Investigating Data Center Development in Northern Virginia

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On my honor as a University student, I have neither given nor received unauthorized aid

on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Northern Virginia (NoVA) is home to the most data centers (DCs) in the world and growing (Kidd, 2023). The exponential growth of DCs in NoVA was spurred by its location near the capital with plentiful land, DC tax incentives, few natural disasters, and an advanced fiber optic network. DCs play a central role in IT infrastructure, enabling data storage, information processing, and network communication (Maclean, 2024). NoVA is a major US technology hub (NVTC, 2024), so close access to DCs is vital to supporting its digital economy: cloud services, e-commerce, big data, and more. Development in NoVA is expected to continue to grow as DC demand from AI and cloud computing is insatiable, with data creation expected to increase at a 23% compound annual growth rate through 2030 (Batson, 2024).

DCs are a significant economic driver in the area, both during and after development, but incentives are becoming exceedingly finite. DCs consume a lot of power, meaning a large density of DCs will strain the power grid (Virginia DEQ, 2022). Dominion Energy, a primary energy provider in the area, has reported that its power grid infrastructure has not kept up with DC growth (Judge, 2022). DCs also consume a lot of water for cooling including freshwater, which could increase water scarcity for residents (Zhang, 2024). Lastly, environmental and historical landmarks may be destroyed to make room for profitable DCs as environmental and historical groups fight to protect these lands (Sanchez, 2023). DCs are also being built closer to residential areas as land becomes scarce, leading to residents experiencing constant noise and subsequent health problems (JLARC, 2024). Complex conflicts over land-use, water-use, and power-use, with the unintended consequence of noise pollution, are being played out in NoVA counties right now as organizations, governments, and residents grapple with how to best develop an important part of the economy.

It is difficult to determine what DCs' future role in Virginia will be. My goal is to investigate the state of DC development in Northern Virginia, see if it is being carried out in an ethical and sustainable manner, and provide some direction for future growth. This is important because Virginians should have a say on some of the largest infrastructure developments in the state and should be informed as soon as possible as it is easier to influence development projects ideally before they begin.

Background and Significance

The role of DCs has drastically changed over the decades in tandem with innovations in computer design. DCs, or mainframes in the 1940s, were home to the Electronic Numerical Integrator and Computer (ENIAC) used by the military to calculate artillery firing tables (Robertson, 2024). Airflow and cooling were a priority for DCs. With the development of the transistor and TRAnsistor DIgital Computer (TRADIC) in 1954, DCs began to host IT infrastructure for commercial use, meaning reliability, or the uptime of computing services, became a priority (Robertson, 2024). Further developments in computing and memory led to the first personal computer in 1981. Throughout the 1980's and 1990's, personal computing following a client-server model set by UNIX became mainstream giving rise to the DC model we know today (Robertson, 2024). In a client-server model, clients or end user devices request resources or services from a server. This distributed structure allows for scalability of the servers to meet client demands. Throughout the 2000's, with the dot-com bubble crash, DCs began to consolidate, and major DC holders began to offer cloud services such as Amazon Web Services (Robertson, 2024). Cloud services were popular because businesses wouldn't have to invest in the capital or maintain DCs on premises and could rent what they needed from service providers.

Over 38% of organizations were using cloud services in 2012, leading to highly centralized hyperscale DCs (Robertson, 2024). The hyperscale DCs of today are massive facilities able to accommodate large data processing and connectivity needs (Robertson, 2023). NoVA is a hub for these hyperscale DCs that require massive investment and planning, so it is more important now than ever that proper planning and sustainability considerations guide development.

While this paper primarily discusses DC development. DCs are a part of a much larger web of infrastructure that must be considered. Understanding how DCs play a role in this web of infrastructure will allow us to better understand the considerations that go into DC development.

DCs require a large amount of power, which necessitates a strong power grid and means of power generation at the development location (Dominion Energy Virginia, 2025). Modern hyperscale DCs require power capacities over 100 megawatts which is equivalent to 400,000 electric vehicles (Robertson, 2024). In Virginia, the primary power utility is Dominion Energy which operates power plants across Virginia mostly powered by natural gas but increasingly adding other renewable sources (Dominion Energy Virginia, 2025). Dominion also operates the power distribution networks. For power to get to a DC, it is generated at a power plant, carried through transmission lines, transformed for the end customer, and taken to a DC substation where it is further transformed for use in a DC facility (Liquid Web, 2025). This process requires a strong presence of infrastructure for a prospective DC development as well as promises for continued investment in power infrastructure.

DCs also rely on dense and available network infrastructure. In NoVA, SummitIG and Lumen Technologies are primary bandwidth infrastructure providers connecting DCs through fiber optic cables to other facilities and the Internet. This bandwidth infrastructure is made up of miles of cables and wireless links for transmission, network equipment, cell towers, and more on

land. International transmission is handled through submarine cables. There are major submarine cables located on the east coast. The closest undersea cables to NoVA are located in Virginia Beach. MAREA connects with Spain, and BRUSA connects with Brazil and Puerto Rico (Submarine Networks, 2025). One reason for NoVA's DC development is that building a DC close to these cables allows businesses to offer services internationally at ultra low latency. Of course DCs also require services of other utilities such as municipal or regional water utility companies, roadworks, and drainage systems. DCs are a massive investment, and developers must make this decision with the entire infrastructure landscape in mind.

Not all DCs are created equal. The primary sustainability advancements have been in DC power systems. By prioritizing energy efficiency in DC design, operators can reduce economic and environmental costs and enhance the performance of their facilities. In relation to a DC's infrastructure landscape, a DC must consider its energy source, cooling methods, and IT equipment design. Khosravi found that standardized DC designs, location, and strong national-level energy policies, are major factors in promoting energy efficiency. A key metric in accessing DC energy efficiency is a DC's power usage effectiveness (PUE) score. PUE is the ratio of total facility energy to IT equipment energy, ideally 1. While residents may not understand how a DC will be designed, they can push for proper PUE standards like the European Union's EN 50600-4-2:2016 (Khosravi et al., 2024).

This study will analyze and comment on the state of DC development in NoVA. The study will highlight the benefits and drawbacks of current DC development and encourages the reader to participate in development discourse at the local level. The study will recommend guidelines at the county and regional level, however, DC development is a complex issue

because each DC is different. DCs fill varied computing and connection needs and have different infrastructure landscapes.

Methodology

To explore the sociotechnical implications of DC development, a holistic approach was taken, reviewing sources ranging from market analysis reports, sustainability models, county interviews with stakeholders, news articles, noise pollution medical journals, and environmental impact analyses. Through the information collected in the literature review, I analyze DC development with a sustainability framework (Lykou et al., 2017) and comment on the state of DC development considering that a DC is 1 actor in a network of people and infrastructure.

I begin by reviewing the economics of DCs. I reviewed a Northern Virginia Technology Council (NVTC) NoVA economic analysis (Parson et al., 2024), and I reviewed a cost-benefit analysis of Prince William County (PWC), a major NoVA county for DC development (PFM Group, 2022). The research describes the revenue DCs bring to the state, jobs created, and related development. There is some consideration of negative externalities, but the reports argue that DC development is a net positive. The reports give me a state and county-level view and affirm that DCs play a vital role in the digital economy, their development is inevitable, and their development is beneficial if planned correctly.

To better understand the need for change, I next review the negative externalities associated with DCs. There are problems both during and after development that are important to address.

The main problem during development is land use in a land-scarce environment. I reviewed a collection of interviews related to the Prince William County Data Center Opportunity Zone Overlay District (DCOZOD) to identify stakeholders with land concerns

(Stantec, 2021). I then reviewed associated media and articles related to the stakeholders concerned with land-use. The interviews showed me that these stakeholders are concerned with the preservation of historical landmarks and local wildlife ecosystems. The interviews also helped me better understand other negative externalities, such as cost and performance of farmland and other development paths like redeveloping retail and commercial space. Interviews with local stakeholders are critical to finding equitable solutions.

After development, power, water, and noise pollution are major concerns of involved stakeholders. With growing power demands, I review news articles on power concerns and Dominion Energy's long-term Integrated Resource Plan (IRP) (Dominion Energy Virginia, 2025). The articles describe the power problem and how it pertains to specific counties (Judge, 2022). Both power supply and high-voltage transmission lines are needed to support DCs. Dominion Energy's IRP, which lays out a comprehensive 15-year plan, is a great indicator of long-term sustainability goals and the capacity of power systems in NoVA.

I reviewed news articles on DC water consumption. The articles highlight the water sources DCs use, to what extent, and the magnitude of the water scarcity problems around DCs (Klappholz, 2024). They also distinguish between the types of water DCs use to provide a good characterization of the water-use problem.

To better understand noise pollution, I reviewed a news article interviewing residents on their perspective of a local DC as well as medical journals analyzing the effects of noise pollution on mental health. The news article shows what people complain about and how they worked through their local government to push for reforms and mitigate the problem (Lover, 2023). It is a good example to show that reform at the local level is possible. To characterize the impact of this noise from an academic perspective, I reviewed effects of general noise pollution

and low frequency noise pollution, the primary type of noise pollution emitted from DCs. Both studies show that noise pollution should be taken seriously as it could lead to a wide range of consequences including cardiovascular problems, behavioral problems, and neurological problems (Hahad et al., 2024; Araújo Alves et al., 2020). The sources I reviewed highlight serious negative externalities that affect stakeholders who must be a part of an equitable decision making process for DC development.

To foster productive discourse and consider the concerns of major stakeholders, I review Fairfax County's 2024 Data Center Report and Recommendations (Department of Planning & Development, 2024). The report outlines comprehensive plans and ordinances for land-use, energy, water, air quality, noise, and building design. This report shows the county's current position on DC development and is a good frame of reference for new local recommendations or regional recommendations. To aid in future recommendations and perform my own analysis, I use a sustainability framework to evaluate DCs on their ability to preserve "the environment, along with economic, operational and social longevity" (Lykou et al., 2017, p. 1). The framework will enable me to perform a holistic cost-benefit analysis of DCs. The analysis will also be carried out with actor-network theory. I will analyze DCs' role in their infrastructure landscape and the ripple effects development decisions will have on local stakeholders. This comprehensive approach will allow me to accurately comment on DC development and suggest effective actions for residents.

Literature Review

I have reviewed a wide range of resources to better understand the impacts of DCs in Northern Virginia: market analysis reports, sustainability models, county interviews with

stakeholders, news articles, and more. To best inform my view of the DC landscape, I turn to primary resources used by the Virginia General Assembly and the top 3 counties with the largest DC presence in NoVA as shown in Table 1.

Table 1

A Strong Economic View from State and County Sponsored Data Center Impact Analyses

Year	Studies	Study Background	Stance on DC Development per Topic				
			Economy	Power Use	Water Use	Land Use	Noise Pollution
2024	Kimberly et al.	Requested by the Virginia General Assembly.	Very positive. Local tax and labor benefits.	Slightly negative. Infrastructure growth rate can't keep up with demand and may pose an investment risk.	Slightly positive. Sustainable use that should be watched.	Slightly negative. Projects built close to neighborhoods.	Slightly negative. Some produce low-frequency noise that may affect health.
2024	NVTC	Sponsored by Loudon County and associated business partners.	Very positive. Significant tax, construction, and capital investment in the area.	Slightly positive. Constrained by power availability but a significant driver of clean energy initiatives.	No comment	Slightly positive. Land availability is sufficient for current and future demands in Fairfax County.	No comment
2022	PFM Group	Conducted by PFM Group for Prince William County's DCOZOD	Very positive. Local tax, construction, and minimal public service cost.	Mixed. Significant impact on power-grid but may not affect other energy customers.	Slightly negative. Large amounts of water use, some from resource scarce locations. Innovation may curb use.	Slightly negative. Lack of suitable land and cost that is becoming a concern.	Slightly negative. No qualitative analysis but acknowledgement of some low-frequency noise pollution.
2024	Fairfax County	Fairfax County planning and development staff in collaboration with Clarion Associates	Slightly positive. Initial employment with few long-term well paid jobs.	Slightly negative. Concerns over power reliability that should be watched from significant power usage.	Slightly positive. Lower average water use than retail and hotel space per square feet.	Slightly negative. May impact surrounding uses, environmental resources, and infrastructure that isn't considered in current ordinances.	Slightly negative. Measures needed and updated to reduce noise.

Table 1 is a synthesis of my understanding of key DC issues as described in the reports. It can be seen from the heatmap of the table that DC development is a complex issue that cannot be dealt with at the state or regional level as many concerns are county-specific, related to a county's land, water, and infrastructure capabilities. Many of the drawbacks and negative externalities are considered in the county-level recommendations, but the reports agree that DC development is an overall net benefit (PFM Group, 2022). I aim to validate this conclusion in my analysis and help residents shape DC development.

Much of the core literature in this discussion agrees that DCs are a significant driver of the local economy. A major part of this economic benefit comes during the initial construction of a DC. This is because significant capital investment remains within the state's economy. An average DC project takes up to 18 months, where as many as 1500 workers could be on-site related to various construction (Kimberly et al., 2024). DCs also require significant computer equipment capital that has generated over $34 million in taxes for PWC in 2022 (PFM Group, 2022). After initial construction, DCs employed above average, but fewer jobs per square foot compared to other commercial spaces (Kimberly et al., 2024). DCs have been a major economic driver throughout Virginia; according to the Virginia Development Partnership, DCs have accounted for 92% of investment in 2023 (NVTC, 2024). The significant economic benefits cannot be ignored, but the county's do acknowledge negative externalities.

DC power use is mixed as the infrastructure landscape of counties varies. All counties seem to agree that DCs require significant power to operate. A typical 400,000-square-foot data center requires as much power as 15,000 homes (Fairfax County, 2024). Both business and residential customers are worried that investments by power providers like PJM to build out infrastructure to meet DC demand will lead to additional power costs, but Dominion Energy has denied that this would be the case (Kimberly et al., 2024). Certain counties such as PWC are working to meet the power demand and have seen growth in clean energy initiatives through methods like power purchase agreement (PPA) investment. DC operators account for more than 60% of renewable power purchase agreements in the United States. Overall, there will have to be a slowdown in development or a significant increase in energy infrastructure as even meeting half of Virginia's infrastructure demand will be difficult (Kimberly et al., 2024).

Water is used for cooling and electricity in a DC. Water use primarily depends on the location and cooling method. Proper zoning ordinances to avoid resource-scarce locations are vital to preventing water scarcity. Luckily, Virginia is relatively water-rich (Siddik et al., 2021). Water use can also be significantly reduced based on the cooling implementation. According to Fairfax Water, the evaporative cooling systems of today that use techniques such as rainwater harvesting and closed-loop cooling systems have reduced water consumption by 90% (Fairfax County, 2024). Fairfax Water characterizes DC water usage as more than office spaces, but less than retail and hotels (Fairfax County, 2024). Thus, the general consensus is that water use should be watched and new methods should be promoted, but it isn't an obstacle that can't be overcome.

The factors I have analyzed up to this point have come from academic sources, consulting groups, and governmental committees. However, the impacts of DCs on land and its production of noise seem to more directly affect residents and other stakeholders. "25 environmental, conservation, historic preservation, and climate advocacy groups" have formed the Virginia Data Center Reform Coalition to address these concerns (PECVA, 2024). The reviews sponsored by the primary NoVA counties acknowledge that DC development impacts surrounding areas. This impact comes from power infrastructure needs, as DCs must be near a substation that is connected to major transmission lines, blocking scenic views, noise pollution, transportation, and other public services (Fairfax County, 2024).

The majority of land use problems come from zoning and redistricting that leaves DCs too close or in conflict with protected areas. In 2023, a rezoning led to the approval of 20 million square-feet on the edge of the Manassas National Battlefield Park, a historic national park. This

development would block the viewshed's main trail and increase stormwater runoff in nearby watersheds (NPCA, 2023). There have been similar situations throughout the state exposing residents and protected locations to the negative externalities of heavy industrial projects. While county reports do not analyze the qualitative impacts of noise pollution, they acknowledge that some DCs produce low-frequency noise that may have negative health impacts as shown in Table 1. Residents living near DCs have reported low hums from as much as miles away from a DC. This constant noise has "led to anxiety and affected their sleep, mental health, and productivity" (Chan, 2023). A comprehensive review on low-frequency noise outlines the extremes of its effects, including "sleep disorders, discomfort, sensitivity to and irritability from noise, annoyance, hearing loss, and cardiovascular diseases" (Araújo Alves et al., 2020).

Counties are on board with future DC development, but there is a stark disconnect in impact analyses and reporting between counties and activist stakeholders. This can be seen by the coalition-supported bills that were defeated or postponed from the 2024 Virginia General Assembly session to 2025 (PEC, 2024). However, the results of the report from the Joint Legislative Audit and Review Commission (Kimberly et al., 2024) corroborates many of the concerns of the advocacy groups, and a review of the passed bills in the 2025 Virginia General Assembly Session seems to show that legislatures also agree. I have hope that Virginia and its counties can effectively reform and find an equitable balance of DC development that will benefit all its stakeholders.

Discussion and Results

The state has put a lot of thought into answering the question, "What is the future for data centers in NoVA?". It is clear that DCs are here to stay and that development will continue. DCs

are one actor in this infrastructure network that continues to grow. As described earlier, power providers and bandwidth infrastructure providers are committing to long-term developments in development that rely on the business of major consumers like DCs. Dominion Energy, a prominent power provider in the area, has developed a 15-year plan to build out new power generation, 80% being carbon-free (Dominion Energy, 2025). Ultra low-latency access to DCs attracts many technology companies who set up shop in NoVA, increasing the demand for more DC services. Attracted by the presence of technology companies that plan to stay long-term, Virginia has become the second-largest hub for technology employment (NVTC, 2024). DCs are part of a growing network. They are supported by an advanced and growing infrastructure and offer computing and communication resources to a growing customer base that is attracted by a growing pool of technology talent. Data center demand is growing in this network and should not be stopped.
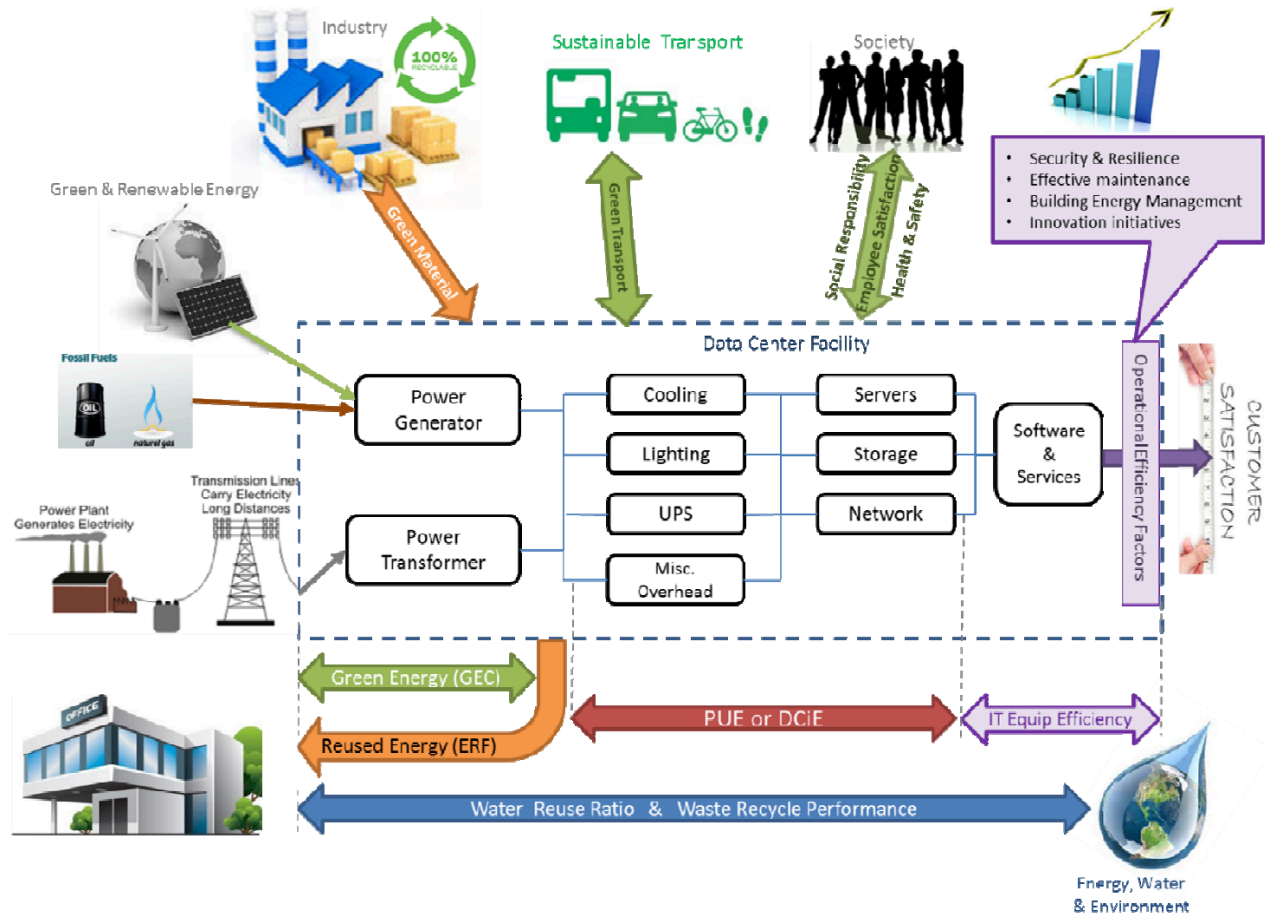
Figure 1: Data Center Sustainability Model Overview (Lykou et al., 2017)

However, as described in Lykou's sustainability model, we must ensure that each new DC is built in a sustainable way, assessing its environmental impact, resource utilization, resource recyclability, operational efficiency, and societal impact. I will not get into industry-specific measures, but residents should be familiar with what makes a sustainable DC.

A sustainable DC maintains a small environmental footprint by primarily using green energy and recyclable goods (e.g. recycled paper, refilled toners) in their business operations (Lykou et al., 2017). The energy load from an efficient DC primarily comes from the IT equipment and an efficient data center can recycle energy to, for instance, heat nearby offices. A sustainable DC maximizes the recycling of materials such as glass, paper and cardboard, and metal used in business operations and reuses water for other purposes like flushing toilets. An

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operationally efficient data center keeps security and resiliency in mind with plans to quickly identify and prevent problems. A socially aware DC commits to social efforts in the community beyond statutory requirements and maintains employee health and satisfaction.

These ideals of a DC can be assessed and enforced by county regulations, through incentives, and through fees to offset negative externalities. The reports in Table 1 and throughout my research have described many reforms that bring DCs closer to these ideals and that work to mitigate the concerns of local stakeholders. Luckily, many reforms are already in committee or have been passed by local legislatures.

Backed by the support of the Virginia Data Center Reform Coalition, the 2025 session of the Virginia General Assembly passed a key bill that will make DC development more equitable to stakeholders. Taken into effect on March 11, 2025, HB1601 requires new high-energy use facilities to submit a site assessment on noise pollution of nearby residents within 500 ft of a facility as well as optional assessments of water and natural landscape effects that may be enforced by a locality. This bill protects residents from noise pollution complications as well as gives all Virginia localities power to assess the holistic sustainability of a facility. Because data centers are a large investment and long-term commitment, it is important to require rigorous assessments to ensure a symbiotic development for the community.

Key reports in Table 1 provide the Virginia Assembly and counties with important recommendations backed by rigorous review. Recommendations touch on all aspects of an environmentally sustainable DC. Recommendations aim to tackle power consumption by holding power providers and DCs accountable. In these recommendations, electric utilities would be able to delay, but not deny service to customers when the load cannot be supported. To prevent this problem, JLARC recommends that energy providers like Dominion Energy develop a plan for

transmission infrastructure costs and that DCs commit to a demand response program (Kimberly et al., 2024). Recommendations aim to expand upon environmental factors considered in site assessment by requiring data centers to submit water use estimates as some counties like Fairfax County, currently don't have zoning ordinances to regulate water demand (Fairfax County, 2024). Sound modeling and specific low-frequency guidelines are also recommended. It has been determined that tax incentives have played a large role in attracting DCs. Nullified sales tax on IT equipment and other tax incentives can be used to not only attract DCs, but also incentivize best practices. Residents should reach out to Virginia lawmakers to express their opinion on reforms to the IT sales tax incentive before it is set to expire in 2035 (Kimberly et al., 2024).

Conclusion

NoVA is the world's densest DC hub, with the clear goal of becoming even denser. The benefits of DC development are substantial and have shaped NoVA's socio-economic landscape. However, these developments are large, long-term, and come with direct negative externalities to people and the environment. Thus, precautions must be taken in DC development, and all stakeholders should be considered.

This thesis was written to inform residents on the largest capital investment projects in the state, DC developments. I hope to shed light on the benefits and drawbacks of DC development and give NoVA residents a voice and the ability to create real change close to home.

With the completion of the comprehensive 2024 JLARC study and continued DC development, local governments are informed and willing to guide the development of data centers for all stakeholders. As a key stakeholder, residents should reach out to local county

officials on their planning and development board to express concerns and ideas for reforms. Residents who want to make DCs more sustainable should advocate for the recommendations in these reports to be passed at the county level. However, the biggest impact for local residents will be the location of the DC, so residents should advocate for proper zoning ordinances to reduce the possibility of noise complaints. Residents who want to stay informed should stay up to date with the bills passed by the Virginia General Assembly and the top 5 biggest counties for DC development in NoVA: Loudoun, Prince William, Fairfax, Mecklenburg, and Henrico county. NoVA has been my home for over 22 years, and in the future, with proper checks and balances in place, I hope to see it continue to thrive because of DC development.

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