Technical Report

Powering Virginia's Future

Supply-Side Strategies to Meet Rising Energy Demand

Prepared By
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Prepared For
Director, Virginia Department of Energy, Glenn Davis

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Disclaimer

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University *of* Virginia Honor Code

On my honor as a University of Virginia student, I have neither given nor received unauthorized aid on this assignment.

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Executive Summary

Virginia is facing an impending energy supply crisis. Forecasts project an 85% increase in electricity demand over the next 15 years, driven by growth in energy-intensive industries (VA IRP, 2024). Current in-state generation is insufficient, and despite investments in offshore wind and renewables, the state remains dependent on aging infrastructure, non-renewable sources, and inefficient regulatory processes. This imbalance threatens higher energy prices, grid instability, and setbacks to Virginia's clean energy goals if left unaddressed (Lupu et al., 2024).

To address this challenge, this report recommends the deployment of Small Modular Reactors (SMRs) as Virginia's most effective, scalable, and sustainable long-term energy solution. SMRs offer high capacity, low emissions, and consistent output.

Three policy alternatives were analyzed to close the projected supply gap: Retail Choice, Solar Photovoltaic Behind-the-Meter (BTM), and Small Modular Reactors (SMRs). Each is evaluated on cost, effectiveness, and political and environmental feasibility criteria.

- **Retail Choice** introduces competition by allowing consumers to choose their electricity providers. It offers potential price reductions and renewable access but does not create new generation capacity. Its impact on supply is minimal and implementation faces stiff resistance from Virginia's dominant utility monopolies and regulatory barriers (Craig & Savage, 2013).
- **Solar PV BTM** systems allow households and businesses to generate electricity on-site, reducing grid dependency and emissions. With substantial environmental benefits and a low levelized cost of electricity, this option is financially attractive. However, limited scalability, a low capacity factor, and high upfront cost limit its ability to meet large-scale energy needs (Aponte & McConky, 2021).
- **Small Modular Reactors (SMRs)** provide a dispatchable, low-carbon power source with a high capacity and minimal land use. Just 10 SMRs could supply approximately 25 percent of the projected shortfall. While the upfront costs are substantial and some public resistance remains, SMRs enjoy growing political and industry support, align with Virginia's energy legislation, and represent the most viable path forward (Paullin, 2024).

Terminology

VDOE: Virginia Department of Energy, the lead state agency responsible for energy planning, regulation, and policy implementation.

All-of-the-Above Energy Plan: Virginia's strategy combining fossil fuels and renewables to meet present and future energy demands.

Retail Choice: Policy allowing consumers to choose their electricity supplier from a competitive market instead of a monopoly utility.

Solar Photovoltaic (PV): Converts sunlight directly into electricity using solar panels.

Behind-the-Meter (BTM): Energy systems, like rooftop solar, installed on the consumer's side of the utility meter for on-site energy use.

Small Modular Reactor (SMR): Compact nuclear reactors generating 50–300 MW, designed for scalable and flexible deployment.

Levelized Cost of Electricity (LCOE): The average cost per megawatt-hour of electricity over a system's lifetime, used for comparing energy sources.

Capacity Factor: The ratio of actual energy produced to the maximum possible if operating at full capacity 24/7.

Grid Reliability: The grid's ability to consistently deliver electricity without interruption.

Net Metering: A policy allowing solar customers to send excess electricity to the grid in exchange for utility bill credits.

Distributed Generation: Small-scale, on-site energy production near the point of consumption.

Transmission Infrastructure: Networks (lines, transformers, substations) that transport electricity from producers to consumers.

Energy Storage: Technologies like batteries that store surplus energy for use when generation is low or demand spikes.

Stranded Costs: Investments in energy infrastructure that become financially unrecoverable due to policy or market shifts.

RPS (Renewable Portfolio Standard): Legal mandate requiring a certain percentage of energy to come from renewables.

Load Balancing: The management of electricity supply and demand to maintain grid stability.

Energy Transition: The shift from fossil fuel systems to cleaner, renewable energy sources.

Modular Construction: Building method where parts (e.g., SMR components) are manufactured off-site and assembled on location.

Introduction

The following report examines Virginia's growing energy supply crisis, focusing on innovative strategies to increase energy supply to meet rising demand. This report aims to lay the groundwork for actionable policy recommendations that will guide the Virginia Department of Energy in addressing the state's energy challenges. The report synthesizes evidence related to three critical policy options: (1) Retail Choice, (2) Solar Photovalic Behind-the-Meter Power Generation, and (3) Small Modular Nuclear Reactors. This analysis evaluates the policies' cost, effectiveness, and feasibility to determine the best course of action for the state to pursue to increase energy supply by 2040. The report recommends deploying Small Modular Reactors (SMRs) as a long-term solution to enhance energy supply. The report also begins to scope the implementation and challenges to operationalize 10 SMRs by 2040. By operationalizing SMRs, the VDOE can ensure that Virginia will be able to achieve a sustainable, resilient, and affordable energy future while balancing environmental goals and economic growth.

Problem Statement

The Virginia Department of Energy (VDOE) faces an urgent challenge: ensuring reliable and affordable energy supply amid a rapidly growing demand from energy-intensive industries. Despite substantial state-level investments in renewable and advanced energy projects, Virginia's energy production has not kept pace with demand, putting the state on the brink of a supply crisis. Projections show an 85% increase in energy demand over the next 15 years, fueled by the expansion of data centers, port activities, and electrified transportation. This surge is stark compared to the 2% growth observed from 2010 to 2020 (VA IRP, 2024). Current efforts to diversify energy generation, such as offshore wind and micronuclear initiatives, have yet to deliver sufficient output to close the gap. As energy supply lags behind demand, prices have risen by three cents per kWh over the past year. While Virginia's energy prices remain below the national average at 14 cents per kWh, continued increases threaten the affordability and accessibility of energy for households, which account for 25% of consumption (Virginia Electricity Profile, 2023). VDOE's mission is to ensure that an energy system that is reliable, sustainable, and affordable is at risk without targeted intervention. The department must explore innovative policy solutions to incentivize energy production, stabilize supply, and support economic growth while minimizing the impact of price increases on Virginia consumers.

Client Overview

The Virginia Department of Energy (VDOE) is the central agency responsible for shaping, regulating, and implementing the Commonwealth's energy strategy. As the state's primary authority on energy policy, the Virginia Department of Energy (VDOE) is uniquely positioned to address Virginia's current energy supply imbalance.

Its core responsibilities include regulatory oversight, technical planning, inter-agency coordination, and stakeholder engagement. Through its specialized divisions, including Offshore Wind, Gas and Oil, and Mined Land Repurposing, the department manages Virginia's diverse energy resources and infrastructure, balancing environmental sustainability with economic viability (Iweh et al., 2021).

The department's statutory authority under the Virginia Energy Plan enables the agency to guide the development and deployment of energy infrastructure. Its technical expertise supports the integration of advanced technologies and renewable energy systems (Dorrell & Lee, 2021). In collaboration with key stakeholders such as Dominion Energy, the State Corporation Commission (SCC), and the Virginia General Assembly, the department plays a critical role in translating legislative intent into actionable energy policy.

In the fiscal year 2023, the VDOE had an operating budget of approximately $112 million. This funding supports the department's efforts to enhance energy reliability, promote sustainable practices, and ensure that infrastructure developments align with the state's economic and environmental objectives (The 2023 Executive Budget Document, 2024). By effectively utilizing its budget, the VDOE can implement strategies to balance energy supply and demand, support the integration of renewable energy sources, and foster collaborations that drive Virginia toward a more resilient and sustainable energy future.

Current Virginia Energy Composition

Virginia's current energy supply is primarily sourced from natural gas, followed by a combination of coal, nuclear, and renewable sources such as wind and solar. As of 2024, natural gas accounts for approximately 40-25% of the state's electricity generation, making it the largest power source. Coal, once the backbone of Virginia's energy supply, now provides a much smaller share, hovering around 20-25% (Virginia Electricity Profile*,* 2023). Nuclear energy from the North Anna and Surry nuclear plants contributes about 30-35% to Virginia's electricity generation. While renewable energy still represents a smaller share of the state's energy mix, it is a rapidly growing sector. Wind and solar together make up approximately 10-15% of the total power supply, with solar energy providing around 5-7% of the total, and wind energy contributing about 3-5%. The remainder of energy comes from other renewable sources including biomass and hydroelectricity (Virginia Department of Environmental Quality, 2022).

Virginia's "All-of-the-Above" Energy Plan

Virginia's energy strategy is built on an 'All-of-the-Above' approach, which aims to balance a mix of traditional and renewable energy sources to meet current and future energy demands. The plan allows for the continued use of fossil fuels, such as natural gas, while transitioning toward cleaner, renewable sources like wind and solar. A crucial aspect of this strategy is the state's commitment to reducing carbon emissions. By 2030, Virginia aims to reduce power sector emissions by 30%, and by 2050, it aspires to achieve a fully carbon-free electricity grid (Commonwealth of Virginia's Energy Plan, 2022). This commitment is a significant step towards a cleaner energy grid and a testament to Virginia's dedication to environmental sustainability. The plan also includes the expansion of renewable energy, particularly offshore wind and solar, alongside investments in energy storage solutions and diversification to stabilize the grid (2024 VA IRP). By integrating new technologies and increasing efficiency in energy production, Virginia's 'All-of-the-Above' strategy aims to create a diversified energy portfolio that can meet the state's long-term needs while reducing its environmental impact.

Why Not Just Expand Current Offerings?

While expanding existing energy sources, such as natural gas, solar, or wind, may seem like a straightforward solution to Virginia's energy needs, doing so alone presents several challenges that make it insufficient for meeting long-term demands. Continued reliance on natural gas as the dominant energy source contributes to greenhouse gas emissions, delaying efforts to achieve a cleaner energy grid. Expanding natural gas infrastructure could also lock Virginia into a long-term dependence on fossil fuels (Commonwealth of Virginia's Energy Plan, 2022). Additionally, renewable energy sources like solar and wind are intermittent and cannot produce the necessary supply needed. Expanding these renewable sources would not provide the reliable, baseload power required for grid stability unless paired with energy storage solutions or backup systems

(Benforado, 2023). Coal, once the primary energy source in Virginia, is being phased out due to environmental concerns and the increasing competitiveness of cleaner alternatives. Furthermore, the state's growing energy capacity necessitates substantial investments in grid infrastructure and energy storage to ensure reliable power (Freihaut & Hallacher, 2012).

Current Large-Scale Energy Projects in Virginia

Virginia is currently undertaking several large-scale energy projects. These projects primarily focus on offshore wind, solar energy, and energy storage solutions. The most significant of these is the Coastal Virginia Offshore Wind (CVOW) project developed by Dominion Energy. Located off the coast of Virginia Beach, this project aims to deploy 2,600 MW of offshore wind capacity, enough to power over 600,000 homes. The first phase, which consists of two turbines, is already operational, with the entire project expected to be completed by the 2030s (Dorrell & Lee, 2021). In addition to offshore wind, Virginia is also expanding its solar energy capacity through large utility-scale solar farms. Dominion Energy is in the process of constructing a 100 MW solar farm in Pittsylvania County (United, 2023). The state has also been integrating energy storage technologies as part of its energy transition. Dominion Energy plans to build a 300 MW battery storage facility to help manage renewable energy availability and support grid reliability (Larson, 2024). These large-scale projects highlight Virginia's efforts to diversify its energy portfolio. However, they also emphasize the ongoing need for additional solutions, such as Small Modular Reactors (SMRs), to ensure the reliability and stability of the energy grid as the state moves toward a cleaner, more sustainable energy future (Liou, 2023).

Background

Causes of Virginia's Energy Imbalance

Three primary factors drive Virginia's energy imbalance: rapidly increasing energy demand, regulatory inefficiencies, and challenges transitioning to renewable energy.

Rising Energy Demand

The sharp increase in energy demand represents a significant cause of Virginia's energy imbalance. Data centers alone are expected to account for 38% of this growth (Shobe, 2021).

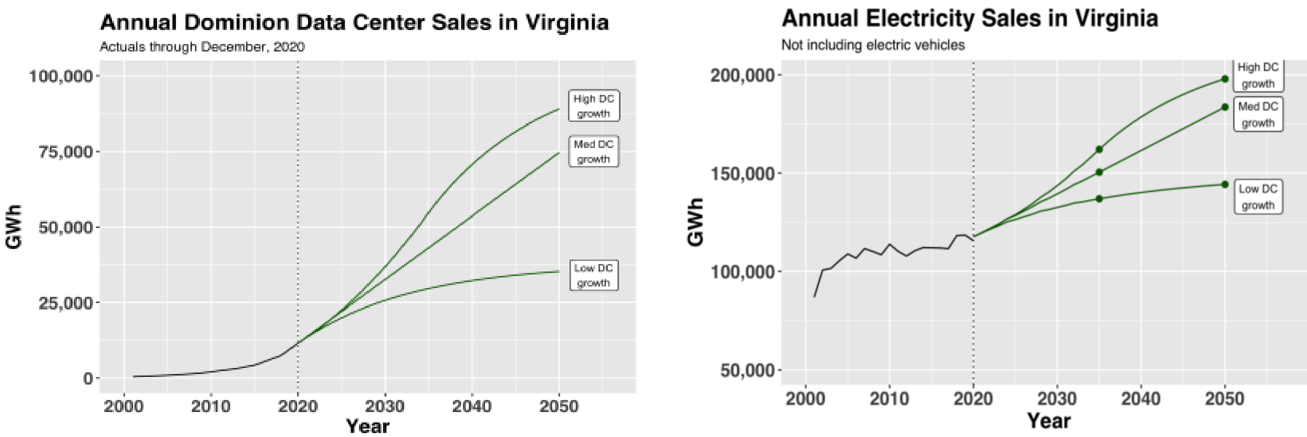

Figure 2. Energy Demand Increase. Adapted from Weldon Cooper Center, by Shobe, 2021.

While critical to Virginia's economy, these facilities place substantial strain on the energy grid due to their intensive power and cooling needs. Erden and Khalifa (2012) examine the energy impacts of on-site power and cooling systems in data centers, emphasizing their considerable contribution to rising energy demand. The study highlights how inefficient cooling systems exacerbate energy consumption and notes that on-site solutions could mitigate some impacts. However, economic feasibility and advances in data center technology since the study's publication present ongoing challenges to fully addressing their energy footprint.

Regulatory Inefficiencies

Virginia's regulatory environment is another major factor contributing to the energy imbalance. According to Fershee (2007), fragmented legislative, regulatory, and market frameworks have led to inefficiencies, underinvestment, and an inability to address systemic infrastructure challenges. This regulatory uncertainty discourages long-term investments in critical infrastructure and innovation, further exacerbating the energy imbalance. While Fershee acknowledges that unfavorable regulations are a significant contributor, he also identifies broader systemic issues, such as market failures and inadequate policy frameworks, that amplify the imbalance. The absence of clear pathways to integrate renewable energy into existing regulatory and market structures further compounds the problem, highlighting the need for comprehensive reform.

Transition Challenges to Renewable Energy

Although essential for long-term sustainability, Virginia's push toward renewable energy introduces short-term economic and logistical challenges that worsen the energy imbalance. Lupu et al. (2024) identify high upfront costs, market volatility, and insufficient coordination between fiscal, monetary, and energy policies as barriers to a smooth transition. These factors deter investment and delay progress in renewable energy development. The lack of alignment between state-level energy goals and broader financial and economic strategies exacerbates the difficulty of balancing renewable energy integration with grid reliability. While Lupu et al. emphasize the role of regulatory reform, they also highlight broader financial complexities, suggesting that addressing these issues will require both state and national-level solutions.

Consequences of Inaction

Increase in Energy Prices

Virginia's rising energy demand presents significant risks that, if unaddressed, could have wide-ranging economic, social, and environmental consequences. As the state's population grows and its economy expands, the electricity demand is outpacing current supply capacities, creating a widening energy imbalance. Without proactive measures, households and businesses will bear escalating energy costs, disproportionately affecting low-income families and small businesses that are less equipped to absorb higher utility bills (Smith, 2024). These rising costs may deter new businesses from establishing operations in Virginia, weakening the state's economic competitiveness.

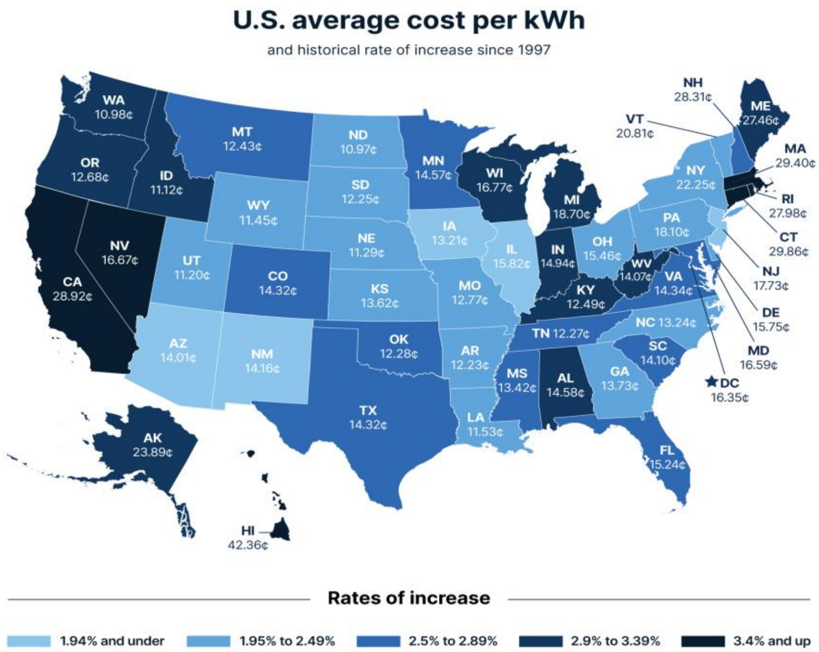

Figure 3. State Energy Map. Adapted from Solar Reviews, by Smith, 2024.

Electricity Grid Failure

The strain on Virginia's aging electricity grid exacerbates the risk of power outages, which could disrupt critical infrastructure such as hospitals, schools, and transportation systems. Prolonged or frequent blackouts pose safety risks and lead to significant economic losses as industries and businesses experience downtime and interruptions in production. High-energy industries, particularly those in manufacturing and technology, may face difficulties securing stable and reliable energy supplies, threatening their operations and long-term viability (Haghighi et al., 2024). This challenge undermines Virginia's efforts to attract and retain industries crucial for economic growth and job creation.

Reliance on Non-renewable Energy

The imbalance has also intensified the state's reliance on traditional, less sustainable energy sources, such as coal and natural gas, contributing to higher greenhouse gas emissions. This dependency delays progress toward Virginia's climate and environmental goals and leaves the state vulnerable to fluctuations in fossil fuel prices and supply disruptions (Snead, 2009). Moreover, the reliance on non-renewable resources conflicts with the growing demand from consumers and businesses for cleaner and more sustainable energy options. Failing to address the energy imbalance also hampers the development and integration of renewable energy projects, which is essential for enhancing grid resilience and diversifying energy sources. Without a more sustainable and robust energy strategy, Virginia risks falling behind other states in transitioning to a clean energy economy, missing opportunities for innovation, job creation, and economic growth in emerging green industries (Tsalidis et al., 2024). These cumulative pressures underscore the need for immediate and coordinated action to develop a forward-looking energy policy that ensures affordability, reliability, and sustainability.

Stakeholders

The energy supply imbalance in Virginia requires coordinated action from a wide range of stakeholders, each playing a critical role in shaping the state's energy landscape. At the strategic level, the Governor's Office and Chief of Staff establish the policy vision, guiding the Secretary of Commerce and Trade and the VDOE in implementing initiatives that ensure reliable, sustainable, and affordable energy (Tran & Smith, 2018). The success of these initiatives depends heavily on the collaboration and alignment of external stakeholders, including Dominion Energy and the Virginia legislature.

Dominion Energy, Virginia's largest utility provider, is a key player in determining the state's energy trajectory. As the primary entity responsible for producing and distributing electricity, Dominion Energy has significant influence over infrastructure development, renewable energy integration, and grid reliability. The company's investment decisions directly impact the pace and feasibility of Virginia's energy transition. Dominion Energy's renewable energy projects, such as the Coastal Virginia Offshore Wind Project, represent critical steps toward diversifying the state's energy mix (Dominion Energy, 2023).

Dominion, however, also faces challenges, including regulatory constraints, market uncertainties, and the need for substantial capital investments to modernize aging infrastructure and expand capacity. Dominion's cooperation with the VDOE and other stakeholders ensures that energy supply initiatives align with grid demands and state policy goals (Dominion Energy, 2023). Dominion's dual role as a private enterprise and a quasi-public utility means it must balance profitability with public service obligations, making its engagement in policy discussions vital for achieving long-term energy stability.

The Virginia legislature also plays a pivotal role in addressing the energy supply imbalance. Lawmakers shape the regulatory framework that governs energy production and consumption, allocate funding for infrastructure projects, and establish mandates for renewable energy targets. Legislative actions like incentives for renewable energy development or streamlining regulatory processes can significantly influence the speed of the energy transition (Young et al., 2022). The legislature's collaboration with Dominion Energy and the Governor's Office is critical in ensuring policies are actionable and effective in meeting Virginia's energy goals (Virginia Department of Environmental Quality, 2022).

In addition to governmental and utility stakeholders, advocacy groups across Virginia contribute to shaping public discourse, promoting environmental justice, and pushing for ambitious clean energy policies. Organizations such as the Southern Environmental Law Center, Appalachian Voices, and the Virginia League of Conservation Voters work to hold utilities and policymakers accountable while mobilizing public support for sustainable energy initiatives (Benforado, 2023). These groups play a key role in amplifying community voices, influencing legislative proposals, and ensuring that Virginia's energy transition prioritizes environmental protection, equity, and long-term climate resilience.

Virginia Legislation

The Virginia Clean Economy Act (VCEA), enacted in 2020, represents a landmark piece of legislation designed to position Virginia as a leader in combating climate change and transitioning to a sustainable energy future. The VCEA reflects a comprehensive approach to decarbonizing the state's energy sector, setting Virginia on a trajectory toward achieving a net-zero carbon electricity grid by 2045. Central to the Act is its ambitious Renewable Portfolio Standards (RPS), which establish legally binding targets for Dominion Energy and Appalachian Power to progressively increase their reliance on renewable energy sources, culminating in 100% renewable energy for Dominion Energy by 2045 and for Appalachian Power by 2050.

To support this transition, the VCEA includes specific provisions to enhance energy storage capacity and ensure grid reliability amidst the growing reliance on intermittent renewable resources like solar and wind. The law mandates the deployment of 3,100 megawatts (MW) of energy storage by 2035. Notably, it reserves a portion of this capacity for third-party providers, encouraging competition and innovation within the energy market (United, 2023).

The act also prioritizes energy efficiency as a critical component of the clean energy transition. By establishing aggressive efficiency targets, the VCEA compels utilities to implement programs and technologies that lower energy consumption, reduce greenhouse gas emissions, and minimize the need for additional energy generation capacity (Benforado, 2023).

Further emphasizing its commitment to environmental sustainability, the VCEA mandates the closure of nearly all coal-fired power plants in the state by 2035. The Act also identifies over 16,100 MW of solar and wind projects, including offshore wind, as public interest investments. These projects contribute to the state's renewable energy goals, stimulate economic growth, create jobs, and position Virginia as a hub for renewable energy industries (Benforado, 2023).

Policy Alternatives

Retail Choice

Retail choice allows consumers to select their electricity supplier rather than being restricted to the utility provider in their region. The concept emerged in the 1990s as part of electricity market deregulation, aiming to enhance competition and reduce costs. While some states have fully embraced retail choice, others remain under regulated monopolies (Deng et al., 2022). Virginia currently has limited retail choice, with large energy consumers able to procure power from competitive suppliers under specific conditions. Residential and small business customers remain restricted to sourcing their energy from the utility monopolies (Pfeifenberger, 2016). By allowing Virginians access to power generated in other states, retail choice can help address supply shortages and enhance grid resilience.

Retail choice increases competition by enabling purchases from competitive service providers rather than a single utility. It promotes lower prices by providing consumers access to out-of-state energy suppliers, increasing the total supply (Craig & Savage, 2013). Transitioning from the current vertically integrated utility model to a system where generation, transmission, and distribution operate in competitive markets encourages innovation and investment. This further enhances efficiency, lowering consumer costs.

Additionally, retail choice allows consumers to select energy suppliers that prioritize clean, renewable energy sources, facilitating a more immediate shift to green energy. As competition increases, power suppliers would be incentivized to offer cleaner, more efficient energy options to attract customers (Dorrell & Lee, 2021). More renewable energy providers would also be able enter the competitive market, granting consumers access to an increased supply of renewable energy (Iweh et al., 2021).

Expanding retail choice in Virginia's energy market offers potential benefits but also comes with drawbacks. Opening the market to independent power producers and competitive service providers creates challenges in maintaining grid reliability, as a more fragmented system complicates coordination and oversight (Haghighi et al., 2024). The transition could also lead to increased consumer costs if regulatory safeguards fail to prevent price volatility or if incumbent utilities pass on stranded costs from existing infrastructure investments (Pfeifenberger, 2016). Additionally, increased competition may reduce incentives for utilities to invest in long-term projects like grid modernization or renewable energy integration (Freihaut & Hallacher, 2012).

Implementing Retail Choice in Virginia

Transitioning to a retail choice model in Virginia would require significant changes in infrastructure, regulatory frameworks, and market operations. The state must first expand its transmission infrastructure to accommodate increased energy imports from out-of-state suppliers while ensuring grid stability. This would include upgrading existing power lines, expanding interconnection capacity, and implementing innovative grid technologies to improve monitoring and load balancing (Deng et al., 2022).

With the necessary infrastructure in place, Virginia would then need to establish a competitive wholesale energy market where power producers could sell electricity to retailers, who would then offer it to consumers. This would require the creation of an independent system operator (ISO) or the integration of Virginia into an existing regional transmission organization (RTO) to oversee market operations and prevent price manipulation (Ros, 2017).

Additionally, regulatory measures would be needed to protect consumers from predatory pricing, ensure fair competition, and provide transparency in energy contracts. Consumer protection policies, such as price caps, anti-discrimination rules, and mandatory disclosures on pricing structures, are crucial to prevent unfair market practices (Haghighi et al., 2024).

Lastly, policymakers must address the financial implications for incumbent utilities, including potential stranded costs from existing infrastructure investments. Transition plans could involve securitization mechanisms to mitigate financial losses and maintain utility solvency while ensuring a smooth shift to a competitive market structure (Freihaut & Hallacher, 2012).

Solar Photovoltaic Behind-the-Meter (BTM) Power Generation

Solar Photovoltaic BTM power generation uses solar cells that can be installed on the roofs of residential or commercial buildings for energy generation. These systems generate electricity directly at the point of consumption, reducing demand on the grid and increasing overall energy supply by utilizing underutilized spaces for local power production (Zaboli et al., 2024). The growing interest in BTM solar PV generation stems from advancements in solar panel efficiency, declining costs of installation, and policy incentives such as tax credits and net metering programs (Tsalidis et al., 2024). With the integration of energy storage systems, BTM solar PV has evolved beyond simple self-consumption to provide grid services like demand response and peak shaving (Gorman et al., 2023).

In some cases, excess energy can be returned to the grid, depending on local regulations and net metering policies. Net metering is a billing arrangement that allows consumers who generate their own electricity from solar power to feed excess electricity back into the grid and receive credit on their utility bills. This policy encourages the adoption of solar PV systems and further adds additional supply to the grid (Aponte & McConky, 2021).

BTM solar PV energy generation offers many benefits but has potential drawbacks. High initial costs for installing solar panels can deter users and intermittency issues with solar energy may lead to inconsistent power supply, requiring backup systems (Bayram & Ustun, 2017). Regulatory and policy barriers, such as restrictive net metering rules, can limit financial incentives and the ability to return excess energy to the grid (Shaker et al., 2020). Moreover, system owners are responsible for maintenance, which can be costly and complex (Prapanukool & Chaitusaney, 2020).

Implementation of Solar PV BTM Power Generation

To effectively implement solar photovoltaic (PV) behind-the-meter (BTM) power generation, several factors must be addressed to ensure broad adoption, integration, and long-term success. A primary barrier to widespread adoption is the high upfront cost of installation. Therefore, expanding financial incentives, such as tax credits, grants, and rebates, would be essential to reduce the initial capital burden on consumers (Aponte & McConky, 2021). Additionally, utility companies and state programs could offer low-interest loans or financing options to make these systems more accessible (Comello et al., 2018).

While BTM solar generation can help reduce grid demand, its large-scale integration requires substantial upgrades to the existing grid infrastructure. Investment in smart grid technology, which includes advanced metering infrastructure, distribution automation, and integrated communications, is necessary to manage solar energy's intermittency and enable smooth integration of decentralized energy generation (Zaboli et al., 2024). Modernizing the grid will help ensure that energy generated from BTM systems can be utilized effectively and that power remains reliable during periods of low solar production (Deng et al., 2022).

Another critical aspect of BTM solar PV implementation is updating net metering policies to make solar energy more financially viable for consumers. Expanding net metering programs to allow consumers to sell excess energy back to the grid at fair compensation rates would incentivize more installations (Gorman et al., 2023). Policymakers must ensure that these changes balance concerns about grid stability while providing consumers a fair and transparent way to participate in the energy market (Bayram & Ustun, 2017).

Small Modular Reactors

Small Modular Reactors (SMRs) are an emerging class of nuclear reactors designed to be more flexible and scalable than traditional large nuclear power plants. SMRs typically produce between 50 and 350 MW of power per unit, compared to the 1,000 MW or more generated by conventional nuclear plants. They rely on nuclear fission to heat water, creating steam that drives turbines to produce electricity (Liou, 2023). Unlike traditional nuclear reactors, SMRs are designed with passive safety systems, which are safety features that do not require human intervention or additional energy sources to function, reducing the risk of catastrophic failures (Erden & Khalifa, 2012). The energy production generates nuclear waste, which must be managed and stored safely to prevent environmental contamination (Young et al., 2022).

One key advantage of SMRs is their modular design, which allows for factory assembly and streamlined deployment. They can be installed incrementally to match demand growth, making them suitable for remote areas and industrial applications (Liou, 2023).

Because of this, SMRs are currently being developed and deployed in various locations worldwide. In the United States, the Department of Energy (DOE) has supported multiple SMR projects, including NuScale Power's design, which received regulatory approval from the Nuclear Regulatory Commission (NRC). Canada has identified several sites for potential SMR deployment, including projects in Ontario and Saskatchewan. China and South Korea are also advancing SMR technologies as part of their nuclear energy strategies (Honney, 2024). This global interest and investment in SMRs underscore their potential to reshape the future of nuclear energy.

In Virginia, Dominion Energy has partnered with Amazon to explore SMR projects near the North Anna site, aiming to meet the increasing energy demands driven by data centers in the area. Similarly, Appalachian Power has identified a potential SMR site on its Joshua Falls property in Campbell County and is initiating the Early Site Permit Application process (Paullin, 2024). The state's interest in SMRs reflects its commitment to diversifying its energy portfolio and ensuring long-term energy reliability. However, successful implementation will require overcoming regulatory hurdles, securing investment, and addressing public concerns about nuclear energy.

Criteria

Cost

The cost analysis evaluates the financial viability of each policy alternative by calculating the levelized cost of electricity (LCOE). This metric represents the average cost per kilowatt-hour (kWh) of electricity generated over the lifetime of an energy asset. LCOE accounts for all costs associated with electricity production, including capital expenditures for construction, financing, and infrastructure; ongoing operational and maintenance expenses; fuel costs, where applicable; and decommissioning costs at the end of the asset's lifecycle. These costs are discounted to present value using an industry-standard discount rate of 10% to reflect the time value of money (Matsuo, 2022). *See Appendix A for further calculation details.*

Additionally, the analysis will include the total cost of implementing the 2040 projected number of infrastructure units for each policy alternative: Retail Choice at a level equal to Ohio; Solar PV BTM utilized by 15% of Virginia households; and 10 SMRs. *See Appendix B for further calculation details.*

Infrastructure costs are also included. It is defined as the cost to construct the smallest operational unit: the necessary infrastructure to offer retail choice to Virginia consumers, one solar panel with behind-the-meter (BTM) infrastructure, and one small modular nuclear reactor (SMR).

Effectiveness

The effectiveness analysis evaluates the extent to which each policy alternative can help meet Virginia's projected energy shortfall by 2040. To calculate this, the analysis multiplies each alternative's per-unit capacity by the maximum feasible level of implementation by 2040, accounting for both technological limitations and practical deployment constraints. Effectiveness will be expressed as the percentage of the total projected additional capacity (112.5 million megawatt-hours) each alternative can supply based on the 2040 projection (Shobe, 2021). *See Appendix C for further calculation details.*

The following implementation assumptions are used to calculate the percentage:

- **Retail Choice:** The analysis assumes it will be universally available across the state by 2040, with Virginia able to import a similar quantity of energy as Ohio currently does through its statewide retail choice program (Ohio customer choice activity, 2025).
- **Solar Photovoltaics (PV) Behind-The-Meter (BTM):** The Virginia Clean Energy Act mandates that 15% of the state's homes be equipped with this technology by 2040 (United, 2023).
- **Small Modular Reactors (SMRs):** Virginia is projected to have 10 operational units by 2040 (EY, 2016).

Feasibility

Feasibility will be evaluated based on two key considerations: political and environmental.

Political feasibility assesses the likelihood that a policy alternative can secure the necessary funding, gain political traction, and obtain support from key stakeholders, including energy suppliers, consumers, and policymakers. This criterion is evaluated by analyzing legislative precedents in Virginia and other states, assessing existing private investments, and determining the level of government funding required. Additionally, stakeholder interviews, polling data, and documented resistance inform the degree of buy-in from relevant parties. A policy facing significant political opposition or lacking industry support will be considered to have low political feasibility, regardless of its technical viability. Conversely, policies that align with stakeholder interests, enjoy broad political support, and offer an expedient implementation path will be rated highly feasible.

Environmental feasibility assesses the degree to which a policy alternative supports sustainability and responsible land use. This criterion is evaluated by measuring the environmental footprint of each option in terms of kilowatt-hours per unit of carbon emissions (kWh/Carbon) and the total land area required for implementation. Policies that significantly increase carbon emissions or require extensive land use will be considered to have low environmental feasibility, whereas those that minimize emissions, utilize resources efficiently, and have a minimal ecological impact will be rated as highly feasible.

Analysis

Retail Choice

Cost

The LCOE for electricity under a retail choice model in Virginia depends on the sources of electricity procured and the infrastructure required to deliver it. If Virginia implements retail choice and imports nationally average-cost electricity at a similar scale as Ohio's retail choice model, the LCOE is estimated to be between **$50 and $60 per megawatt-hour (MWh)** (Morey & Kirsch, 2016). If Virginia were to import electricity at a national average cost, the total cost would range between **$225 million and $270 million a year**.

This estimate is based on 4% of the additional required capacity (approximately 112.5 million MWh) being provided through retail choice by 2040. Ohio currently imports at levels that would provide 4% of the additional required capacity (Ohio Customer Choice Activity, 2025). This calculation also uses the current Dominion projection of **$6.7 billion as the necessary infrastructure investment** (Dominion, 2023). This includes upgrading transmission lines, new substations, and regulatory changes to support the increased electricity flow. Assuming Virginia could import at levels similar to Ohio is a reasonable assumption based on the infrastructure, geographical, and availability factors. This estimate does not account for transmission constraints, regulatory adjustments, or price fluctuations in regional electricity markets.

Effectiveness

The analysis assumes universal availability across Virginia by 2040. It further assumes that Virginia could import an amount of electricity equivalent to what Ohio currently procures through its retail electricity market—approximately 216,000 megawatt-hours per month (Ohio Customer Choice Activity, 2025). Based on this benchmark, retail choice could contribute up to **2,592,000 MWh per year** toward Virginia's additional demand, equating to approximately **2.5%** of the projected 112.5 million MWh increase by 2040 (Shobe, 2021).

While retail choice introduces competition and consumer flexibility, potentially reducing costs and improving supply responsiveness, it does not itself create new generation capacity. Its effectiveness is, therefore, constrained by the availability of surplus power in regional markets, which may face transmission bottlenecks or pricing volatility (Rose et al., 2024). Based on these findings, in isolation, retail choice can only provide a minuscule contribution to meeting future energy needs.

Feasibility

Political

Retail choice faces significant political feasibility challenges in Virginia due to the strong opposition from incumbent utilities, which currently hold monopolistic control over the state's energy market. These utilities are opposed to retail choice because it would introduce increased competition, potentially eroding their market dominance and impacting their bottom line (Armoo et al., 2024). As monopolies, these utilities rely heavily on the state to maintain their stability, which is supported by massive investments, long-term contracts, and projected growth in consumer demand for energy. The prospect of retail choice disrupts this model, as it would allow consumers to choose from a broader range of energy suppliers, diminishing the utilities' ability to control pricing and demand (Tsalidis et al., 2024). Because of their current market dominance, they have significant lobbying power and political influence, which they use to shape policy decisions in their favor.

In addition to the utility companies' resistance, retail choice requires sweeping regulatory changes, including establishing new pricing structures, consumer protection measures, and oversight mechanisms. These changes are often politically contentious and difficult to pass (Ros, 2017). The existing monopoly structure grants these companies substantial political and economic leverage, making it difficult for retail choice to gain traction without overcoming considerable resistance from well-entrenched industry players.

Beyond utilities, consumer advocacy groups, environmental organizations, and renewable energy industry groups support retail choice, seeing it as an opportunity to lower energy costs and increase access to clean energy (REBA, 2020). However, the political feasibility of retail choice will depend on overcoming the entrenched interests of the monopoly utilities and navigating the political landscape shaped by their lobbying efforts and influence over state policymakers.

Environmental

The environmental benefits of retail choice lie in its potential to give consumers access to cleaner energy sources. By creating a competitive marketplace, retail choice incentivizes utilities to offer a wider variety of renewable energy plans, leading to increased investments in low-emission technologies (California Senate & Office of Research, 2021). This would, in turn, promote cleaner energy consumption and reduce the carbon footprint of electricity generation.

The energy that Virginia would be able to import from other states under retail choice would largely reflect the current energy profile of the broader United States. While retail choice would increase the availability of renewable energy plans, a significant portion of the energy imported would still come from fossil fuel-based sources (Rose et al., 2024).

Currently, the U.S. energy mix consists of approximately 60% fossil fuels (including natural gas, coal, and oil), with the remaining split between nuclear and renewable sources such as wind and solar. As a result, the carbon emissions from electricity generated in the U.S. grid are roughly **0.83 pounds of CO2 per kilowatt-hour (kWh)** of electricity produced (Tran & Smith, 2018). This carbon output would be representative of the energy imported into Virginia through retail choice.

The environmental effectiveness of retail choice is contingent on the specific market structure and regulatory safeguards. Without careful regulation, retail choice could lead to unintended consequences, such as consumers opting for cheaper fossil fuel-based energy providers, which may offer lower prices than renewable options (Tran & Smith, 2018). If low-cost, high-emission energy plans dominate the market, the environmental goals of retail choice could be undermined.

In addition, implementing retail choice would require significant infrastructure upgrades, including the construction of 415 miles of new transmission lines, each requiring five acres of land per mile, and two new transmission centers, each requiring 15 to 20 square miles of land (Rose et al., 2024). These infrastructure expansions would require approximately **450 to 500 square miles of land**. This substantial land-use impact highlights the need for careful planning and regulation when introducing retail choice to address environmental and land-use concerns adequately.

Solar Photovoltaics (PV) Behind-The-Meter (BTM)

Cost

The LCOE of Solar PV BTM systems has declined significantly over the past decade, with estimates now ranging from **$30 to $40 per MWh**, depending on location, incentives, and system scale. Technological improvements, declining solar panel costs, and advancements in energy storage have made Solar PV BTM increasingly competitive with grid electricity (Obi et al., 2017). Additionally, Solar PV BTM systems reduce transmission and distribution costs, lowering energy expenses. While upfront installation costs remain a barrier for some consumers, continued price reductions and policy incentives will drive down the LCOE of Solar PV BTM (Matsuo, 2022).

This estimate considers the current required implementation targets outlined in the VCEA, which mandates 15% of households be equipped with Solar PV BTM by 2040 (United, 2023).

To estimate the total cost of implementing Solar PV BTM systems to meet the mandate of equipping 15% of Virginia households with Solar PV by 2040, we calculate the costs based on the LCOE range of $30 and $40 per MWh. Given that 15% of homes could produce approximately 5% of the energy increase required to meet Virginia's projected energy shortfall by 2040, the total cost would be based on 6,750,000 MWh of capacity. Based on these projections, the total cost is projected to be **$168.75 million to $225 million** annually.

Implementing Solar PV BTM systems at scale would require substantial infrastructure investments in residential installations and grid integration. Infrastructure costs include the solar panels, energy storage systems, and necessary upgrades to the grid to handle distributed generation. The projected infrastructure investment needed to equip 15% of Virginia households with Solar PV BTM systems by 2040 (approximately 3.5 million homes) is around **$110 billion**.

While these upfront costs may pose a barrier for some consumers, financial incentives, such as tax credits and rebates, and continued advancements in solar technology are expected to help drive down costs over time (Prapanukool & Chaitusaney, 2020). The long-term benefits of reduced energy costs and lower reliance on grid electricity make Solar PV BTM a cost-effective option for meeting Virginia's energy needs.

Effectiveness

The analysis uses the implementation target established by the Virginia Clean Economy Act, which mandates that 15% of the state's homes be equipped with rooftop solar systems by 2040. With approximately 3.5 million housing units in Virginia, this equates to around 525,000 rooftop installations (Population and Housing Unit Estimates, 2025).

Due to weather and daylight limitations, each rooftop system is assumed to have a nameplate capacity of 5 kilowatts (kW), with an average capacity factor of 15% (Kabeyi & Olanrewaju, 2022). The capacity factor is the ratio of actual energy produced over a given period compared to the amount the system could have produced if it operated 100% of the time at full capacity. This translates to an annual output of approximately 6,570 kWh (or 6.57 MWh) per system (Temiz et al., 2024). Multiplied by the projected 525,000 systems, BTM solar could contribute an estimated **3.45 million MWh annually**, which equates to roughly **5%** of the 112.5 million MWh projected shortfall.

While BTM solar offers distributed, emissions-free generation benefits, its relatively low capacity factor and limited scalability within the residential sector constrain its effectiveness. Meeting the entire projected shortfall through rooftop solar alone would require more than 17 million installations—over five times the total number of housing units currently in the state (O'Donnell & Su, 2023). Therefore, while BTM solar can play a supportive role in Virginia's future energy mix, it must be paired with broader-scale generation strategies to close the supply gap fully.

Feasibility

Political

Despite recent shifts in federal politics and efforts to roll back components of the Inflation Reduction Act (IRA), the political feasibility of Solar PV BTM power generation in Virginia remains strong due to supportive policies, financial incentives, and net metering regulations. Virginia benefits from initiatives such as the federal Investment Tax Credit (ITC), which allows homeowners to deduct 30% of installation costs from federal taxes (O'Donnell & Su, 2023). Additionally, local property tax exemptions in counties like Fairfax, Loudoun, and Prince William further enhance the financial feasibility of solar adoption. Consumer adoption, however, presents significant challenges. High upfront costs, limited public awareness, and complex installation processes deter widespread uptake (Kabeyi & Olanrewaju, 2022). Without substantial consumer incentives or educational campaigns to drive demand, the overall feasibility of Solar PV BTM in Virginia remains constrained.

Utility companies present a complex political factor in the feasibility of Solar PV BTM. Historically, utilities in Virginia have resisted distributed energy generation due to concerns over lost revenue and grid management challenges (Carley & Konisky, 2020). However, Solar PV BTM also offers utilities potential advantages. Through net metering and power purchase agreements, utilities can buy excess energy generated by households, integrating additional renewable energy into the grid without bearing the full cost of new infrastructure. Additionally, shifting the upfront costs of solar installation to consumers reduces the financial burden on utilities while expanding renewable energy availability (Higgins & Glazer, 2021).

Bipartisan political support further enhances the feasibility of Solar PV BTM initiatives in Virginia. Recent legislative efforts demonstrate cross-party collaboration aimed at expanding small-scale solar projects. A 2025 bill sponsored by Delegate Katrina Callsen (D-Charlottesville) and Senator Schuyler T. VanValkenburg (D-Henrico) seeks to increase the percentage of Virginia's Renewable Portfolio Standard derived from small-scale solar, wind, or renewable gas projects from the current 1% to 3% in 2026 and 15% by 2040 (Paullin, 2025). This legislation reflects a growing consensus among Democratic and Republican lawmakers on promoting distributed renewable energy solutions in the state.

Environmental

Solar PV BTM environmental feasibility is high due to its minimal greenhouse gas emissions and limited land use requirements. Solar PV BTM systems generate significantly fewer emissions than fossil fuel-based grid electricity, reducing carbon footprints and improving air quality (Shaker, Manfre, & Zareipour, 2020). On average, these systems produce only **0.066 pounds of carbon per kilowatt-hour (kWh)** of energy (Armoo et al., 2024). Many Solar PV BTM installations also incorporate energy storage solutions, further optimizing renewable energy use and reducing reliance on high-emission backup power sources.

Unlike utility-scale solar farms, Solar PV BTM does not alter land usage because it is installed on existing structures such as residential and commercial rooftops. On a per-household basis, the effective land footprint is approximately **1/13 of an acre** (Comello, Reichelstein, & Sahoo, 2018). Since this land is already in use for housing or commercial purposes, Solar PV BTM avoids the land-use conflicts associated with large-scale energy projects.

Negatively impacting Solar PV BTM's environmental feasibility is the materials and processes used in solar panel and battery production. The extraction and manufacturing of photovoltaic cells, inverters, and lithium-ion batteries require resource-intensive mining and industrial processing, which can contribute to pollution and habitat destruction. Additionally, improper disposal of solar panels and batteries at the end of their lifecycle presents a potential environmental challenge. Without robust recycling programs and sustainable material sourcing, the long-term environmental benefits of Solar PV BTM could be undermined (Shaker, Manfre, & Zareipour, 2020).

Small Modular Reactors (SMRs)

Cost

The Levelized Cost of Electricity (LCOE) for SMRs varies depending on design and deployment factors. For instance, a study by the Pacific Northwest National Laboratory (PNNL) calculated LCOEs ranging from $51 to $54 per megawatt-hour (MWh) for large-scale production designs and $44 to $51 per MWh for smaller-scale designs (Locatelli, Bingham, & Mancini, 2014). However, other analyses, such as the UK's SMR Cost Reduction Study, suggest that achieving cost parity with large reactors requires a process known as 'cumulative deployment and learning'.

This process involves deploying multiple SMRs over time and learning from each deployment to improve efficiency and reduce costs.

Because of this, initial SMR projects may incur higher LCOEs until economies of scale are realized. The most extensive distribution of cost estimates falls between **$50 to $60 per MWh** (EY, 2016). The LCOE estimates are comprehensive, incorporating capital recovery, operations and maintenance, fuel procurement, waste management, and decommissioning.

If 10 SMRs are deployed by 2040, as the Weldon Cooper Center projected, they will account for approximately 27.5% of the anticipated demand increase, generating around 30,937,500 MWh annually (Temiz & Dincer, 2024). At an LCOE of $50 to $60 per MWh, the total annual cost would range from **$1.55 billion to $1.86 billion**.

Deployment at this scale would also require significant infrastructure investment. This includes grid modernization to accommodate decentralized generation, construction of transmission lines linking reactor sites to demand centers, upgrades to cooling water systems, and development of interim waste storage and emergency response infrastructure. Based on U.S. Department of Energy benchmarks and comparable SMR deployment cases, these investments in addition to the cost of the reactor are projected to be between **$6 billion and $10 billion per reactor** (Schlissel, 2023).

Effectiveness

Based on current planning and development projections, the analysis assumes that Virginia will have approximately 10 operational units by 2040 (Balaraman, 2022). Each SMR is assumed to have a nameplate capacity of 350 megawatts (MW) and a capacity factor of 90% (Small Modular Reactors, 2021). The capacity factor measures how often a power plant runs at full output over a specific period. A 90% capacity factor means the unit produces near-maximum output for most of the year, making SMRs highly reliable.

At this performance level, each SMR would generate approximately 2.37 million MWh annually. With 10 SMRs, the total generation would be **28.7 million MWh annually,** representing approximately **25%** of the 112.5 million MWh projected shortfall.

While SMRs offer a consistent and dispatchable source of low-carbon energy, their effectiveness is tempered by high upfront capital costs, regulatory hurdles, and extended construction timelines (Locatelli, Bingham, & Mancini, 2014). If these barriers can be overcome, SMRs have the potential to contribute significantly to Virginia's energy needs by 2040. SMRs far exceed the output of the other alternatives considered in this analysis.

Feasibility

Political

The political feasibility of Small Modular Reactors (SMRs) in Virginia is moderately high but faces key challenges. Governor Glenn Youngkin has publicly supported nuclear energy as part of his "All-of-the-Above" energy strategy, signaling strong executive backing for SMRs (Finocchio, 2024). Republican legislators generally favor nuclear expansion, viewing SMRs as a potential solution to meet growing energy demands, particularly with the increasing need for power to support data centers in the state. However, Democratic support remains mixed and often hinges on addressing concerns about cost, waste management, and environmental risks associated with nuclear energy (Link, 2024).

The funding feasibility for SMRs in Virginia is also mixed. While the state could leverage federal incentives, including support from the U.S. Department of Energy and the Inflation Reduction Act, funding competes with other energy priorities, and securing the necessary capital for large-scale deployment remains a challenge (Slochsher, 2025).

Private companies present an opportunity for an additional funding source. Dominion Energy has partnered with Amazon to explore SMR projects near the North Anna site, aiming to meet the increasing energy demands driven by nearby data centers. Similarly, Appalachian Power has identified a potential SMR site on its Joshua Falls property in Campbell County and is beginning the Early Site Permit Application process (Paullin, 2024). By investing in or operating their own SMRs, businesses can better control their energy supply, reduce dependence on grid power, and meet sustainability goals (Balaraman, 2022). This interest further strengthens the political feasibility, as private industry could provide significant lobbying power for SMRs.

Opposition, however, from environmental and consumer advocacy groups could slow progress. These groups often raise concerns about the long-term environmental impacts of nuclear energy, including waste storage and the risk of accidents, even at a smaller scale (Link, 2024).

Consumer sentiment on nuclear energy is divided. According to a 2023 Gallup poll, 44% of American adults oppose the use of nuclear energy, a decrease from 54% in 2016. While this represents a significant portion of the population still wary of nuclear power, it also indicates a shift in public opinion, suggesting growing support for nuclear energy (Brenan, 2023).

Environmental

The environmental feasibility of SMRs is largely positive, as they offer significant benefits compared to fossil fuel-based power generation. Unlike traditional coal and gas plants, SMRs do not emit air pollutants such as sulfur dioxide, nitrogen oxides, or particulate matter, which contribute to smog, acid rain, and respiratory illnesses (Balaraman, 2022). Furthermore, SMRs exhibit high efficiency in terms of carbon output. They produce just **0.026 pounds of carbon per kWh** of energy (Locatelli, Bingham, & Mancini, 2014).

Another key environmental advantage of SMRs is their reduced land footprint. SMRs require significantly less land compared to large-scale renewable projects like wind or solar farms. A typical SMR generating 350 MW requires as little as **10 acres of land** (Liou, 2023). This compact land requirement is a significant environmental benefit, particularly in densely populated areas or regions where land use is highly contested.

Although SMRs offer smaller-scale solutions compared to traditional nuclear plants, they carry certain environmental risks similar to large scale nuclear power. The largest risk stems from the management of nuclear waste. Long-term waste storage remains a significant challenge for the nuclear industry (National Inventory of Radioactive Materials and Waste, 2021). Furthermore, the potential for accidents is still a risk that cannot be entirely ruled out. SMRs are at significantly lower risk, however, due to the smaller scale and more advanced safety features. This remains a contentious issue for environmental and consumer advocacy groups who are wary of any form of nuclear power (Adelman, 2024).

Outcome Matrix

	Retail Choice	Solar PV BTM	SMRs
Effectiveness **Percentage of total energy demand increase can supply** **Total Production**	**2%-4%** **2,592,000MWh** *Assumes similar import totals as Ohio Annual Production	**4%-6%** **3,450,000MWh** *Assumes 15% uptake, 2040 Projection Annual Production	**25%-30%** **28,700,000MWh** *Assumes 10 unit operation by 2040 Annual Production
Total Cost **LCOE** **Infrastructure Cost**	**$225M-$270M** *Annually **$60 to $70** *per Megawatt **$6.7B** *Universally available	**$168.75M-$225M** *Annually **$30 to $40** *per Megawatt **$110B** *3.5M Homes	**$1.55B-$1.86B** *Annually **$50 to $60** *per Megawatt **$6B - $10B** *Per Reactor
Overall Feasibility **Political Feasibility** **Environmental Feasibility**	**Low/Moderate** Faces resistance from existing energy suppliers .83lbs of carbon per kWh and 500 mi² of land	**Moderate/High** Favorable policies, but high costs & low awareness .066lbs of carbon per kWh and 1/13 acres of land	**Moderate** High cost & divided public opinion; Political & Utility support 026lbs of carbon per kWh and 10 acres of land

SMRs are the most effective, supplying 25-30% of the energy demand increase with 28.7M MWh of annual production. However, they are also the most expensive, costing $1.55-$1.86B annually, with infrastructure costs of $6-$10B per reactor. Solar PV BTM offers moderate effectiveness (4-6%) with lower annual costs ($168.75-$225M) and the lowest LCOE ($30-$40 per MWh), though it requires $110B in infrastructure to support 3.5 million homes. Retail Choice has the lowest effectiveness (2-4%) and moderately high costs ($225-$270M annually) but benefits from a lower infrastructure cost ($6.7B). Regarding feasibility, Retail Choice faces political resistance and has the highest environmental impact. Solar PV BTM enjoys favorable existing policies and low carbon emissions. SMRs have moderate feasibility because they have the lowest carbon footprint but face divided public opinion.

Recommendation

Small Modular Reactors (SMRs) offer the best path forward for the Virginia Department of Energy to address the state's projected 85% increase in electricity demand over the next fifteen years. When evaluated against the key criteria, cost, effectiveness, and feasibility, SMRs outperform other alternatives in providing a reliable, scalable, and low-carbon energy supply. With an estimated LCOE of fifty to sixty dollars per MWh, SMRs are cost-competitive with retail choice (sixty to seventy dollars) and only slightly more expensive than Solar PV BTM (thirty to forty dollars). Unlike retail choice, which depends on fluctuating market conditions and does not create new generation capacity, SMRs provide in-state energy independence and long-term price stability. Their high capacity factor (90%) means they can generate power continuously, making them far more effective than Solar PV BTM, which has a low 15% capacity factor and would require 17.1 million rooftop installations to meet demand. Additionally, one SMR can produce 2.37 million MWh annually, indicating Virginia would only need forty-eight SMRs to close the entire projected supply gap.

While SMRs face moderate political and environmental feasibility challenges, they remain the most potent long-term solution. Governor Youngkin's "All-of-the-Above" energy strategy and industry interest from Dominion Energy and Appalachian Power indicate growing support, though concerns about nuclear waste and high upfront costs remain. Unlike retail choice, which requires regulatory overhauls and significant transmission investments, SMRs offer more predictable, in-state energy production. When compared to solar PV BTM, SMRs provide more continuous, larger-scale power generation with a much smaller land footprint (≈ten per three hundred MW versus thousands of acres for equivalent solar or wind projects). **Given the urgency of Virginia's energy crisis, the Virginia Department of Energy should prioritize SMRs as the most effective and sustainable path forward.**

Implementation

The successful implementation of Small Modular Reactors (SMRs) in Virginia will require a coordinated effort among policymakers, regulators, industry stakeholders, and local communities. While SMRs offer a promising solution to the state's projected energy supply shortfall, their deployment is not without challenges. Similar projects have faced regulatory hurdles, financing difficulties, public resistance, and extended construction timelines. Learning from past experiences and structuring a clear, phased implementation strategy will be critical to ensuring the viability of SMRs in Virginia.

Stakeholders and Their Roles

Several key stakeholders will play essential roles in the implementation of SMRs:

1. **Virginia Department of Energy (VDOE)** – This Agency is the lead agency for overseeing regulatory approvals, interagency coordination, and policy guidance.
2. **Governor's Office & State Legislature –** Provides legislative support, secures funding, and establishes incentives for nuclear investment.
3. **Dominion Energy & Appalachian Power** – Industry leaders responsible for financing, construction, and operation of SMRs.
4. **U.S. Department of Energy (DOE) & Nuclear Regulatory Commission (NRC)** – Provides regulatory oversight, grants, and technical assistance.
5. **Local Governments & Community Organizations** – Facilitates community engagement, addresses public concerns, and manages local infrastructure needs.
6. **Environmental & Consumer Advocacy Groups** – Ensures sustainability measures and consumer protections are incorporated into SMR projects.
7. **Universities & Research Institutions** – Supports workforce development and technological innovation.

Steps for Implementation

The deployment of SMRs in Virginia will follow a structured approach, divided into key phases:

Phase 1: Regulatory & Policy Foundations (Years 1-2)

- Secure state legislative support for nuclear energy expansion.
- Work with the NRC to obtain early site permits for proposed SMR locations.

- Develop financial incentives, such as tax credits or public-private partnerships, to attract investment.
- Engage in public outreach campaigns to address concerns about nuclear safety and waste disposal.

Phase 2: Site Selection & Preliminary Development (Years 2-4)

- Conduct feasibility studies and environmental impact assessments.
- Collaborate with utilities to determine the most suitable sites.
- Secure federal funding and initiate contract negotiations with SMR developers.
- Establish partnerships with universities for workforce training programs.

Phase 3: Engineering & Construction (Years 4-9)

- Finalize reactor designs and obtain necessary NRC construction permits.
- Begin infrastructure development, including grid integration plans.
- Launch workforce development initiatives to ensure a skilled labor supply.
- Implement risk management strategies to address potential cost overruns and delays.

Phase 4: Testing & Commissioning (Years 9-12)

- Conduct safety and operational testing in accordance with NRC guidelines.
- Ensure compliance with all environmental and public safety regulations.
- Establish emergency preparedness protocols in collaboration with local authorities.
- Begin phased operation, integrating SMR-generated electricity into Virginia's power grid.

Challenges & Mitigation Strategies

1. **Regulatory Delays** – NRC licensing and state-level permitting can take years. Early engagement with regulators and pre-emptive compliance planning can help mitigate delays.
2. **Public Resistance** – Concerns about nuclear safety and waste storage may result in opposition. Proactive public education campaigns, transparent risk communication, and community benefit agreements can improve public support.

3. **Financial & Market Risks** – The high capital costs of SMRs may deter investors. State and federal incentives, loan guarantees, and cost-sharing mechanisms can alleviate financial burdens.
4. **Construction & Technological Challenges** – Cost overruns and delays are common in nuclear projects. Implementing modular construction techniques and leveraging past SMR deployment experiences can enhance efficiency.
5. **Grid Integration Issues** – Ensuring that SMRs are seamlessly integrated into Virginia's existing grid will require modernization efforts and coordination with utility providers.

Stakeholder Perspectives & Leadership Needs

- **Political Leaders & Regulators** – Mixed support; will need strategic bipartisan advocacy to secure long-term policy commitments.
- **Utility Companies** – Likely supportive; must balance nuclear investments with existing renewable energy initiatives.
- **Local Communities** – Some resistance is expected; local economic benefits and safety assurances are critical for gaining support.
- **Environmental Advocates** – Divided; some support nuclear as a low-carbon option, while others oppose it due to waste disposal concerns.

Strong leadership from the VDOE, the Governor's Office, and industry leaders will be essential to navigating opposition and maintaining momentum. Engaging stakeholders early and maintaining transparency will help mitigate resistance and foster collaboration.

Worst-Case Scenario Analysis & Contingency Planning

1. **Regulatory Gridlock** – If NRC licensing is delayed, Virginia may need to explore alternative energy solutions to prevent shortages.
2. **Public Backlash & Political Reversals** – Strong opposition could stall projects. A robust public engagement strategy emphasizing economic and environmental benefits is necessary.
3. **Cost Overruns & Financing Challenges** – If costs exceed projections, securing additional federal funding or adjusting project timelines may be required.
4. **Technological Failures** – If SMRs fail to meet performance expectations, hybrid solutions integrating renewables with backup gas or battery storage should be considered.

The implementation of SMRs in Virginia presents a viable pathway to addressing the state's growing energy demands while ensuring long-term energy security. While challenges exist, a well-structured, phased approach incorporating regulatory coordination, stakeholder engagement, and financial incentives will maximize the likelihood of success. Learning from past nuclear projects and applying best practices in governance, financing, and public communication will be key to navigating the complexities of SMR deployment. Virginia can position itself at the forefront of next-generation nuclear energy innovation by fostering strong leadership and aligning incentives.

Appendix

A. Calculation Methodology for LCOE:

The simplified formula for LCOE is:

$$LCEO = \sum_{t=1}^{n} ((I(t) + M(t) + F(t)) \div (1 + r) \wedge (t)) \div \sum_{t=1}^{n} (E(t) \div (1 + r) \wedge (t))$$

Where:

- I(t) = Investment expenditures in year t
- M(t) = Operations and maintenance costs in year t
- F(t) = Fuel costs in year t
- E(t) = Electricity generated in year t
- r = Discount rate
- n = Operational lifespan of the plant

Key Inputs:

1. **Capital Expenditures (CapEx):** Initial costs for land acquisition, equipment, construction, and financing.
2. **Operations and Maintenance (O&M) Costs:** Regular expenses for labor, maintenance, administrative activities, and periodic overhauls.
3. **Fuel Costs:** Expenses for fuel procurement and transportation, applicable to fuel-dependent technologies.
4. **Decommissioning Costs:** Projected expenses for safely dismantling the facility at the end of its operational life.
5. **Discount Rate:** Reflects the time value of money, accounting for the opportunity cost of capital and investment risks.
6. **Capacity Factor:** The ratio of actual energy produced to the maximum possible, indicating utilization efficiency.
7. **Economic Life:** The expected operational duration of the plant, influencing cost and revenue projections.

Uncertainty and Probabilistic Modeling:

Accurately determining LCOE is challenging due to uncertainties in factors like construction timelines, fuel price volatility, and O&M costs. Traditional LCOE calculations often rely on point estimates, which may not capture the full range of possible outcomes. To address this, probabilistic approaches model input variables as distributions rather than fixed values, providing a more comprehensive risk assessment.

B. Total Cost Calculations

Formula: Annual Cost = High Projection Annual Output (MWh) × LCOE Cost per MWh

Retail Choice

Inputs:

- Annual Output **= 4,500,000 MWh**
- LCOE Range **= $50–$60 per MWh**

Calculation:

- **Low End**: $4{,}500{,}000 \times 50 = \$225{,}000{,}000$
- **High End**: $4{,}500{,}000 \times 60 = \$270{,}000{,}000$

Solar PV BTM

Inputs:

- Annual Output **= 6,750,000 MWh**
- LCOE Range **= $30–$40 per MWh**

Calculation:

- **Low End**: $6{,}750{,}000 \times 30 = \$168{,}750{,}000$
- **High End**: $6{,}750{,}000 \times 40 = \$225{,}000{,}000$

SMR

Inputs:

- Annual Output **= 30,937,500 MWh**
- LCOE Range **= $50–$60 per MWh**

Calculation:

- **Low End**: $30{,}937{,}500 \times 50 = \$1{,}546{,}875{,}000$
- **High End**: $30{,}937{,}500 \times 60 = \$1{,}856{,}250{,}000$

C. Effectiveness Calculations

Total Projected Shortfall: 112,500,000 MWh/year

Retail Choice

Monthly Benchmark from Ohio:

- 216,000 MWh/month

Annualized for Virginia:

- 216,000 × 12 = 2,592,000 MWh/year

Effectiveness Against Virginia's Projected Shortfall:

- **Effectiveness**: (2,592,000/112,500,000) × 100 = 2.30% (rounded in report as 2.5%)

Solar PV BTM

Total Homes in Virginia: 3.5 million
Target Installations: 15% × 3,500,000 = 525,000 homes
Nameplate Capacity per Home: 5 kW
Capacity Factor: 15% (due to weather, daylight)

Annualized for Virginia:
- **Annual Output per System**: 5 × 8,760 × 0.15 = 6,570 kWh = 6.57 MWh
- **Total Output**: 6.57 MWh/system × 525,000 systems = 3,449,250 MWh/year

Effectiveness Against Virginia's Projected Shortfall:

- **Effectiveness:** (3,449,250/112,500,000) × 100 = 4.57% (rounded in report as 5%)

SMRs

Number of Units: 10
Nameplate Capacity per Unit: 350 MW per hour
Capacity Factor: 90%
Hours per Year: 8,760

Annualized for Virginia:
- **Annual Output per SMR**: 350 × 8,760 × 0.90 = 2,758,800 MWh
- **Annual Output for 10 SMRs**: 2,758,800 × 10 = 27,588,000 MWh

Effectiveness Against Virginia's Projected Shortfall:

- **Effectiveness:** (27,588,000/112,500,000) × 100 = 24.53% (rounded in report as 25%)

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