P O W E R L E S S

Data Center Campus in Ashburn, Virginia*

Loudoun County as a Case Study for Data Centers as a Local Paradigm

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Contents

1 Executive Summary

On February 24th, 2026, President Donald J. Trump addressed concerns about the effects of data centers on affordability and community well-being in his State of the Union speech. The President promised that data centers would "build their own plant and produce their own electricity," and thus institute "ratepayer protection pledges" (POLITICO 2026).

The buildout has presented a force for residents to reckon with: increased energy costs and significant strain on local ecological resources. Recent reporting from S&P Global indicates that the proliferation of data centers across the US will require 22% more grid power by the end of 2025, as compared to 2024, and three times as much power in 2030 (Dlin and Hering 2025). 451 Research [1] projects that in 2026, US data center demand will reach 75.8 GW for IT equipment, cooling, lighting, and other uses, scaling to 108 GW in 2028 and 134.4 GW in 2030. Notably, these projections exclude enterprise-owned data centers outside of hyperscale facilities.

Data centers, a newer form of infrastructure used by many of the largest technology companies to store, share, and manage the distribution of data, lack regulatory precedent in the United States. They elicit 3 main concerns: constraining resources and thus increasing the cost of utilities, primarily energy, but including water, the degradation of the natural environment, including human health and ecological wildlife due to air pollution and land use, and an apparent lack of transparency in reporting, thus harming community quality of life.

Currently, data centers are a national phenomenon. To understand the potential negative externalities and policy responses that data centers may inflict on the community they operate in, a case study is necessary. I chose Loudoun County, Virginia, part of what is called "Data Center Alley" in Northern Virginia, and home to 200 operational data centers.

In this thesis, I hypothesize that Loudoun County, Virginia, is the optimal area to use as a case study on the impacts and response of data centers in a community because of its unique historical position and high exposure to data centers, and that the increases in energy and water rates, the concealment of information, and the impacts to the environment and human health are the driving negative externalities.

To answer the question, "What impacts are data centers driving in Loudoun County and what makes it special?" I engaged in a few methods. First, I completed a political economy analysis of Loudoun County's history and regulatory landscape to understand the utilities and systems of change. Then, I analyzed the impacts of data centers on Loudoun County, honing in on energy, water, and health by combing through peer-reviewed papers, government and industry reports, utility documents, and newspaper articles. To visualize data center relationships with the community and understand their impact on energy infrastructure, I created three resources. These include a map in ArcGIS Online that plots data centers in relation to distribution and transmission, a series of graphics to visualize the regulatory dynamics among data centers, energy, land, and water resources, and reporting data. The ArcGIS Online Map includes two web apps: an Interactive Legend and a Sidebar. I complemented this visualization with anecdotal research. I interviewed two Loudoun County residents to determine their relationship with the data center development. Finally, to demonstrate the potential harm from inconsistencies and omission of data center consumption information, I estimated an energy-use equivalency and emissions calculation.

Regarding results, I have found that Loudoun County's nascent nature in the data center space makes it an optimal case study. In Loudoun County, data centers, both existing and proposed, have increased residential bills due to Virginia Power and Electric Company requesting a significant revenue increase to account for additional energy infrastructure build, and PJM Interconnection raising electricity market prices. Loudoun Water has also raised water rates due to the strain on recycled-water systems. Mapping illustrates a strong visual correlation between data centers and energy infrastructure. Residents corroborate concerns regarding transparency and reductions to the quality of life. Air pollution from on-site generation has a significant impact: emitting air pollutants and greenhouse gases.

As for policy responses, residents have formed coalitions against data center development. During local public hearings, common residential concerns include the data center being perceived as an eyesore, producing significant noise, unknown health impacts, and fears of rising utility bills. In contrast, data center advocates often respond by emphasizing the economic benefits to the community, like job creation and tax revenue, while donating to local politicians

[1] A subsidiary of S&P Global.

This community dynamic highlights two gaps in the data center policy space.

1. There is a lack of data transparency. Public-grade utility infrastructure is treated as a private commercial technology asset.
2. Data centers can rely on a lack of individual knowledge to deflect attention from themselves to the broader community. Residents are ill-equipped with the knowledge to resist such responses.

At a macro level, the results are clear: Loudoun County demonstrates that data centers must be reclassified as new large-load infrastructure items and approached through defensive environmental policy to prevent externalities generated by data centers, such as rising rates and increased emissions, from being shifted onto the community and residents. Loudoun County also represents that data center development is a uniquely local paradigm. The significance of resources constrained by data centers is defined by the resources within the local environment.

Some analysts predict that the current data center build is speculative and fueled by an AI economic bubble. Speculative requests may result in overbuilding. Because there is no consensus on data center utilization rates and a need for redundant capacity remains, the construction frenzy in Loudoun County may suggest that our energy projections are bullish. Assuming overbuild, data centers may have future use, but the stranded costs associated with required infrastructure are of greatest concern. This shifts from a local to a regional issue, as ratepayers are not always localized.

2 Introduction: Context Setting

2.1 The Rise of Data Centers

We are amidst a new technological epoch. The current rise of artificial intelligence (which can be considered a catch-all term encompassing machine learning, deep learning, generative, and agentic artificial intelligence) and our increasing reliance on data storage and processing in cloud environments have led to a boom in data center utilization. Data centers are traditionally a type of physical infrastructure that powers the building, processing, and delivery of software. They have increasingly become involved in cloud-based data storage and AI training and functionality because of new, powerful graphics processing unit (GPU) chips (Jonker and Gomstyn 2025; Susnjara and Smalley 2024). Initially, data centers were owned and operated by companies that ran their own technology stack on these servers. This has transitioned to managed facilities, such as colocation data centers.

Initially, this thesis intended to focus on a smaller number of dominant players–specifically hyperscale data centers, a loosely defined term that roughly translates to an architecture with significant server capacity, and thus a large built area with a heavy energy load (Powell and Smalley 2024). Hyperscale data centers are significant because they house servers dedicated to powering proprietary software or retail cloud services. Thus, it may be easier to analyze their individual contribution to externalities. These hyperscale data centers may be clearly identified as "resource-consumption culprits" because they are not co-managed (where multiple company servers are housed in the same space). Co-managed data centers function as service providers, meaning they provide the real estate, servers, and power, but do not run their technology stack on servers (unlike a hyperscale facility). Rather, their tenants determine server workloads and power consumption; thus, they can be effectively examined as potential contributors to the spike in energy demand. The International Data Corporation (IDC) definition of a hyperscale data center: greater than 5,000 servers, 10,000 square feet, and at least 100 megawatts (VIAVI Solut., n.d.). Due to the size and continuity of these operations, these data centers are energy-intensive.

Thus, redundancy in power is necessary to prevent catastrophe if one power source fails because the internet and software functionality require continuity (Powell and Smalley 2024), incentivizing data centers to prioritize a cheap, reliable power source and land. Many of these traditional hyperscale data centers are operated and owned by "Big Tech" corporations, which are large companies offering cloud services such as Amazon Web Services, Microsoft, and Google (Powell and Smalley 2024).

Unfortunately, due to data limitations on these centers and privacy restrictions, it is currently not possible to attribute individual consumption data to existing hyperscale data centers. Thus, the scope of this thesis shifted from focusing on developing quantitative outcomes to understanding the impact of the hyperscale market on Loudoun County to a pure case study of the local impacts and response of all data centers in Loudoun County, Virginia. Loudoun County's unique primacy makes it an optimal location for analyzing the effects of resource utilization, community responses, and policies elicited by data centers.

2.1.1 What is a data center?

Data has a new home: we call this the "cloud". But this term obscures a very real physical infrastructure, data centers. In their book, "Cloud Data Centers and Cost Modeling: A Complete Guide to Planning, Designing and Building a Cloud Data Center", Wu, Caesar, and Rajkumar Buyya (2015), a data center "is a place [that] can accommodate many computing resources that collect, store, share, manage, and distribute a large volume of data" (155) (Wu and Buyya 2015). The key terminology for understanding the essential functionality of a data center is data (data processing and storage). Data centers are a strange amalgam of technology and real estate. However, I have observed narratives, especially among investors and regulators, that blur the line between technology and public infrastructure. For the scope of this thesis, they will be viewed as a public-grade utility (they provide services so essential that there is a strong argument for regulation) that consumes public-grade utility levels of resources. To understand the significance of a data center, one must bridge the gap between the "cloud" and data centers because data centers are the physical manifestation of the cloud. However, data centers are dynamic, consisting, "of all necessary data center facility elements (space, power, and cooling) and IT infrastructure elements (server, storage, and network) based on business requirements" (155) (Wu and Buyya 2015).

2.1.2 Data center types

The 2024 United States Data Center Energy Usage report segments data centers into Enterprise (branch and remote offices to power internal tools), Internal (internal enterprise functions), Commercial Edge (edge locations for customer and business operations), Teleco (small rooms throughout the telecom network), SMB (internal to small and medium businesses), Colocation (retail and wholesale leasing), and Hyperscale (Companies that deploy internet and platform services at large scale). The latter two are of most significance. Hyperscale data centers are considered purpose-built facilities for major technology companies[2], colloquially referred to as "hyperscalers". On the other hand, colocation data centers are wholesale retailers that provide multiple tenants with power, cooling, and security (Shehabi et al. 2024; Sarte et al. 2024).

Data centers were traditionally enterprise facilities, on-premises, and deeply tied to the telecommunications industry. However, due to the proliferation of cloud services, GPUs (owing to their parallel processing capabilities that enhance artificial intelligence), and the cost efficiency of renting cloud storage or server space, colocation and hyperscale data centers are on the rise (Shehabi et al. 2024). Regarding the total number of servers in the United States data centers, the percentage has shifted from primarily internal to a majority of colocation and hyperscale data centers.

2.1.3 Data center components

Data centers have undergone rapid changes, not just in server advancements, but also in labor. Due to rapid automation, the total number of employees per facility has decreased by 50% since 2015 to an average of 10 per facility, according to figures from the United States Bureau of Labor Statistics. In their methodology, they used NAICS codes that represent data processing and computer storage facilities. This classification is broad, and current estimates of data centers in the United States, at least of large server retailers, are around 5,000 to 6,000. Larger hyperscale facilities are likely closer to 20 to 30 employees due to sheer management requirements. The 2024 Virginia Joint Legislative Audit and Review Commission (JLARC) Report on Data Centers in Virginia found that "a typical 250,000-square-foot data center may have approximately 50 full-time workers (one employee per 5,000 square feet versus one employee per 650 square feet for some distribution [traditional warehouse labor sites] centers)" (Sarte et al. 2024). Ultimately, the general trend that quotidian operations at these facilities require less manpower than in previous years remains true.

[2] They are typically owned and operated by a hyperscaler technology company, but are sometimes leased from third-party entities.

	Totals			Year-over-Year Change		
	Establishments	Employment	Employment/DC	Establishments	Employment	Employment/DC
2015	17,796	362,467	20.4	-	-	-
2016	19,486	366,656	18.8	1,690	4,189	(1.6)
2017	21,240	383,740	18.1	1,754	17,084	(0.7)
2018	23,694	407,639	17.2	2,454	23,899	(0.9)
2019	26,390	418,982	15.9	2,696	11,343	(1.3)
2020	30,108	435,144	14.5	3,718	16,162	(1.4)
2021	37,157	463,894	12.5	7,049	28,750	(2.0)
2022	46,690	545,668	11.7	9,533	81,774	(0.8)
2023	52,766	565,842	10.7	6,076	20,174	(1.0)
2024	55,256	562,789	10.2	2,490	(3,053)	(0.5)

Figure 1: Employment figures from the Quarterly Census of Employment & Wages, NAICS codes 51820 and 541513, image sourced from the Ohio River Valley Institute (O'Leary 2025)

Data center employees primarily consist of on-site maintenance workers, including electrical engineers, network staff, and various technicians, as well as security personnel tasked with protecting the highly secure data center. Most value creation from data center development occurs during the construction phase, as elucidated in the next section.

A data center's physical layout can be separated into three main components: the IT infrastructure, the cooling systems, and the power infrastructure (Sarte et al. 2024) (Shehabi et al. 2024). The IT essentially comprises the network fiber cables and the server racks. Cooling systems vary, as the industry has shifted from air-chilling to closed-loop water-cooling systems, and typically contain specific cooling systems for each rack level. There are two common types of coolers: water chillers that use evaporation (which does not rely on intensive electricity use) and IT liquid cooling that goes directly to the chip (which does not rely on water as much).

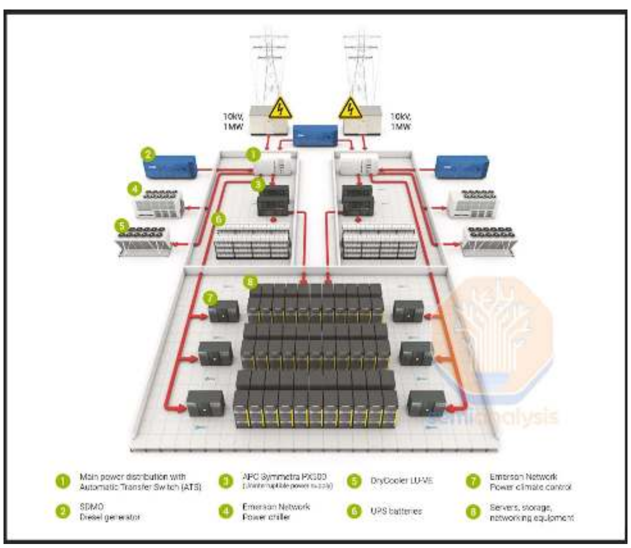


Figure 2: Data center electrical system layout (Jeremie Eliahou Ontiveros et al. 2024)

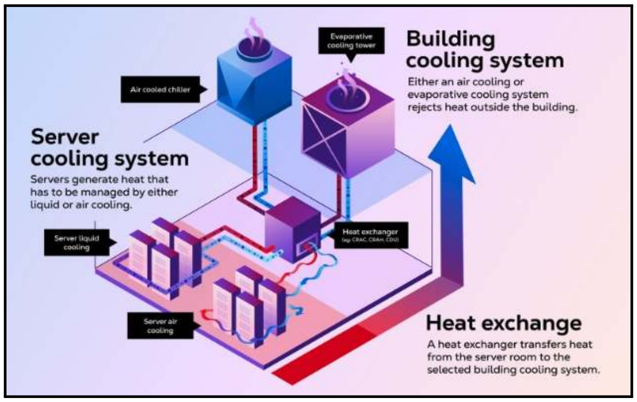


Figure 3: Data center cooling system diagram (Setmajer 2024)

Crucially, the data center power supply is fitted with a transformer to receive power from the grid, a UPS (Uninterrupted Power Supply) system fueled by batteries, and a system of backup generators for additional redundancy (Jeremie Eliahou Ontiveros et al. 2024). The main power distribution, complete with an Automatic Transfer Switch (ATS) that switches to backup generation during an outage, is supplied by the relevant electricity utility. The diesel generator and UPS batteries provide redundancy that prevents power outages.

2.1.4 Data center owners

Data centers are owned by a variety of players, namely "Big Tech" and wholesale data center retailers, but increasingly by private equity and real estate companies, and traditionally by telecommunication corporations and government entities. Major hyperscale technology providers include Google, Amazon Web Services, and Microsoft, while the leading colocation retailers are Digital Realty and Equinix (Global Data Center Market Report 2025). However, there are multiple players in the colocation space, including CyrusOne, Flexential, and Iron Mountain (not exhaustive) (Gartner, n.d.). Even with this litany of players, the market is considered relatively consolidated at the top level. Increasingly, asset managers and private equity companies are taking part ownership of these entities, and much of the capital expenditure is funded through leveraged debt from various banks.

Notably, data centers require significant initial investment, and both construction and operational costs are variable. Some recent influences on cost variability include tariffs increasing the cost of construction materials, new environmental regulations requiring power supply shifts, and evolving cloud and physical security risks necessitating upgrades.

2.1.5 Corporate hierarchy in the data center value chain

Data centers operate within a notably long value chain. Their recent economic success has led to an outburst of players competing to extract value throughout the life of a data center. Understanding the key players in the corporate hierarchy of a data center's life is essential for defining the parameters for data center regulation and identifying the roots of data center externalities.

Data centers are extraordinarily capital-intensive, relying on leveraged debt and private credit from asset managers and private equity, including major players such as EQT and Blackstone (Geiger 2026). Regarding data center operations and ownership, the three major hyperscaler players are Amazon Web Services, Google, and Microsoft, and other colocation providers such as Digital Realty and Equinix hold a major stake in the industry.

The initial construction of a data center engages with real estate companies to select sites, construction contractors to build the project, and consultants and surveyors to ensure compliance with relevant codes (KPMG 2024; Sarte et al. 2024). Furthermore, there are a host of equipment manufacturers responsible for the technology inside a data center, including cooling, power, and chips (which includes its own chain of niche semiconductor designers and manufacturers). Data centers rely on critical networking infrastructure, namely on-site networking equipment and access to fiber-optic internet cables. For seamless operation, data centers rely on electrical utilities and water utilities to provide constant power and cooling. Increasingly, additional capacity to ensure redundancy has become a de facto requirement, meaning energy companies that supply anything from diesel generators to Distributed Energy Resources (DER) batteries to natural gas power plants are relevant.

2.1.6 What is driving data center growth?

The total number of facilities has increased by around 100% since 2021, according to data extrapolated from the U.S. International Trade Commission's "Recent Trends in U.S. Services: 2022 Annual Report." The U.S. facility count rose approximately 2,750 in 2021 to over 5,000 operational data centers as of 2026. The U.S. market is not alone in this growth, as "from 2010 to 2020, the volume of data that the world generated and replicated increased from 2 zettabytes (ZB) to 64.2 ZB." However, the U.S. dominates global hyperscale markets, with 54% of market share according to Synergy Energy Group, and has effectively doubled its total hyperscale facility count to 1,136. Data center markets in the U.S. are consolidating, with big tech hyperscalers and major colocation companies driving the increase in facility count.

That being said, one of the best ways to quantify growth is to compare existing energy capacity with projected capacity. Recent reporting from S&P Global indicates that the proliferation of data centers across the US will require 22% more grid power by the end of 2025, as compared to 2024, and three times as much power in 2030. 451 Research projects that in 2026, US data center demand will reach 75.8 GW for IT equipment, cooling, lighting, and other uses, scaling to 108 GW in 2028 and 134.4 GW in 2030. Notably, these projections exclude enterprise-owned data centers outside of hyperscale facilities.

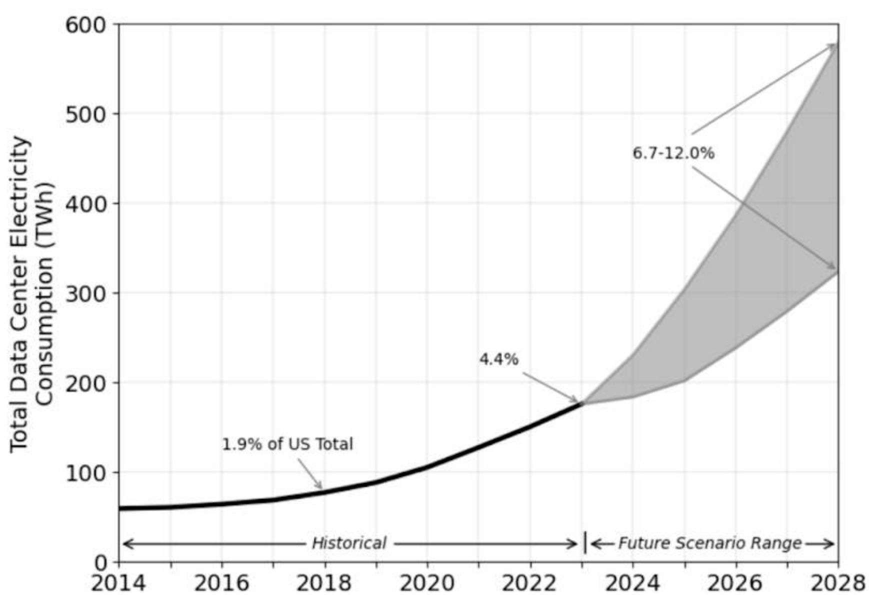


Figure 4: Total data center electricity usage from 2014 to 2028 (Shehabi et al. 2024)

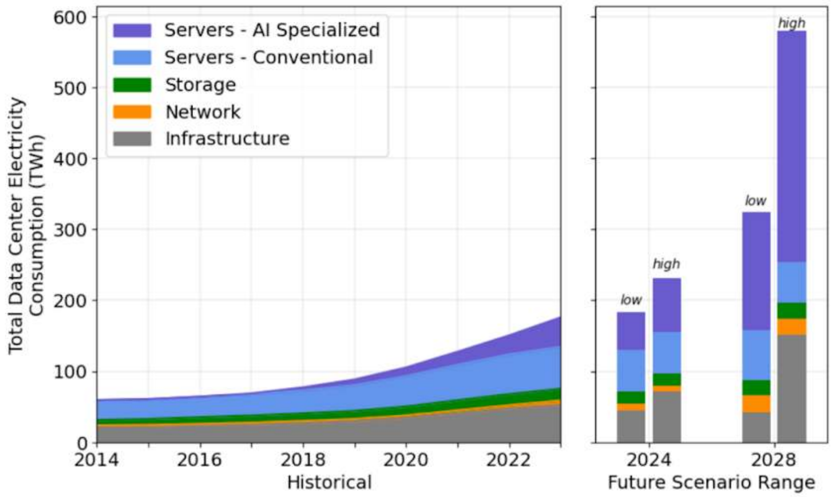


Figure 5: Total data center energy use by equipment type (Shehabi et al. 2024)

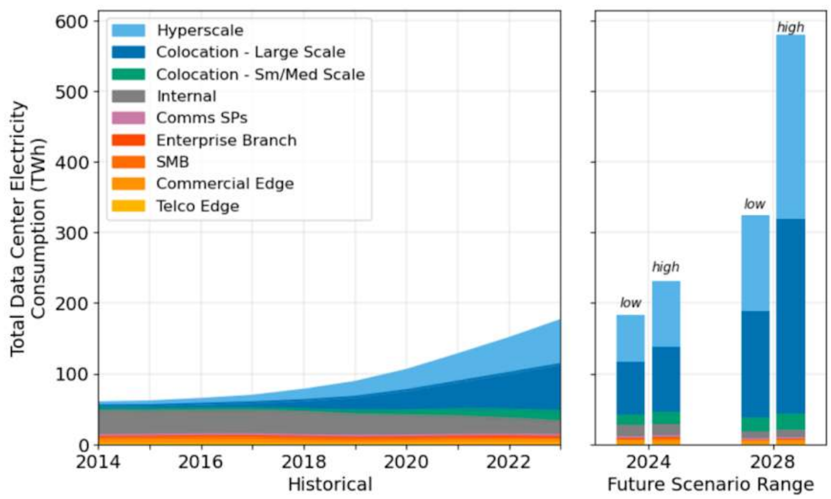


Figure 6: Total data center energy use by data center type (Shehabi et al. 2024)

Although demand is growing globally and across server types according to GPU shipment data, the majority of demand is driven by the U.S. market, with a projected 60 GW of capacity to be added by 2030. According to the 2024 DOE U.S. Data Center Energy Usage Report, consumption will be driven primarily by hyperscale facilities and AI-specialized servers. Demand is thus mainly driven by the "appetite for AI", and it is important to note that this demand is not realized. Rather, the infrastructure is being built to meet such projected demand.

3 Regulatory Mechanisms

3.1 How are data centers regulated?

According to Fiorino in "The New Environmental Regulation", United States environmental regulatory methods often conformed to a "command-and-control model" or "rules-and-deterrence model" (6). However, the landscape has shifted from purely "tort" law to "reflexive" law, like "market incentives, information disclosure, and management systems" with more dynamic "social-political governance" (19-20). Understanding how environmental law functions in the United States is fundamental to the discussion of regulating data centers from a political ecology and political economy framework. In "The Making of Environmental Law", Lazarus points out that environmental law is convoluted and hindered by a "fragmentation of authority" at the federal level, which is paralleled throughout the hierarchy (Lazarus 2004). Furthermore, federalism and decentralization principles engender additional legal complexity within the data center regulatory landscape. Thus, Loudoun County, Virginia, retains its own unique set of rules that data centers must follow. For instance, and this regulatory landscape will be elucidated later, Virginia is subject to United States EPA standards like the NAAQS (National Ambient Air Quality Standards), but provides its own state emission regulations under the Virginia DEQ (Department of Environmental Quality), and through state legislation, like the Clean Economy Act (2020). Loudoun County has its own Board of Supervisors, which governs local issues through its zoning legislation, but environmentally, it is subject to the Virginia DEQ's standards.

According to a Congressional Research Service report, the U.S. Department of Energy (DOE) "has published guidance on how to optimize energy use in data centers used by the federal government. [But,] currently there are no legally binding energy standards that apply explicitly to operation of data centers in the private sector" (Offutt and Zhu 2025). Legally, "Section 453(a)(1) of the Energy Independence and Security Act of 2007 (P.L. 110-140) defines a data center as "any facility that primarily contains electronic equipment used to process, store, and transmit digital information, which may be (A) a free-standing structure; or (B) a facility within a larger structure, that uses environmental control equipment to maintain the proper conditions for the operation of electronic equipment."

This ambiguity and fragmentation have enabled significant experimentation at the local policy level, placing Loudoun County in a unique position as a "trailblazer" of sorts in its field. Due to the novelty of data centers, policy is relatively nascent. It primarily exists at the local level through zoning and tax laws that treat data centers as real estate entities. However, this is shifting, as there is a growing movement to classify data centers as infrastructure assets. Consequently, data centers fall under a quasi-command-and-control regulatory system in which they must abide by standards set by the local government. However, more libertarian ideas of industry efficiency, in which data centers dynamically interact with the grid in BYOG (Bring Your Own Generation), are gaining traction. Thus, there is no linear path or panacea for data center regulation, and many existing precedents are likely subject to change.

In analyses of global data center regulation, Loudoun County was previously classified as taking a "no policy change" stance[3] (Soares et al. 2024). This is a stark contrast to the disruptive and reformist regulations the article delineates in Germany, Ireland, and Singapore. In Singapore, the government temporarily halted all new data center permits, creating a de facto data center moratorium in 2019. Ireland's moratorium was more overt. Implemented by the Commission for Regulation of Utilities (CRU) and EirGrid between 2021 and 2025, it effectively banned new data center grid connections. Frankfurt, Germany, a data center hotspot, adjusted the commercial zoning rules of data centers in 2022, prioritizing energy efficiency and the reuse of heat waste. Treating data centers as resource-competing infrastructure, as some of these countries have, is starkly different from previous Loudoun County policies.

3.2 Defining the parameters of the thesis: how are data centers being evaluated?

Data centers are a unique infrastructure because most of their impacts do not come directly from their facilities, but rather enable negative externalities that impact bystander parties. In this thesis, I will explore Loudoun County's data centers, regardless of type, in terms of their impact on local affordability, grid resilience, water supply, land equity, and ecological and emissions impacts. I will categorize the negative externalities into three main boxes: tightening of constrained resources, degradation of the natural environment, and residential perspectives regarding a decline in quality of life. In this thesis, I will use existing benchmarks, such as grid reliability metrics or emission thresholds, to provide more objective analysis of the impact to qualify the more implied and anecdotal discussions.

The thesis will flow as follows: I will introduce the Loudoun County case study, providing historical context and a description of the regulatory landscape (of data centers and their resources). Then, I will present the impacts on energy and water systems. I conducted a spatial analysis using ArcGIS Online of the

[3] However, the Loudoun County TLUC (Transport and Land Use Committee) began reviewing "by-right" development at the time of the article's publication.

relationship between Loudoun County data centers and energy infrastructure. I supplemented the robust spatial analysis with interviews with Loudoun County residents to explore personal relationships with data centers, and preliminary emissions calculations, primarily to convey the variability arising from limited data. After the case study, I will embark on my analysis of externalities and tensions in Loudoun County, where I will discuss the economic and environmental impacts residents feel from data centers, discuss the response dynamics between community and industry, and analyze the apparent policy shifts. I will then highlight the local Paradigm-like nature of data center impact variability and how this can be applied to the rest of the United States. Finally, I will discuss how communities can move forward with data centers, which are here to stay, but while mitigating the negative externalities.

4 A Case Study on Loudoun County

4.1 Historical Context

Office Park Zoning, Latency, and How it Came to Be a Data Center Hub

Loudoun County has a storied history, reaching back to 1649, when the British Empire absorbed it as part of the Northern Neck of Virginia Proprietary granted to King Charles II (Loudoun Cty. VA - Off. Website, n.d.). Exemplar of the colonial United States, Loudoun was home to many European pilgrims, Germans, and Irish immigrants, featured protests against the Colonial-era Stamp Act, and harbored soldiers who fought in the Revolutionary War. Northern Virginia's political leanings are aptly delineated by its Civil War tensions: the population was evenly split on the issue of secession. More recently, after decades of agricultural tradition, Loudoun County developed into a suburban home to businesspeople and politicians. This coincided with the construction of the local Dulles International Airport, as the county served as a commuter region for the rapidly expanding Washington, D.C., area.

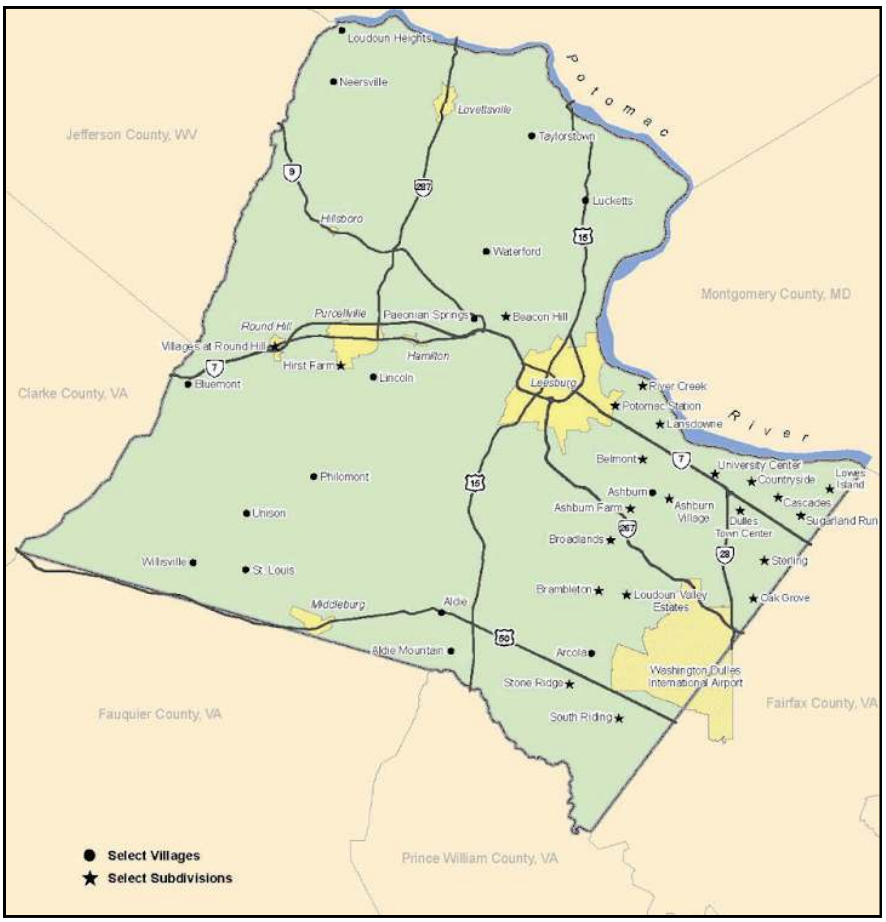


Figure 7: Map of Loudoun County ("Loudoun County Adopted Fiscal Plan" 2010)

Viewing data center development as an issue of environmental justice paints Loudoun as an anomalous hotbed. The county has most recently posted the highest median household income in the United States, at \$181,765 (2024), across an enormous population of 443,380 (July 1, 2024) (US Census Bur., n.d.). Primarily a white-dominated county, it has recently become more diverse with increasing Asian and Hispanic populations, and most residents work in the defense and technology sectors. Prominent census-recognized areas and incorporated towns, particularly regarding data center development, include Ashburn, Leesburg, Sterling, and Purcellville (the latter a lesser data center hub).

Historically, Loudoun County has become the prime place for data center development. In 1992, as a result of federal projects like ARPANET, Metropolitan Fiber Systems established the foundational IXP (Internet

Exchange Point): the MAE-East NAP (Metropolitan Area Exchange) (Network Access Point) in 8100 Boone Boulevard in Tysons Corner, Fairfax County, Virginia, and later moved to 1919 Gallows Road, Vienna, Virginia ("The Dawn of Data — Virginia Economic Development Partnership," n.d.; Swinhoe 2026). It moved to Loudoun County at the turn of the century, as AOL established its headquarters in Ashburn. MAE-East was the beginning of a common nomenclature for server regions, but its nascency made it a national internet hub. Created to empower the many defense contractors in Washington, D.C., a series of underground fiber-optic cables was built throughout Northern Virginia, including Loudoun County. This gave the region some of the lowest latency rates in the U.S., and thus a primary advantage for data center infrastructure. Capitalizing on this potential economic interest, as part of the 2000 Revised Zoning Ordinance, Loudoun County rezoned data center build-to-suit as commercial office parks, thereby granting data centers the "by right" authority to build wherever an office park could be built (Pampaloni 2025a). Thus, from 2009 to 2018, Loudoun County marketed itself to data center developers using these advantages. Following 2018, data center construction skyrocketed, and the county raked in billions of dollars in data center equipment and property taxes, enabling it to reduce income taxes for its residents (Turner 2025). However, issues began to arise. In 2022, PJM Interconnection, the regional transmission operator, recognized that power demand was set to increase significantly, labeling the Dominion Energy zone, which includes Loudoun County and the surrounding "Data Center Alley" Fairfax and Prince William Counties, as power-constrained. Arguably, Loudoun County illustrates the potential impacts on many Midwestern and Southern states. In fact, they have reacted to such impacts. On March 18, 2025, data centers were rezoned under a Special Exception (SPEX) classification, requiring Board of Supervisors approval for construction (Pampaloni 2025a).

The exemplar case study

Loudoun County's data center development is a unique story. The wealthiest county in the United States, laden with a rich history of traditional American ideals and inhabited by enfranchised suburbanites, Loudoun did not lack a voice in development, but rather, became a product of its technological environment that lay fertile ground for data center development alongside a government that sowed the seeds of regulatory flexibility. Loudoun, unlike the rest of the United States, experienced data center development and the accompanying whirlwinds on an expedited timeline. Thus, it positions itself as an excellent case to study data center effects on a local region, effective for analysis that can inform takeaways for the looming, or arguably currently penetrating, movement of data centers to develop across the United States (primarily in the Midwest and South regions, as Northern Virginia is now considered relatively saturated).

Current state of data centers in Loudoun County

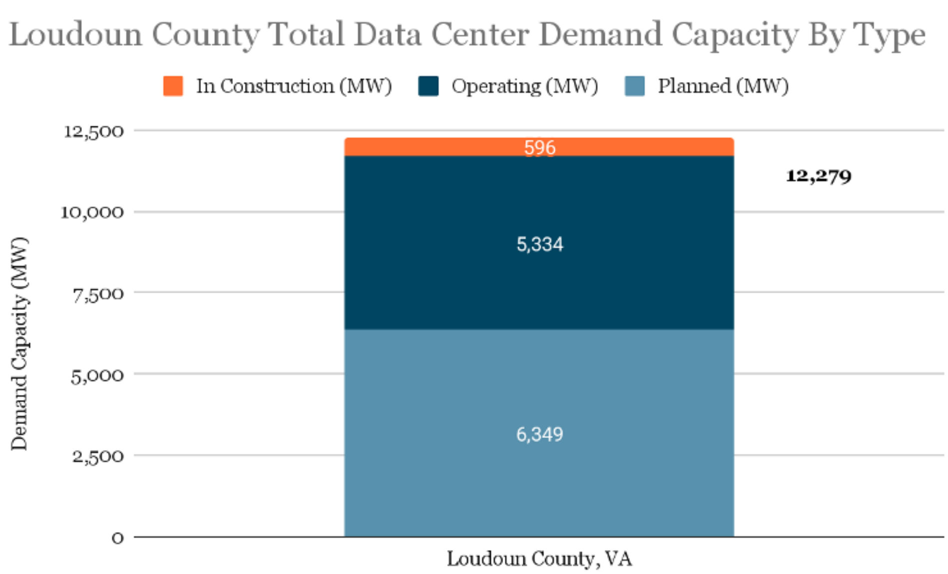


Figure 8: Loudoun County energy demand by data center stage

As of 2025, there were 199 operational data centers in Loudoun County, with 117 data centers in the development pipeline. Development can range from construction to planned. Notably, the current energy consumption of data centers in Loudoun County exceeds 5 GW, meaning pipeline data centers represent 7 GW of demand capacity (National Laboratory of the Rockies, n.d.). Between 2009 and 2024, Loudoun County oversaw the construction of 30 million square feet of data centers, with significant increases from 2018 through to the present.

To discern the bottlenecks and potential impacts of data centers, we must analyze the political economy of data centers in Loudoun County. This thesis will elucidate the trifurcated structure of resource regulations below.

4.2 Regulatory Landscape

Data centers in Loudoun County are subject to the regulatory authority of multiple players due to the multi-resource requirements of data centers and the lack of a centralized authority.

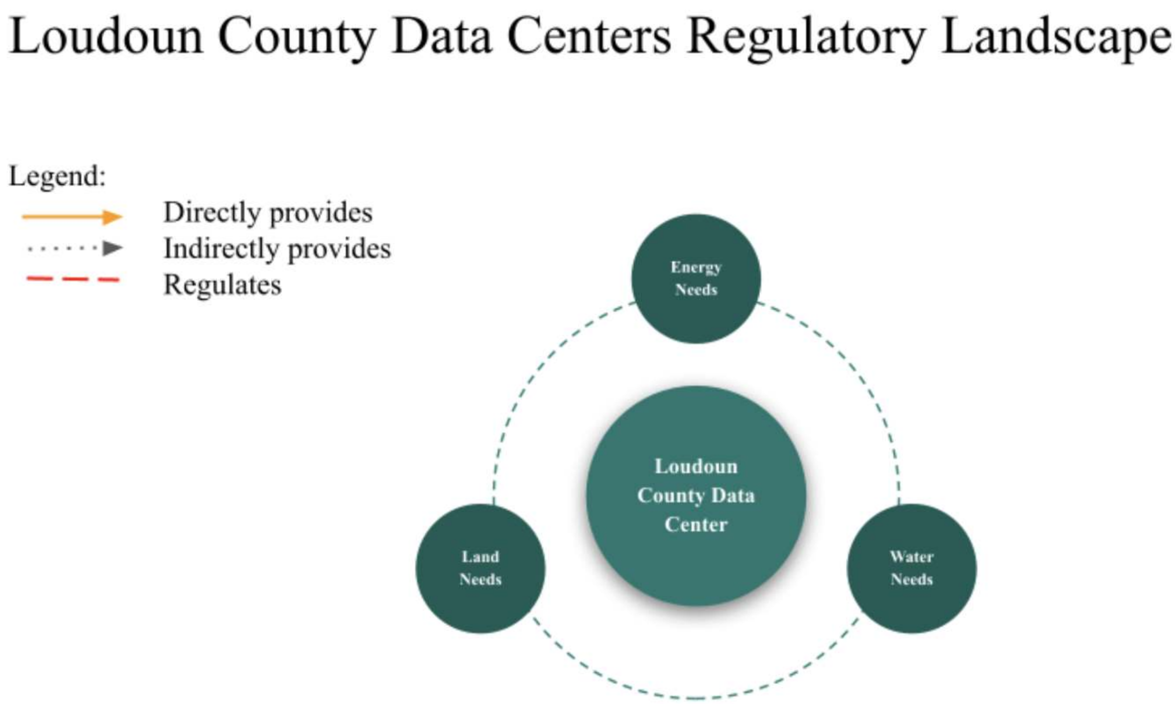
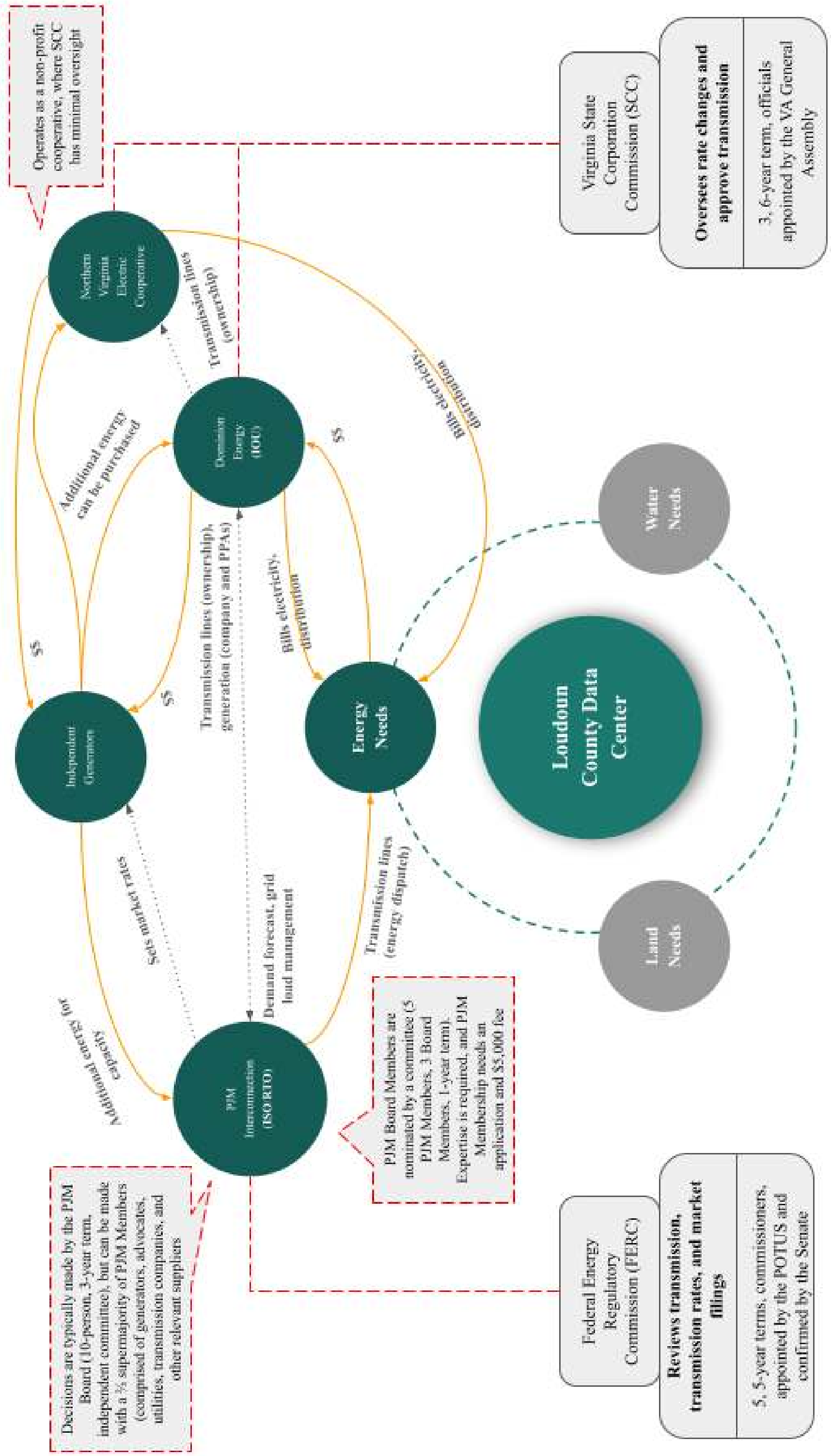


Figure 9: Regulatory landscape diagram

4.2.1 Energy Needs



Starting with the dominant focus, energy. The direct energy biller and distributor in Loudoun County is

Dominion Energy, an investor-owned utility (IOU) that owns transmission lines and some generation. Generation is supplied via Dominion Energy and Power Purchase Agreements (PPAs) (VIRGINIA ELECTRIC AND POWER COMPANY 2024 Integrated Resource Plan 2024). Outside of Dominion, in northern Loudoun County, energy is delivered by the Northern Virginia Electric Cooperative (NOVEC), which operates as a non-profit cooperative (NOVEC, n.d.). Its rates are regulated by the Virginia SCC (State Corporation Commission) but are set by its 7 selected board members from the region. NOVEC also handles transmission line ownership and bills for electricity distribution, but the SCC has minimal oversight of NOVEC.

Significantly, the status quo of IOUs like Dominion Energy is to add customers to the grid. Dominion is incentivized to utilize its existing transmission infrastructure to the fullest capacity, often straining it, and to build additional infrastructure if needed, as it is legally allowed to earn a 9%-10% profit margin for investors; it can cover any additional infrastructure costs by raising rates for residential and commercial ratepayers (Pampaloni 2025b).

PJM Interconnection, the Regional Transmission Operator or Independent System Operator (ISO/RTO) for the county, dispatches electricity using Dominion's transmission lines. As an independent system/regional transmission organization, PJM reviews transmission, transmission rates, and market filings ("PJM — Federal Energy Regulatory Commission," n.d.) ("An Introductory Guide for Participation in PJM Processes — Federal Energy Regulatory Commission," n.d.). PJM is a nonprofit entity, meaning it does not seek to make revenue on energy market rates. In addition to responsibility for energy dispatch from transmission lines, PJM forecasts demand and manages grid load, which is pertinent to Data Center Alley. PJM sets electricity market floors and ceilings, and this energy can be purchased through its yearly auction system. As for energy capacity, this is primarily supplied by independent generators. These generators are entities that provide energy capacity and sell at market rates set by PJM. Market decisions are made by the PJM Board, a 10-person (9 voting members, the PJM CEO is the 10th member) independent committee, each serving a 3-year term ("An Introductory Guide for Participation in PJM Processes — Federal Energy Regulatory Commission," n.d.; "PJM Board Nominations Fact Sheet" 2025). Decisions are also made with a $\frac{2}{3}$ supermajority of PJM Members, composed of generators, advocates, utilities, transmission companies, and other relevant suppliers. PJM Board Members are nominated by a nominating committee (5 PJM Members, 3 Board Members, 1-year term). Participating as a PJM Member or Board member requires sufficient expertise, and PJM Membership requires an application and a \$5,000 fee. The diagram below illustrates the flow of energy players with respect to billing.

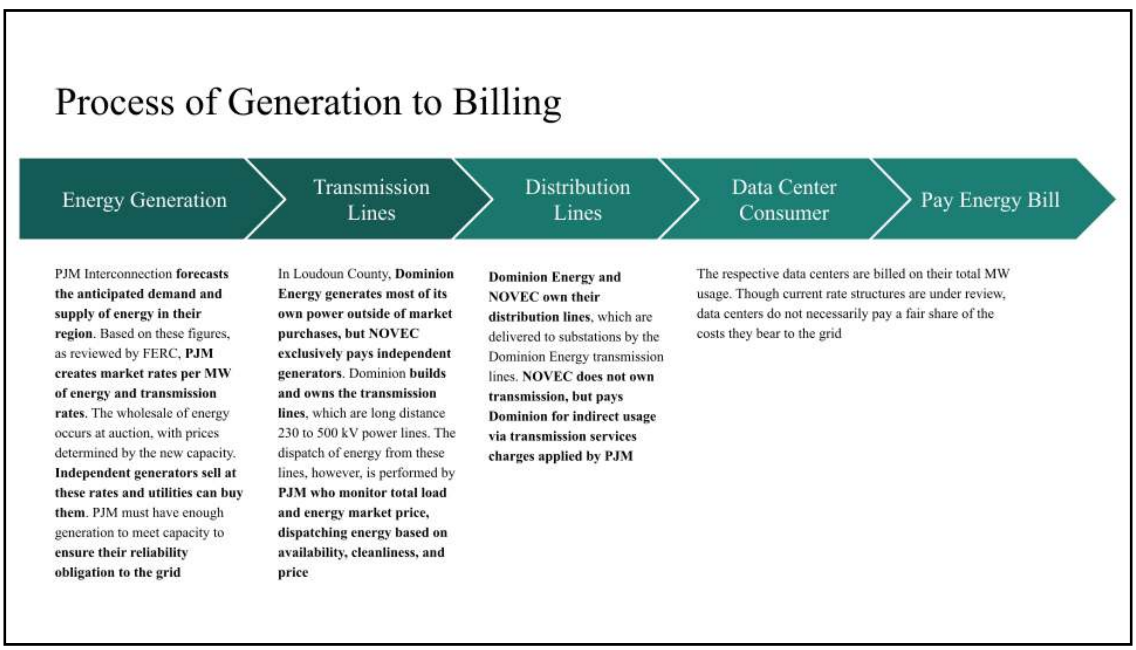


Figure 10: Diagram illustrating the process of energy generation to billing the customer

The regulatory body that oversees PJM is the Federal Energy Regulatory Commission (FERC), which reviews transmission, transmission rates, and market filings ("The Federal Energy Regulatory Commission (FERC)," n.d.). FERC consists of 5 commissioners, serving 5-year terms, appointed by the President of the United States and confirmed by the Senate, meaning PJM decisions can be influenced by the executive branch.

Locally, Dominion Energy, which operates as a Loudoun County subsidiary called the Virginia Power and Electric Company, is regulated by the Virginia State Corporation Commission (SCC), which oversees rate changes and approves transmission for Dominion Energy (Virginia.Gov, n.d.). The SCC has 3 officials, who are appointed by the Virginia General Assembly and serve 6-year terms.

The diagram on the next page further illustrates the energy-to-data center chain.

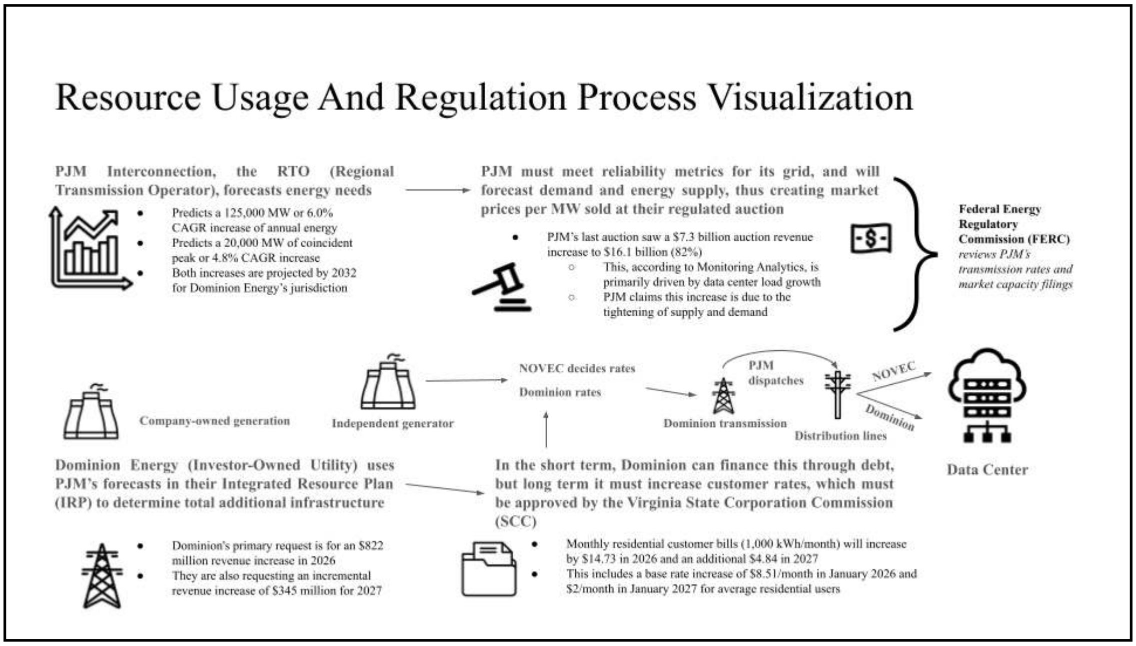


Figure 11: Diagram illustrating the process of energy generation to delivery, along with the regulatory process

4.2.2 Water Needs

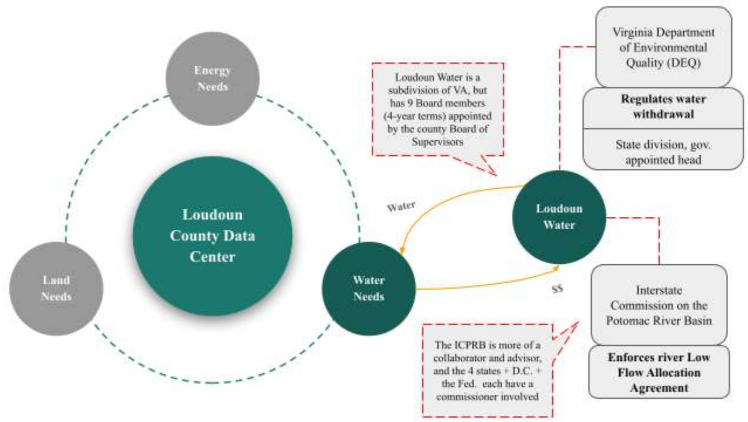


Figure 12: Regulatory landscape of water

Water is a much murkier environment, where players use subterfuge to avoid releasing individual data. There is also little precedent for restrictions on data center water consumption. In Loudoun County, water is regulated by Loudoun Water, a subdivision of Virginia with 9 Board members (4-year terms) appointed by the county Board of Supervisors (DRINKING WATER QUALITY 2024 ANNUAL REPORT, n.d.). They manage water resources and associated billing. They are directly overseen by the Virginia Department of Environmental Quality (DEQ), a state division with a government-appointed head that regulates water withdrawal.

Regarding water resources, Loudoun Water states that county customers receive their drinking water from the shared Potomac River and local Goose Creek ("Source Water Protection — Loudounwater.Org," n.d.). The Potomac River is augmented by reservoirs in Maryland, Virginia, and West Virginia under a shared supply agreement with neighboring providers, the Interstate Commission on the Potomac River Basin [4] (ICPRB), which enforces the river's Low Flow Allocation Agreement. Water is also supplied via reclaimed water systems. "Most of the wastewater Loudoun Water collects from customers (13.8 million gallons per day) is treated by DC Water at their Blue Plains Advanced Wastewater Treatment Plant (Blue Plains) through an agreement held between the authorities. Blue Plains has the capacity to treat up to 384 million gallons of sewage a day. To accommodate future growth in our service area and reduce the loading sent to Blue Plains, Loudoun Water constructed the Broad Run Water Reclamation Facility (BRWRF) in Ashburn. The BRWRF was first opened in 2008 and currently treats about 4 million gallons per day (MGD) of sewage with a total current capacity of 11 MGD. Of the 4 MGD that is currently treated, about 1 MGD is distributed back to Loudoun Water customers as reclaimed water" (Loudoun Water 2026).

Despite the marketed incentive for data centers to use reclaimed water, potable water usage has skyrocketed. Currently, Data Center (Water Cooled) - Process Meter has a maximum usage rate of 1 GPD/SF of \$15.62 to connect and \$4.42 per 1,000 gallons thereafter (or \$7.59 if exceeding reserved capacity) ("Rates, Fees, Charges and Penalties — Loudounwater.Org," n.d.). I will elucidate more on the significance of potable water in the "Water" discussion under the Data Center Impacts section.

[4] The ICPRB acts as a collaborator and advisor with the 4 aforementioned states, D.C., and the Federal government, with each stakeholder having a commissioner involved.

4.2.3 Land Needs

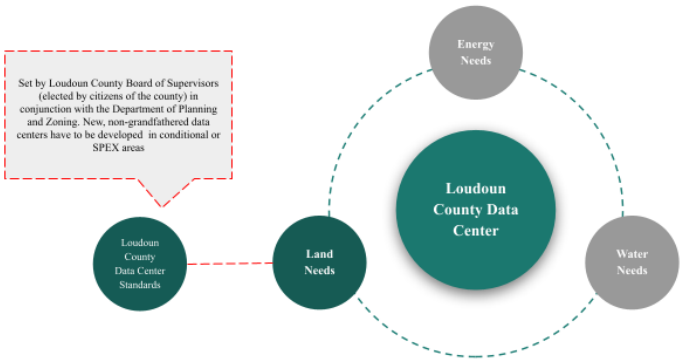


Figure 13: Regulatory landscape of land use

Land development and usage standards are set by the Loudoun County Board of Supervisors (essentially the county council elected by residents of the county) in conjunction with the Loudoun County Department of Planning and Zoning. As previously stated, new, non-grandfathered data centers must be developed in conditional or SPEX (Special Exception) areas. Of all data center applications submitted before February 12th, 2025, but not yet approved, 41 proposals were grandfathered in (Pampaloni 2026b). On July 2, 2024, the Board approved an Intent to Amend the Zoning Ordinance and the Revised Project Plan for Data Center Standards and Locations (CPAM-2024-0001 and ZOAM-2024-0001), which separated the project into two phases (Loudoun County Government, n.d.; Abdul Jaffari, Planning and Zoning and Daniel Galindo, Planning and Zoning 2025). Phase 1, approved on March 18, 2025, focused on proposed map and text amendments to the Loudoun County 2019 Comprehensive Plan, and amendments to the Loudoun County Zoning Ordinance, to designate data centers as a conditional or Special Exception (SPEX) use in areas where the uses were previously allowed by-right. Phase 2, now underway, will focus on new policy guidance and use-specific zoning standards for data centers and utility substations.

Most data centers were developed when data centers were under the "by-right" jurisdiction, meaning that if the development application met the standards in the previous Zoning Ordinance, it was only subject to staff-level review. In some cases, data centers would require additional legislative action, moving to the Planning Commission and Board of Supervisors, which would hold public hearings.

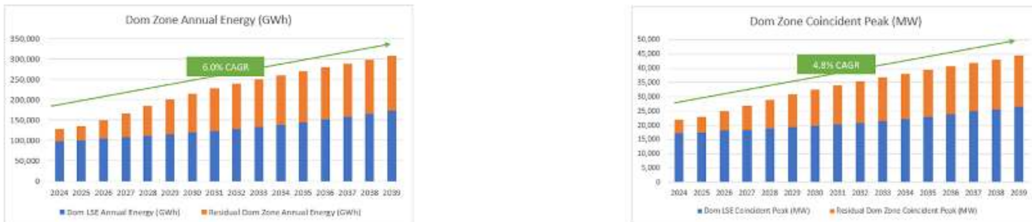
5 Data Center Impacts

5.1 Resource Constraints

5.1.1 Energy

As evident in the decision to represent data center development in gigawatts, energy load is recognized as a critical data center resource and impact. Dominion Energy uses PJM Interconnection's forecasts, which its market monitor, Marketing Analytics, has criticized as uncertain. Based on Dominion Energy's IRP, the Northern Virginia Dominion Energy zone, DOM Zone, which includes Loudoun County, power demand is projected to reach 14.2 GW (or 11.59 GW by 2028, per Kimley-Horn), not including a massive AI-induced demand surge. The current regional available capacity is 9.3 GW (VIRGINIA ELECTRIC AND

POWER COMPANY 2024 Integrated Resource Plan 2024; Power Transmission Evaluation Due Diligence Report 2024). Planned additions of 6.3 GW by 2028 from PJM/Dominion are insufficient to meet predicted demand, especially for "Data Center Alley," and don't account for the AI increase. Looking at the PJM data below, both the total load and coincident peak, which lead to brownouts and blackouts, are increasing and expected to continue.



(a) Load Forecast Energy

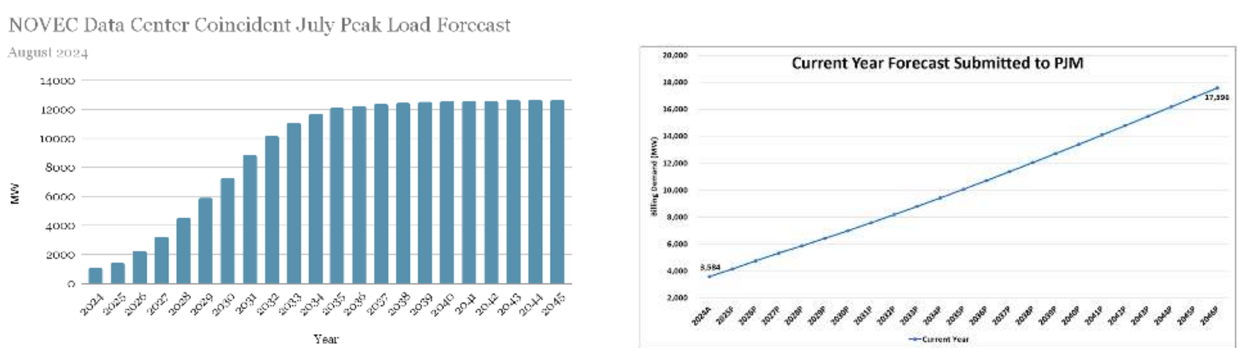
(b) Load Forecast Peak

Figure 14: PJM Load Forecasts
(VIRGINIA ELECTRIC AND POWER COMPANY 2024)

Between December 2024, when the 2024 IRP was published, and October 2025, the 2025 IRP update, the data center demand forecast increased by 7 GW (Virginia Electric and Power Company's 2025 Update to the 2024 Integrated Resource Plan 2025). This is a 17% increase in 10 months. At the same time, the total number of data center customer contracts has increased primarily across CLOAs (Construction Letter of Authorization) and SELOAs (Substation Engineering Letter of Authorization), of which CLOAs prevent Dominion Energy from incurring costs if the customer abandons the request.

Although much smaller than Dominion Energy, the Northern Virginia Electric Cooperative is the other energy provider in Loudoun County (2.5-2.7 million customers in Dominion Energy territory versus 180 thousand customers) (David Carnevali et al. 2025; Dominion Energy, n.d.). NOVEC still serves some data centers in western Loudoun County. According to PJM Interconnection, NOVEC anticipates data center summer peak loads will grow from 1,050 MW in 2024 to 5,900 MW in 2029 due to the construction and operations of over 100 data centers in the service territory ("NOVEC 2025 Large Load Adjustment Request" 2025). NOVEC believes many customers currently impacted by transmission constraints in Eastern Loudoun County will be able to access fully contracted capacity by the end of 2026.

Most projections have been underestimated. For instance, in January 2025, NOVEC received an additional roughly 3,000 MW of new data center inquiries, which are now at the LOA (Letter of Authorization) stage, and were not included in the 2024 forecast ("NOVEC 2025 Large Load Adjustment Request" 2025). This chart indicates metered demand, as capacity is expected to be 16,500 MW.



(a) NOVEC data center July peak load forecast from 2024

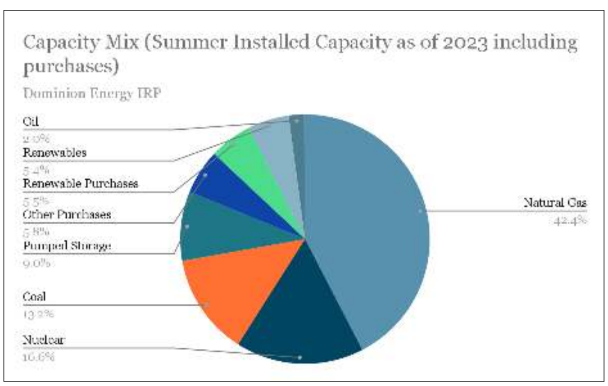
(b) NOVEC data center load forecast ("NOVEC 2025 Large Load Adjustment Request" 2025)

Figure 15: NOVEC Forecasts

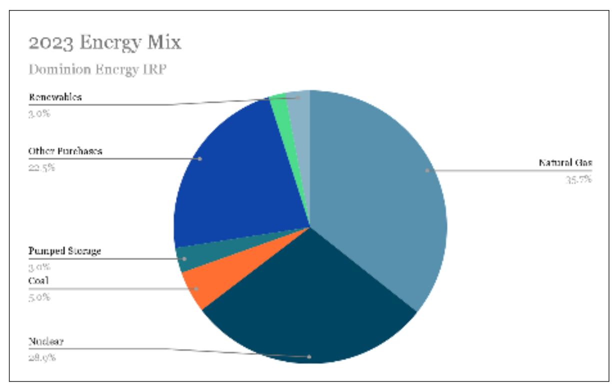
The primary concern regarding data center energy consumption is the high risk of community outages from load-loss events. A load loss event occurs when there is a sudden shift of load to the grid. Typically, if large-load data centers are disconnected, it causes an influx of high-frequency signals to transmission lines. These voltage irregularities can lead to brownouts and blackouts. In July 2024, Loudoun County experienced a 1,500 MW load loss event, exclusively from data center activity ("Incident Review Considering Simultaneous Voltage-Sensitive Load Reductions" 2025). The cause, a fire at an electrical substation, led the data centers to switch to their backup generators, leading to a 1.5 GW load disappearance and a critical voltage irregularity. Grid operators managed to avoid a local blackout. More recently, in February 2025, a 1,800 MW load-loss event was felt across Fairfax and Loudoun County (Henry C. Eickelberg, "Support for Further Examination of Undergrounding Alternatives, Grid Stability, and Compliance with Va. Code § 56-46.1").

PJM is also barely hitting reliability requirements. Looking at PJM's recent load growth history, trends are relatively flat except for expected increases during the summer months. In fact, peak load across the past 10 years before 2024 was approximately 0%. However, the 2024 forecast predicted significant load growth increases during the summer peak (the most grid-strained part of the year, primarily due to rampant air-conditioning use, with future projections accounting for extreme weather patterns due to climate change), with data centers increasing from 4% of share to 12% by 2030 and 16% by 2039 (Pampaloni 2025c) (PJM Resource Adequacy Planning Department 2025). Furthermore, PJM Interconnection, which does not exclusively represent Northern Virginia but does act as the Regional Transmission Operator (RTO) for 67 million people, the largest in the United States, is below its reliability metrics. PJM's planned reserve margin (PRM[5]) for their 2027/2028 auction is 14.8% (2027/2028 Base Residual Auction Report 2025). This is a 25% undershoot from the reserve margin target of 20%, and Loudoun County's concentration of data centers is undoubtedly the driving force.

Evidently, the bottleneck leading to grid unreliability is insufficient energy capacity. However, adding additional energy generation is not seamless. Generation depends on capacity factor, the ratio of actual electrical energy produced to the potential or nameplate energy production at continuous full power. For instance, nuclear is 92.3%, while solar is 23.4%, but achievable natural gas is 59.7% (Turner 2025). Current PJM capacity differs from Dominion Energy's mix because of PJM's independent role in energy dispatch, and most PPAs consist of some natural gas and an increasing mix of renewables (mainly solar) (VIRGINIA ELECTRIC AND POWER COMPANY 2024 Integrated Resource Plan 2024).



(a) Dominion Energy 2023 Capacity Mix



(b) Dominion Energy 2023 Energy Mix

Figure 16: Comparison of Dominion Energy Mixes

Loudoun County's primary concern is that additional utility infrastructure driven by intense energy demand will result in stranded costs to residents. Presently, the rise in infrastructure costs, primarily transmission in Dominion's case, is increasing Loudoun County ratepayers' bills. Notably, while energy rates are rising across the country, Loudoun County's rates are almost exclusively being driven by data center resource needs of the present and future. Recently, the Virginia SCC (State Corporation Commission) has

[5] PRM is a measure of electric supply adequacy by comparing peak demand to additional resource capacity. It is calculated as available capacity minus peak demand divided by peak demand and expressed as a percentage.

reviewed the 2025 Biennial Review of Dominion Energy under case file PUR-2025-00058 (*Application of Virginia Electric and Power Company, For a 2025 biennial review of the rates, terms and conditions for the provision of generation, distribution and transmission services pursuant to § 56-585.1 A of the Code of Virginia*, n.d.). Loudoun County is under a Dominion Energy subsidiary, the VEPC (Virginia Electric and Power Company), which manages most of the Ashburn and Sterling area that dominates Data Center Alley. In the review, Dominion stated its primary request was to increase revenue to $822 million in 2026 and an additional incremental increase of $345 million in 2027 (Heckt 2025). For a residential customer using 1,000 kilowatt-hours per month, this represents a monthly bill increase of $14.73 in 2026 and an additional increase of $4.84 in 2027. In January 2026, the base rate increased by $8.51, monthly, for the average residential user, and in January 2027, an additional $2 will be added monthly. The cost of natural gas is increasing, so the fuel rate was increased by $8.92, and subsequently by $2. These increases are due to approved transmission project, namely the Golden to Mars 500/230 kV Project, like the 500 kV and 230 kV Golden-Mars Lines, Lockridge 230 kV Loop, Sojourner 230 kV Loop, and in Loudoun County, and upcoming projects like Aspen to Golden 500 kV/230 kV lines and Wish Star to Mars 500 kV/230 kV high voltage electric transmission line and two new substations in the Brambleton/Dulles area (*Application of Virginia Electric and Power Company, For a 2025 biennial review of the rates, terms and conditions for the provision of generation, distribution and transmission services pursuant to § 56-585.1 A of the Code of Virginia*, n.d.).

To put demand into perspective, PJM's 2024/2025 auction, which includes 13 states with 67 million customers, saw a $7.3 billion auction revenue increase to $16.1 billion, an 82% year-over-year meteor. According to Monitoring Analytics, these trends are primarily driven by data center load growth. However, PJM claims this increase is due to tighter supply and demand. Notably, as Monitoring Analytics points out, the load forecast remains extremely uncertain, which is concerning to market rates and consumers footing the bill.

Building this transmission efficiently is quelled by an "infrastructure-time gap" where there is an apparent disconnect between the 7-to-10-year process (Blake Deeley 2024) needed to approve, permit, and complete the transmission line required by a data center slated to go online and the time it takes to construct and bring a data center online, which is estimated to be between 18 and 36 months. Regulation cannot keep pace with this data center demand, and the disparity, at least a 4-year difference, between data center development and utility construction is indicative of the difficulty.

In sum, current capacity is struggling to meet data center energy demands. Future projections of increased energy demand do not bode well for the reliability of the Loudoun County grid and residential energy affordability. The reason is twofold. First, infrastructure timelines are not commensurate with data center operational timelines. Second, individual large-load entities have never been responsible for such a high level of energy demand at the speed of data center interconnection requests.

5.1.2 Water

Separately, the water supply may become further constrained. Since 2019, potable water use in Northern Virginia has increased by 63%, and by 250% in Loudoun County (almost exclusively driven by data center needs) (Miguel Yañez-Barnuevo 2025). As of 2024, 900 million gallons of water were used among 200 operational data centers. In a white paper authored by Loudoun County Board of Supervisors Mike Turner, it is estimated that while data center totals quadrupled between 2019 and 2025, additional water capacity increased by a meager 25% across 20 years (Turner 2025). Significantly, the data center pipeline, from design to construction complete, can range from 18 months to 3 years. However, local water upgrades for treatment plants and greywater reuse facilities can take an additional 5 to 10 years (Heximer 2026).

The trend in potable water consumption is twofold. First, data centers are averse to recycled grey water due to the potential microbial buildup. This buildup is driven by exposure to something as ubiquitous as air, which would inhibit cooling systems and hinder data center operations. Thus, potable water is seen as a must-have.

Second, cooling systems are trending toward water cooling rather than air chilling, due to water's higher heat capacity. An estimated 80% of the water consumed by data centers evaporates, with the remaining 20% water flowing to wastewater facilities. However, current water systems in Loudoun County are restricted to a shared resource, the Potomac River, and a local body, Goose Creek. Currently, Loudoun Water diverts most wastewater from residential customers ($\tilde{1}$3.8 million gallons per day) to DC Water at their Blue Plains Advanced Wastewater Treatment Plant. However, Blue Plains only "has the capacity to treat up to 384 million gallons of sewage a day". Thus, Loudoun Water constructed the Broad Run Water Reclamation

Facility (BRWRF) in Ashburn, notably close to data center operations. This singular reclaimed water system, an infrastructure that takes multiple years to complete, is capped at 11 million gallons per day and returns 1 million gallons per day of recycled water to Loudoun County. However, each data center that uses water cooling (not every data center in Loudoun County) can use up to 100 thousand gallons of water per day.

Interestingly, water usage associated with data centers is not exclusively driven by cooling systems; much of the water usage increase is due to water used for power. In this way, water and energy intersect because power plants require water to generate the energy that powers these data centers. However, the location of these power plants presents its own issues. These issues may be burdened by the community relevant to the power plant, but not necessarily the community with the data center.

6 Spatial Relationship Analysis of Data Centers in Loudoun County

What resources are data centers draining from the community? Residents are uncertain about the effects of data centers on local infrastructure. Furthermore, they lack evidence to validate their concerns, as much of the evidence is proprietary. Thus, visualizing data centers in relation to energy infrastructure in Loudoun County enables tangible inferences about their impact or cost to the community.

6.1 Data and Methods

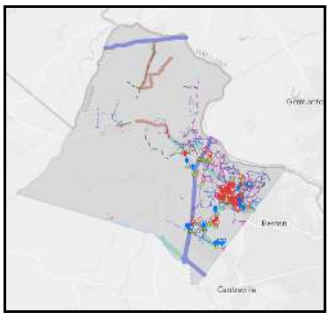
There are multiple layers to this map, including data centers (segmented by type), Loudoun County zoning classifications, recent electric substations (infrastructure that bridges distribution and transmission lines, hosting capacity (in megawatts) via distribution lines, and existing transmission lines (in kilovolts).

The data centers and substations were retrieved from existing ArcGIS Online maps produced by the Piedmont Environmental Council. See here: Existing and Proposed Data Centers – A Web Map and Initial Transmission Proposals – PEC Web Map – The Piedmont Environmental Council. These layers were transformed by overlaying both of them on the Loudoun County Boundary layer. The Proposed Substations layer was classified by the Build_Status field to create the Electric Substations layer. The PJM data field in the substations layer was classified to include recently proposed substations (as of September 30, 2025), and the Extract Data tool was used to produce a new layer titled Recently Proposed PJM Substations. The three data center layers were created by duplicating the original overlaid layer and manually filtering. The Owner_Applicant data field was filtered to synthesize the three different layers: Hyperscale Tech Data Centers (Amazon Web Services, Google Cloud, and Microsoft Azure), Colocation Data Centers (any multi-tenant data center corporations), and Other Data Centers (listed under addresses, contractors, developers, enterprise-owned, and LLCs).

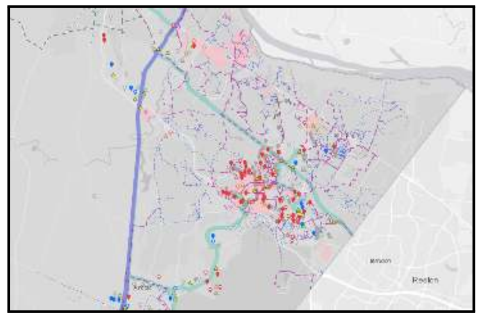
The transmission lines layer was created using the publicly available layer, U.S. Electric Power Transmission Lines (Archive), which has unfortunately not been updated since 9/30/2024. The Virginia Electric and Power was created by overlaying the transmission lines to the Loudoun County Boundary layer, as they are all owned by Dominion Energy. Local distribution lines were sourced from this Hosting Capacity Tool — Dominion Energy by choosing the Utility Scale map because "the utility-scale map shows the hosting capacity limit calculated from the distribution lines and other distribution facilities, not including any distribution transformers", which was most relevant to this analysis. To extract the data, the map's feature server was located from Primary Hosting Capacity Feature Server. The map's initial JSON data required conversion to GEOJSON format for compatibility with ArcGIS Online. This was achieved using the Feature Server's Query page with the following parameters: Where=1=1, Out Fields=*, and Format=GEOJSON. The resulting GEOJSON file was then uploaded as a layer into ArcGIS, where it was classified according to the specifications on the Dominion Energy website and subsequently clipped to the Loudoun County Boundary layer.

The Loudoun County zoning layer was acquired from the county's GeoHub, accessible here. This layer was subsequently filtered to include the zoning classifications "ODP" (existing office parks) and "PDOP" (planned office parks), which denote parks predating 1972. Furthermore, the Loudoun County Boundary layer was obtained through the Loudoun County GIS via ArcGIS Online.

For visualization purposes, the transmission and distribution line layers were classified by voltage and capacity, respectively, with the highest values shown in purple and green, and the lowest values in blue and red. Both were made increasingly transparent to reduce distraction. Hyperscale and colocation data centers were colored blue and red to draw the viewer in, while other data centers were colored grey. However, the symbology remained the same across types: existing data centers were represented as a filled waypoint, and proposed data centers were depicted as a floating waypoint. Similarly, electric substations, represented by the yellow triangles, were split into existing and proposed categories based on transparency, with the latter being more transparent. Any recently proposed PJM substations were outlined in red for emphasis. Finally, the zoning was classified as "Office Parks (2023)" using a light red fill, while the "Planned Office Parks (1972)" were given a hatched yellow fill to indicate discrepancy. Finally, the Loudoun County Boundary was given a darker grey so the county would pop out relative to the Light Grey Canvas Basemap. The bookmarked "Main View" section shows the county center.



(a) Original view



(b) Main view

Figure 17: Loudoun County Data Center Visualizations

There are two web apps for optimal viewing with pop-up features and calculated fields, such that the new view would be more readable (e.g., omitting underscores):

1. Allows for legend filtering
2. Allows for layer selection

Source	Data Type
U.S. Electric Power Transmission Lines (Archived Overview)	ArcGIS Layer/Map Service
Dominion Energy Hosting Capacity Tool	Overview
Dominion Energy Hosting Capacity Tool	ArcGIS Feature Server
Piedmont Environmental Council Resources	Data Centers Virginia (ArcGIS Layer)
Piedmont Environmental Council Resources	Proposed Substations (ArcGIS Layer)
Loudoun County GIS Data	Zoning (GIS Dataset)
Loudoun County GIS Data	Boundary (ArcGIS Layer)

Table 1: ArcGIS Mapping Sources

6.2 Results

Notably, the data centers cluster around the light red Office Parks zoning and along the distribution lines with the highest capacity, up to 24 MW, and the highest transmission lines, 500 and 220-287 kV. Thus, residents can infer that data centers are either driving the construction of more energy infrastructure or crowding around existing infrastructure. Ultimately, this distribution is likely due to a combination of both. The clustering of waypoints (existing data centers are filled, and proposed data centers have a white bubble) around the light red indicates the result of early-2000s legislation that allowed data centers to be built by right and were considered office parks.

Figure 18: Data centers in relation to distribution and transmission lines

Figure 19: Data centers in relation to previous Office Park zoning

Residents can anticipate further data center builds along distribution lines by identifying proposed substations, as the grid operator, PJM Interconnection, anticipates the extension of transmission and distribution lines.

Additionally, there are a few relevant charts. The pie chart shows the distribution of lines by hosting capacity, with a bottom-heavy distribution indicating that lower-capacity lines primarily occupy Loudoun County.

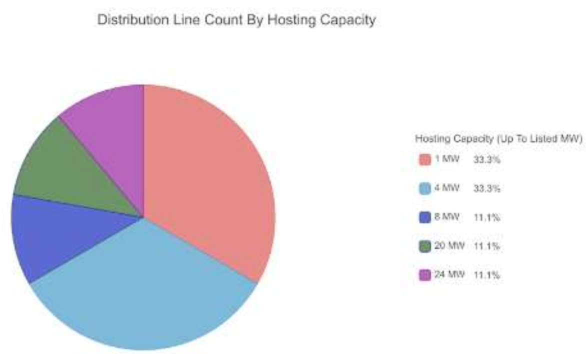


Figure 20: Distribution line pie chart organized by hosting capacity in Loudoun County

The three data center charts display the three data center types organized by build status and categorized by owner/applicant, with the dependent variable being the number of data centers with reported MW.

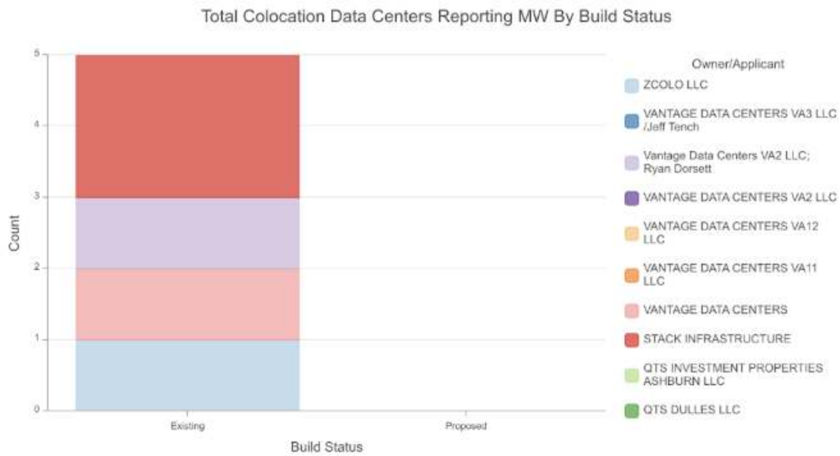


Figure 21: Colocation data centers in Loudoun County reporting energy consumption

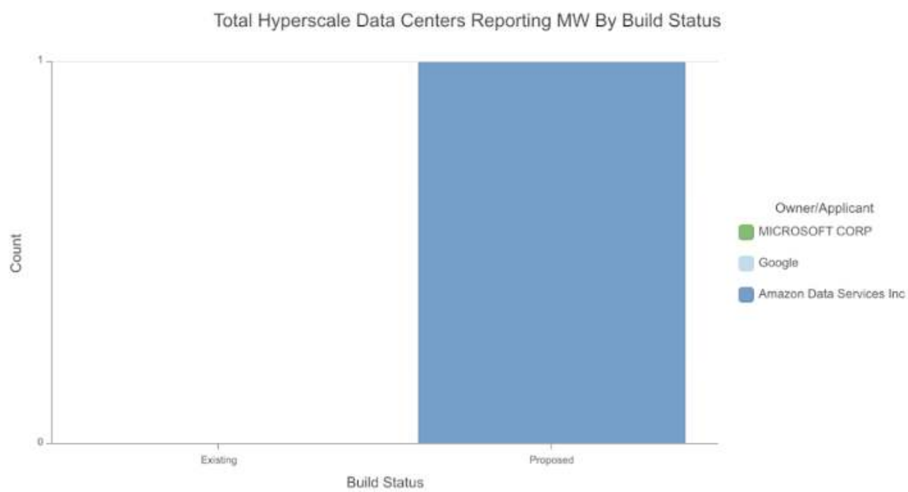


Figure 22: Hyperscale data centers in Loudoun County reporting energy consumption

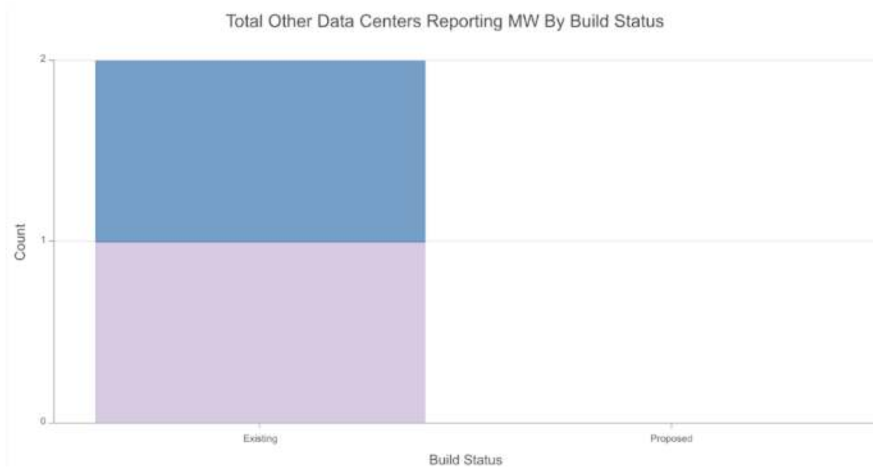


Figure 23: Other data centers in Loudoun County reporting energy consumption

Evidently, colocation data centers report more frequently, likely due to their interest as a multi-tenant provider. Hyperscale tech data centers seldom report such metrics.

6.3 Discussions and Limitations

The map demonstrates the proximity of data centers to existing distribution and transmission lines, yielding two possible implications. First, energy infrastructure is driven by the location of data centers. Second, we can extrapolate that data centers tend to cluster around such infrastructure. Regardless of the cause, data centers are driven directly by past policy decisions, as indicated by their clustering around office park zoning areas. Problematically, most energy consumption data is proprietary at an individual data center level. Thus, residents should act defensively and anticipate such visual relationships as evidence of the energy costs that data centers incur on a community. Nonetheless, this analysis is conducted with data limited by a lack of transparency and obscured by a constant cycle of regulatory updates. Distribution and transmission lines are constantly being built and proposed in the county due to Dominion Energy and PJM Interconnection's state of urgency. Significantly, given the paucity of current hosting capacities, one can anticipate a lack of infrastructure to support the proposed data center build. Ultimately, this data should be analyzed across timescales for a more robust conclusion.

6.4 Future Research

If this research had access to proprietary data, restricted by strong barriers like non-disclosure agreements, it would be more useful for quantifying impact. However, if this research allocated more time, a more powerful narrative would demonstrate the change in data centers and energy infrastructure. The foremost question the map poses is the importance of transparent electricity consumption for data centers. Further research should be conducted to model the expected electricity consumption of proposed data centers and to determine the relationships among proposed, under-construction, and operational data centers, and how, over a set timescale, the existence and distribution of utility-scale transmission and distribution shifted. If this can be modeled using timescales and heatmaps to illustrate increases in energy rates, this would be visually impactful.

7 Boots On The Ground: Interviewing Loudoun County Residents

Spatial analysis, especially with limited data, can only go so far in revealing community relationships with data centers. To contextualize the personal relationship between residents and data centers, I conducted personal interviews with two staunch Loudoun County community members, Chris Tandy and Gregory Pirio.

In my conversations with Chris, co-founder of the Loudoun Climate Project (his thoughts do not reflect those of the organization), he emphasized the power imbalance between residents and corporate players. Chris's work primarily examines the ecological impacts of data centers, analyzing purple air monitors that measure PM 2.5 (particulate matter 2.5 microns), a pollutant emitted by diesel generators, among other sources. Data center backup power is often provided by diesel or natural gas generators and turbines. There are two types of diesel generators–emergency and non-emergency. Non-emergency generators are regulated as Tier IV generators, which are subject to stricter emissions controls, and emergency generators as Tier II generators, described as "dirty" and limited to 500 hours of "emergency" use. However, the distinction between emergencies and non-emergencies seems murky. For instance, if additional capacity is predictable during peak load, Chris argues that this equates to a planned outage rather than an emergency.

Furthermore, Tandy and other residents have found that PM 2.5, a pollutant most detrimental to respiratory health, is being emitted using Virginia DEQ (Department of Environmental Quality) Article 6 Minor NSR permits, which do not require public notice or a public hearing to qualify. To move forward, Chris encouraged using a message that highlighted public health concerns, thereby shifting data center concern narratives from the external looming force of climate change to one of local human health. These sentiments Chris discussed are held by many residents, as per the public comments I analyzed from the March 18th, 2025, Loudoun County Board of Supervisors meeting: people are afraid of not knowing what could be polluting their backyard.

One imbalance that I identified was the disparity between corporate power and residential concerns. Chris echoed this in our interview, discussing the players in a denoted "corporate capture" camp, which includes data centers, and which he believes has permeated the Virginia DEQ, local labor unions (especially those who are data center technicians), rezoning companies, and local politicians. These premonitions are not just mere conjecture–more on this in the following section.

As Phase 2 of the CPAM/ZOAM (Comprehensive Planning and Zoning Amendments) is underway in Loudoun County, residents are advocating for increased setbacks and increased transparency in governance (Chris hopes that quarterly reports will be available at every level of local governance).

In my personal interview with Gregory Pirio, similar calls for transparency were echoed. Gregory had a deeply personal experience with data centers, dating back to 2022 (he moved to Loudoun County 10 years prior), when Vantage Data Centers proposed a data center at 22318 Glenn Drive. This marked the beginning of a distrustful relationship with Gregory and the Vantage data center. He attended a community meeting organized by Vantage, where representatives presented the project. After it was built, Vantage's project was six times larger than initially proposed to Gregory by the individuals who researched the rezoning process, and it serves as a source of air and noise pollution.

Initially, Pirio reported operational whirring of up to 90 decibels, equivalent to the sound of a constantly running subway train. Since then, it has decreased to a self-reported range of 60 to 75 decibels, which is thus allegedly still in violation of Loudoun County's code of 60 decibels.

Furthermore, Gregory is profoundly concerned about the health of his human and other ecological neighbors. Anecdotally, he has seen a decrease in the flocks of birds typical to the area. Recently, he found that his frustration is shared by a myriad of residents. Gregory, along with many other community members, attended a meetup he and the Piedmont Environmental Council organized via local flyering. Since then, he has become much more active in local activism and wants to increase transparency, advocating for the establishment of a new Loudoun County Office of Community Engagement. Ultimately, Gregory, among many other residents, feels betrayed by a local government they deem incompetent to effectively manage issues and deceived by a dysfunctional system of residential input.

8 The Data Secrecy Problem

In the spatial analysis and interviews I conducted, I realized I was confronting a dearth of information, as data centers, despite their apparent significance as a public-grade utility, remain beholden to regulatory frameworks as private entities. Consequently, although Dominion Energy, Loudoun Water, and PJM Interconnection can report area-wide consumption from data centers, it cannot be attributed to an individual player.

Regarding energy, for instance, data centers are required to file a "Data Center Load Letter" with Dominion Energy ("Load Letter - Data Center" 2021). Dominion is not required to report these filings because data centers are private customers. Furthermore, I searched at the county level, using the Loudoun County permit filing system, LandMARC. This is the filing system that Loudoun County uses to track public permit requests. The relevance to data centers would be the permits classified as construction and electrical service, classified as new buildings. However, the only relevant files noted building amperage, not accounting for energy from servers. Honing in on energy, the “actual” server load is the key data point for determining individual data center consumption. Withholding this data required the thesis pivot its scope from hyperscale-specific players to a Loudoun County case study analysis.

These specific metrics are important because land, resource availability, and emissions impact vary within localities. A lack of data inhibits regulators from effective decision-making, prevents residents from being informed, and buttresses prediction-based calculations, which are inherently volatile. One way I chose to represent data center impact was spatially using ArcGIS mapping software, where I transposed data center facilities on energy infrastructure. Another way to quantify impact is by calculating expected emissions. To do this, I determined the TWh totals of data centers in Loudoun County based on requested demand capacity, using the EPA’s GHG Emissions Calculator to produce a Loudoun County-specific impact.

However, this “market-sizing” method is inherently flawed. For one, the requested demand capacity often exceeds operational consumption, meaning potential overestimates favor the data center industry. As established, data centers rely on energy redundancy to prevent widespread server failure. Similarly, there is no generally accepted method of calculating data center utilization rates. This is important because server type and workload yield different energy consumption data points. Existing utilization rate estimates range from 50% to 80% (Norris 2025), implying a 60% overestimate at the higher range or a 37.5% underestimate at the lower range.

I have provided an example calculation below. This assumes a demand capacity of 6 GW, a utilization capacity rate of $\tilde{5}$0% (determined by energy redundancy and workload variability), and an annual operating hours of 8,760, which yields 26.28 TWh. Using the EPA’s GHG Calculator and a Loudoun County Zip Code (Ashburn, 20146), we find the following estimates: an equivalent of 2.1 million homes’ electricity used for a given year and an estimated 7,827,573 metric tons of carbon dioxide equivalents (CO2e).

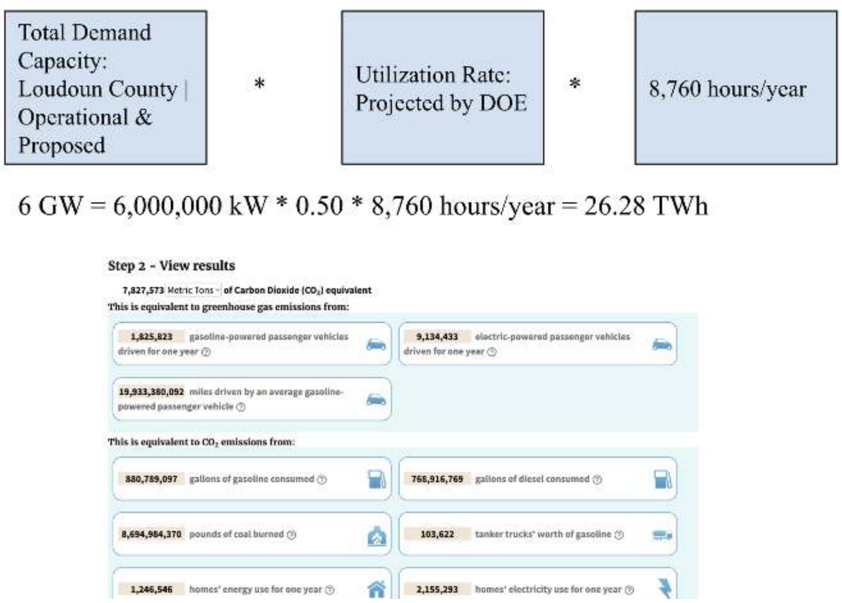


Figure 24: Estimated energy use and emissions calculation for Loudoun County data centers

However, even this Loudoun County CO2e estimate is problematic. Data center energy sources may be based on the utility transmission mix, meaning data center energy “cleanliness” depends on whether backup supply is activated and whether that supply is a solar battery or a diesel generator. The ultimate takeaway is that a lack of transparency weakens decision-making because few people know what is occurring on a per-facility basis.

Furthermore, the obscurity of data center reporting metrics prevaricates the specificity of local impact.

For instance, data centers report WUE (Water Usage Efficiency), which has decreased (lower values correspond to higher efficiencies), but does not account for local water impact. Despite efficiency gains, total water usage is increasing across the industry. Notably, this does not address conservation because water efficiency does not equate to total consumption.

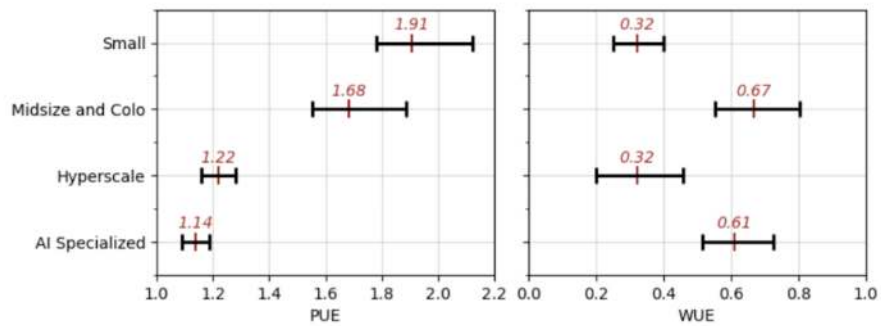


Figure 25: PUE and WUE by data center type (Shehabi et al. 2024)

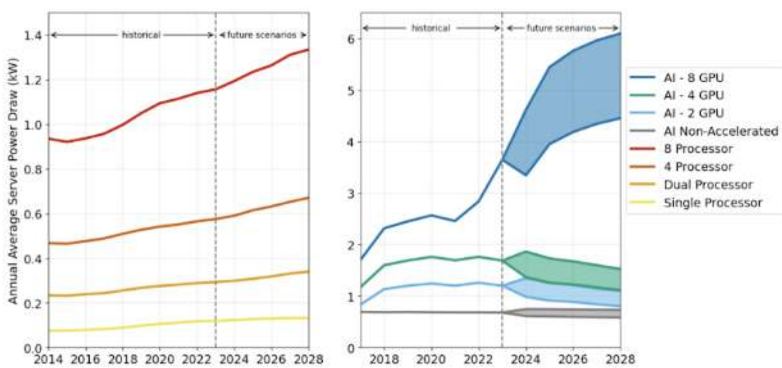


Figure 26: Server power draw by server type (Shehabi et al. 2024)

In a similar vein, PUE (Power Usage Efficiency) is expected to decrease over time due to GPU efficiency gains. However, the variability once again obfuscates. As the 2024 DoE report shows, the total TWh consumption depends on the server's workload.

The question remains: where, outside of the relationship between the customer and energy providers, does this data reporting happen, and who regulates data collection?

9 Analysis of Loudoun County Externalities and Tensions

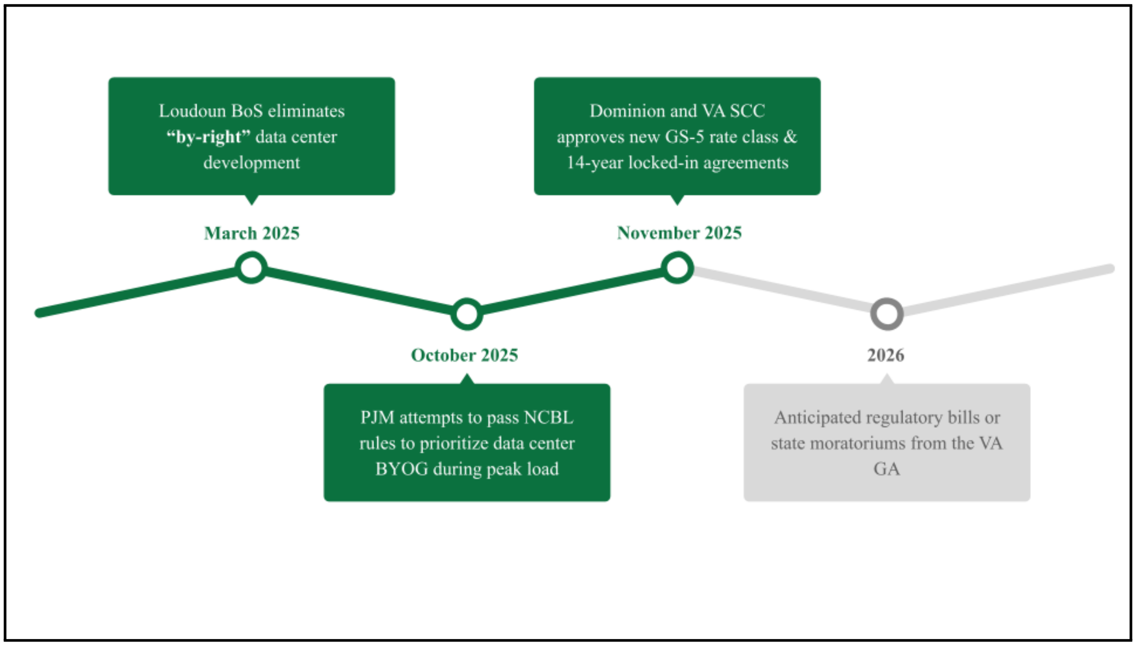


Figure 27: Loudoun County policy response timeline

I will now delve into the local effects on residents and the local responses among data centers, governments, and Loudoun County residents. I will rely on the established impacts from the case study section and discuss the second and third-order effects of these impacts. A timeline of events relevant to data center development in Loudoun County is pictured below, illustrating established changes and looming policies.

9.1 Results Analysis

Tangible Economic Externalities

Based on the 2025 Dominion Energy IRP, using the Virginia SCC Directed Methodology, a Virginia resident's monthly energy bill is projected to grow from \$159.57 to \$308.77 by 2035. Accounting for U.S inflation of 2%, monthly residential bills should be around \$215 at most by 2035, a 50% increase in energy payment or 2-3x the U.S. annual. inflation ($\tilde{2}$%). The \$160 to \$309 increase represents an additional \$1,788 per year for a Virginia household. Dominion's Company Methodology projects \$255 by 2035, driven by cost spreading and new class allocation rates. Regardless, the range from \$255 to \$308 remains a 4-6% increase in energy bills and a yearly increase of at least \$1,140.

Although water resources remain adequate, rampant usage warrants similar concerns for potential rate increases; for example, in 2024, the Loudoun Water Board of Supervisors set proposed water and sewer usage rates that represent a 7.0% increase each year for 2025-2027 ("Information on Rate Changes — Loudounwater.Org," n.d.). Because Loudoun relies on Fairfax County for source water and is constrained in its reclaimed water production, and thus supply, scrutiny is warranted.

From the perspective of a residential ratepayer, these increases are blasphemous. Notably, energy costs, although primarily driven by Loudoun County data center development, are burdened by all of Virginia's Dominion Energy customers. Furthermore, the sudden 17% increase in data center demand (the 2025 IRP update) indicates the capriciousness of the moment, particularly as Dominion Energy has allotted CLOAs to cover lost projects.

Loudoun County residents also have to bear a different economic externality–the social cost. As mentioned in the case study section, one such infrastructure project is the infamous Golden to Mars project, a 500 kV line designed to connect the intersection of Route 28 and Washington & Old Dominion Trail and a new substation, each at 100-300 MW, for 22 miles (SCC Talking Points 2025). Critically, this 165-foot-plus line is not slated to be buried underground, though the Loudoun County Board of Supervisors supports burying portions within 500 feet of residential areas and schools. Residents report concern for their health and ecology as massive wires take over their city.

Human health and Loudoun's local environment externalities

Further externalities include harm to ecological and human health from emissions. There are 4,700 generators in Loudoun County of the 9,000 total in the state of Virginia (8,000 of which are Tier II emergency generators) (Paullin and Inside Climate News 2025). These backup diesel generators can reportedly emit up to 9,000 tons of NOx in Northern Virginia, which is double that of all other sources. Tier II emergency generators are the cheapest and "dirtiest" backup generators. Despite most data centers reporting 1 to 2 instances in which backup generators were activated for 1 to 5 hours, the Virginia DEQ has permitted these generators to operate up to 500 hours per year, the equivalent of 1.4 hours of diesel pollution per generator per day (Ann Bennet, n.d.). Backup generators are typically run 5% of the time, but they still emit 30% or more of permitted emissions, meaning data centers in Northern Virginia could emit 10 to 20 times more pollution (Reinsel 2026).

Pollutant	**Current Emissions (% of Point Sources)**	**Maximum Allowable Emissions (% of Point Sources)**
Carbon dioxide	3%	49%
Nitrous oxide	11%	74%
Particulate matter	3%	50%

Table 2: Current and Potential Data Center Pollution in Northern Virginia (Reinsel 2026)

NOx and PM2.5 are toxic pollutants that increase the risk of carcinogenic and respiratory diseases. Ultimately, despite climate pledges from hyperscalers, data centers remain a significant GHG emitter. Loudoun's 50% increase in carbon emissions is due to data centers, worsening the climate crisis (Ann Bennet, n.d.).

Ecologically, data centers can be detrimental to local environments. Because land is finite, data centers have begun to encroach on local wildlife. A recently proposed Loudoun County campus, the Spring Valley Technology Park, would be a 362-acre data center campus that would directly harm local mature forests and increase total impervious surfaces near Goose Creek, hindering water cycling (Mills 2026).

Further impacting residential life, the data center's acoustic impact is a subtle yet tangible difficulty. Data centers produce a low-frequency buzzing or humming from cooling units, servers, and backup generators (The Sierra Club, n.d.). Although there are no official data corroborating health impacts induced by data center noise, persistent low-frequency exposure can impair sleep and mental health (Coyle 2025). Most importantly, the community feels this was imposed on them without their consent.

The ultimate anger that has spurred backlash has not come from analysts disputing emissions accounting or energy affordability dynamics. Although the latter has gained significant traction and now represents the anti-data-center movement, much of what sparked community outrage was far simpler. Residents developed a negative attitude toward the construction because they felt they were not appropriately consulted about the development. People purchased their houses assuming these negative externalities would not affect values, but they have been blindsided.

9.1.1 The Opposition Playbook

Residential Backlash

In public hearings, data centers claim to aid the community through tax revenue, local jobs, and local volunteering. Residents push back due to concerns about energy rates, property values, community health, disruptive architecture (including noise and light), and data usage ethics. *How can we quantify and compare the local impacts on residents?*

Experiences similar to those of Chris Tandy and Gregory Pirio have prompted a robust network of opposition among Loudoun County residents. Chief among them in its aggregation of information and reporting speed is the Piedmont Environmental Council, a grassroots environmental organization founded in Northern Virginia in 1972 (*About Us - The Piedmont Environmental Council* 2019), which used community efforts to track data center development and energy infrastructure. Other organizations include the Faith Alliance for

Climate Solutions, the Loudoun Wildlife Conservancy, and the Loudoun Climate Project. Members of these organizations and other community advocates have become a part of a larger group created by the Piedmont Environmental Council, the Virginia Data Center Reform Coalition (*Virginia Data Center Reform Coalition - The Piedmont Environmental Council* 2024).

Efforts to aggregate local complaints and form an overarching narrative or greater advocacy organization have contributed to a collective concern–one that defined the Virginia gubernatorial race–where energy affordability was a center-stage talking point. In personal communication with Shannon Heckt of the Virginia Mercury, I learned she found that residents, independent of political leanings, across numerous localities are growing upset about data center development. In fact, Shannon spoke with residents of traditionally red counties who have felt disaffected with federal efforts to prop up AI data centers. Thus, the spread of data center projects across localities in Northern Virginia has morphed from purely community-based to statewide. This is reflected in the narratives and results from the recent Virginia gubernatorial race, won by Democrat Abigail Spanberger, whose primary campaign message was on affordability (Schmidt 2025).

These narratives continue to command the Virginia political climate. Currently, data center bills are dominating the 2026 General Assembly floor. In the most recent Virginia General Assembly, Democrat Senator Russet Perry began the Wednesday session with a focus on data centers, promulgating, "Protecting ratepayers was a winning issue in my district in this last election [...] And this issue isn't a partisan issue. I represent a purple district, consistent with the polling this is a top issue across the political spectrum" (Pampaloni 2026a).

9.1.2 The Data Center Playbook

Industry Communication and Policy

The data center narrative in Loudoun County has been one of economic might. The industry has championed billions of dollars in tax revenue, additional local jobs, and social efforts. Many of these reported figures are accurate. For instance, Google reports a $1.1 billion ($800 million directly, $100 million directly, and $180 million induced) contribution to Loudoun County's GDP, with 3,500 jobs created, 400 of which are direct, from its data centers (Troyer and Tillman 2024).

According to Google, "the direct economic impacts of these investments include the headcount of Google employees and contractors (including their payroll and benefits) and annual spend on Google's suppliers. Indirect effects include the headcount of Google's suppliers' employees and contractors, the suppliers' payroll and benefits due to Google orders, and suppliers' spend. Induced effects are generated by the household spending of Google's employees and their suppliers in their local economies" (Troyer and Eliaz 2023). Notably, Google excluded machinery capital investments from its calculation, but the significance of the $1.1 billion metric as a net benefit unique to Google's operations is difficult to evaluate. However, negative externalities induced by individual data centers are often omitted from the debate. Currently, no aggregated estimation exists.

Philanthropic efforts, such as Google's $2.4 million donation to Loudoun County STEM programs, are also prevalent (Troyer and Tillman 2024). Multiple industry players push these statistics. At the March 18th, 2025 Loudoun County Board of Supervisors meeting, when the by-right development precedent was eliminated, representatives from Amazon Web Services and Equinix discussed the economic growth induced by their facilities.

Due to Loudoun County's low tax rates, data centers are incentivized to develop. In 2023, data center tax revenue made up 31% or $733 million of the budget–a very tangible contribution. In response to Google's GDP contribution assertions, it is worth analyzing the 2024 JLARC "Report on Data Centers in Virginia" analysis of economic benefits. The economic impact of data centers is, at face value, attractive, but additional context is needed to evaluate strong claims. The chart below indicates that the data center tax exemption yields moderate economic benefits compared to the average incentives of all industries in Virginia.

	Annual average	
	Data center exemption	Average Virginia incentive
Economic impact per $1 million spent on the exemption		
Jobs added	84 jobs	58 jobs
Income added	\$6 M	\$5 M
Virginia GDP increase	\$10 M	\$9 M
Impact on state revenue per $1 spent on the exemption		
Return in revenue per \$1 spent	48¢	41¢

Figure 28: Economic impacts of data center tax exemption compared to the average Virginia incentive (Sarte et al. 2024)

Industry capture is speculative, but there are some telling data points. For instance, in 2023, Dominion Energy contributed over \$1.7 million to legislators who would decide the final seats of the Virginia SCC, the primary regulator of the utility (Green 2024). According to Virginia Public Access Project records, the Data Center Coalition donated \$432,000 to Loudoun County elections between 2024 and 2026 to various campaigns, inaugural funds, and PACs, making it the second-highest donor to county elections (Va. Public Access Proj., n.d.). In Virginia, the Data Center Coalition spent \$640,100 on elections, meaning roughly 67% of the funds went to Loudoun County. Top donors include STACK Infrastructure, CloudHQ, Vantage, Amazon, and CyrusOne.

9.1.3 Direct Shifts

Despite Dominion's unprecedented rate requests, the SCC only approved a partial increase, bringing average monthly bills up by \$13.60 by 2027, 51.2% lower than Dominion requested. This paradigm shift has sparked a policy war.

There have also been a litany of policy shifts. Toward the end of 2025, the Virginia SCC locked into a new rate class, GS-5, for high-load users under Dominion Energy. Relevant customers are bound to 14-year agreements with minimum demand charges of 85% for distribution, 60% for generation, and 85% for transmission (Pampaloni 2025b). PJM Interconnection, though not exclusively influenced by Loudoun County, proposed, unsuccessfully, to introduce NCBLs (Non-Capacity Backed Loads) as a large-load classification for data centers (Howland 2025; Behr 2025). NCBL data centers would receive credit for disconnecting from the grid during unsustainable load events (Howland 2025). Instead, PJM instituted Reliability Backstop Procurement, which will prioritize new gas plants for grid connection (Howland 2026). Due to apparent reliability issues, PJM's Board recommended an improved process of projecting demand growth, allowing faster grid connection if data centers provide their own generation (referred to as BYOG or Bring Your Own Generation), and penalizing data centers that do not implement their own generation. Notably, there are no regulations regarding the fuel source of on-site generation, meaning fossil fuel use and thus greenhouse gas and toxic air pollutants may spike.

Data Center Alley has significantly shifted the political environment in Virginia. Recently proposed bills[6] span from emissions to energy regulation. Newly proposed bills include HB 155 and HB 906, which would require GS-5 customers to obtain a certificate of operation from the SCC to determine if grid capacity is available and if potential data centers can engage in “load flexible” energy generation (Heckt 2026). Some bills even seek to restructure the current status quo of utilities as a regulated monopoly, as HB 153, HB 155, and HB 503 seek to prevent utilities from passing the costs of transmission lines and energy generation infrastructure that primarily serve data centers onto residential ratepayers.

Regarding water use, HB 589 would require water providers to report monthly water volume used by data centers to the State Water Control Board to increase transparency regarding the industry's consumption (Heckt 2026). HB 496 would require additional site assessments and water-use disclosures. HB 323 would direct the Virginia DOE (Department of Energy) to identify opportunities for waste-heat conversion.

Concerning air pollution, HB 154 would require data centers to report backup generation operations within 24 hours. HB 607 calls for a new re-examination of aggregate air pollution from backup generators. HB 507 encourages further air monitoring, but not abatement (Heckt 2026).

[6] Many of the proposed bills will likely have changed or not passed by the time of publication.

9.2 A Local Paradigm

This thesis will now transition from an analysis of Loudoun County and its results to a discussion of its implications for other communities. Using the aforementioned methods and synthesizing my observations, I will extrapolate the clearest and most likely shared negative externalities and demonstrate parallelisms across disparate locations undergoing data center development. Applying data center impacts at a large scale is challenging because it is heavily context-dependent. Impacts are shaped by their local environment, thus making impacts variable. However, at least in the United States, the current state of energy systems, the confusion between data holders and the public, and the type or speed of government response are most consistently repeated.

9.3 Local Variability

Data center impact depends on resources, or the lack thereof

One complexity that stands out is the inherent variability influenced by local environmental factors. For instance, Loudoun County is not traditionally a drought-risk region, meaning water supply, although marred by issues regarding fair consumption, is not necessarily poignant to residents, particularly because they share access to the relatively abundant Potomac River. However, how might this affect a traditionally drought-stricken region like Southern California? Furthermore, who will have the power to decide on data center development? If the wealthiest county by MHI in the United States struggles to find transparency within its local government and has taken years to evoke legislative change, it does not bode well for the traditionally disenfranchised communities in the United States.

Ultimately, Loudoun County is an apt case study for what can result from unfettered data center development, but it is not a mirror image. Resource constraints, ecological issues, land availability, and point-source pollution will vary by local environment. However, two points stand out as potential parallelisms. First, stranded costs from energy capital recovery are a collective hardship that can be understood as a tragedy of the commons, in which electricity is the commons. Depending on the city, energy infrastructure is overseen by investor-owned or municipal utilities. In the case of the former, stranded costs are borne by the utility's district, not just the source of the infrastructure build-out. Second, transparency is, and will remain, a barrier to communities.

9.3.1 Applying Learnings From Loudoun County to the United States

1. **Energy Woes**

   Loudoun County is forcing people to reckon with an already underprepared grid. As peak energy increases during the summer months due to cooling applications, as the United States prepares to electrify operations (primarily via electric vehicle charging), and as technology grows alongside its power demand, infrastructure updates were inevitable. Furthermore, reliable energy and the transition away from fossil fuels, not just due to climate and health concerns, but due to inefficiency (in the case of coal) and finiteness (in the case of oil), would have required similar concerted efforts to scale. However, the costs from sheer demand that residents of Loudoun County have dealt with, and the rest of the United States is poised to experience, are simply untenable.

   Compounding this issue, existing energy billing and regulatory systems were not designed to deal with such demand. There are no strong regulatory precedents for large loads at the scale of data centers. But the concept of an investor-owned utility functioning as a regulated monopoly, in which raising customer rates covers the utility's infrastructure expenses, has been treated as a relatively stable status quo. For the rest of the United States, getting ahead of the policy curve, passing new load-based rate classifications, or regulating hegemonic power delivery, will be significant. Technologically, scaling on-site renewables, managing grids through smart systems, and investing in reliable, clean services are essential.

2. **The Need for Transparency**

   In Loudoun County, the primary issue facing policymakers, residents, and community groups is the lack of transparency. Private entities are not succumbing to scrutiny for additional data. In Loudoun County, although the growth in residential energy bills and degradation of local landscapes remain the primary concern, the most common frustration was the uncertainty surrounding data center development and its impacts.

Chris Tandy and Gregory Pirio's conversations echoed sentiments at the international level. Across Mexico and Ireland, Paul Mozur, Adam Satariano, and Emiliano Rodríguez Mega from the New York Times write that issues surrounding data centers "have been compounded by a lack of transparency. Google, Amazon, Microsoft and other tech companies often work through subsidiaries and service providers to build data centers, masking their presence and revealing little about the resources that the facilities consume". Thus, they conclude, "directly linking any data center to local power and water shortages is difficult. Yet building in areas with unstable grids and existing water strains has pressured already frail systems, according to experts, increasing the potential for cascading effects". Significantly, localities like Loudoun County have been signing NDAs (Non-Disclosure Agreements) with various data center companies to prevent the release of information pertaining to development. In fact, 25 of the 31 localities with existing or proposed data center projects in Virginia have signed NDAs. This information was obtained through FOIA (Freedom of Information Act) requests. Further obfuscating data, many data center permits are filed under shell companies or through external consultants, making it difficult to track specific corporate-led development (information corroborated by the Piedmont Environmental Council and my personal experience on the Loudoun County LandMARC government filing site).

3. **Policy Responses**

Despite the externalities, Loudoun County shows that a relaxed regulatory landscape encourages development. Loudoun's "by-right" development precedent, the "fast-track" permitting process, and exemption from the 6 percent sales and use tax for servers, generators, chillers, and server-related equipment have formed the current environment, in which data centers have been under construction every day since 2010. The New York Times echoes this sentiment, as "many governments are eager for an A.I. foothold, too. They have provided cheap land, tax breaks and access to resources and are taking a hands-off approach to regulation and disclosures." Therefore, proactive regulation, rather than reactive, is the best route for localities in the U.S. to ensure they are prepared.

4. **Narratives**

In Loudoun County, public hearings center around emotion, an important consideration, but not one chosen by choice, but by necessity. Residents lack evidence to criticize local data centers because there is no resource consumption information on a data center-by-data center basis. Additionally, industry advocates push back using quantitative evidence: taxes, economic development, and the "good of the community." This narrative is pervasive and is growing across the United States. For instance, in Tucson, during a city council meeting that actually resulted in the elimination of a data center proposal, Beale Infrastructure, a developer for Amazon Web Services, claimed that "it is a missed opportunity for the city to gain tens of millions of dollars in tax revenue, hundreds of millions of dollars in infrastructure to serve the community, and thousands of high-paying local and union jobs" (Davis 2025).

10 Moving Forward

Figure 29: Profit/Earnings Ratios and Weight of T10 compared to rest of S&P 500 Companies ("Artificial Intelligence," n.d.)

10.1 Accommodating Data Centers While Mitigating Externalities

Due to the immense value to markets from data center build, which largely drove U.S. GDP growth in the first half of 2025 (Lichtenberg 2025), there is significant cash flow and debt in the space. Stakeholders in this success include investors, the government (due to narratives about a technological race), and the technology corporations (due to interest in being first-past-the-post). If you look at U.S. GDP growth from H1 2025, it is almost flat when you remove data center construction. Similarly, the S&P 500 is growing at a flat rate when you remove the top 7 companies. Private markets are beginning to turn their backs on startups they funneled cash into as they doubt the lack of returns. There is a proclaimed "AI Bubble", and the question we need an answer to. When will it burst?

Markets are volatile. Most ot the narrative is dedicated to predicting the apparent "losers" and "winners" of the investment bubble, but there is minimal mainstream discussion about how this will affect data centers. Data center demand is driven by the same speculation that drove markets, as they house the backbone of the industry–servers, the body and power, and a vehicle for chips, AI, and cloud applications. Building and sourcing the resources (from capital to energy) for data centers is a prospective process. This begs the question: Are data centers proposed in anticipation of the needs of an unpredictable industry going to become sunk costs, and who will bear this cost? As the status quo stands, finite resource constraints most affect the nearest communities, and capital infrastructure costs remain subsidized by residents. Some data centers may fail to house enough occupants due to unfulfilled demand or more efficient servers, becoming derelict buildings that result in billions of dollars in debt and unnecessary infrastructure. But there is an opportunity to mitigate costs, which requires a reframing of energy systems.

10.2 A Myriad of Solutions: Policy and Technology

Data centers are not treated adequately because there is no cohesive regulatory classification. Land rights and zoning classifications must reflect a new data center category. Data centers are the physical manifestation of the cloud and artificial intelligence, and must be treated as a working entity, not an office park. Furthermore, there are multiple layers to a data center build. For example, multiple contractors, developers, and surveyors are involved in the construction process, and significant debt is used to finance construction. These details argue that data centers should be treated as public infrastructure or a telecommunication asset. Taking a hands-off approach to data centers paints them as quasi-real estate technology centers, which is not a successful management method. The aforementioned reclassifications would enable a more dynamic regulation of data centers. Ultimately, data centers are powering a new public commons, data. The current and future digital ages have a physical form, and data centers cannot simply be removed from the environment. They must be managed sustainably, and not as a buzzword, but as a practice. Mitigating the negative externalities caused by data centers is essential, but requires policy rewriting and technological advancements.

A policy's appropriateness depends on the values of the community and local government. More draconian measures include Ireland's 2021 data center moratorium. As of 2025, Ireland reformed this rule, requiring data centers to provide generation back to the national grid and follow specific on-site generation requirements. More liberal rules include Loudoun County's SPEX (Special Exception) rule, which requires local input and review for development permitting.

Some examples of different policies include:

1. Holding long-term accountability–California SB 57 (as initially proposed)

   Recently signed into law by Governor Gavin Newsom, Senate Bill 57, or the Ratepayer and Technological Innovation Protection Act, permits an assessment of potential electrical costs associated with data center energy consumption and an identification of mitigation strategies (Electrical Corporations: Data Centers: Report 2025). Authored by Senator Padilla, the bill initially required a data center tariff with 12-year binding contracts to cover transmission and distribution costs. Additional energy infrastructure costs would be "prepaid" by data centers. By locking data centers into paying for the utility costs they cause, the bill facilitated long-term accountability and prevented stranded costs from burdening residents. It would reduce frivolous requests, ensuring the built data centers would be used.

2. Mandating industry efficiency–German Energy Efficiency Act

   The Act works more directly with the industry. For instance, large data centers are required to conduct regular energy audits to find ways to reduce energy consumption and improve efficiency (Nguyen, n.d.). It mandates energy audits, meeting performance standards, and public reporting to reduce facility energy consumption and improve efficiency. Similar in principle to the U.S. EPA's BACT (Best Available Control Technology), excluding the focus on emissions, the Act targets energy efficiency standards with an emphasis on the best available technology. Far from the Energy Star program set out by the U.S. government, mandating efficiency may be successful if a community wants development without stranded costs.

3. Casting a wide net of standardization–Virginia HB 2578 (killed in subcommittee)

   Virginia's House Bill 2578, which was killed in subcommittee, intended to expand eligibility for the current sales and tax exemption by mandating that data centers purchase renewable energy for their annual load and that backup generators adhere to specific emissions standards (HB2578 - 2025 Regular Session — LIS, n.d.). HB 2578, similar to the German Energy Efficiency Act, would have worked with data centers if they met requirements to prevent externalities, such as air pollution from backup diesel generators. Similar state-level congressional bills have been criticized as interfering with existing regulations implemented by energy providers and regulatory agencies.

As previously stated, data centers are forcing us to reckon with an underprepared utility system. Thus, other important solutions include the redesign of the electrical grid and the addition of generation. Contrary to today's energy landscape, a corporate microgrid system may be effective. Data centers would remain connected to the grid but have access to separate backup and distributed generation. But they would not put strain on one source with a "smart" system that switches between power sources based on load and "islands" itself from the public grid to prevent community strain and its own outages. This idea is corroborated by Loudoun County Supervisor Mike Turner, who discusses microgrids as a part of Loudoun County's solution. However, microgrids require additional land to facilitate on-site generation, and that land may not be available to Loudoun. However, other communities across the United States can consider this before mass development.

Microgrids are part of a new movement for load flexibility. In a study by Camus Energy, flexible grid connection is defined as, "a data center receives both firm (uninterruptible) service and conditional firm service, where a portion of the load uses grid power in normal conditions and relies on on-site or co-located resources - including demand-side flexibility during limited periods of system stress" (Carlo Brancucci et al.

2025). The study found that flexible grid connection and BYOC (Bring Your Own Capacity), defined as off-site PPAs or on-site generation, would "avoid 273 MW of new build, primarily battery storage and natural gas, eliminating $78 million in incremental system costs per GW." Utilities will have to permit such off-site contracting and on-site generation, allowing for a new dynamic between utilities and large-load customers.

Regarding on-site generation, backup sources are primarily diesel. The cheapest alternative to diesel generators is to use natural gas turbines, an energetically more efficient but still, from an emissions perspective, undesirable form (Ericson and Olis 2019). More renewable forms include Battery Energy Storage Systems (BESS) and Long-Duration Energy Storage (LDES). Batteries are the most renewable if powered by solar and wind, but are subject to reliability issues. Any renewable LDES system is more reliable, but not yet sufficiently scaled. Nuclear power in the form of Small Modular Reactors (SMRs) and Advanced Nuclear Reactors (ANRs) is promising, but does not exist at the scale needed and is expensive. Innovative technologies like nuclear, however, still justify investment due to their potential benefits.

Successful hope is not just emotion, but putting your conviction into action. Rather than steaming ahead, asking "*Will this data center be built?*" or "*What problems could development drive?*" is part of the healthy skepticism needed to inform protective solutions and standards. Moving forward proactively, preventing our new digital infrastructure from becoming a source of climate and health problems, is critical. Increasing transparency among data centers, governments, and local communities, rewriting energy standards, and investing in renewable technology are part of this proactive movement to enfranchise people. Throughout this research, I found that the modern community-data center paradigm aptly reflects what Nate Hagens said: we are "energy blind." In this case study, I want to extend that phrase further: we are "community blind." Understanding the problem must be collective, yet with data centers, communities have been left in the dark. As our systems of power, both electrical and political, stand, we, the people, just as much as the data centers in multi-year utility permitting queues, are rendered powerless.

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