a way that unlocks renewable resources and improves reliability for high renewable systems by expanding the geographic diversity of energy sources.[19] Our modeling supports

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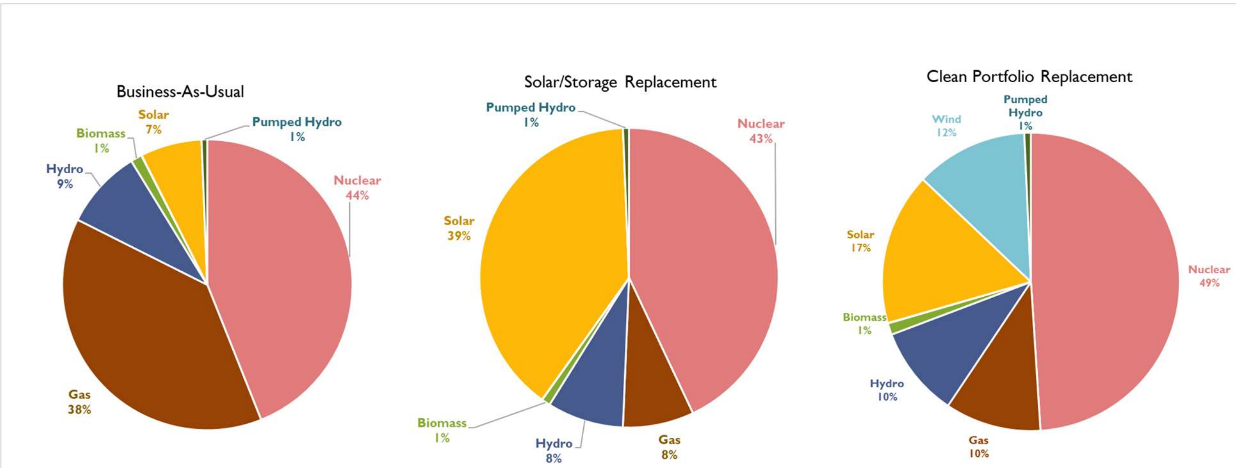
[19] Energy Systems Integration Group. February 2022. "Design Study Requirements for a U.S. Macrogrid," available at: https://www.esig.energy/wp-content/uploads/2022/02/ESIG-Design-Studies-for-US-Macrogrid-2022.pdf; Grid Strategies and the Brattle Group. October 2021. "Transmission Planning for the 21st Century: Proven Practices that Increase Value and Reduce Costs," available at: https://www.brattle.com/wp-content/uploads/2021/10/2021-10-12-Brattle-GridStrategies-Transmission-Planning-Report_v2.pdf; National Renewable Energy Laboratories. "Transmission Integration Studies," available at: https://www.nrel.gov/grid/transmission-integration.html.

the recommendation of these approaches that improving the transmission connections between grids—similar to the MISO/SPP Seam proposal this year—will improve outcomes for ratepayers.[20]

Figure 9 shows the generation mix in 2042 for all three scenarios. Generation from distributed and utility-scale solar resources have been combined under the "Solar" label. Battery discharge is not shown on this chart, given that it is a redistribution of electric generation from another source.

Figure 9. Generation by fuel type as a percent of total, 2042



From a reliability perspective, TVA must meet its hourly demand requirements in all modeled days and hours during the analysis period. All scenarios maintain a planning reserve margin of 17 percent and a winter planning reserve margin of 25 percent. Figure 10 shows the hourly generation in the *BAU* scenario over a peak winter day in 2035. The solid line represents demand over the course of the day, while the dashed line shows instances in which batteries are charging as a result of excess generation. TVA's current system is largely depending on nuclear and gas, with smaller amounts of hydro and pumped hydro generation over the course of the day. Solar and battery storage contribute very little, with batteries discharging during the morning and evening peaks, and solar generating during the mid-day trough period.

[20] Ethan Howland. February 2022. "SPP, MISO identify 7 cross-seam transmission projects that could unlock up to 53 GW of new generation," *Utility Dive,* available at: https://www.utilitydive.com/news/spp-miso-identify-seven-cross-seam-transmission-projects-renewable-wind/618152/.

Figure 10. Sample winter peak generation by fuel type, January 2035, BAU scenario

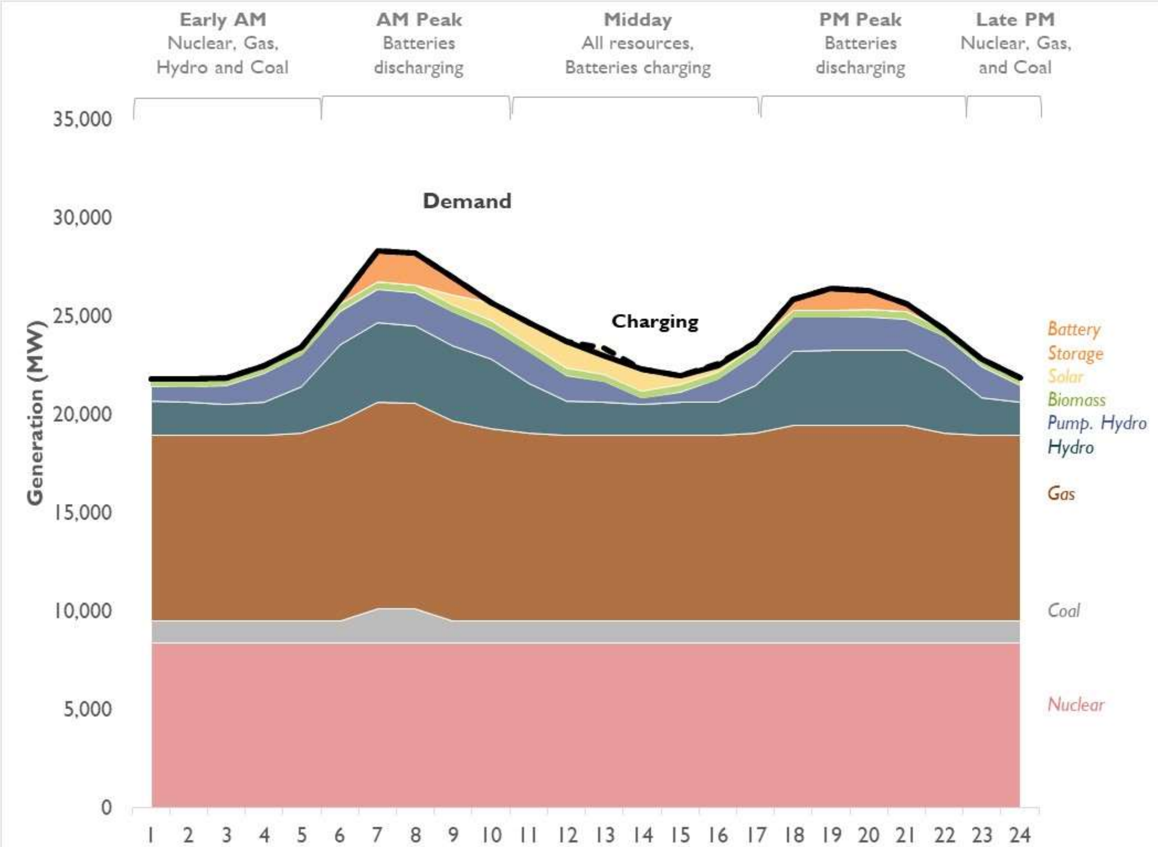


Figure 11 shows hourly generation during the January 2035 peak in the *Solar/Storage Replacement* scenario. Generation follows a similar pattern as in the *BAU* scenario; however, solar and battery storage make up a much larger portion of total generation over the course of the day. Generation from gas stays flat during the morning and evening peaks, and it drops during the afternoon trough when solar is at its peak output.

Figure 11. Sample winter peak generation by fuel type, January 2035, Solar/Storage Replacement scenario

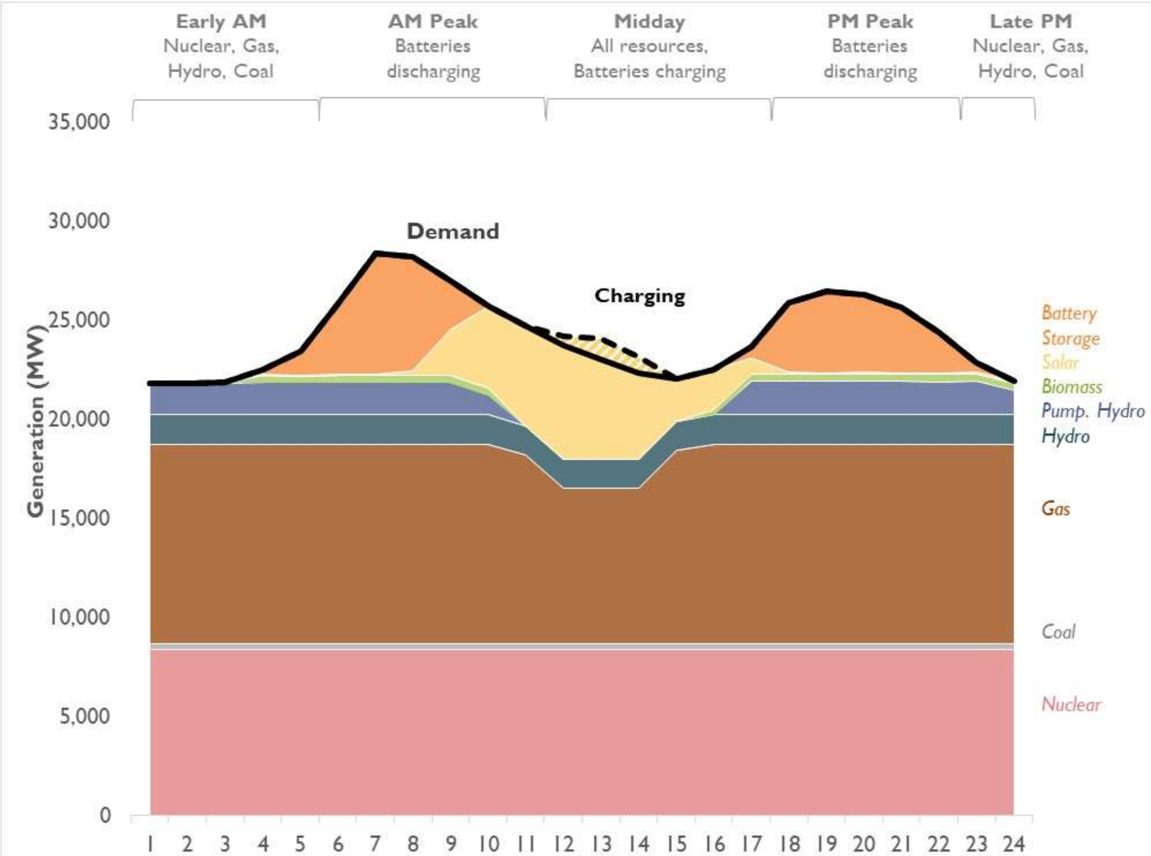
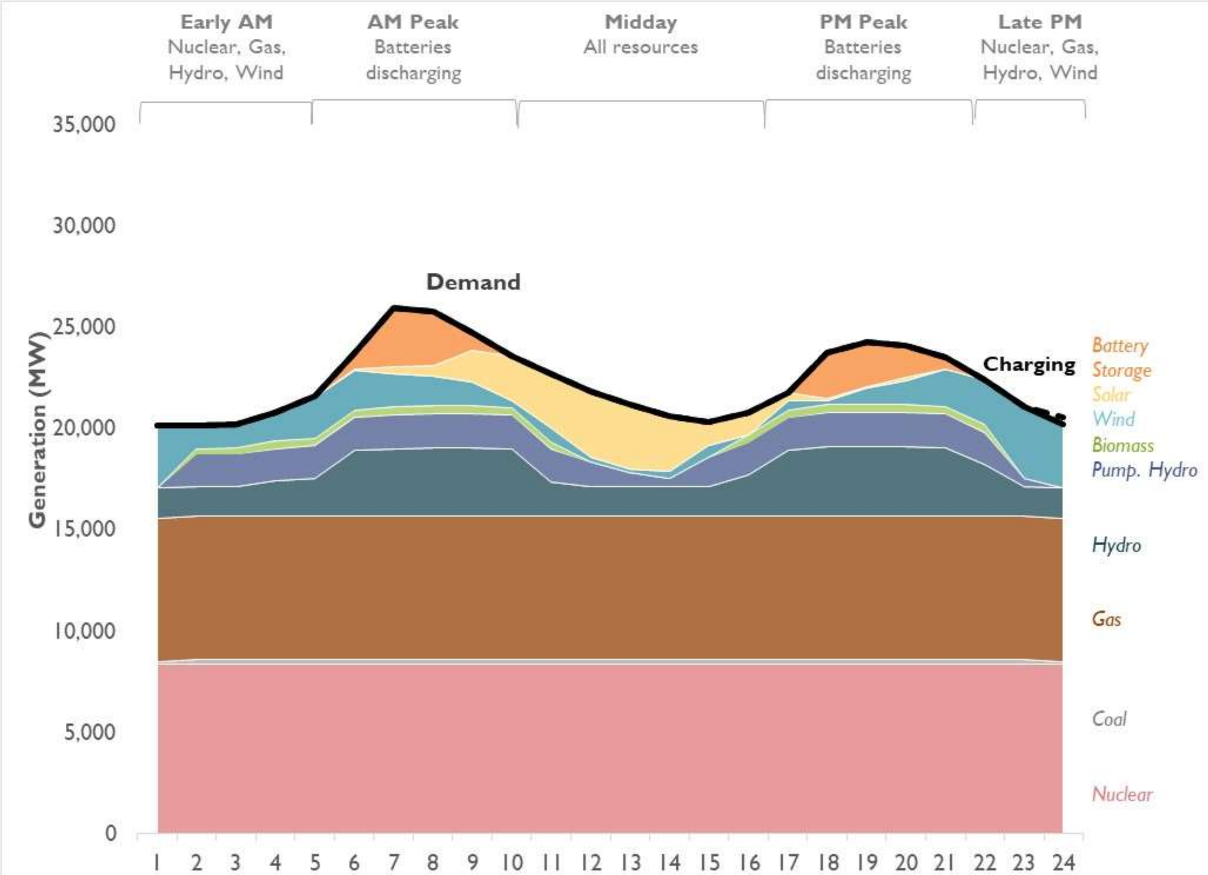


Figure 12 shows the hourly generation over a representative January 2035 peak day in the *Clean Portfolio Replacement* scenario. Hourly energy demand is reduced in this scenario due to the increased energy efficiency savings. This portfolio has the least reliance on gas-fired generation of the three modeled portfolios, as well as a more diverse fuel mix overall. While electricity discharged from battery resources is still used to meet the morning and evening peaks, wind generation also contributes during the morning and overnight hours. Solar capacity produces energy during the midday trough, but at reduced amounts compared to the *Solar/Storage Replacement* scenario.

Figure 12. Sample winter peak generation by fuel type, January 2035, Clean Portfolio Replacement scenario

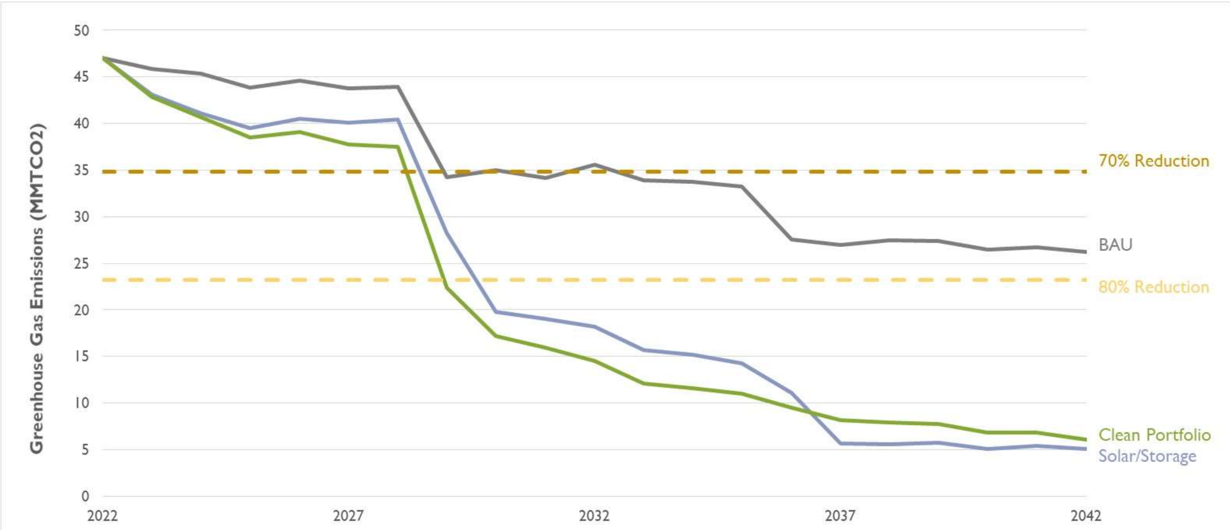


3.3. Carbon Dioxide Emissions

The importance of near-term investments in energy efficiency and renewable generation is most evident in the greenhouse gas emission results from our scenario. The *BAU* scenario, which builds over 7 GW of new gas and does not allow early coal retirements, results in an additional 277.2 million tons of CO_2 compared to the *Solar/Storage Replacement* scenario and an additional 301.7 million tons of CO_2 compared to the *Clean Portfolio Replacement* scenario.

As Figure 13 shows, the emission reductions in the *Solar/Storage Replacement* and *Clean Portfolio Replacement* scenarios begin immediately. In fact, due to the model's decision to immediately replace retiring coal units at Cumberland and Kingston with a combination of solar, wind, and storage, the annual emissions in the *Solar/Storage Replacement* and *Clean Portfolio Replacement* scenarios are lower by 2030 than annual emissions in the *BAU* scenario are in 2042. Although *Solar/Storage Replacement* emissions are lower on an annual basis in 2042 when compared to the *Clean Portfolio Replacement* scenario, *Clean Portfolio Replacement* remains the scenario with the lowest cumulative emissions between 2022 and 2042.

Figure 13. Greenhouse gas emissions by scenario



Emissions data for sulfur dioxide (SO_2) and oxides of nitrogen (NO_X) are shown in Figure 14 and Figure 15, respectively.

Figure 14. SO_2 emissions by scenario

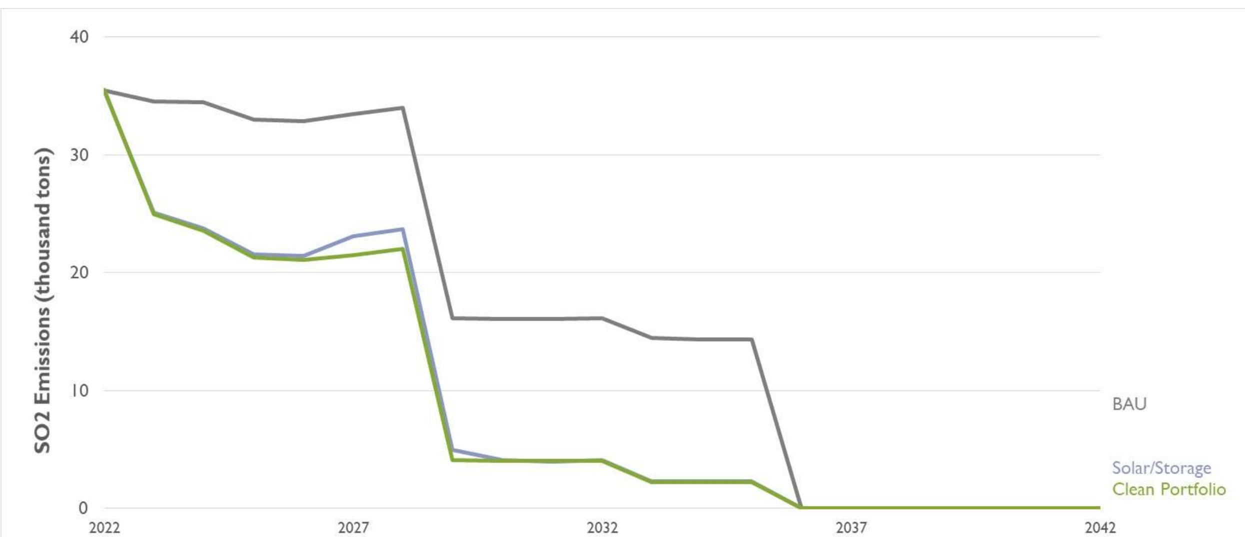
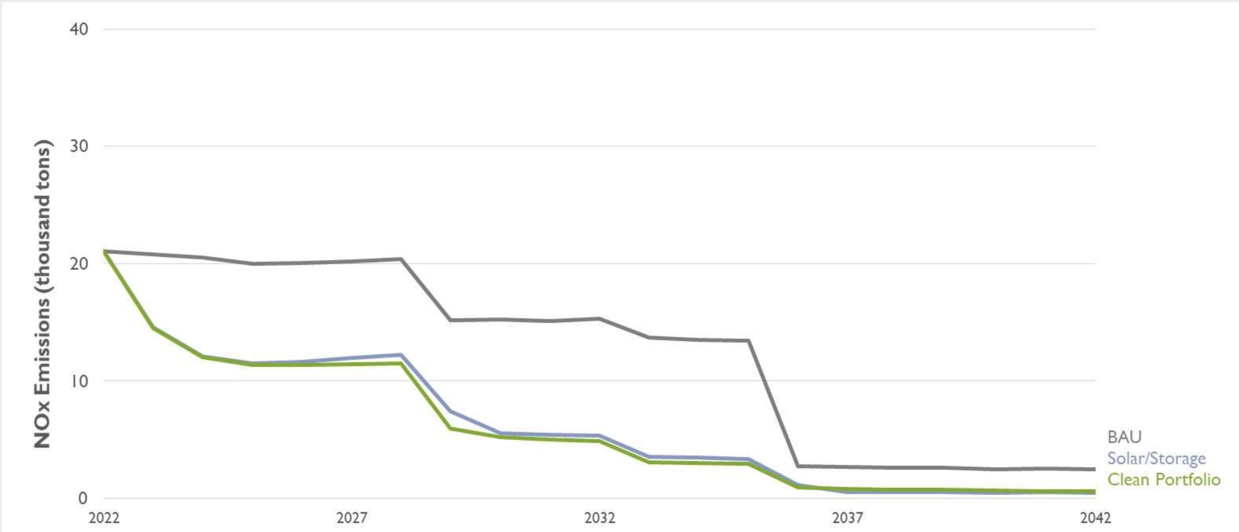


Figure 15. NO_X emissions by scenario



3.4. Revenue Requirements

The metric for measuring cost in the Synapse analysis was the net present value of revenue requirements (NPVRR). A utility revenue requirement is the amount of revenue that will need to be collected from ratepayers to pay for the resource portfolio over the course of the study period, discounted to present dollars using a discount rate of 8 percent. As shown in Table 3, the *BAU* scenario is the most expensive, and all modeled alternative scenarios would yield savings to ratepayers. Put another way, TVA customers would benefit from the utility retiring coal ahead of schedule, adding fewer MW of gas, and increasing procurements of new solar, wind, battery storage, and energy efficiency.

Table 3. Net present value revenue requirement, by scenario

Results (2022–2042)	Business-As-Usual	Solar/Storage Replacement	Clean Portfolio Replacement
NPV with Energy Efficiency ($billion)	$78.2	$71.7	$68.7
Delta From BAU ($billion)	-	-$6.4	-$9.4
Delta from BAU (%)	-	-8.2%	-12.1%

Only the *Clean Portfolio Replacement* scenario included additional energy efficiency assumptions. Synapse included the cost of these additional programs in the NPVRR totals above. Those cost assumptions are provided in Appendix A. Overall, the *Solar/Storage Replacement* scenario—which prioritizes new solar and storage instead of gas builds—costs $6.4 billion less than the *BAU* scenario. By contrast, the increased energy efficiency investment and the addition of candidate wind resources in the *Clean Portfolio Replacement* scenario results in approximately $9.4 billion in savings compared to the

BAU scenario, a reduction of 12.1 percent. The savings that result from the *Clean Portfolio Replacement* scenario support a full portfolio approach to decarbonization and illustrate the value that TVA could provide to customers through investments in solar, storage, wind, and energy efficiency.

4. CONCLUSIONS

The results of the Synapse modeling analysis show that TVA can reliably and economically meet its customers' needs for capacity and energy without relying on continued coal generation or new gas units. Instead, early investment in energy efficiency and the deployment of new solar, wind, and battery resources can result in a least-cost portfolio that also accelerates TVA's pathway towards decarbonization. This option enables earlier retirement of TVA's existing coal-fired generators while avoiding replacement with new gas capacity.

The Synapse modeling resulted in the following overarching findings:

- Replacement portfolios that rely exclusively on renewables and storage will achieve the same level of reliability as a replacement portfolio that consists largely of combined cycle and combustion turbine replacement capacity.
- Both replacement portfolios result in customer savings relative to the *BAU* scenario. The *Solar/Storage Replacement* scenario saves an estimated $5.8 billion from 2022 to 2042 compared to the *BAU* scenario, while the *Clean Portfolio Replacement* scenario saves $8.9 billion.
- A resource portfolio that avoids investments in new gas capacity results in greater emissions reductions over the next 20 years and puts TVA on a more linear path toward net-zero CO_2 emissions in 2050.

There are no silver bullets in the energy transition. The need to balance reliability, affordability, emission reductions, and intermittent generation demands a portfolio approach that considers each type of resource. Energy efficiency is the "first fuel," and should be considered alongside more traditional supply-side resources as a solution to energy and capacity needs. TVA should also actively pursue a mix of solar, wind, and storage resources, as these complementary resources together lead to lower overall capacity builds than a more limited set of renewable options.

This diverse resource approach supports reliability, leads to reduced emissions, and is lower cost than both the *BAU* scenario and the *Solar/Storage Replacement* scenario. In addition, one of the main takeaways of the *Clean Portfolio Replacement* scenario is that it highlights the importance of a total "all-of-the-above" portfolio approach to decarbonization, especially when compared to the *Solar/Storage Replacement* scenario. While the *Solar/Storage Replacement* scenario, even when limited to only solar and storage, is able to meet load at a reasonable cost, it requires a vast amount of new resource builds—a combined 60 GW of utility-scale solar and storage. All that capacity must be developed, sited, and permitted and would likely require a substantial amount of land. By contrast, the *Clean Portfolio*

Replacement scenario, which augments solar and storage with additional wind and energy efficiency, results in less than 17 GW of utility-scale solar, storage, and wind. Although the impacts of lower land use are beyond the scope of this report, it is likely that the reduced need for land in the *Clean Portfolio Replacement* scenario will make achieving decarbonization more feasible in the required timeframe. The results of this analysis show that TVA can decarbonize its current resource portfolio at a faster rate at a lower cost to customers while also maintaining the reliability of the system.

APPENDIX A: METHODOLOGY

Modeling Inputs

Synapse used EnCompass to model resource choice impacts in TVA's service territory. Developed by Anchor Power Solutions, EnCompass is a single, fully integrated power system platform that provides an enterprise solution for utility-scale generation planning and operations analysis. It is an optimization model that covers all facets of power system planning, including:

- Short-term scheduling, including detailed unit commitment and economic dispatch, with modeling of load-shaping and -shifting capabilities;
- Mid-term energy budgeting analysis, including maintenance scheduling and risk analysis;
- Long-term integrated resource planning, including capital project optimization, economic generating unit retirements, and environmental compliance; and
- Market price forecasting for energy, ancillary services, capacity, and environmental programs.

Synapse used the EnCompass National Database created by Horizons Energy to model TVA. Horizons Energy has benchmarked dispatch and prices resulting from its comprehensive dataset to actual, historical data across all modeling zones. More information on EnCompass and the Horizons dataset is available at www.anchor-power.com.

Load and Peak Energy

Synapse used the load and peak energy forecasts as stated in the 2019 TVA IRP, using the *Current Outlook* forecast, which projects a constant 0.1 percent and 0.3 percent annual growth rate from 2018 through 2038, for annual energy and peak demand, respectively. Synapse then derived a compound annual growth rate value based off this forecast and extrapolated values for 2038 through 2042. Synapse next applied the 2019 TVA hourly demand from FERC Form 714 to derive hourly load profiles over time.[21]

Resource Mix and Retirements

Synapse used the 2021 Horizon's National Database as the foundation for representing the TVA system and its resources in Encompass; Synapse confirmed that the resources in the National Database

[21] Federal Energy Regulatory Commission (FERC). 2021. "Form No. 714: Annual Electric Balancing Authority Area and Planning Area Report". *https://www.ferc.gov/industries-data/electric/general-information/electric-industry-forms/form-no-714-annual-electric/data.*

matched the resources listed in the 2019 TVA IRP, and calibrated/updated resources where any substantial differences existed.

Key updates that Synapse made to the model included the following:

- Adjusting resource capacities to fit seasonal summer and winter trends: Given TVA's seasonally varying reserve margin, Synapse used the summer dependable capacity value listed in the IRP as the summer capacity values and used the 2020 EIA Form 860 as the source for the winter capacity values.

- Updating fixed resource retirement dates to be consistent with TVA's most recently stated plans or outlooks, particularly regarding coal plants: Synapse set a fixed retirement date[22] of 2028 for Kingston and Cumberland based on scoping reports released by TVA proposing to retire units from both plants as early as 2026 but no later than 2030.[23] Synapse also set a fixed retirement date of 2035 for the Shawnee and Gallatin plants, considering the earlier, broader announcement by TVA of its intent to retire its entire coal fleet by 2035.[24]

- Ensuring that long-term PPAs stated in the IRP were captured in the EnCompass model as dispatchable resources until the end of the PPA contract.[25]

- Updating the fixed operations and maintenance (FOM) costs for existing TVA coal resources based on the information presented in the IRP.

Additions

Synapse allowed the EnCompass model to build a suite of expansion resources in the modeling horizon if deemed economic to do so. Available fossil fuel resources included, but were not restricted to, new combined cycle gas-fired units in units of or increments of 645 MW, new internal combustion units in increments of 65 MW and new gas turbine units in increments of 178 MW.

Available clean energy resources were limited to PPAs for utility solar and wind, given TVA's inability to directly take advantage of tax and other investment incentives offered by the government to encourage greater builds of renewable resources. Synapse offered the model the choice of wind PPAs in TVA, MISO, and SPP, with the minimum size of the wind resources at 100 MW per unit. Synapse also allowed

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[22] EnCompass fixed retirement dates are the dates by which a resource must go offline.

[23] Tennessee Valley Authority. 2021. "Cumberland and Kingston Fossil Plant Retirement EIS- Scoping Report." *https://www.tva.com/environment/environmental-stewardship/environmental-reviews*

[24] The Future of Coal at TVA. Tennessee Valley Authority (2021). Available at:*https://www.tva.com/newsroom/articles/the-future-of-coal-at-tva*

[25] Tennessee Valley Authority. 2019. "2019 Integrated Resource Plan Volume II – Final Environmental Impact Statement". Table 2-6: Major Power Purchase Agreement Contracts/Facilities. *https://www.tva.com/environment/environmental-stewardship/integrated-resource-plan*

the model to select utility solar PPAs at 20 MW per unit within the TVA area. Furthermore, Synapse gave the model the ability to build 4-hour utility-scale batteries, distributed batteries, biomass power plants,[26] and rooftop solar within TVA.

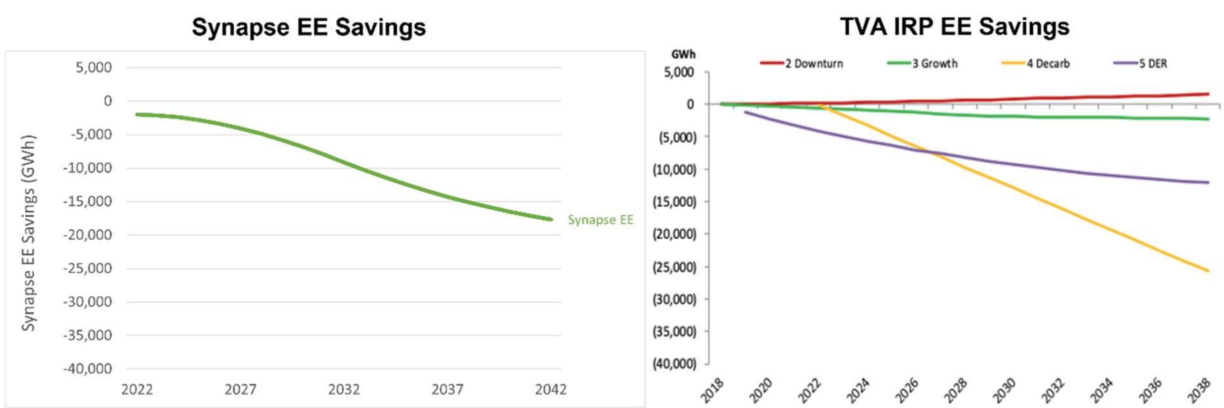
Synapse also updated energy costs of the wind and solar PPAs using the 2021 National Renewable Energy Laboratory's *Annual Technology Baseline* moderate values.[27] Wind costs are in-line with Class 8 resources for TVA, Class 6 in MISO, and Class 4 in SPP. Solar costs are consistent with Class 7 solar costs. Fixed Operation and Maintenance (FOM) costs for batteries were also updated using the 2021 *Annual Technology Baseline* values.

Energy Efficiency

Synapse developed an internal energy efficiency forecast and modeled energy efficiency as a load modifier in the *Clean Portfolio Replacement* scenario. The other two scenarios were modeled using the TVA reference energy and peak forecasts from the 2019 TVA IRP.

Synapse's reason for developing the internal energy efficiency forecast For the *Clean Portfolio Replacement* scenario was the low level of planned energy efficiency included in TVA's IRP baseline energy forecasts. As shown in Figure 16, TVA did model additional scenarios with higher levels of energy efficiency.[28] Overall, the Synapse internal forecast lies between TVA's DER (distributed energy resources) energy efficiency forecast and TVA's decarbonization energy efficiency forecast, most closely tracking TVA's decarbonization energy efficiency pathway.

Figure 16. Synapse energy efficiency forecast compared to TVA IRP forecasts



Synapse developed its energy efficiency forecast by adjusting the baseline load used by TVA in its 2019 IRP. The first step in developing an energy efficiency forecast was to establish first-year incremental

[26] Biomass is not considered a zero-carbon resource in this analysis.

[27] National Renewable Energy Laboratory. 2021. *2021 Annual Technology Baseline*. Golden, CO: National Renewable Energy Laboratory. *https://atb.nrel.gov/.*

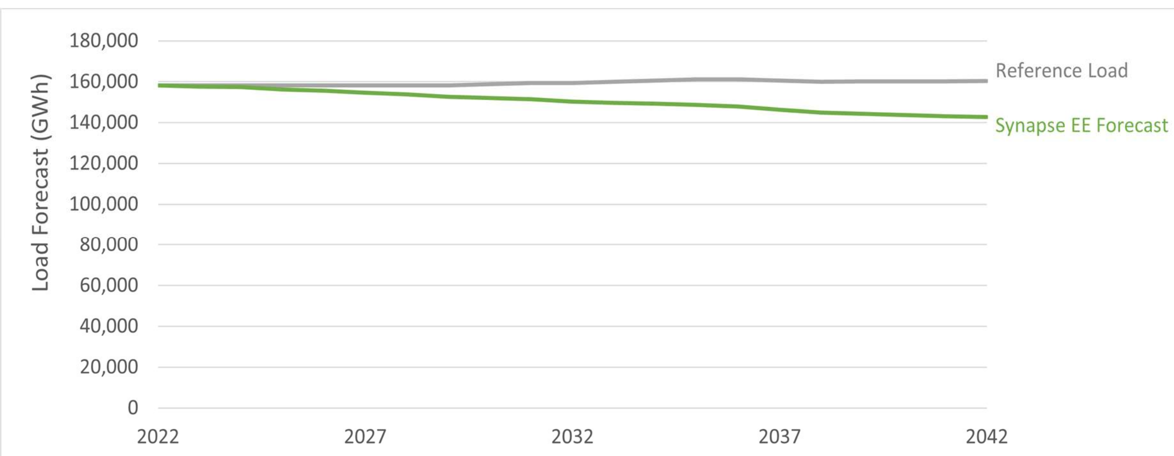
[28] TVA 2019 IRP.

savings. TVA provided this information in its IRP by charting both the utility's reference load and then a separate load adjusted for TVA's existing programmatic energy efficiency. We used this level of savings as a starting point and set a target of 1 percent incremental savings by 2035, charting a linear pathway of energy savings to achieve this target. Energy efficiency savings in the Synapse forecast then remained at that level through 2042. Synapse also assumed a 12-year measure life.

After establishing a first-year incremental savings amount, Synapse set a target of 1 percent incremental savings by 2035. According to a 2021 report by the American Council for an Energy-Efficient Economy, several utilities have already reached greater than 2 percent incremental savings. Achieving 1 percent incremental savings by 2035 is thus a conservative target, with leading utilities already aiming for between 2–3 percent. In Synapse's modeling, the incremental savings percentage is held constant once the 1 percent target is achieved in 2035.

The growth rate in energy efficiency savings required for TVA to achieve 1 percent incremental savings by 2035 is gradual. In Synapse's energy efficiency forecast, TVA would need to increase the percentage of annual incremental savings by approximately 0.10 percent each year. This trajectory is at the lower end of studies by the Lawrence Berkley National Laboratory (LBNL), which found that utilities were able to increase the percentage of annual incremental savings by between 0.10 and 0.40 percent per year.[29] Synapse applied the energy efficiency savings from its forecast to the reference energy forecast in TVA's IRP and modeled the savings as reduced load in the *Clean Portfolio Replacement* scenario.

Figure 17. Synapse energy efficiency forecast, energy savings

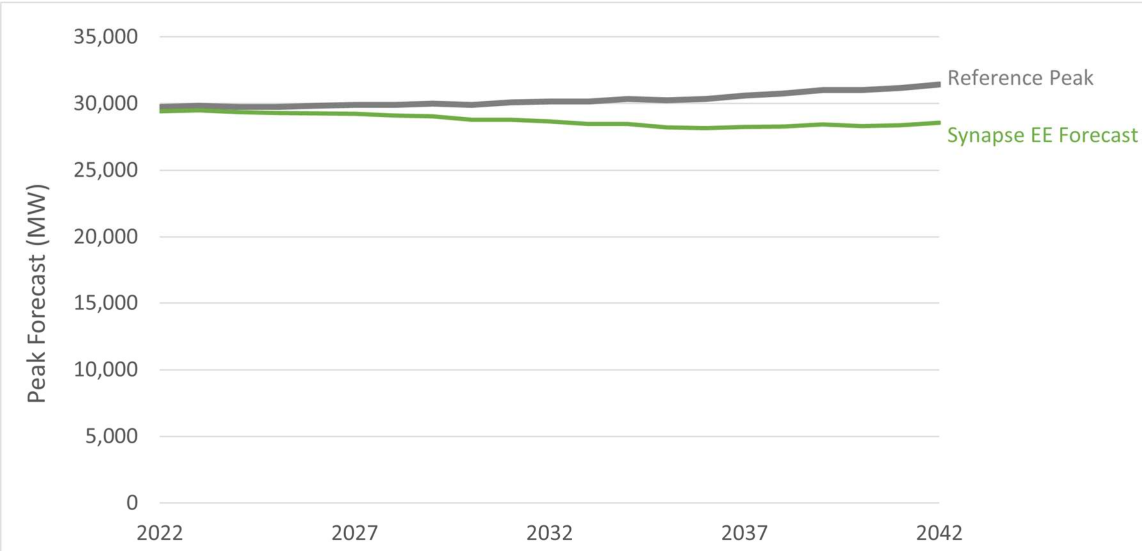


In addition to saving energy, energy efficiency measures can also impact the peak forecast. Synapse used the ratio of historical energy savings and peak reduction impacts in TVA's IRP to develop a peak

[29] U.S. Environmental Protection Agency. June 10, 2014. *GHG Abatement Measures, Technical Support Document (TSD) for Carbon Pollution Guidelines for Existing Power Plants*. Available at: https://archive.epa.gov/epa/sites/production/files/2014-06/documents/20140602tsd-ghg-abatement-measures.pdf.

reduction/energy savings ratio of 0.163 MW/GWh.[30] We applied this ratio our forecasted energy efficiency savings to estimate the associated peak reduction impact, resulting in a peak reduction of 2,882 MW by 2042.

Figure 18. Synapse energy efficiency forecast, peak reduction



Because we added the energy efficiency forecast as a load-modifier, we added the cost of energy efficiency back into the NPVRR during post-processing. We used a cost of 2.7 cents per kWh based on an LBNL study of utility energy efficiency costs from 2011 to 2017. LBNL found that energy efficiency costs in the Midwest were 2.5 cents per kWh in 2017 dollars, equating to 2.7 cents per kWh in 2021 dollars.[31]

Behind-the-Meter Resources

In addition to energy efficiency, each of our scenarios assumed varying levels of BTM solar and storage. These forecasts match various BTM projections developed by TVA in the 2019 IRP. This study used TVA's base projection in the *BAU* scenario, the moderate projection in the *Solar/Storage Replacement* scenario, and the high projection in the *Clean Portfolio Replacement* scenario. The BTM solar and storage capacities were spread across five states in TVA's service territory based on the state allocation percentages in the National Database. See Appendix C of the TVA IRP for more information.[32]

[30] Application of a load shape to the adjusted peak forecast serves to modify the hourly demand forecast used in this analysis.

[31] Schwartz, Lisa et al. November 2019. *Cost of Saving Electricity Through Efficiency Programs Funded by Customers of Publicly Owned Utilities: 2012-2017.* Lawrence Berkeley National Laboratory. Available at: https://eta-publications.lbl.gov/sites/default/files/public_power_cost_of_saving_electricity_final.pdf.

[32] TVA 2019 IRP. Available at: https://tva-azr-eastus-cdn-ep-tvawcm-prd.azureedge.net/cdn-tvawcma/docs/default-source/default-document-library/site-content/environment/environmental-stewardship/irp/2019-documents/tva-2019-integrated-resource-plan-volume-i-final-resource-plan.pdf?sfvrsn=44251e0a_4

Figure 19. BTM solar forecasts

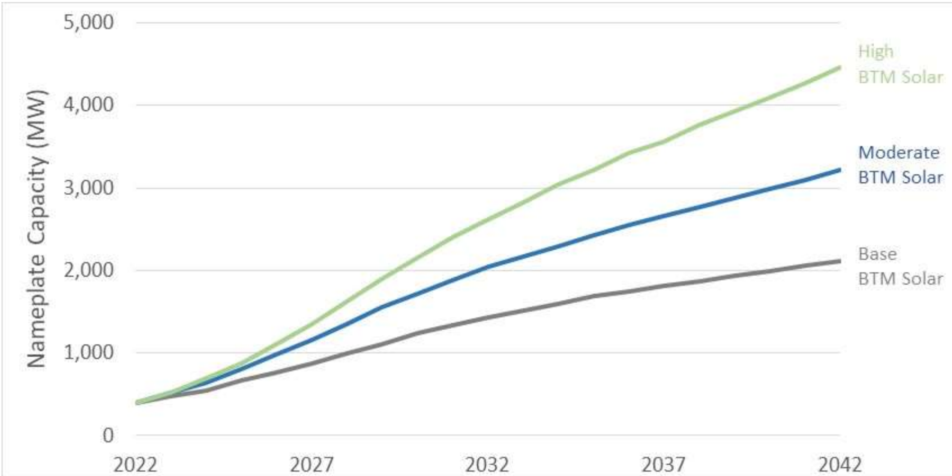
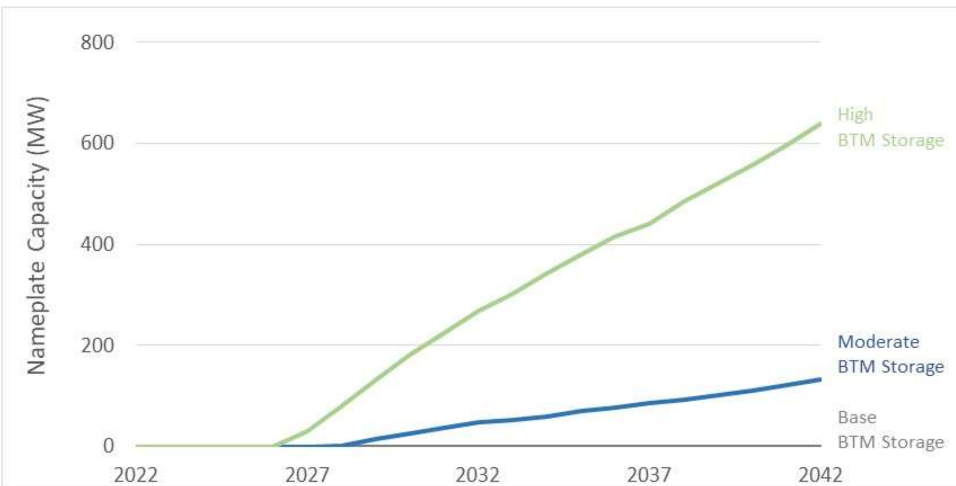


Figure 20. BTM storage forecasts



Fuel Prices

In addition to energy efficiency, Synapse developed an internal gas price forecast that blends near-term NYMEX futures with the *Annual Energy Outlook's* long-term gas price trajectory. Using an internal forecast allowed us to develop a monthly gas price forecast and capture the seasonal variation in gas prices. Synapse's internal forecast is actually lower than the TVA forecast in the 2019 IRP, except for the higher prices in the near term based on the current level of NYMEX futures through 2024. In Figure 21, note that the TVA IRP natural gas price forecast has been extrapolated from 2039 through 2042, based on the growth rate in the preceding five years in TVA's forecast.

Figure 21. Natural gas price comparison