Virginia Data Center Study

Electric Infrastructure and Customer Rate Impacts

Prepared on behalf of the Virginia Joint Legislative Audit and Review Commission (JLARC)

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Energy+Environmental Economics

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Acknowledgements and Disclaimers

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- The authors would like to also thank the experts interviewed for this work, including representatives from load serving entities (Dominion Energy (Dominion), Northern Virginia Electric Cooperative (NOVEC), Mecklenburg Electric Cooperative (MEC)), and several data center companies (Amazon, Cloud HQ, Compass, Google, Meta, QTS, and Stack) for providing their perspectives and insights data center growth, operations, and cost of service studies.

- It is important to note that although this analysis does examine system impacts throughout Virginia including within Dominion’s service territory and the broader PJM region, this modeling exercise has significant differences in scope and intent from Dominion’s Integrated Resource Plan (IRP). The analysis described herein is exploratory in nature and is solely intended to examine the implications of different load growth pathways under different levels of decarbonization ambition in Virginia. This study is not intended to serve the same purpose as an Integrated Resource Planning modeling exercise and should not be interpreted as such nor is it meant to model the PJM market precisely.
- Our analysis is highly technical and reflects industry best practices and as such may not be as accessible to a general lay audience, but we have endeavored to strike a balance between the detail and transparency needed to precisely describe our analysis and modeling vs. being accessible to a broader, more non-technical audience.
- Lastly, the analysis presented in this report are solely reflective of E3’s views and perspectives in the context of the scope of work; all conclusions and takeaways in this report are our own.

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Abbreviations and Acronyms

Table of Acronyms

CCGT	Combined-cycle gas turbine
COSS	Cost of Service Study
DOM Zone	Dominion Transmission Zone
E3	Energy + Environmental Economics
ELCC	Effective Load Carrying Capability
EPA	Environmental Protection Agency
ESA	Energy Service Agreement
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse gas
IOU	Investor-Owned Utility
IRP	Integrated Resource Plan
JLARC	Joint Legislative Audit and Review Commission
LDV	Light-duty vehicle
LOLE	Loss-of-load expectation
LMP	Locational Marginal Price
LSE	Load Serving Entity
MDV	Medium-duty vehicle
MEC	Mecklenburg Electric Cooperative
NOVEC	Northern Virginia Electric Cooperative

Table of Acronyms (continued)

OSW	Offshore wind
PJM	PJM Interconnection, L.L.C.
PUC	Public Utilities Commission
REC	Renewable Energy Certificate
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
RTO	Regional Transmission Organization
SCC	State Corporation Commission
SMR	Small Modular Reactor
VCEA	Virginia Clean Economy Act
VEPCO	Virginia Electric and Power Company
WCC	Weldon Cooper Center

Executive Summary

Energy+Environmental Economics

About This Report

- **E3 was engaged by the Joint Legislative Audit & Review Commission (JLARC) in Virginia to examine the impacts of data center growth on the state's electric infrastructure needs and associated costs, as well as the distribution of these costs across customer classes. This report summarizes E3's analysis and findings from this study.**

- **JLARC conducts program evaluation, policy analysis, and oversight of state agencies on behalf of the Virginia General Assembly. This study is part of a broader set of analyses JLARC conducted on data center growth in the state of Virginia.**

- **This report summarizes:**
  - The background of the study and E3's scope of work
  - The Virginia data center outlook and load growth projections provided by WCC
  - The grid impact modeling and analysis E3 performed to evaluate the impact of data center load growth on Virginia's electric infrastructure needs and associated costs
  - The rate impact analysis E3 performed to evaluate the current energy cost allocation mechanism used by major utilities in Virginia, potential impact of data center load growth on residential customer rates, and recommended policy enhancements and/or considerations

Who is E3?

Technical & Strategic Consulting specializing in the Energy Transition…

125+ full-time consultants | 30 years of deep expertise | Engineering, Economics, Mathematics, Public Policy…

San Francisco

New York

Boston

Calgary

Denver

E3 Clients

300+ projects per year across our diverse client base

E3 Project Examples

Data center analysis working with utilities, regulators, independent power produces, and data center companies on strategy, siting, rate design, power supply, and grid impacts

Integrated System Planning supporting a wide range of North American utilities with system planning at the distribution and bulk system level across investor-owned and public power utilities

Policy analysis supporting many state regulatory bodies and energy agencies across the U.S.

Market design and expansion analysis working with ISOs/RTOs directly (ERCOT, MISO, AESO, etc.) on design issues including resource adequacy and capacity accreditation as well as analyzing and supporting Western U.S. market expansion between CAISO EDAM and SPP Markets+

Supporting project developers, asset owners, and investors with strategic and market advisory services across **all major power asset classes like renewables, energy storage, gas, transmission, etc.**

Study Background

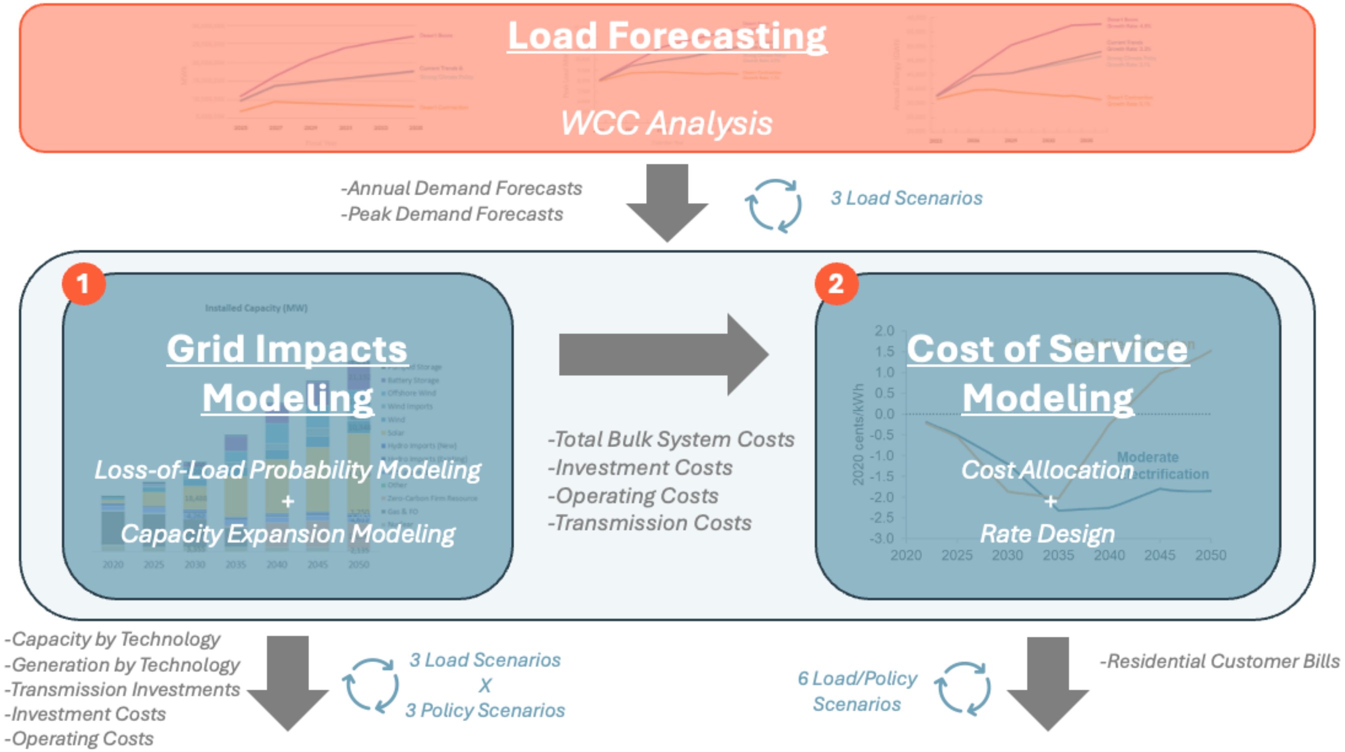
+ **Northern Virginia has the highest concentration of data centers globally and remains the fastest-growing market**
  - About 70 percent of **global internet traffic** flows through northern Virginia, according to certain estimates[1]
  - Most facilities are served by Dominion Energy (VEPCO), the state's largest investor-owned utility
+ **The recent rapid expansion of the data center industry, which is highly power intensive has driven a significant rise in electricity demand in Virginia**
+ **Data center growth is impacting the broader PJM region as well**
  - PJM capacity market auction prices recently hit record highs, due in part to market design changes such as to capacity accreditation and a significant expected increase in energy demand from data centers, combined with supply challenges such as from power plant retirements and congested, slow moving generation interconnection queues
+ **In parallel, Virginia is working to achieve an ambitious energy transition**
  - Under the Virginia Clean Economy Act (VCEA) of 2020, investor-owned utilities, such as Dominion Energy, must transition to 100% zero-carbon generation portfolios
  - Dominion and other LSEs are also modernizing an aging grid to achieve multiple objectives one of which is renewable generation integration
+ **Given this broader energy landscape, Virginia faces a two-pronged challenge: 1) meeting surging data center growth while 2) also rapidly decarbonizing its electricity supply to meet the goals of the VCEA**
+ **E3 has conducted this study to (1) identify the infrastructure investments required to maintain reliability and achieve state policy goals, and (2) to examine current ratemaking and cost allocation practices to assess the associated ratepayer impacts**

[1] Source: https://www.novaregion.org/1598/Data-Centers; https://www.vedp.org/news/dawn-data

Scope of Work and Analytical Framework

- E3 was commissioned by JLARC to examine the impacts of data center growth on electric infrastructure needs and associated costs, as well as the distribution of these costs across customer classes
- Data center growth projections under a Moderate and Unconstrained scenario were provided by WCC as inputs into E3's analysis
- E3 leveraged its in-house electric sector models, RECAP[1] and RESOLVE[2], to identify the least-cost portfolios to meet load growth while also achieving policy goals and maintaining reliability
- Electric sector infrastructure investments were then assessed through a Cost of Service framework to examine existing and modified rate designs and the distributional impacts of these investments under different methods

[1] https://www.ethree.com/tools/recap-renewable-energy-capacity-planning-model/
[2] https://www.ethree.com/tools/resolve/



The Grid Impacts Modeling included the entire PJM region while focusing on data center load growth projections from WCC for the DOM transmission zone. The Cost of Service assessment then focused on three load-serving entities within the DOM transmission zone (Dominion, Mecklenburg electric co-op (MEC), and Northern Virginia electric co-op (NOVEC)).

Electric Infrastructure Study Overview

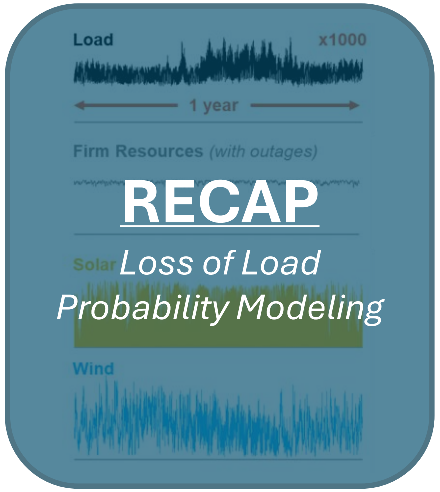
Key Objective of Infrastructure Analysis: Examine electricity system infrastructure and associated investments required to meet the VCEA goals under a wide range of potential data center-driven load growth scenarios

To perform this work, E3 leveraged a ***capacity expansion model*** *in tandem with a* ***loss of load probability model****, in order to ensure the resulting portfolios are reliable over a broad range of weather conditions.*

E3 modeled the entire PJM region within its capacity expansion framework to allow more detailed examination of the interaction between Virginia and the broader market in the context of rapid data center growth. However, by design we did not model the PJM market construct precisely in terms of price formation of energy and capacity prices.

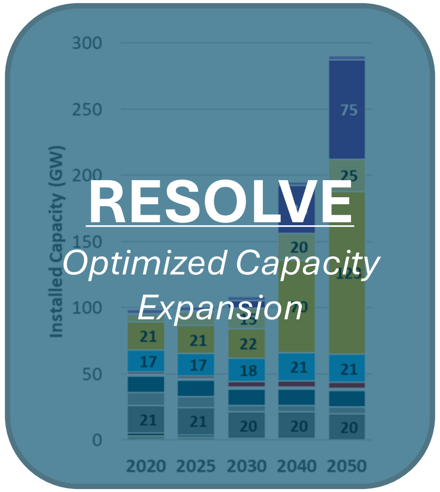
This analytical framework identifies the total infrastructure requirements but does not distinguish between utility-owned infrastructure vs. 3rd party owned vs. "behind-the-meter" generation at data center facilities.

1a Use LOLP model to quantify "effective load carrying capability," which measures contribution of each resource to reliability across 100s of simulations



Technology ELCC curves

Optimized Portfolios



1b Use capacity expansion to optimize future portfolios to meet reliability and clean energy goals while minimizing cost

1c Use LOLP model to simulate resulting portfolios across wide range of conditions, validating resource adequacy

Rate Impact Study Overview

Key Objective of Rate Impact Analysis: Determine if current rate and fee structures lead to an equitable distribution of costs between data centers and other customers

How does the magnitude and pace of data center growth in Virginia influence these cost components?

Where do data center rates exist on this spectrum?

What is the range of equitable outcomes?

Marginal Costs | New Costs | Contribution to System Fixed Costs

Data Centers must pay at least their marginal costs of service to avoid shifting the burden inequitably to existing customers

New costs may be direct (e.g., administrative) or indirect (e.g., network upgrades) and may be difficult to quantify or assign

Contributions by data centers to system fixed costs benefit existing customers; however, excessive contributions are inequitable to data centers

Scenario Design Considerations

The analytical framework for this study intended to capture key sources of uncertainty along two dimensions:

1. **Load growth uncertainty |** To address uncertainty around how quickly new data center loads can be constructed and interconnected to the system, this study examined three bookends: a counterfactual "No New Data Centers" load projection, a High (Unconstrained) Data Center Growth projection, and a Moderate (half of Unconstrained) projection.
   - The High (Unconstrained) projection assumes that data center facilities can be sited, built, and interconnected as fast as the market desires; in practice, constraints on the pace of infrastructure development may limit how quickly these facilities can add electric demand to the system.
2. **Level of decarbonization ambition |** To address uncertainty around the implementation of Virginia decarbonization policy and facilitate understanding of the impact of current state policy, this study examined three cases: a counterfactual No Policy scenario for each load projection, an IOU-Only VCEA case (consistent with current law), and a Statewide VCEA scenario in which all statewide sales are subject to similar requirements as set forth in the VCEA. Key sources of uncertainty include:
   - **Accelerated Renewable Energy Buyers Program** | The VCEA indicates that commercial or industrial customers are able to purchase their own Renewable Energy Credits from projects within the PJM region, and their sales would be exempt from the VCEA requirements; this would effectively have the impact of lowering the in-state requirements and potentially leading to a shift in resources from Virginia to neighboring PJM states.
     - Data center customers are also exploring the concept of co-location with generating facilities or "bring-your-own-generation"; our electric system infrastructure modeling is focused on the total quantity of infrastructure required in the state, which would not meaningfully change regardless of whether the infrastructure is built by the utility or the data center customer, though it may have implications for cost allocation and ratemaking.
   - **Applicability of VCEA to Electric Cooperatives** | The VCEA only applies to the retail sales of Investor-Owned Utilities (IOUs), and therefore any data centers that choose to purchase their energy from electric co-ops would not be subject to the VCEA requirements. We examined a set of IOU-only VCEA cases (consistent with current law) in which a significant share of new data center loads are met by co-ops which are exempt from the VCEA requirements. However, tech companies that purchase their power from electric co-ops may still have similar levels of decarbonization ambition; as a result, we also examined Statewide VCEA cases which assume that sufficient clean energy is installed to supply all statewide sales with VCEA-compliant electricity, regardless of provider.

Overview of Scenarios and Sensitivities (1/2)

Scenarios for this analysis were constructed to examine the impacts of data centers on the Virginia electric system along two dimensions:

1. **Levels of data center growth**
   - [Counterfactual] No Data Center Growth (“S1” cases)
   - Moderate (half of Unconstrained) Data Center Growth (“S2” cases)
   - Unconstrained Data Center Growth (“S3” cases)
2. **Levels of VCEA achievement**
   - [Counterfactual] No VCEA Compliance (“A” cases)
   - Achievement of VCEA by Investor-Owned Utilities (“B” cases)
     - The VCEA only applies to investor-owned utilities, and electric co-operatives are exempt from the VCEA requirements; in other words, the “B” cases are consistent with current law.*
   - Full Statewide Achievement of VCEA (“C” cases)
     - By 2045 around 62% of the projected data center loads in Virginia are served by co-operatives in WCC’s forecast; E3 examined the full statewide achievement cases for better understanding of a potential bookend scenario

All scenarios include current “on-the-books” federal policies, including the Inflation Reduction Act and EPA carbon dioxide regulations, as well as current state policies and targets in the rest of PJM; exploring scenarios incorporating potential changes to currently enacted policies and rules was outside the scope of this study

VCEA Achievement →

Higher Data Center Growth ↓

S1A *No data center growth; non-compliant with VCEA*	**S1B** *No data center growth; IOUs comply with VCEA* *(current requirements)*	**S1C** *No data center growth; all statewide sales meet VCEA* *(beyond current requirements)*
S2A *Moderate data center growth; non-compliant with VCEA*	**S2B** *Moderate data center growth; IOUs comply with VCEA*	**S2C** *Moderate data center growth; all statewide sales meet VCEA*
S3A *Unconstrained data center growth; non-compliant with VCEA*	**S3B** *Unconstrained data center growth; IOUs comply with VCEA*	**S3C** *Unconstrained data center growth; all statewide sales meet VCEA*

*All references to VCEA compliance scenarios in the JLARC Report refer to existing VCEA requirements, or the “B” scenarios. Full statewide achievement of the VCEA in the “C” scenarios is strictly exploratory and only for reference in the E3 Report.

Overview of Scenarios and Sensitivities (2/2)

+ **Across all core scenarios analyzed, constraints were implemented within the model to reflect the feasibility of building out new resources in Virginia within a given timeframe, based on historical pace of build, expected constraints on in-state development such as availability of land, and other factors**
  - Under the most aggressive scenario combining unconstrained data center growth with statewide VCEA achievement (**S3C**), which goes beyond current legislated requirements, E3 also examined bookend sensitivities in which specific constraints were relaxed:
    - **High In-State Renewables**: Higher levels of onshore wind available and accelerated deployment of offshore wind allowed in Virginia and North Carolina
    - **Regional Coordination**: Relaxed constraints on transmission build-out post-2035
    - **Nuclear Renaissance**: No constraints on nuclear build-out post-2035 such as on small modular reactors

VCEA Achievement →

Higher Data Center Growth ↓

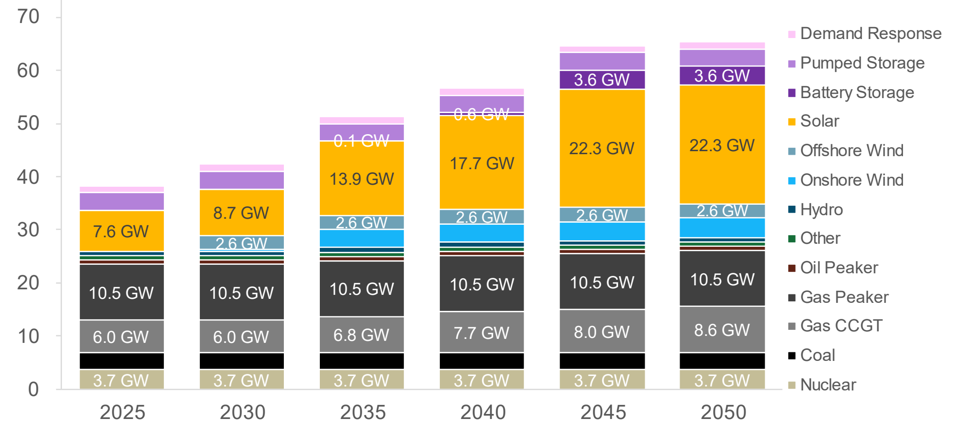
S1A *No data center growth; non-compliant with VCEA*	**S1B** *No data center growth; IOUs comply with VCEA* *(current requirements)*	**S1C** *No data center growth; all statewide sales meet VCEA* *(beyond current requirements)*
S2A *Moderate data center growth; non-compliant with VCEA*	**S2B** *Moderate data center growth; IOUs comply with VCEA*	**S2C** *Moderate data center growth; all statewide sales meet VCEA*
S3A *Unconstrained data center growth; non-compliant with VCEA*	**S3B** *Unconstrained data center growth; IOUs comply with VCEA*	**S3C** *Unconstrained data center growth; all statewide sales meet VCEA*

Key Findings | Electric Infrastructure (1/4)

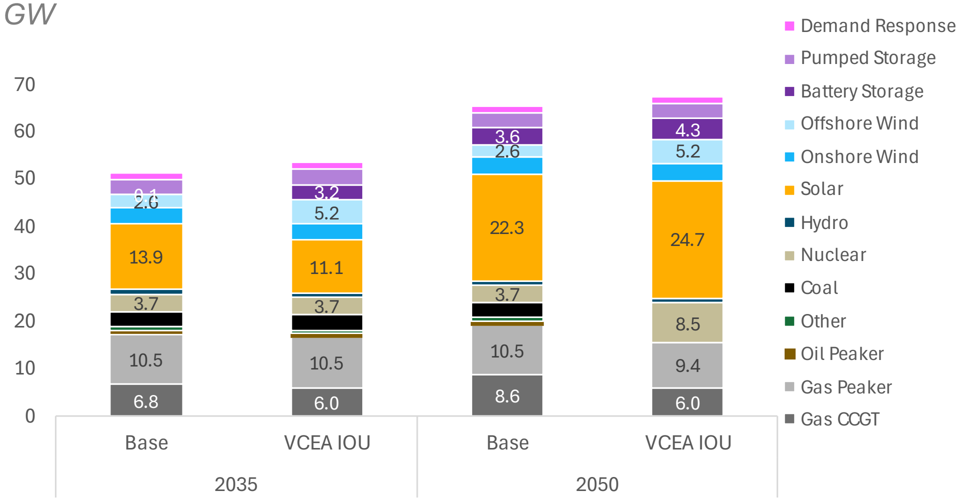
Achievement of VCEA Goals without Data Center Growth

1. **In the No Growth scenario without the VCEA, Virginia is projected to meet new demands through an expansion of solar and battery energy storage capacity, coupled with a moderate increase in natural gas generation capacity to meet reliability needs**
2. **In the No Growth scenario, achievement of the VCEA is projected to drive the development of new nuclear capacity (in the form of SMRs), additional solar builds, as well as conversion of gas facilities to hydrogen to meet system reliability needs**
    1) Incremental investments in renewable capacity driven by the VCEA are moderate and not outsized relative to planned and economic-driven investments
        1) Solar and battery storage are projected to be an economic part of Virginia's portfolio, with or without the VCEA
        2) In the near to medium term, the VCEA technology targets also drive the build-out of additional offshore wind, reducing the state's reliance on natural gas
    2) In the longer term, the VCEA requires the retirement of all carbon-emitting generation by 2045, which leads to a build-out of substantial amounts of nuclear capacity to replace generation from coal and gas, as well as a conversion of gas-fired units to hydrogen to remain online for electric system reliability needs, i.e. maintaining acceptable loss of load probability on a system level

Virginia Installed Capacity (S1A)
GW



Virginia Installed Capacity [1]
GW



[1] Unless otherwise noted, all gas capacity shown for VCEA cases in 2050 throughout this report represents gas resources that are converted to run hydrogen for compliance with state policy.

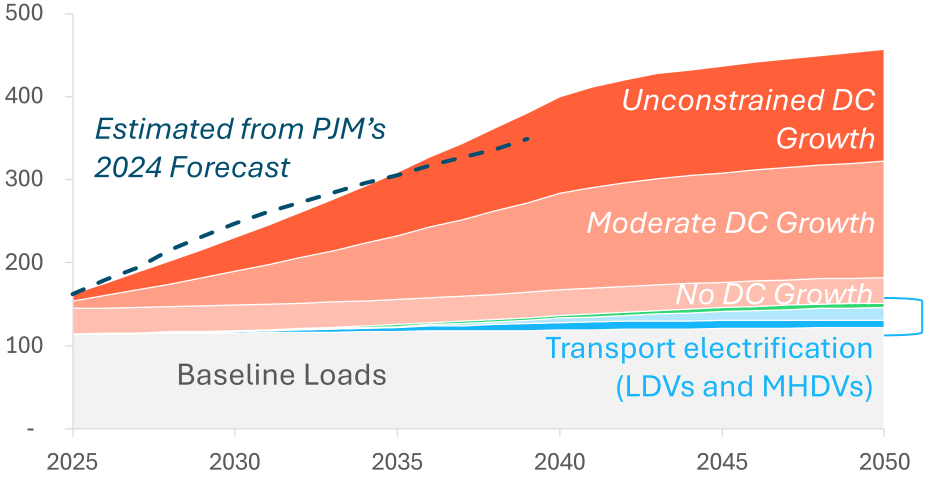
Key Findings | Electric Infrastructure (2/4)

Impacts of Data Center Growth on Total Demand and System Reliability Needs

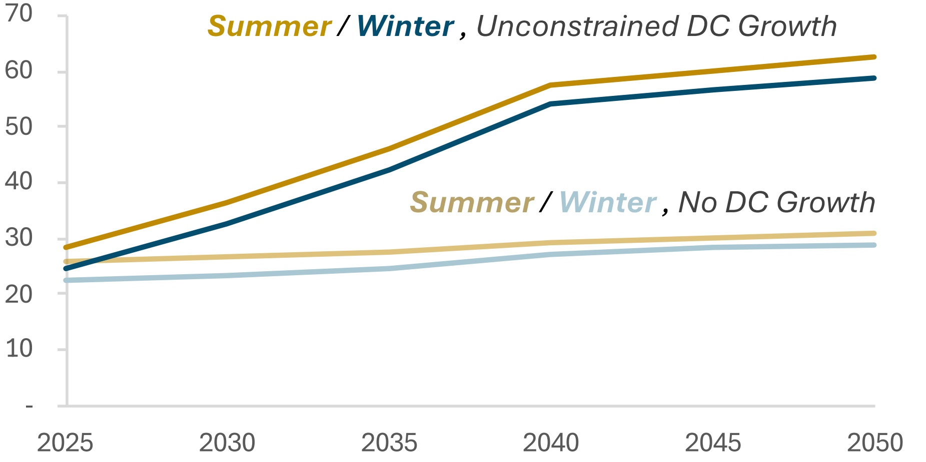
3. **If current trends continue, data center load growth could lead to as large as a tripling of electric sector demand in Virginia in the Unconstrained Data Center Growth scenarios, relative to today's levels, by 2050**

4. **This level of large and sustained demand growth driven by a single large customer type would be unprecedented in recent U.S. history, and would place significant pressure on system planners' ability to build sufficient generation, transmission, and distribution infrastructure to keep pace**
   1) Peak demand in Virginia could increase to over 60 GW, requiring substantial investments in new infrastructure
   2) While data center computing loads do not vary significantly between seasons or within a day, the sheer volume of data center growth shifts the timing of reliability needs to times when total facility demand is marginally higher due to cooling needs, in the summer afternoons and evenings
   3) The high cooling demand of data centers which typical peak in afternoon summer hours, creates opportunities for synergistic pairings of solar and battery storage although their reliability contributions eventually saturate. Large quantities of firm, dispatchable capacity will also be needed to meet demand growth reliably

Virginia - Annual Load Projection (TWh)



Virginia - System 1-in-2 Peak Projection (GW)

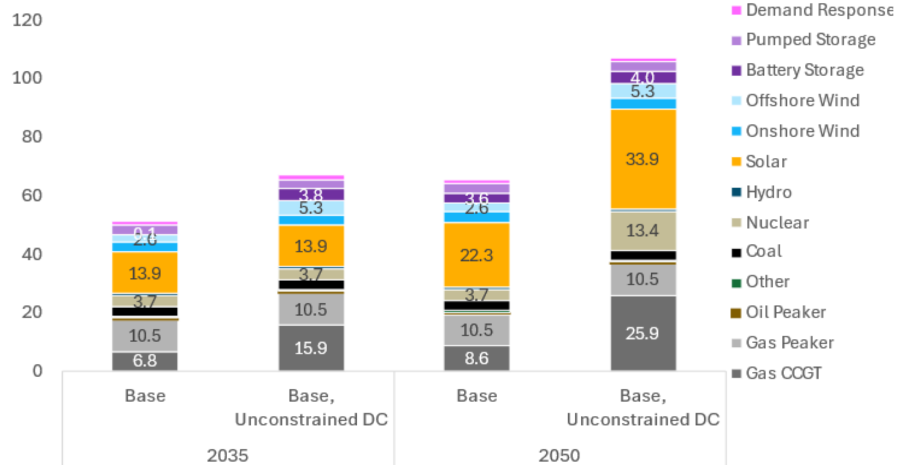


Key Findings | Electric Infrastructure (3/4)

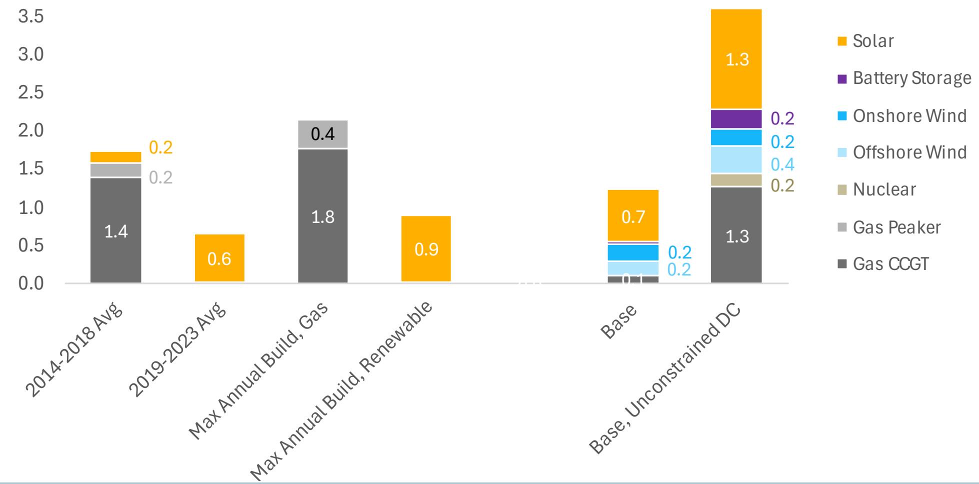
Impacts of Data Center Growth on Electric Infrastructure Needs

5. **In the absence of state policy, data center load growth is projected to drive a build-out of a diverse mix of resources, including gas, solar, nuclear, offshore wind, and battery storage**
6. **Without the VCEA in place, data center growth could lead to a significant increase in the region's reliance on gas generation**
    1) This expansion of gas capacity and generation would also lead to up to an ~80% increase in electric sector GHG emissions in the state; however, current EPA regulations would limit the run-times of new gas units and lead to a significant build-out of low-carbon generation as well, including new nuclear generation to meet baseload energy demands
7. **Meeting demand growth would require sustaining a very high pace of new capacity additions through 2040, including new resources that have not been widely deployed today such as SMRs and offshore wind**
    1) The pace of needed, continual electric infrastructure development is high compared to recent history (3.6 GW/yr needed on average over the next 15 years, compared to a historical single-year high of 2.2 GW/yr)
    2) As a result, infrastructure constraints could act as a constraint on data center growth in the near to medium term

Virginia Installed Capacity
GW



Annual Build Rate, Virginia [1]
GW/yr



[1] Scenario build rates represent the annual average build rate between 2025-2040.

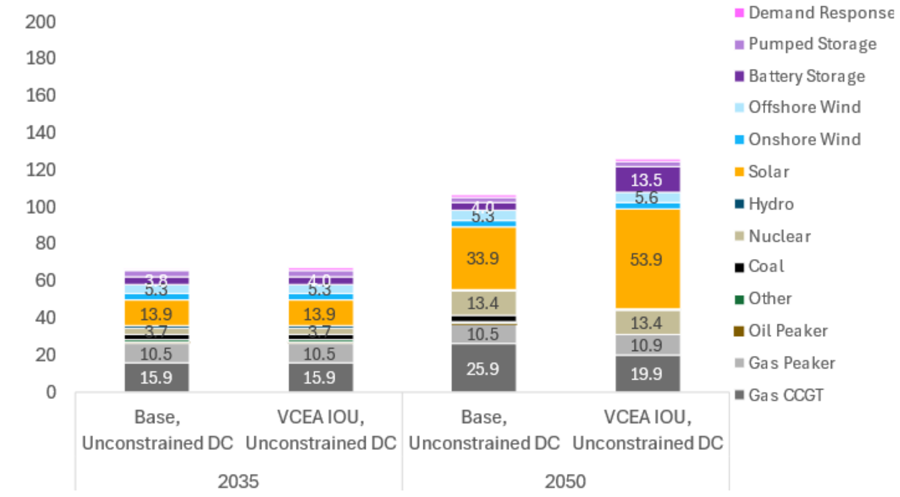
Key Findings | Electric Infrastructure (4/4)

Achievement of VCEA Goals with Data Center Growth

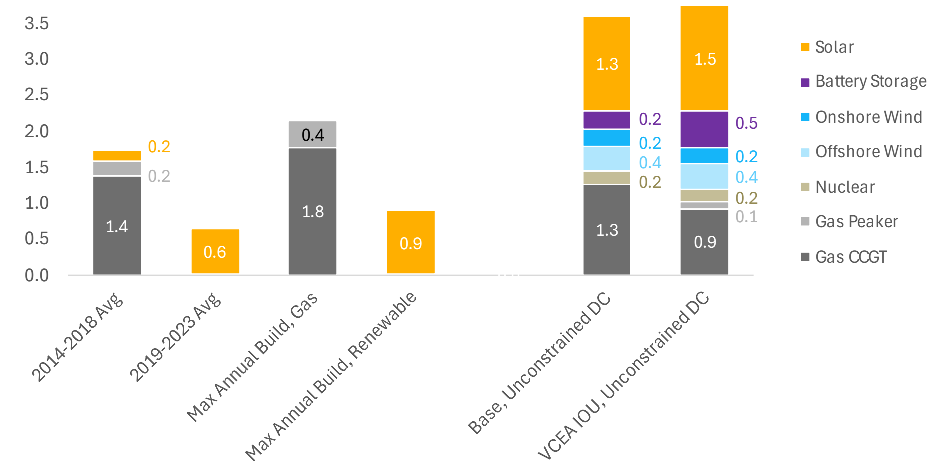
8. With the VCEA in place, Virginia would likely require unprecedented investments to accelerate the deployment of both existing and emerging clean energy resources

1) Under high levels of data center growth, achievement of the VCEA would drive a sustained acceleration of solar deployment compared to recent history (1.5 GW/yr over the next 15 years, compared to a single-year high of 0.9 GW/yr)
2) Achievement of the VCEA would also require transformative investments in several long lead-time resources by 2050, including new nuclear capacity (10 GW), hydrogen-capable combustion turbines (31 GW of new builds and retrofits) and associated production and delivery infrastructure, as well as new transmission capacity (8.7 GW) and a significant increase in the state's reliance on market purchases
    1) Building out one of these resources at the scale envisioned under this scenario would be challenging but potentially feasible with a significant investment of time and resources; however, building out each of these resources at this scale in parallel would require a sustained mobilization of capital and planning staff
3) In total, meeting unconstrained demand growth with clean energy would require a build-out of over 3.8 GW/yr between 2025-2040, including new nuclear, hydrogen, and offshore wind, compared to a single-year high of 2.2 GW/yr

Virginia Installed Capacity [1]



Annual Build Rate, Virginia [2]



[1] Unless otherwise noted, all gas capacity shown for VCEA cases in 2050 throughout this report represents gas resources that are converted to run hydrogen for compliance with state policy.
[2] Scenario build rates represent the annual average build rate between 2025-2040.

Key Findings | Retail Rate Equity

1. **Current rates appropriately apportion costs to classes and customers responsible for incurring them including large loads like data centers, which means there has been no historic cost shifting based on our analysis**
2. **Load growth is expected to increase system costs in Virginia with some effects directly attributable to new large loads (i.e., data centers)**
3. **Fixed costs associated with generation and transmission are difficult to effectively assign; these represent the largest sources of potential ratepayer inequity with data center growth vs. distribution costs that can be more easily assigned to specific customers**
   1) Generally, specific load interconnection costs (such as at the distribution level) are easily assessed and recovered; likewise, incremental variable costs associated with energy or demand, can also be effectively measured and assigned
   2) Periodic adjustment of retail rate design and cost allocation factors will mitigate some impacts of potential and unintended cross-subsidization between rate classes; however, without frequent and precise adjustments and/or significant rate reform, the cumulative impact of data center load growth is projected to cause cost shifts between ratepayers that may be inequitable
4. **Ultimately, while it is possible to scale the existing, embedded (average cost based on existing infrastructure) rate structure to accommodate data center loads accounting for the marginal costs to serve that new load in a manner that is equitable for existing ratepayers, the cost shifting risk from a variety of sources makes the path to navigate that transition complex and potentially narrow**
   1) One such source of risk, beyond the scope of this study, would be the impacts of the scale of investments (and associated risk of those investments) on utility balance sheets, which has the potential to raise borrowing costs and thus increase costs for existing ratepayers
   2) Adjustments to rate structures can be implemented to reduce risks and improve proper apportioning of costs while still promoting strong economic development and allowing access to potential benefits associated with data center growth; tools to mitigate rate impact might include: Improving frequency of updates for cost allocation factors; assessing additional charges for data centers that further balance costs; improving forecasting of data center demand through features like a waitlist for service that can derisk load attrition; implementation of long-term service commitments that may include more significant minimum charges, ramping provisions, exit fees, and/or contract length; promoting self supply of resources; or more direct assignment of new infrastructure costs as well as increased credit or collateral protection for the utility and its ratepayers

Key Sources of Uncertainty | Infrastructure

Scenario analysis was performed to examine uncertainty surrounding load growth trajectories as well as the impacts of VCEA compliance. However, there are many sources of uncertainty that warrant further exploration that were not examined within this study.

Key sources of uncertainty that would impact the infrastructure findings include but are not limited to:

+ **Magnitude and timing of computing loads |** This study examined two scenarios for future computing load growth provided to E3 by the Weldon Cooper Center at UVA. The study assumed that data center loads in Virginia continue to primarily consist of flat, inflexible/non-interruptible load, due to the attractiveness of low latency infrastructure in Virginia. However, advances in chip efficiency, overall data center design and power usage, and/or ability to utilize on-site or adjacent generation resources could reduce the amount of power that needs to be supplied to data centers. Additionally, some portion of projected data center load may be used for artificial intelligence training, which is expected to be a much more flexible load relative to conventional computing because it may have less stringent latency requirements as well as response time in addition to future AI driven workloads that may also not require stringent latency requirements with flexibility on completion timing.
+ **Federal and regional policy uncertainty |** This study kept demand growth in the rest of the PJM region consistent across scenarios, leveraging PJM's publicly available forecast, e.g. it includes data center load growth across the region. Additionally, the modeling assumed that all states meet their currently legislated policies and do not alter their policy ambition, and that existing federal policies (e.g. Inflation Reduction Act, EPA carbon limits) remain in place. As an interconnected market, any shifts in the overall supply and demand balance in the rest of PJM will impact Virginia's own infrastructure needs and associated costs as well as the overall PJM market prices for energy and capacity along with regional renewable energy credit or environmental attribute prices.
+ **Resource costs |** This study leveraged publicly available cost projections to represent the costs of future technologies, relying primarily on the Annual Technology Baseline "Mid" trajectory published by the National Renewable Energy Laboratory, with adjustments to reflect regional and state-specific costs for materials, labor, etc. The trajectory of future technology costs is uncertain, and that uncertainty grows over time; this study did not explore the sensitivity of results to changes in the future costs of technologies.
+ **Resource availability and pace of deployment |** This study applied near-term constraints that limited the pace of technology additions to historical maxima; after 2035, the model was unconstrained in its build-out of resources (although costs are escalated within a given region as lower-cost sites are exhausted). However, siting, permitting, and interconnection processes are time-intensive and the pace of resource additions may continue to be limited by regional, state, and/or local constraints on development. E3 notes that all new bulk system infrastructure, including nuclear, new natural gas, new renewables, energy storage, and new transmission, each face constraints on their development.
+ **Emerging technologies |** This study assumed that new nuclear power plants, and in the VCEA case, hydrogen-fired combustion plants, would be available after 2035. However, neither of these technologies has been deployed at commercial scale to-date, and if either or both of these resources do not become commercially available, this would alter Virginia's portfolio under each scenario. Each of these technologies also faces even greater cost uncertainty than technologies that are available today given their readiness levels.
+ **Transmission and imports |** Related to policy uncertainty in the rest of PJM, this study assumes that Virginia is able to continue – and in many scenarios, expand – its reliance on imported capacity and energy from the PJM market. If the market is more constrained than projected, Virginia may not be able to expand its trading capabilities across the region.

Key Sources of Uncertainty | Retail Rate Equity

Scenario analysis was performed to examine uncertainty surrounding load growth trajectories as well as the impacts of VCEA compliance; however, there are a number of sources of uncertainty that warrant further exploration that were not examined within this study.

In addition to the sources of uncertainty detailed above for the infrastructure analysis, key sources of uncertainty that would impact the retail rate equity findings include but are not limited to:

+ **Risk of load departures |** There is a fundamental misalignment in the timescales of investments being made in generation and transmission infrastructure relative to the lifetime of data center facilities. Electric infrastructure consists of long lifetime assets (often 30+years) whose costs are allocated to electric ratepayers across many decades. However, data center facilities depreciate quickly, and this presents risks that companies and facilities choose to leave the region or that their demand shrinks considerably, in which case infrastructure would be "overbuilt" and remaining customers on the system – including residential ratepayers – would be required to pay significantly more in order for the utility to recover the costs of its investments.

+ **Impacts on PJM market prices |** Although this study captured Virginia's position within the broader PJM market, the model assumes that the market is able to reach equilibrium in the long run. However, constraints on the pace of infrastructure development, coupled with high levels of data center growth, has the potential to place continued strain on region-wide capacity, energy, and renewable energy credit prices. The resulting market scarcity, and corresponding increases in prices, could place additional pressure on non-data center customers. This may also trigger various market reforms and actions by other market participants that impact price formation in the PJM market which was not analyzed.

+ **Impacts of expenditures on utility balance sheets |** The scale of investments required to meet data center load growth can place significant pressure on an investor owned utility's balance sheet or a public utility's borrowing ability as it brings on more capital to finance these investments. This may in turn lead to increasing costs given the scale of the capital and perceived risk around the utilization and recovery of the costs including a fair return on these infrastructure investments, which could impact all utility ratepayers.

+ **Rate design of utilities not examined in this study |** While this study performed a detailed review of rate design for utilities where major data center development is expected to occur, like NOVEC and Dominion, there may be other utilities in Virginia that manage data center costs and load growth in ways not considered herein including novel structures.

Study Background

Data Center Growth in Virginia

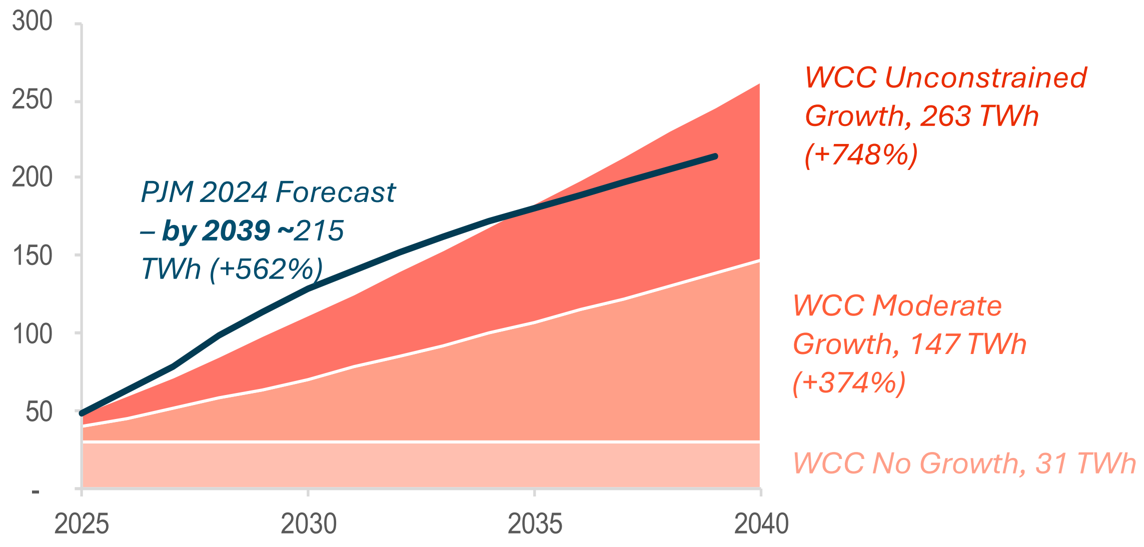
+ **Northern Virginia has the highest concentration of data centers globally and remains the fastest-growing market**
  - About 70 percent of **global internet traffic** flows through northern Virginia, according to certain estimates[1]
  - Most facilities are served by Dominion Energy, an investor-owned utility that is the state's largest load serving entity (LSE)
  - The rest of the state is a secondary market, with the central and southern regions seeing increasing development, served by Northern Virginia Electric Cooperative (NOVEC) and other non-profit co-ops
+ **The recent boom in data center growth has driven a significant uptick in energy demand in Virginia**
  - Dominion's 2024 IRP highlighted that metered data center demand growth doubled from 2017 to 2020 and again from 2020 to 2024
  - This growth is not expected to subside soon, with Dominion forecasting data center peak demand reaching 9 GW (contributing to a 25% increase above current total system peak) in the next 10 years
  - However, there is significant uncertainty around key variables that could greatly reduce demand forecasts, such as processor efficiency improvements and new technologies such as liquid cooling
+ **Data center growth is impacting the broader PJM region as well**
  - PJM capacity market auction prices recently hit record highs, due in part to a significant increase in energy demand from data centers, combined with supply challenges such as from power plant retirements and congested interconnection queues
  - These increased costs can lead to higher rates for customers across the region, including neighboring states
+ **Geographically, data center demand is and will likely continue to be highly uneven, with data centers tending to cluster, suggesting Virginia will continue to be a major market**

[1] Source: https://www.novaregion.org/1598/Data-Centers; https://www.vedp.org/news/dawn-data

Data Center Growth Scenarios

- **UVA's WCC researches a wide variety of issues and provides data and services to communities, governments and public sector leaders, with particular expertise in Virginia energy markets, policy and demand forecasting**
- **WCC developed load projections for 3 data center growth scenarios**
  - The Unconstrained and No Growth scenarios serving as bookends to illustrate the difference between a sustained unconstrained growth BAU scenario vs. a counterfactual of no growth post 2023
  - The WCC scenario projections focused on data center growth in Virginia, assuming it is all located in the DOM transmission zone (including customers of Dominion, NOVEC, and Rappahannock)
    - The PJM public forecast was used for data centers outside DOM and VA - in AEP, APS, and East – and kept constant across scenarios
  - The WCC "Unconstrained" projections are generally aligned with the public 2024 PJM load forecast
- **WCC also provided load projections for Virginia for baseline loads and vehicle electrification loads by utility, in order to capture the rest of the Commonwealth's system with the same level of detail**

Virginia - **Data Center Load Projections**
Annual Load, TWh

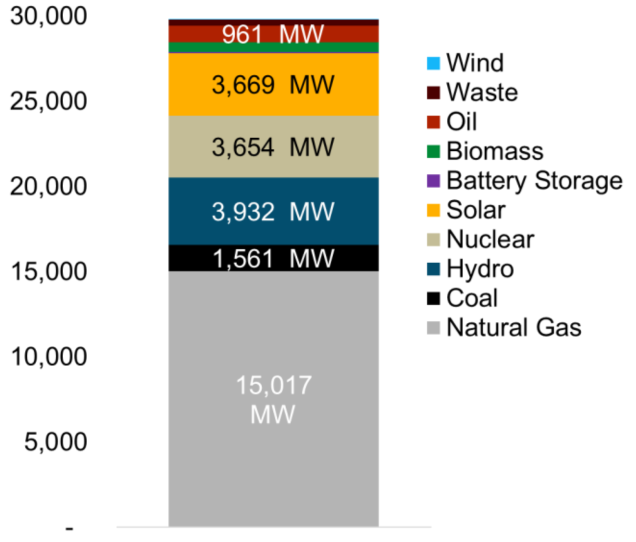


Note: WCC data center growth projections were developed for Virginia, assuming all growth occurs in the DOM transmission zone. Unless otherwise specified, all references to demand and infrastructure build-out in the Dominion area or "DOM Zone" throughout this deck refer to the entire **Dominion transmission zone** within PJM, not just sales and generation provided by the Dominion utility.

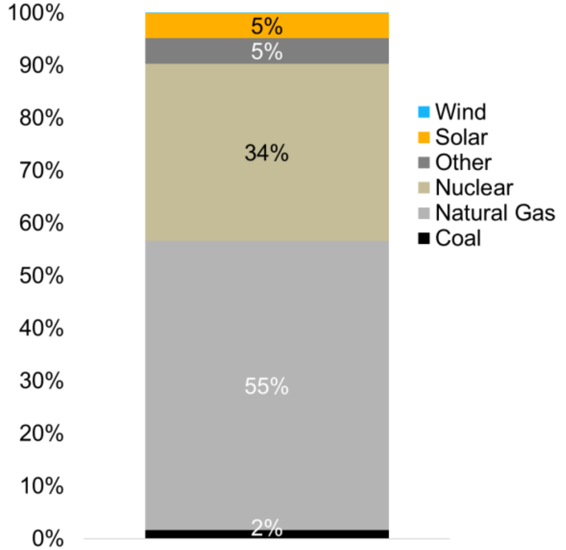
Electric Resource Mix in Virginia | 2023

- Virginia's existing resource mix is largely natural gas, representing 50% of the installed capacity and 55% of in-state generation in 2023
- Nuclear was the second largest segment representing 12% of installed capacity and 34% of generation in 2023
- While renewables are only a minority of Virginia's existing resource mix, solar and storage makes up a large share of capacity in the Interconnection Queue (55% solar; 33% storage)

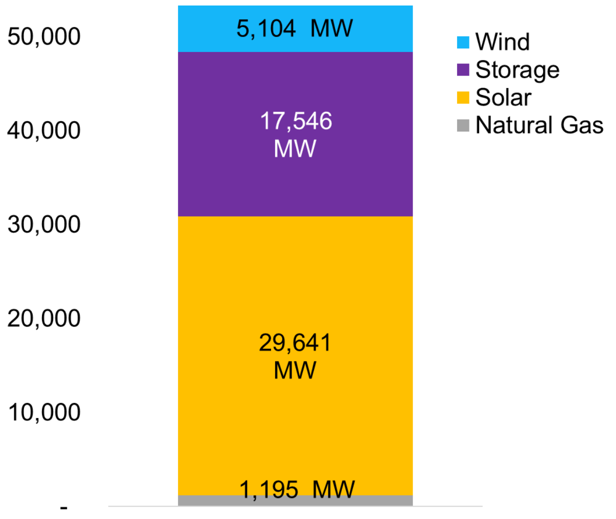
Virginia Existing Capacity 2023 [1]
MW



Virginia Annual Generation 2023 [2]
% of generation mix



Virginia Queued Capacity "Active" in PJM Queue as of April 1, 2024 [2]
MW



[1] EIA, 2023 [2] https://pjm.com/-/media/library/reports-notices/state-specific-reports/2023/virginia.ashx

Policy Landscape in Virginia

- **In 2020, the Virginia legislature passed the Virginia Clean Economy Act (VCEA), which commits the state to an ambitious clean energy transition via several key provisions:**
  - Zero-Carbon Electricity: Established a mandatory renewable portfolio standard (RPS) program requiring the investor-owned utilities such as Dominion Energy and American Electric Power (AEP) to deliver electricity from renewable and other zero-carbon sources by 2045 and 2050 respectively
    - 100% of sales not met by non-renewable forms of zero-carbon electricity (e.g. nuclear) must be supplied by renewables
    - Of the zero-carbon electricity supplied by renewables, 75 percent of generation must be supplied by in-state projects; the remaining 25 percent can be supplied in the form of "unbundled" RECs purchased from out of state renewable projects
    - 16 GW of in-state solar and onshore wind, 5 GW of offshore wind and 3 GW of energy storage were determined to be "in the public interest"
    - Requires the retirement of existing fossil fuel plants by 2045 except when addressing specific reliability concerns; prior to 2045; requires the SCC to consider the social cost of carbon when considering construction of a new generating facility
  - Established schedule of noncompliance deficiency payments, starting at $45 to $75 per MWh and increasing by 1% annually after 2021
  - The legislation also includes important provisions to advance Environmental Justice and Energy Efficiency objectives, which are not modeled and are beyond the scope of this study
- **Status of VCEA Compliance and Planning**
  - Utilities in the state, including Dominion, have expressed concerns about costs and implementation timelines in light of projected data center demand growth
    - Dominion's 2024 IRP stated the modeled compliance case, with no new gas and no fossil retirements by 2045, is infeasible due to the unrealistic amount of imports and renewable builds that would also cause reliability concerns
    - SCC has indicated concerns, such as in response to past IRPs, about Dominion's progress in complying with VCEA and identifying least cost options
- **Virginia recently attempted to withdraw from the Regional Greenhouse Gas Initiative (RGGI); however, the Circuit Court of Floyd County recently ruled that the withdrawal was unlawful and without effect. This study assumed no RGGI requirement for Virginia since the analysis was performed prior to the recent court ruling**

https://energy.virginia.gov/renewable-energy/documents/VCEASummary.pdf
https://cdn-dominionenergy-prd-001.azureedge.net/-/media/pdfs/global/company/irp/2024-irp-w_o-appendices.pdf?rev=c03a36c512024003ae9606a6b6a239f3
https://www.governor.virginia.gov/newsroom/news-releases/2023/june/name-1005558-en.html

Scope of Work

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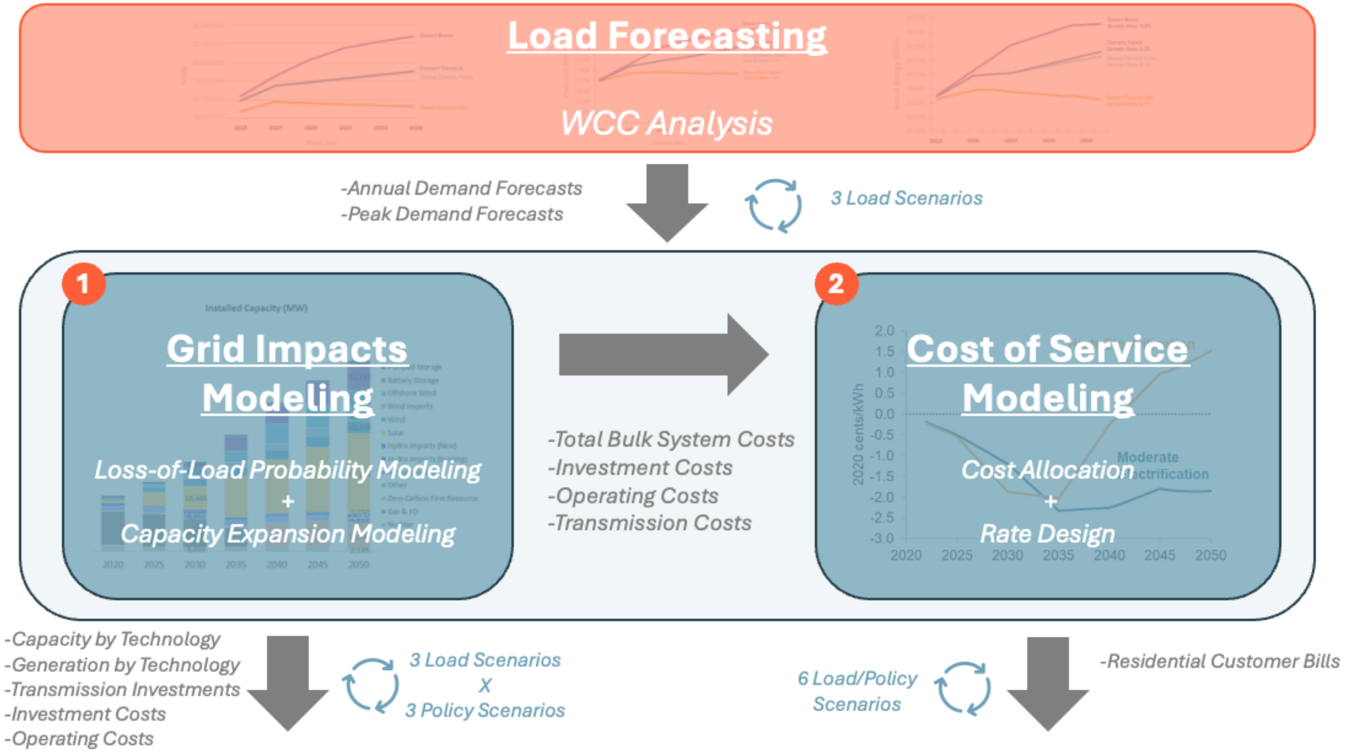
Scope of Work and Analytical Framework

- E3 was commissioned by JLARC to examine the impacts of data center growth on electric infrastructure needs and associated costs, as well as the distribution of these costs across customer classes
- Data center growth projections under a Moderate and Unconstrained scenario were provided by WCC as inputs into E3's analysis
- E3 leveraged its in-house electric sector models, RECAP[1] and RESOLVE[2], to identify the least-cost portfolios to meet load growth while also achieving policy goals and maintaining reliability
- Electric sector infrastructure investments were then assessed through a Cost of Service framework to examine existing and modified rate designs and the distributional impacts of these investments under different methods

[1] https://www.ethree.com/tools/recap-renewable-energy-capacity-planning-model/
[2] https://www.ethree.com/tools/resolve/



The Grid Impacts Modeling included the entire PJM region while focusing on data center load growth projections from WCC for the DOM transmission zone. The Cost of Service assessment then focused on three load-serving entities within the DOM transmission zone (Dominion, Mecklenburg electric co-op (MEC), and Northern Virginia electric co-op (NOVEC)).

Electric Infrastructure Study Overview

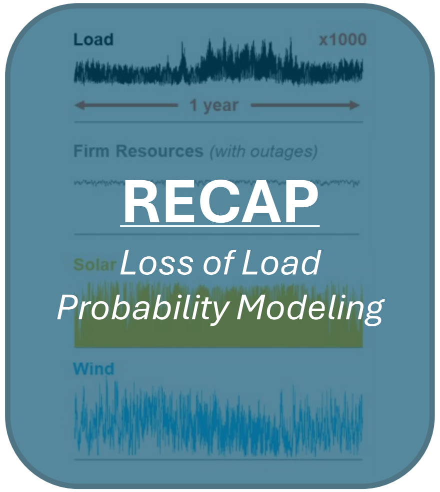
Key Objective of Infrastructure Analysis: Examine electricity system infrastructure and associated investments required to meet the VCEA goals under a wide range of potential data center-driven load growth scenarios

To perform this work, E3 leveraged a ***capacity expansion model*** *in tandem with a* ***loss of load probability model****, in order to ensure the resulting portfolios are reliable over a broad range of weather conditions.*

E3 modeled the entire PJM region within its capacity expansion framework to allow more detailed examination of the interaction between Virginia and the broader market in the context of rapid data center growth. However, by design we did not model the PJM market construct precisely in terms of price formation of energy and capacity prices.

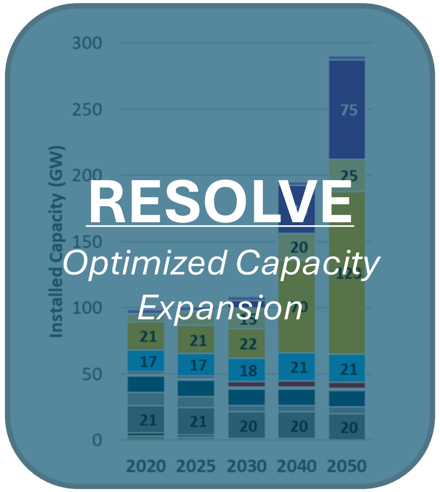
This analytical framework identifies the total infrastructure requirements but does not distinguish between utility-owned infrastructure vs. 3rd party owned vs. "behind-the-meter" generation at data center facilities.

1a Use LOLP model to quantify "effective load carrying capability," which measures contribution of each resource to reliability across 100s of simulations



Technology ELCC curves →

← *Optimized Portfolios*



1c Use LOLP model to simulate resulting portfolios across wide range of conditions, validating resource adequacy

1b Use capacity expansion to optimize future portfolios to meet reliability and clean energy goals while minimizing cost

Rate Impact Study Overview

Key Objective of Rate Impact Analysis: Determine if current rate and fee structures lead to an equitable distribution of costs between data centers and other customers

How does the magnitude and pace of data center growth in Virginia influence these cost components?

Where do data center rates exist on this spectrum?

What is the range of equitable outcomes?

Marginal Costs	New Costs	Contribution to Fixed Costs
Data Centers must pay at least their marginal costs of service to avoid shifting the burden inequitably to existing customers	**New costs may be direct (e.g., administrative) or indirect (e.g., network upgrades) and may be difficult to quantify or assign**	**Contributions by data centers to system fixed costs benefit existing customers; however, excessive contributions are inequitable to data centers**

Overview of Scenarios and Sensitivities (1/2)

Scenarios for this analysis were constructed to examine the impacts of data centers on the Virginia electric system along two dimensions:

1. **Levels of data center growth**
   - [Counterfactual] No Data Center Growth ("S1" cases)
   - Moderate (half of Unconstrained) Data Center Growth ("S2" cases)
   - Unconstrained Data Center Growth ("S3" cases)
2. **Levels of VCEA achievement**
   - [Counterfactual] No VCEA Compliance ("A" cases)
   - Achievement of VCEA by Investor-Owned Utilities ("B" cases)
     - The VCEA only applies to investor-owned utilities, and electric co-operatives are exempt from the VCEA requirements; in other words, the "B" cases are consistent with current law.*
   - Full Statewide Achievement of VCEA requirements ("C" cases)
     - By 2045 around 62% of the projected data center loads in Virginia are served by co-operatives in WCC's forecast; E3 examined the full statewide achievement cases for better understanding of a potential bookend scenario

All scenarios include current "on-the-books" federal policies, including the Inflation Reduction Act and EPA carbon dioxide regulations, as well as current state policies and targets in the rest of PJM; exploring scenarios incorporating potential changes to currently enacted policies and rules was outside the scope of this study

VCEA Achievement →

Higher Data Center Growth ↓

S1A *No data center growth; non-compliant with VCEA*	**S1B** *No data center growth; IOUs comply with VCEA* *(current requirements)*	**S1C** *No data center growth; all statewide sales meet VCEA* *(beyond current requirements)*
S2A *Moderate data center growth; non-compliant with VCEA*	**S2B** *Moderate data center growth; IOUs comply with VCEA*	**S2C** *Moderate data center growth; all statewide sales meet VCEA*
S3A *Unconstrained data center growth; non-compliant with VCEA*	**S3B** *Unconstrained data center growth; IOUs comply with VCEA*	**S3C** *Unconstrained data center growth; all statewide sales meet VCEA*

*All references to VCEA compliance scenarios in the JLARC Report refer to existing VCEA requirements, or the "B" scenarios. Full statewide achievement of the VCEA in the "C" scenarios is strictly exploratory and only for reference in the E3 Report.

Overview of Scenarios and Sensitivities (2/2)

+ **Across all core scenarios analyzed, constraints were implemented within the model to reflect the feasibility of building out new resources in Virginia within a given timeframe, based on historical pace of build, expected constraints on in-state development such as availability of land, and other factors**
  - Under the most aggressive scenario combining unconstrained data center growth with statewide VCEA achievement (**S3C**), which goes beyond current legislated requirements, E3 also examined bookend sensitivities in which specific constraints were relaxed:
    - **High In-State Renewables**: Higher levels of onshore wind available and accelerated deployment of offshore wind allowed in Virginia and North Carolina
    - **Regional Coordination**: Relaxed constraints on transmission build-out post-2035
    - **Nuclear Renaissance**: No constraints on nuclear build-out post-2035 such as on small modular reactors

VCEA Achievement →

Higher Data Center Growth ↓

S1A *No data center growth; non-compliant with VCEA*	**S1B** *No data center growth; IOUs comply with VCEA* *(current requirements)*	**S1C** *No data center growth; all statewide sales meet VCEA* *(beyond current requirements)*
S2A *Moderate data center growth; non-compliant with VCEA*	**S2B** *Moderate data center growth; IOUs comply with VCEA*	**S2C** *Moderate data center growth; all statewide sales meet VCEA*
S3A *Unconstrained data center growth; non-compliant with VCEA*	**S3B** *Unconstrained data center growth; IOUs comply with VCEA*	**S3C** *Unconstrained data center growth; all statewide sales meet VCEA*

Contextualizing this Study within the PJM Market

- **The modeling framework for this study relied on a PJM-wide capacity expansion framework, which allowed us to endogenously capture key market dynamics between Virginia utilities and the rest of PJM at a high level. This modeling assumes that the region can achieve long-run equilibrium; constraints on the pace of infrastructure development may remain a limiting factor in practice**
- **This study leveraged publicly available inputs and assumptions for the rest of PJM, e.g. using load growth projections from the 2024 PJM load forecast and assuming that all other states in the region meet their existing policy targets**
  - This study was narrowly focused on the impacts of different data center growth trajectories **within Virginia**; in other words, the amount of data center-driven load growth in all other states in the region was held constant across all scenarios at the levels assumed in the PJM 2024 load forecast
  - Similarly, policies in all neighboring states were held constant across all scenarios
- **The capacity expansion framework allowed Virginia utilities to access capacity and RECs from outside of their service territories; however, it is important to note that this was a high-level representation and did not seek to directly capture the nuanced dynamics of capacity and REC markets:**
  - **Capacity:** Dominion was assumed to be able to purchase capacity from the PJM market at a fixed price up to 3 GW, after which it would also need to build new transmission to access firm capacity
  - **RECs:** The capacity expansion model was able to build out-of-state renewables to meet the VCEA, up to the 25% limit. Note that this study did not consider the potential for Accelerated Renewable Energy Buyers to purchase their own RECs, which are not subject to the in-state requirements
- **While beyond the scope of this study, a detailed exploration of the impacts of data center growth on PJM capacity and REC markets is a worthwhile subject for future analysis, in order to more comprehensively understand how changes in these markets and corresponding price impacts will affect affordability in Virginia and the region as a whole**

Data Center Load Growth Projections

Key Finding #3: *If current trends continue, data center load growth could lead to as large as a tripling of electric sector demand in Virginia in the Unconstrained Data Center Growth scenarios, relative to today's levels, by 2050*

Key Finding #4: *This level of large and sustained demand growth driven by a single large customer type would be unprecedented in recent U.S. history, and would place significant pressure on system planners' ability to build sufficient generation, transmission, and distribution infrastructure to keep pace*

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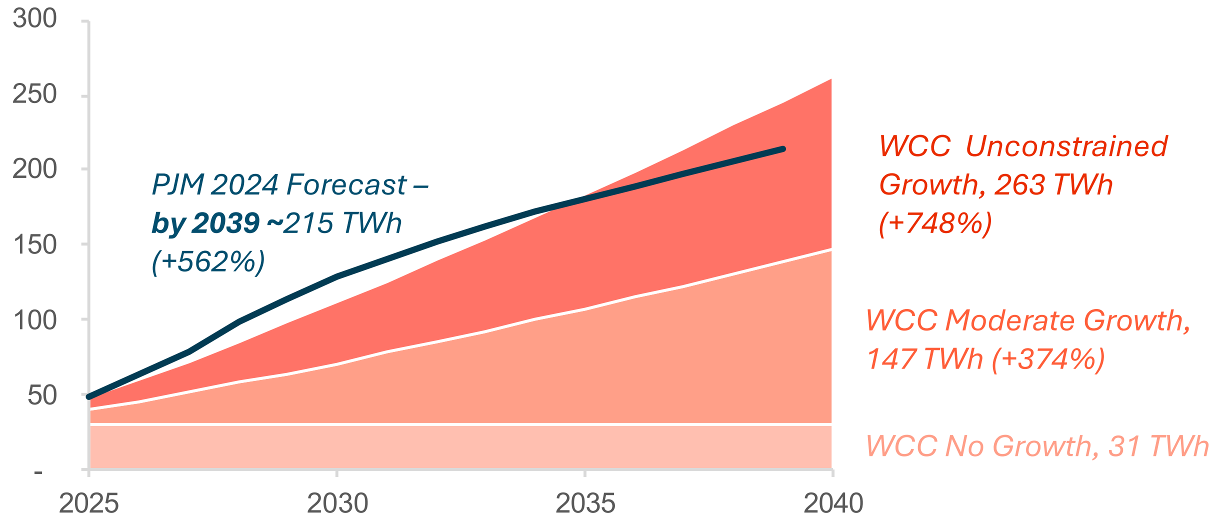
Data Center Load Projections from WCC

- **UVA's WCC developed load projections for 2024-2040 for 3 data center growth scenarios**
  - The Unconstrained and No Growth scenarios serving as bookends to illustrate the difference between a sustained unconstrained growth BAU scenario vs. a counterfactual of no growth post 2023
  - The WCC scenario projections focused on data center growth in Virginia, assuming it is all located in the DOM transmission zone (including customers of Dominion, NOVEC, and Rappahannock)
    - The 2024 PJM public forecast was used for data centers outside DOM and VA - in AEP, APS, and East – and kept constant across scenarios
- **The WCC projections are generally aligned with the 2024 PJM load forecast**
  - PJM forecasted that 2039 peak data center demand in DOM will be close to 25 GW, which translates to ~215 TWh annual loads with E3's estimated load factor and losses

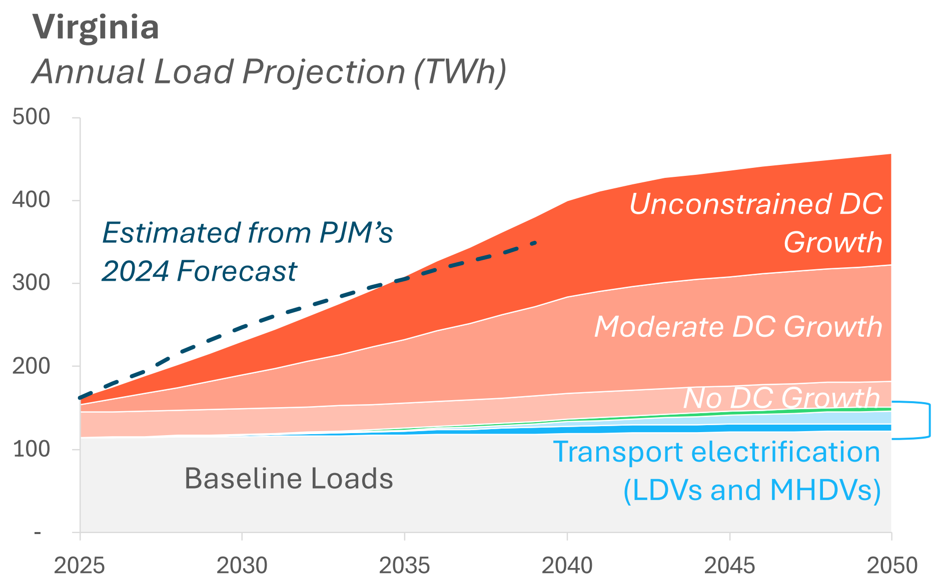
Virginia - Data Center Load Projections
Annual Load, TWh



Note: WCC data center growth projections were developed for Virginia, assuming all growth occurs in the DOM transmission zone. Unless otherwise specified, all references to demand and infrastructure build-out in the Dominion area or "DOM Zone" throughout this deck refer to the entire **Dominion transmission zone** within PJM, not just sales and generation provided by the Dominion utility.

Virginia Annual Load Projections

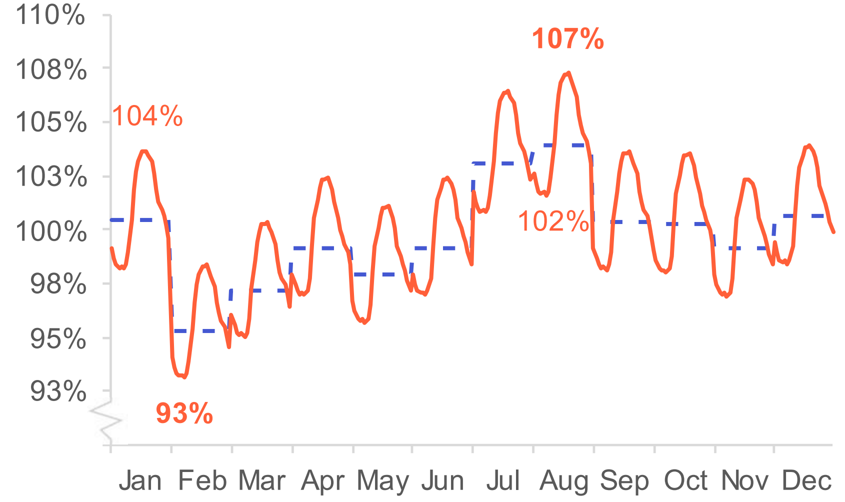
- **WCC also provided projections for Virginia for baseline residential and commercial loads as well as vehicle electrification loads by utility, in order to capture the rest of the Commonwealth's system with the same level of details**
- **Annual energy demand in Virginia, before data centers, grows steadily around 1% per year, leading to a cumulative growth of 26% in Virginia by 2050**
  - The non-data center load forecasts are extended beyond 2040 with constant growth rates
- **The ~300 TWh of data center loads by 2050 under the Unconstrained Data Center Growth scenarios triple loads in Virginia**
  - Only data center loads in Dominion, from WCC's forecast, are assumed for Virginia
  - After 2040, when WCC's forecast ends, E3 assumes data center load growth slows down to 1%/year



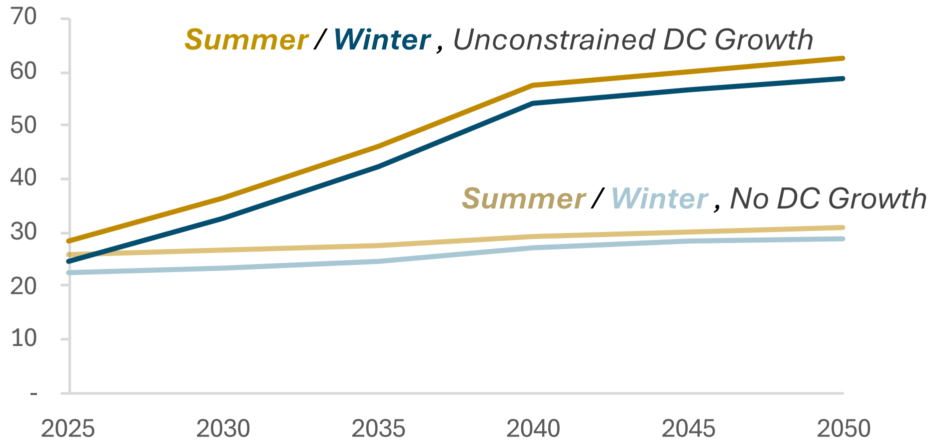
Peak Load Projections

+ **Peak demand is calculated by applying hourly load profiles for the baseline loads, electrification loads, and data center loads, respectively**
+ **In the next few decades, baseline load and transportation electrification load grows steadily in both Virginia and PJM-wide**
    - In both regions, system slowly transitions from summer peaking to dual peaking by 2050, without data center load growth
+ **With the growth of data centers, the system remains summer peaking in Virginia**
    - Data centers more than double Virginia's peak load by 2050 in the Unconstrained Growth case
    - The difference between summer and winter data center peak loads is only around 3%, but given the magnitude of these loads this effect is noticeable

Month-hour Data Center Load Profile
% of average annual load



Virginia - System 1-in-2 Peak Projection (GW)



Grid Impact Analysis

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Modeling Framework and Key Assumptions

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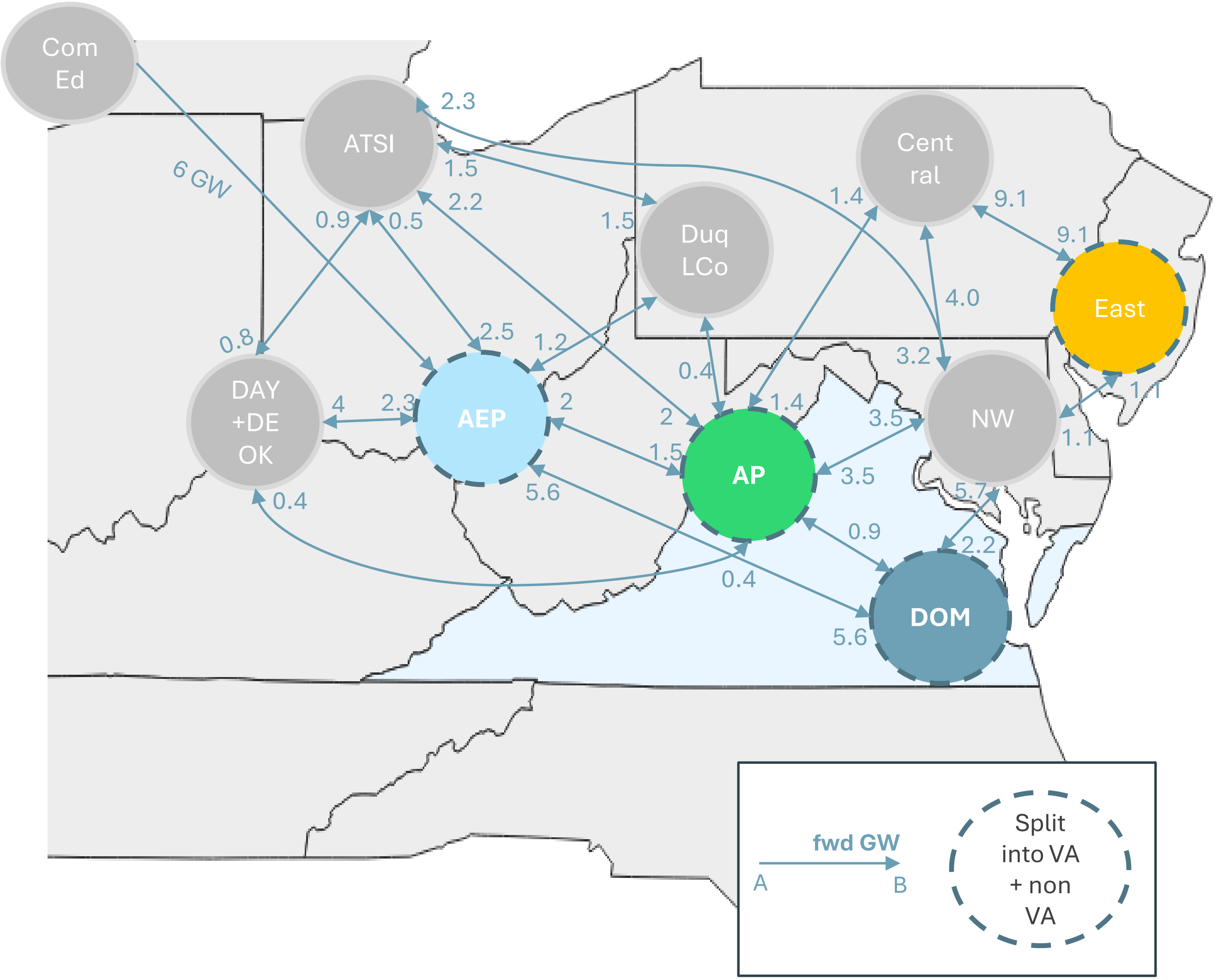
Capacity Expansion Topology

+ **E3 modeled capacity expansion for the PJM market in RESOLVE with 10 load and capacity zones - with those overlapping with Virginia (DOM, AEP, AP, East) broken into VA vs non-VA subzones**
  - This topology allows us to model VA specific assumptions and constraints (e.g. WCC's load forecast and VCEA policies) while capturing the broader market dynamics within PJM
  - Transmission constraints between these zones are derived from information provided by Energy Exemplar
  - Transmission upgrades between DOM and its neighboring zones (AEP, AP, and NW) are modeled as an option to allow more detailed examination of transmission infrastructure upgrade needs to support data center load growth in Northern Virginia
+ **The modeling horizon covers 2025-2050 for this study**



Key Modeling Assumptions

+ **Load Forecasts** derived from information provided by WCC and published by PJM (2024)
+ **Existing Resources** grouped by zones, technology, fuel, and quality tiers (e.g. high/mid/low heat rates for thermal units)
  - Planned resources expected through 2027/2028 included as expected additions
+ **Candidate Renewable Resource Potential** drawn from the National Renewable Energy Laboratory's (NREL) ReEDS supply curve
  - Potentials, capacity factors, and interconnection costs for solar PV, onshore wind, and offshore wind candidate resources
+ **Candidate Resource Costs** developed leveraging NREL's 2024 Annual Technology Baseline (ATB) forecast and standard E3 financing assumptions
  - Includes escalating local network upgrade costs for renewables which are developed based on transmission projects recently approved by PJM in the DOM zone, in addition to the specific resource interconnection costs from NREL ReEDS
+ **Policy Assumptions**
  - EPA regulations, post 2030, constrain new gas builds to a 40% annual capacity factor and require existing coal units to co-fire with natural gas
  - RGGI modeled for participating states (NJ, MD, DE) in the East transmission zone, with price forecast developed by E3
  - States' RPS policy and clean energy carveouts modeled
  - VCEA requirements considered in the VCEA compliance scenarios

Regional and Sub-Regional Resource Build Limits

+ **Build limits are implemented by technology, location, and future model year**
  - *Resource potentials* - Based on NREL ReEDs and with further adjustments, each resource type has a **total potential build amount** available for each of several subzones (also known as NREL's "p-zones"). These potentials inform the **quality and location** for an exhaustive list of candidate resources.
  - *Interconnection limits* – Based on geographical location relative to the grid and **how much new transmission would need to be built** to link resources to the existing grid. These limits also dictates the **pace of resource potential availability** over the modeling period, assuming further out resources are not available right away in 2030 and 2035.
  - *Build rate limits* – Based on historical build rates and the interconnection queue by zone and by technology, the model constrains **how much can reasonably be built by 2030** (more stringent) and by 2035 (less stringent) in each major zone. These **build rates apply to renewables as well as thermal resources and storage**.
+ **The amount of capacity that can be added in a given area also incurs higher transmission network upgrade costs**
  - *Deliverability limits* – Based on estimated **grid upgrade requirements** in each subzone, new renewable resources need to be accompanied by substation and transmission line upgrades which have their own **implied costs and upgrade rate limits**. Solar and wind resources in the same subzones share the same deliverability limits and required upgrade costs.

Scenario Matrix

Assumptions/Scenarios	No DC Growth No VCEA	No DC Growth With VCEA	Moderate/Unconstrained DC Growth No VCEA	Moderate/Unconstrained DC Growth With VCEA
Load	No Data Center load growth in VA post 2023	No Data Center load growth in VA post 2023	Moderate or Unconstrained Data Center load growth	Moderate or Unconstrained Data Center load growth
VCEA Compliance	No	Yes (IOU or Statewide)	No	Yes (IOU or Statewide)
Existing Thermal	Economic Retirement	Coal/oil/biomass retire in 2045; Gas optional to convert to hydrogen by 2045 with incremental costs	Economic Retirement	Coal/oil/biomass retire in 2045; Gas optional to convert to hydrogen by 2045 with incremental costs
Candidate Renewables, Storage, Gas	Build rate limits through 2035	Build rate limits through 2035	Build rate limits through 2035	Build rate limits through 2035
Hydrogen	Not available	Available [1]	Not Available	Available [1]
SMR (nuclear)	Not available	Available 2035+ with build limits	Available 2035+ with build limits	Available 2035+ with build limits
Capacity Purchases and Transmission Upgrades	Capacity purchase allowed up to 3 GW; No transmission upgrade allowed	Capacity purchase allowed up to 3 GW; No transmission upgrade allowed	Capacity purchase allowed with transmission upgrades required beyond 3 GW; Transmission upgrades allowed post 2035+ with limits	Capacity purchase allowed with transmission upgrades required beyond 3 GW; Transmission upgrades allowed post 2035+ with limits

[1] The consumption of hydrogen for power generation would also require additional fuel delivery and storage infrastructure; the costs of such infrastructure is captured at a high level on a $/MMBtu basis. However, these costs assume that Virginia is able to access a robust regional hydrogen economy that is already in place in the future, and costs would be higher if Virginia is building new / first-of-a-kind infrastructure.

Impacts of Data Center Load Growth on System Reliability Needs

Key Finding #4-2: *While data center computing loads do not vary significantly between seasons or within a day, the sheer volume of data center growth shifts the timing of reliability needs to times when total facility demand is marginally higher due to cooling needs, in the summer afternoons and evenings*

Key Finding #4-3: *The high cooling demand of data centers which typical peak in afternoon summer hours, creates opportunities for synergistic pairings of solar and battery storage although their reliability contributions eventually saturate. Large quantities of firm, dispatchable capacity will also be needed to meet demand growth reliably*

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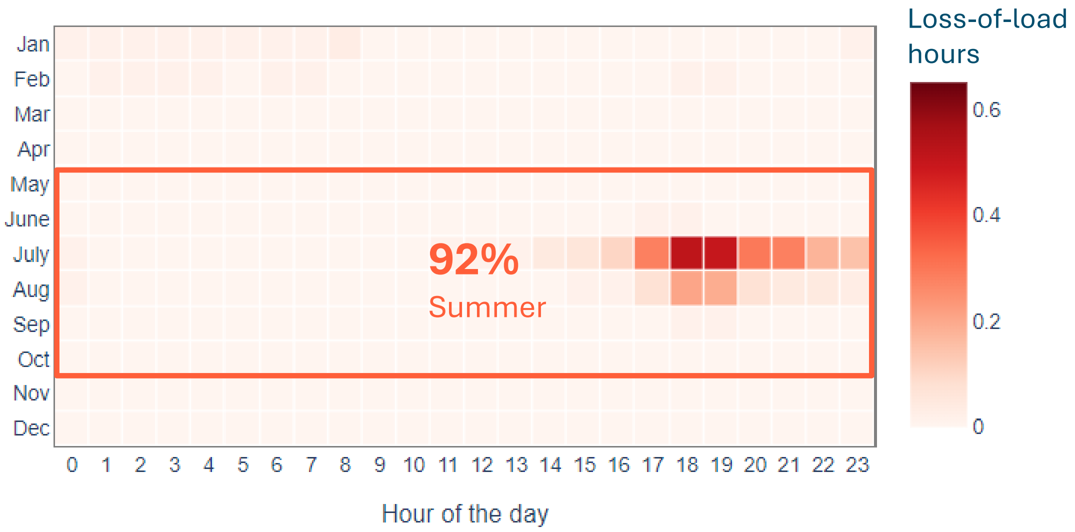
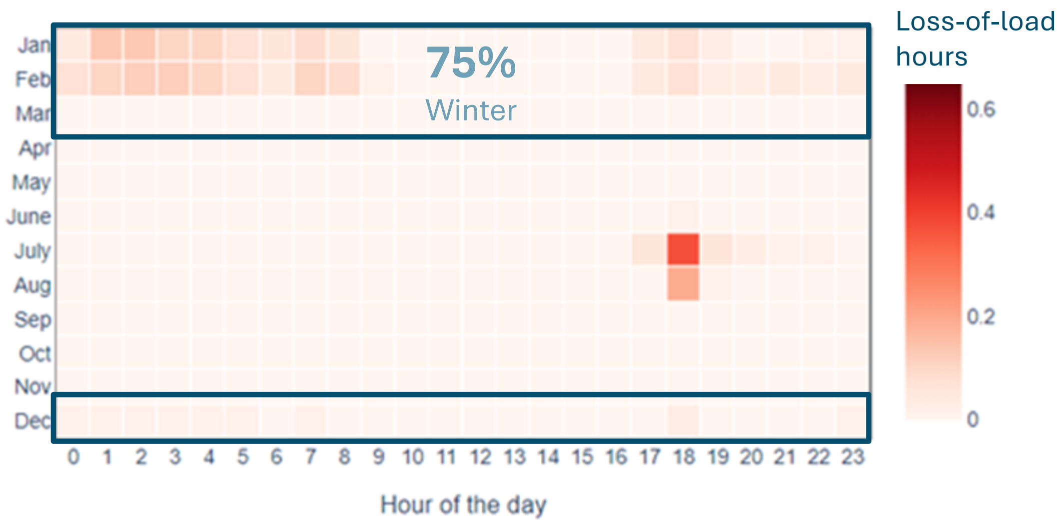
System Reliability Risks without Data Center Growth

- **E3 modeled system reliability needs for the Dominion transmission zone, where all data center growth are projected for Virginia, and the entire PJM, in order to evaluate resource capacity contributions in these areas**
- **In 2025, most of the loss of load risks in Dominion system are observed in summer months**
  - The most challenging periods are concentrated in late afternoons after sunset
- **Without data center load growth, system loss of load risks shift to winter by 2050 when high gross load coincides with thermal unit outages**
  - Resources that can generate during summer early evenings or can provide energy for an extended time window in winter tend to have higher capacity value

2025 – Existing Dominion System



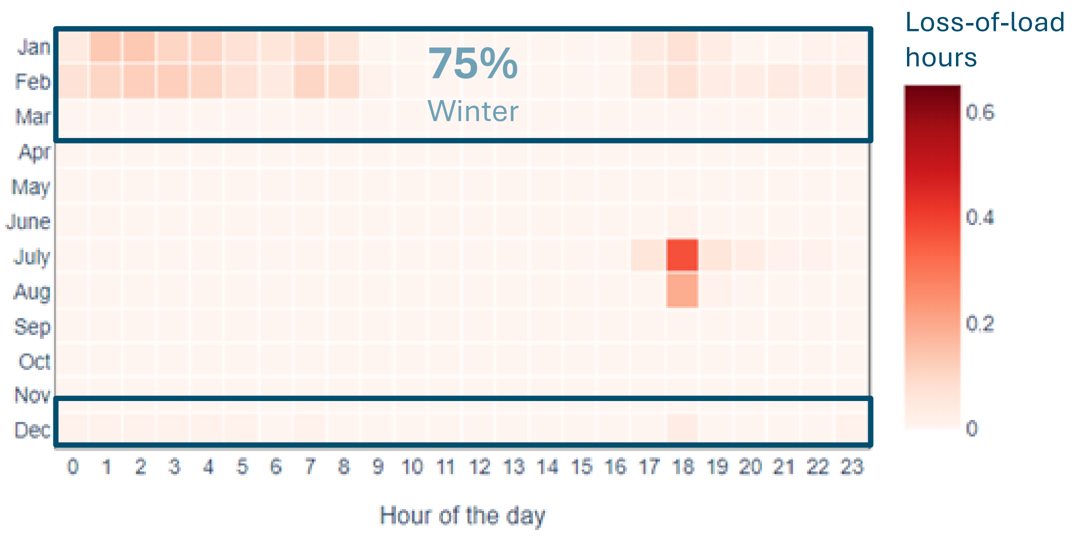
2050 – Dominion System, No Data Center Growth



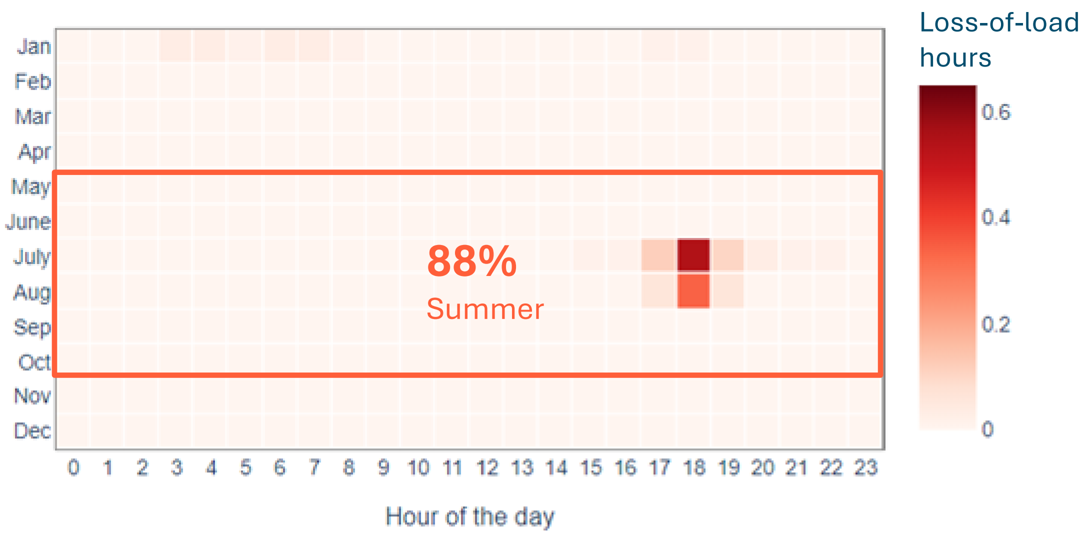
System Reliability Risks with Data Center Load Growth

- Projected annual load for Dominion almost triples by 2050 under the unconstrained data center load growth scenarios
- While data center computing loads do not vary significantly between seasons or within a day, the sheer volume of data center load growth shifts the timing of system reliability needs to times when total facility demand is marginally higher due to cooling needs, in the summer afternoons and evenings
- Resources that can generate during summer early evenings have higher capacity value

2050 –Dominion System, No Data Center Growth



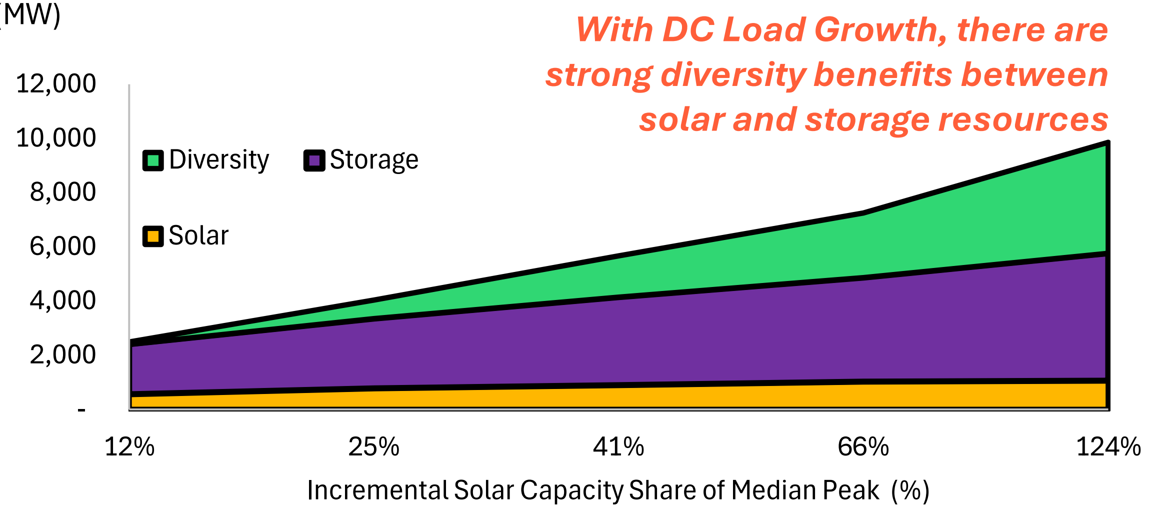
2050 – Dominion System, with Unconstrained Data Center Growth



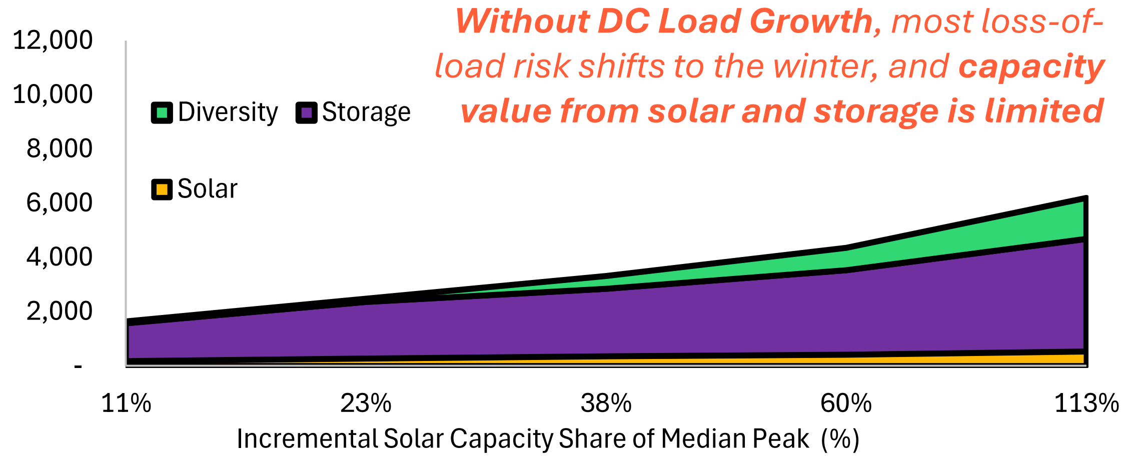
Complementary Reliability Impacts between Solar and Storage

- **Adding solar and storage can quickly exhibit saturation effects, while combinations of the two resources exhibit interactive benefits**
  - Positive interactive effects between solar and storage are referred to as "diversity benefits"
- **This comes from the complimentary nature of the two resources**
  - Abundant solar makes the net load evening peaks sharper, which increases value of limited duration energy storage resources
  - This is more prominent when data center load growth is presented, which creates concentrated reliability challenges in summer afternoons

Combined Capacity Value from Solar +Storage (MW)



Combined Capacity Value from Solar +Storage (MW)



Impacts of Data Center Load Growth on Electric Sector Resource Portfolios

Energy+Environmental Economics

Baseline Results (S1A)

Key Finding #1: *In the No Growth scenario without the VCEA, Virginia is projected to meet new demands through an expansion of solar and battery energy storage capacity, coupled with a moderate increase in natural gas generation capacity to meet reliability needs*

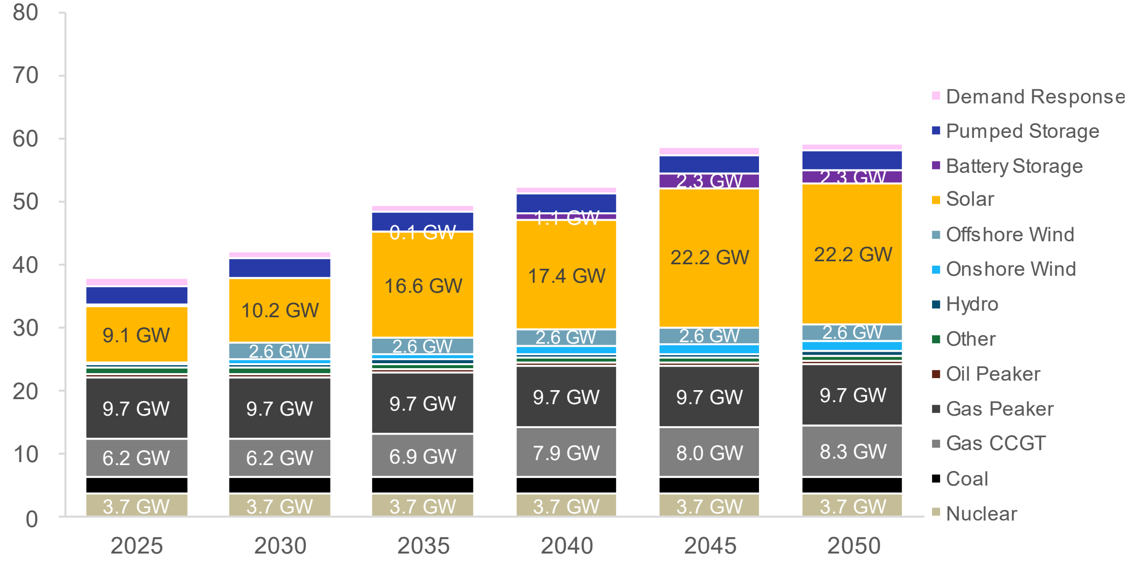
S1A: No Data Center Growth, No VCEA
Dominion – *Capacity and Generation*

S1A

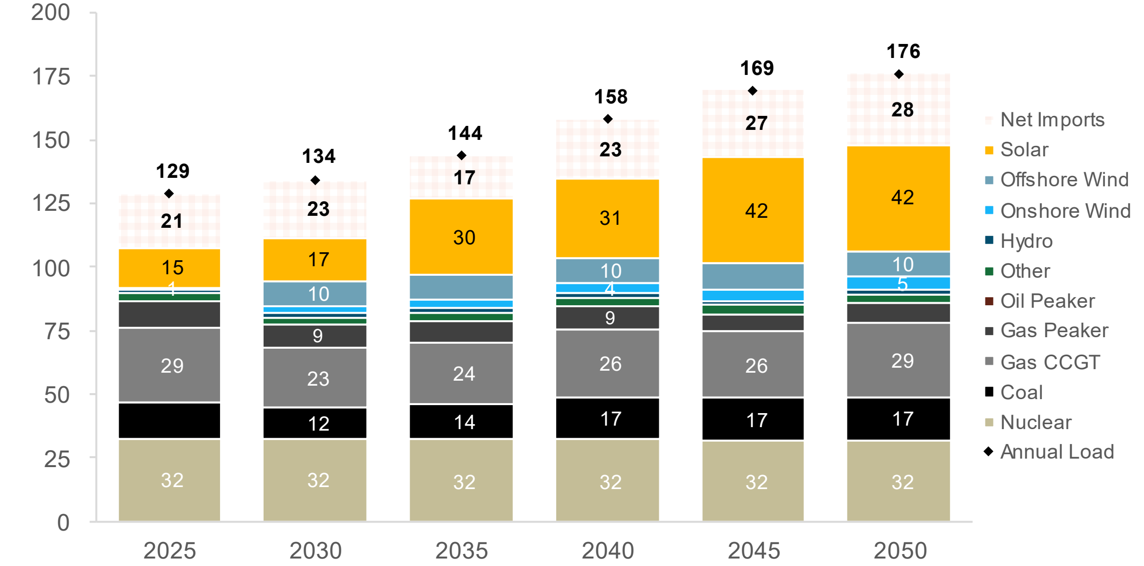
No data center growth; non-compliant with VCEA

- **Majority of increased energy demand is met by growth in solar generation, as costs decline and the Inflation Reduction Act tax credits provide additional support**
- **Storage provides complementary capacity value for solar, and additional reliability needs are met with gas CCGT additions**
  - Onshore wind selected where available, but the total amount is limited considering land and development constraints in Virginia and North Carolina
- **All thermal resources remain online through 2050 in the absence of carbon policy**

Dominion Installed Capacity
GW



Dominion Annual Generation
TWh



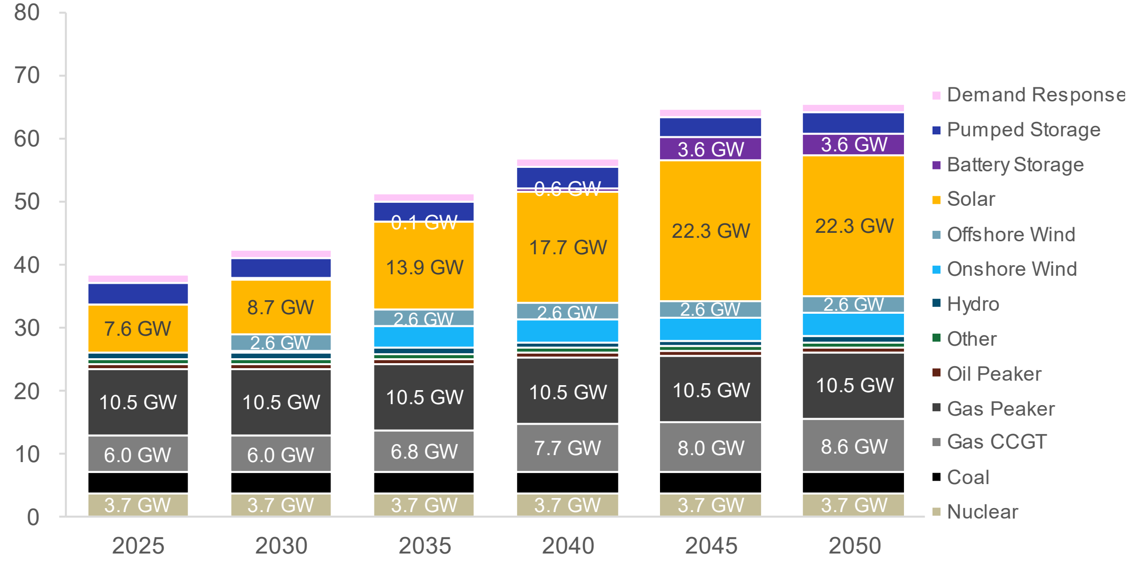
S1A: No Data Center Growth, No VCEA
VA – *Capacity and Generation*

S1A

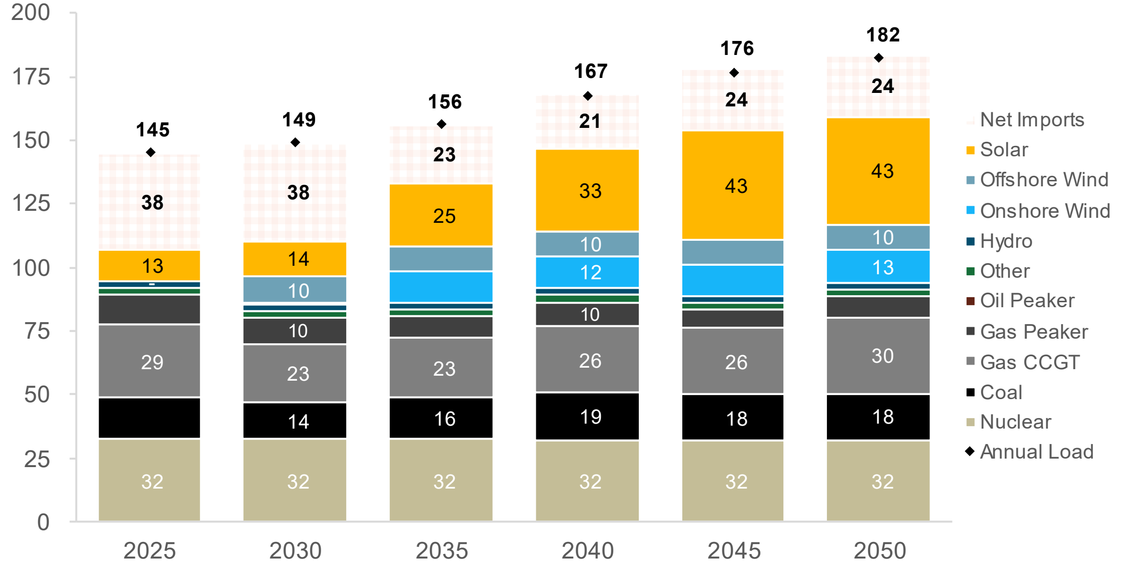
No data center growth; non-compliant with VCEA

- **By 2050, Virginia is projected to meet nearly 24% of its energy demand with solar generation**
- **In the absence of policy, there is still a significant role for coal and gas generation, comprising another ~30% of demand**
- **The remaining demand is met through a combination of nuclear, onshore and offshore wind, and market purchases**

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh

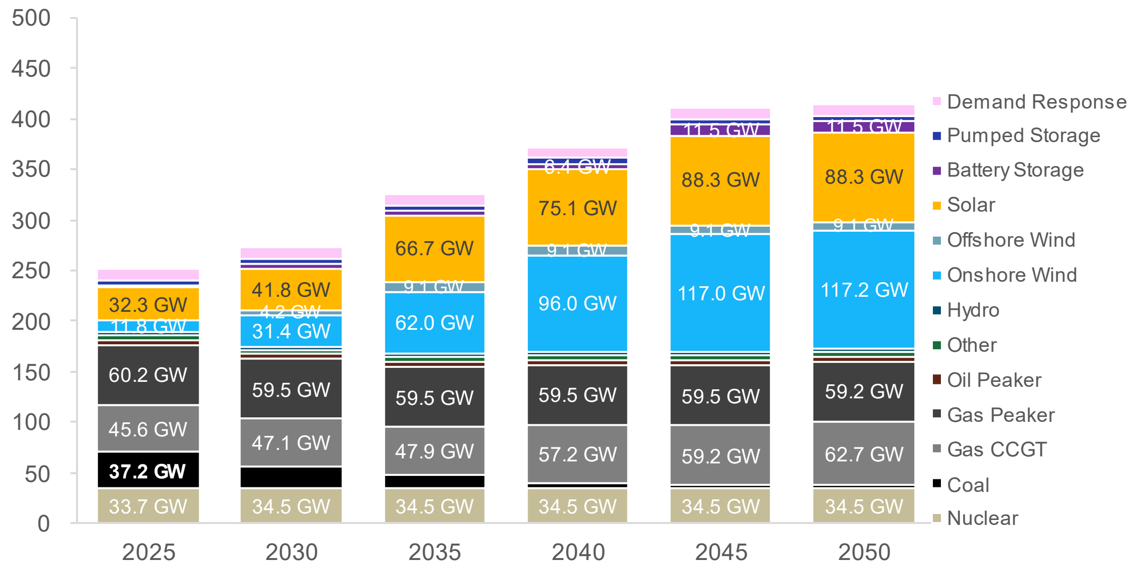


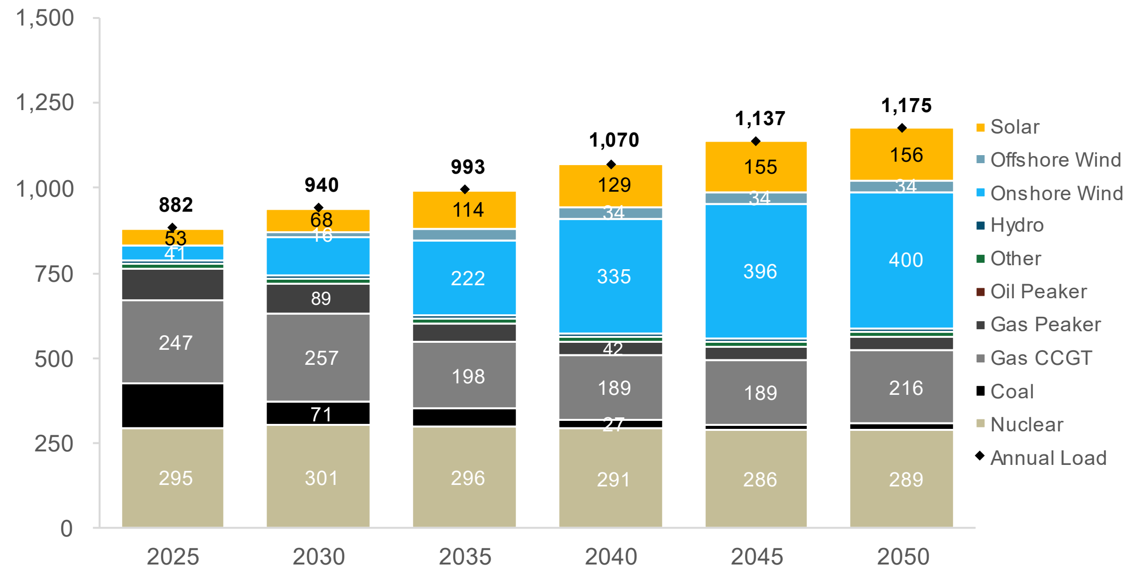
S1A: No Data Center Growth, No VCEA
PJM – *Capacity and Generation*

S1A

No data center growth; non-compliant with VCEA

- **Large amount of coal retirements, coupled with mild demand growth, drive economic additions of onshore wind, solar+storage, and gas CCGT capacity**
  - Significant amounts of onshore wind are added across the PJM region due to strong resources and favorable economics, coupled with the impacts of the Inflation Reduction Act tax credits
- **Renewable generation increases significantly across the PJM region; gas generation declines slightly, due in part to the impacts of EPA regulations on new gas units**





Impacts of VCEA

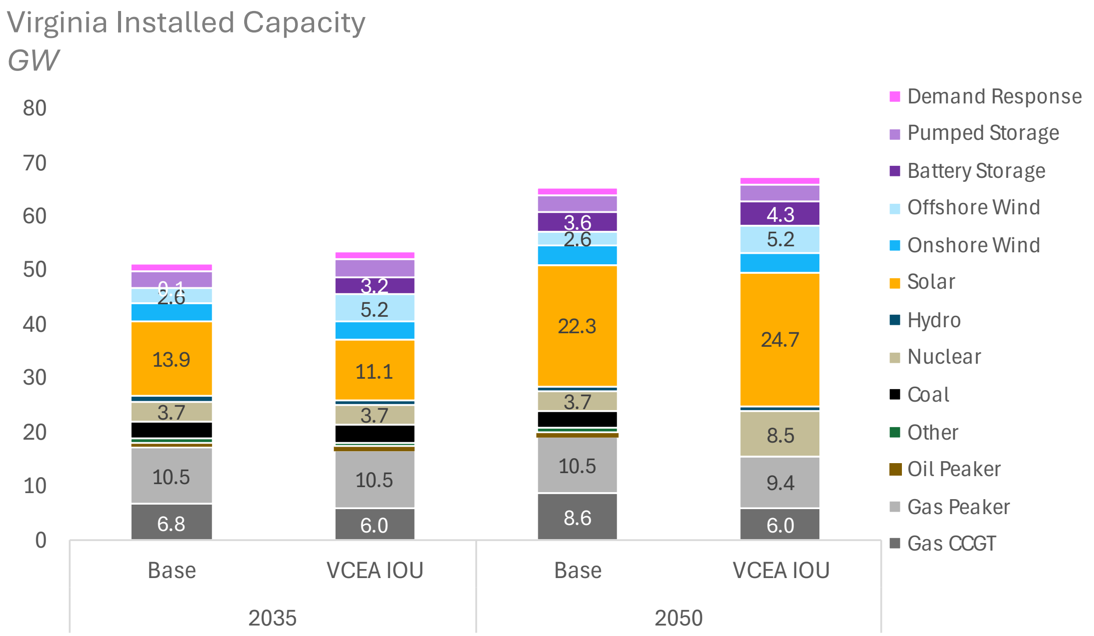
Without Data Center Growth

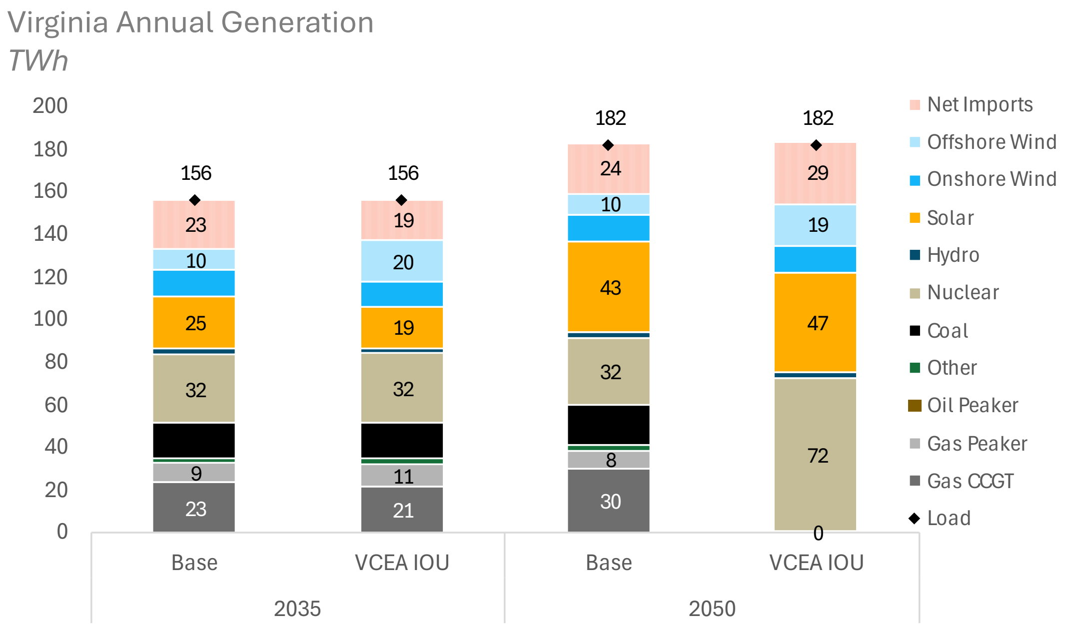
Key Finding #2: *In the No Growth scenario, achievement of the VCEA is projected to drive the development of new nuclear capacity (in the form of SMRs), additional solar builds, as well as conversion of gas facilities to hydrogen to meet system reliability needs*

Impacts of VCEA Compliance: S1B vs S1A VA – *Capacity and Generation*

S1A	S1B
No data center growth; non-compliant with VCEA	*No data center growth; IOUs comply with VCEA*

- **The VCEA has a limited impact in the near term, primarily driving an acceleration of offshore wind builds coupled with additional battery storage resources**
- **In the longer term, the VCEA has a more significant impact, leading to an increase in nuclear capacity, while gas resources are converted to run on hydrogen and remain online to maintain system reliability**



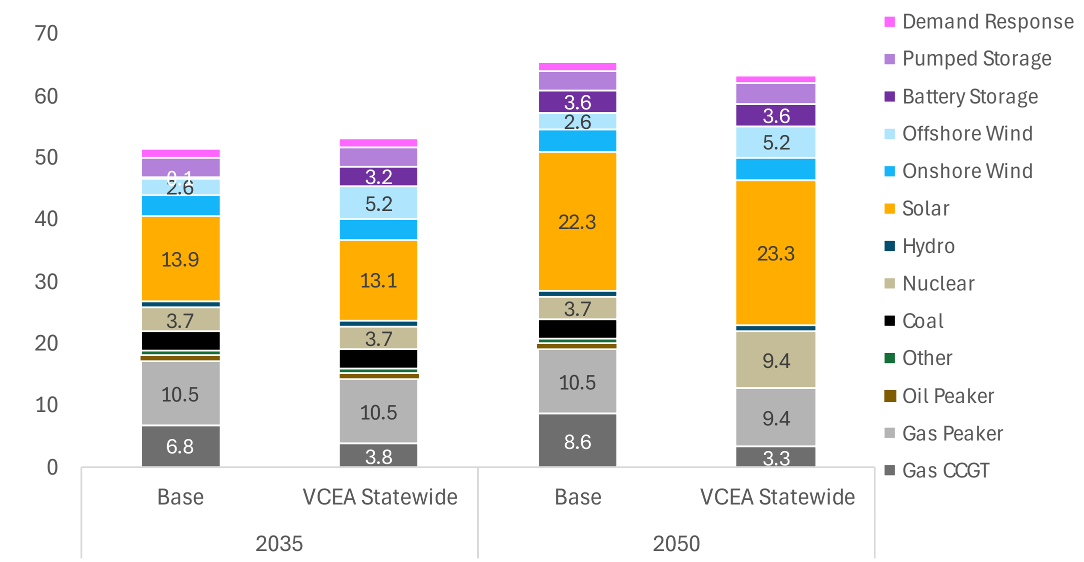


Impacts of VCEA Achievement: S1C vs S1A VA – *Capacity and Generation*

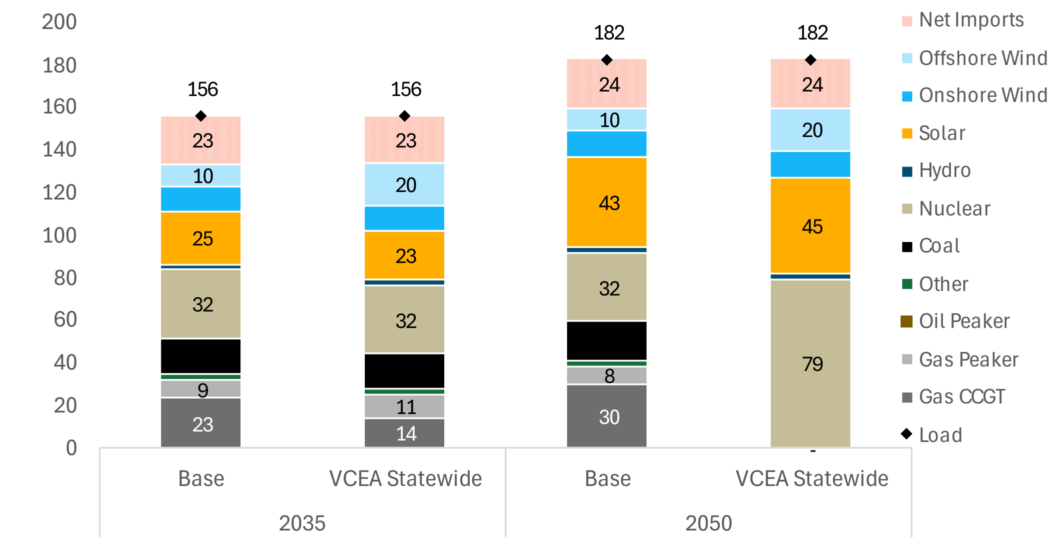
S1A	S1C
No data center growth; non-compliant with VCEA	*No data center growth; all statewide sales meet VCEA*

- Expanding the VCEA requirements to all utilities in Virginia (including co-ops) has marginal impacts on system buildout dynamics in the absence of data center load growth
  - Loads served by electric co-operatives remain a relatively small share of total load in Virginia

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh



Impacts of Data Center Growth

Without VCEA Compliance

Key Finding #5: *In the absence of state policy, data center load growth is projected to drive a build-out of a diverse mix of resources, including gas, solar, nuclear, offshore wind, and battery storage*

Key Finding #6: *Without the VCEA in place, data center growth could lead to a significant increase in the region's reliance on gas generation*

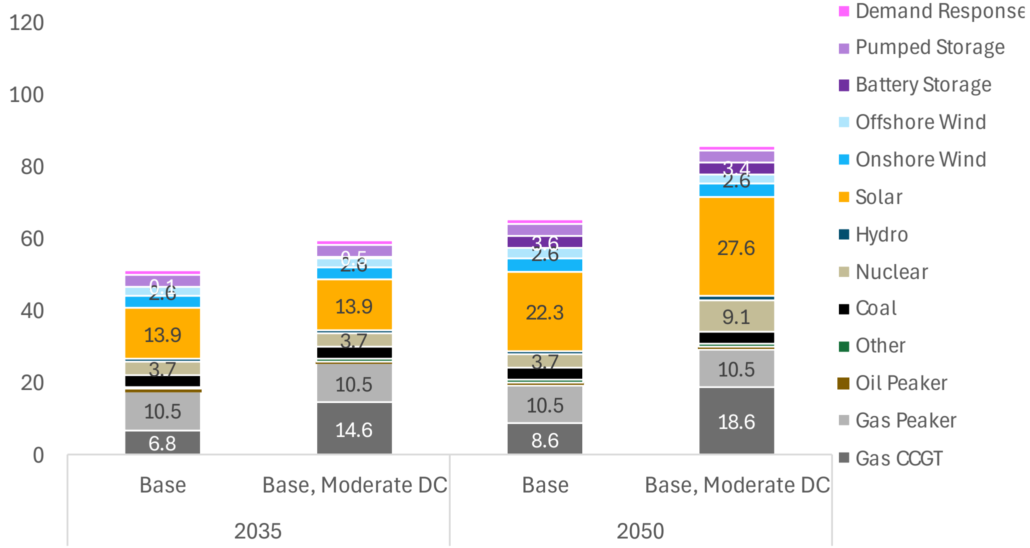
Key Finding #7: *Meeting demand growth would require sustaining a very high pace of new capacity additions through 2040, including new resources that have not been widely deployed today such as SMRs and offshore wind*

Impacts of Data Center Growth: S2A vs S1A
VA – *Capacity and Generation*

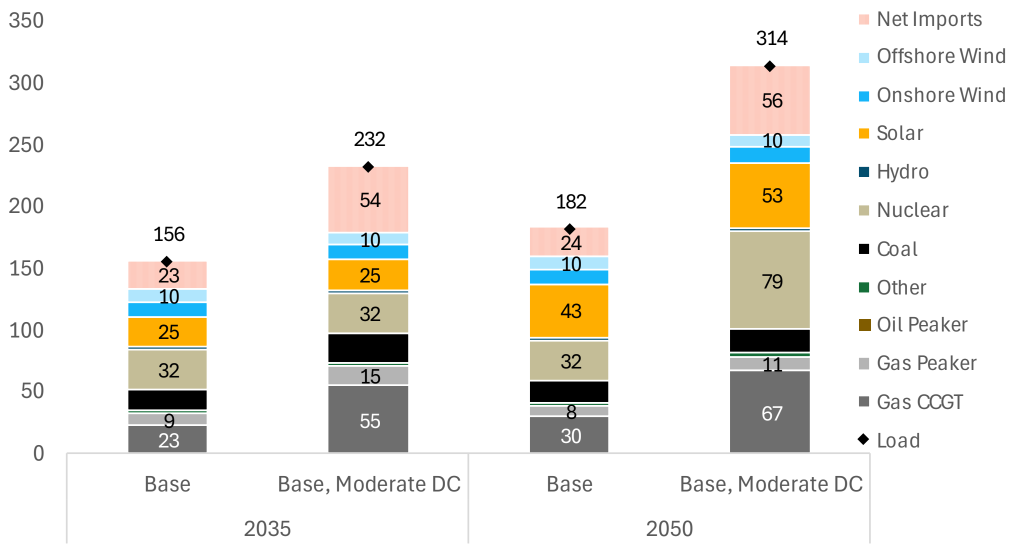
S1A	S2A
No data center growth; non-compliant with VCEA	*Moderate data center growth; non-compliant with VCEA*

- Under Moderate levels of data center growth, Virginia will need to invest in significant new gas capacity over the next decade in order to keep pace with demand growth
- In the longer term, over 5 GW of additional nuclear capacity, along with additional solar and storage capacity, are projected to be added in order to meet increasing energy demands
- Import for Dominion increases compared to the no growth case, driving the need for 3.1 GW transmission expansion between the DOM zone and AP/Northwest

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh



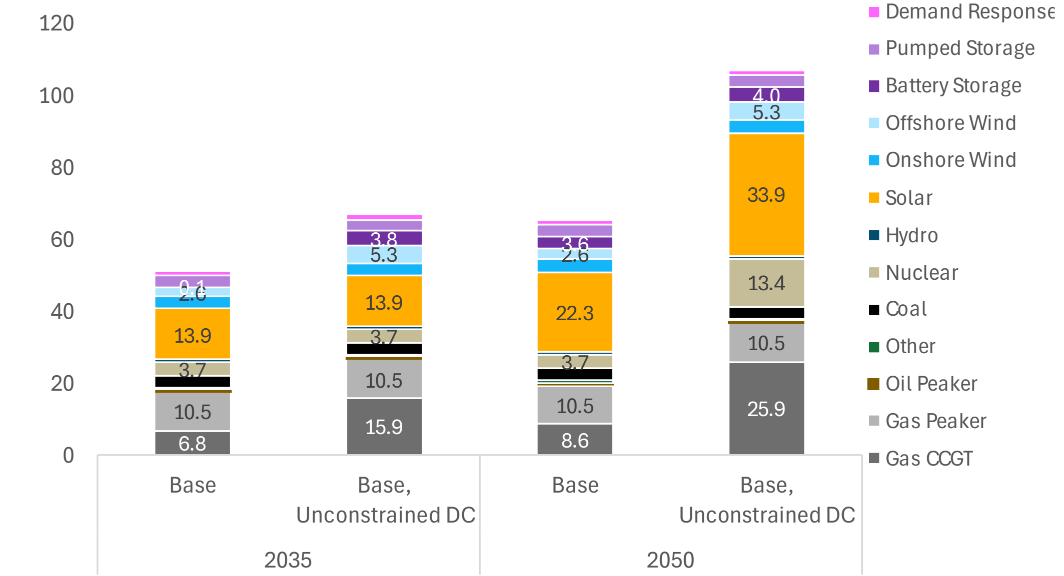
Impacts of Data Center Growth: S3A vs S1A
VA – *Capacity and Generation*

S1A	S3A
No data center growth; non-compliant with VCEA	*Unconstrained data center growth; non-compliant with VCEA*

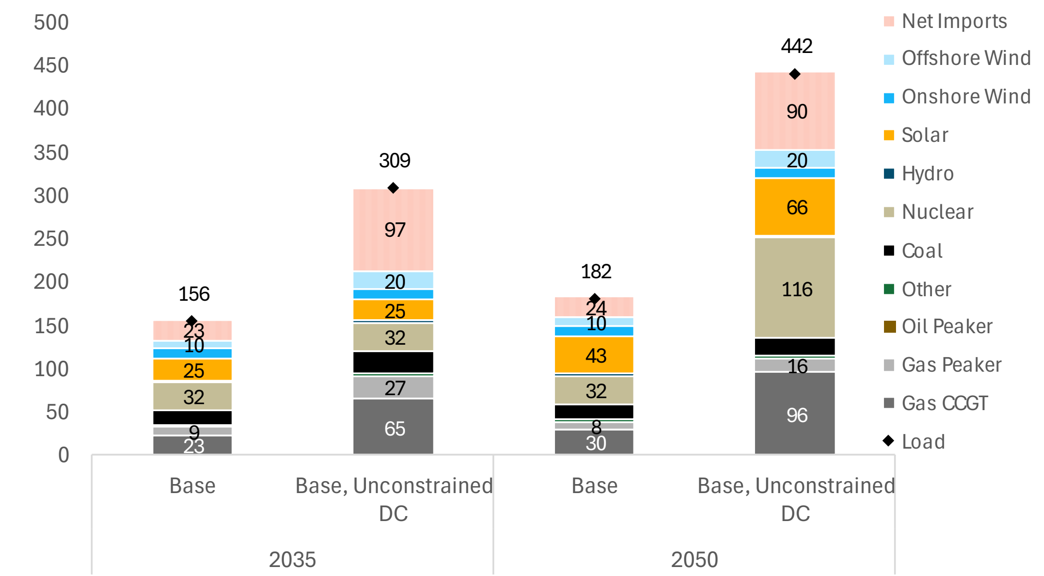
+ **Under Unconstrained Data Center Growth, Virginia is projected to add significant amounts of new gas capacity at an accelerated rate in the near term, compared to the no growth case**
  - Keeping up with demand growth in the next decade would require Virginia to add capacity at a rate of 1 GW/yr for 15 consecutive years, double its average rate of capacity additions over the past decade
  - The Dominion system experiences challenges in meeting system demand in 2030, when the addition of resources are bounded by historical build rate and new technology options like SMRs are not available

+ **In the long term, Virginia is projected to add a diverse mix of resources, including 10 GW of new SMR capacity, over 25 GW of solar capacity, 20 GW of new gas, around 5 GW capacity purchases, coupled with additional offshore wind and battery storage, to meet sharply increasing energy demands**
  - 3.5 GW transmission expansion between the DOM zone and AEP, AP, and NW are needed to support increased capacity purchase and imports

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh



Impacts of VCEA

With Data Center Growth

Key Finding #8: *With the VCEA in place, Virginia would likely require an unprecedented investment in an “all-of-the-above” strategy to meet demand growth with clean energy resources*

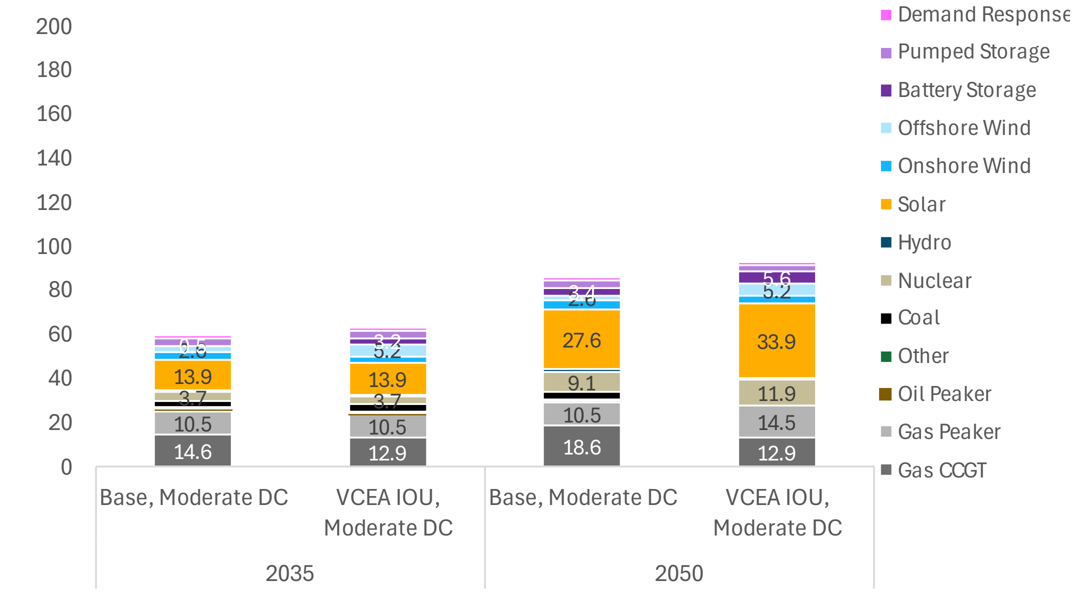
Impacts of IOU VCEA Achievement: S2B vs S2A VA – *Capacity and Generation*

S2A	S2B
Moderate data center growth; non-compliant with VCEA	*Moderate data center growth; IOUs comply with VCEA*

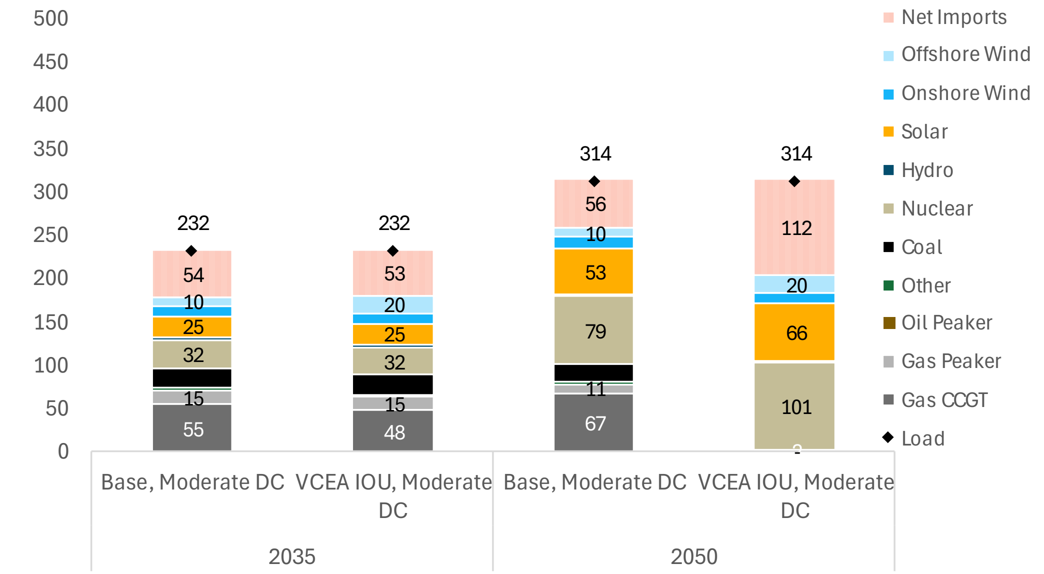
+ Meeting the goals of the VCEA under Moderate levels of demand growth would require significant shift towards investments in new renewables and transmission expansion, compared to the S2A case

- Virginia could add up to 26 GW of solar capacity and up to 5.5 GW of battery storage, coupled with offshore wind
- Nuclear capacity continues to be projected to play a significant role in meeting data center growth, increasing to nearly 12 GW
- Hydrogen-ready turbines, either through retrofits or new additions, play a significant role in maintaining system reliability
- Virginia relies on imported energy from the rest of PJM to meet 36% of total demand by 2050, as co-ops which are exempt from the VCEA requirements rely heavily on imports to meet increasing data center loads

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh

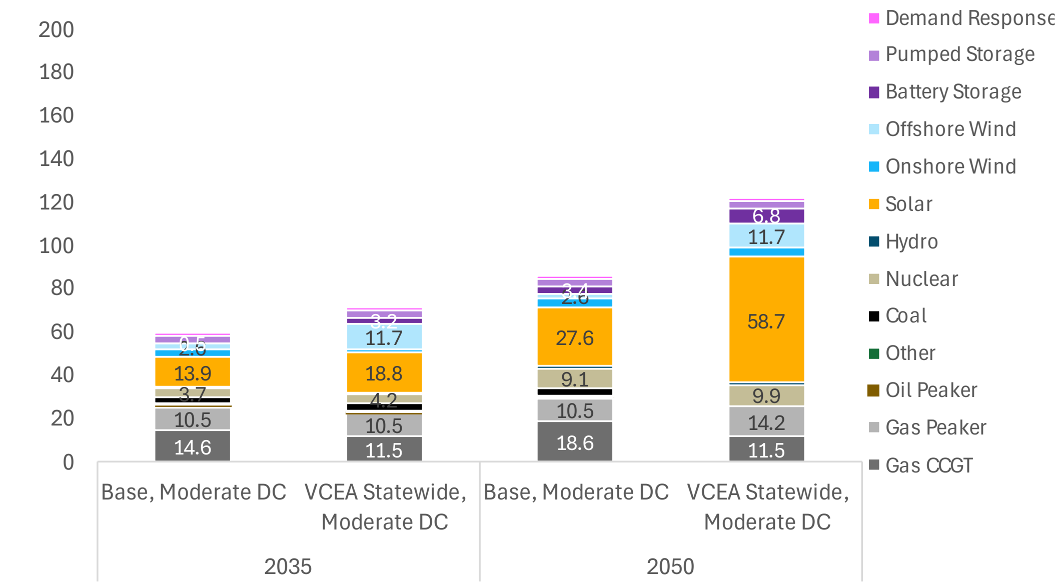


Impacts of Statewide VCEA Achievement: S2C vs S2A VA – *Capacity and Generation*

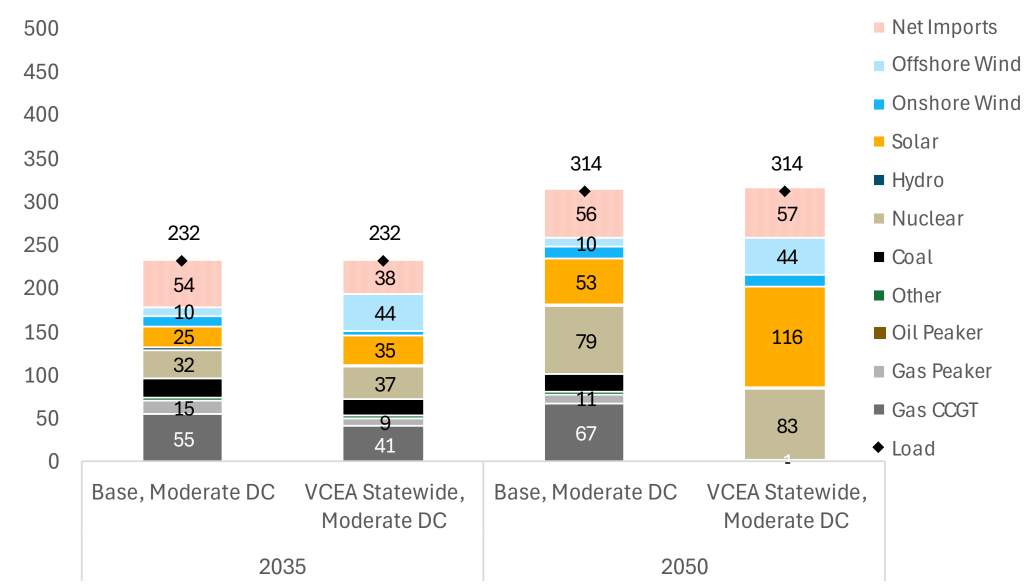
S2A	S2C
Moderate data center growth; non-compliant with VCEA	*Moderate data center growth; all statewide sales meet VCEA*

+ **Expanding the VCEA requirements to all utilities in Virginia (including co-ops) drives more in-state renewable investments and would reduce the state's reliance on imported energy from the PJM market**
  - Applying the VCEA goals to all statewide sales leads to an even higher build-out of renewable capacity in-state; Virginia is projected to add up to 51 GW of solar capacity and up to 12 GW of offshore wind capacity, coupled with 7 GW of battery storage
  - Nuclear and hydrogen continue to play a significant role in meeting data center growth and maintaining system reliability, respectively
  - The statewide application of the VCEA goals reduces the state's reliance on imported energy compared to the VCEA IOU case (S2B); however, new transmission is still projected to be developed to increase transfers between DOM and its neighboring zones

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh



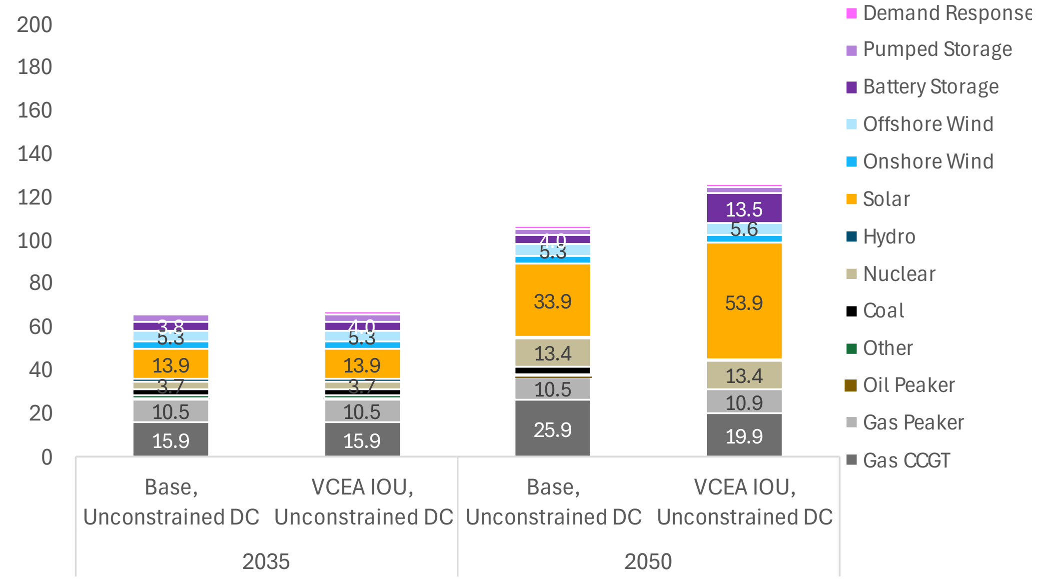
Impacts of IOU VCEA Achievement: S3B vs S3A VA – *Capacity and Generation*

S3A	S3B
Unconstrained data center growth; non-compliant with VCEA	*Unconstrained data center growth; IOUs comply with VCEA*

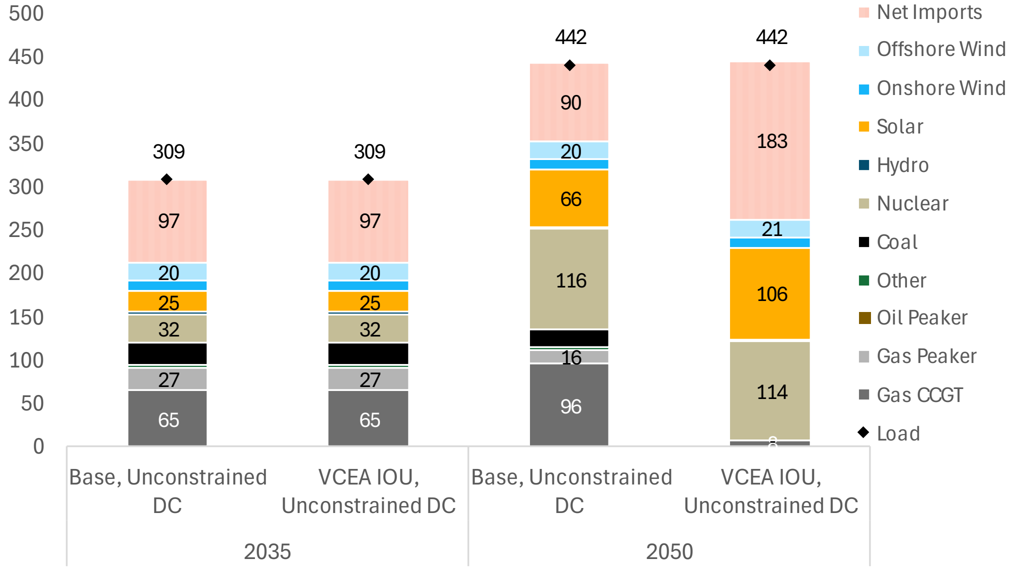
+ Under the Unconstrained Data Center Growth case, meeting the goals of the VCEA would drive significant new investments across multiple strategies and technologies, as well as a heavy reliance on the PJM market

- To meet increased energy demands with zero-carbon energy, Virginia is projected to add up to 46 GW of in-state solar and 13 GW of battery storage, in addition to 10 GW of new SMR capacity, 6 GW of new offshore wind capacity, and the conversation of existing gas fleet to run hydrogen by 2045
- Virginia is also projected to build close to 9 GW of new transmission to import higher quantities of energy from the PJM market, relying on 180 TWh of imported energy or over 40% of total electric demand, with VCEA-exempt co-ops serving large quantities of data center demand with energy imported from the PJM market

Virginia Installed Capacity
GW



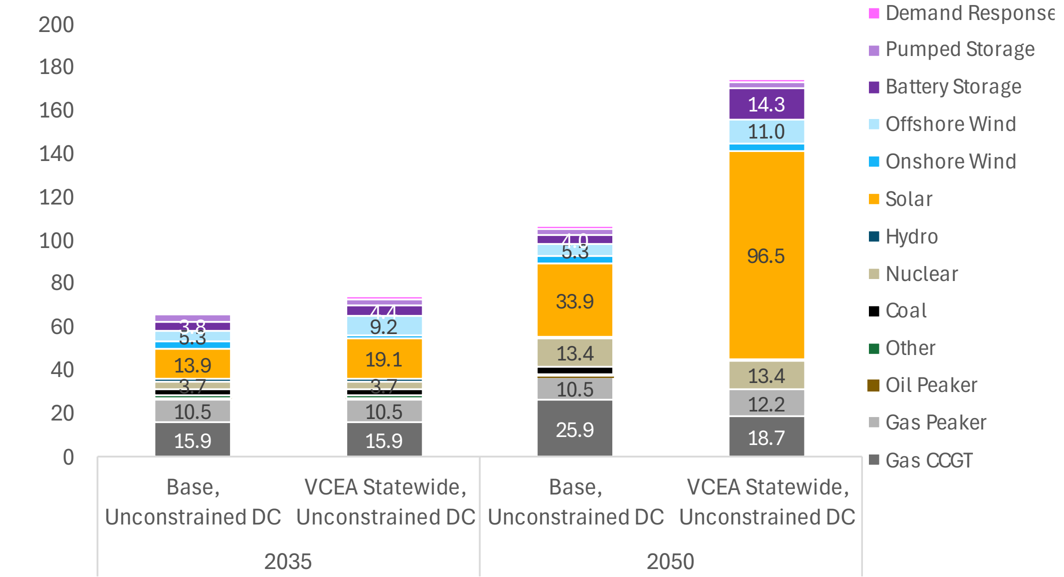
Virginia Annual Generation
TWh

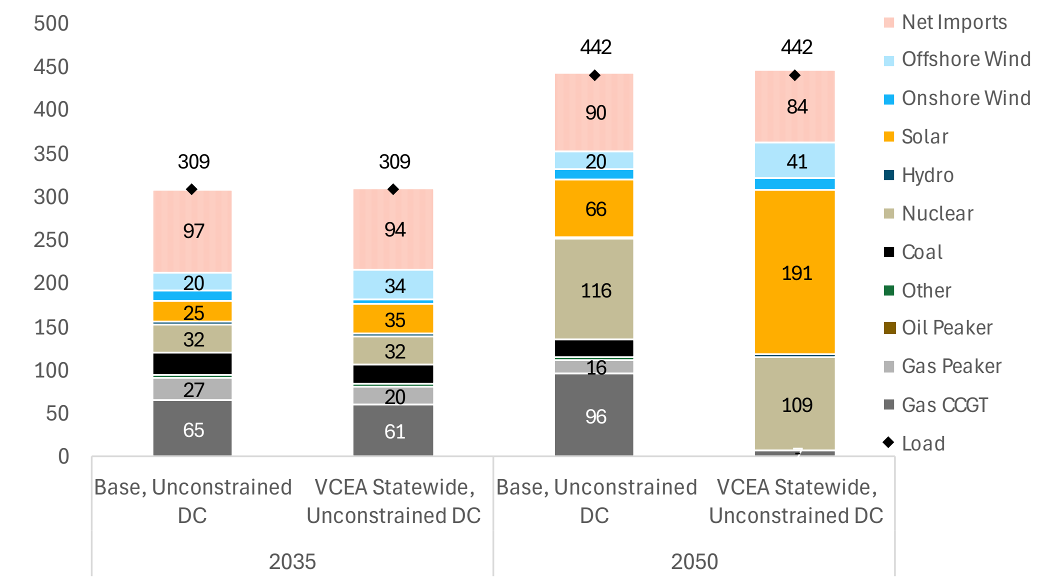


Impacts of Statewide VCEA Achievement: S3C vs S3A VA – *Capacity and Generation*

S3A	S3C
Unconstrained data center growth; non-compliant with VCEA	*Unconstrained data center growth; all statewide sales meet VCEA*

+ **Expanding the VCEA requirements to all utilities in Virginia (including co-ops) drives significantly more in-state solar and offshore wind builds, while reducing the use of import energy to meet system demand**
  - Virginia is projected to add close to 90 GW of solar and 11 GW of offshore wind by 2050 when the VCEA requirements are applied to all utilities
  - Import energy reduces compared to the VCEA IOU case (S3B) as new in-state renewable additions are required to serve data center loads with co-ops; however, around 9 GW transmission expansion is still projected to support the high amount of energy purchases needed in this scenario





Additional Sensitivities

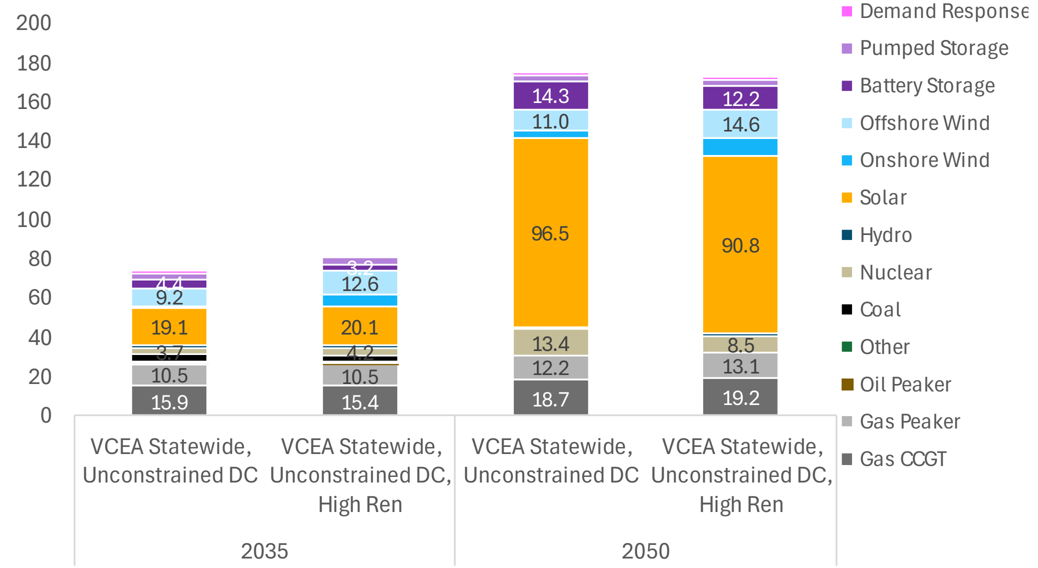
+ **While each scenario examined presents both challenges and opportunities for the Virginia electric sector, the Unconstrained DC Growth + Statewide VCEA Achievement scenario (S3C) appears the most challenging based on the pace and scale of builds coupled with a high reliance on emerging technologies that have not yet been commercially demonstrated at scale**
+ **E3 applied feasibility constraints within the model that limit the state's reliance on any one pathway or strategy; however, the scale of build-out is unprecedented and thus by definition the constraints are highly uncertain. Technology breakthroughs, permitting reform, and myriad other factors could accelerate (or constrain) the availability of specific technologies. To perform an initial, directional exploration of this uncertainty, E3 conducted three additional sensitivities:**
  - **S3C: High In-state Renewables (HiRen)**
    - Higher levels of onshore wind available in VA and NC;
    - Accelerated deployment of offshore wind allowed;
    - More conservative cost trajectory assumed using conventional nuclear costs and more stringent SMR build limits
  - **S3C: Regional Coordination (RegCoord)**
    - Relaxed constraints on transmission build-out post-2035
    - More conservative cost trajectory assumed using conventional nuclear costs and more stringent SMR build limits
  - **S3C: Nuclear Renaissance (NucRen)**
    - No constraints on nuclear build-out post-2035
+ **These sensitivities were only explored under S3C assumptions; however, the same uncertainty applies to other scenarios as well**

High Renewables: Compared to S3C VA – *Capacity and Generation*

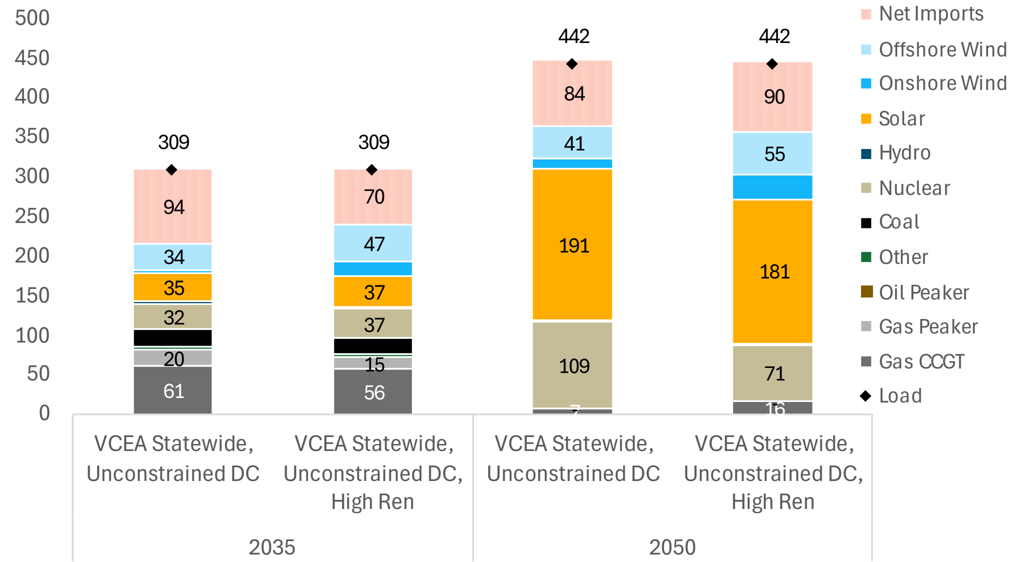
S3C	S3C: HiRen
Unconstrained data center growth; all statewide sales meet VCEA	*Relaxed renewable development constraints*

- In a scenario in which barriers to building onshore wind are overcome in VA and NC, and the development of offshore wind can be accelerated, Virginia is projected to add 5 GW more onshore wind and accelerate the build of offshore wind in the near term to meet the rapidly growing system demand
- More hydrogen-compatible turbines are added to meet system capacity need, complementary to renewable additions
- Under this scenario, the costs and availability of nuclear are also treated more conservatively, but nuclear still plays a critical role in meeting energy demands (constrained to the build levels in Dominion's 2023 IRP)

Virginia Installed Capacity
GW



Virginia Annual Generation
TWh

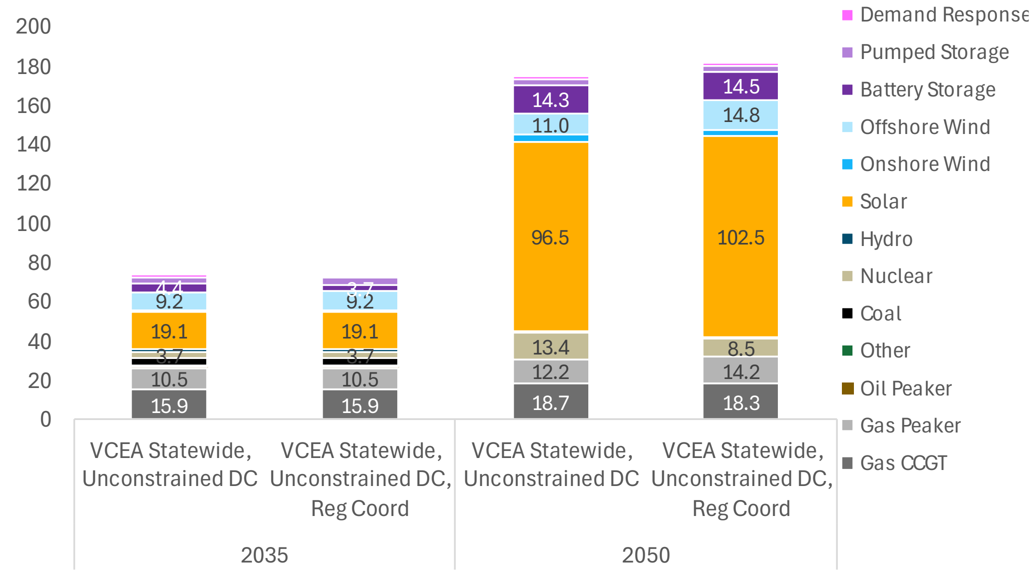


Regional Coordination: Compared to S3C VA – *Capacity and Generation*

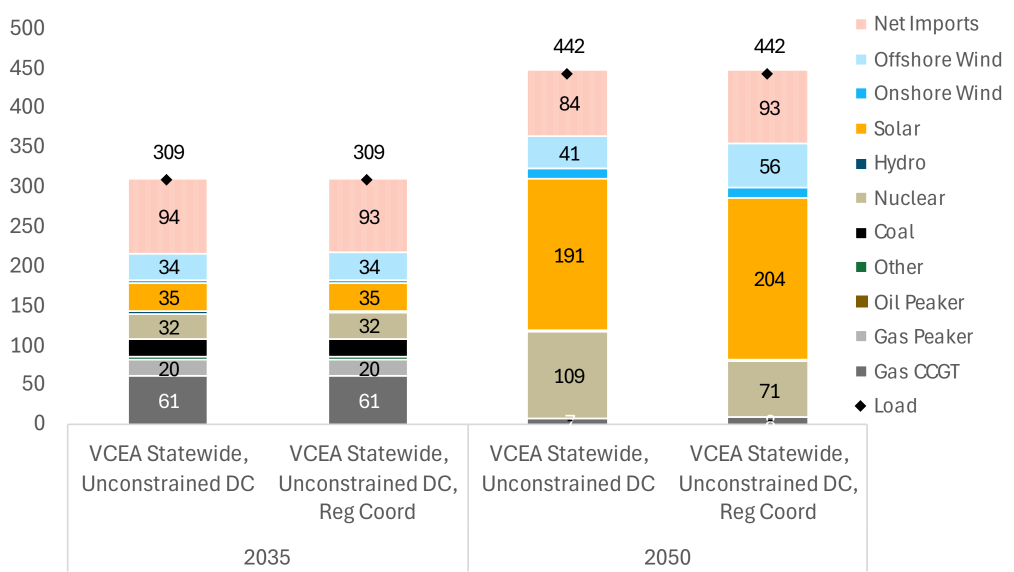
S3C	S3C: RegCoord
Unconstrained data center growth; all statewide sales meet VCEA	*Relaxed transmission development constraints*

- **Additional 3.4 GW transmission upgrade between DOM and AEP, AP, and NW, when made available, are selected by 2050 to support expanded economic imports and capacity purchases, despite higher cost of the expansion compared to expansion at a lower amount**
- **More solar, offshore wind, and hydrogen-compatible turbines are added, on top of transmission expansion, when SMR builds are further limited**

Virginia Installed Capacity
GW



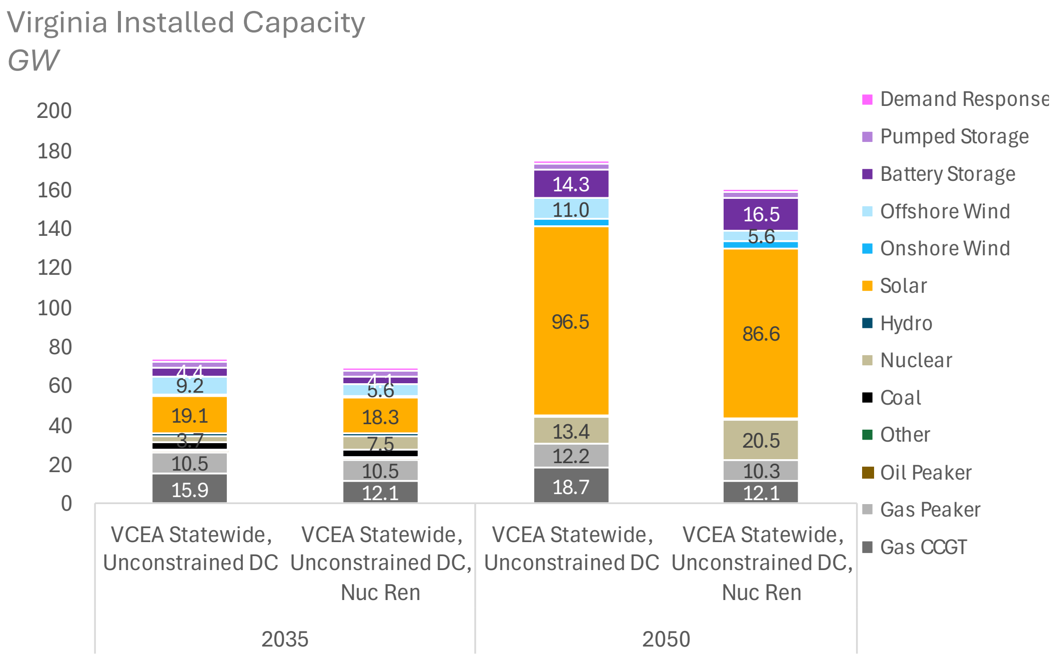
Virginia Annual Generation
TWh

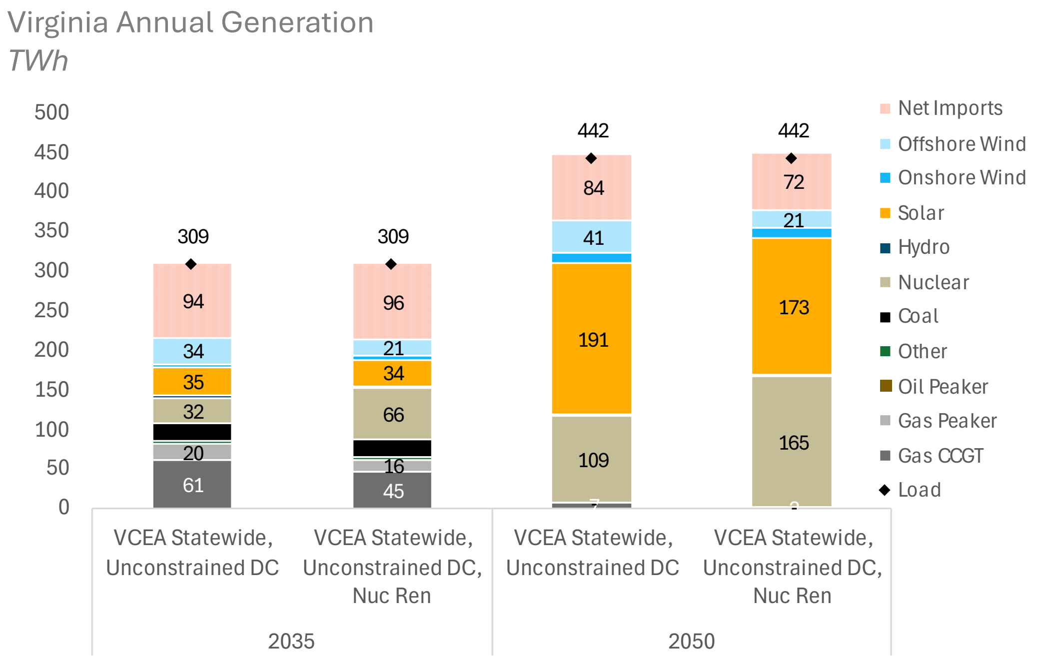


Nuclear Renaissance: Compared to S3C VA – *Capacity and Generation*

S3C	S3C: NucRen
Unconstrained data center growth; all statewide sales meet VCEA	*No nuclear development constraints*

- An incremental 7 GW SMR capacity is economically added in Virginia by 2050 when there are no constraints placed on the rate of capacity build-out
- This significant expansion of nuclear capacity, coupled with 2.3 GW of battery storage, offsets the need for around 10 GW of solar, 5.3 GW of offshore wind, and 8.5 GW of hydrogen-compatible turbines





Rate Impact Analysis

Energy+Environmental Economics

Rate Impact Considerations

- **E3 focused on a representative subset of Virginia utilities to assess rates using best available data and documented assumptions**

- **The following approach was used to assess rate impacts resulting from data center growth in Virginia:**
  - A broad review of existing rates, fees, cost-of-service studies, and policies was conducted for utilities identified
  - Costs and revenues associated with data center rate classes were assessed for equitable apportioning of costs under current and forecasted conditions
  - Residential rate impacts were evaluated based on modeled cost shifts due to data center load growth

- **Specific sources of potential uncertainty in this study include:**
  - Significant differences in $ / unit costs by customer class – ideally these should be similar across classes
  - Dominion Virginia's service territory contains a small jurisdiction in North Carolina; instances where associated data was unable to be disaggregated is not expected to be consequential to findings in this report
  - The most recent, available rate schedules and cost-of-service studies were used as a basis for assessment; values were escalated, where necessary, to align most recent data with forecast
  - Distribution costs were not included in the forecast due to an expectation that most new data center loads will interconnect at transmission voltages; any distribution network investments are anticipated to be modest and easily attributed based on cost causation

Approach to Assessing Rate Impacts

Utility tariffs and cost-of-service studies informed how cost shifting may occur with escalating forecasts of costs and load

1. **Relevant tariffs for each utility were reviewed to determine current methods of revenue collection**
2. **Cost-of-service studies were examined to determine basis of volumetric and fixed costs**
3. **Compare volumetric revenue and cost components against each other and across rate classes**
4. **Calculate total cost and revenue by rate class using load forecast data**
   - Determine where total cost/revenue values do not align within classes
5. **Compare and highlight specific impacts for Residential customers served by Dominion Virginia under various cost recovery scenarios**
   - Extension of existing cost allocations
   - Updated cost allocations using current methodology to adapt to anticipated load growth

Revenues	
Values	**Description**
$ / kW	Demand charges (if applicable)
$ / kWh	Delivery + supply + other volumetric adders
Fixed charges	Customer or minimum monthly charges
Data Sources	Utility Tariffs

Costs	
Values	**Description**
$ / kW	Capacity-driven investment / Coincident demand
$ / kWh	Consumption-driven costs (e.g., generation)
Fixed costs	Utility billing, overhead, etc.
Data Sources	Project forecasts, cost of service studies, etc.

Utility Profiles, Costs, & Rates

Energy+Environmental Economics

Utility System Profiles

Dominion Virginia

>100 Data Centers

- **Customer count**
  - Residential: 2.3 million
  - Commercial & Industrial: 267,143
- **Peak demand:** 17.1 GW
- **Annual sales:** 92.9 TWh (8.5 TWh of which is delivery only)
- **Load growth:** Projected to increase from 17 GW in 2023 to 33 GW in 2048, including data centers and vehicle electrification[2]

MEC

1 Data Center

- **Customer count**
  - Residential: 29,816
  - Commercial & Industrial: 1,910
- **Peak demand:** 153 MW
- **Annual sales:** 860 GWh

NOVEC

~28 Data Centers

- **Customer count**
  - Residential: 164,645
  - Commercial & Industrial: 14,258
- **Peak demand:** 1.5 GW
- **Annual sales:** 8,526 GWh
- **Peak electric load growth:** >**12%/year** over 15 years, almost exclusively driven by data centers[1]

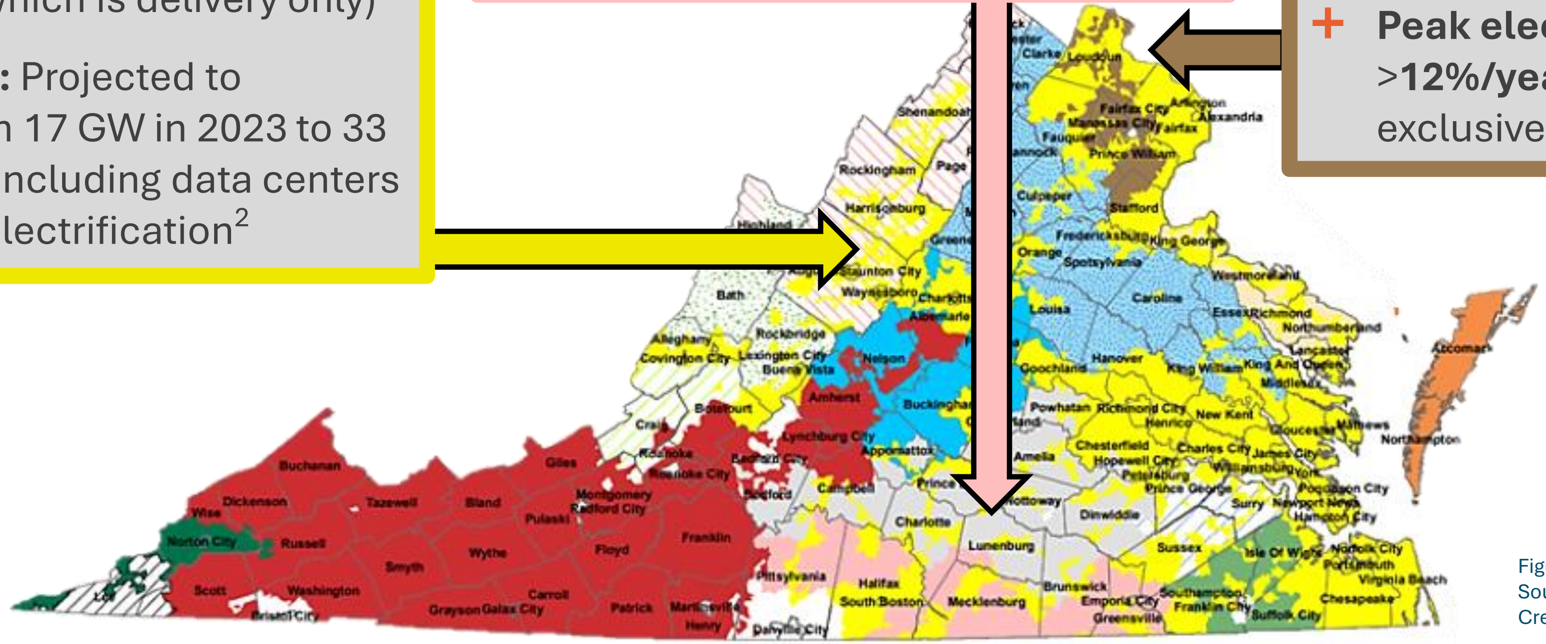


Figure is an approximation
Source: State Corporation Commission, 2020
Created by: Division of Public Utility Regulation, 2020

[1] NOVEC 2022-2023 Annual Report
[2] Dominion Virginia 2023 Integrated Resource Plan

Utility Assessment

E3 examined rate designs for three utilities in Virginia, each with different needs, interests, and approaches

+ **Dominion Virginia (“Dominion”)**
  - The largest load serving entity of the three examined with the most significant existing and forecasted data center load
  - An investor –owned utility with vertically integrated transmission service
    - Regulation compels biennial review of rates and other periodic stipulations by Virginia SCC
    - Serves as the transmission provider for PJM’s Dominion Load Zone (“DOM Zone”)
+ **Northern Virginia Electric Cooperative (NOVEC)**
  - As a public power cooperative NOVEC receives transmission service from Dominion and provides distribution service to its members
+ **Mecklenburg Electric Cooperative (MEC)**
  - A public power cooperative receiving transmission service from Old Dominion Electric Cooperative (ODEC) and providing distribution services to its members

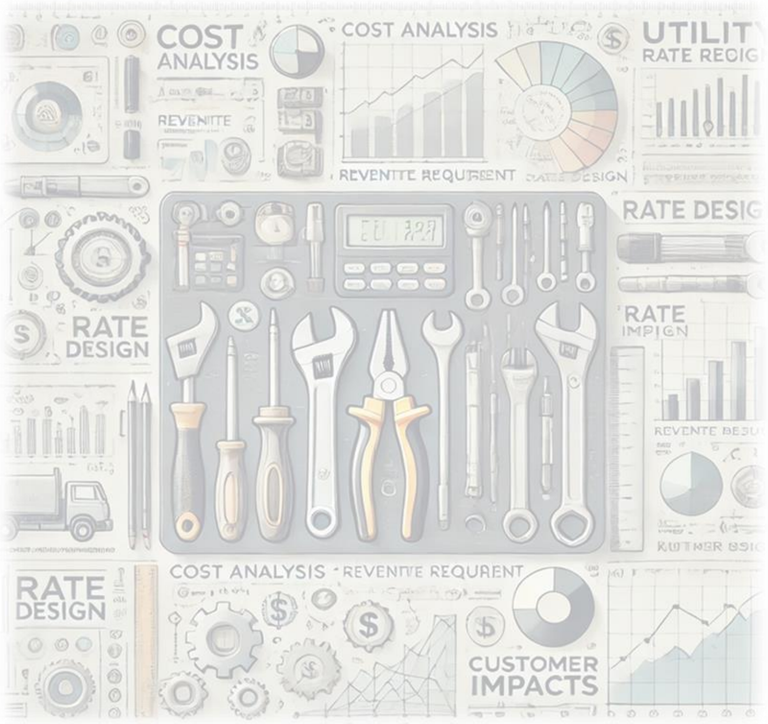


Image generated with AI

Cost Recovery and Rate Adjustment

Wholesale Cost Recovery

- **PJM allocates capacity cost obligations from its Reliability Pricing Model to load zones based on five coincident peak (5-CP) demand; Dominion allocates these capacity costs to utilities based on a 5-CP methodology**
  - Utilities further apportion their share of the allocated wholesale costs according to their individual rates
- **PJM allocates transmission costs on 1-CP construct; Dominion then allocates these transmission costs to utilities based on a 12-CP average**
  - Utilities apportion their share of the allocated wholesale costs according to their individual rates
- **Wholesale market design and transmission tariffs undoubtably influence retail costs, beyond the scope of this analysis and may warrant additional study**

Retail Cost Recovery

- **Under Virginia law, the State Corporation Commission (SCC) conducts biennial reviews of the Commonwealth's investor-owned utilities, including an examination of its earnings, consideration of adjustments to its base rates, or modifications of terms and conditions**
- **Riders are reviewed by the SCC separately on an annual basis**
- **Requirements are less strict for public power cooperatives, like NOVEC and MEC**

Retail Rate Equity

Energy+Environmental Economics

Rate Equity Today

- **Current rates appropriately apportion costs to classes and customers responsible for incurring them**
- **Load growth is expected to increase system costs in Virginia with some effects directly attributable to new, large loads (i.e., data centers)**
- **Investor-owned utilities and public power cooperatives use different approaches to manage the costs of new loads joining the system; each effectively insulates existing customers from potential cost shifts and rate impacts resulting from large loads entering the system**
  - Investor-owned utilities absorb infrastructure investments in rate base and recover costs over time from the interconnecting customer through cost allocations
    - Long-term, minimum, monthly cost recovery structure, like Dominion’s “Monthly Contract Dollar Minimum” guarantee, can reduce risk, but not mitigate it entirely
    - Accurate recovery of infrastructure investments made on behalf of the interconnecting customer requires proper calibration of cost allocation factors
  - Public power cooperatives tend to assign all infrastructure investment costs to the interconnecting customer upfront while structuring direct passthrough of all incremental costs; some contribution to embedded (i.e. existing or average system) fixed costs are made through distribution charges
    - Upfront payment for interconnection costs mitigates risk of stranding assets or under-recovery of investments

Various Approaches to Cost Recovery

Cost Recovery Method

Embedded Cost Allocation ⟷ **Directly Assigned Costs**

Dominion

- Data centers are included with other industrial customers in GS-3 (distribution voltage) and GS-4 (transmission voltage) rates
- All non-redundant investments necessary for service and interconnection are provided by the utility, with costs recovered over time through cost allocation factors applied to the corresponding rate class.
- Variable costs are based on metered contribution to average costs of transmission and generation
  - Unbundled generation is offered through retail choice
- Contribution to system fixed costs is recovered through cost allocation as determined by the portion of plant costs attributed to each rate class portion of plant

NOVEC

A dedicated HV-1 rate class strictly serves data center customers

- Interconnection costs are assigned to the customer through a series of deposits and installment payments as the project develops
- Generation is offered as an embedded rate or through an unbundled option
- System costs recovered through rate design whereas delivery charges are cross-subsidized
- The load factor requirement under HV-1 rate class ensures demand charges recover the cost if the dedicated substation use is below contracted capacity.
- The HV-2 rate class, for the largest data center customers, limits energy supply options to market rate, protecting other customers from the increased risk and cost due to growing load from data centers

MEC

With only one data center customer, Mecklenburg has a dedicated rate class tailored specifically to the facility that fully and directly assigns all costs

- Interconnection costs are paid by the customer concurrent with development
- All generation is paid for directly through a separate Energy Services Agreement (ESA)
- The data center built and paid for dedicated substations that are metered for direct allocation of contributions toward system transmission and capacity costs
- Distribution charges are designed to recover costs for supporting system operations and maintenance
- Delivery charges are intended to collect contribution toward embedded fixed costs and provide some benefit (i.e., return) to other cooperative members

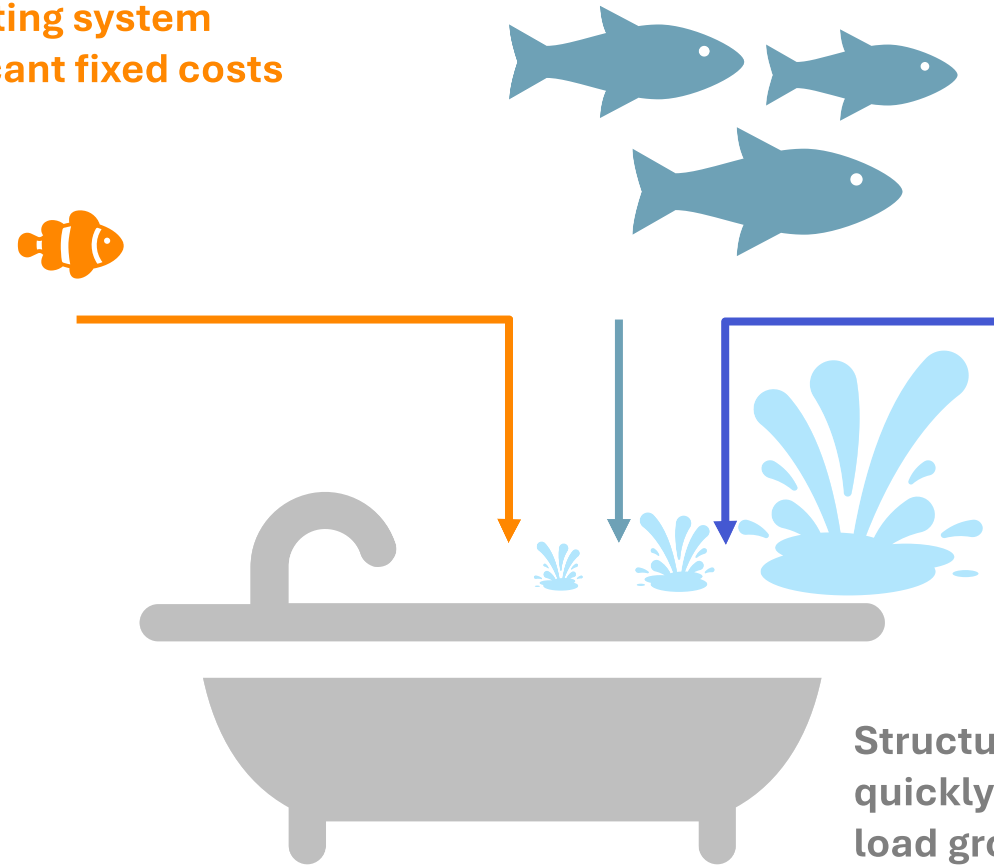
Rate Dynamics

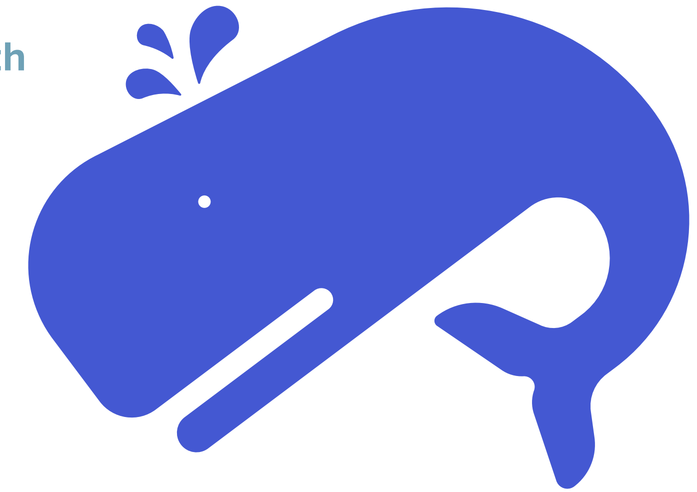
Energy+Environmental Economics

Incremental vs. Transformational Loads

Typically, incremental loads are easily managed within the existing system without incurring significant fixed costs

Larger, incremental loads can be absorbed if integrated over time or with targeted upgrades



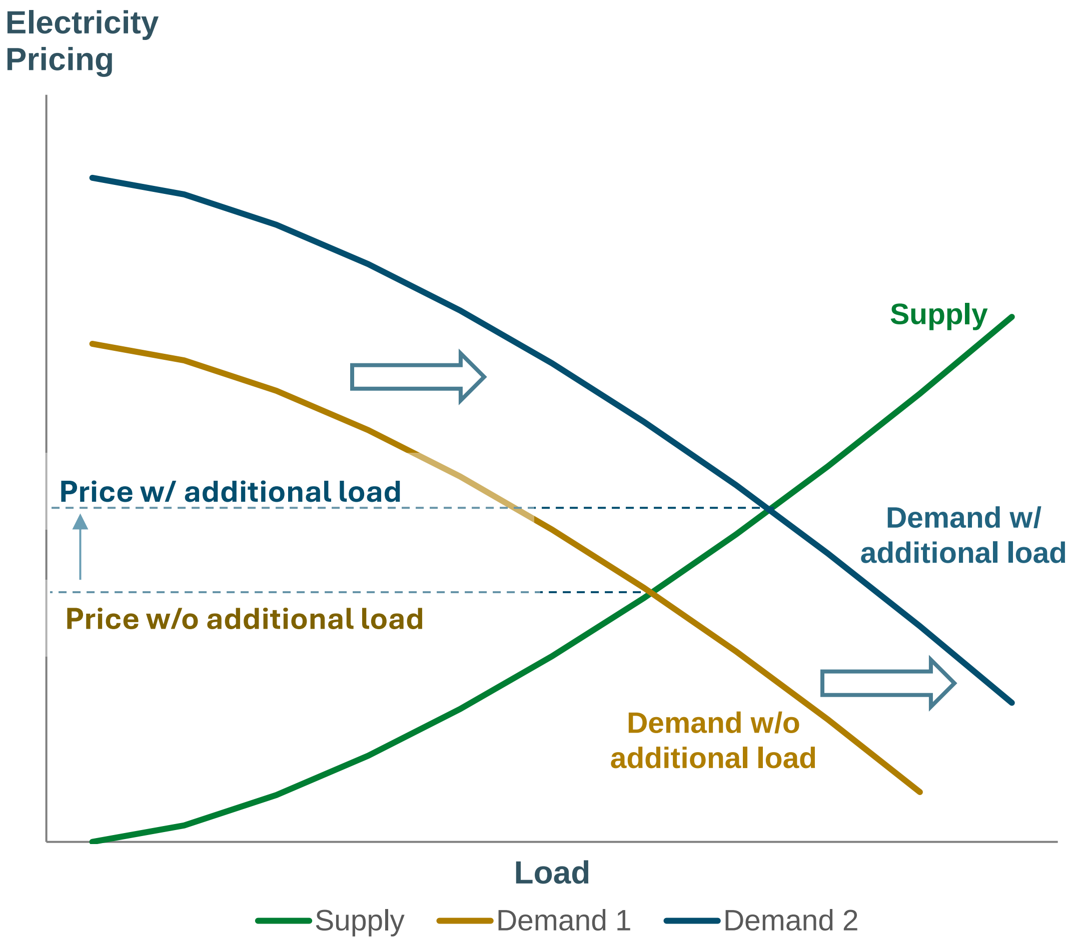


Transformational loads can disrupt the system and require significant new infrastructure investment with large upfront fixed costs and long asset lifetimes; system attributes such as new generation supply costs can also be impacted due to a large demand shift

Structural inefficiencies can make it difficult to quickly reach new equilibria under transformational load growth

Supply and Demand Dynamics in the Wholesale Market

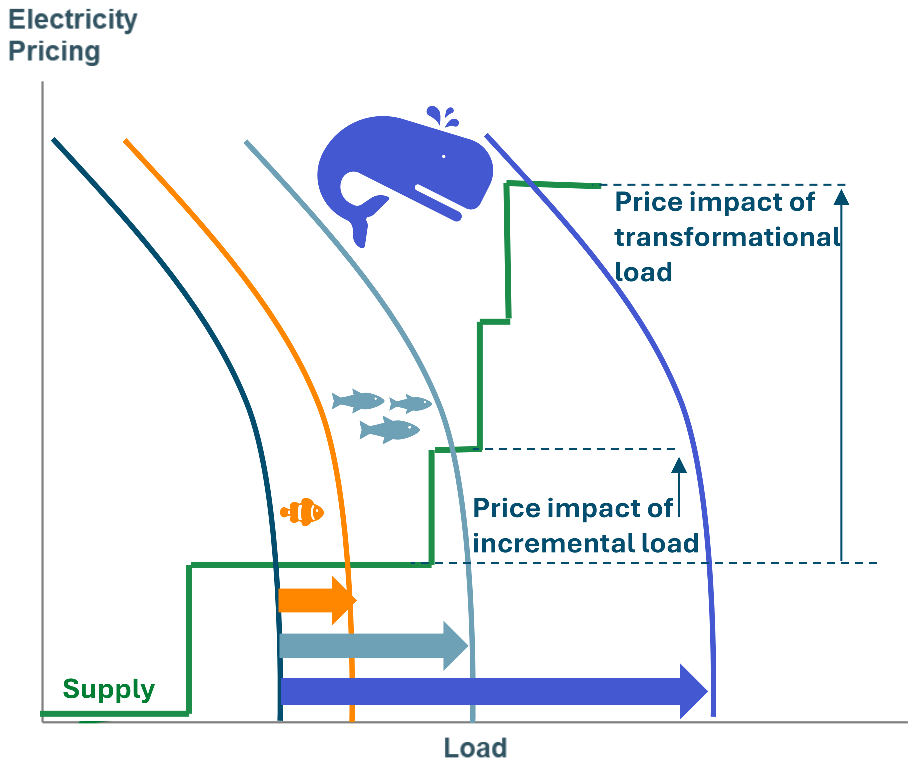
Conceptual Impact of Additional Load on Demand Curve



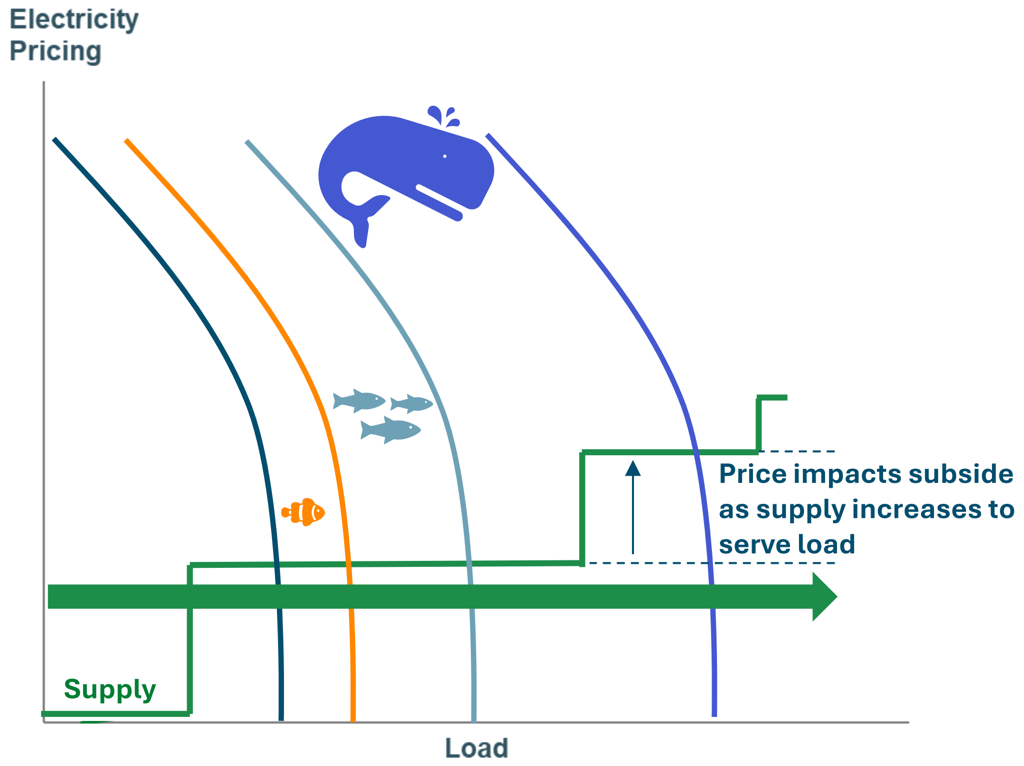
+ **In a marginal cost market structure as demand increases, the demand curve shifts to the right, raising the marginal price point for supply to serve all load**
  - The supply curve is a step function dependent upon price and quantity of various resources
  - Electricity consumption is relatively inelastic; therefore, load is unlikely to contract in response to higher market prices
+ **Energy costs (inclusive of capacity, generation, and environmental attributes) are expected to increase as the corresponding markets; climbing the supply curve will initially raise costs for all customers until more supply is added and the system regains equilibrium**
+ **As data centers pay their 'fair share' of costs based on their contribution of load, elevated market conditions resulting from the additional demand will affect all ratepayers; this effect is not generally considered to be an explicit source of inequity between rate classes especially from the perspective of a single data center being added but in aggregate the impact can be significant**

Disruption & Reestablishment of Market Equilibrium

Illustrative Impact of Additional Load on Electricity Pricing



Illustrative Impact of Additional Supply Electricity Pricing



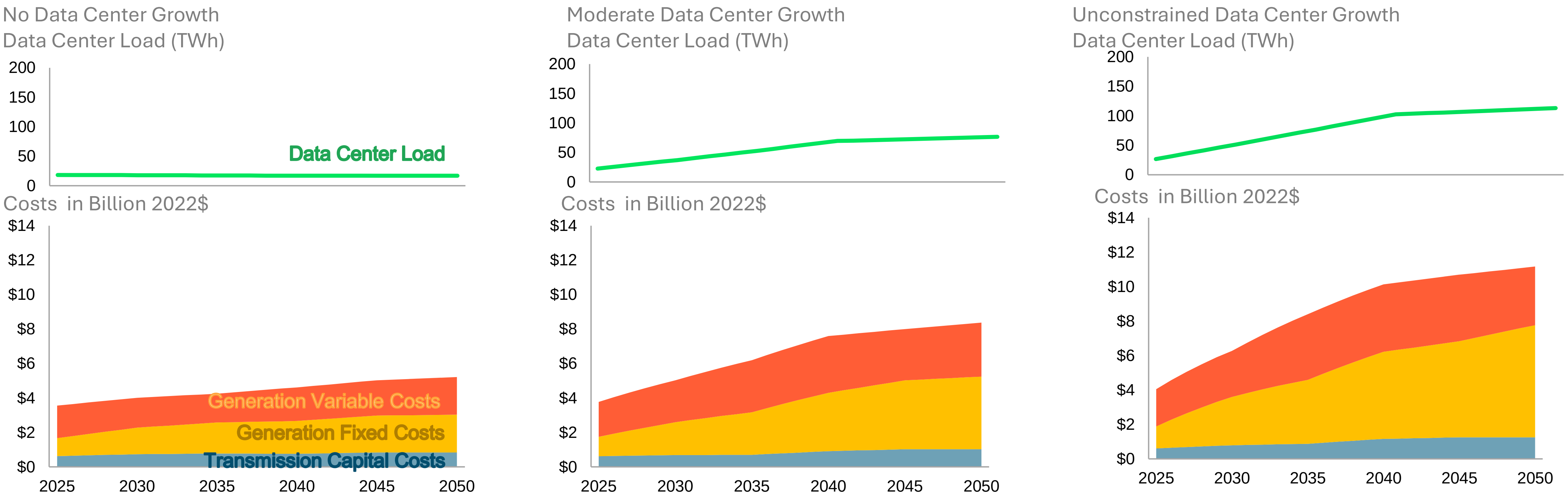
- Load growth in Virginia and elsewhere in PJM creates disequilibrium due to supply taking time to respond to demand signals; constraints causing lag include project development and interconnection
- Eventually, supply will respond to meet the higher load bringing equilibrium conditions and subsiding costs which will also depend on the initial "steepness" of the supply curve as well as how that supply curve shifts over time

Projected Cost Impacts – Dominion

Energy+Environmental Economics

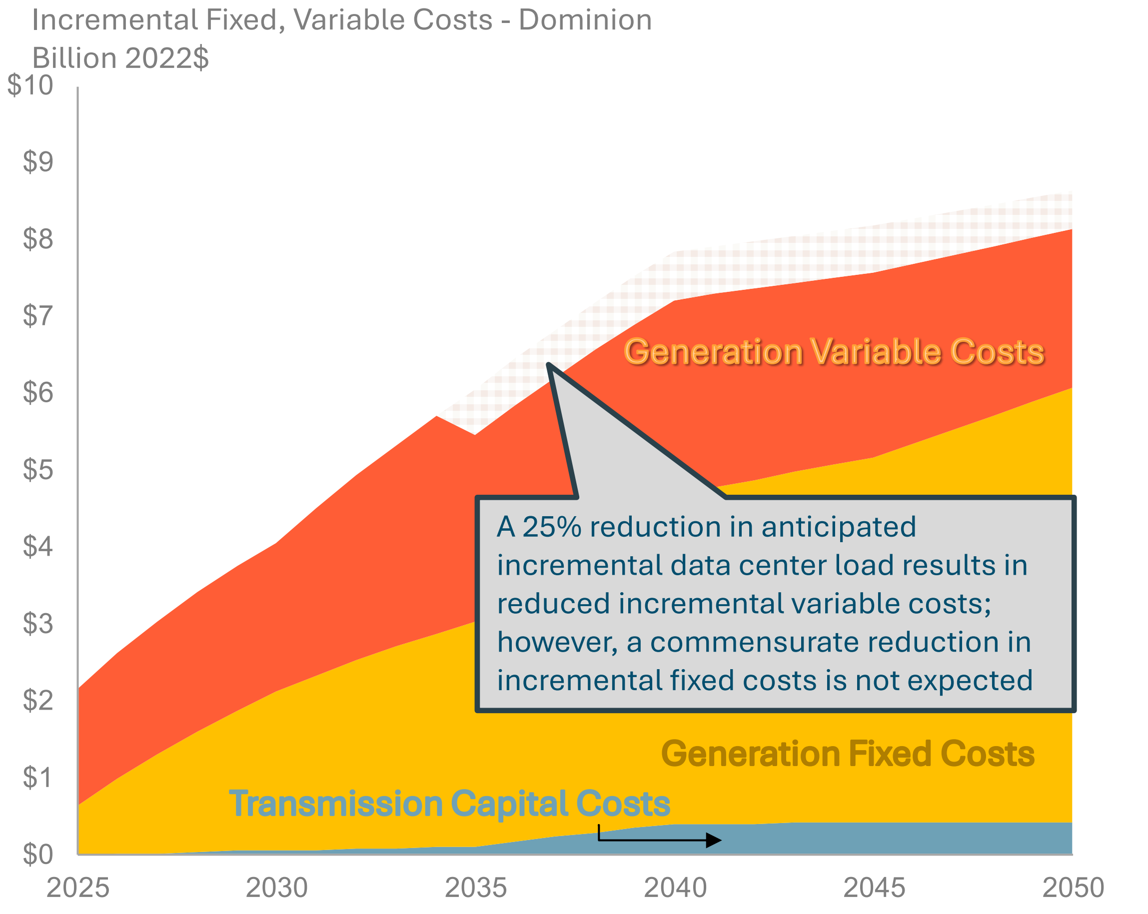
Load and Cost Projections

- Variable costs of new generation supply (inclusive of capacity, energy, and environmental attributes) are expected to increase as the corresponding markets tighten due to increasing demand relative to supply
- Generation fixed costs will increase as a result of new resources being built to meet the anticipated increase in demand
- Transmission costs are also expected to rise, as power from new resources is interconnected with growing load centers; local transmission projects and regional network upgrades and extensions for reliability and improved system efficiency will further contribute to increasing costs but are not included in this analysis.



Cost Impacts of Underachieving Load Forecast

Unconstrained Data Center, Relaxed Policy
(25% lower incremental data center demand in 2035)

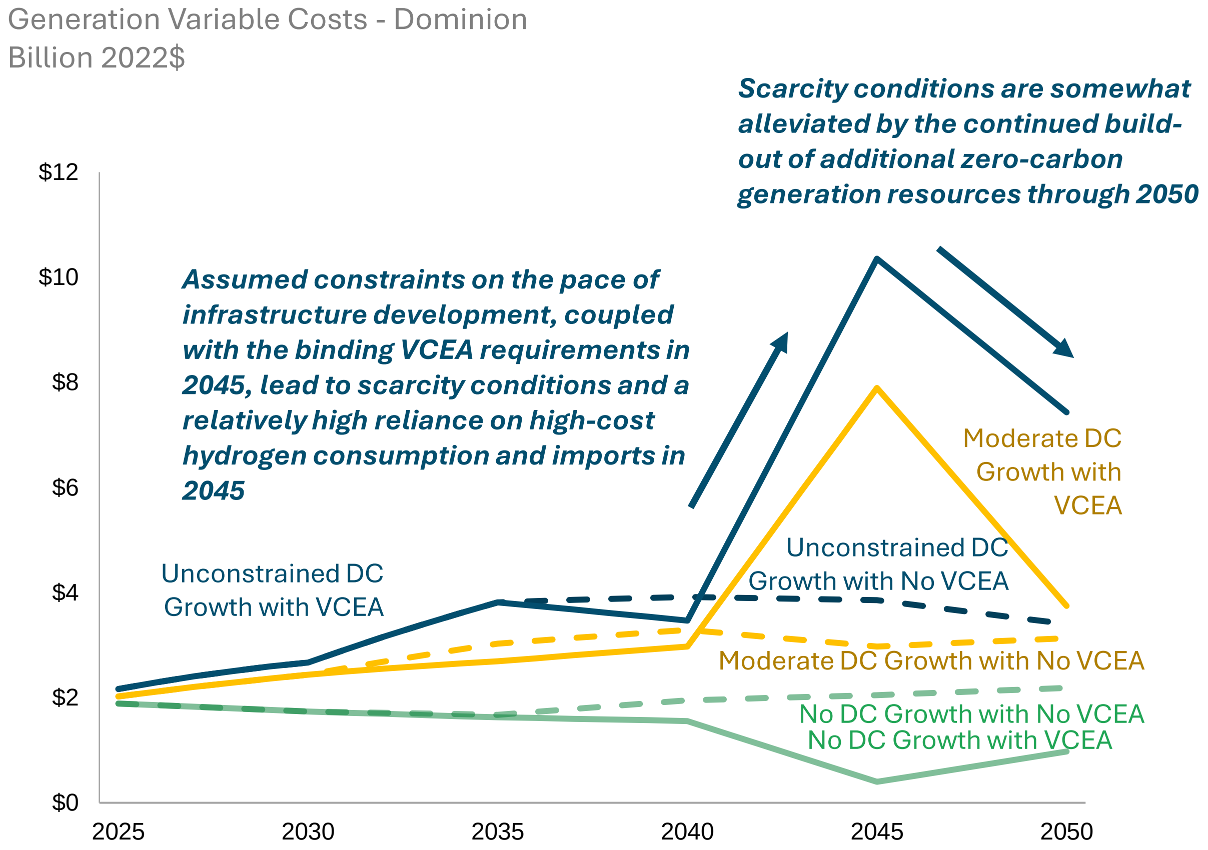


- In a scenario where fixed costs are committed based on a data center load forecast that fails to fully materialize on time, committed fixed costs, triggered by the anticipated load, will be spread across a smaller system load, resulting in higher costs to all customers
- An equivalent shift in data center load to third party supply would similarly increase cost burdens to other customers, driven by the reallocation of fixed costs

$$Retail\ Rates \uparrow = \frac{(Fixed\ Costs \uparrow\uparrow + Variable\ Costs \uparrow)}{System\ Consumption\ (MWh) \uparrow}$$

Variable Costs of Generation

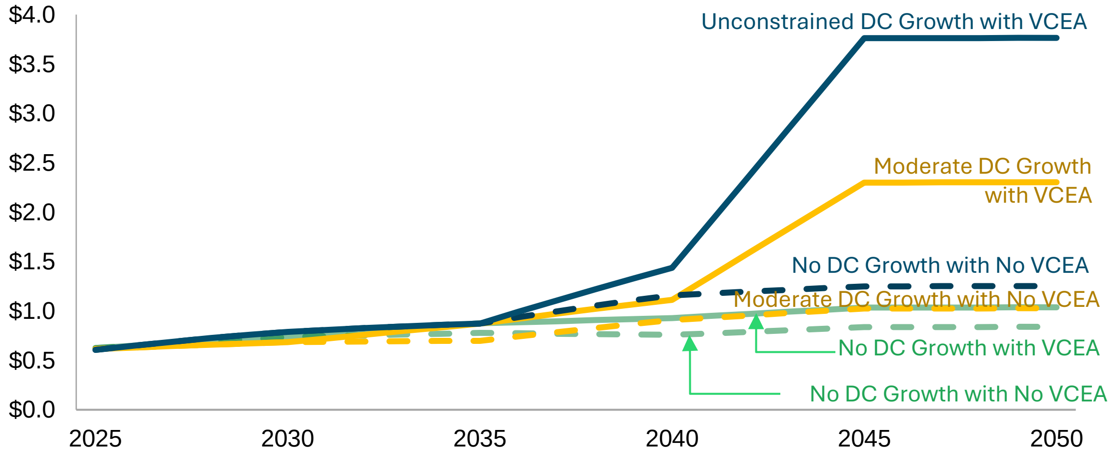
+ **Near-term surge in data center load growth is forecasted across different growth scenarios before moderating after 2040; resources used to meet demand across scenarios exhibit different cost characteristics**
  - Resources like wind, solar, and SMRs tend to have higher fixed costs with lower variable costs
  - Combustion-based resources tend to have lower fixed costs and higher variable costs
+ **Policy conditions also influences variable costs**
  - Relaxed policy scenarios see higher variable costs in early years due to more use of gas and fewer renewable resources
  - VCEA policy scenarios indicate lower variable costs in early years with increasing costs approaching 2045 as hydrogen is used to meet compliance until sufficient transmission, SMRs, and renewable resources can be developed
+ **In addition to a larger volume of generation, higher-growth scenarios are expected to result in tighter supply-demand conditions, increasing the price of energy market products and imports on a per unit basis**



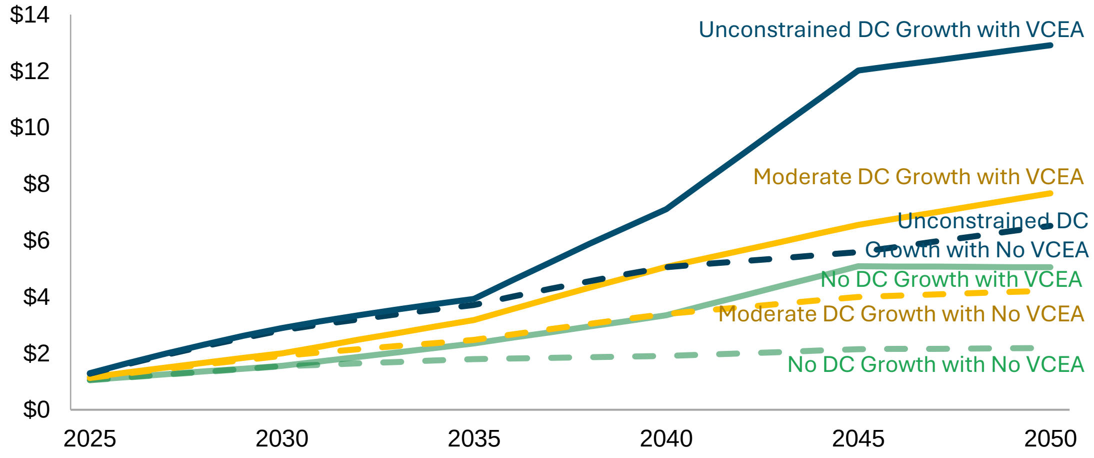
Fixed Costs of Generation & Transmission

- Resource builds are committed in anticipation of load growth to allow for the necessary lead times for development
- As load growth moderates in the 2040's costs continue to climb as resource builds are brought online to meet continued demand growth and the VCEA policy requirements
- Policy influences fixed costs
  - VCEA policy drives higher fixed costs due to development of renewable resources
  - Increased transmission investments is required to deliver new renewable resource builds to load centers

Transmission Fixed Costs - Dominion
Billion 2022$



Generation Fixed Costs - Dominion
Billion 2022$



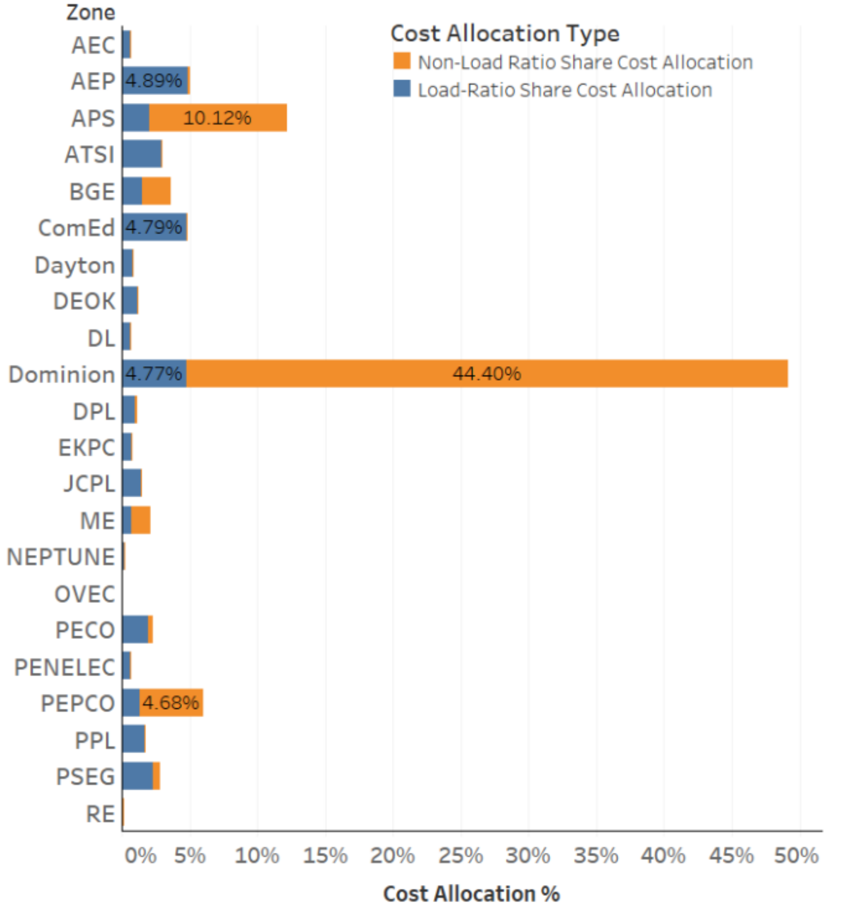
Additional Generation Cost Considerations

- Generation sources and procurement method will also have cost allocation impacts, with respect to fixed and variable costs of generation; for example, a solar PPA would represent a high variable cost with no fixed costs, whereas a utility-owned combustion turbine would likely represent lower variable costs with significant fixed costs
- While utilities are exposed to marginal pricing in the wholesale market, retail customers typically pay average (embedded) cost, which often includes physical and financial contracts that hedge against full exposure to marginal costs
  - There are other factors that can also mitigate ratepayer impact to higher marginal pricing such as an investor owned vertically integrated utility owning generation that is a hedge against higher market prices
- Deviations from load forecasts could result in cost shifting under current cost allocation methodologies
  - Data centers that outperform load expectations or operate with equipment beyond the budgeted lifespan will over contribute more to system costs
  - Data centers that underperform load expectations or that fail to reach the projected payback period of infrastructure investments made on their behalf will contribute less than an equitable amount to system costs and have a negative impact on other customers

Additional Transmission Cost Considerations

- **E3 modeling contains a high-level representation of bulk and local transmission costs to ensure new resources can be delivered to loads [see slides 122-123]**
- **However, E3 modeling does not capture local reliability constraints; the full set of transmission system needs as a result will likely be greater than projected**
  - Supplemental projects intended to improve reliability or system efficiency within the Dominion load zone would be conducted at additional costs
- **In its Regional Transmission Expansion Plan (RTEP) PJM's Transmission Expansion Advisory Committee (TEAC) identifies and recommends approximately $5 billion of additional reliability projects over the next several years**
  - These projects are not directly incorporated into E3's analysis; instead, a subset of these investments likely overlap with the identified transmission system needs in E3's modeling
  - Reliability upgrades serving a single zone are the sole responsibility of the associated transmission provider, while projects serving multiple zones are socialized more broadly across market participants and/or project beneficiaries
  - Nearly 50% of the costs associated with transmission reliability upgrades (~$2.5 billion) identified by the TEAC are prescribed for the Dominion load zone through a combination of load-share and non-load-share cost allocations
- **As the transmission provider, Dominion allocates transmission costs among load serving utilities within the transmission zone, who then recover those costs through retail rates**

Cost Allocation of Recommended Transmission Reliability Investments in PJM by Load Zone for RTEP, Window 3

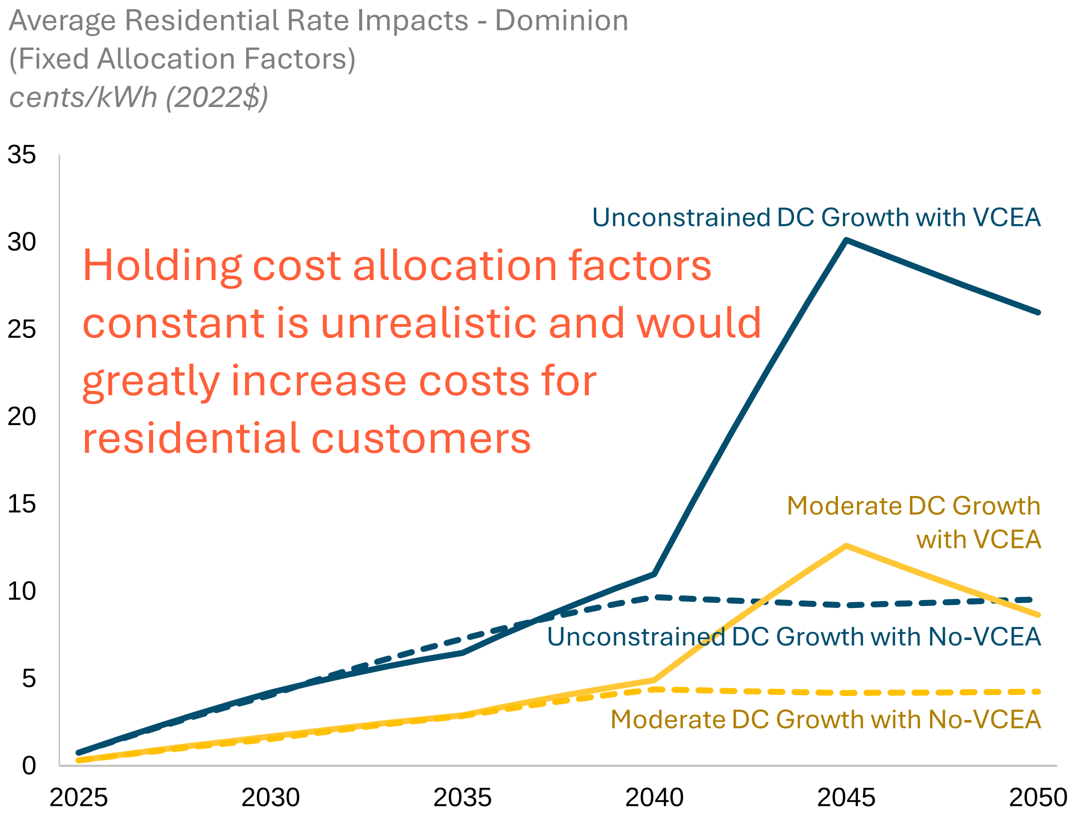


Transmission Expansion Advisory Committee Recommendations to the PJM Board, December 2023. 20231205-pjm-teac-board-whitepaper-december-2023.ashx

Projected Rate Impacts – Dominion

Comparative Impact of Data Center Loads on Residential Rates: Fixed Cost Allocation Factors

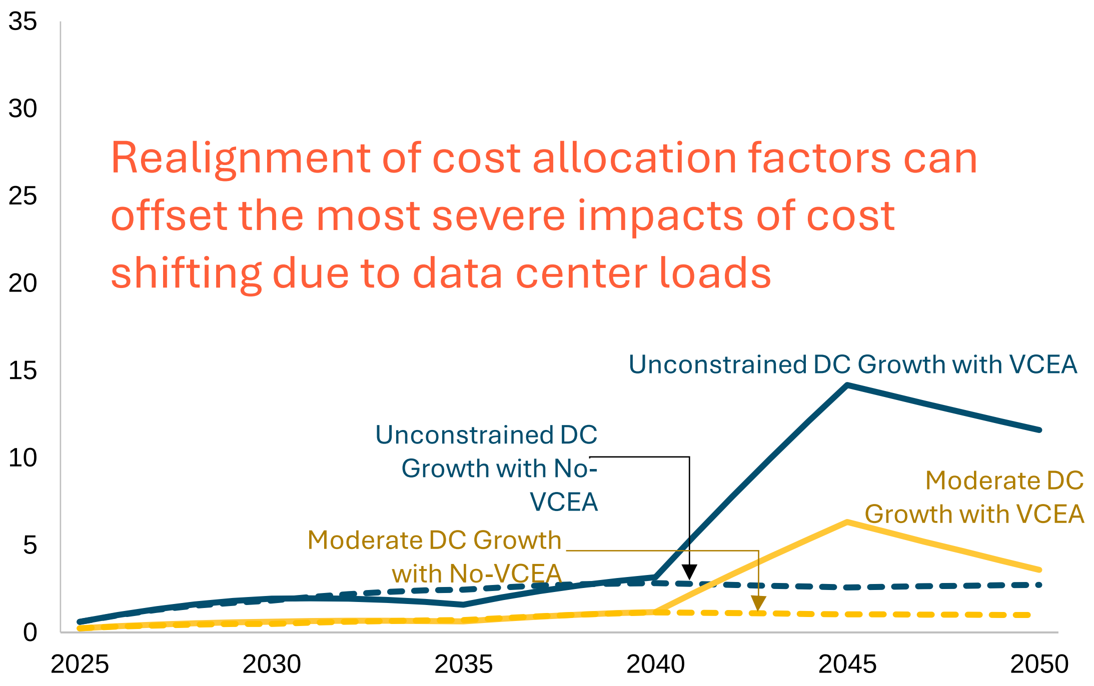
- **If current cost allocation factors are held consistent, Dominion's residential electric rates will experience significant upward pressure with growing data center load**
  - Note, this is not a realistic case as cost allocation factors would adjust per normal ratemaking practices, but is useful to illustrate impacts under current rates if those factors were "frozen"
- **While maintaining consistent cost allocation factors is not a realistic expectation, this perspective helps to establish an upper bound for residential ratepayer impact**
- **Distribution costs are intentionally omitted from the rate impact analysis**
  - Distribution costs incurred on the system to serve new, interconnecting loads will also increase total system cost; however, causation of these costs is more easily assessed and assigned to loads either directly (upfront) or indirectly (cost allocation)
  - Data centers are increasingly interconnecting at transmission voltages and contributing less to distribution network costs



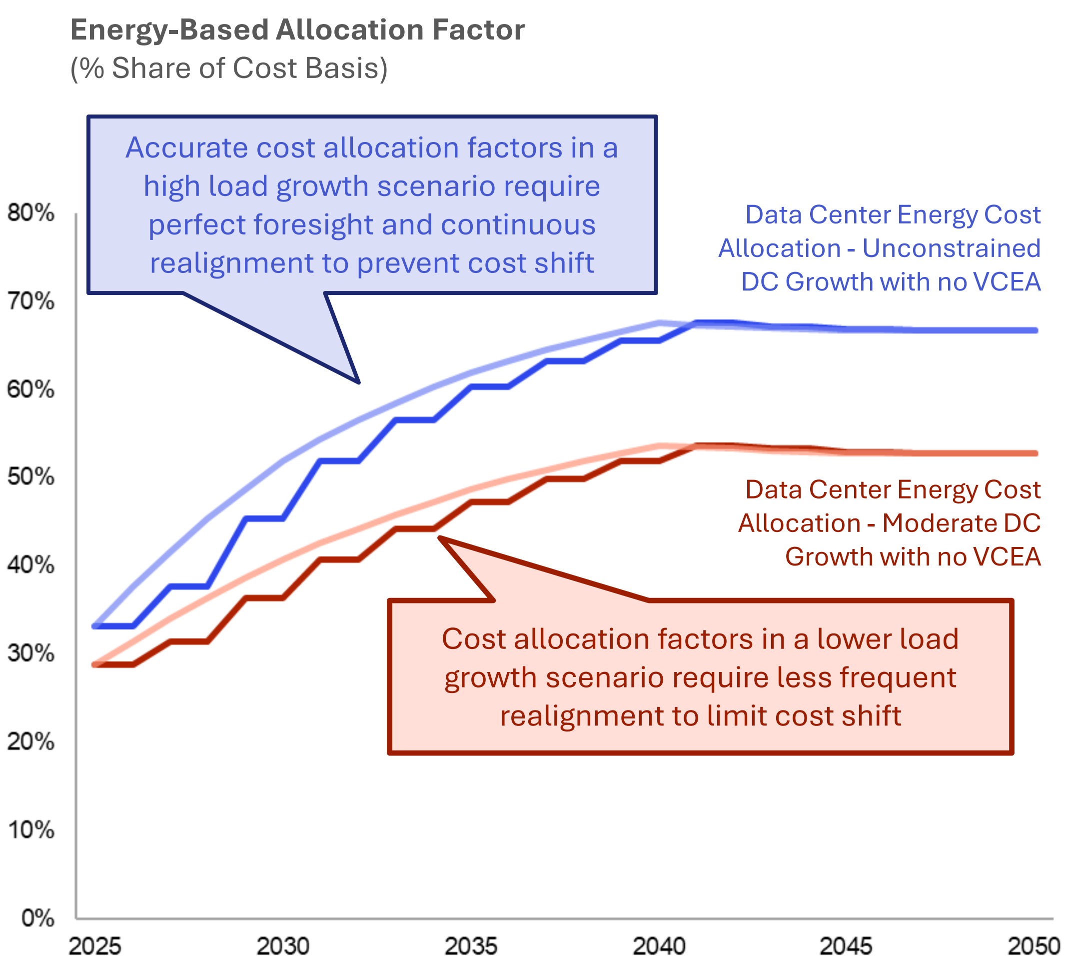
Anticipated Impact of Data Center Loads on Residential Rates: Updated Cost Allocation Factors

- **Cost allocation factors can be updated using current methodologies, which assess contributions of each rate class toward total system demand and consumption**
- **Growth forecasts were used to estimate new cost allocation factors for the residential rate class, showing a necessary reduction by about half by 2050 under the most aggressive growth scenarios**
  - Residential customers currently account for 37% of energy consumption and 51% of demand
  - Under the conditions of projected data center growth, the contribution of residential customers to system consumption and demand could fall to as low as 17% and 33%, respectively by 2050
- **Ideal realignment of cost allocation factors can inform a lower bound for residential ratepayer impact**

Average Residential Rate Impacts - Dominion
(Adjusted Allocation Factors)
cents/kWh (2022$)

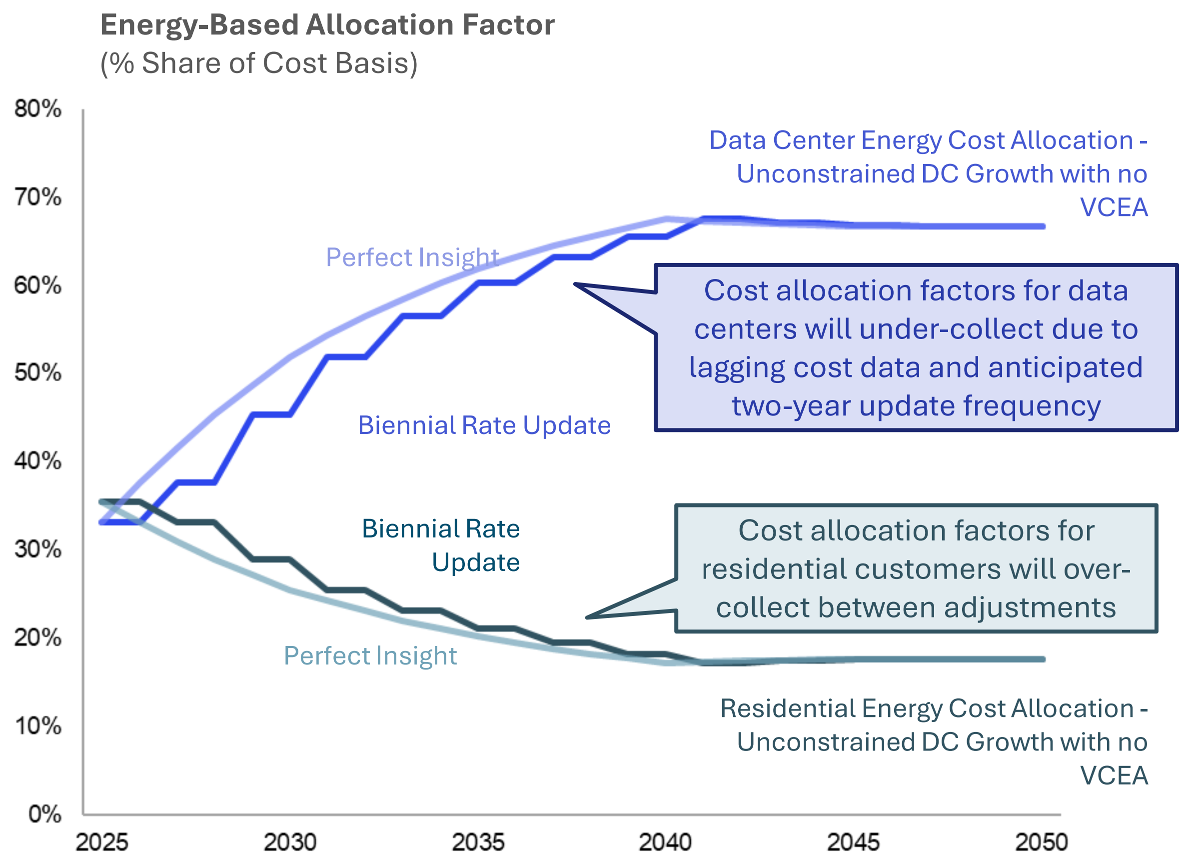


Influence of Regulatory Lag: Scenario Comparison



- **Current practices for realigning cost allocation factors are likely insufficient for keeping pace with anticipated rate of load growth**
  - Those practices were not designed to account for this level and continued pace of large load growth from essentially a single customer type
- **Introduction of new resource costs and load growth between rate reviews will meaningfully change the allocation of portfolio costs**
- **The Virginia SCC reviews cost allocation factors for Dominion every two years; while historically, this has been sufficient to address incremental load growth, the pace and magnitude of data center growth is likely to require reconsideration of this approach.**

Influence of Regulatory Lag: Rate Class Comparison

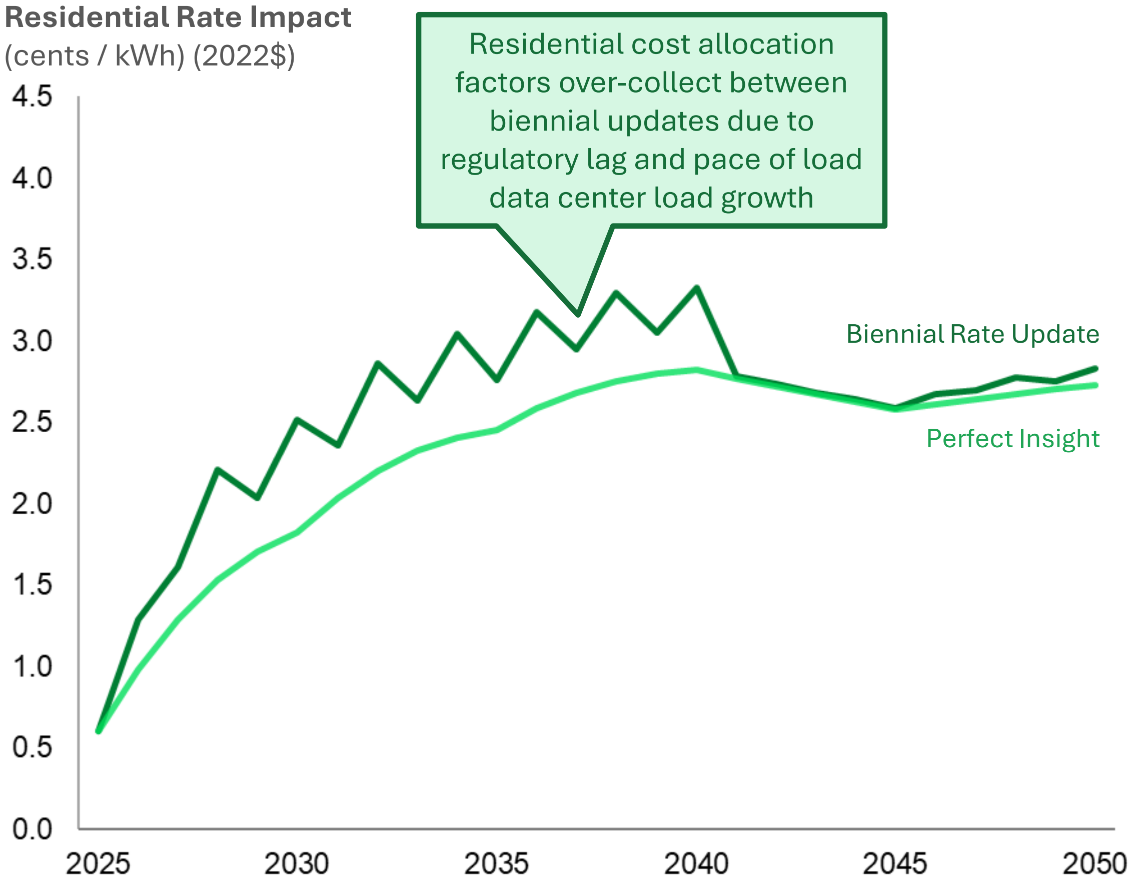


- **Best efforts to realign cost allocation factors are still likely to lag costs due to regulatory process and inaccuracies of forecasted data**
- **Such regulatory lag may shift costs away from data centers until associated load growth moderates**
  - Realignment of data center cost allocation factors is expected to increase over time, as their contribution to system consumption and demand grows; periods between cost allocation adjustments will favor data centers
  - Realignment of residential cost allocation factors is expected to decrease over time, as the class contribution to system consumption and demand falls, relative to data centers; periods between cost allocation adjustments will disadvantage residential customers

Influence of Regulatory Lag: Potential Rate Impact

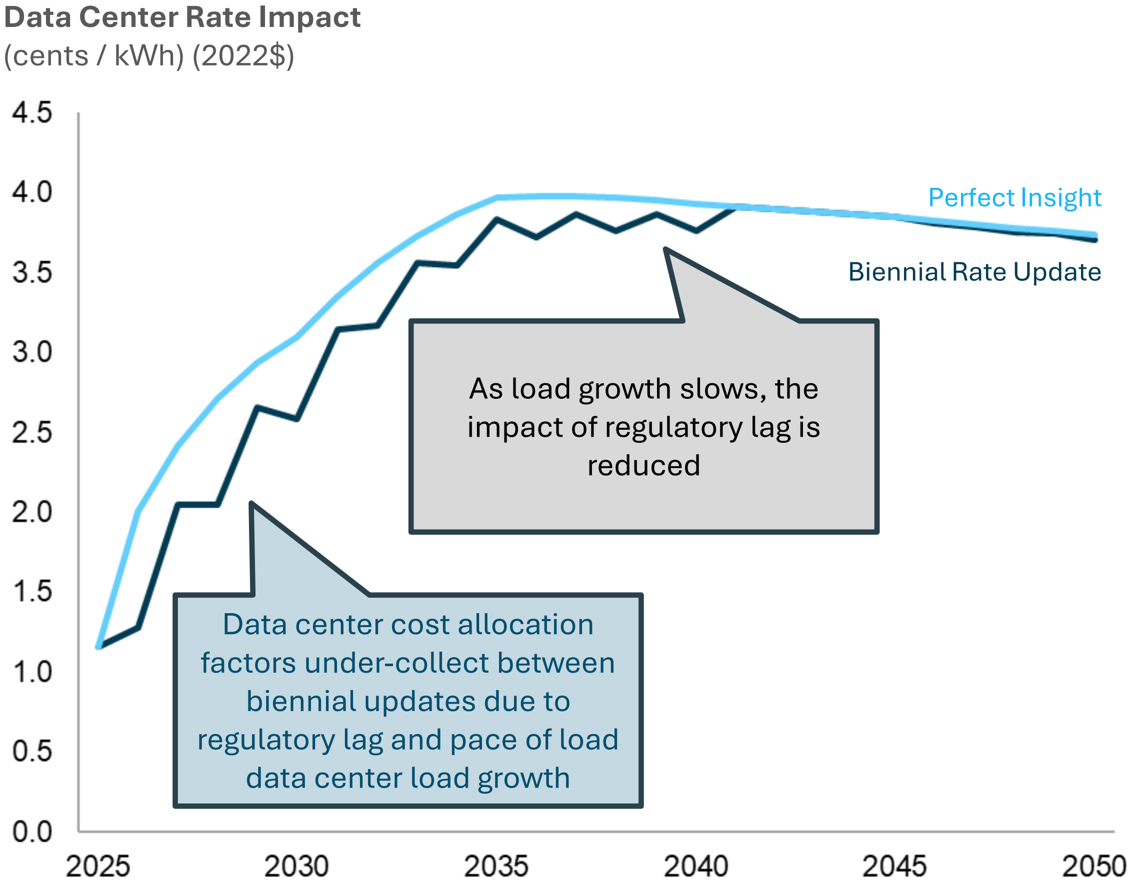
Influence of Regulatory Lag on Residential Rates

Unconstrained DC Load Growth, without VCEA



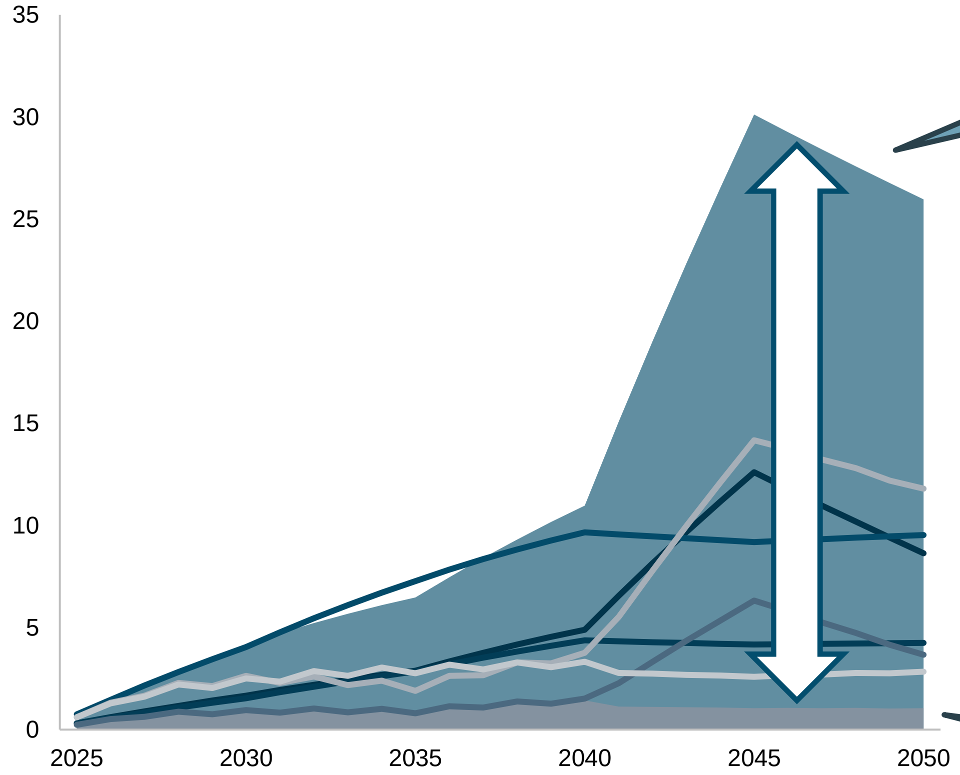
Influence of Regulatory Lag on Data Center Rates

Unconstrained DC Load Growth, without VCEA



Range of Potential Impacts

Range of Anticipated Residential Rate Impacts for Dominion Virginia
cents/kWh (2022$)



Upper boundary assumes no adjustment of cost allocation factors, which is not realistic, but shown for illustrative purposes

- **Range of possibilities is influenced by several factors:**
  - Data center growth rate
  - Cost allocation adjustments
    - Where applicable, periodic adjustment of cost allocation factors is anticipated to occur as required by the Commonwealth of Virginia
  - VCEA policy
- **Rate impacts correspond only to those from incremental data center load; other cost increases are expected**
- **Rate impacts stabilize as the load forecast levels, but effects will persist beyond load growth**

Lower boundary assumes perfect foresight and real-time adjustment of cost allocation factors, which is not practical

Residential Rate Impact
Dominion Utility – *Example Bill*

Billing Details
Learn more at DominionEnergy.com/YourBill.

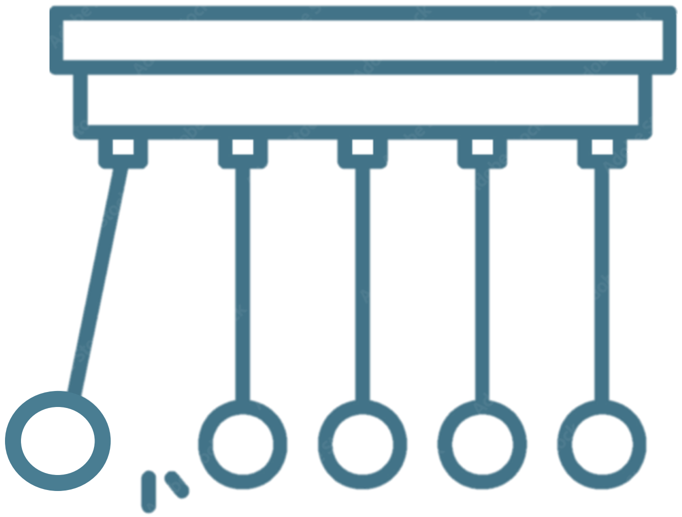
Electric Charges and Credits	
Previous Electric Charges and Credits	
Previous Balance	120.32
Payment Received	120.32 CR
Balance Forward	**0.00**
Current Electric Charges and Credits	
Residential (Schedule 1)	***03/02-04/02***
Distribution Service Charges	**30.37**
Electricity Supply Service (ESS)	
Generation	41.31
Transmission	12.14
Fuel	22.27
Electricity Supply Charges	**75.72**
Deferred Fuel Cost Charge	2.40
PIPP Universal Service Fee	0.57
Sales and Use Surcharge	1.75
State/Local Consumption Tax	1.22
City / County Utility Tax	2.00
Taxes, Fees and Charges	**8.59**
Current Electric Charges	**114.68**
Account Balance	**114.68**
Amount Due	**$114.68**

- **Incremental allocations and associated rate impacts on residential costs of transmission and generation resulting from investments supporting data center growth are expected to increase, on average, by over 12% annually through 2050, putting upward pressure on residential utility bills for Dominion customers**
- **Under the Unconstrained Data Center Growth with VCEA scenario, associated transmission and generation costs would increase the average bill for a Dominion residential customer, in real terms, from $114.68/month today to $139.37/month by 2050**
  - This increase is independent of cost impacts resulting from distribution upgrades, transmission reliability investments, or inflation
  - Assumed consumption is with 779 kWh/month of usage

https://www.dominionenergy.com/-/media/images/virginia/billing/bill-redesign/new-va-res-same-customer-example

Additional Cost Influences

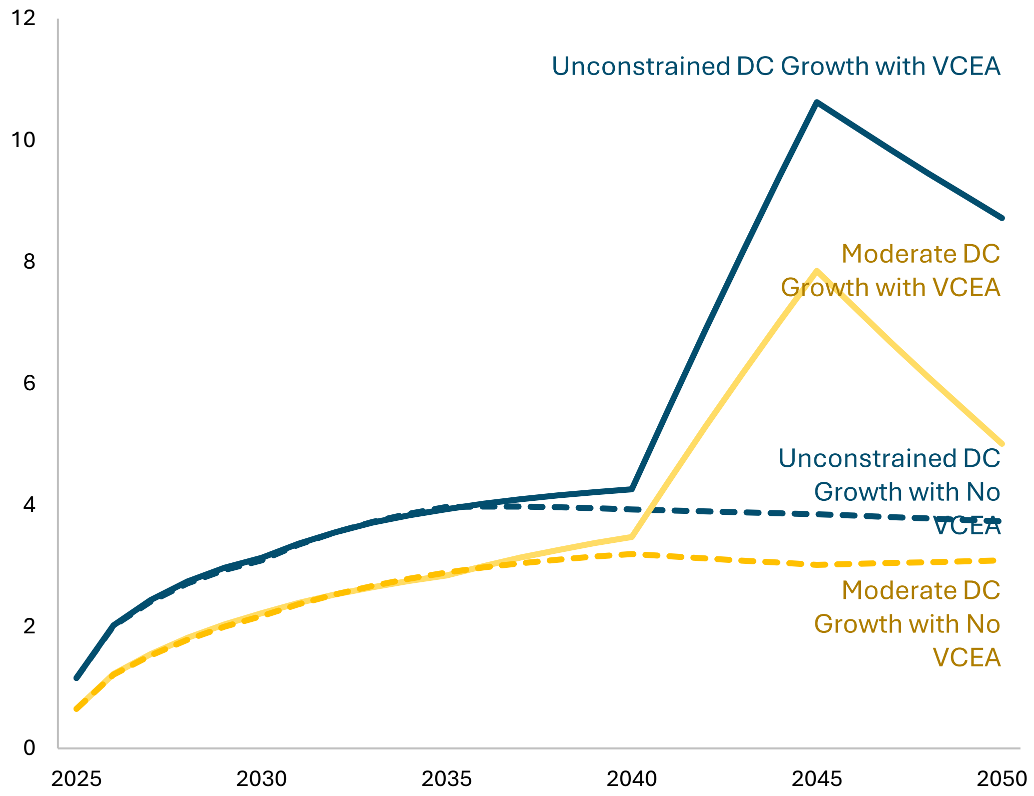
- The significant investments required by utilities to serve the anticipated data center loads are potentially likely to put pressure on both 1) their ability to raise capital from markets and 2) the cost of that capital, which would directly impact rates although that impact could be mitigated with de-risking certain data center related investments
- Renewable accelerated buyers program may promote acquisition of renewable energy from outside Virginia, which would likely alleviate some pressure on the price of in-state RECs required for VCEA compliance
- Retail choice has potential to result in stranded costs if large loads elect to transition away from bundled energy supply from their utility; though a five-year commitment period reduces volatility, a mechanism to hold customers responsible for fixed costs of generation incurred on their behalf prior to departing for a retail choice provider may help to ensure customers remain indifferent to such decisions of large loads (e.g., California's Power Charge Indifference Adjustment (PCIA) serves as one example of this approach)
- Increasing load density is likely to raise locational marginal price (LMP) in areas of higher need and constraint; utilities with high exposure to import markets will experience a commensurate upward pressure on energy prices until markets adjust and reach a new equilibrium due to increased demand



Data Center Rate Impacts

- **Data centers bear a greater financial burden than residential customers for the economic impacts of data center development under existing rate structures**
  - Data centers are projected to experience an increase in 3-4 cents/kWh by 2040, compared to an estimated increase of 1-3 cents/kWh for residential customers
- **The same economic pressures influencing residential rates are likely to have similar impacts on data center rates**
  - Data centers are expected contribute three-to-seven times more toward incremental costs than residential customers by 2050
  - Total incremental cost contributions from data centers are anticipated to range from $2-$10 billion by 2050, depending on scenario

Average Data Center Rate Impacts - Dominion (Adjusted Allocation Factors)
cents/kWh (2022$)



Future Rate Equity Considerations

Energy+Environmental Economics

Narrow Path to Equitable Outcome Under Existing Rate Structures

<u>Transformational load growth is unlikely to benefit other ratepayers under current rate structures</u>

- **Data centers are unlikely to produce downward pressure on rates until load growth stabilizes, and system equilibrium is regained, which is expected to extend beyond 2040**
- **Fixed cost impacts are expected to endure beyond the surge in data center development as resource additions and associated costs lag load growth**
- **Deviations from forecasts will exacerbate different cost concerns**
  - Failure of data center loads to fully materialize as forecasted will reduce the diffusion of fixed costs across system load, increasing upward pressure on rates for existing customers
  - Accelerated or increased data center load will further tighten marginal cost markets, exacerbating the upward pressure on variable generation costs for existing customers
- **Failure to update cost allocation factors in an accurate or timely manner will produce inequities**

Expanding the Path to an Equitable Outcome

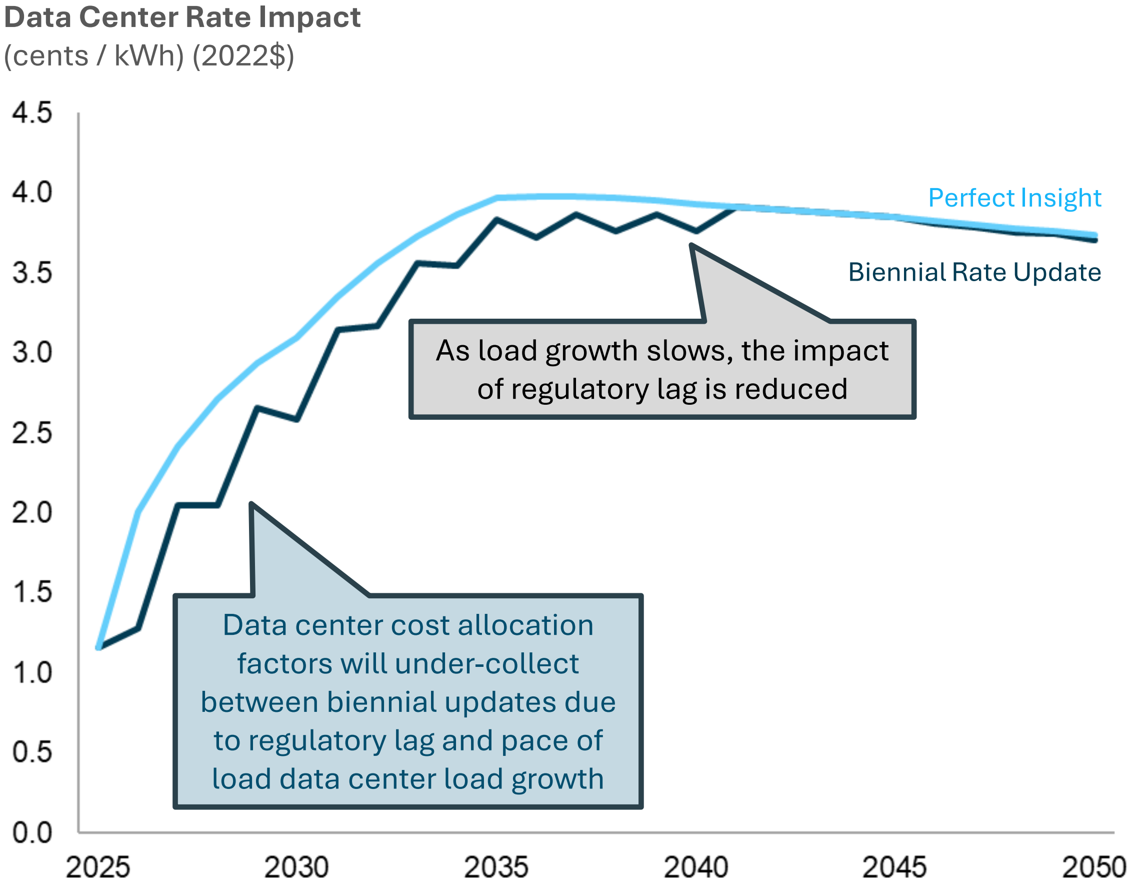
<u>Various tools can help manage risk and widen the path to equitable integration of data center loads</u>

+ Updating cost allocation factors and reducing regulatory lag given pace and scale of data center load growth
+ Additional charges for data centers that balance historical ratemaking for individual large loads and potential impacts of transformational load growth
+ Better forecasting of data center demand, which can also include a waitlist for service and other load interconnection queue reforms
+ Long-term service commitments that may include ramping provisions, exit fees, and/or minimum terms for energy and demand charges such as "take or pay" constructs
+ Self supply of resources or "bring your own generation" of both existing and emerging technologies like SMRs along with leveraging continued innovation from data center companies on energy efficiency as well as flexible operations
+ Direct assignment of new infrastructure costs as well as enhanced collateral / credit requirements

Rate Impact Toolkit:
Updating Cost Allocation Factors

- **Improving processes for updating cost allocation factors may help mitigate the potential for cross-subsidization between classes due to regulatory lag**
  - More frequent adjustments could help to maintain more accurate apportioning of costs
  - Automatic adjustments, within an approved framework and subject to periodic review, could enable utilities to keep pace with rapid load growth
- **Reducing oversight and regulation of cost allocation factors may introduce risk due to the magnitude and frequency of adjustments that are likely to be required**

Influence of Regulatory Lag on Data Center Rates
High DC Load Growth, without VCEA



Rate Impact Toolkit:
Additional charges for data centers

Inclusion of a surcharge for associated data center rates would recover additional contributions to embedded costs and could be set to offset indirect costs incurred due to data center load and to guarantee a net benefit for existing customers

If data centers were to be mostly or fully assigned costs incurred on the system on their behalf, existing customers would be insulated from many of the direct cost impacts

Excessive contributions by data centers, above marginal cost, could be viewed as discriminatory and may stifle new data center development

Marginal Costs	New Costs	Contribution to Fixed Costs
Data Centers must pay at least their marginal costs of service to avoid shifting the burden inequitably to existing customers	**New costs could be direct (e.g., administrative) or indirect (e.g., network upgrades) and may be difficult to quantify or assign**	**Contributions by data centers to system fixed costs benefit existing customers; however, excessive contributions are inequitable to data centers**

Rate Impact Toolkit:
Data Center Interconnection Queue Management

- To reduce risks associated with forecast error and potential stranded assets, a "wait list" of data centers could be developed to take the place of any data center that ceases operation
- Given Virginia's unique position as the premier data center market, other data center customers may be likely to take the place of a load that fails to materialize or one that exits the market prematurely
- Assets would have higher assurance of being fully and consistently utilized if new data center loads were actively waiting for opportunities to take over any load that drops out or is not meeting certain development milestones

Image generated with AI

Rate Impact Toolkit: Service Commitments

+ **Recent settlement agreements across diverse stakeholders including data center companies filed with regulators in Ohio and Indiana aim to address provisions for interconnecting large data center loads**
+ **The proposals contains several key elements that address concerns over committed fixed costs**
  - Minimum payment threshold requires data centers to pay for a percentage of their projected energy needs upfront
  - Contractual obligations mandate extended contract terms with exit fees for data centers that cancel projects early
  - Focus on consumer protection ensures that data centers contribute adequately to grid upgrades needed to serve them
+ **While the concept has shared support from a wide variety of stakeholders, disagreement over the specific terms and rates has led to two competing proposals to be filed with the PUC**
  - Advocates for proactive management of data centers growth include:
    - Utilities
    - Regulatory staff
    - Ratepayer advocates
    - Traditional industry representatives, like Walmart
  - Some data center developers and energy suppliers are advocating for similar, but more modest terms to balance their perceived risk such as the utility failing to interconnect them on schedule

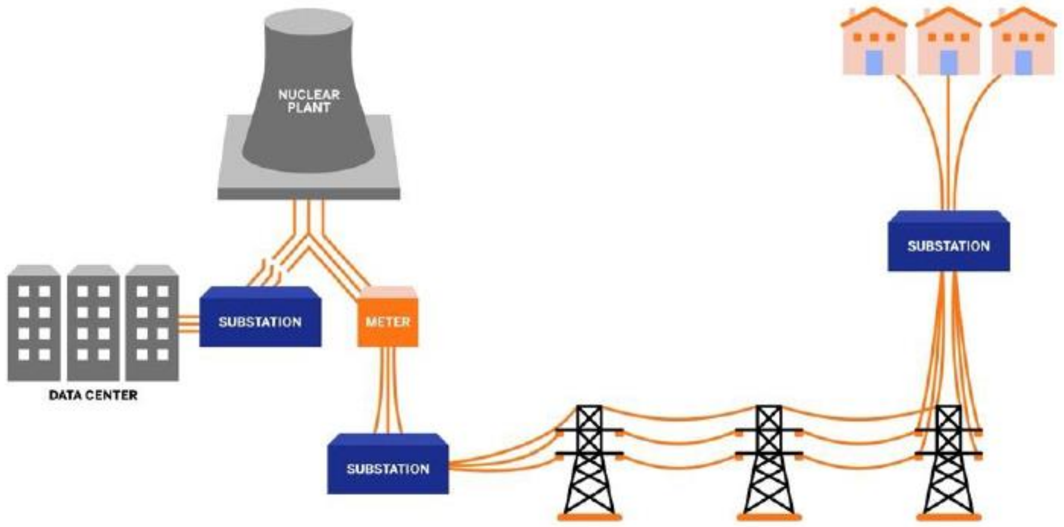
One proposal would require new data center customers to pay a minimum of 85% of the contracted capacity, regardless of actual demand or consumption. Such a commitment would be in place for 12 years, including a 4-year ramp up period.[1]

[1] AEP Ohio, PUCO Staff, Ohio Consumers' Counsel, Ohio Energy Group and Others Agree on How to Address Growing Data Center Power Needs
PUCO case no. 24-508-EL-ATA, Joint Stipulation And Recommendation. https://dis.puc.state.oh.us/

Rate Impact Toolkit:
Self Supply of Resources

Data centers have several options for procuring their own resources:

Co-location: On-site generation is the primary power supply for the data center with direct, bilateral agreements between the power developer and the data center owner/operator



Power Purchase Agreement (PPA): Agreement between data center and power supplier within the same service territory with utility acting as an intermediary

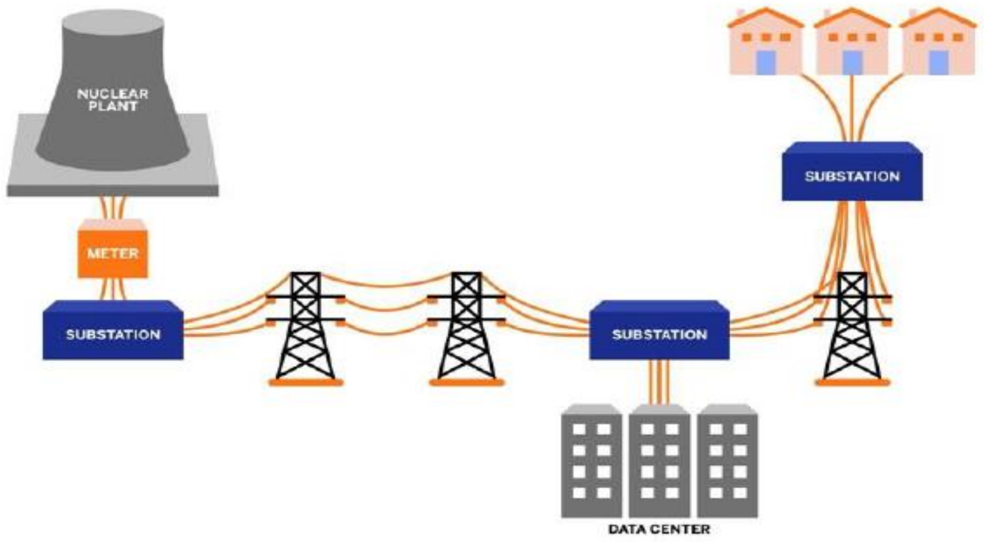


Figure source: Kormos, Michael, The Co-located Load Solution, July 2024. https://ferc.gov/libraries/

Benefits and Concerns of Self Supply

- The concept of "bring-your-own-generation" ("BYOG") has gained recent interest by data center developers and utility regulators
- In March 2024, Talen Energy sold its data center campus linked to the Susquehanna Nuclear Station in Pennsylvania to Amazon Web Services with a 10-year power purchase agreement for up to one-third (960MW) of the facility's total capacity to be delivered directly to the data center; the amended interconnection agreement was subsequently rejected by FERC in November 2024
- FERC held a technical conference in November 2024 to begin addressing the issue of co-location of data centers with generators
- FERC, PJM, and many other stakeholders including utilities and data center companies are continuing to actively explore the issue of data centers co-locating with generation, with additional guidance anticipated

> "Co-location arrangements of the type presented here present an array of complicated, nuanced and multifaceted issues, which collectively could have huge ramifications for both grid reliability and consumer costs"
>
> –FERC Commissioner Mark Christie

Susquehanna Nuclear Plant and Data Center

Photo: Talen Energy

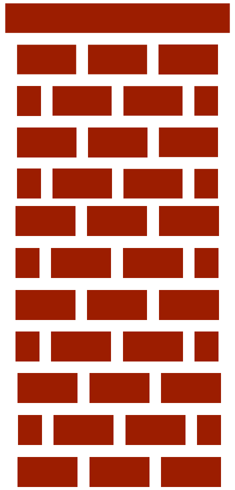
FERC Docket No. AD24-11-000, October 2024. https://www.ferc.gov/news-events/events/commissioner-led-technical-conference-regarding-large-loads-co-located
PJM Guidance on Co-Located Load. April 2024. https://www.pjm.com/-/media/markets-ops/rpm/rpm-auction-info/pjm-guidance-on-co-located-load.ashx

Rate Impact Toolkit:
Direct Assignment of Costs

- Mitigating the cost impacts of extreme load growth for existing general service customers may warrant isolating data centers and directly assigning costs
- Resource portfolios would effectively be separated with costs sourced through energy service agreements or otherwise acquired exclusively to serve data center load
- Insulating existing customers from data center customers provides downside protection, but also limits opportunity for the potential upside impacts like margin sharing, clean energy generation acceleration, or long-range diffusion of fixed costs over time
- Historically public power utilities use this technique more frequently than investor-owned utilities primarily due to business model differences and other factors

General Service Customers

Cost Component	Cost Recovery
Energy Capacity Ancillary Services RECs Embedded Fixed Costs Administrative Costs Interconnection Costs	Embedded Cost



Data Center Customers

Cost Component	Cost Recovery
Energy Capacity Ancillary Services RECs	Marginal Cost
Embedded Fixed Costs	Fixed Cost Adder
Administrative Costs Interconnection Costs	Directly Assigned

Indirect influences unable to be effectively measured and assigned based on cost causation would continue to be socialized putting upward pressure on costs for all utility ratepayers

- Utility bond rating
- Marginal cost markets
- Locational marginal pricing

Rate Impact Management: Spectrum of Rate Design Tools

	Promotes Data Center Growth	Protects Existing Customers	Potential Benefits for Existing Customers	Relative Ease of Implementation
Fully Embedded Rate Structure (Current Methodology)				
Cost Allocation Adjustments				
Additional Charges for Data Centers				
Waitlist for Service				
Service Commitments				
Self Supply of Resources				
Direct Assignment of Costs				

Additional Considerations

- If data center loads are constrained or discouraged in Virginia, they may take root elsewhere in PJM, which would likely have similar generation and transmission marginal cost rate impacts without the associated local economic development
- In some cases, the resource development and network upgrades required to serve increasing data center load may be an *acceleration* of improvements that would otherwise be warranted, not necessarily an outright addition such as the needed rebuild of an aging grid as well as the need to expand the grid for successive waves of load growth such as from electric vehicles, building electrification, and advanced manufacturing
- Load growth, led by data centers, will likely accelerate the development of clean energy resources due to their preferences along with developing new energy resources such as first-of-a kind technologies that traditional utilities and customers cannot easily support which can spur more rapid innovation and improved cost efficiencies, unlocking long-term benefits to all consumers
- In a scenario where data center growth is low or lower than expected and native load growth is high, due to electrification of building and transportation sectors and/or other new industrial loads, the additional load from data centers would help diffuse those native load driven incremental fixed costs which could potentially put downward pressure on rates
- The addition of stable loads and beneficial system upgrades prompted by data centers will likely provide a long-term advantage for all consumers once load growth eases, fixed costs are recovered, and market pressure subsides

Recommended Improvements to Utility Retail Rate Design

Energy+Environmental Economics

Recommendations

Dominion

- Cost recovery exposes the utility and its other rate payers to risk if data center does not fully subscribe or fails to operate for sufficient time to collect full system investment through allocations
- Adjustment of cost allocation factors should be made more frequently to mitigate cost shifts due to regulatory lag
- Data centers represent an industry with sufficient size and unique attributes (e.g., load factor) to likely warrant separate rate class; comingling different industries at this scale unnecessarily complicates the process of fair and equitable allocation of system costs, especially for other industrial customers with other needs and operating patterns who are served under the same class.

MEC

- A tailored approach seeks to assign all costs incurred by the Cooperative’s only data center to the customer directly. This approach likely underutilizes the infrastructure, reducing system efficiency and placing sole onus on data center customer, rather than having opportunities for shared costs and resources among several customers
- While very effective at insulating costs between rate classes, MEC’s tailored approach to its data center customer is so prescriptive that expansion from a single customer to a class of customers is not realistic under the existing structure; therefore, unless a more flexible framework is implemented, future data center customers will require their own unique rate designs, which may be seen as impractical or discriminatory

NOVEC

- There are limited updates to its cost-of-service study on file with the SCC; more frequent reviews would help to ensure that assumptions and cost recovery methods are maintained well-calibrated with growing data center loads

General

- Leveraging on-site generation during peak loads via a demand response program or interruptible (non-firm) rate could help reduce fixed costs associated with building and maintaining additional system capacity; a variance measure was proposed by Virginia’s Department of Environmental Quality in 2023, which would authorize such action, but it was eventually cancelled for lack of customer interest

DEQ Proposes Measure to Preserve Data Center Reliability | News Releases | Virginia DEQ

Appendices

Energy+Environmental Economics

Appendix Contents

Appendix A: Methods and Inputs

Electric Infrastructure Study Overview

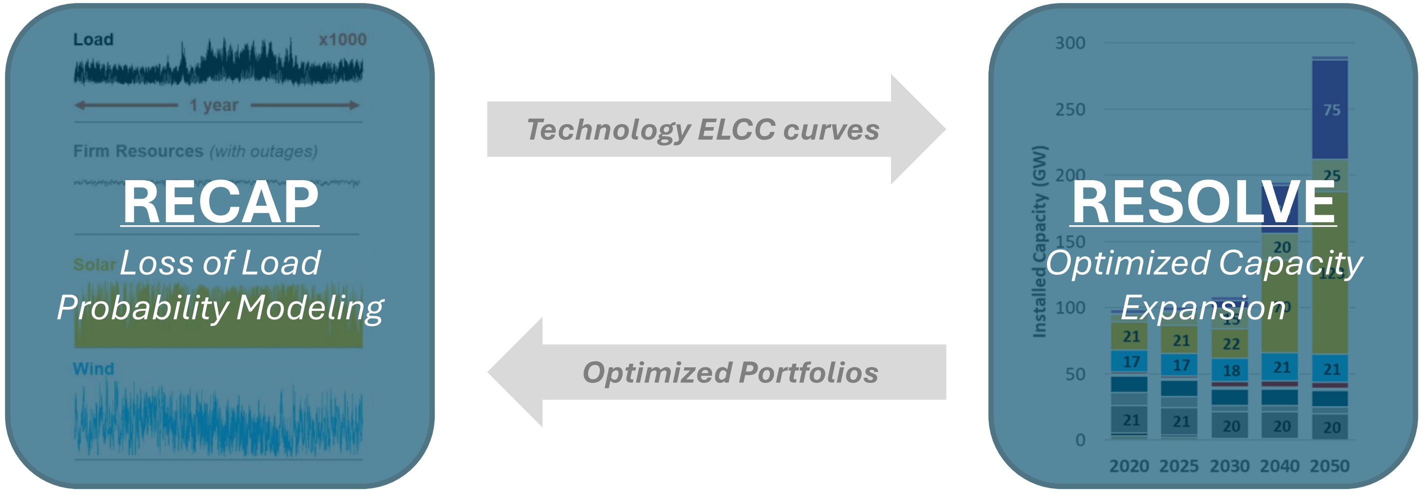
Key Objective of Infrastructure Analysis: Examine electricity system infrastructure and associated investments required to meet the VCEA goals under a wide range of potential data center-driven load growth scenarios

*To perform this work, E3 leveraged a **capacity expansion model** in tandem with a **loss of load probability model**, in order to ensure the resulting portfolios are reliable over a broad range of weather conditions.*

E3 modeled the entire PJM region within its capacity expansion framework to allow more detailed examination of the interaction between Virginia and the broader market in the context of rapid data center growth. However, by design we did not model the PJM market construct precisely in terms of price formation of energy and capacity prices.

This analytical framework identifies the total infrastructure requirements but does not distinguish between utility-owned infrastructure vs. 3rd party owned vs. "behind-the-meter" generation at data center facilities.

1a Use LOLP model to quantify "effective load carrying capability," which measures contribution of each resource to reliability across 100s of simulations



1c Use LOLP model to simulate resulting portfolios across wide range of conditions, validating resource adequacy

1b Use capacity expansion to optimize future portfolios to meet reliability and clean energy goals while minimizing cost

RECAP: Loss-of-Load Probability Modeling to understand grid reliability needs

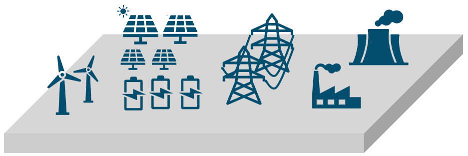
+ **RECAP is a loss-of-load-probability model developed by E3 to study the reliability dynamics of high-renewable electricity systems**
+ **RECAP simulates the operations of the electricity system under thousands of scenarios to capture different conditions**
  - Including load variability, weather variability, renewable output variable, forced outage events
+ **Key RECAP outputs:**
  - System reliability
  - Target planning reserve margin
  - Capacity need shortfall
  - Capacity value of resources

Temperature and Load Artificial Neural Network Simulation

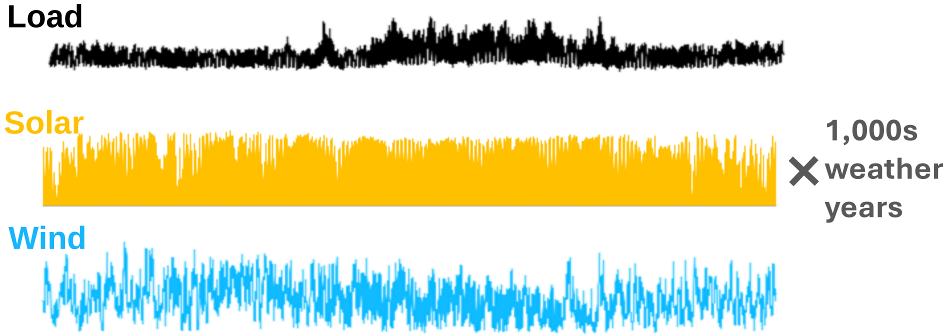
Capturing hourly load conditions under mild and extreme historical weather

Operational Module

Dispatching resources based on outage characteristics, weather dependency, state of charge availability, and demand-side management

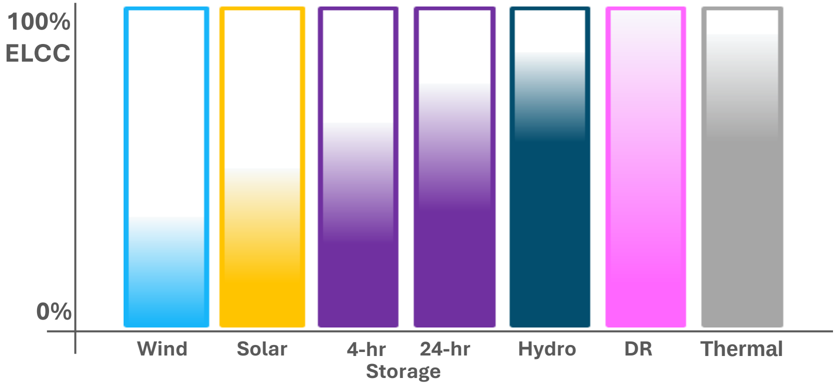


System Reliability: simulates the operations of the electricity system under thousands of scenarios to capture different conditions



Resource Capacity Value: measures resource's ability to contribute to reliability under a marginal or average ELCC methodology

Illustrative ELCC Values Across Technologies

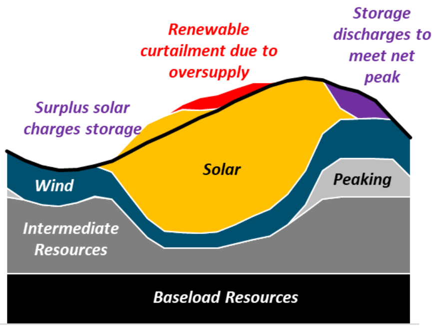


RESOLVE Model Overview

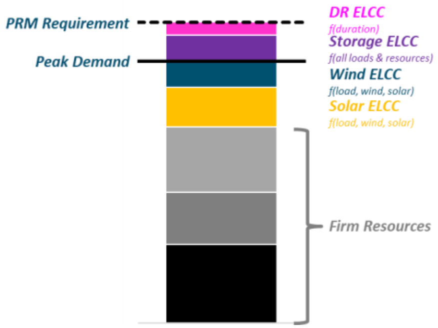
+ **RESOLVE is a linear optimization model explicitly tailored to study of electricity systems with high renewable & clean energy policy goals**

+ **Optimization balances fixed costs of new investments with variable costs of system operations, identifying a least-cost portfolio of resources to meet needs across a long time horizon**

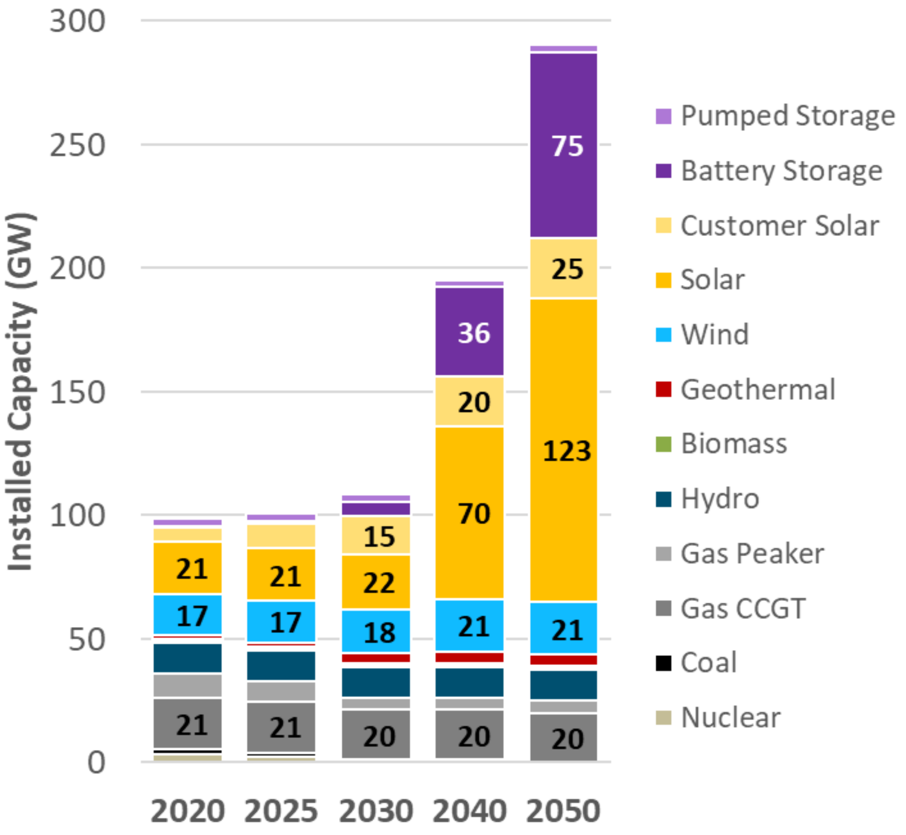
Operational module simulates hourly system operations for a sample of representative days



Reliability module ensures portfolio can meet load during extreme conditions using an ELCC approach



Least-cost plan co-optimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, DSM, and natural gas, etc.



Example RESOLVE result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

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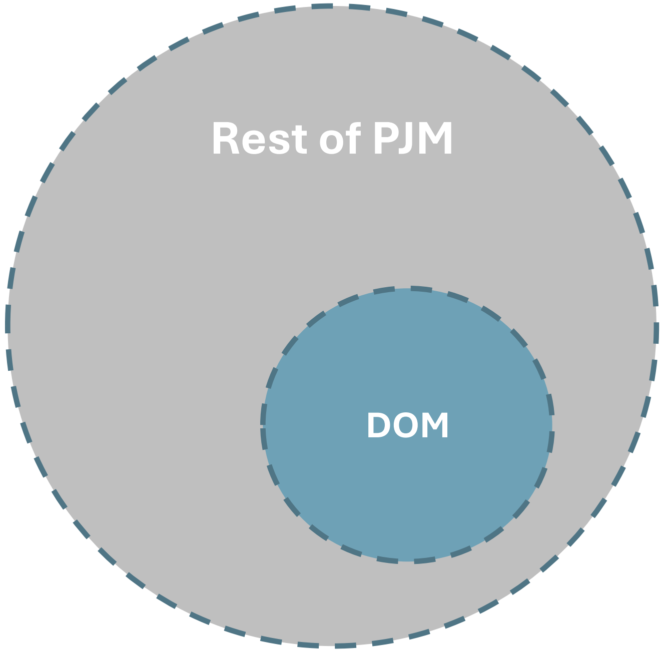
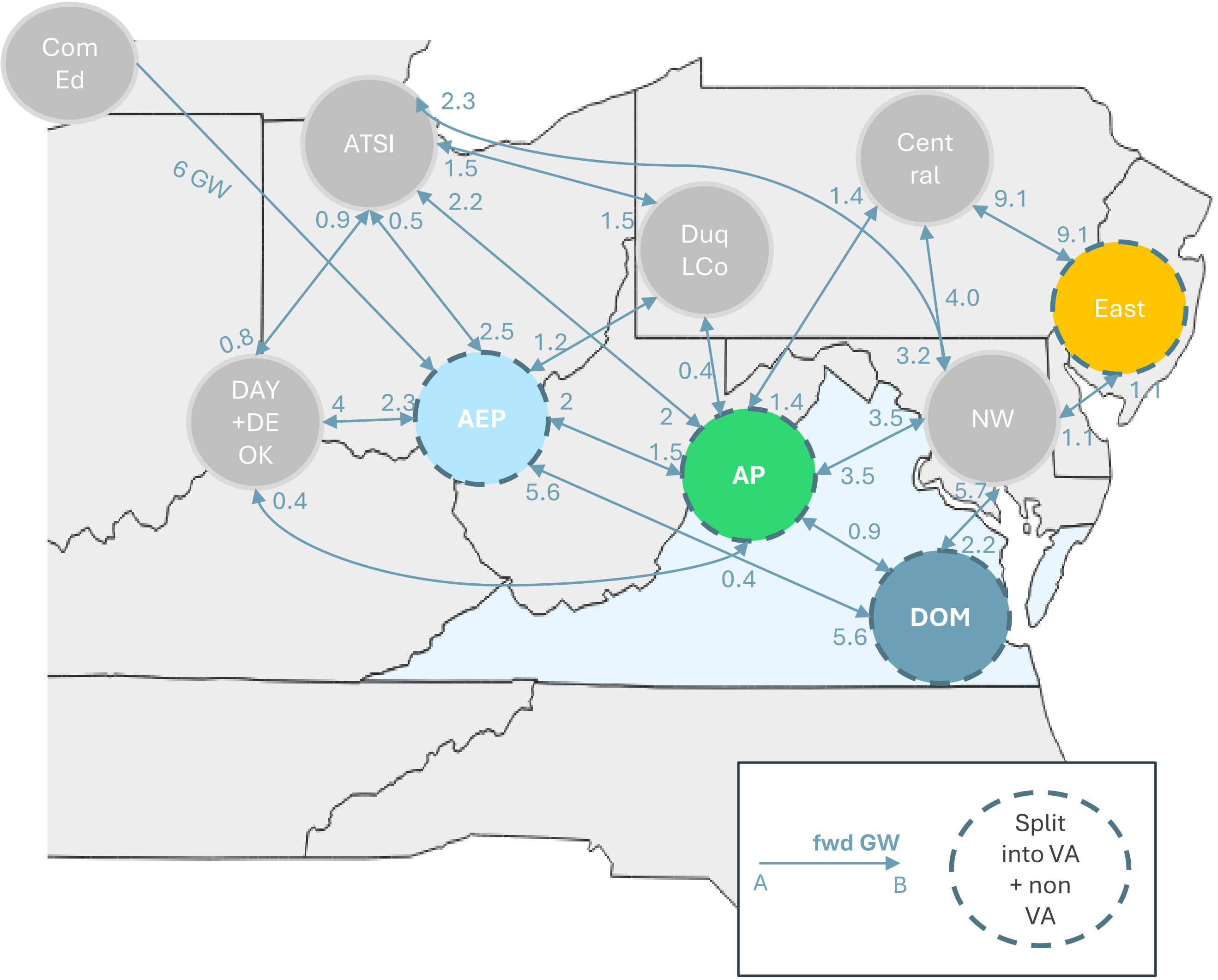
Model Topology and Scope for RECAP

- **E3 estimated the evolution of system reliability need using RECAP for (1) DOM transmission zone and (2) the entire PJM**
  - Benchmarked to current planning reserve margin constructs, the effective capacity needs for maintaining a reliable system were set for future years through 2050 and under each data center growth scenario
- **E3 produced resource Effective Load Carrying Capability (ELCCs) for existing and candidate future resources**
  - Resource ELCCs for DOM are used to reflect the specific resource adequacy constraints with increased data center load and renewable build-out in that area
  - Resource ELCCs for PJM are used for all other zones modeled in RESOLVE
  - The ELCC approach was also later used to estimate the reliability contribution of potential data center load flexibility
- **This approach ensures that both the DOM transmission zone and the entire PJM region will meet the reliability criteria (1 day in 10 year loss-of-load expectation, i.e., 0.1 LOLE)**
  - The ability to access the capacity market is still present for the DOM transmission zone, but this construct ensures most of its capacity requirements are met internally



Capacity Expansion Topology

+ **E3 modeled capacity expansion for the PJM market in RESOLVE with 10 load and capacity zones - with those overlapping with Virginia (DOM, AEP, AP, East) broken into VA vs non-VA subzones**
  - This topology allows us to model VA specific assumptions and constraints (e.g. WCC's load forecast and VCEA policies) while capturing the broader market dynamics within PJM
  - Transmission constraints between these zones are derived from information provided by Energy Exemplar
  - Transmission upgrades between DOM and its neighboring zones (AEP, AP, and NW) are modeled as an option to allow more detailed examination of transmission infrastructure upgrade needs to support data center load growth in Northern Virginia
+ **The modeling horizon covers 2025-2050 for this study**



Key Modeling Assumptions

- **Load Forecasts** derived from information provided by WCC and published by PJM (2024)
- **Existing Resources** grouped by zones, technology, fuel, and quality tiers (e.g. high/mid/low heat rates for thermal units)
  - Planned resources expected through 2027/2028 included as expected additions
- **Candidate Renewable Resource Potential** drawn from the National Renewable Energy Laboratory's (NREL) ReEDS supply curve
  - Potentials, capacity factors, and interconnection costs for solar PV, onshore wind, and offshore wind candidate resources
- **Candidate Resource Costs** developed leveraging NREL's 2024 Annual Technology Baseline (ATB) forecast and standard E3 financing assumptions
  - Includes escalating local network upgrade costs for renewables which are developed based on transmission projects recently approved by PJM in the DOM zone, in addition to the specific resource interconnection costs from NREL ReEDS
- **Policy Assumptions**
  - EPA regulations, post 2030, constrain new gas builds to a 40% annual capacity factor and require existing coal units to co-fire with natural gas
  - RGGI modeled for participating states (NJ, MD, DE) in the East transmission zone, with price forecast developed by E3
  - States' RPS policy and clean energy carveouts modeled
  - VCEA requirements considered in the VCEA compliance scenarios

Transmission Upgrades

Transmission upgrades can be broadly categorized into the following groups:

+ **Intra-zonal transmission upgrades**

Captured in model at high level; see next slide for details

- **Resource interconnection |** Spur line constructed to connect individual projects to nearest substation
- **Resource-driven local network upgrade |** Upgrade needed for medium to high voltage local transmission system to allow delivery of new resources to loads

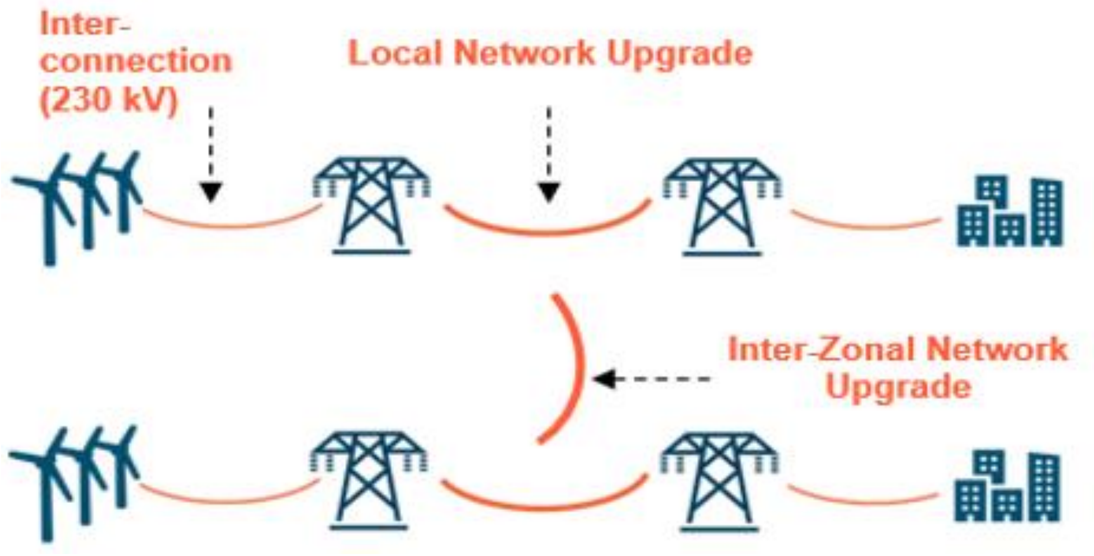
Not captured in model

- **Load growth-driven local network upgrade |** Upgrade needed for local transmission system to address reliability/thermal dynamic issues associated with interconnection of new loads

+ **Inter-zonal transmission upgrade**

Captured in model at high level; see next slide for details

- Upgrade needed to increase transfer capability between regions in the bulk power system



Transmission Assumptions in RESOLVE

+ **Existing transmission constraints:**
  - **Inter-zonal constraints |** Our capacity expansion model (RESOLVE) captures existing transmission constraints between PJM's load and capacity zones using a "pipe-and-bubble" framework, leveraging the PJM database from Energy Exemplar

+ **Potential transmission expansion and costs:**
  - **Interconnection |** Our analysis considers and reports potential interconnection costs associated with the additions of new renewable capacity
  - **Local network upgrades |** Our analysis considers and reports local network upgrade costs associated with the additions of new renewable capacity; a transmission cost curve was developed for new renewables in each zone (higher transmission upgrade costs as a function of increased renewable deployment), which was considered as part of the total resource cost for renewables in capacity expansion
  - **Inter-zonal upgrades |** Our analysis also includes an option for the model to select inter-zonal transmission upgrades between DOM and neighboring transmission zones (AEP/AP/NW) with escalating costs
    - Our model topology was built on existing system constraints since the detailed transfer limit impacts of the recently approved PJM RTEP Window 3 projects are still being studied; as a result, the reported incremental investments can be considered a mix of both approved (Window 3) and new projects

+ **Notes and caveats:**
  - We did not model load growth-driven intra-zonal transmission upgrades, which would require more detailed transmission system modeling and information regarding the placement of new data center loads
    - Many of the RTEP window 3 projects were approved to address reliability challenges to connect new large loads within the DOM zone; as a result, our model results should not be compared on an apples-to-apples basis with the RTEP study
  - We assumed new capacity resources (e.g. gas, battery, SMR) can be located near loads and thus do not require significant amount of transmission upgrades. Should there be potential constraints on where those resources can be added, additional transmission upgrade costs might be incurred with the addition of those resources
  - The transmission upgrade costs reported from our modeling reflects annualized transmission upgrade costs, which cannot be directly compared to the upgrade costs reported in PJM's RTEP study, which reflects the total upfront investments needed

Regional and Sub-Regional Resource Build Limits

+ **Build limits are implemented by technology, location, and future model year**
  - *Resource potentials* - Based on NREL ReEDs and with further adjustments, each resource type has a **total potential build amount** available for each of several subzones (also known as NREL's "p-zones"). These potentials inform the **quality and location** for an exhaustive list of candidate resources.
  - *Interconnection limits* – Based on geographical location relative to the grid and **how much new transmission would need to be built** to link resources to the existing grid. These limits also dictates the **pace of resource potential availability** over the modeling period, assuming further out resources are not available right away in 2030 and 2035.
  - *Build rate limits* – Based on historical build rates and the interconnection queue by zone and by technology, the model constrains **how much can reasonably be built by 2030** (more stringent) and by 2035 (less stringent) in each major zone. These **build rates apply to renewables as well as thermal resources and storage**.
+ **The amount of capacity that can be added in a given area also incurs higher transmission network upgrade costs**
  - *Deliverability limits* – Based on estimated **grid upgrade requirements** in each subzone, new renewable resources need to be accompanied by substation and transmission line upgrades which have their own **implied costs and upgrade rate limits**. Solar and wind resources in the same subzones share the same deliverability limits and required upgrade costs.

Scenario Matrix

Assumptions/Scenarios	No DC Growth No VCEA	No DC Growth With VCEA	Moderate/Unconstrained DC Growth No VCEA	Moderate/Unconstrained DC Growth With VCEA
Load	No Data Center load growth in VA post 2023	No Data Center load growth in VA post 2023	Moderate or Unconstrained Data Center load growth	Moderate or Unconstrained Data Center load growth
VCEA Compliance	No	Yes (IOU or Statewide)	No	Yes (IOU or Statewide)
Existing Thermal	Economic Retirement	Coal/oil/biomass retire in 2045; Gas optional to convert to hydrogen by 2045 with incremental costs	Economic Retirement	Coal/oil/biomass retire in 2045; Gas optional to convert to hydrogen by 2045 with incremental costs
Candidate Renewables, Storage, Gas	Build rate limits through 2035	Build rate limits through 2035	Build rate limits through 2035	Build rate limits through 2035
Hydrogen	Not available	Available [1]	Not Available	Available [1]
SMR (nuclear)	Not available	Available 2035+ with build limits	Available 2035+ with build limits	Available 2035+ with build limits
Capacity Purchases and Transmission Upgrades	Capacity purchase allowed up to 3 GW; No transmission upgrade allowed	Capacity purchase allowed up to 3 GW; No transmission upgrade allowed	Capacity purchase allowed with transmission upgrades required beyond 3 GW; Transmission upgrades allowed post 2035+ with limits	Capacity purchase allowed with transmission upgrades required beyond 3 GW; Transmission upgrades allowed post 2035+ with limits

[1] The consumption of hydrogen for power generation would also require additional fuel delivery and storage infrastructure; the costs of such infrastructure is captured at a high level on a $/MMBtu basis. However, these costs assume that Virginia is able to access a robust regional hydrogen economy that is already in place in the future, and costs would be higher if Virginia is building new / first-of-a-kind infrastructure.

Additional Sensitivities on Feasibility

Assumptions/Scenarios	Unconstrained DC Growth With VCEA (S3C)	Unconstrained In-State Renewables (S3C: HighRen)	Regional Coordination (S3C: RegCoord)	Nuclear Renaissance (S3C: NucRen)
Load	Unconstrained VA DC load growth	Same as S3C	Same as S3C	Same as S3C
VCEA Compliance	Yes	Same as S3C	Same as S3C	Same as S3C
Existing Thermal	Coal/oil/biomass retire in 2045; Gas optional to convert to hydrogen by 2045 with incremental costs	Same as S3C	Same as S3C	Same as S3C
Candidate Renewables, Storage, Gas	Build rate limits through 2035	Higher onshore wind availability and accelerated offshore wind allowed	Same as S3C	Same as S3C
Hydrogen	Available	Same as S3C	Same as S3C	Same as S3C
SMR	Available 2035+ with build limits	More stringent SMR build limits and higher costs	More stringent SMR build limits and higher costs	No SMR build limits
Capacity Purchases and Transmission Upgrades	Capacity purchase allowed with transmission upgrades required beyond 3 GW; Transmission upgrades allowed post 2035+ with limits	Same as S3C	Relaxed transmission build limits	Same as S3C

Additional Sensitivities on Load Flexibility

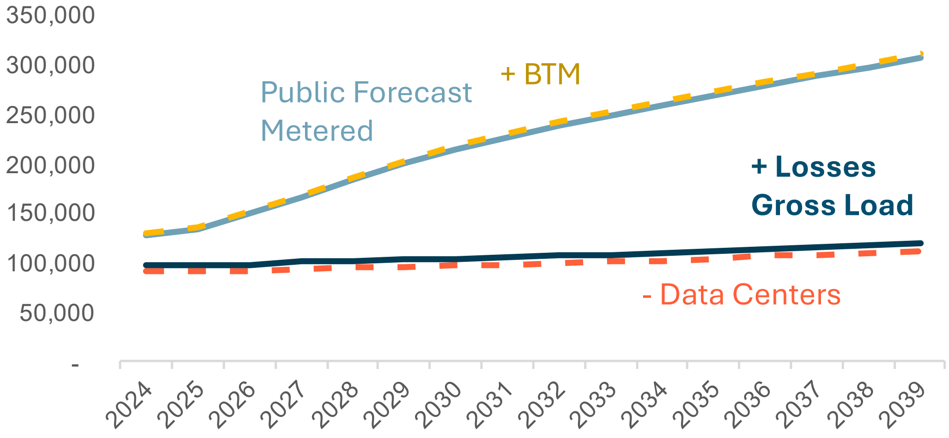
Assumptions/Scenarios	Unconstrained DC Growth With VCEA (S3C)	2-hr Flexible Load	4-hr Flexible Load	8-hr Flexible Load	120-hr Flexible Load
Load	Unconstrained VA DC load growth	10% DC load modeled as 2-hr battery in 2050	10% DC load modeled as 4-hr battery in 2050	10% DC load modeled as 8-hr battery in 2050	10% DC load in 2050 modeled as 120-hr demand response or on-site generation, with 5 24-hr calls per year
VCEA Compliance	Yes	Same as S3C	Same as S3C	Same as S3C	Same as S3C
Existing Thermal	Coal/oil/biomass retire in 2045; Gas optional to convert to hydrogen by 2045 with incremental costs	Same as S3C	Same as S3C	Same as S3C	Same as S3C
Candidate Renewables, Storage, Gas	Build rate limits through 2035	Same as S3C	Same as S3C	Same as S3C	Same as S3C
Hydrogen	Available	Same as S3C	Same as S3C	Same as S3C	Same as S3C
SMR	Available 2035+ with build limits	Same as S3C	Same as S3C	Same as S3C	Same as S3C
Capacity Purchases and Transmission Upgrades	Capacity purchase allowed with transmission upgrades required beyond 3 GW; Transmission upgrades allowed post 2035+ with limits	Same as S3C	Same as S3C	Same as S3C	Same as S3C

Appendix B:
Load Benchmarking

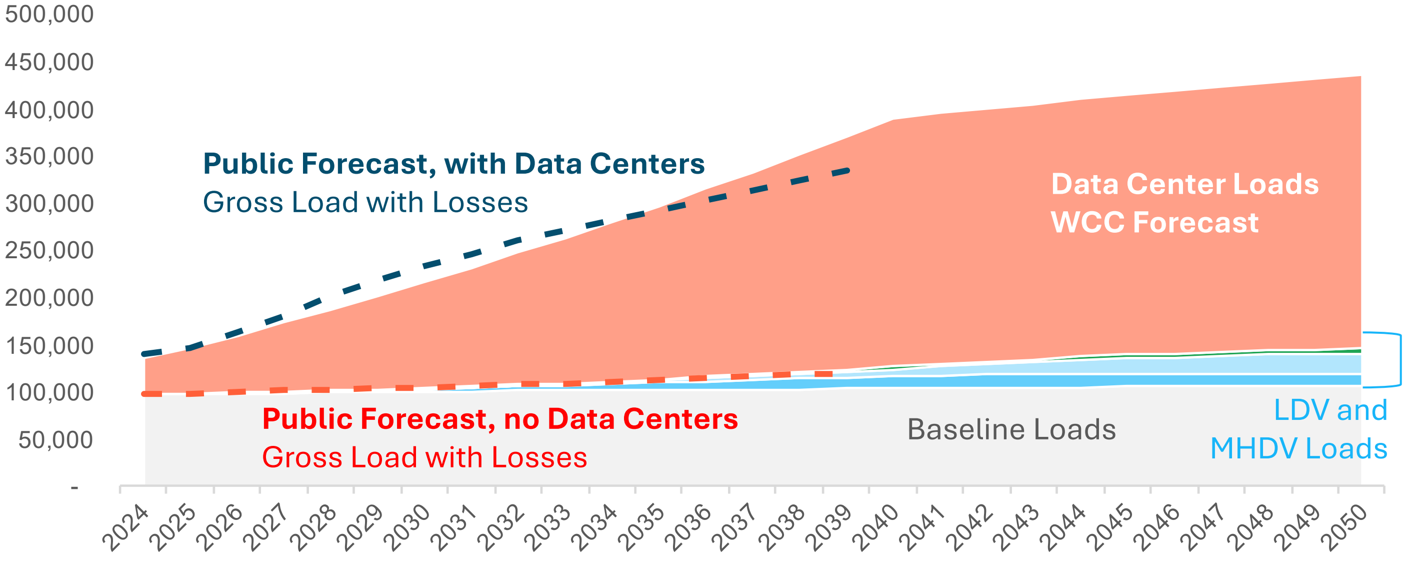
Load Projections Compared to 2024 PJM Forecast

- **E3 supplemented WCC's forecast with PJM's 2024 load forecast in our grid impact modeling**
  - Load growth outside of Virginia, including data center loads, were derived from the public PJM forecast and kept constant across different VA data center load growth scenarios
  - E3 also extrapolated the load forecasts from WCC and PJM to 2050
    - Data center load growth is assumed to slow down to 1%/year between 2040 and 2050
    - Baseline and vehicle electrification loads each are assumed to grow at a constant rate based on the last 5 years of the forecast
- **As a benchmark, energy forecasts for the DOM zone using a combination of WCC forecast (for VA portion) and the PJM public forecast (for non-VA portion) are generally aligned through the end of the PJM forecast period (2039)**
  - E3 adjusted the PJM forecast by adding back BTM generation so that gross load can be compared

PJM 2024 Forecast - Dominion (DOM Zone)
Annual Load, GWh

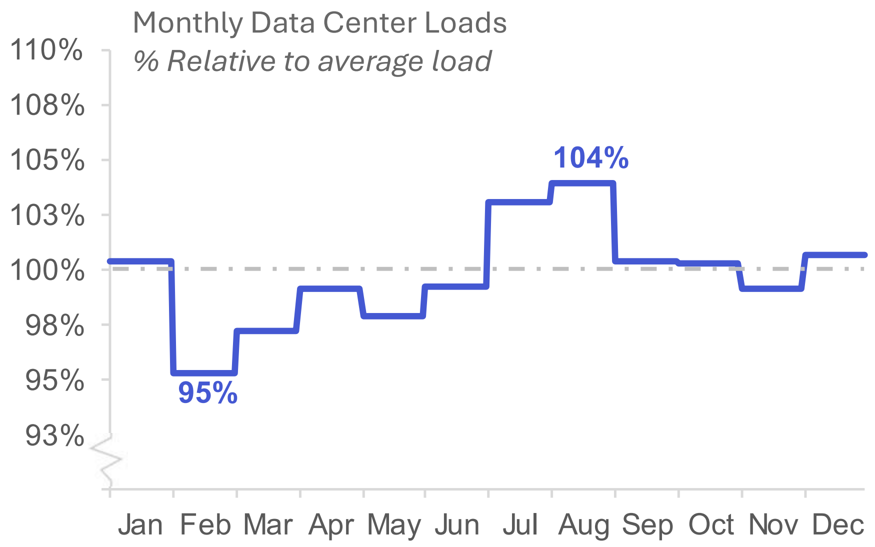


Adjusted with WCC Forecast - Dominion (DOM Zone)
Annual Load, GWh

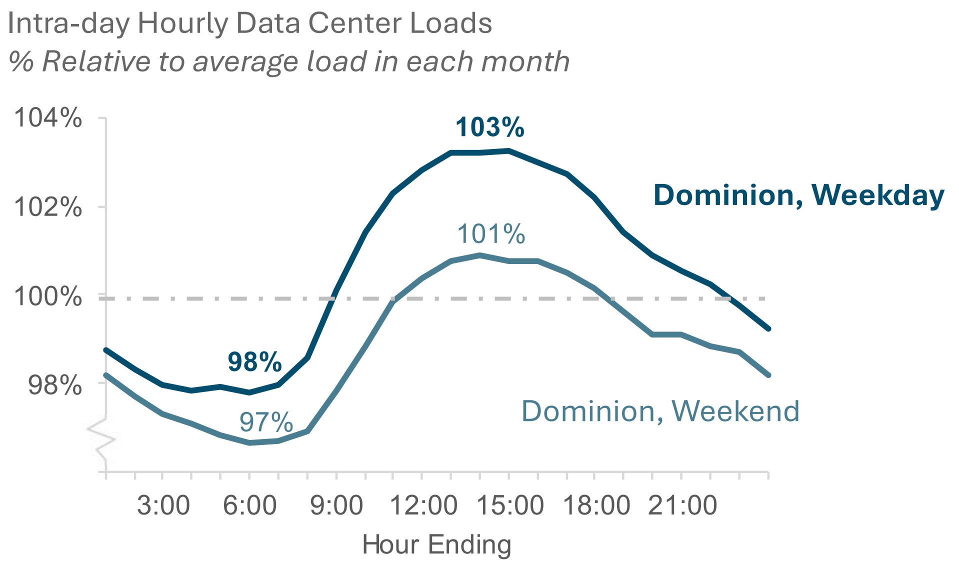


Hourly Data Center Load Profiles

- **The data center load projections provided by WCC are in annual and monthly energy**
- **Seasonal variations of data center loads are driven by cooling needs amongst other factors**
  - Loads are the highest in summer months, with August having average loads 4% higher than the annual average
  - With lower cooling needs and ideal operating temperatures, the spring months see the lowest average loads

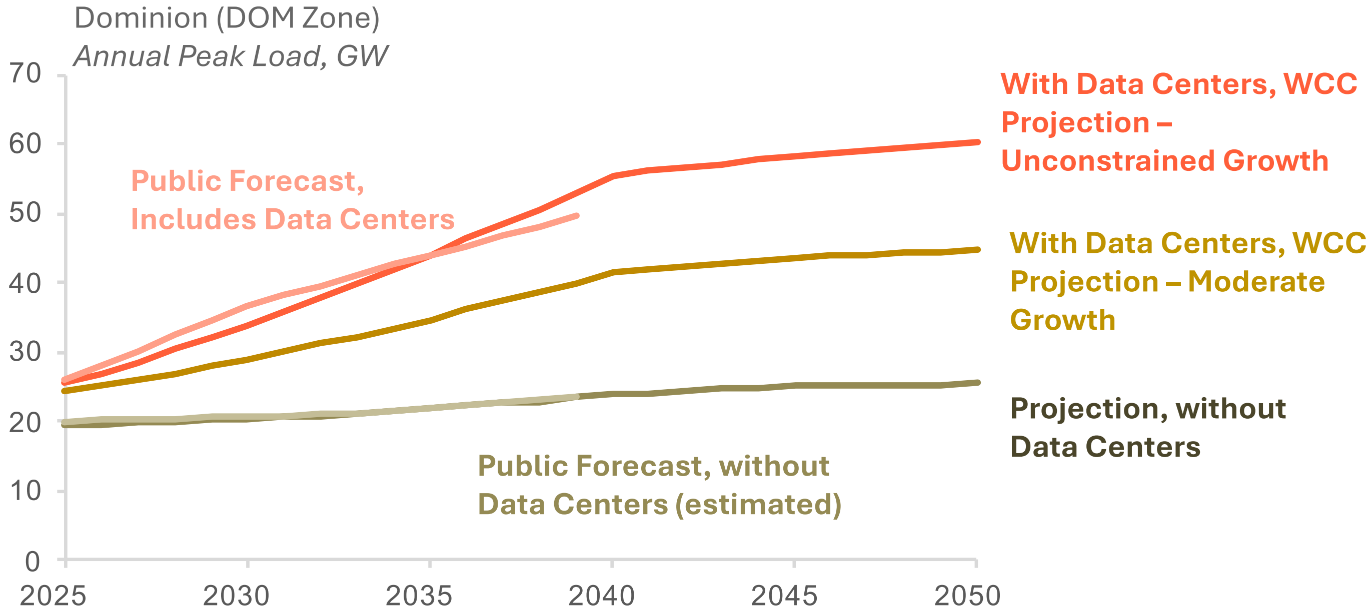


- **Hourly data center load shapes were developed by E3**
  - **Monthly average loads** from WCC forecast, with +-5% variation throughout the year
  - **Intra-day hourly loads** from PJM's public report of example July peak day July hourly load for Dominion and NOVEC data centers, with +-2.5% variation hour-by-hour
  - **Final load shapes** from applying hourly variations to each month's load, with maximum annual variation of +-6.5%



Peak Projections Compared to PJM Forecast

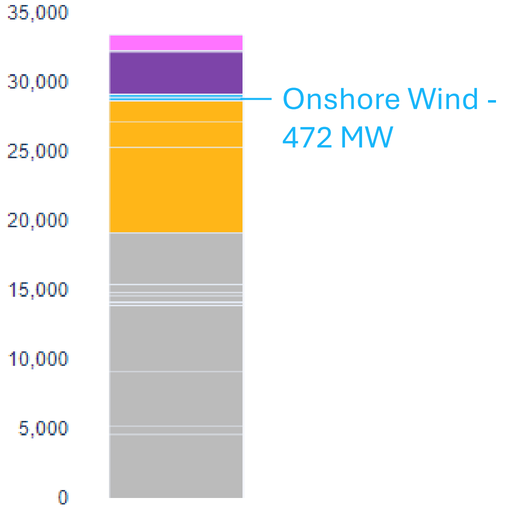
- **Projected median peak for the DOM zone using E3 assumed load profiles generally aligns with PJM's 2024 load forecast**
  - Small differences can result from variations in the weather dependent hourly profiles for the baseline and transport electrification loads
  - The peak impact of data centers in the PJM 2024 forecast is estimated from the July peak loads reported in the forecasts' supplement
- **While data center loads in Dominion came from WCC, other projected data center loads in AEP, APS, and East outside Virginia were kept from PJM's 2024 forecast**



Appendix C: Reliability Modeling

Dominion Wind ELCCs

Incremental additions relative to existing resource portfolio

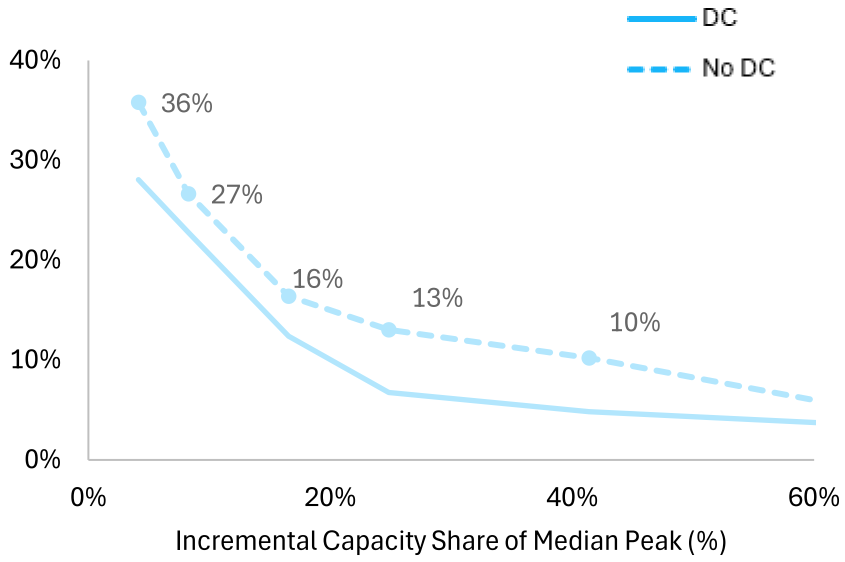


Modeled 2050 DOM Portfolio in RECAP

Wind ELCCs are <u>lower</u> when data center loads are presented

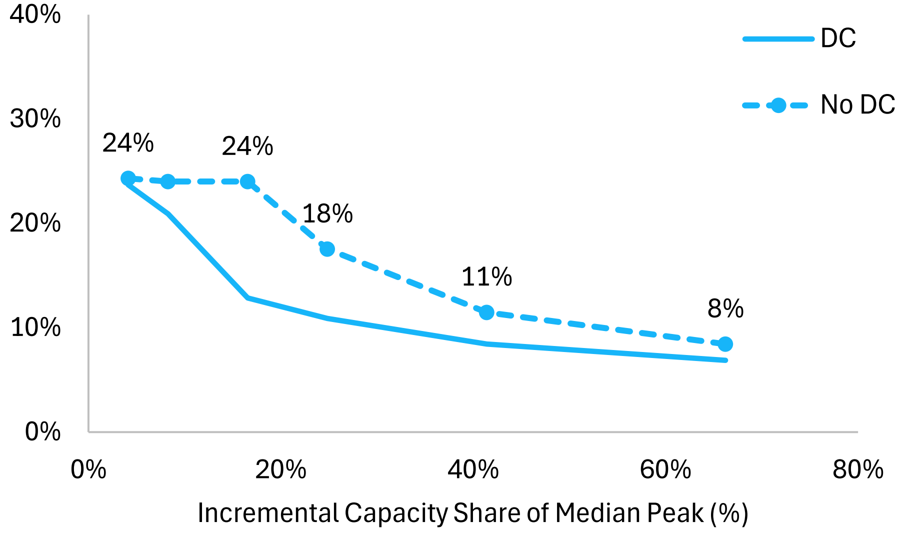
which shift system loss of load risks to summer when wind generation is lower

Offshore Wind Incremental ELCC
(%)



Onshore Wind ELCC is generally lower than Offshore Wind given the lower capacity factor

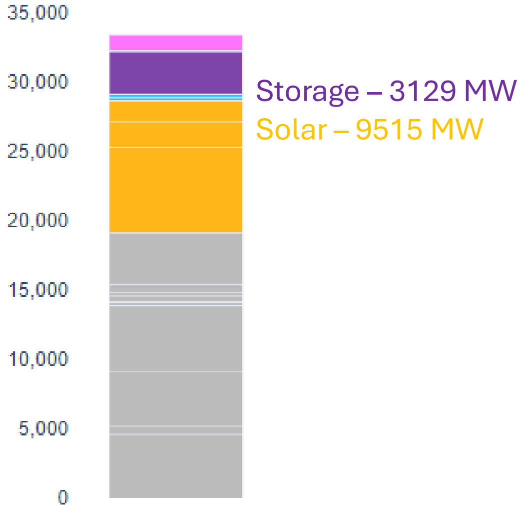
Onshore Wind Incremental ELCC
(%)



Med peak w DC: 68 GW
Med peak w/o DC: 31 GW

Dominion Solar and Storage ELCCs

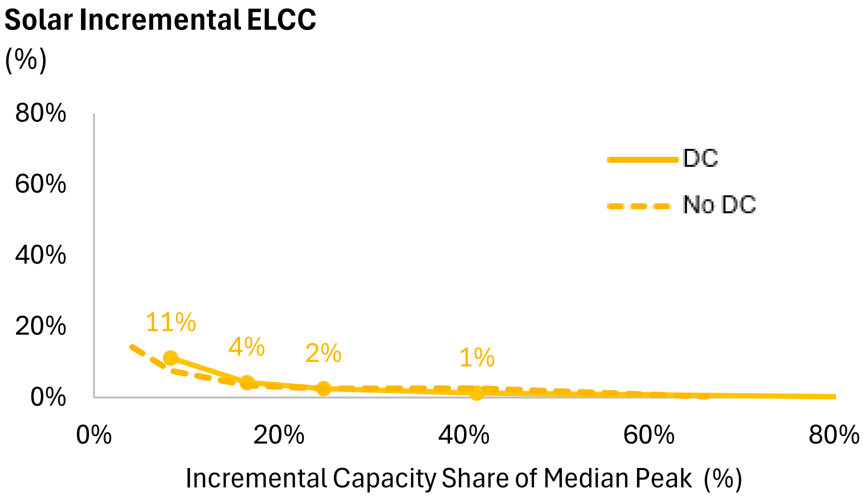
Incremental additions relative to existing resource portfolio



Modeled 2050 DOM Portfolio in RECAP

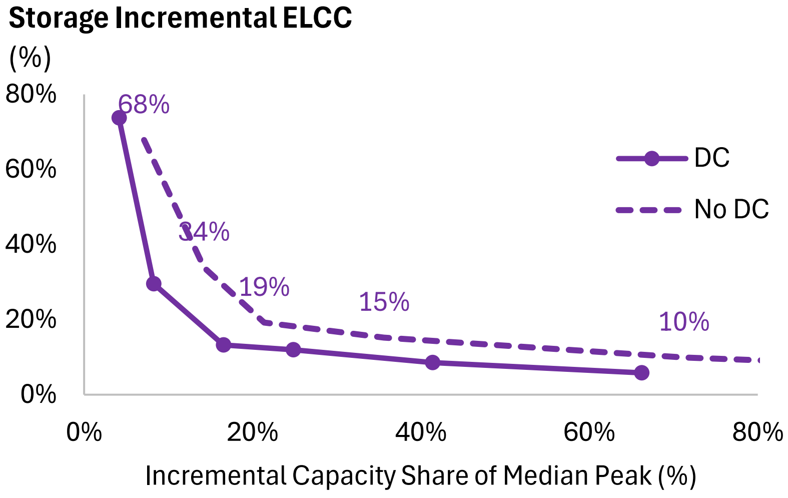
Solar ELCCs are slightly higher when data center loads are presented

when most of the loss-of-load expectations are in summer when solar generation peaks



Storage ELCCs start higher, but saturate quickly when data center loads are presented

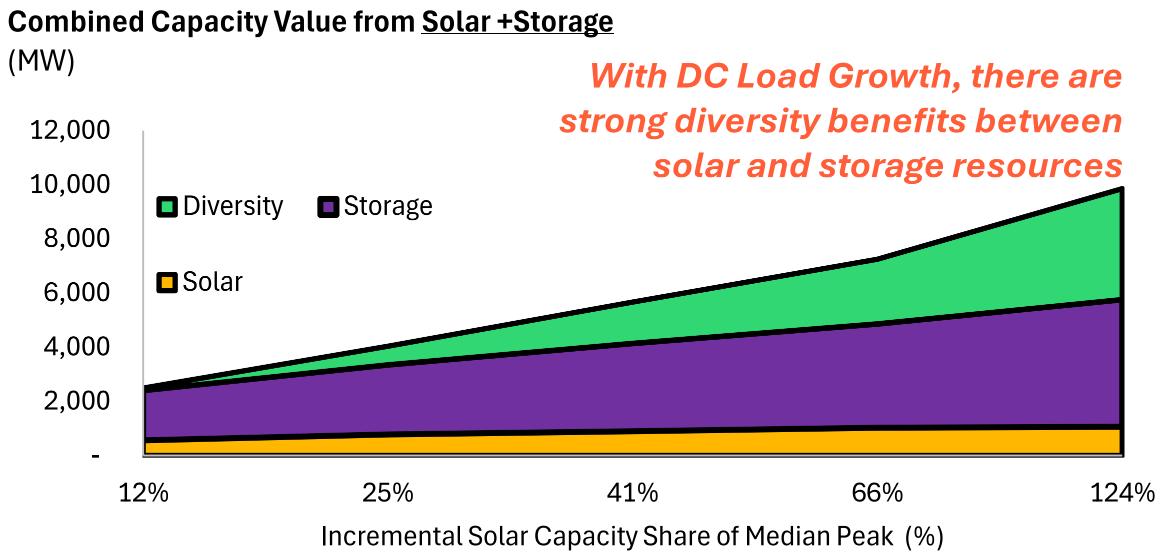
given the strong saturation effect in summer early evenings when storage are quickly needed to discharge for a long time-frame

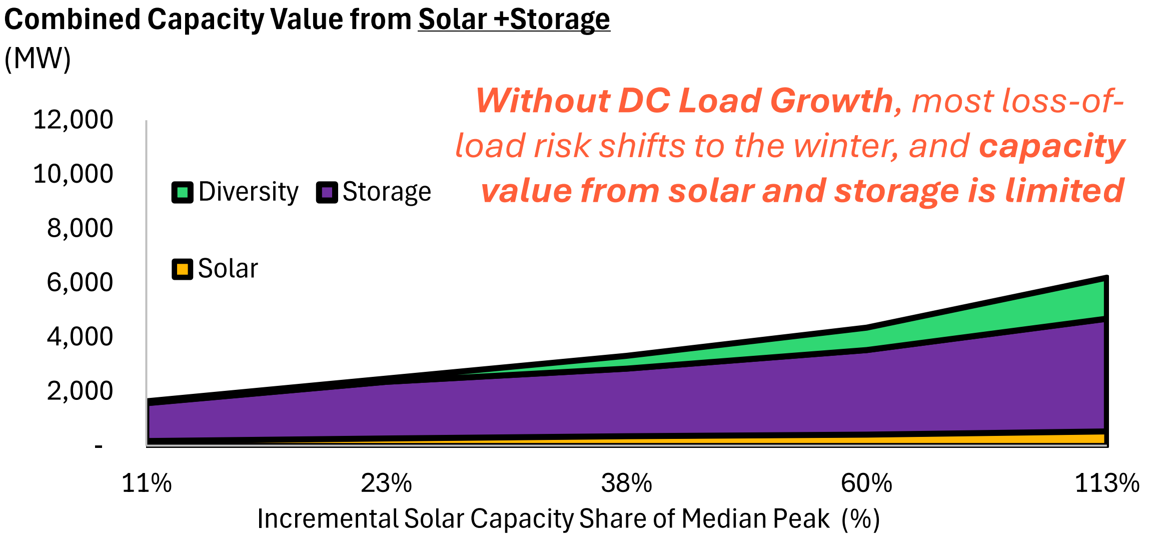


Med peak w DC: 68 GW
Med peak w/o DC: 31 GW

Complementary Reliability Impacts between Solar and Storage

- **Adding solar and storage can quickly exhibit saturation effects, while combinations of the two resources exhibit interactive benefits**
  - Positive interactive effects between solar and storage are referred to as "diversity benefits"
- **This comes from the complimentary nature of the two resources**
  - Abundant solar makes the net load evening peaks sharper, which increases value of limited duration energy storage resources
  - This is more prominent when data center load growth is presented, which creates concentrated reliability challenges in summer afternoons

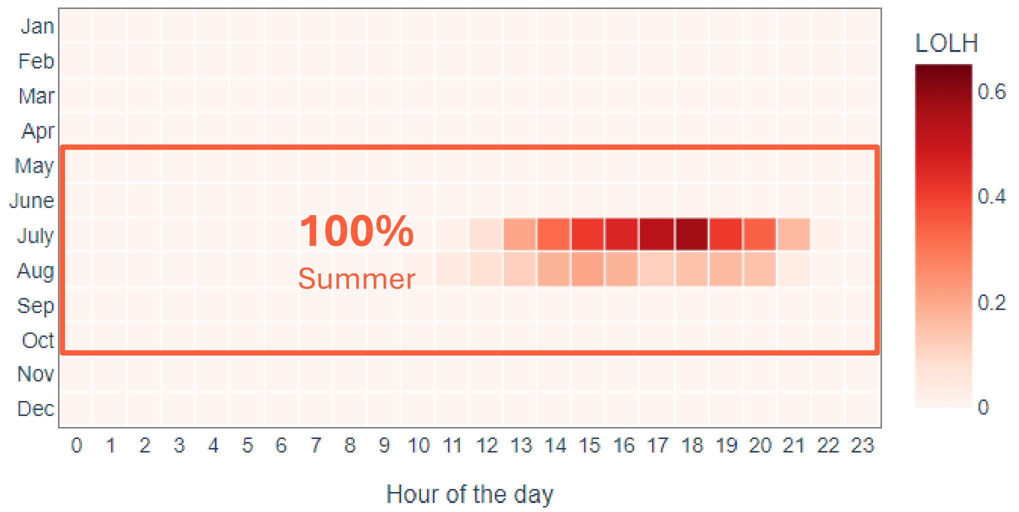




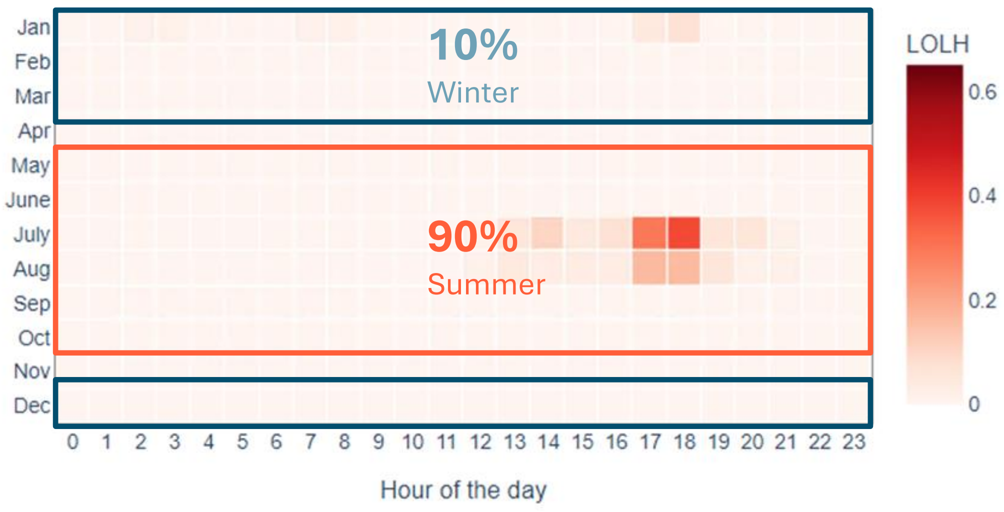
PJM System Reliability Risks

- In 2025, all loss of load risks are concentrated in summer in PJM
- While winter becomes more challenging in 2050, the majority of system needs are still in summer afternoon through evenings
- Higher data center load growth in Virginia is expected to drive more concentration of loss of load risks in summer and will have limited impacts on system reliability needs or resource accreditation across PJM

2025 – Existing PJM System

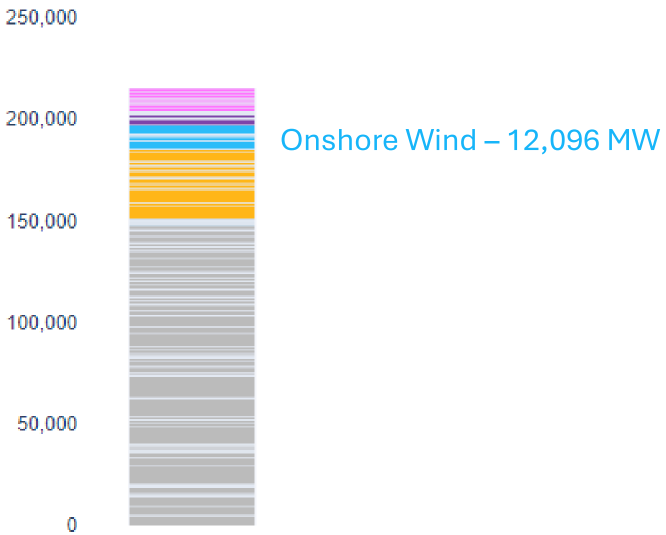


2050 – Existing PJM System, No Data Center Growth



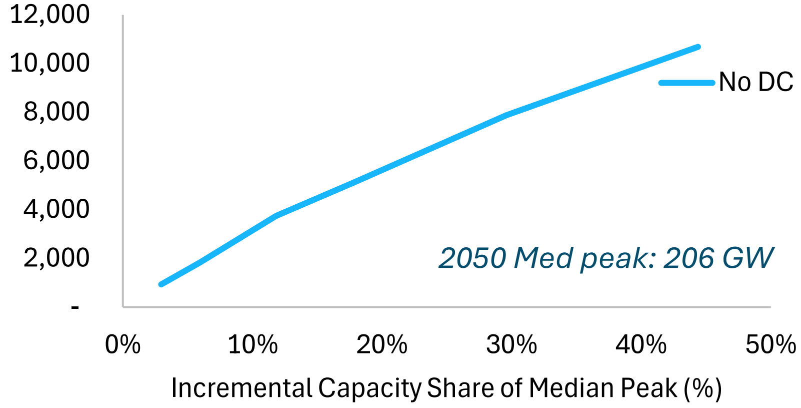
PJM Wind ELCCS

Incremental additions relative to existing resource portfolio

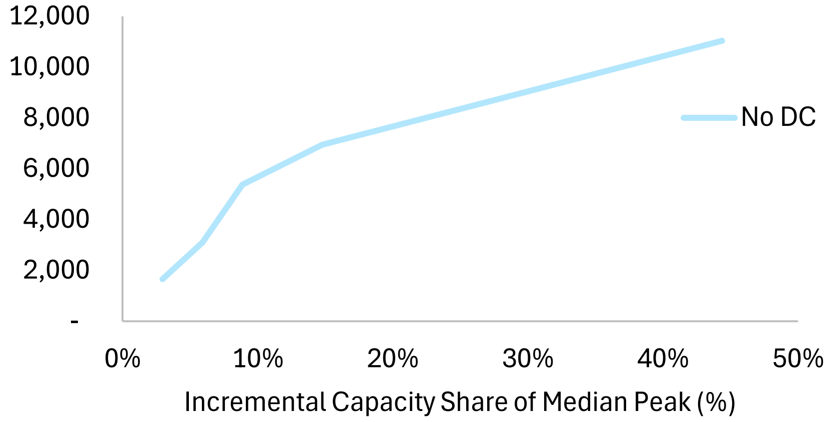


Modeled 2050 PJM Portfolio in RECAP

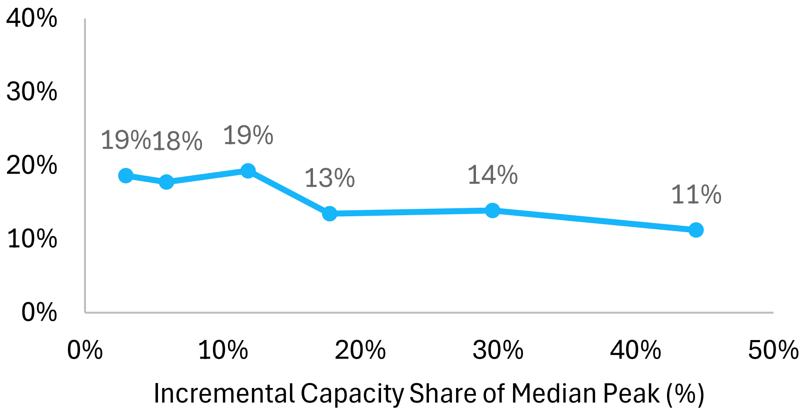
Onshore Wind Capacity Value (MW)



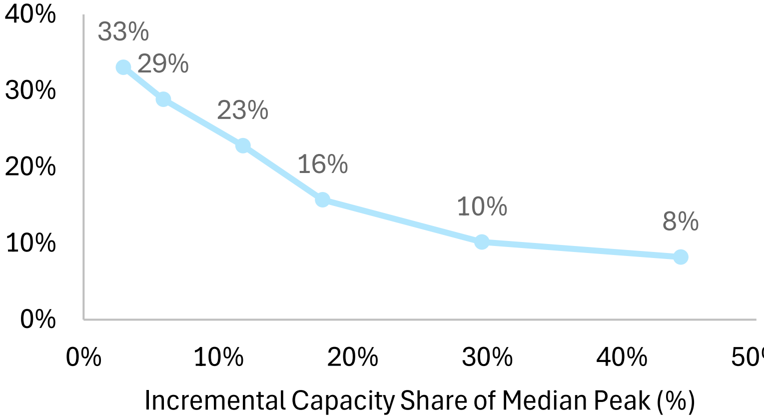
Offshore Wind Capacity Value (MW)



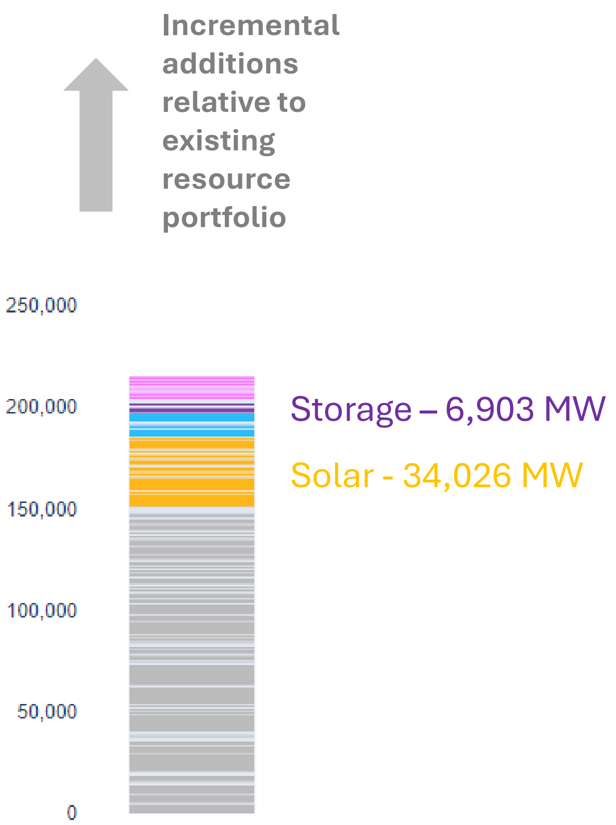
Onshore Wind Incremental ELCC (%)



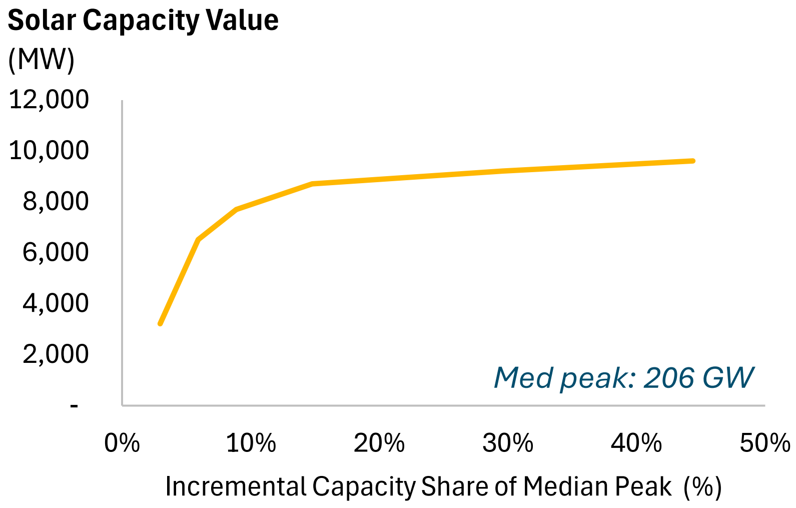
Offshore Wind Incremental ELCC (%)

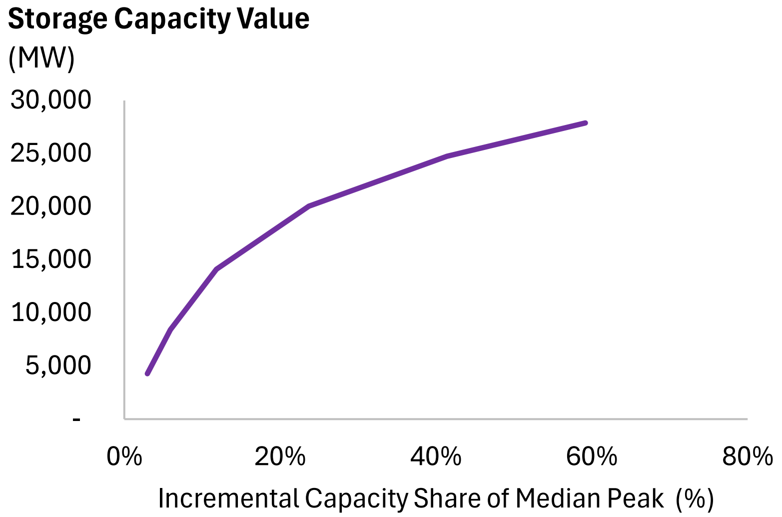


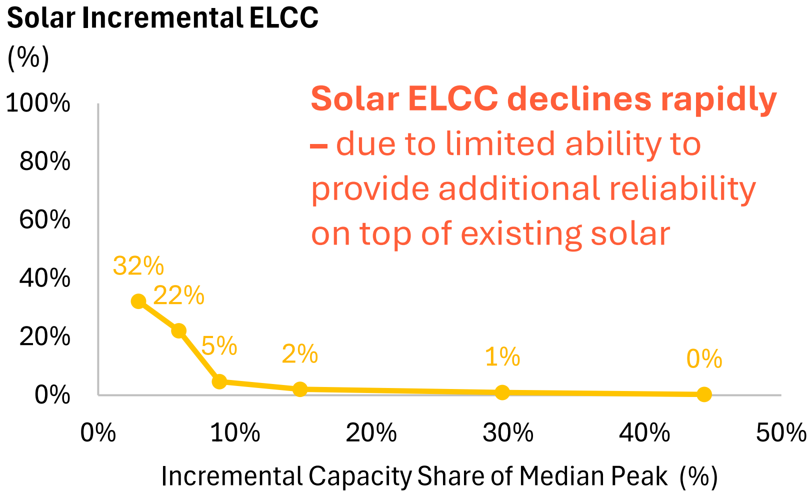
PJM Solar and Storage ELCCs

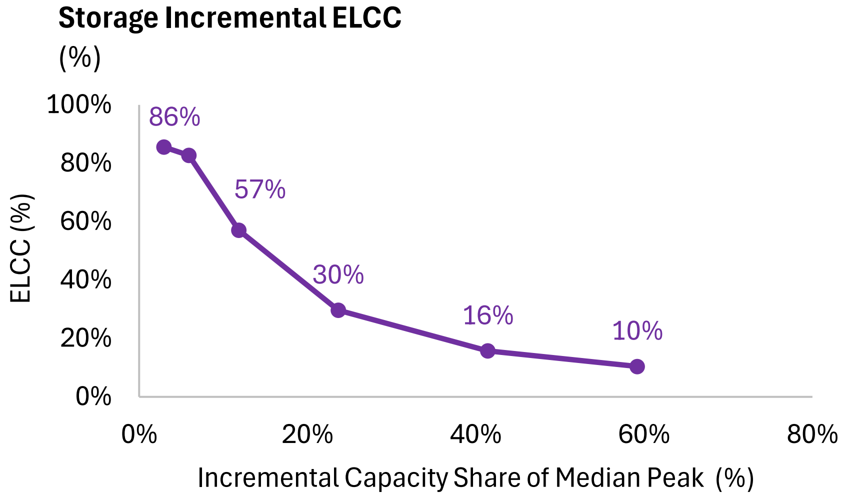


Modeled 2050 PJM Portfolio in RECAP









Appendix D: Value of Flexibility

With Unconstrained Data Center Growth and Statewide VCEA Achievement (S3C)

Context of the Flexibility Sensitivity Study

- **Most of the data center facilities currently located in Virginia are cloud computing facilities, which have low latency (and thus high power intensity) requirements and are generally not flexible**
  - DC load shapes are roughly flat throughout the year, with small seasonal variations due to higher cooling requirements in the summer
- **Data center facilities providing AI training services may have higher flexibility, but are generally less expected to be located in Virginia**
- **Data center customers are generally less incentivized and not required by policy to explore demand response and load flexibility options**
- **E3 performed a few exploratory sensitivity analysis to examine the potential value of load flexibility in Virginia in a future with high data center load growth and stringent requirements of the VCEA to inform potential policy discussions**
  - Flexibility in load is generally expected to offset the need for capacity additions in a system, which could help mitigate the pressure of rapid resource and transmission expansion
  - E3 examined the capacity value of short-duration on-site backup generators and technologies allowing longer-duration load shedding/shifting through RECAP modeling as an approximation of the capacity offset these technologies could provide

Flexibility in Data Center Load Offsets System Capacity Need

- **Assuming 10% of the total DC load in 2050 (~3GW) is coupled with short-duration onsite storage, which enables load shifting during emergency events, 266 to 606 MW of system capacity need can be offset when these resources are added on top of a reliable system**
  - This approach shows the value in a scenario in which this flexibility is called upon only in emergencies (e.g. a diesel generator violating its air permit, or a data center shedding very valuable load)
- **2,223 to 2,410 MW of system capacity need can be offset when these resources are added upfront before other capacity resources are added to the system**
  - This approach represents a scenario in which this flexibility is made more readily available when the new data center load is added to the system, e.g. if data centers are required have on-site storage that they can dispatch, or if there are AI loads that are not critical, etc.
  - The value is higher when the load flexibility can be called more often or on a regular basis, which offsets some of the need of adding new capacity at utility level
- **The capacity value is higher when longer-duration load reduction can be achieved in the last-in case, potentially enabled through onsite backup gas generator or other emerging technologies**
  - The 120-hr backup generator was modeled as a demand response resource with up to 5 call times per year; This specific assumption and model setup limits the capacity value under the first-in case

Last-in ELCC

Proxy Data Center Resource	Capacity Value (MW)	ELCC (%)
2-hour storage 3 GW	266	9%
4-hour storage 3 GW	331	11%
8-hour storage 3 GW	606	20%
120-hour backup generator 3 GW	1,292	43%

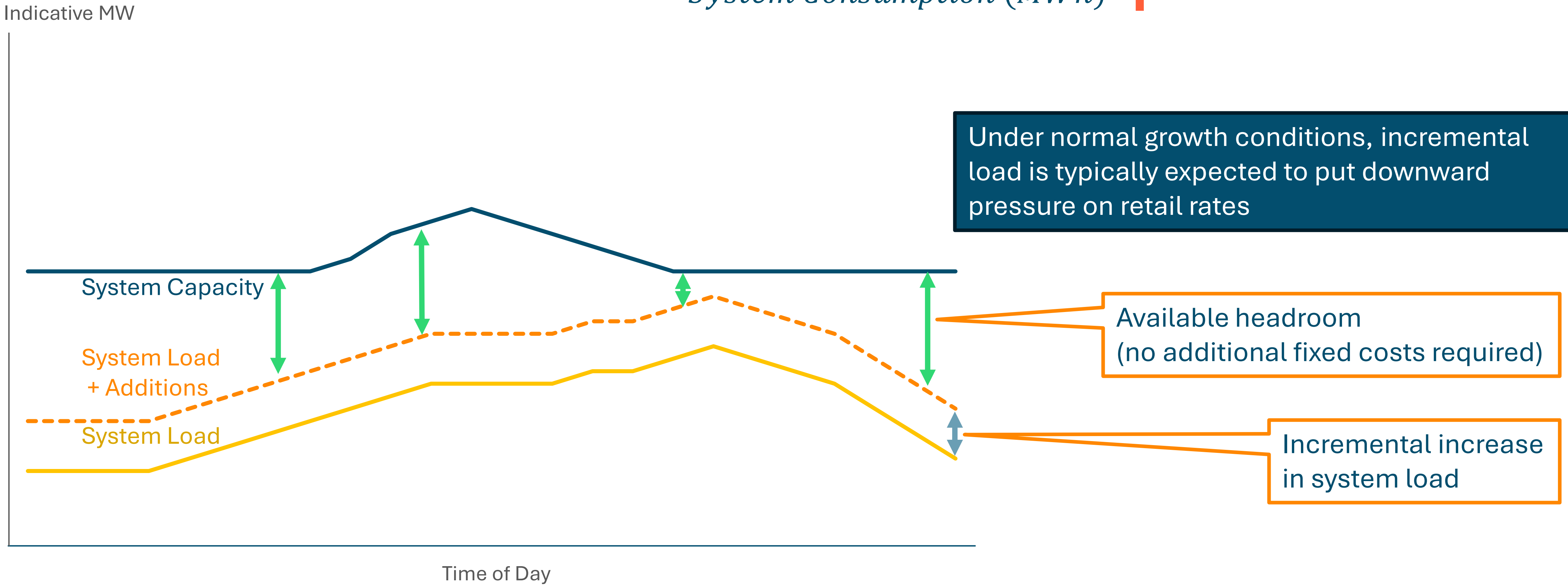
First-in ELCC

Proxy Data Center Resource	Capacity Value (MW)	ELCC (%)
2-hour storage 3 GW	2,223	74%
4-hour storage 3 GW	2,375	79%
8-hour storage 3 GW	2,410	80%
120-hour backup generator 3 GW	1,963	65%

Appendix E: Rate Dynamics

Modest Incremental Load Growth

$$\downarrow Retail\ Rates \propto \frac{(Fixed\ Costs + Variable\ Costs)\uparrow}{System\ Consumption\ (MWh)\uparrow}$$

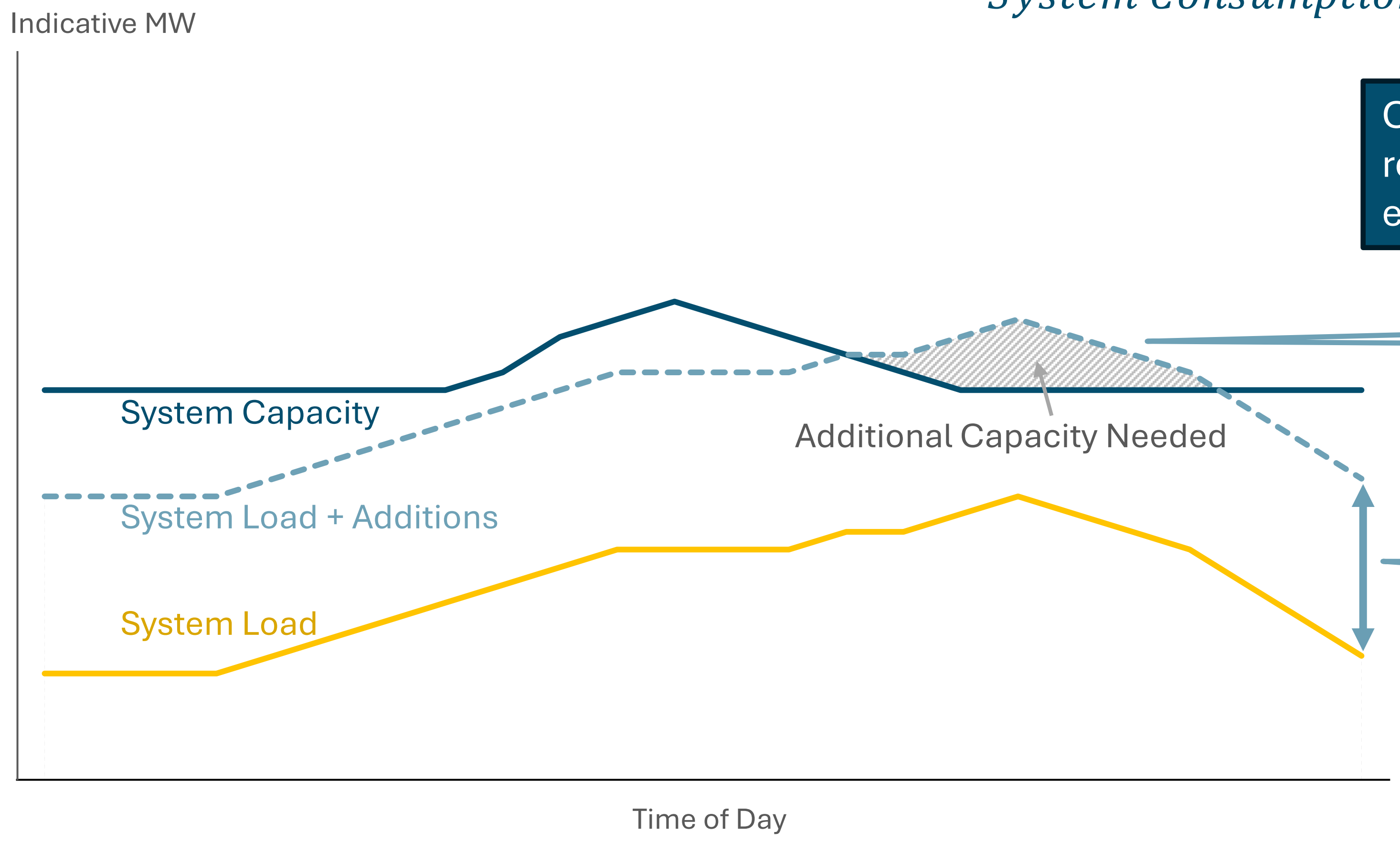


Under normal growth conditions, incremental load is typically expected to put downward pressure on retail rates

Moderate Incremental Load Growth

$$Retail\ Rates \propto \frac{(Fixed\ Costs \uparrow + Variable\ Costs \uparrow)}{System\ Consumption\ (MWh) \uparrow}$$

Once available headroom is exhausted, resource additions are required to meet extensive new load



Additional fixed costs required

Incremental increase in system load

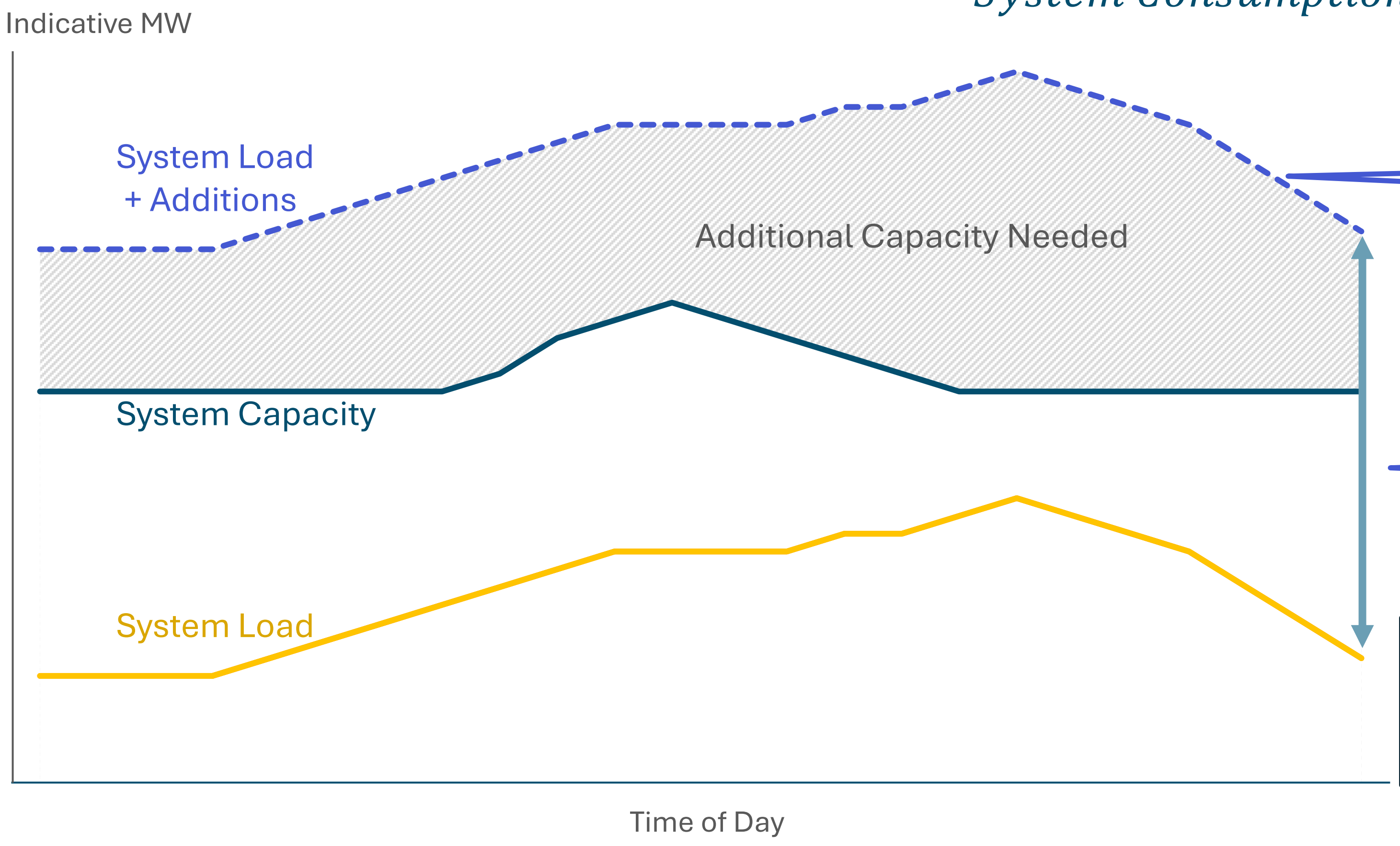
Transformational Load Growth

$$Retail\ Rates \propto \frac{(Fixed\ Costs + Variable\ Costs)}{System\ Consumption\ (MWh)}$$

Shift in supply-demand curve increases variable costs

Required resource additions increase fixed costs

Transformational increase in system load



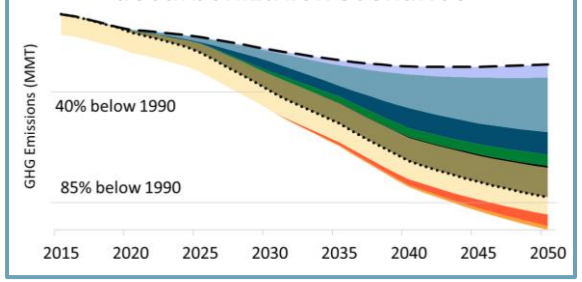
Typical rate dynamics may break down as load and resource additions exceed incremental and trigger new costs

Appendix F: Overview of E3 Modeling Capabilities

E3's comprehensive modeling toolkit positions E3 well to study future energy system dynamics

PATHWAYS

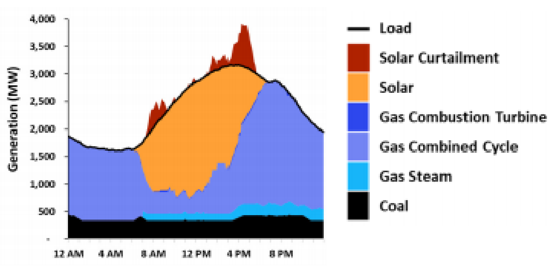
Economy-wide accounting of energy supplies and demands under deep decarbonization scenarios



Production Simulation

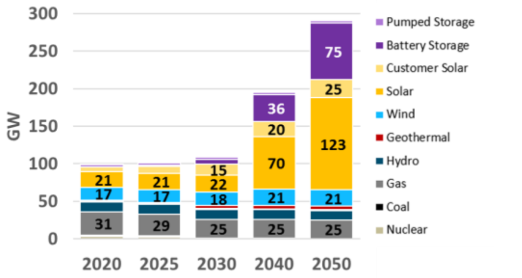
(AuroraXMP and PLEXOS)

Detailed operational simulations of system dispatch and flexibility needs



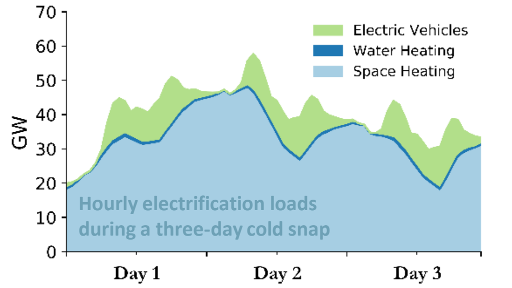
RESOLVE

Optimal capacity expansion model for electric systems



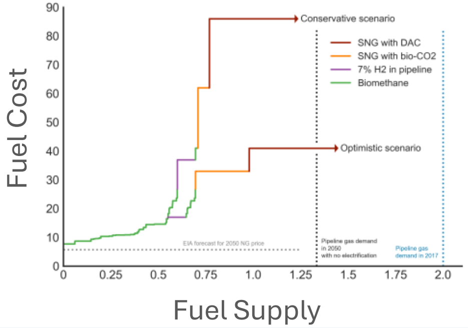
RESHAPE & EVGrid

Hourly simulations of electric loads for specific end uses



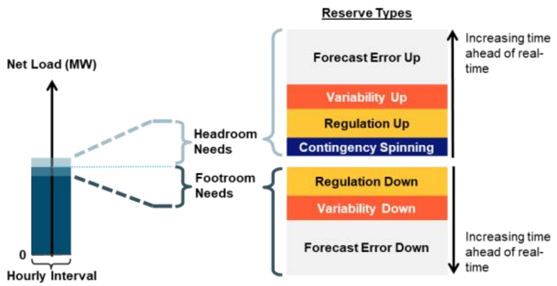
Low-Carbon Fuels and Future of Gas

Role of fuels in deep decarbonization



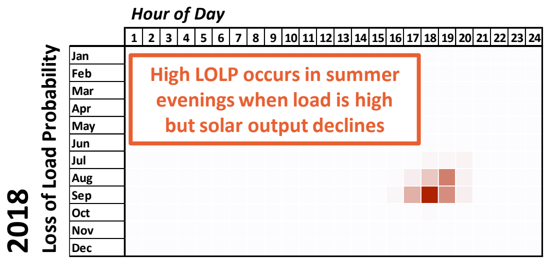
RESERVE

Dynamic operating reserves for renewable integration



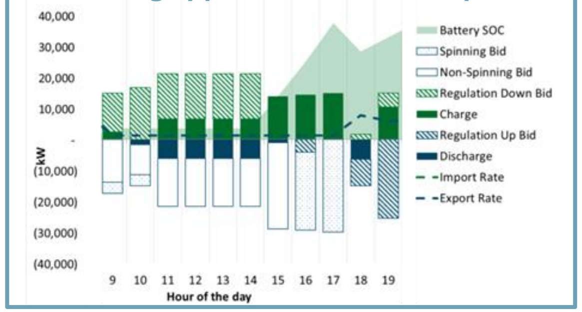
RECAP

Loss of load probability simulation to measure resource adequacy



RESTORE & IDSM

DER Toolkit for optimizing DER value stacking opportunities and adoption



Economy-wide energy systems ⟷ Bulk grid power systems ⟷ Grid edge & behind-the-meter

E3's Best-in-Class Modeling for Grid Decarbonization

- E3's integrated analytical framework combines a detailed accounting model of energy supplies and demands across the entire economy with an optimized capacity expansion model in the electric sector
- Detailed modeling of the rest of the economy provides a clear picture of how both the magnitude and timing of electric sector loads will need to change, as electrification plays a key role in the decarbonization of buildings, transportation, and industry

1 Use detailed energy accounting model to examine pathways to reaching long-term economy-wide goals and implications for electric loads

PATHWAYS

Economy-wide accounting of energy flows

+

Hourly simulations of electrified end uses

Future System Load Shapes →

← *Electric Sector Emissions*

Electricity Sector

Optimized Capacity Expansion (RESOLVE)

+

Loss of Load Probability Modeling (RECAP)

3 Iterate between different levels of electrification-driven load growth and resulting electric sector impacts

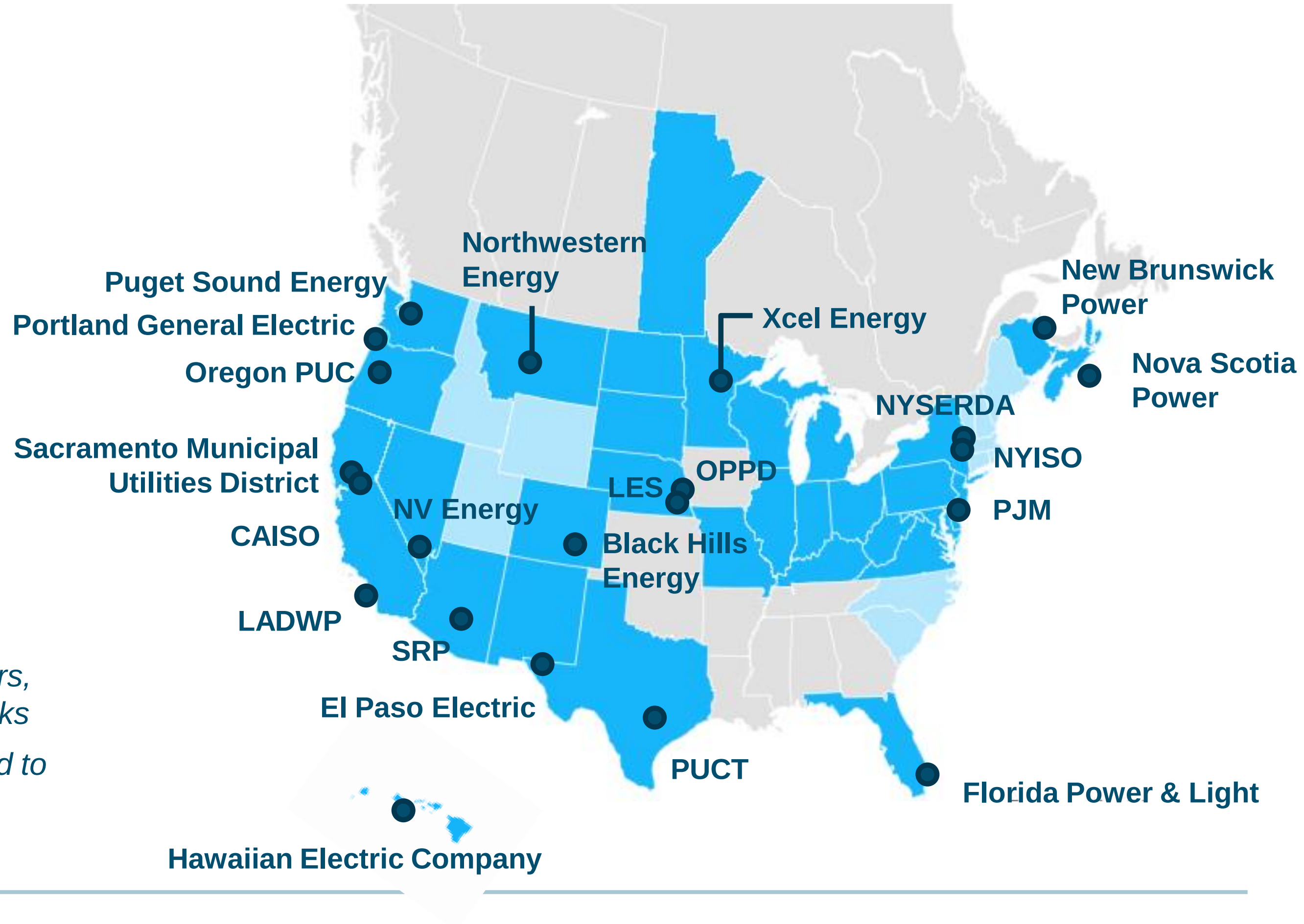
2 Use capacity expansion to optimize future portfolios to meet electric sector policy goals while maintaining reliability

Recent Applications of RECAP

E3 has developed RECAP, a proprietary model for performing loss of load analysis

- Simulation model for assessing resource availability over **hundreds of simulation years**
- **Time-sequential dispatch** for capturing energy-limited resource dynamics for hydro, energy storage, and demand response

E3 has worked directly with utilities across North America to study resource adequacy needs



States where E3 has provided direct support to utilities, market operators, and/or state agencies to perform RA modeling or develop RA frameworks

Areas where E3 has worked with other clients to examine issues related to resource adequacy

E3 Model Ecosystem for Market Price Forecasts: Built on Decades of Experience and 360° Analysis

E3 Model Toolkit

Input Models

E3 PATHWAYS
Least-cost decarbonization pathways across sectors to meet GHG targets

E3 RESHAPE
Load simulation for building electrification & EVs

E3 Pro Forma Model
Levelized costs of new resources including financing and tax incentives

E3 RECAP
Stochastic reliability modeling for ELCCs of renewables and storage

Output Models

E3 RESTORE
Optimized battery operations and revenues

E3 Scarcity + RT Price Model
Forecasts scarcity and real-time energy prices with regression analysis

E3 Nodal Price Model
Node-zone basis forecast for nodal prices

E3 Ancillary Services Model
Forecasts AS prices with regression analysis and market saturation

E3 Capacity Market Models
Capacity price formation by market, aligned with unique market dynamics

E3 REC Market Models
Renewable Energy Credit prices aligned with unique market dynamics

Market Price Forecasting Approach

Key Scenario Variables

1. **Load Forecasts**
Regional load growth, energy efficiency, building electrification, and EVs

2. **Policies**
RPS, CES, GHG, other mandates

3. **Regional Coordination**
Transmission, Trading, and policy alignment

4. **Costs:**
- New resource costs
- Gas prices
- Carbon prices

PLEXOS Model Outputs

5. **Long-Term Capacity Expansion (Annual)**

New Resource Additions
- Economics
- Policies and mandates (RPS, CES, GHGs)
- System reliability needs
- Retirements

6. **Production Cost Simulation (Hourly)**

Energy Market Forecasts
- Hourly day-ahead energy prices by zone
- Dispatch, renewable curtailment, and transmission flows

E3 Forecasts

Market Product	Geographic Granularity	Temporal Granularity
Energy (Day-Ahead and Real-Time)	Zonal	Hourly
Capacity (low, medium, high forecasts)	System / Local	Annual
Ancillary Services (Reg, Spin, Non-Spin)	ISO	Hourly
ELCC Curves	Regional	Annual
RECs	State / ISO	Annual
System Operations	System / Local	Hourly / Monthly

Fundamentals-based market modeling built on day-ahead energy prices