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Electric Vehicles and Socioeconomic Inequity in Access to the Charging Network on Virginia Roads

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Electric vehicles (EVs) are becoming attractive to consumers due to their ability to reduce greenhouse gas (GHG) emissions, lower operating costs, and benefit from government incentives. Yet a barrier to EV adoption is the lack of direct current fast charging (DCFC) stations, which contributes to range anxiety. Studies also show that DCFC stations are more commonly found in affluent communities than in disadvantaged communities (DACs). Achieving convenient and equitable access to EV infrastructure requires thoughtful planning and policymaking, tailored to the demographic characteristics of different communities. This study investigates the current state of EV charging infrastructure in Virginia, projects battery electric vehicle (BEV) adoption and future EV charging needs, and proposes optimized solutions to tackle the shortage of DCFC stations and address socioeconomic disparities. To achieve these goals, this study utilizes data from the Alternative Fuels Data Center, S&P Global Mobility, Virginia Clean Cities, the American Community Survey, the Justice40 Initiative, Daily Vehicle Miles Traveled estimates, Alternative Fuels Corridors, Mile Marker and Exit Numbers, and the EVI-Pro Lite: Daily Charging Need Tool. This study's analysis spans multiple geographic scales, including census tracts, counties, Virginia Department of Transportation (VDOT) districts, and metropolitan statistical areas (MSAs). This study's key results include:

- By 2030, Virginia is projected to have 0.46, 0.77, or 1.2 million BEVs, reflecting growth of 30%, 40%, or 50%, respectively. Under each scenario, an additional 238, 342, or 694 DCFC ports would need to be added to the state's existing 1,096 ports as of 2023.
- In 2023, advantaged communities (ACs) had 684 charging stations, including 403 DCFC ports, compared to DACs, which had 165 charging stations and 156 DCFC ports. This results in a ratio of 4.1:1 for charging stations and 2.6:1 for DCFC ports between ACs and DACs. However, careful consideration is needed. ACs had 53,676 BEVs spread across 696 census tracts, while DACs had 1,737 BEVs across 350 census tracts. The land area of DACs is 6,588 square miles, which is more than double that of ACs.
- As of 2023, the Washington, Richmond, and Virginia Beach MSAs had high BEV adoption. In the Washington MSA, DACs accounted for 4% of DCFC electric vehicle supplier equipment (EVSE). The Charlottesville and Roanoke MSAs had moderate levels of BEV adoption. The Roanoke MSA had no DCFC stations in ACs. Other MSAs with low BEV adoption included Lynchburg, Winchester, Blacksburg-Christiansburg, Harrisonburg, and Staunton-Stuarts Draft, which had no DCFC infrastructure in ACs.
- In 2023, the annual savings in the social cost of GHG estimates due to BEVs was $61 million in Virginia. With a BEV adoption rate of 0.9% in 2023, Virginia has significant untapped potential. Expanding the DCFC infrastructure to address range anxiety could increase BEV adoption. A 30% increase in adoption could elevate annual savings to $415 million in terms of the social cost of GHG estimates.
- When considering only locations within two miles of Virginia's interstates, the areas categorized as advantaged and disadvantaged were similar in size, yet there were roughly four times as many EV charging stations in advantaged areas.

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FINAL REPORT

ELECTRIC VEHICLES AND SOCIOECONOMIC INEQUITY IN ACCESS TO THE CHARGING NETWORK ON VIRGINIA ROADS

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ABSTRACT

Electric vehicles (EVs) are becoming attractive to consumers due to their ability to reduce greenhouse gas (GHG) emissions, lower operating costs, and benefit from government incentives. Yet a barrier to EV adoption is the lack of direct current fast charging (DCFC) stations, which contributes to range anxiety. Studies also show that DCFC stations are more commonly found in affluent communities than in disadvantaged communities (DACs). Achieving convenient and equitable access to EV infrastructure requires thoughtful planning and policymaking, tailored to the demographic characteristics of different communities. This study investigates the current state of EV charging infrastructure in Virginia, projects battery electric vehicle (BEV) adoption and future EV charging needs, and proposes optimized solutions to tackle the shortage of DCFC stations and address socioeconomic disparities. To achieve these goals, this study utilizes data from the Alternative Fuels Data Center, S&P Global Mobility, Virginia Clean Cities, the American Community Survey, the Justice40 Initiative, Daily Vehicle Miles Traveled estimates, Alternative Fuels Corridors, Mile Marker and Exit Numbers, and the EVI-Pro Lite: Daily Charging Need Tool. This study's analysis spans multiple geographic scales, including census tracts, counties, Virginia Department of Transportation (VDOT) districts, and metropolitan statistical areas (MSAs). This study's key results include:

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LIST OF ACRONYMS

AC	Advantaged Community
ACS	American Community Survey
AFC	Alternative Fuels Corridor
AFDC	Alternative Fuels Data Center
APT	Apartment
BEV	Battery Electric Vehicle
DAC	Disadvantaged Community
DC	Direct Current
DCFC	Direct Current Fast Charging
DOE	U.S. Department of Energy
DVMT	Daily Vehicle Miles Traveled
EV	Electric Vehicle
EPA	U.S. Environmental Protection Agency
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse Gas
ICE	Internal Combustion Engine
MPO	Metropolitan Planning Organization
MSA	Metropolitan Statistical Area
MUD	Multi-Unit Dwelling
NEVI	National Electric Vehicle Infrastructure
PDC	Planning District Commission
PHEV	Plug-In Hybrid Electric Vehicle
SES	Socioeconomic Status
SFA	Single-Family Attached
SNAP	Supplemental Nutrition Assistance Program
TRP	Technical Review Panel
VDOT	Virginia Department of Transportation
VTRC	Virginia Transportation Research Council

FINAL REPORT

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INTRODUCTION

Electric vehicles (EVs) are heralded as sustainable and environmentally friendly transportation choices due to their zero tailpipe emissions of greenhouse gases (GHGs) (He et al. 2023). With reduced operating expenses and government incentives, consumers are increasingly drawn to EVs. In 2022 and 2023, the number of registered light-duty battery electric vehicles (BEVs) in the United States surged by 68% and 46%, respectively, compared to 2021, reaching a total of 2.4 million vehicles in 2022 and 3.6 million in 2023, according to the Alternative Fuels Data Center (AFDC), a division of the U.S. Department of Energy (DOE) (AFDC, 2024c). According to S&P Global Mobility (2024), Virginia has experienced similar significant growth in new BEV registrations, with a 64% increase in 2022 and a further 57% increase in 2023. To put this growth into perspective, the total number of new vehicle registrations in Virginia decreased by 15% in 2022, followed by a 13% increase in 2023. Due to their lower operating costs and environmentally friendly nature, EV ownership is beneficial to consumers. In 2022, approximately 65.3% of households that owned an EV went on to purchase another one (Muller 2022). In conjunction with consumer interest and concerns about climate change, the U.S. Environmental Protection Agency's (EPA) final rule, noting some legal challenges, mandates that the automotive industry ensure 56% of new vehicle sales be electric and at least 13% be plug-in hybrids by 2032 (Daly and Krisher 2024). Although EVs have not yet become the dominant presence on the road, their numbers have increased rapidly in recent years and are expected to continue rising. This underscores the importance of establishing proper infrastructure, implementing necessary policies, and considering the demographic characteristics of each locality.

While internal combustion engine (ICE) vehicles have become more efficient, research demonstrates that EVs are superior for the climate in almost all circumstances (Moseman and Sergey 2022). According to the EPA (2024), transportation is the leading source of GHG emissions, with light-duty vehicles being major contributors within this sector. Addressing emissions from these vehicles presents a significant opportunity to improve air quality and offer consumers more cost-effective transportation. The Commonwealth Clean Energy Policy (Code of Virginia § 45.2-1706.1, 2021) established a goal of reaching net-zero GHG emissions by 2045, and identifies the promotion of zero-emission vehicles and infrastructure as an element of the Commonwealth's policy to achieve this goal. In essence, EVs can be a powerful tool for achieving a healthier environment and promoting environmental justice.

Despite the growing value and innovation of EVs, several challenges within the EV ecosystem persist. The difficulty of finding EV charging stations during daily commutes, long-distance travels, or while using car-hailing services (Wood et al. 2023) has been identified as a key factor in deterring consumers from making the switch from ICE vehicles to EVs (Crothers 2023). While the number of charging stations is steadily increasing, their distribution remains uneven, leaving some areas underserved (Englund 2021). This can present a challenge for EV owners who need to undertake long trips. In addition, BEV drivers who rely on their vehicles for daily commutes face considerable difficulties keeping their cars charged, particularly if they do not have charging equipment at home. Adding to these challenges are clear disparities in EV infrastructure access between affluent and lower-income communities (Fitzpatrick et al. 2023). Some neighborhoods lack any charging facilities at all, which exacerbates the challenges faced by potential EV buyers in these areas. This uneven distribution of charging infrastructure not only hinders the widespread adoption of EVs but also raises concerns about equity and accessibility for all drivers (Hsu and Fingerman 2021).

The proliferation of EVs is linked to the growing demand for electric vehicle supply equipment (EVSE). As more EVs hit the road, the availability of charging stations becomes increasingly essential for ensuring a seamless and convenient driving experience. Studies show that a robust network of EVSE is crucial to fostering the widespread adoption of EVs, as it empowers drivers to recharge their vehicles efficiently and reliably (Qadir et al. 2024; Sierzchula et al. 2024; Egnér and Trosvik 2018). Research indicates a strong correlation between the availability of EVSE and the sales of EVs. Narassimhan and Johnson (2018) found that each additional charging station led to a 3% increase in plug-in hybrid electric vehicles (PHEVs) and a 7% increase in BEVs per 100,000 drivers. This positive relationship between charging infrastructure and EV adoption was consistent across regions, weather conditions, and grid networks (Power and Johnson 2024).

The EV market is rapidly expanding and gaining prominence in the automotive industry. However, the installation of EV chargers in urban, multi-unit dwelling (MUD) areas, low-income communities, rural regions, and along highways and in residential communities remains an important consideration. Investment in this infrastructure, combined with incentives and grants, will promote social mobility, mobility justice, and economic growth. Electric vehicles represent not just a technological innovation but a shift toward a sustainable future, and all communities should have the opportunity to participate in this transition. Consumers, manufacturers, and the government view EVs as a cleaner, more efficient, and more sustainable alternative to gasoline-powered vehicles (Ketter et al. 2023; Moseman and Sergey 2022). To facilitate EV adoption, the federal government aims to install 500,000 EV charging stations along major highways by 2030 (Osborne 2022). During this growth phase, proper guidance and structure are essential. Developing a well-designed framework can optimize the operation of EVs on Virginia roads by maximizing EV demand and charging infrastructure, improving customer experience, and informing program development at the Virginia Department of Transportation (VDOT). For this purpose, holistic research on the current state of the EV charging infrastructure in Virginia, projections of EV use, and potential solutions is crucial for understanding the EV ecosystem and addressing socioeconomic disparities in charging access. This project seeks to provide VDOT and Virginians with integrated knowledge and insights to establish a robust EV ecosystem and promote mobility justice on Virginia roads.

PURPOSE AND SCOPE

Purpose

Mobility justice ensures equitable access to transportation and mobility options, regardless of income, region, housing structure, or other factors. Transportation is not merely a means of getting from one place to another, but rather a foundation for determining access to education, employment, healthcare, and green ecosystems. In this context, this project examines the availability and accessibility of EV charging stations, with consideration of socioeconomic status (SES). Through a comprehensive analysis of spatial and socioeconomic data, this research will shed light on the interactions among BEVs, the EV charging infrastructure, and socioeconomic inequity. The findings will inform policy recommendations focused on ensuring that the transition to electric mobility is inclusive and leaves no one stranded on the side of the road. Specific objectives of this project include:

- Considering the critical role of charging infrastructure availability in the sustainability of EVs, is there a risk of socioeconomic inequity in access to EV charging stations on Virginia roads?
- Considering the growing adoption of EVs and potential inequities in charging infrastructure, what priorities should be established to optimize the placement and accessibility of EV charging stations and promote mobility justice?

Scope

This comprehensive study examined EV adoption and infrastructure access in Virginia, including a focus on socioeconomic disparities. By leveraging diverse data sources such as the Alternative Fuels Data Center (AFDC) (2024b), S&P Global Mobility (2024), Virginia Clean Cities (2024), American Community Survey (ACS) 5-year estimates (ACS 2024), Justice40 Initiative data (Council on Environmental Quality 2022), Daily Vehicle Miles Traveled (DVMT) estimates (VDOT 2024b), Alternative Fuels Corridors (AFCs) (VDOT 2024c), Mile Marker and Exit Numbers (VDOT 2024a), and EVI-Pro Lite: Daily Charging Need Tool (AFDC 2024a), the analysis provides a multifaceted understanding of Virginia's EV ecosystem. Table 1 outlines the data sources utilized in this study, along with the scope of each dataset and the specific time periods covered.

This study’s scope is comprehensive, spanning various geographical levels within Virginia, from the granular detail of census tracts to the broader scales of counties, VDOT districts, and metropolitan statistical areas (MSAs). This multi-level approach allows for a nuanced exploration of the current state of EV adoption, emerging trends across different regions, and potential solutions tailored to specific areas. By examining data at these various levels, this study was able to identify disparities, pinpoint areas of success, and develop targeted strategies to promote the widespread adoption of EVs. While this research primarily focuses on BEVs, it also acknowledges the role of PHEVs in Virginia.

The outcomes of this research are useful and impactful. They include a comprehensive assessment of BEV adoption trends across all of Virginia's MSAs. In addition, this study provides localized recommendations tailored to the specific needs and challenges of different regions within MSAs. These insights are designed to empower stakeholders across Virginia, from policymakers to utility companies to individual consumers, with actionable strategies to ensure that the benefits of the EV transition are accessible to all, regardless of location or socioeconomic status. By addressing disparities and promoting equitable access, Virginia can accelerate the shift toward a cleaner, more sustainable transportation system.

Table 1. Overview of Data Sources

Source	As of Date	Major Variables	Research Levels
Alternative Fuels Data Center	2023	Electric Vehicle Charging Stations with Level 2 and Direct Current Fast Charging	County and Census Tract
Virginia Clean Cities	2023	Battery Electric Vehicles	County
S&P Global Mobility	2023	New Registrations of Battery Electric Vehicles	County and Census Tract
American Community Survey	2022 5-Year Estimates	Median Household Income, Educational Attainment, Poverty Rate, Supplemental Nutrition Assistance Program Participation, Gini Coefficient, Apartment Ratio, Single-Family Attached Ratio, Travel to Work, etc.	County and Census Tract
Justice40	2019	Disadvantaged Communities	Census Tract
Daily Vehicle Miles Traveled	2022	Secondary, Primary, and Interstate	County
Mile Marker Signs and Exit Numbers	2024	Exit Coordinates of Alternative Fuels Corridors	County and Virginia Department of Transportation District
EVI-Pro Lite: Daily Charging Need Tool	2024	Public Direct-Current Fast Charging Ports	Metropolitan Statistical Area

METHODS

Overview

To investigate the current state of BEVs in Virginia and project their growth by 2030, along with the corresponding demand for charging infrastructure, this study adopted a multifaceted approach. The project conducted a series of tasks to thoroughly understand the current state of BEVs and the charging network in Virginia and calculate projected estimates for 2030 under different scenarios and possible alternatives.

Task 1: Analyze the current state of BEVs in Virginia and estimate their growth by 2030 under different scenarios, and then estimate the number of charging stations needed to support those estimates
Task 2: Assess trends in the charging network both within Virginia and across the United States
Task 3: Analyze BEVs and charging stations through the lens of equity considerations
Task 4: Examine BEVs and charging networks within VDOT's districts, along with AFCs and MSAs
Task 5: Conduct a five-priority assessment to identify localities within MSAs with the most urgent need for direct current fast charging stations

BEV Landscape in Virginia and 2030 Estimates

This study utilized data from Virginia Clean Cities (2024) to examine BEV adoption in Virginia. The county-level BEV data provided by Virginia Clean Cities (2024), covering up to 2023, formed the basis of this analysis. By integrating the data, this study projected the trajectory of BEV adoption in the state, using compound growth rates of 30%, 40%, and 50% by 2030. This approach aimed to provide policymakers and Virginia residents with a better understanding of BEV trends and the broader implications of this emerging technology.

Virginia Charging Infrastructure

This project investigated the dynamic reality of EV charging infrastructure in Virginia, utilizing data from AFDC (2024b) to analyze trends in the total number of charging stations, the distribution of Level 2 stations versus direct current fast charging (DCFC) stations, and the overall availability of charging ports across the state. By comparing these trends to national-level data, this study attempted to provide a comprehensive evaluation of Virginia's progress in EV charging infrastructure development and its relative standing within the broader context of the United States. It is crucial to acknowledge that this analysis concentrated on statewide trends, recognizing that individual localities within Virginia might present unique circumstances and disparities, which are examined in greater detail in a later section of this report.

Equity Considerations of the Charging Network

Previous reports have highlighted the uneven distribution of charging networks across the Unites States, underscoring the importance of examining the equity of the charging infrastructure within Virginia (Englund 2021; Fitzpatrick et al. 2023). Equitable access to charging stations is important for mitigating range anxiety among all EV drivers and fostering economic opportunities for disadvantaged communities (DACs) (Hsu and Fingerman 2021). This analysis employed two complementary approaches to assess equity: the Justice40 Map Tool and a cluster analysis utilizing ACS data. The Justice40 Map (Council on Environmental Quality 2022), developed for the Justice40 Initiative, identifies DACs. However, a limitation of this tool is its reliance on 2019 ACS 5-year estimates, which may not fully reflect changes in demographics and census tract boundaries since 2020. To address this challenge and enhance the analysis, this project incorporated 2022 ACS data, including median household income, educational attainment, poverty level, supplemental nutrition assistance program (SNAP) participation rate, and Gini coefficients, which align with established research practices (Yoo 2023). By clustering localities based on these socioeconomic factors, communities were classified as advantaged, disadvantaged, or intermediate.

The two classifications from the Justice40 and 2022 ACS data were then integrated with AFDC (2024b) data to reveal socioeconomic disparities in charging infrastructure access across Virginia, contributing to a deeper understanding of the equitable distribution of EV charging resources within the state. While the primary approaches centered on the statewide distribution of charging stations, a subsequent, smaller-scale analysis focused specifically on the distribution of stations near Virginia’s interstate to address the needs of longer-distance travelers.

BEV Adoption and Charging Infrastructure by VDOT District and MSA

Recognizing Virginia's diverse regions with varying demographics, economic activities, and travel patterns, this analysis was conducted within the framework of VDOT's districts, enabling a nuanced understanding of regional differences and facilitating the development of tailored infrastructure solutions. Furthermore, the study examined the physical distances of DCFC stations from exits along alternate fuel corridors (AFC) to assess the accessibility of fast charging options on interstates.

In addition, MSAs were employed to analyze both current levels in 2023 and projected BEV adoption and charging station needs in 2030. To estimate the required number of charging stations to accommodate the projected growth in BEVs, the study utilized the EVI-Pro Lite: Daily Charging Need tool (hereafter EVI-Pro Lite). This tool informs the optimal number and types of charging stations needed based on anticipated EV adoption. By leveraging this tool, the project sought to develop comprehensive and optimized solutions for EV charging infrastructure across Virginia, ensuring sufficient and accessible charging options to support the state's transition to electric mobility.

Five-Priority Assessment Framework

This project established a framework of five key priorities to optimize the deployment of EV charging stations in Virginia. Each locality within the state was assessed based on these priorities to determine the urgency of their charging infrastructure needs by 2030, with particular emphasis on areas within MSAs. This analysis was designed to provide a granular understanding of the specific charging infrastructure requirements for each locality, highlighting those with the most pressing needs in the context of their respective MSAs. Ultimately, this information can be used to guide the strategic allocation of resources and investments in EV charging infrastructure across Virginia, ensuring that charging stations are deployed where they are most needed and will have the greatest impact on supporting the widespread adoption of EVs. The five key priorities guiding this optimization effort are:

Priority 1: Localities Lacking DCFC Infrastructure: This analysis prioritizes areas currently without DCFC stations but projected to experience significant growth in BEV adoption by 2030. The need for additional stations is determined using a ratio of 3.4 DCFC ports per 1,000 BEVs (Wood et al. 2017), with each station assumed to have four charging ports, and factoring in a 50% increase in BEV adoption.

- Initial Two Conditions: $DCFC_{2023}^{(locality)} = 0 \;\&\; DCFC_{2030}^{(locality)} \geq 1$

- List the localities in descending order based on:

$$DCFC_{2030}^{(locality)} = \left(BEV_{2023}^{(locality)} \times (1 + GrowthRate)^7 \times \frac{3.4\, Ports}{1{,}000\, BEVs} \times \frac{1\, DCFC}{4\, Ports}\right)$$

Priority 2: Localities by Greatest Need: Localities are ranked based on the calculated demand for additional charging stations. This ensures that areas with the highest projected need for infrastructure expansion are prioritized. Thus, list the localities in descending order based on additional DCFC demand in 2030:

$$DCFC_{2030}^{(locality)} - DCFC_{2023}^{(locality)}$$

Priority 3: Multi-Unit Dwellings: Localities are further ranked based on the percentage of residents living in MUDs. This prioritization recognizes that MUD residents often face challenges with home charging due to limited access to personal charging outlets, emphasizing the importance of public charging infrastructure in these areas.

Priority 4: Shorter Commutes: Localities are ranked based on the percentage of residents with commutes under 30 minutes. This prioritization aligns with research findings that indicate that longer commutes can deter EV adoption due to range anxiety. In addition, focusing on areas with shorter average commute times allows policymakers to strategically target urban areas with higher population density, where EV adoption is likely to be more readily embraced due to the convenience of a public charging infrastructure and shorter distances between destinations.

Priority 5: Long-Distance Travel: Localities are ranked based on the proportion of daily vehicle miles traveled (DVMT) on interstates. This priority emphasizes the importance of supporting long-distance travel and ensuring a sufficient charging infrastructure along major transportation corridors within the MSA.

By strategically considering these five priorities, policymakers can develop a comprehensive and targeted approach to expanding the EV charging infrastructure that addresses the diverse needs of communities within MSAs and fosters the widespread adoption of EVs.

RESULTS

BEV Landscape in Virginia and 2030 Estimates

In Virginia, the number of EVs is on the rise, with 72,881 BEVs and 24,578 PHEVs on the road as of 2023, totaling 97,459 EVs according to Virginia Clean Cities (2024). Battery electric vehicles, specifically, have seen exceptional growth in recent years, with annual growth rates surpassing 50% over the last three years (see Table 2). However, it should be noted that in 2023, the growth rate slightly moderated despite the implementation of a $7,500 federal tax credit in January 2023. While EVs are not yet the majority of vehicles on Virginia roads, their presence is becoming increasingly noticeable. Data from S&P Global Mobility revealed a significant increase in the percentage of BEVs among new vehicle registrations, with rates of 118.5%, 63.9%, and 57.3% over the past three years. This upward trend suggests that BEVs will continue to gain traction in the Virginia market in coming years, gradually becoming a more common sight on the state's roads.

Based on the current growth trajectory, the number of BEVs in Virginia is poised for significant expansion in the coming years. If the current trend of a 20% annual increase continues, the state could see approximately 261,146 BEVs on its roads by 2030. However, with accelerated adoption and a more ambitious annual growth rate of 50%, the number of BEVs could reach an impressive 1.2 million by the same year. These projections highlight the potential for exponential growth in the Virginia BEV market, especially with sustained policy support and increasing consumer interest in electric mobility. It is important to note that these are just projections, and the actual number of BEVs in 2030 may vary depending on various factors such as government incentives, regulatory requirements, charging infrastructure development, and technological advancements.

Table 2. Overview of Battery Electric Vehicles (BEVs) in Virginia, 2019 - 2023

	2019	2020	2021	2022	2023
Number of BEVs	14,197	20,305	30,484	47,892	72,881
BEV Growth Rates		43%	50%	57%	52%
Total Registered Vehicles	7,647,692	7,669,209	7,702,236	7,765,074	NA

Results are from Virginia Clean Cities (2024), but the 2023 vehicle registration totals have not yet been reported.

As shown in Table 3, projections from the EVI-Pro Lite (AFDC 2024a) estimate the number of Level 2 and DCFC ports needed to meet future demand. Notably, if Virginia experiences a 50% annual increase in EV adoption over the next seven years, it will necessitate approximately 1,790 DCFC stations to adequately serve EV drivers. This figure emphasizes the importance of continued infrastructure development to keep pace with the growing EV market. The current status of DCFC availability in Virginia is explored in a later section.

Table 3. Projected Estimates of BEV Adoption and Needed Charging Stations in Virginia by 2030

Growth Rate	20%	30%	40%	50%
Projected BEV Number †	261,146	457,317	768,264	1,245,240
Single Family Charging Ports ††	237,222	415,423	667,926	1,045,240
Shared Private Charging Ports ††	5,727	10,028	15,068	22,070
Public Level 2 Charging Ports ††	7,931	13,895	19,531	27,425
Public DC Fast Charging Ports ††	762	1,334	1,438	1,790

BEV = Battery Electric Vehicle, DC = Direct Current. † Using 2023 BEV figures as a foundation, the projected number of BEVs was calculated employing a compound growth model. †† The data presented was sourced from the EVI-Pro Lite (AFDC 2024a), accessed in July 2024, using projected estimates for BEVs.

Virginia Charging Infrastructure

The increasing presence of EVs on Virginia's roads and across the United States has spurred significant growth in charging infrastructure. Both Virginia and the United States have witnessed a substantial rise in the installation of Level 2 and DCFC stations. In Virginia, between 2022 and 2023, the number of Level 2 charging stations grew from 2,199 to 2,954, a notable increase of 34%. Similarly, the availability of DCFC stations expanded from 844 to 1,096, reflecting a 30% growth rate. This trend mirrors the national development. Within the same timeframe, the United States experienced a 25% increase in Level 2 charging stations, growing from 96,091 to 120,235, while DCFC stations saw an even more significant boost, jumping from 27,296 to 38,000, a 39% increase. These figures, as shown in Table 4, emphasize the concerted effort to accommodate the growing EV market through an expanded charging infrastructure.

Table 4. Number of Level 2 and DCFC Ports, 2020 - 2023

	Virginia			United States		
Date	Stations	Level 2 Ports	DCFC Ports	Stations	Level 2 Ports	DCFC Ports
12/31/2020	557	1,246	511	20,117	45,277	15,083
12/31/2021	807 (45%) †	1,692 (36%)	709 (39%)	34,787 (73%)	73,000 (61%)	20,561 (36%)
12/31/2022	1,039 (29%)	2,199 (30%)	844 (19%)	45,844 (32%)	96,091 (32%)	27,296 (33%)
12/31/2023	1,418 (36%)	2,954 (34%)	1,096 (30%)	58,449 (27%)	120,235 (25%)	38,000 (39%)

DCFC = Direct Current Fast Charging. † Parentheses show the growth rates compared to the previous year. Source: AFDC (2024a), accessed on July 22, 2024.

Projections from the EVI-Pro Lite (AFDC 2024a), as shown in Table 3, and the current number of charging stations, as shown in Table 4, reveal a potential shortfall in Virginia's charging infrastructure. If Virginia experiences a 30% increase in EV adoption, the state will need 1,334 DCFC ports, while a more substantial 50% increase would necessitate 1,790 ports. Yet, at this time, Virginia only has 1,096 DCFC ports. This data underscores the importance of proactively expanding Virginia's charging network to keep pace with the growing demand for EVs. A lack of accessible DCFC ports has been a significant obstacle to EV adoption, as these stations provide rapid charging capabilities essential for reducing range anxiety (Qadir et al. 2024; Sierzchula et al. 2024; Power and Johnson 2024). By investing in adequate charging infrastructure, Virginia can ensure that its EV charging capacity aligns with the projected growth in BEV ownership, thereby facilitating a smoother transition toward a more sustainable transportation system.

Equity Considerations of the Charging Network

To achieve widespread EV adoption, it is crucial to ensure that charging stations are easily accessible, as a lack of charging infrastructure remains a major barrier. While expanding the availability and accessibility of EV charging stations, it is equally important to guarantee equitable access, especially in DACs, to foster an inclusive transition.

Statewide Distribution of Charging Stations

This study examined the current distribution of EV charging stations with a focus on equity considerations. Two approaches were employed: (1) the Justice40 map (Council of Environmental Quality 2022) and (2) a cluster analysis based on socioeconomic factors. The Justice40 Initiative is a federal program aimed at addressing environmental and economic inequalities by identifying DACs for prioritized federal investment. While the Justice40 map uses data from the 2019 ACS 5-year estimates, this project utilized data from the 2022 ACS 5-year estimates due to updated census tract boundaries in 2020. To address this discrepancy, a cluster analysis was conducted, categorizing communities into advantaged, intermediate, and disadvantaged based on socioeconomic indicators such as median household income, education levels, poverty rates, SNAP participation rates, and Gini coefficients (Yoo 2023).

The EV Justice40 Map Tool (Council on Environmental Quality 2022) identified 438 localities out of 1,907 census tracts as DACs. Subsequent analysis of charging station locations, which is detailed in Table 5, revealed 146 stations within DACs. However, 565 locations were deemed inapplicable due to inconsistencies between the 2019 census tract data used in the Justice40 map and the 2022 data utilized for this analysis. This study analyzed the locations of all existing EV charging stations using the more recent 2022 census tract data. This discrepancy indicated the challenges in accurately assessing charging station distribution. Despite these data limitations, it is noteworthy that there are 120 DCFC EVSE in DACs, compared to 685 in non-DACs. This finding emphasizes the necessity for further investigation into the equitable distribution of EV charging infrastructure, especially considering the potential disparity in charging access for disadvantaged communities.

Table 5. Census Tracts Per Justice40 Map and Charging Infrastructure

	Non-DAC	DAC	NA
Number of Census Tracts Identified by Justice40 Map	1,469	438	
Number of Charging Locations	716	146	565
Number of Level 2 EVSE	1,462	246	1,218
Number of DCFC EVSE	685	120	264

DCFC: Direct Current Fast Charging, EVSE: Electric Vehicle Supply Equipment, DAC: Disadvantaged Community

Recognizing the limitations of the Justice40 map's data, this study employed a complementary approach to enhance the understanding of community-level disparities. Utilizing established methodologies (Yoo 2023) and drawing upon the 2022 ACS 5-Year estimates, a comprehensive categorization of communities was conducted based on key socioeconomic factors. This analysis yielded three distinct community types: advantaged, intermediate, and disadvantaged, as visually depicted in Figure 1, where gray, green, and red, respectively, denote each category. Census tracts marked in yellow were omitted from the cluster analysis because they lacked data for one or more of the following factors: median household income, educational attainment, poverty level, SNAP participation rate, or Gini coefficients. The cluster analysis of DACs, ACs, and intermediate communities necessitates complete datasets. The cluster analysis, as summarized in Table 6, revealed significant socioeconomic disparities among communities. A total of 686 census tracts were classified as advantaged, characterized by a high average median household income of $153,088.81 and a substantial proportion (64.91%) of residents possessing a college degree or higher. Conversely, 350 census tracts were identified as disadvantaged, exhibiting a lower average median household income of $44,755.89 and a smaller percentage (20.89%) of residents with college-level education.

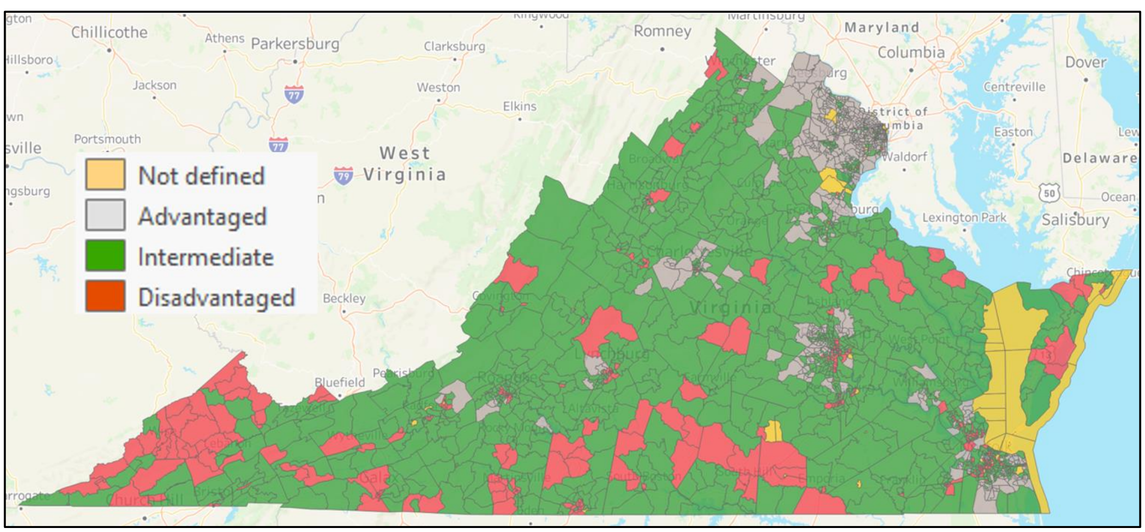

Figure 1. Cluster Analysis

Table 6. Overview of Socioeconomic Indicators

Category	Number of Census Tracts	Land Area ($mile^2$)	Median Household Income	College+ Education	Poverty Rate	SNAP Participation Rate	Gini Coefficient
Advantaged	686	3,001	$153,088.81	64.91%	4.24%	2.51%	0.37
Intermediate	1,118	30,603	$76,244.87	30.61%	10.05%	9.00%	0.41
Disadvantaged	350	6,588	$44,755.89	20.89%	26.79%	28.85%	0.47

SNAP = Supplemental Nutrition Assistance Program. Source: ACS (2024)

Cluster analysis revealed socioeconomic disparities in EV charging infrastructure access. Using data from AFDC (2024b) and S&P Global Mobility (2024) at the census tract level, this project found that ACs possessed a substantially higher concentration of charging stations compared to DACs. Specifically, as indicated in Table 7, ACs had 403 DCFC ports, compared to just 156 in DACs, resulting in a ratio of about 2.6 to 1. However, it is important to note that the total number of ACs (i.e., 686) is nearly double that of DACs (i.e., 350). Furthermore, the number of BEVs registered in ACs is disproportionately higher, with 53,676 BEVs compared to 1,737 in DACs, a ratio of roughly 30.9 to 1. Disadvantaged communities span 6,588 square miles (Table 6), while ACs cover 3,001 square miles. In other words, DACs have about half the number of census tracts as ACs, but their size is nearly double. This highlights the sparse distribution of DCFCs in DACs.

Table 7. Equity and Accessibility in EV Charging Stations

	Advantaged	Intermediate	Disadvantaged	NA
Number of Charging Locations †	684	569	165	9
Number of Level 2 EVSE †	1,526	1,006	300	94
Number of DCFC EVSE †	403	510	156	0
Number of BEVs ††	53,676	17,348	1,737	32
DCFC Density	0.134	0.017	0.024	

EV = Electric Vehicle, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. † AFDC (2024b) data, accessed on July 22, 2024, were used to calculate figures as of December 2023. †† S&P Global Mobility (2024). The number was analyzed at the census tract level as of December 2023 and DCFC density was calculated as the total number of DCFC stations in the cluster divided by the total land area of each census tract.

In addition, a more localized analysis was conducted to gain a deeper understanding of socioeconomic disparities in the distribution of EV charging stations. These findings are discussed in detail in the section covering VDOT's districts and MSAs.

Distribution of Charging Stations Near Interstates Only

Near the conclusion of the study, a Technical Review Panel (TRP) member asked if, along high-volume roadways used by through travelers, DACs have fewer charging stations than one might expect. This question is not necessarily affected by nearby residents' use of EVs, such as BEV adoption rates by county, if charging stations along such roadways are used more by persons traveling longer distances than by nearby residents.

To address this question, the research team determined the distribution of EV charging stations within two miles of interstates (Figure 2). The results were combined with the cluster analysis for ACs, intermediate communities, and DACs. Table 8 provides a summary of the EV charging station distribution and the land area intersected by Virginia's interstates. Advantaged communities contain more than four times as many stations (436 square miles), although most of the land intersected by interstates falls within intermediate areas (2,355 square miles). Table 8 also suggests that these areas might not be equally represented within the two-mile buffer. Advantaged areas span 531.8 square miles, while DACs cover 495.8 square miles, with a station density of 0.820 for ACs, significantly higher than the 0.200 for DACs. A higher density of EV charging stations indicates greater availability per unit of land area.

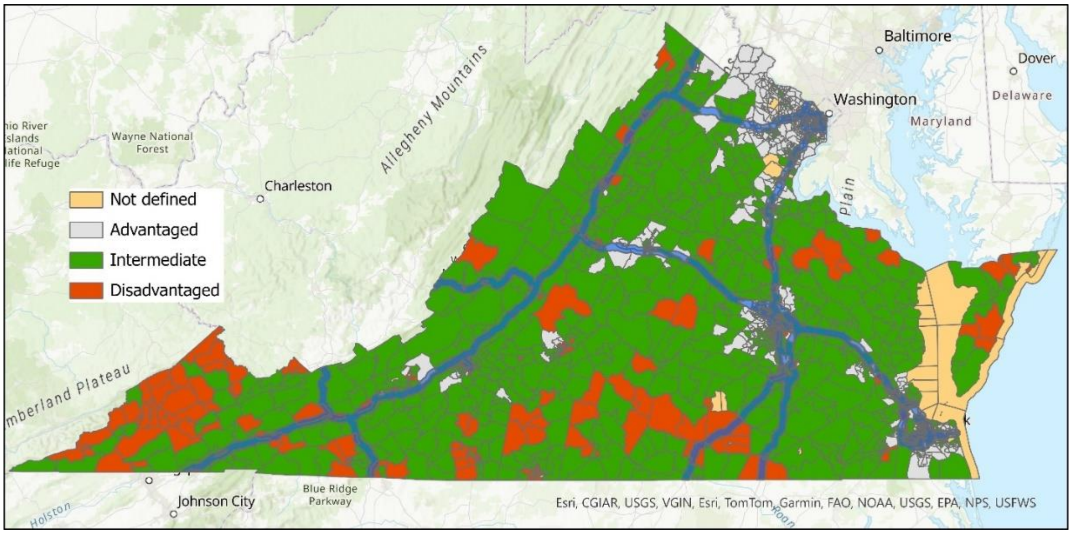

Figure 2. Roads Classified as Interstates (VDOT, 2024d) with a Two-Mile Buffer

Table 8. Summary of EV Charging Stations within Two Miles of Virginia Interstates

Community	Number of EV Charging Stations	Land Area (mile^2)	Charging Stations per Square Mile
Advantaged	436	531.8	0.820
Intermediate	350	2,355.0	0.149
Disadvantaged	99	495.8	0.200

Community classification was based on ACS data (2024). EV charging station data, sourced from AFDC (2024b) and accessed on July 22, 2024, were used to calculate figures as of December 2023.

BEV Adoption and Charging Infrastructure by VDOT District and MSA

The project analyzed regions in Virginia with higher numbers of BEVs and charging infrastructure. Recognizing the uneven distribution of EV adoption across the state, this study initially targeted the urban areas of Richmond, Hampton Roads, and Northern Virginia, as shown in Table 9. These regions, with their more mature EV markets, demonstrated existing infrastructure demands and usage patterns. In subsequent phases of the analysis, the project broadened its scope to encompass areas with lower BEV adoption, including Staunton, Culpeper, Lynchburg, Salem, and Bristol. This expansion aimed to identify tailored strategies for stimulating EV adoption and ensuring sufficient charging infrastructure in these developing EV markets.

The Virginia Department of Transportation's division of the state into nine distinct geographical districts provides a useful framework for examining regional differences in EV adoption and the development of charging infrastructure, as illustrated in Figure 3. Given that

BEV adoption rates and charging infrastructure are more advanced in a metropolitan district like Northern Virginia than in a rural district like Salem, examining district-level nuances can help policymakers tailor policies and infrastructure investments to the unique needs of each region, while also promoting equitable access to electric mobility across the state. To analyze the proximity of DCFC stations to highway exits, this study also examined AFCs (see Figure 4) within the associated VDOT districts.

Table 9. Overview of Direct Current Fast Charging Infrastructure Analyses for Eight Virginia Areas

Area	VDOT District	Alternative Fuel Corridor	Metropolitan Statistical Area
Richmond	Richmond District	I-95, I-64, I-85, I-295	Richmond
Hampton Roads	Hampton Roads District	I-95, I-64	Virginia Beach – Norfolk – Newport News, VA – NC
Northern Virginia	Northern Virginia District	I-95, I-66, I-495	Washington – Arlington – Alexandria, DC – VA – MD – WV
	Fredericksburg District	I-95	
Staunton	Staunton District	I-64, I-81, I-66	Staunton – Stuarts Draft Harrisonburg Winchester VA – WV
Culpeper	Culpeper District	I-64, I-66	Charlottesville
Lynchburg	Lynchburg District		Lynchburg
Salem	Salem District	I-81, I-77	Blacksburg – Christiansburg Roanoke
Bristol	Bristol District	I-81, I-77	

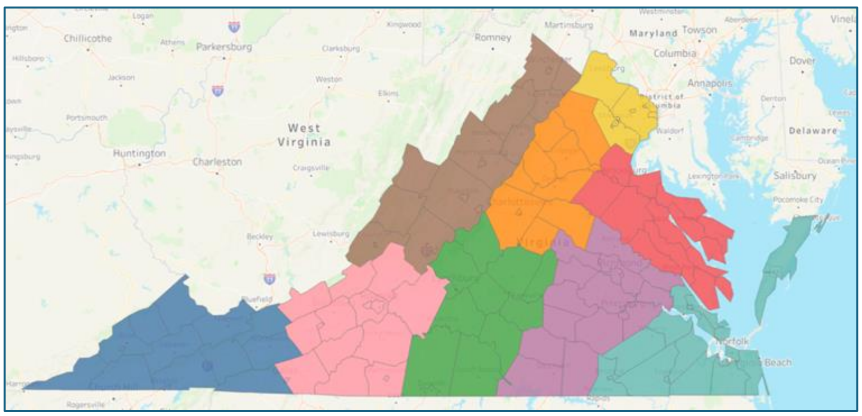

Figure 3. Virginia Department of Transportation Districts

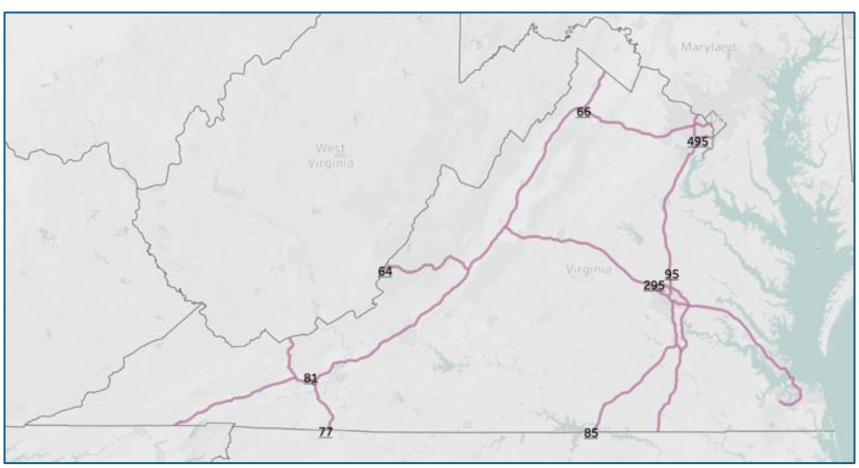

Figure 4. Alternative Fuels Corridors in Virginia through 2022

In addition to the district-level analysis, evaluating these trends at the MSA level provides further insights into the specific dynamics of urban and suburban areas. Metropolitan statistical areas, which encompass both urban cores and their surrounding suburbs, offer a granular perspective on EV adoption patterns and charging infrastructure requirements, as shown in Figure 5. Tools like the EVI-Pro Lite (AFDC 2024a), which utilizes MSA-level data, enabled us to estimate the number of EV charging stations needed to support the projected growth of BEVs in different regions of Virginia. Since they share an MSA, VDOT's Northern Virginia and Fredericksburg districts were grouped under the Northern Virginia subheading. Kingsport-Bristol, the TN-VA MSA within the Bristol District, was excluded from the project's analysis because the BEV fleet size was too small to meet the minimum threshold of EVI-Pro (AFDC 2024a) for DCFC estimates.

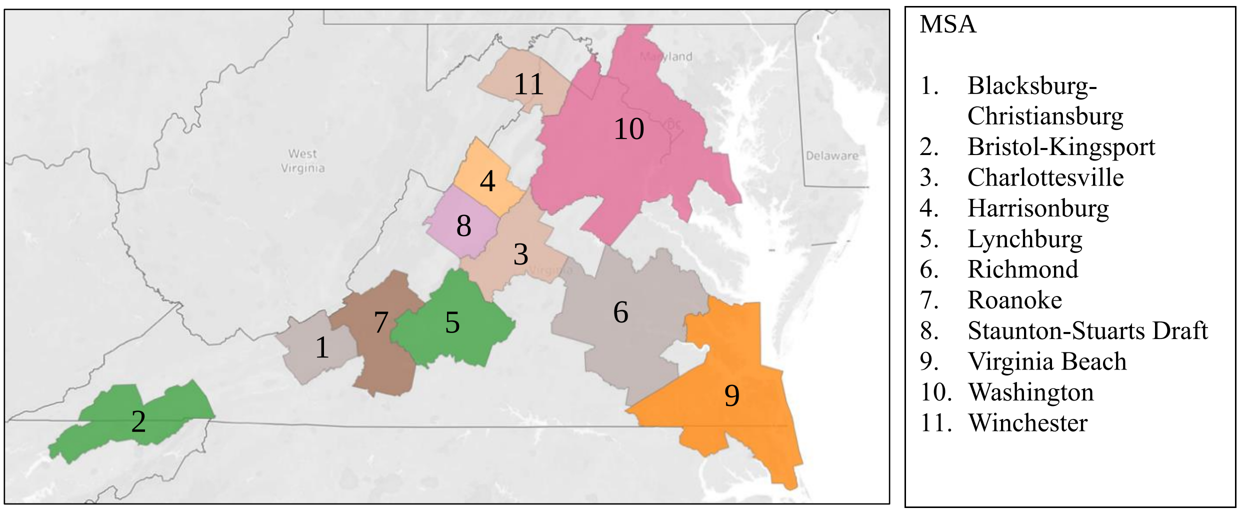

Figure 5. Metropolitan Statistical Areas in Virginia

Tables 10-17 present the results for the Richmond District and Richmond MSA. The results for the remaining districts and MSAs are presented in Appendix A. This data-driven approach ensures that charging infrastructure development is aligned with actual demand, thereby fostering seamless EV adoption and alleviating range anxiety concerns. By combining district-level and MSA-level analyses, this project offers a comprehensive understanding of the multifaceted factors that influence the transition to electric mobility across Virginia. The insights gleaned from this research will inform targeted policy interventions, infrastructure investments, and public awareness campaigns aimed at accelerating the adoption of BEVs and creating a sustainable transportation future for the Commonwealth.

Five-Priority Assessment Framework: Richmond District and Richmond MSA

Figure 6 illustrates the geographic boundaries of VDOT's Richmond District and the Richmond MSA. While both encompass the suburban areas immediately surrounding Richmond City, the maps reveal differences in their outer limits. The VDOT Richmond District extends further outwards, encompassing additional rural areas.

VDOT’s Richmond District

Figure 6 shows that, as of the end of 2023, ten out of eighteen counties in VDOT's Richmond District did not have access to any DCFC stations. These localities are highlighted in red on the map. Table 10 explores this issue by providing a detailed breakdown of EV charging infrastructure by locality, including the number of available Level 2 and DCFC stations, and further dissecting DCFC availability within advantaged, intermediate, and disadvantaged communities. A notable trend emerges: DACs, as identified in Table 10, frequently lack DCFC stations, underscoring the need for greater attention to equitable infrastructure development.

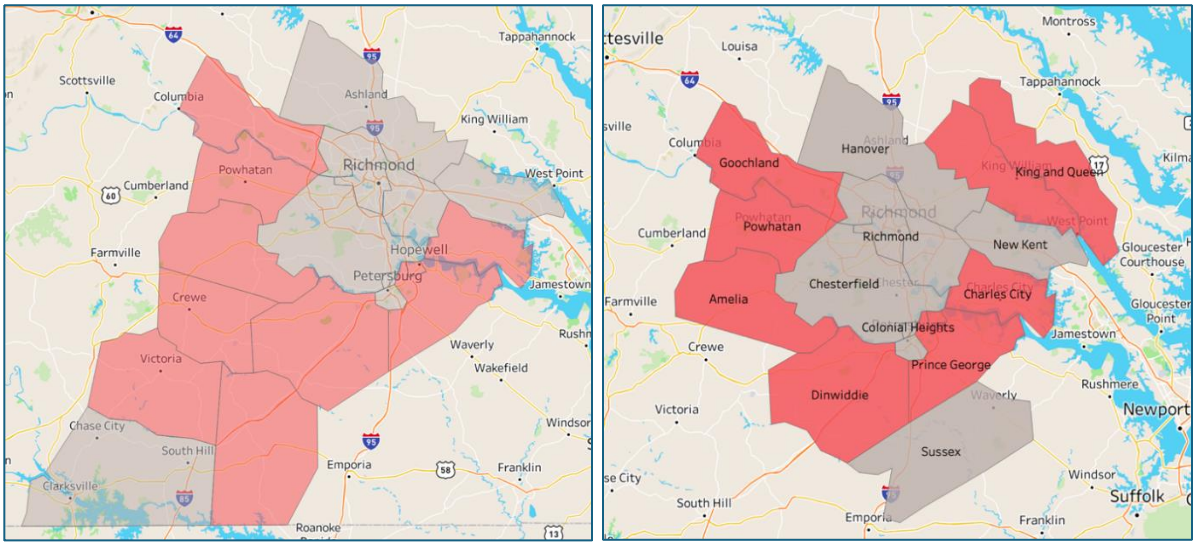

Figure 6. VDOT’s Richmond District (left) and Richmond MSA (right)

While many DACs grapple with the absence of DCFC stations, Henrico County stands out as a notable exception. This county boasts a robust EV charging network, with DCFC stations available across diverse communities, and also demonstrates a high rate of BEV adoption, making it a leading example of how to foster equitable and accessible EV infrastructure.

Table 10. Summary of the Richmond District

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
										Cluster		
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	AC	Inter	DAC
Amelia	8	12	22	83.3	0.7							
Brunswick	1	7	11	57.1	0.2	1	1					
Charles City	3	8	17	112.5	0.8							
Chesterfield	913	1,508	2,367	57	2.1	22	18	7	28	3	25	
Colonial Heights	18	34	49	44.1	0.9	1		1	8		8	
Dinwiddie	12	23	35	52.2	0.5							
Goochland	117	193	288	49.2	2.7	16	16					
Hanover	265	453	687	51.7	1.8	11	9	3	17		17	
Henrico	1,151	1,890	3,134	65.8	3.7	54	44	11	58	7	33	18
Hopewell	8	18	33	83.3	0.5	2	2					
Lunenburg	3	9	7	-22.2	0.3							

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
										Cluster		
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	AC	Inter	DAC
Mecklenburg	13	23	35	52.2	0.4	1		1	6			6
New Kent	55	86	146	69.8	2.0	1		1	1		1	
Nottoway	10	12	13	8.3	0.6	1	1					
Petersburg	10	16	39	143.8	0.7	2		1	8		8	
Powhatan	47	92	139	51.1	1.4	1	1					
Prince George	34	48	64	33.3	0.5	1	1					
Richmond	532	799	1,193	49.3	2.6	69	66	3	8		8	

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero.

Table 11. Proximity of Each Pair of DCFC Stations in the Richmond District

Locality	Min	Median	Mean	Max	Proxy Location
Amelia	22.9	32.6	34.2	54.5	County Administration Building
Brunswick	14.1	59.9	56.2	71.2	County Administration Building
Charles City	10.7	27.6	27.0	70.0	County Administration Building
Chesterfield	0.3	15.6	16.5	58.6	
Dinwiddie	14.5	35.3	32.5	46.4	County Administration Building
Goochland	15.7	24.2	30.1	66.3	County Administration Building
Hanover	0.5	11.2	14.6	73.1	
Henrico	0.001	8.7	13.8	72.7	
Lunenburg	17.3	59.9	59.1	77.6	County Administration Building
Mecklenburg	50.9	66.1	65.0	77.1	
New Kent	18.2	25.6	27.9	78.4	
Nottoway	26.2	44.7	45.0	63.3	County Administration Building
Powhatan	16.6	26.6	29.1	55.4	County Administration Building
Prince George	4.8	26.8	24.2	55.7	County Administration Building
Colonial Heights	3.4	3.4	3.4	3.4	
Hopewell	3.8	23.6	21.4	55.7	5103 Plaza Drive, Hopewell, VA 23860
Petersburg	5.0	28.0	24.6	38.7	
Richmond	0.1	7.7	9.6	21.1	

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Furthermore, this study examined the distances between pairs of DCFC stations in VDOT's Richmond District, as shown in Table 11. While these distances alone do not reveal the complete distribution of DCFC stations across localities and VDOT districts, they provide useful information about the relative proximity and spread of these stations. In localities that lack DCFC stations, proxy locations like county administration buildings, city halls, or sites chosen by the National Electric Vehicle Infrastructure (NEVI) Formula program were utilized to estimate distances.

Community-based and corridor-based public fast charging stations have garnered significant attention as essential components in developing a robust infrastructure for EV drivers.

By strategically placing charging stations within communities and along travel corridors, EV owners can easily and conveniently recharge their vehicles, facilitating both daily commutes and long-distance travel. Recognizing the importance of corridor-based infrastructure, this study has focused on examining DCFC stations along major transportation routes.

Figure 7 visually represents the placement of DCFC stations within VDOT's Richmond District, a region serviced by five AFCs: I-95, I-64, I-85, I-195, and I-295. Table 12 provides a detailed breakdown of the distances between highway exits and their nearest DCFC stations, categorized into ranges exceeding two miles, five miles, and ten miles. Notably, 69% of I-95 exits boast convenient access to DCFC stations within a two-mile radius, while I-64 demonstrates slightly less accessibility, with just under 50% of its exits meeting this standard. However, I-85, I-195, and I-295 present a contrasting picture, necessitating substantial infrastructure enhancements to achieve a similar level of charging accessibility for electric vehicle drivers.

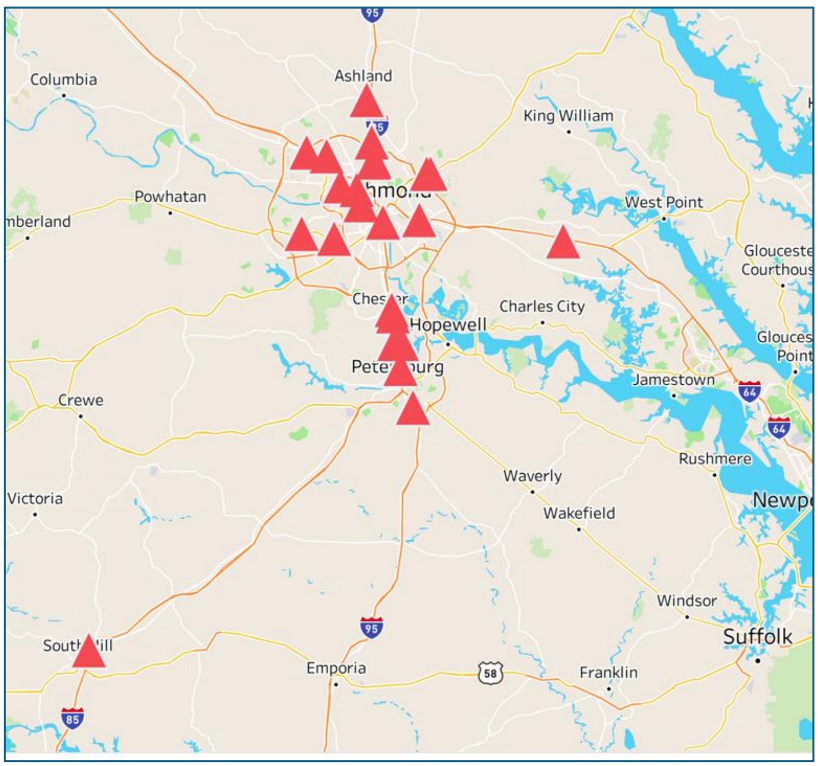

Figure 7. Direct Current Fast Charging Stations in the Richmond District

Table 12. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles		> 10 Miles	
		#	%	#	%	#	%	#	%
I-95	59	41	69%	18	31%	4	7%	0	0%
I-64	42	20	48%	22	52%	12	29%	8	19%
I-85	29	1	3%	28	97%	22	76%	16	55%
I-295	26	8	1%	18	69%	2	8%	0	0%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Richmond MSA

Previous sections of this report highlighted the benefits of employing an MSA-level analysis to estimate the quantity of BEVs, utilizing the EVI-Pro Lite (2024a). Figure 6 provides a visual representation of the geographical boundaries of the Richmond MSA, juxtaposed with VDOT's Richmond District. By the end of 2023, the Richmond MSA had a total of 8,243 registered BEVs, making up 6.6% of new vehicle registrations that year. The area is served by a network of 28 DCFC stations, equipped with a total of 136 charging ports, as detailed in Table 13. In an effort to promote equitable access to charging infrastructure, 13% of these ports (18 ports) were located in DACs. Additionally, 7% of the ports were situated in advantaged areas. The current network had an average distance of 16 miles between stations within the Richmond MSA.

Table 13. Overview of the Richmond MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster			Min	Median	Mean	Max
						AC	Inter	DAC				
8,243	6.6%	182	158	28	136	10 (7%)	108 (79%)	18 (13%) †	0	14.3	15.9	3.6

AC = Advantaged community, Inter = Intermediate community, DAC = Disadvantaged community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment.
# BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal 100% due to rounding adjustments.

Table 14 projects a notable rise in BEVs within the Richmond MSA by 2030, ranging from a conservative 20% increase to a more ambitious 50% increase. The table also outlines the corresponding number of charging ports required to support each growth scenario. The analysis suggests that the existing charging infrastructure could likely handle a 30% increase in BEVs. However, meeting the demands of a 50% increase would necessitate substantial investment in DCFC stations. Expanding the charging network, particularly DCFC stations, is not only essential for meeting the needs of current BEV owners but also for incentivizing future adoption and mitigating range anxiety concerns.

Table 14. Projected BEVs and Needed Charging Infrastructure in the Richmond MSA by 2030

	20%	30%	40%	50%
BEVs	29,536	51,724	86,892	140,839
Public DC Fast Charging Ports †	45	91	143	263
Number of Additional Stations with 8 EVSE Needed			0.88	15.88
Number of Additional Stations with 4 EVSE Needed			1.75	31.75

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

Table 15 presents detailed information regarding BEVs, including the number of DCFC stations and their associated EVSE. Additionally, this project incorporated socioeconomic factors and interstate ratios to differentiate between local and non-local traffic patterns. Notably, with the exception of Henrico County, this MSA demonstrated a lack of DCFC availability in DACs. This absence is concerning, as several localities within the MSA are experiencing significant growth in BEV adoption yet remain underserved by DCFC infrastructure.

Table 15. Richmond MSA-Level Summary

Locality	BEVs			Number of DCFC EVSE						Travel to Work		
	2023	Growth Rate	DC FC	Rate	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Amelia	22	83.3						1.4	0	68.7	15.6	0
Charles City	17	112.5						2.4	0.7	70.1	9.4	0
Chesterfield	2,367	57	7	11.8		3	25	14.9	5.3	39.6	4.3	15.2
Colonial Heights	49	44.1	1	163.3			8	17.2	3.5	35.2	2.5	60
Dinwiddie	35	52.2						4.7	0.2	51.8	12.3	54.1
Goochland	288	49.2						6.5	0.6	50.1	6.6	50.5
Hanover	687	51.7	3	24.7			17	7.8	4.9	37.3	5.3	54.2
Henrico	3,134	65.8	11	18.5	18	7	33	24.4	10.3	25.2	4.1	38.2
Hopewell	33	83.3						21.3	4.2	36	5.3	28.7
King And Queen	3	50						0.9	0.7	61.2	17.2	0
King William	24	118.2						2.3	2.1	64.5	13.8	0
New Kent	146	69.8	1	6.8			1	0.7	0.8	59.2	5.5	70.6
Petersburg	39	143.8	1	205.1			8	41.6	3.7	33.8	5.4	52.8
Powhatan	139	51.1						1	1.9	60.8	9	0
Prince George	64	33.3						7.7	11.6	34.9	7.1	47.4
Richmond City	1,193	49.3	3	6.7			8	45.7	7.3	24.6	4.5	36.6
Sussex	13	18.2	1	615.4			8	7.3	0.9	63.1	12.9	59.4

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged community, Inter = Intermediate community, DAC = Disadvantaged community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Richmond MSA

The previous section outlined the five-priority assessment process used to determine the relative importance of factors affecting DCFC installation. Table 16 summarizes the results of the priority assessment of EV charging infrastructure needs in the Richmond MSA. The results are listed in order of areas with the greatest BEV adoption, with prioritized localities listed first. Table 16 presents the number of BEVs in 2023; the projected number of BEVs by 2030 under scenarios of 30%, 40%, and 50% growth; the number of DCFC stations as of 2023; the DCFC EVSE as of 2023, categorized by advantaged, intermediate, and disadvantaged communities; and relevant demographic factors.

The localities identified as having the highest priority needs for further BEV development and investment include Goochland, Powhatan, Richmond City, Henrico, and Chesterfield. The detailed information provided in the table for each of these localities should be used to develop targeted strategies and initiatives to accelerate BEV adoption and build a robust charging network across the Richmond MSA region.

Table 16. Five-Priority Assessment of the Richmond MSA

	BEVs as of 2023			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
County	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Goochland	288	5.3	49	1,807	3,036	4,921				6	1	50	50
Powhatan	139	3.7	51	872	1,465	2,375				1	2	39	0
Richmond City	1,193	6.4	49	7,486	12,576	20,384		8		46	7	75	37
Henrico	3,134	10.3	66	19,665	33,037	53,547	7	33	18	24	10	75	38
Chesterfield	2,367	6.1	57	14,853	24,951	40,442	3	25		15	5	60	15
Hanover	687	4.7	52	4,311	7,242	11,738		17		8	5	63	54
New Kent	146	5.8	70	916	1,539	2,495		1		1	1	41	71
Petersburg	39	2.8	144	245	411	666		8		42	4	66	53
Hopewell	33	2.3	83	207	348	564				21	4	64	29
Colonial Heights	49	3.1	44	307	517	837		8		17	4	65	60
Prince George	64	1.3	33	402	675	1,094				8	12	65	47
Sussex	13	1.6	18	82	137	222		8		7	1	37	59
Dinwiddie	35	0.9	52	220	369	598				5	0	48	54
King William	24	1.9	118	151	253	410				2	2	36	0
Charles City	17	3.9	113	107	179	290				2	1	30	0
King And Queen	3		50	19	32	51				1	1	39	0
Amelia	22	1.7	83	138	232	376				1	0	31	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged community, Int = Intermediate community, DAC = Disadvantaged community.
#: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities 92024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Table 17. Projected DCFC Stations Needed by Locality in the Richmond MSA by 2030

	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
County	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Goochland	0	1.5	2.6	4.2	1.5	2.6	4.2
Powhatan	0	0.7	1.2	2	0.7	1.2	2
Richmond City	3	6.4	10.7	17.3	3.4	7.7	14.3
Henrico	11	16.7	28.1	45.5	5.7	17.1	34.5
Chesterfield	7	12.6	21.2	34.4	5.6	14.2	27.4
Hanover	3	3.7	6.2	10	0.7	3.2	7
New Kent	1	0.8	1.3	2.1		0.3	1.1
Petersburg	1	0.2	0.3	0.6			
Hopewell	0	0.2	0.3	0.5	0.2	0.3	0.5
Colonial Heights	1	0.3	0.4	0.7			
Prince George	0	0.3	0.6	0.9	0.3	0.6	0.9
Sussex	1	0.1	0.1	0.2			
Dinwiddie	0	0.2	0.3	0.5	0.2	0.3	0.5
King William	0	0.1	0.2	0.3	0.1	0.2	0.3
Charles City	0	0.1	0.2	0.2	0.1	0.2	0.2
King And Queen	0	0	0	0	0	0	0
Amelia	0	0.1	0.2	0.3	0.1	0.2	0.3

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values.

Table 17 identifies the number of additional DCFC stations with four ports needed to accommodate 30%, 40%, and 50% growth scenarios by 2030, taking into account their projected growth rates. This analysis assesses the current state of DCFC infrastructure, forecasts its development through 2030, and identifies areas where additional stations are needed. For instance, Goochland County, the area of highest priority in the Richmond MSA and currently without any DCFC stations, would require 1.5, 2.6, or 4.2 charging stations (each with 4 DCFC ports) by 2030 to accommodate a 30%, 40%, or 50% increase in BEV adoption, respectively. Richmond City, the area of third highest priority within the MSA and currently equipped with three DCFC stations, would need to add 3.4, 7.7, or 14.3 more stations to meet projected BEV growth rates of 30%, 40%, or 50% by 2030, resulting in 6.4, 10.7, or 17.3 stations, respectively. This information serves as a valuable resource for planning and implementing a comprehensive charging infrastructure to meet the growing demand for BEVs. It enables stakeholders to strategically allocate resources and ensure adequate infrastructure development in anticipation of future needs.

Analysis of Remaining VDOT Districts and Associated MSAs

Appendix A provides detailed results for the remaining eight VDOT districts; Hampton Roads, Northern Virginia, Fredericksburg, Staunton, Culpeper, Lynchburg, Salem, and Bristol, along with their respective MSAs, Virginia Beach, Washington, Staunton-Stuarts Draft, Harrisonburg, Winchester, Charlottesville, Lynchburg, Blacksburg-Christiansburg, and Roanoke. Each analysis includes:

- District-based summary of BEVs, DCFC stations, and socioeconomic disparity
- Proximity of each pair of DCFC stations within the district
- Number of AFC exits with DCFC stations located within or more than two miles from the exit
- Metropolitan Statistical Area overview of BEVs, EV infrastructure, and socioeconomic disparities
- Projected number of BEVs and charging infrastructure needed by 2030
- Metropolitan Statistical Area-level summary detailing each locality's BEV, DCFC availability, and socioeconomic disparities
- Five-priority assessment ranking of localities, by number of DCFC installations needed
- Projected number of DCFC stations needed by 2030, by locality

A supplemental file provides data on locality area, the number of BEVs and DCFCs as of 2023, population in 2022, cluster analysis results (1: ACs, 2: intermediate communities, and 3: DACs), BEVs per 1,000 people, DCFCs per 1,000 people, and DCFCs per 1,000 BEVs. As discussed in the Implementation subsection, this information may help policymakers better understand the current state of BEVs and charging infrastructure, supporting efforts to strengthen the EV ecosystem.

Detailed analyses were conducted for each locality within each VDOT district and their corresponding MSAs. This section aims to synthesize these results to provide a comprehensive view of BEV adoption, EV charging infrastructure, and socioeconomic disparities across the state. The insights gained from this analysis can guide Virginians and policymakers in fostering the development of a more equitable and inclusive EV ecosystem throughout Virginia. By addressing disparities, these efforts can help ensure that all communities benefit from the growing EV infrastructure.

MSAs with High BEV Adoption Rates

As of 2023, the Virginia MSAs with high BEV adoption rates were Washington, Richmond, and Virginia Beach (Table 18). The Washington MSA, in particular, needs to address socioeconomic disparities, as DACs accounted for only 4% of DCFC EVSE. With significant projected growth, Table 19 indicates that the Washington MSA will need 31 additional DCFC stations to accommodate a 40% increase in BEVs and 218 more stations for a 50% increase by 2030. For a 50% increase, the Richmond and Virginia Beach MSAs will require 32 and 11 additional DCFC stations, respectively.

Table 18. BEV Adoption Rates for the Washington, Richmond, and Virginia Beach MSAs

Metropolitan Statistical Area (MSA)	BEVs		Number of Charging Stations			Number of DCFC EVSE			
	# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster		
							AC	Inter	DAC
Washington MSA	55,045	13.4%	769	677	110	496	352 (71%)	122	22 (4%)
Richmond MSA	8,243	6.6%	182	158	28	136	10 (7%)	108	18 (13%)
Virginia Beach MSA	7,540	4.6%	163	130	37	124	20 (16%)	78	26 (21%)

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged community, Inter = Intermediate community, DAC = Disadvantaged community.

Table 19. Potential Charging Station Needs for the Washington, Richmond, and Virginia Beach MSAs

MSA	Quantity	20%	30%	40%	50%
Washington MSA	BEVs	176,497	309,080	519,235	841,602
	DCFC Port Requirements for BEV Growth	223	449	620	1,369
	Number of Additional Stations with 4 EVSE Needed			31.00	218.25
Richmond MSA	BEVs	29,536	51,724	86,892	140,839
	DCFC Port Requirements for BEV Growth	45	91	143	263
	Number of Additional Stations with 4 EVSE Needed			1.75	31.75
Virginia Beach MSA	BEVs	27,017	47,312	79,482	128,828
	DCFC Port Requirements for BEV Growth	40	59	108	166
	Number of Additional Stations with 4 EVSE Needed				10.50

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, MSA = Metropolitan Statistical Area.

MSAs with Moderate BEV Adoption Rates

As of 2023, the Charlottesville and Roanoke MSAs had moderate levels of BEV adoption (Table 20). The Charlottesville MSA had a higher level of new BEV registrations in 2023, but economic disparities exist in access to DCFC stations. In the Roanoke MSA, there were no DCFC stations in ACs, a trend observed in MSAs with lower BEV adoption rates in Virginia. Table 21 shows that these two MSAs with modest levels of BEV adoption may need 13 and 7 DCFC stations in order to meet a 50% increase in BEVs.

Table 20. BEV Adoption Rates for the Charlottesville and Roanoke MSAs

	BEVs		Number of Charging Stations			Number of DCFC EVSE			
	# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster		
							AC	Inter	DAC
Charlottesville MSA	2,286	9.6%	52	41	12	31	17 (55%)	13	1 (3%)
Roanoke MSA	2,953	2.8%	41	28	14	44	0	40	4 (9%)

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community.

Table 21. Potential Charging Station Needs for the Charlottesville and Roanoke MSAs

MSA	Quantity	20%	30%	40%	50%
Charlottesville MSA	BEVs	8,191	14,344	24,098	39,058
	DCFC Port Requirements for BEV Growth	18	25	39	84
	Number of Additional Stations with 4 EVSE Needed			2	13.25
Roanoke MSA	BEVs	10,581	18,530	31,129	50,455
	DCFC Port Requirements for BEV Growth	24	44	63	73
	Number of Additional Stations with 4 EVSE Needed			4.75	7.25

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment

MSAs with Low BEV Adoption Rates

Table 22 presents five MSAs with low BEV adoption rates: Lynchburg, Winchester, Blacksburg-Christiansburg, Harrisonburg, and Staunton-Stuarts Draft. The MSAs had no DCFC infrastructure in ACs. Table 23 suggests the MSAs with lower levels of BEV adoption may only require two or three DCFC stations, although the number of BEVs increases by 50% by 2030.

Table 22. Metropolitan Statistical Areas with Low BEV Adoption Rates

MSA (Metropolitan Statistical Area)	BEVs		Number of Charging Stations			Number of DCFC EVSE			
	# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster		
							AC	Inter	DAC
Lynchburg	624	2.9%	16	13	3	18	0	8	10 (56%)
Winchester, VA-WV	590	3.7%	13	11	3	13	0	13	0
Blacksburg-Christiansburg	558	3.5%	38	36	2	6	0	2	4 (67%)
Harrisonburg	393	3.2%	24	21	2	12	0	0	12 (100%)
Staunton-Stuarts Draft	367	2.3%	22	12	10	27	0	27	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community.

Table 23. Potential Charging Station Needs for Metropolitan Statistical Areas with Low BEV Adoption

MSA	Quantity	20%	30%	40%	50%
Lynchburg MSA	BEVs	2,236	3,916	6,578	10,662
	DCFC Port Requirements for BEV Growth		9	12	26
	Number of Additional Stations with 4 EVSE Needed				2
Winchester, VA-WV MSA	BEVs	2,114	3,702	6,219	10,081
	DCFC Port Requirements for BEV Growth	7	11	17	24
	Number of Additional Stations with 4 EVSE Needed				2.75
Blacksburg-Christiansburg MSA	BEVs	1,999	3,501	5,882	9,534
	DCFC Port Requirements for BEV Growth	7	9	15	18
	Number of Additional Stations with 4 EVSE Needed		0.75	2.25	3

MSA	Quantity	20%	30%	40%	50%
Harrisonburg MSA	BEVs	1,408	2,466	4,143	6,715
	DCFC Port Requirements for BEV Growth	6	8	14	21
	Number of Additional Stations with 4 EVSE Needed			0.50	2.25
Staunton-Stuarts Draft MSA	BEVs	1,315	2,303	3,869	6,271
	DCFC Port Requirements for BEV Growth	5	8	14	16
	Number of Additional Stations with 4 EVSE Needed				

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, MSA = Metropolitan Statistical Area.

Summary of Findings

While BEVs account for a tiny fraction of total registered vehicles in Virginia (e.g., 0.6% in 2022), the year-on-year growth rates for 2019-2023 have shown an average value of 51%, ranging from 43% to 57% (Table 24). For the 2021-2023 period, BEVs' share of new vehicle registrations increased, rising from 3.1% in 2021 to 8.3% as shown in Table 25.

Table 24. Summary of Battery Electric Vehicle (BEV) Growth in Virginia, 2019-2023

	2019	2020	2021	2022	2023
Number of BEVs	14,197	20,305	30,484	47,892	72,881
BEV Growth Rates		43%	50%	57%	52%
Total Registered Vehicles	7,647,692	7,669,209	7,702,236	7,765,074	NA

Data source: Virginia Clean Cities (2024). NA = the total number of registered vehicles for 2023 is not yet published.

Table 25. Summary of Battery Electric Vehicle New Vehicle Registrations in Virginia, 2021-2023

	2021	2022	2023
Number of BEVs in New Vehicle Registrations	10,925	17,902	28,162
BEV Growth Rates among New Vehicle Registrations	118.5%	63.9%	57.3%
Percentage of BEV Registrations in Total New Vehicle Registrations	3.1%	5.9%	8.3%
Total New Vehicle Registrations	356,126	301,309	341,317

Data Source: S&P Global Mobility (2024)

Looking ahead to 2030, these growth rates suggest Virginia may need hundreds of additional DCFC ports beyond its 2023 total of 1,096. With a modest growth rate of 20% in BEVs, Virginia does not need additional ports—but with a 50% growth rate, Table 26 indicates Virginia may need almost 700 such ports.

Table 26. Possible Battery Electric Vehicle (BEV) Growth in Virginia, 2023-2030

Growth Rate	20%	30%	40%	50%
Projected BEV Number	261,146	457,317	768,264	1,245,240
Required Public DCFC Ports	762	1,334	1,438	1,790
Additional Public DCFC Ports Needed		238	342	694

Data Sources: Virginia Clean Cities (2024) and EVI-Pro Lite (2024a)

Presently, advantaged communities have more BEVs—and more charging infrastructure—than DACs, even though DACs have more land area. For instance, in 2023, ACs had 4.1 times as many charging stations (684) as DACs (165) as shown in Table 27. For DCFC EVSE, ACs had 403 units compared to 156 in DACs, yielding a ratio of 2.6 to 1. To put these figures in context, ACs had 53,676 BEVs, whereas DACs had only 1,737, creating a ratio of 30.9

to 1. Advantaged and disadvantaged areas, however, are not equal in size: 686 census tracts are advantaged and 350 are disadvantaged (ratio of 1.96 to 1), while the ratio of advantaged to disadvantaged land area is 0.51 to 1, as shown in the last row of Table 27.

Table 27. Distribution of Electric Vehicle Infrastructure and BEV Use in Virginia, 2023

	Advantaged Community	Disadvantaged Community	Ratio
Number of Charging Locations	684	165	4.1 to 1
Number of DCFC EVSE	403	156	2.6 to 1
Number of BEVs	53,676	1,737	30.9 to 1
Number of Census Tracts	686	350	1.96 to 1
Land Area	3,001	6,588	0.5 to 1

Data Sources: AFDC (2024b), ACS (2024) and S&P Global Mobility (2024).

CONCLUSIONS

- *The total number of BEVs grew substantially from 2019 through 2023.* However, BEVs still make up less than 1% of all registered vehicles, suggesting there is considerable potential for further growth in Virginia (Table 24).

- *The percentage of new BEV registrations rose significantly in recent years.* In 2023 alone, BEV registrations increased by 57.3%, making up 8.3% of all new vehicle registrations. With similar growth rates, Virginia is likely to see more BEVs on its road (Table 25).

- *Virginia is expected to have 1.2 million BEVs on its roads by 2030, if BEV adoption increases by 50%, or about 260,000 BEVs if a more conservative 20% increase is achieved.* As of 2023, Virginia had 1,096 DCFC ports. If the state experiences a 30%, 40%, or 50% increase in BEVs, it will need an additional 238, 342, or 694 DCFC ports, respectively (Table 26).

- *Advantaged communities have more charging infrastructure and BEVs, but less land area than DACs*. For example, advantaged communities have 4.1 times the number of charging stations, 2.6 times the number of DCFC EVSE, and 30.9 times the number of BEVs than DACs—while only having half the land area of DACs (Table 27).

- *Within two miles of interstates in Virginia, ACs have significantly more EV charging infrastructure compared to DACs.* Although the land area designated as advantaged (531 square miles) and disadvantaged (495.8 square miles) is nearly equal, ACs host approximately four times as many charging stations, with 436 in ACs compared to 99 in DACs (Table 8).

RECOMMENDATION

1. *VDOT's Office of Transportation Sustainability should incorporate these results as one factor in support of the "equity considerations" noted in the Virginia Electric Vehicle Infrastructure Deployment Plan (VDOT 2023) and the "equitable access" goal noted in the distribution of NEVI formula funds (VDOT 2024).*

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations (i.e., planning, program development, delivery, maintenance, and daily activities). The implementation plan and the accompanying benefits are outlined in this section.

Implementation

There are two mechanisms through which VDOT will implement *Recommendation 1*. First, the VDOT Office of Transportation Sustainability will use the results to support VDOT's planning and deployment of over $100 million received as part of the NEVI program beginning in 2025 and prior to 2028. Second, during calendar year 2025, the Virginia Transportation Research Council (VTRC), in coordination with the Office of Sustainability and the author, will share selected results with metropolitan planning organizations (MPOs) and planning district commissions (PDCs) that may be interested in applying for federal grants.

Use by VDOT

The Virginia Department of Transportation (2024) has identified three key factors for distributing funds under the NEVI program, the third of which is "providing equitable access to EV charging stations across suburban, rural, and disadvantaged communities." VDOT's Office of Sustainability will, as appropriate, incorporate district, MSA, or statewide findings from this report into the distribution of NEVI funds. Findings for districts and MSAs are presented in Tables 10-17 (Richmond District and Richmond MSA) and Appendix A (for the remaining districts and MSAs). Statewide findings are presented in Table 8 and Figure 2.

As an example, consider the Richmond MSA. While other factors, such as convenience and reliability, will influence the location of charging stations, if all other factors are equal, one could use Tables 16 and 17 to identify Goochland as one of several locations, from an equity perspective, where chargers are needed. If BEV demand is expected to increase by 30% from 2023 to 2030, Goochland (which currently has no DCFC stations) will require roughly two charging stations, each with four DCFC ports. In this example, the supplemental files which show per-capita results support this analysis: of the nine counties or cities in the Richmond MSA that have no DCFCs, Goochland has the largest number of BEVs (Table 28).

As another example, suppose a charging station is proposed near the southern portion of Interstate 95 or 85 where the market is largely expected to consist primarily of long-distance travelers. Again, multiple factors will influence where a station is placed. If all other factors are equal, however, then the DACs shown along these corridors in red near Virginia's southern border (see Figure 2) may be identified as desirable locations.

Use by Regions

The Virginia Department of Transportation will share the “Five Priority Assessment” and “Projected DCFC Stations Needed by Locality” for each MSA with the appropriate MPO and PDC staff to support local and regional applications for grant funding for charging stations. Sharing this information with localities aligns with VDOT’s (2023) *Electric Vehicle Infrastructure Deployment Plan*, which states that “Potential locations and benefits to urban, rural, and underserved or disadvantaged communities will be further clarified through dialogue with those communities.”

The five-priority assessment and projected DCFC stations needed by each MSA, such as those shown in Tables 16 and 17 for the Richmond MSA, provide a roadmap for MPOs, PDCs and localities to address the increasing number of BEVs in their regions. By prioritizing areas with the greatest need, limited resources can be allocated more effectively to support EV adoption. This approach also ensures equitable access to this new technology, particularly among DACs. For instance, in the case of the Richmond Regional PDC (known as PlanRVA) and the Crater PDC, the results of the five-priority assessment, shown in Tables 16 and 17, identify the number of DCFC stations needed, with supplemental files provided for additional context. Table 28 subsequently presents the combined results for the Richmond MSA, including per capita metrics such as BEVs per 1,000 people and DCFC per 1,000 BEVs.

Table 28. Per Capita Results of BEVs and DCFC in the Richmond MSA

Locality	BEVs	BEVs per 1,000 people	DCFC	DCFC per 1,000 BEVs
Goochland	288	12	0	0
Powhatan	139	5	0	0
Richmond (city)	1,193	5	8	7
Henrico	3,134	9	58	19
Chesterfield	2,367	7	28	12
Hanover	687	6	17	25
New Kent	146	6	1	7
Petersburg	39	1	8	205
Hopewell	33	1	0	0
Colonial Heights	49	3	8	163
Prince George	64	2	0	0
Sussex	3	0	8	2,667
Dinwiddie	35	1	0	0
King William	24	1	0	0
Charles City	17	3	0	0
King And Queen	3	0	0	0
Amelia	22	2	0	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, MSA = Metropolitan Statistical Area

A suitable venue for introducing these results to MPOs and PDCs (and by extension their member localities) is the MPO quarterly coordination meeting hosted by the Office of Intermodal Planning and Investment.

Benefits

Studies show that a robust DCFC network is essential for promoting widespread EV adoption, with a positive relationship between charging infrastructure and EV uptake observed consistently across different regions, weather conditions, and grid networks (Power and Johnson 2024; Qadir et al. 2024; Sierzchula et al. 2024). This report reinforces that access to charging stations yields two types of benefits: (1) mitigating range anxiety among EV drivers and (2) fostering DCFC opportunities for DACs. Using existing data, it is possible to quantify the first benefit from a societal perspective, drawing on sources such as U.S. DOE (2024) and U.S. EPA (2024).

Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have long-term economic consequences. The estimated social cost of GHG (SC-GHG) represents the estimated economic damage arising from an additional metric ton of these gases in a given year (Bledsoe et al. 2024; Fisher 2024). This measure seeks to account for the long-term economic impact of GHG emissions, including agricultural losses, negative health outcomes, increased property damage, and changes in energy costs driven by rising temperatures.

On an annual basis, one BEV produces 2,059 pounds of CO_2 equivalent in Virginia, whereas an ICE vehicle emits 12,594 pounds of CO_2 equivalent (U.S. DOE 2024). Thus, each BEV on the road that replaces one ICE vehicle can reduce emissions by 10,535 pounds of CO_2 equivalent. The U.S. EPA (2024) has also reported that the social cost of carbon dioxide is $190 per metric ton. This implies that replacing one ICE vehicle with a BEV could save society $907.93 per vehicle annually.

Virginia had 72,881 BEVs as of 2023, and that number resulted in an estimated annual savings of approximately $66 million in social costs. However, with a BEV adoption rate of about 0.9% in 2023, the state possesses significant untapped potential. Addressing range anxiety and expanding DCFC infrastructure are crucial steps to accelerate BEV adoption. By investing in these areas, Virginia can significantly enhance its environmental benefits and economic savings. For instance, a 20% increase in BEV adoption could elevate annual savings to $237 million, while a 50% increase could boost savings to $1.1 billion (Table 29). These figures underscore the substantial economic advantages of a more widespread transition to EVs.

Table 29. Potential Societal Benefits of Providing Electric Vehicle Charging Infrastructure in Virginia

BEV Growth Rate	20%	30%	40%	50%
Projected BEVs	261,146	457,317	768,264	1,245,240
Required DCFC Ports	762	1,344	1,438	1,790
Yearly Social Cost of GHG Savings	$237 million	$415 million	$698 million	$1.1 billion

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, GHG = Greenhouse gas

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APPENDIX A.
BEV ADOPTION, DCFC INFRASTRUCTURE, AND SOCIOECONOMIC DISPARITIES ACROSS VIRGINIA

Tables 10-17 in the main report provide analyses of BEVs, EV charging infrastructure, and the socioeconomic contexts of DCFC stations within VDOT’s Richmond District and the Richmond MSA. Analyses for the other VDOT’s districts and their respective MSAs are included in Tables A1-A60 of this Appendix.

Hampton Roads District and Virginia Beach MSA

VDOT's Hampton Roads District largely coincides with the Virginia Beach-Norfolk-Newport News, VA-NC MSA, hereafter referred to as the Virginia Beach MSA, as depicted in Figure A1. This geographical overlap provides a framework for our subsequent analysis of BEVs, charging infrastructure, and socioeconomic disparities within a region. It is important to acknowledge that the Virginia Beach MSA encompasses portions of North Carolina, as illustrated in Figure A2. However, for the purposes of this study, our analysis was limited to the Virginia portion of the MSA. This deliberate focus allowed for a more in-depth examination of the factors influencing BEV adoption and charging infrastructure development within the Commonwealth of Virginia.

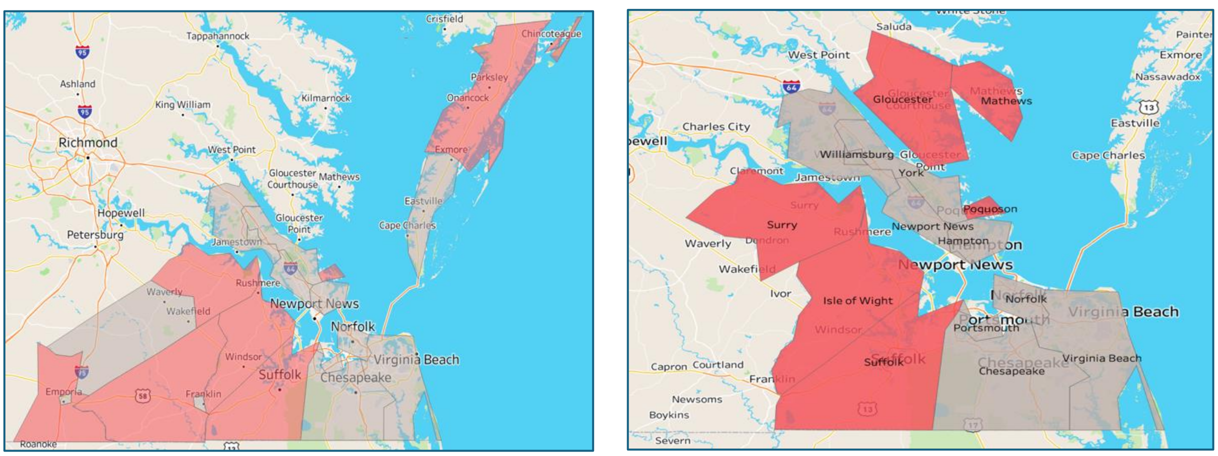


Figure A1. VDOT’s Hampton Road District (left) and Virginia Beach MSA (right)

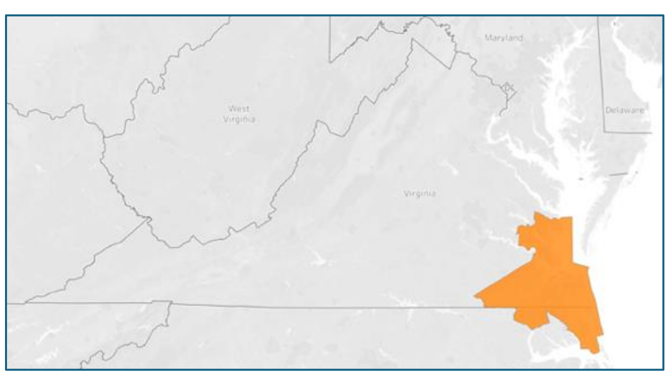


Figure A2. Virginia Beach-Norfolk-Newport News, VA-NC MSA

Hampton Roads District

The Hampton Roads region comprises twenty localities, of which seven lacked DCFC stations in 2023, a crucial element for widespread BEV adoption. The areas without DCFC stations and marked red in Figure A1, are predominantly rural and distant from major urban centers, underscoring the correlation between geography and charging infrastructure availability. Table A1 offers a granular look at BEV adoption in Hampton Roads by detailing number of BEVs, charging stations (both DCFC and Level 2), and socioeconomic disparities for each locality. This comprehensive overview provides policymakers and stakeholders with essential data to identify areas underserved by EV charging infrastructure and develop targeted strategies to ensure equitable access across the region.

Table A1. Summary of the Hampton Roads District

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster		
										AC	Inter	DAC
Accomack	145	179	116	-35.2	0.8	3	3					
Chesapeake	504	834	1,161	39.2	1.5	18	12	7	15	8	7	
Emporia	2	2	0	-100	0.1	2	1	1	4		4	
Franklin City	3	3	8	166.7	0.2	2	1	1	8		8	
Greensville	2	4	7	75	0.5							
Hampton	157	248	376	51.6	1.1	9	7	3	6		5	1
Isle of Wight	64	114	170	49.1	1.6	1	1					
James City	271	487	687	41.1	2.5	6	5	1	4	4		
Newport News	215	330	491	48.8	1.0	23	17	7	30		30	
Norfolk	436	617	868	40.7	2.0	30	24	7	22		14	8
Northampton	26	37	39	5.4	1.4	1		1	4			4
Poquoson	22	38	55	44.7	1.5							
Portsmouth	73	111	158	42.3	0.8	4	3	1	8			8
Southampton	4	12	18	50	0.5							
Suffolk	165	291	436	49.8	1.5	5	5					
Surry	5	4	7	75	0.4							
Sussex	5	11	13	18.2	0.8	2	1	1	8		8	
Virginia Beach	1,587	2,509	2,470	-1.6	1.4	41	34	7	25		16	9
Williamsburg	51	71	89	25.4	2.9	12	10	2	5		5	
York	166	276	458	65.9	2.0	14	12	2	9	8	1	

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.

To better understand the distribution of DCFC stations within the Hampton Roads District, Table A2 provides detailed statistics on the physical distances between each pair of stations. As some areas within the district lacked DCFC stations, proxy locations were utilized to ensure comprehensive analysis. This information on the proximity of DCFC stations is crucial for effectively planning and developing future charging infrastructure to support the growing adoption of BEVs.

Table A2. Proximity of Each Pair of DCFC Stations in the Hampton Roads District

Locality	Min	Median	Mean	Max	Proxy Location
Accomack	16.5	65.3	68.1	124.7	County Administration Building
Chesapeake	0.0	18.4	24.3	72.1	
Emporia	20.5	68.8	68.4	109.9	
Franklin City	21.6	90.2	88.3	131.5	City Hall
Greensville	2.6	67.6	65.4	107.5	County Administration Building
Hampton	0.4	18.8	20.6	68.2	
Isle of Wight	65.4	134.7	131.8	173.3	County Administration Building
James City	2.9	37.1	31.0	49.0	
Newport News	0.0	22.6	22.7	64.5	
Norfolk	0.1	14.5	20.6	75.0	
Northampton	44.3	51.5	54.3	93.8	
Poquoson	4.1	20.9	21.6	69.7	City Hall
Portsmouth	6.5	37.8	31.3	61.1	
Southampton	7.2	44.5	45.3	87.9	County Administration Building
Suffolk	13.4	25.5	28.0	68.6	City Hall
Surry	10.3	35.8	32.6	61.3	County Administration Building
Sussex	32.5	32.5	32.5	32.5	
Virginia Beach	0.3	20.5	25.1	80.6	
Williamsburg	0.1	40.9	33.3	49.3	
York	2.8	40.6	33.6	61.9	

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Understanding the distribution of DCFC stations from a corridor-based perspective is vital, as highways such as I-64 and I-95 serve as major transportation routes for many drivers who require convenient access to charging infrastructure. Figure A3 illustrates this corridor-based analysis, highlighting the importance of strategic DCFC station placement along these key thoroughfares within the Hampton Roads District. Notably, as shown in Table A3, half of the exits along I-64 within the district had DCFC stations located within a two-mile radius, ensuring relatively convenient charging options for drivers traveling this major highway. However, it is important to note that approximately 21% of exits still had charging stations located more than five miles away, indicating potential gaps in coverage that could pose challenges for some BEV drivers. This analysis emphasized the need for continued development of DCFC infrastructure along these crucial corridors to ensure comprehensive and equitable access to charging for all BEV users.

Table A3. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles	
		#	%	#	%	#	%
I-64	56	28	50%	28	50%	12	21%
I-95	18	7	39%	11	61%	8	44%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

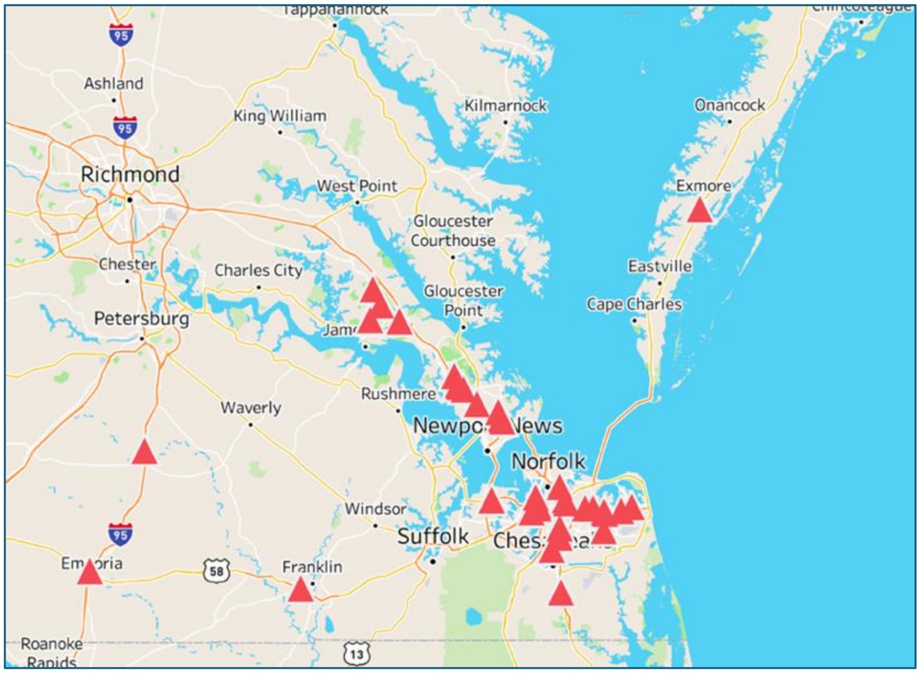


Figure A3. Direct Current Fast Charging Stations in the Hampton Roads District

Virginia Beach MSA

The Virginia Beach MSA, illustrated in Figure A1, shares a common geographical boundary with VDOT's Hampton Roads District. Table A4 presents an overarching view of the Virginia Beach MSA's BEV landscape. With a total of 7,540 BEVs and a notable 4.6% increase in new registrations in 2023, the MSA demonstrates a growing EV market. The current infrastructure comprises 37 DCFC stations, with 21% positioned within DACs. The average physical distance between two DCFC stations within the MSA is 19.7 miles.

Table A4. Overview of the Virginia Beach MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster AC	Cluster Inter	Cluster DAC	Min	Median	Mean	Max
7,540	4.6%	163	130	37	124	20 (16%)	78 (63%)	26 (21%) †	0	17.8	19.7	55.4

AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal 100% exactly due to rounding adjustments.

The Virginia Beach MSA, a bustling hub in Virginia, anticipates a significant rise in BEVs by 2030. Table A5 projects that the number of BEVs could reach 47,312, 79,482, or 128,828 by 2030, given a 30%, 40%, or 50% increase, respectively. This growing adoption of EVs is in line with the trends in big cities and their suburbs and reflects a shift towards more sustainable transportation options. The MSA's existing infrastructure is sufficiently robust to accommodate an impressive 40% surge in BEVs. However, a more rapid increase could strain the current charging network. Should the MSA experience a 50% increase in BEVs by 2030, additional infrastructure would be necessary. Estimates suggest that approximately 11 DCFC stations, each equipped with 4 EVSEs, would be needed to meet the increased demand. These findings highlight the importance of strategic infrastructure planning to ensure the MSA can support the growing popularity of BEVs and maintain its status as a leader in sustainable transportation.

Table A5. Projected BEVs and Needed Charging Infrastructure for the Virginia Beach MSA by 2030

	20%	30%	40%	50%
BEVs	27,017	47,312	79,482	128,828
Public DC Fast Charging Ports †	40	59	108	166
Number of Additional Stations with 8 EVSE Needed				5.25
Number of Additional Stations with 4 EVSE Needed				10.50

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024b).

In addition to the Virginia Beach MSA, Table A6 provides a detailed breakdown of each locality within the MSA, exploring BEV adoption rates, growth projections, existing DCFC infrastructure, and relevant socioeconomic factors. This comprehensive data serves as a robust foundation for the strategic optimization of EV charging stations in the region by 2030.

Table A6. Summary of the Virginia Beach MSA

Locality	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Chesapeake	1,161	39.2	7	12.9		8	7	17.2	13.3	39.3	4.4	30.2
Gloucester	93	57.6						6.8	2.3	58.8	16.6	0
Hampton	376	51.6	3	16	1		5	28.4	6.9	27.1	4.7	47.2
Isle of Wight	170	49.1						10	2.8	48.3	8.9	0
James City	687	41.1	1	5.8		4		18.1	12.6	36	8.1	37.4
Mathews	21	61.5						4.4	0.5	55.8	32	0
Newport News	491	48.8	7	61.1			30	39.4	8.2	29.9	6.1	45.8
Norfolk	868	40.7	7	25.3	8		14	42.6	7.8	27.9	4.5	42.9
Poquoson	55	44.7						6.4	4.2	34.5	6.7	0
Portsmouth	158	42.3	1	50.6	8			28.4	9.7	33.5	4.1	19.2
Suffolk	436	49.8						17	6.1	49.1	8.3	12.6
Surry	7	75						4.4	0.7	66.5	24.2	0
Virginia Beach	2,470	-1.6	7	10.1	9		16	25.8	18.7	31.4	3.7	25
Williamsburg	89	25.4	2	56.2			5	44.4	14.2	20.8	3.9	0
York	458	65.9	2	19.7		8	1	18.7	13.5	30.9	4.9	34.9

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Virginia Beach MSA

This project also applied the five-priority assessment formula to analyze the Virginia Beach MSA. Table A7 offers a granular look at the current status and future projections across the MSA's localities. Based on the assessment, five localities – Suffolk, Isle of Wight, Gloucester, Norfolk, and Virginia Beach – have been identified as priority locations. For instance, Suffolk had 436 BEVs in 2023, but may face 2,736, 4,596, or 7,449 BEVs with a 30%, 40%, or 50% increase by 2030, respectively. However, Suffolk lacked any DCFC stations in 2023. With its anticipated growth, the locality should be equipped with DCFC stations. This detailed analysis provides crucial insights into the anticipated demand for BEVs in each locality. These insights can help decision-makers and stakeholders involved in planning and developing EV charging infrastructure within the MSA. By understanding the unique needs and projected growth of each area, they can strategically allocate resources and ensure that the infrastructure is in place to support the widespread adoption of electric vehicles in the coming years.

Table A7. Five-Priority Assessment of the Virginia Beach MSA

Locality	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Suffolk	436	4.5	50	2,736	4,596	7,449				17	6	51	13
Isle of Wight	170	4.1	49	1,067	1,792	2,905				10	3	52	0
Gloucester	93	2.4	58	584	980	1,589				7	2	41	0
Norfolk	868	4.4	41	5,447	9,150	14,831		14	8	43	8	72	43
Virginia Beach	2,470	5.0	-2	15,499	26,037	42,202		16	9	26	19	69	25
Portsmouth	158	2.7	42	991	1,666	2,700			8	28	10	67	19
Hampton	376	3.2	52	2,359	3,964	6,424		5	1	28	7	73	47
York	458	5.5	66	2,874	4,828	7,825	8	1		19	14	69	35
James City	687	6.3	41	4,311	7,242	11,738	4			18	13	64	37
Chesapeake	1,161	4.1	39	7,285	12,239	19,837	8	7		17	13	61	30
Williamsburg	89	7.3	25	558	938	1,521		5		44	14	79	0
Newport News	491	3.0	49	3,081	5,176	8,389		30		39	8	70	46
Poquoson	55	2.9	45	345	580	940				6	4	65	0
Surry	7	0.7	75	44	74	120				4	1	34	0
Mathews	21	3.0	62	132	221	359				4	0	44	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Building upon the data presented in Table A7, Table A8 provides a deeper dive into the future charging infrastructure needs of the Virginia Beach MSA. It outlines the estimated number of additional charging stations required in each priority locality based on varying growth rates of BEV adoption. For instance, Suffolk, currently without any DCFC stations, would need 2, 4, or 6 additional stations to accommodate a 30%, 40%, or 50% increase in BEVs, respectively. In contrast, Norfolk, which already has seven DCFC stations, could handle a 30% increase with its existing infrastructure. However, to support a 40% or 50% increase, Norfolk would need 1 or 6 additional stations, respectively.

Table A8. Projected DCFC Stations by Locality in the Virginia Beach MSA by 2030

Locality	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Suffolk	0	2.3	3.9	6.3	2.3	3.9	6.3
Isle of Wight	0	0.9	1.5	2.5	0.9	1.5	2.5
Gloucester	0	0.5	0.8	1.4	0.5	0.8	1.4
Norfolk	7	4.6	7.8	12.6		0.8	5.6
Virginia Beach	7	13.2	22.1	35.9	6.2	15.1	28.9
Portsmouth	1	0.8	1.4	2.3		0.4	1.3
Hampton	3	2	3.4	5.5		0.4	2.5
York	2	2.4	4.1	6.7	0.4	2.1	4.7
James City	1	3.7	6.2	10	2.7	5.2	9
Chesapeake	7	6.2	10.4	16.9		3.4	9.9
Williamsburg	2	0.5	0.8	1.3			
Newport News	7	2.6	4.4	7.1			0.1
Poquoson	0	0.3	0.5	0.8	0.3	0.5	0.8
Surry	0	0	0.1	0.1	0	0.1	0.1
Mathews	0	0.1	0.2	0.3	0.1	0.2	0.3

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Northern Virginia

Northern Virginia, a vibrant transportation hub with high population density, overlaps geographically with two key districts: Northern Virginia itself and Fredericksburg, as shown in Figure A4. This region also encompasses the Washington-Arlington-Alexandria, DC-VA-MD-WV MSA (hereafter Washington MSA) (Figure A5). Due to their intertwined nature and shared transportation networks, these two districts and the associated MSA are analyzed collectively in this section. This approach will provide a clearer picture of the transportation dynamics and challenges faced by this interconnected region.

Fredericksburg District

The Fredericksburg District, which consists of fifteen localities, showed a significant disparity in EV infrastructure. As illustrated in Table A9 and Figure A4, ten of these localities lacked any DCFC stations, a critical component for BEV adoption. Although BEVs made up a small percentage of new vehicle registrations, their rapid growth rate, highlighted in Table A9, indicated a swift shift toward electric mobility. The adoption of both BEVs and DCFC stations was predominantly concentrated around the larger cities within the district. This uneven distribution raises concerns about socioeconomic inequality in EV access, as DACs mostly lacked DCFC stations. However, there were exceptions, such as Essex and Spotsylvania, with the latter showing a notable distribution of EVSE across its varied socioeconomic communities.

Table A9. Summary of the Fredericksburg District

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster AC	Cluster Inter	Cluster DAC
Caroline	30	52	92	76.9	1.2							
Essex	2	6	19	216.7	0.6	3	1	2	9			9
Fredericksburg	88	157	227	44.6	2.9	9	8	1	2	2		
Gloucester	30	59	93	57.6	0.9							
King and Queen	2	2	3	50.0								
King George	55	104	159	52.9	1.7	3	2	1	8		8	
King William	7	11	24	118.2	0.6							
Lancaster	33	50	63	26.0	1.9	2	2					
Mathews	9	13	21	61.5	0.9							
Middlesex	25	37	40	8.1	1.4	1	1					
Northumberland	26	43	49	14.0	1.3	1						
Richmond County	14	18	28	55.6	0.5							
Spotsylvania	329	534	863	61.6	2	10	7	4	20	8	5	7
Stafford	519	858	1,397	62.8	2.6	8	5	4	28	20	8	
Westmoreland	23	36	47	30.6	0.8	1	1					

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.

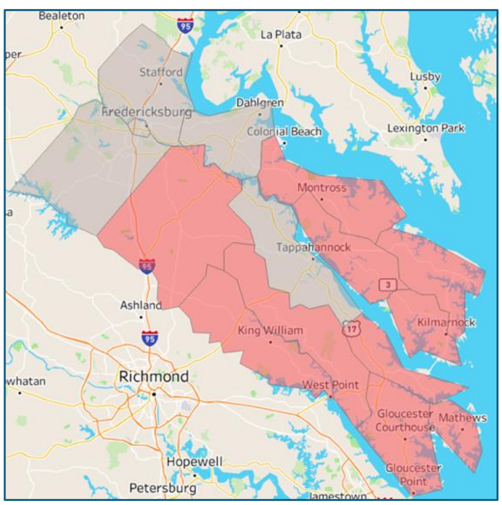


Figure A4. VDOT's Fredericksburg District (left) and VDOT's Northern Virginia District (right)

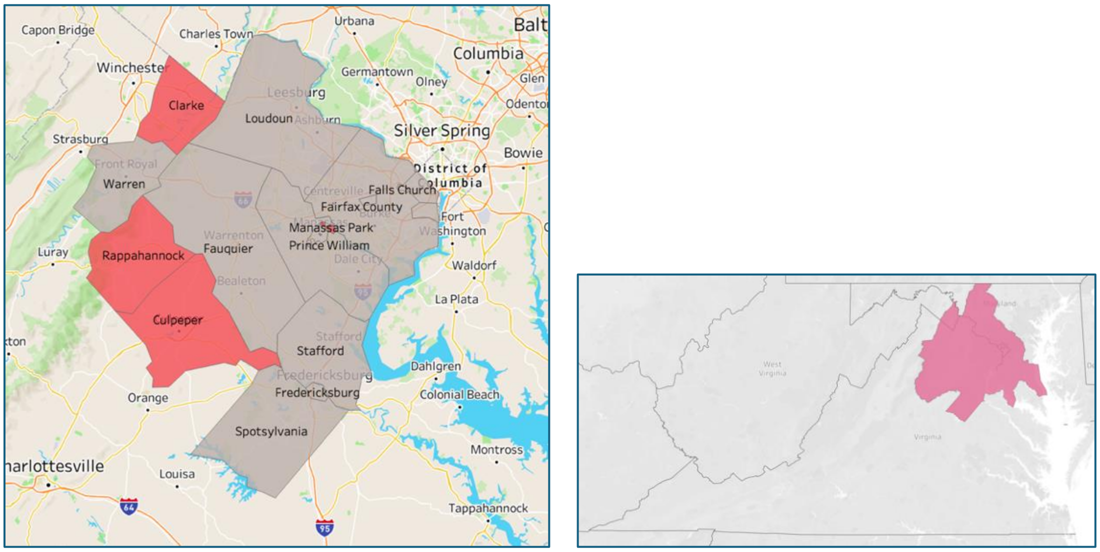


Figure A5. Washington MSA

Table A10 provides a comprehensive analysis of DCFC station distribution within the Fredericksburg District, offering a unique perspective on EV infrastructure accessibility. By pairing all existing DCFC stations and calculating their physical distances, this table sheds light on the spatial patterns of charging availability. In localities without DCFC stations, the county administration building served as a proxy for analysis purposes. The analysis revealed a clear trend: larger cities within the district boasted a higher concentration of DCFC stations, resulting in relatively short distances between them. Conversely, rural areas, often lacking any DCFC stations, faced a challenge of "few and far" charging options. This disparity could hinder BEV adoption in rural communities, as limited and distant charging infrastructure poses a significant barrier to convenient long-distance travel.

Table A10. Proximity of Each Pair of DCFC Stations in the Fredericksburg District

Locality	Min	Median	Mean	Max	Proxy Location
Caroline	13.0	27.4	23.4	29.5	County Administration Building
Essex	1.5	42.0	38.6	50.1	
Fredericksburg	11.6	11.6	11.6	11.6	
Gloucester	38.3	79.0	74.1	88.1	County Administration Building
King and Queen	16.2	53.4	49.6	63.2	County Administration Building
King George	21.2	22.6	25.0	31.3	
King William	16.9	48.1	45.8	58.8	County Administration Building
Lancaster	23.6	65.4	59.0	71.6	County Administration Building
Mathews	44.0	86.1	80.4	94.0	County Administration Building
Middlesex	25.2	67.0	61.6	75.3	County Administration Building
Northumberland	21.0	60.3	53.6	64.9	County Administration Building
Richmond County	5.9	45.1	39.3	51.2	County Administration Building
Spotsylvania	2.1	15.5	18.3	44.3	
Stafford	0.4	17.7	19.8	49.4	
Westmoreland	11.9	37.7	33.3	41.8	County Administration Building

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Figure A6 and Table A11 illustrate the distribution of DCFC stations along the corridors of the Fredericksburg District, highlighting a concentration along I-95. Many stations were situated more than two miles from I-95 exits. This finding indicates the need for strategic planning for the EV charging infrastructure, especially considering the district's proximity to the Washington MSA and the resulting heavy traffic on I-95. Due to the significant interaction between the Fredericksburg District and the Washington MSA, an optimization analysis of charging station placement should be conducted within the context of the Washington MSA.

Table A11. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles		> 10 Miles	
		#	%	#	%	#	%	#	%
I-95	18	5	28%	13	72%	4	22%	4	22%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Figure A6. Direct Current Fast Charging Stations in the Fredericksburg District

Northern Virginia District

Northern Virginia is a vibrant and densely populated region within the state and has witnessed a remarkable surge in BEV adoption in recent years, as shown in Figure A4 and Table A12. This has led to a corresponding increase in the number of DCFC stations, catering to the growing demand for rapid charging infrastructure. However, a closer analysis revealed socioeconomic disparities in the distribution of these stations. While BEVs were increasingly common on the roads of Northern Virginia, many DACs lacked access to DCFC stations, with the exception of Fairfax County and Prince William County. This inequitable distribution of charging infrastructure could hinder the long-term growth of BEV adoption and perpetuate range anxiety among potential buyers. To address this issue, it is crucial that the district assess BEV adoption rates and prioritize the equitable distribution of DCFC stations. By ensuring that all communities have access to convenient and reliable charging facilities, the district can foster a more inclusive and sustainable transportation system.

Table A12. Summary of the Northern Virginia District

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster AC	Cluster Inter	Cluster DAC
Alexandria	920	1,444	2,333	61.6	3.5	46	43	4	10	8	2	
Arlington	1,711	2,479	3,631	46.5	5.7	200	196	5	30	28	2	
Fairfax City	294	602	1,014	68.4	4.9	12	7	6	27	23	4	
Fairfax County	9,061	13,566	21,123	55.7	5.2	324	288	41	207	141	53	13
Falls Church	168	301	484	60.8	5.3	6	4	2	4	4		
Loudoun	4,614	7,327	11,778	60.7	7.3	85	69	20	94	92	2	
Manassas	99	179	219	22.3	1.4	9	8	2	2		2	
Manassas Park	30	62	0		2.1							
Prince William	1,825	2,986	5,032	68.5	3.1	35	24	14	58	26	30	2

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results. Note: According to AFDC datasets, Manassas Park does not currently have any DCFC stations, and according to Virginia Clean Cities datasets, there are no BEVs registered there.

Northern Virginia boasts a relatively dense network of DCFC stations, as depicted in Table A13 and Figure A7. Moreover, a significant number of these stations were located within a two-mile radius of major highways, facilitating convenient charging for EV drivers, as highlighted in Table A14. The primary challenge facing Northern Virginia was not the lack of charging infrastructure, but rather the rapid growth of BEV adoption and keeping pace with the escalating demand for charging services. To ensure a seamless transition to electric mobility, it is imperative that the district proactively prepare for this continued growth and prioritize the needs of EV drivers. This includes not only expanding the charging network but also optimizing its distribution to cater to both local communities and highway corridors. A more in-depth analysis of these dynamics is presented in the section on the MSA analysis.

Table A13. Proximity of Each Pair of DCFC Stations in the Northern Virginia District

Locality	Min	Median	Mean	Max	Proxy Location
Arlington	0.1	14.6	14.1	31.0	
Alexandria	0.1	14.5	14.1	33.6	
Fairfax City	0.1	10.5	10.5	22.2	
Fairfax County	0.1	11.9	12.5	35.1	
Falls Church	0.3	12.4	12.4	26.2	
Loudoun	0.0	16.9	16.6	36.8	
Manassas	1.4	15.2	15.2	24.4	
Manassas Park	1.0	14.3	14.3	24.1	City Hall
Prince William	0.0	18.1	18.3	36.0	

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Table A14. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles	
		#	%	#	%
I-95	18	12	67%	6	33%
I-66	34	31	91%	3	9%
I-495	10	8	80%	2	20%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

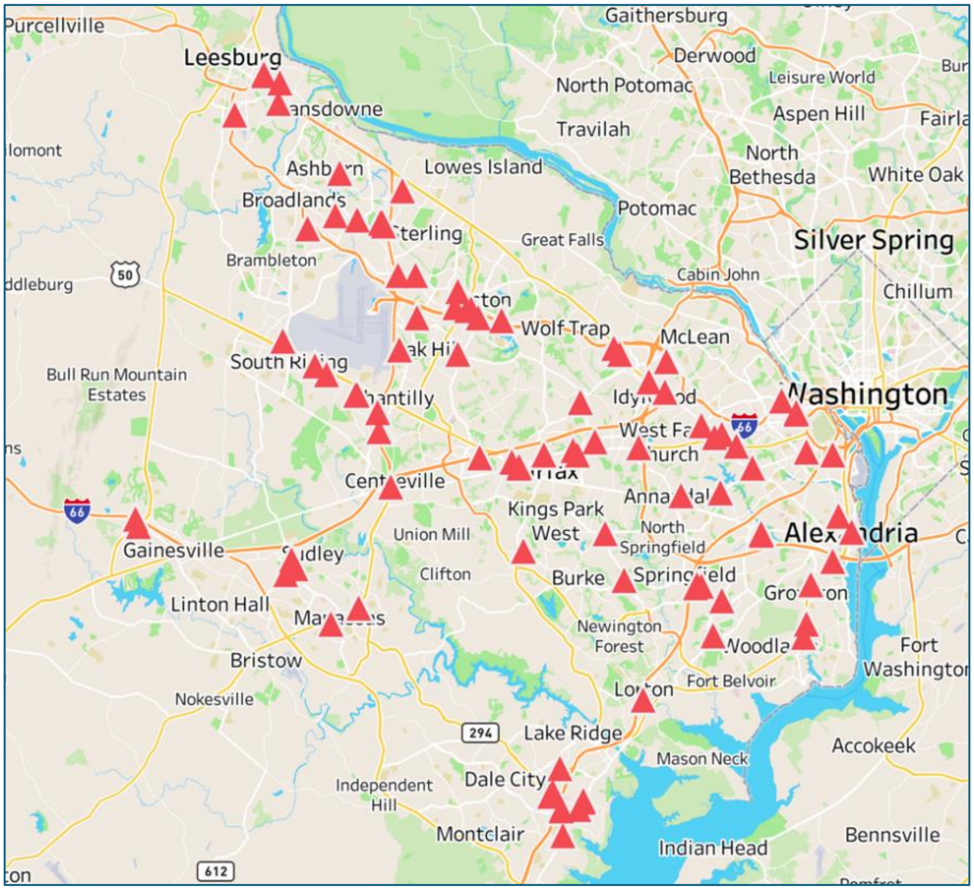


Figure A7. Direct Current Fast Charging Stations in the Northern Virginia District

Washington-Arlington-Alexandria, DC-VA-MD-WV MSA

The Washington-Arlington-Alexandria MSA is one of the most populous and diverse regions in the United States and shows a high adoption rate of BEVs among drivers, as illustrated in Figure A5 and Table A15. As of 2023, the Washington MSA experienced a rapid adoption of BEVs, with 55,045 registered and a new registration rate of 13.4% for the same year. This growth is reflected in Table A15, which provides detailed statistics on BEV adoption in the MSA. To support this expanding fleet, the area had 110 DCFC stations and 496 EVSE units. However, only 4% of these charging resources were situated in DACs, presenting a potential equity concern. The average distance between DCFC stations in the MSA was 21.5 miles.

Table A15. Overview of the Washington-Arlington-Alexandria MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs	% BEVs	All	L2	DCFC	All	Cluster AC	Cluster Inter	Cluster DAC	Min	Median	Mean	Max
55,045	13.4%	769	677	110	496	352 (71%)	122 (25%)	22 (4%) †	0	17.8	21.5	64.7

AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal 100% exactly due to rounding adjustments.

While the current infrastructure could accommodate a 30% increase in BEVs, if 50% growth were achieved by 2030, with a total of 309,080 vehicles, an additional 219 charging stations would be needed to meet demand, as shown in Table A16. Given the Washington MSA's position as one of the fastest-growing regions for BEV adoption, proactive and significant infrastructure development is crucial to keeping pace with the increasing number of EVs and to ensuring equitable access to charging resources across all communities within the MSA.

Table A16. Projected BEVs and Needed Stations in the Washington-Arlington-Alexandria MSA by 2030

	20%	30%	40%	50%
BEVs	176,497	309,080	519,235	841,602
DCFC EVSE †	223	449	620	1,369
Number of Additional Stations with 8 EVSE Needed			15.50	109.13
Number of Additional Stations with 4 EVSE Needed			31.00	218.25

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

To understand BEV adoption and charging infrastructure development, Table A17 presents a comprehensive analysis of BEVs, DCFC stations, socioeconomic disparities, and demographic factors. The data revealed significant growth in BEV ownership between 2022 and 2023, highlighting the increasing popularity of this technology. However, despite the widespread availability of DCFC EVSE, many DACs lacked access to this critical infrastructure. This disparity could potentially hinder the continued growth of BEVs in the region, particularly among lower-income populations. Ensuring equitable access to charging infrastructure is essential for promoting sustainable transportation options for all residents.

Table A17. Summary of the Washington-Arlington-Alexandria MSA

Locality	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Alexandria	2,333	61.6	4	4.3		8	2	64.7	21.1	50.6	8.6	43.3
Arlington	3,631	46.5	5	8.3		28	2	65.3	9.3	45.9	5.6	29.9
Clarke	150	54.6						5.3	6.1	56.9	19	0
Culpeper	196	53.1						10	6.6	49.2	24.2	0
Fairfax City	1,014	68.4	6	26.6		23	4	29.4	16.6	51	7.8	0

Locality	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Fairfax County	21,123	55.7	41	9.8	13	141	53	30.6	23	50.4	10.9	34.8
Falls Church	484	60.8	2	8.3		4		50.7	10.5	42.3	6.1	0
Fauquier	619	36.0	1	12.9			8	7.5	5.1	58.1	23.4	27.4
Fredericksburg	227	44.6	1	8.8		2		48	10.6	40.3	19.8	47.2
Loudoun	11,778	60.7	20	8		92	2	17.4	30.1	49.4	15.5	0
Manassas	219	22.3	2	9.1			2	22.6	33.3	53.6	20.6	0
Manassas Park								28.3	28.8	65.9	25.5	0
Prince William	5,032	68.5	14	11.5	2	26	30	17.9	26.1	64.6	21.5	34.6
Rappahannock	58	45.0						2.1	1	53.8	27.6	0
Spotsylvania	863	61.6	4	23.2	7	8	5	9.7	9.7	51.4	23.3	31.8
Stafford	1,397	62.8	4	20		20	8	9.2	14	56.8	24.6	43.3
Warren	132	43.5	6	45.5			6	9.4	5.7	58.8	30.5	41.1

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Washington MSA

A comprehensive assessment of five key priorities identified two rural areas within the MSA, Culpeper and Clarke, as high-priority locations for the development of DCFC stations. Despite an expected increase in the adoption of BEVs, these localities lacked DCFC infrastructure as of 2023. Following closely behind were several urban areas, including Alexandria, Arlington, Falls Church, and Fredericksburg, which have also been recommended for DCFC station development. Table A18 provides a detailed breakdown of the current number of BEVs in each area, along with projections for 2030. Importantly, the table also highlights existing socioeconomic disparities and relevant demographic factors within the MSA. These insights offer guidance for the planning and development of future DCFC stations.

Table A18. Five-Priority Assessment of the Washington-Arlington-Alexandria MSA

Locality	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Culpeper	196	3.0	53	1,230	2,066	3,349				10	7	51	0
Clarke	150	7.2	55	941	1,581	2,563				5	6	43	0
Alexandria	2,333	9.5	62	14,639	24,593	39,861	8	2		65	21	49	43
Arlington	3,631	13.7	47	22,784	38,276	62,039	28	2		65	9	54	30
Falls Church	484	13.6	61	3,037	5,102	8,270	4			51	10	58	0
Fredericksburg	227	8.9	45	1,424	2,393	3,879	2			48	11	60	47
Manassas	219	4.3	22	1,374	2,309	3,742		2		23	33	46	0
Fairfax County	21,123	14.6	56	13,2544	222,665	360,906	141	53	13	31	23	50	35
Loudoun	11,778	20.6	61	73,905	124,156	201,238	92	2		17	30	51	0

Locality	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Fairfax City	1,014	12.9	68	6,363	10,689	17,325	23	4		29	17	49	0
Prince William	5,032	9.1	69	31,575	53,044	85,976	26	30	2	18	26	35	35
Stafford	1,397	6.8	63	8,766	14,726	23,869	20	8		9	14	43	43
Spotsylvania	863	5.3	62	5,415	9,097	14,745	8	5	7	10	10	49	32
Fauquier	619	5.8	36	3,884	6,525	10,576		8		8	5	42	27
Manassas Park	0	5.9								28	29	34	0
Warren	132	3.8	44	8,28	1,391	2,255		6		9	6	41	41
Rappahannock	58	5.0	45	3,64	611	991				2	1	46	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Table A19 provides a more in-depth analysis of the additional charging infrastructure required in the MSA, taking into account various growth scenarios. For instance, if Fairfax County experiences a 50% increase in BEV adoption by 2030, it will need a total of 307 DCFC stations, necessitating the construction of 266 new stations. Similarly, Loudoun County, if anticipating a 30% increase in BEVs, will require 63 charging stations, meaning 43 new stations will need to be built by 2030. These figures show the critical need for comprehensive planning in urbanized areas to accommodate the substantial growth of electric vehicles. While recent statistics indicate a slight slowdown in BEV adoption in 2024, the overall growth rate remains significant. To ensure a seamless transition to this new technology, it is imperative that the necessary infrastructure be in place and readily available to support the continued expansion of the electric vehicle market.

Table A19. Projected DCFC Needed by Locality in the Washington-Arlington-Alexandria MSA by 2030

	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Needed by 2030 ††		
County	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Culpeper	0	1	1.8	2.8	1	1.8	2.8
Clarke	0	0.8	1.3	2.2	0.8	1.3	2.2
Alexandria	4	12.4	20.9	33.9	8.4	16.9	29.9
Arlington	5	19.4	32.5	52.7	14.4	27.5	47.7
Falls Church	2	2.6	4.3	7	0.6	2.3	5
Fredericksburg	1	1.2	2	3.3	0.2	1	2.3
Manassas	2	1.2	2	3.2			1.2
Fairfax County	41	112.7	189.3	306.8	71.7	148.3	265.8
Loudoun	20	62.8	105.5	171.1	42.8	85.5	151.1
Fairfax City	6	5.4	9.1	14.7		3.1	8.7
Prince William	14	26.8	45.1	73.1	12.8	31.1	59.1
Stafford	4	7.5	12.5	20.3	3.5	8.5	16.3
Spotsylvania	4	4.6	7.7	12.5	0.6	3.7	8.5
Fauquier	1	3.3	5.5	9	2.3	4.5	8
Manassas Park							
Warren	6	0.7	1.2	1.9			

	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Needed by 2030 ††		
County	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Rappahannock	0	0.3	0.5	0.8	0.3	0.5	0.8

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Staunton District and Staunton, Harrisonburg, and Winchester MSAs

The Staunton District encompasses three MSAs: Staunton-Stuarts Draft, Harrisonburg, and Winchester VA-WV, as depicted in Figures A8-A10. While the Winchester MSA includes parts of West Virginia, only the Virginia portion was analyzed in this study. This focus ensured that the analysis was consistent with the study's geographical scope and data availability.

Staunton District

As illustrated in Figure A8 and Table A20, a significant portion of Staunton District localities (eight out of eighteen) lacked DCFC infrastructure as of 2023. Existing DCFC EVSE was primarily concentrated in intermediate communities, with some in DACs. However, advantaged communities within the district had no access to DCFC stations as of 2023. Given the district's rural character, with many rural roadways and communities, BEVs are not yet widely popular. The deployment of additional DCFC stations across the district may accelerate the adoption of BEVs. This expanded infrastructure would not only address the current lack of access in many localities but also alleviate range anxiety concerns associated with longer travel distances in rural areas.

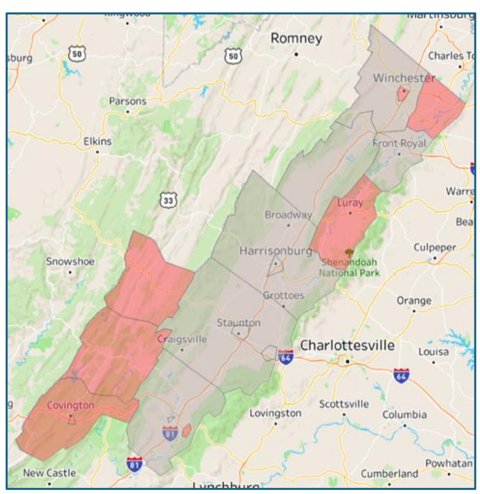


Figure A8. VDOT’s Staunton District

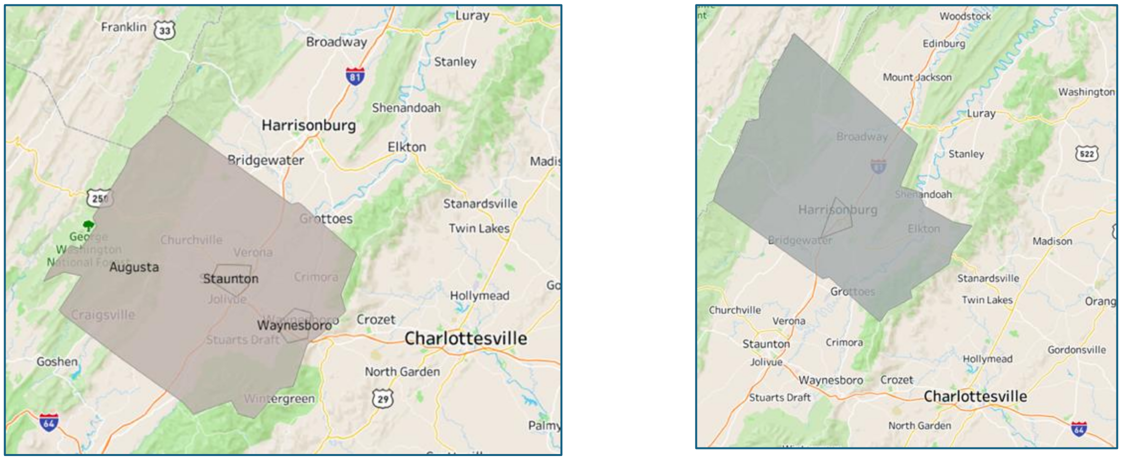


Figure A9. Staunton-Stuarts Draft MSA (left) and Harrisonburg MSA (right)

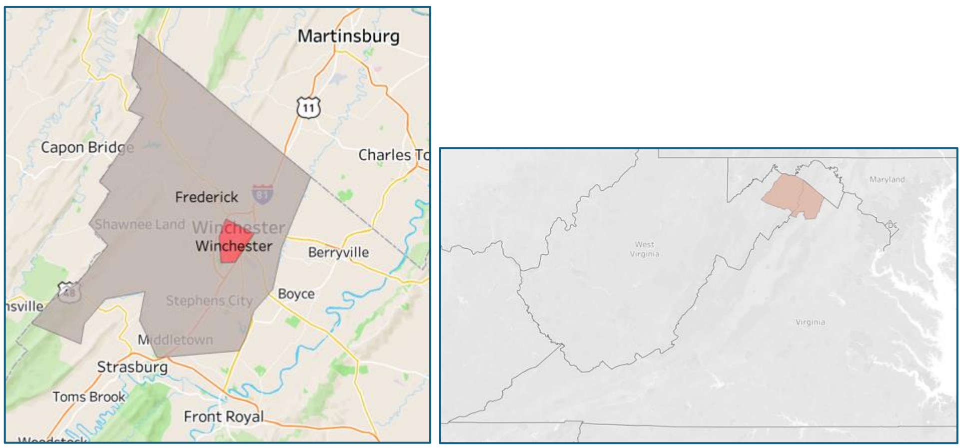


Figure A10. Winchester VA-WV MSA

Table A20. Summary of the Staunton District

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster AC	Cluster Inter	Cluster DAC
Alleghany	3	9	10	11.1	0.2	4	4					
Augusta	84	146	209	43.2	0.9	6	5	1	8		8	
Bath	11	11	9	-18.2	0.3	1	1					
Buena Vista	1	0	4		0.2							
Clarke	63	97	150	54.6	2.7	3	3					
Covington	2	3	0	-100	0.3							
Frederick	168	303	475	56.8	1.5	11	9	3	13		13	
Harrisonburg	60	76	135	77.6	1.5	17	16	1	8			8
Highland	4	5	6	20.0	1.0							
Lexington	17	16	0	-100	1.9	3	1	2	9		9	
Page	11	23	31	34.8	0.5	5	5					
Rockbridge	25	45	63	40.0	1.3	7	5	2	14		14	
Rockingham	123	179	257	43.6	1.2	7	5	1	4			4
Shenandoah	42	68	115	69.1	0.8	11	7	4	26		6	20
Staunton	33	63	97	54.0	1.0	6	4	2	12		12	
Warren	59	92	132	43.5	1.4	10	4	6	6		6	

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster		
										AC	Inter	DAC
Waynesboro	25	38	61	60.5	1.0	10	3	7	7		7	
Winchester	46	83	115	38.6	1.6	2	2					

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.

Table A21 further illustrates the scarcity and dispersed nature of DCFC stations within the Staunton District. The mean distances between these stations were especially long, highlighting the challenge of accessing fast charging infrastructure for EV drivers in the region. In some cases, as shown in Table A21, proxy locations were used for analysis due to the complete absence of DCFC stations within those localities as of 2023. This further showed the limited availability and uneven distribution of fast charging resources in the district, particularly in more rural or underserved areas. The sparse and scattered nature of DCFC infrastructure not only poses a practical inconvenience for current EV owners but also acts as a potential deterrent to those considering a transition to EVs. Addressing this challenge through the strategic deployment of additional charging stations, particularly in underserved areas, may be crucial to fostering EV adoption and supporting the region's transition towards a more sustainable transportation system.

Table A21. Proximity of Each Pair of DCFC Stations in the Staunton District

Locality	Min	Median	Mean	Max	Proxy Locations
Alleghany	31.9	77.9	88.1	141.7	584 E. Madison Street, Covington, VA 24426
Augusta	6.4	6.4	6.4	6.4	
Bath	26.6	57.4	70.3	119.7	County Administration Building
Buena Vista	5.1	55.2	62.8	120.5	City Hall
Clarke	6.4	60.9	56.1	115.8	County Administration Building
Covington	31.9	77.9	88.1	141.7	584 E. Madison Street, Covington, VA 24426
Frederick	2.5	79.3	57.9	120.4	
Harrisonburg	4	35.2	37.6	65.5	
Highland	35	44.4	59	95.2	County Administration Building
Lexington	0.3	35.1	62.2	120.4	
Page	11.1	40.6	40.3	80.7	County Administration Building
Rockbridge	1.5	79	65.2	118.8	
Rockingham	28.1	30.3	30.3	32.5	
Shenandoah	0.6	48.7	43.3	103.4	
Staunton	0.2	26.8	38.5	88.1	
Warren	0.001	47.6	36.1	78.3	
Waynesboro	0.002	29.1	39.8	73.7	
Winchester	2.2	64	57.7	118.9	City Hall

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

An examination of DCFC station distribution by corridor, and as illustrated in Figure A11, revealed a concentration around AFCs as of 2023. This placement, coupled with the relatively low adoption of BEVs in the district and a focus on corridor charging, indicated a unique pattern in its EV infrastructure development. However, as depicted in Table A22, many DCFC stations were located beyond a two-mile radius, and some were even more than ten miles away. These long spatial distances, combined with the existing scarcity and dispersed nature of the charging infrastructure, necessitates a thoughtful and strategic approach to future planning and implementation.

Table A22. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles		> 10 Miles	
		#	%	#	%	#	%	#	%
I-64	37	8	22%	29	78%	25	68%	23	62%
I-81	75	32	43%	43	57%	16	21%	3	4%
I-66	5	1	20%	4	80%	2	40%		

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

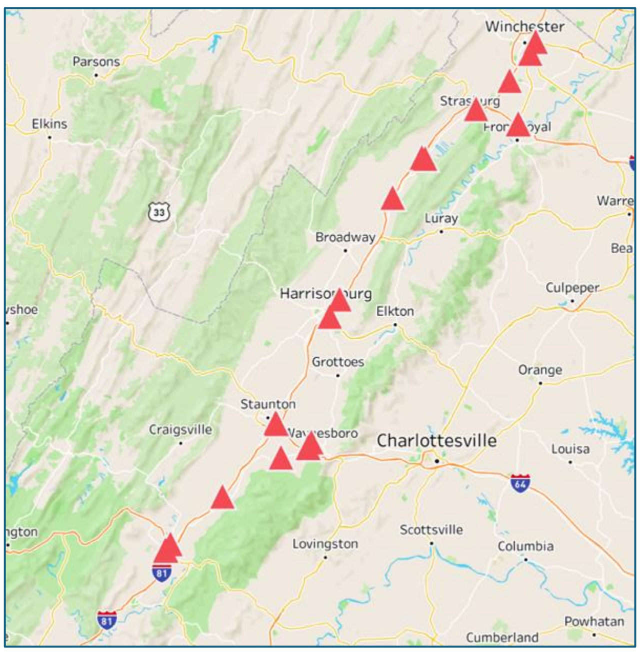


Figure A11. Direct Current Fast Charging Stations in the Staunton District

Staunton-Stuarts Draft MSA, Harrisonburg MSA, and Winchester VA-WV MSA

Figures A8-A10 depict three MSAs located within the Staunton District. While larger MSAs were examined individually in this study due to significant BEV growth rates and the size of DCFC stations, the three MSAs within Staunton District are comparatively small. Consequently, it may be more beneficial to analyze these MSAs collectively to gain a comprehensive understanding of the overall trend.

Table A23 provides a comprehensive overview of BEV adoption and DCFC infrastructure availability within three MSAs in VDOT's Staunton District. The analysis revealed that BEV adoption rates as captured by new vehicle registrations in 2023 remained relatively low, and the overall number of BEVs on the roads as of 2023 was not substantial. All DCFC stations in the Harrisonburg MSA were located exclusively within DACs, limiting their availability to residents outside these designated zones. Furthermore, the table highlights socioeconomic disparities in DCFC distribution. Equitable access to charging infrastructure is crucial for widespread BEV adoption, yet three MSAs lacked DCFCs in advantaged communities. Promoting equitable access to DCFCs is essential for fostering widespread BEV adoption and reducing transportation-related emissions across all communities.

Tables A24-A26 present an analysis of BEV adoption and the corresponding need for DCFC stations within the three MSAs. The findings indicate that the Staunton-Stuarts Draft MSA possesses sufficient DCFC infrastructure to accommodate even a 50% increase in BEVs. In contrast, the Harrisonburg MSA may require two or three additional DCFC stations by 2030 to support a 50% increase in BEV adoption. Similarly, the Winchester MSA will likely need three or four more DCFC stations to meet the demands of a 50% rise in BEVs. These projections offer insights at the MSA level, highlighting the collective charging infrastructure needs within each region. However, it is important to recognize that BEV adoption and charging requirements can vary significantly within an MSA and across its localities. Therefore, the following section will delve deeper into the specific needs of each locality within these MSAs, ensuring a more granular understanding of the charging infrastructure required to support the growing BEV landscape.

Table A23. Overview of Three MSAs within the Staunton District

	BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
MSA	# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster			Min	Median	Mean	Max
							AC	Inter	DAC				
1	367	2.3%	22	12	10	27	0 (0%)	27 (100%)	0 (0%) †	0	5.6	3.7	7.9
2	393	3.2%	24	21	2	12	0 (0%)	0 (0%)	12 (100%)	4	4	4	4
3	590	3.7%	13	11	3	13	0 (0%)	13 (100%)	0 (0%)	2.5	6.4	5.9	8.8

1: Staunton-Stuarts Draft MSA, 2: Harrisonburg MSA, 3: Winchester, VA-WV MSA, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal 100% exactly due to rounding adjustments.

Table A27 reveals that while the growth rates of BEV adoption between 2022 and 2023 were high, the absolute number of BEVs remains relatively low. This suggests there is still considerable room for expansion in the BEV market within these MSAs. While larger MSAs typically have many DCFC stations in advantaged communities, a notable finding in the three

MSAs was the absence of such stations in these areas. Further, beyond the City of Harrisonburg and Rockingham County, no DACs had DCFC infrastructure. To ensure equitable access for all communities as BEV adoption grows, expanding DCFC station coverage is essential.

Table A24 Projected BEVs and Needed Charging Infrastructure in the Staunton-Stuarts Draft MSA by 2030

	20%	30%	40%	50%
BEVs	1,315	2,303	3,869	6,271
Public DC Fast Charging Ports	5	8	14	16
Number of Additional Stations with 8 EVSE Needed				
Number of Additional Stations with 4 EVSE Needed				

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

Table A25. Projected BEVs and Needed Charging Infrastructure in the Harrisonburg MSA by 2030

	20%	30%	40%	50%
BEVs	1,408	2,466	4,143	6,715
Public DC Fast Charging Ports †	6	8	14	21
Number of Additional Stations with 8 EVSE Needed			0.25	1.13
Number of Additional Stations with 4 EVSE Needed			0.50	2.25

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment.
† Data on public DC Fast charging ports was obtained from EVI-Pro Lite in early 2023.

Table A26. Projected BEVs and Needed Charging Infrastructure in the Winchester MSA by 2030

	20%	30%	40%	50%
BEVs	2,114	3,702	6,219	10,081
DCFC EVSE †	7	11	17	24
Number of Additional Stations with 8 EVSE Needed			0.50	1.38
Number of Additional Stations with 4 EVSE Needed			1.00	2.75

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment.
† Data on public DC Fast charging ports was obtained from EVI-Pro Lite in early 2023.

Table A27. Summary of the Staunton-Stuarts Draft, Harrisonburg, and Winchester MSAs

Locality		BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
MSA	County	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Staunton-Stuarts Draft	Augusta	209	43.2	1	38.3			8	8.3	2.7	32.2	3.9	55.9
	Staunton	97	54.0	2	123.7			12	23.7	3.8	27.3	4	0
	Waynesboro	61	60.5	7	114.8			7	28.9	3.1	28.9	2.9	27.4
Harrisonburg	Harrisonburg	135	77.6	1	59.3	8			40.1	23.1	15.1	4.6	39.3
	Rockingham	257	43.6	1	15.6	4			9.2	10.3	26.7	3.6	34.6
Winchester	Frederick	475	56.8	3	27.4			13	9.1	10.1	40.4	19.1	39.5
	Winchester	115	38.6						32.4	9.3	22.4	8.3	1.4

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Staunton-Stuarts Draft, Harrisonburg, and Winchester MSAs

When analyzing each locality within the three MSAs based on the five-priority assessment, as detailed in Tables A28 and A29, most localities can accommodate a 30% increase in BEV adoption with their existing DCFC infrastructure. However, a 50% increase in BEV adoption paints a different picture. In this scenario, Augusta County would require two additional DCFC stations, and Frederick County would need about four more. Tables A28 and A29 offer guidance for each locality as they plan for various BEV adoption growth scenarios. These tables can help localities anticipate and address the infrastructure demands associated with different levels of BEV adoption, ensuring they are prepared for the future of transportation.

Table A28. Five-Priority Assessment of Three MSAs within the Staunton District

		BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	County	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
1	Augusta	209	2.0	43	1,311	2,203	3,571		8		8	3	68	56
	Waynesboro	61	3.1	61	383	643	1,042		7		29	3	71	27
	Staunton	97	2.9	54	609	1,023	1,657		12		24	4	73	0
2	Harrisonburg	135	3.1	78	847	1,423	2,307			8	40	23	85	39
	Rockingham	257	3.6	44	1,613	2,709	4,391			4	9	10	73	35
3	Winchester	115	3.8	39	722	1,212	1,965				32	9	78	1
	Frederick	475	3.7	57	2,981	5,007	8,116		13		9	10	60	40

1: Staunton-Stuarts Draft MSA, 2: Harrisonburg MSA, 3: Winchester, VA-WV MSA. BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Table A29. Projected DCFC Stations by Locality in Three MSAs by 2030

		DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
MSA	County	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Staunton-Stuart Draft	Augusta	1	1.1	1.9	3	0.1	0.9	2
	Waynesboro	7	0.3	0.5	0.9			
	Staunton	2	0.5	0.9	1.4			
Harrisonburg	Harrisonburg	1	0.7	1.2	2		0.2	1.0
	Rockingham	1	1.4	2.3	3.7	0.4	1.3	2.7
Winchester	Winchester	0	0.6	1	1.7	0.6	1.0	1.7
	Frederick	3	2.5	4.3	6.9		1.3	3.9

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Culpeper District and Charlottesville MSA

The Culpeper District and Charlottesville MSA overlap geographically, as depicted in Figure A12. While the Culpeper District is significantly rural, encompassing farms, forests, and small communities, the Charlottesville MSA is a mix of urban and suburban development centered around the City of Charlottesville, with some rural areas in its outskirts. This contrast in land use and the population density within these overlapping regions provides an opportunity to explore the dynamics between rural and urban areas in terms of BEV adoption and charging infrastructure development. Examining these two areas can shed light on the unique challenges and opportunities each faces in the transition to EVs, and the infrastructure needed to support them, ultimately contributing to a more comprehensive understanding of BEV adoption patterns across diverse geographical contexts.

Culpeper District

The Culpeper District comprises ten localities, but as of 2023, only half of them had DCFC facilities, highlighting a gap in charging infrastructure accessibility. In addition, Greene County was the only locality without Level 2 charging stations, while all others provided this practical charging option. The disparity in charging infrastructure availability across the district might be partially explained by the varying BEV adoption rates. The City of Charlottesville and Albemarle County showed relatively high BEV adoption rates, which likely increased the demand for faster charging options such as DCFC stations, as shown in Table A30. In contrast, the more rural localities exhibited lower BEV adoption rates. Due to lower levels of EV adoption, discussions about socioeconomic disparities in EV charging access are less relevant at this stage. However, as BEV adoption grows, addressing potential inequities in charging infrastructure access across different communities within the district is crucial. The distribution of DCFC stations within the Culpeper District revealed an interesting pattern: they are primarily located in intermediate communities, potentially reflecting a focus on areas experiencing growing BEV adoption. Furthermore, Albemarle County stands out as the only locality with a DCFC station situated in a DAC, suggesting a targeted effort to improve charging accessibility for underserved populations.

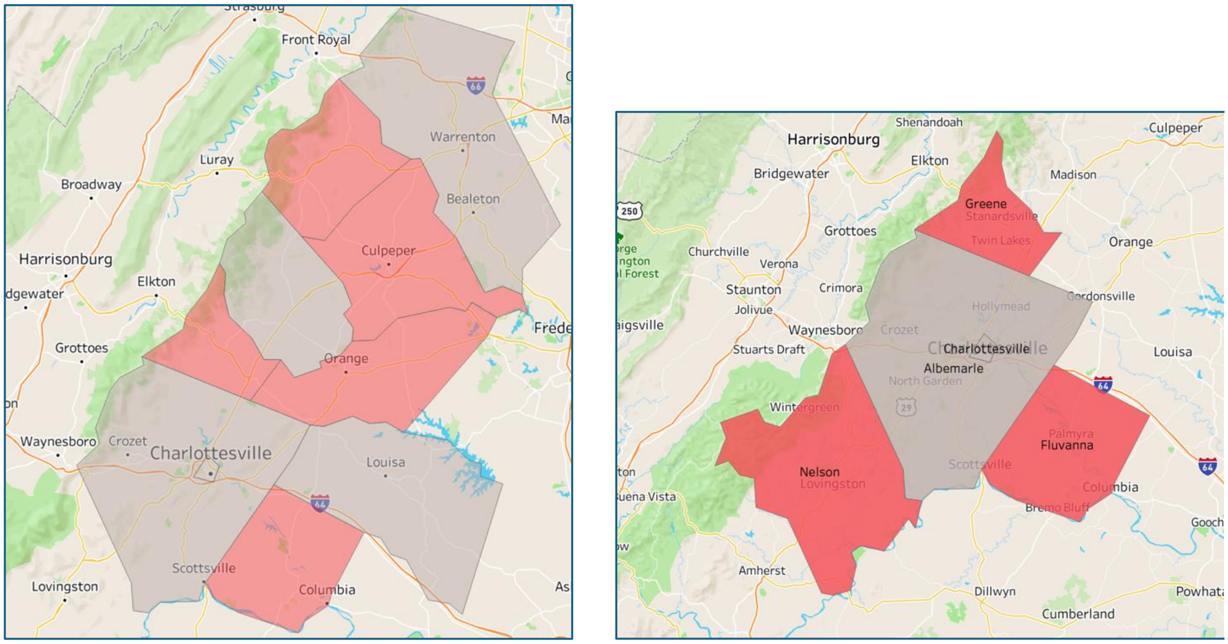


Figure A12. VDOT's Culpeper District (left) and Charlottesville MSA (right)

Table A30. Summary of the Culpeper District

County	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster: AC	Cluster: Inter	Cluster: DAC
Albemarle	647	979	1,521	55.4	5.0	30	25	7	22	12	9	1
Charlottesville	249	387	497	28.4	5.2	19	14	5	9	5	4	
Culpeper	61	128	196	53.1	1.3	2	2					
Fauquier	276	455	619	36.0	2.3	7	6	1	8		8	
Fluvanna	53	85	111	30.6	1.6	1	1					
Greene	32	45	67	48.9	2.5							
Louisa	80	139	209	50.4	1.7	3	1	1	4	4		
Madison	13	26	39	50.0	1.1	3	2	1	8		8	
Orange	46	71	120	69.0	0.9	3	3					
Rappahannock	28	40	58	45.0	2.2	3	3					

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.

Albemarle County and the City of Charlottesville showed a relatively dense network of DCFC stations, ensuring convenient access for EV owners. However, as Table A31 illustrates, the situation in other counties within the Culpeper District was markedly different, with charging infrastructure being sparse and scattered. To gain a comprehensive understanding of the distribution of DCFC stations across the entire district, this study had to rely on proxy locations in several instances due to the absence of stations in half of the localities.

Table A31. Proximity of Each Pair of DCFC Stations in the Culpeper District

Locality	Min	Median	Mean	Max	Proxy Location
Albemarle	0.0	3.9	10.8	57.1	
Charlottesville	0.0	2.5	8.3	54.8	
Culpeper	14.7	40.1	36.5	42.5	County Administration Building
Fauquier	54.8	55.0	55.6	57.0	
Fluvanna	8.8	16.9	20.7	58.3	County Administration Building
Greene	9.3	18.1	19.2	41.5	County Administration Building
Louisa	15.2	15.7	19.0	49.5	
Madison	16.8	24.3	24.9	32.4	
Orange	11.7	24.7	23.8	31.0	County Administration Building
Rappahannock	20.0	50.2	46.3	52.8	County Administration Building

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Figure A13 illustrates the existing corridor-based DCFC stations in the district. Notably, U.S. Route 29, although not designated as an AFC, alongside I-64 and I-66, featured a number of DCFC stations. These stations were complemented by those located within the City of Charlottesville. However, an analysis of I-64 revealed that only about 35% of the charging stations fell within a convenient two-mile radius, with many situated more than eight miles from the highway exit. Similarly, I-66 presented a challenge for EV drivers with numerous stations spaced more the ten miles from the interstate exit, as Table A32 indicates. The rural landscape of the district underscores the potential effectiveness of a corridor-based approach to EV charging infrastructure development. Strategic planning, with a focus on ensuring accessibility from major AFCs, could significantly benefit both long-distance travelers and daily commuters.

Table A32. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles		> 10 Miles	
		#	%	#	%	#	%	#	%
I-64	17	6	35%	11	65%	8	47%	2	12%
I-66	10	0	0	10	100%	10	100%	8	80%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

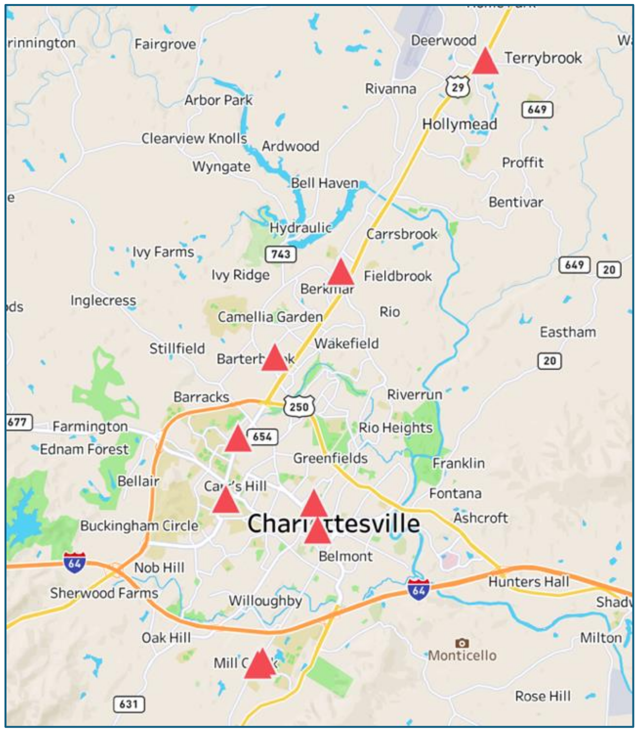


Figure A13. Direct Current Fast Charging Stations in the Culpeper District

Charlottesville MSA

Figure A12 provides a visual representation of the geographical area covered by the Charlottesville MSA. The Charlottesville MSA housed 2,286 BEVs by the end of 2023, with a notable uptick in new BEV registrations that same year, as shown in Table A33. This trend may explain a growing acceptance of BEVs within the MSA. Although there were 52 charging stations available in the area in 2023, the number of DCFC stations was notably lower at just 12. Additionally, the distribution of these charging stations was uneven. A majority, 55% or 17 DCFC stations, were situated in affluent neighborhoods. In stark contrast, DACs were severely underserved with only one DCFC station, which represents a mere 3% of the total. On average, DCFC stations were located approximately 3.2 miles apart. It is essential to recognize the existing socioeconomic disparities within the Charlottesville MSA. As the region transitions towards a more electrified transportation system, addressing these inequities becomes paramount. To ensure equitable access to charging infrastructure and promote environmental justice, prioritizing the installation of new DCFC stations in DACs is crucial.

Projected BEV numbers for the Charlottesville MSA for 2030 range from a conservative estimate of 8,191 vehicles (assuming a 20% increase) to an ambitious forecast of 39,058 vehicles (assuming a 50% increase), as detailed in Table A34. The MSA's current charging infrastructure can accommodate up to a 30% increase in BEVs without significant strain. However, a more substantial growth trajectory would necessitate additional charging stations. Specifically, a 40% increase in BEVs would require an extra two charging stations, while a 50% increase would demand between 13 and 14 additional DCFC stations, assuming four EVSE per DCFC.

Table A33. Overview of the Charlottesville MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster			Min	Median	Mean	Max
						AC	Inter	DAC				
2,286	9.6%	52	41	12	31	17 (55%)	13 (42%)	1 (3%) †	0	2.6	3.2	9.7

AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b). † The total of the percentages may not equal 100% exactly due to rounding adjustments.

Table A34. Projected BEVs and Needed Charging Infrastructure in the Charlottesville MSA by 2030

	20%	30%	40%	50%
BEVs	8,191	14,344	24,098	39,058
Public DC Fast Charging Ports †	18	25	39	84
Number of Additional Stations with 8 EVSE Needed			1	6.63
Number of Additional Stations with 4 EVSE Needed			2	13.25

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

Further details regarding the demographics and characteristics of this MSA can be found in Table A35. An examination of individual localities within the Charlottesville MSA indicates a generally low adoption rate for BEVs. However, it is important to highlight that Albemarle County demonstrates a promising growth trend in BEV adoption. As of 2023, the availability of DCFC stations within the MSA remains limited. Mirroring the situation in the Culpeper District, DCFC infrastructure was primarily concentrated in Albemarle County and the City of Charlottesville, with other counties lacking such facilities. This uneven distribution of charging infrastructure could potentially hinder widespread BEV adoption across the MSA. The lack of comprehensive DCFC coverage may also complicate analyses of socioeconomic disparities within the region. While Table A35 reveals the presence of socioeconomic disparities in Charlottesville MSA, the scarcity of DCFC stations in many DACs could obscure the full extent of these disparities in relation to BEV accessibility. Further investment in charging infrastructure may be necessary to fully understand and address the equity implications of BEV adoption in the Charlottesville MSA.

Table A35. Summary of the Charlottesville MSA

	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
County	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Albemarle	1,521	55.4	7	14.5	1	12	9	23.4	13.1	25.4	4.5	31.3
Charlottesville	497	28.4	5	18.1		5	4	44.4	8.6	13.2	2.8	1.3
Fluvanna	111	30.6						2.5	2.2	58.2	9.2	11.7
Greene	67	48.9						6.7	2.9	45.2	6.9	0
Nelson	87	40.3						13.2	1.6	54.7	8.5	7.4

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Charlottesville MSA

The five-priority assessment, outlined in Table A36, identified Nelson, Greene, and Fluvanna Counties as priority areas for DCFC station installation. These counties are considered rural, located in central Virginia, and have low population density compared to nearby urban areas. For instance, Nelson County could potentially have 1,486 BEVs if adoption rates increase by 50%. As DCFC stations are installed in localities like Nelson, Greene, and Fluvanna Counties, DACs should be prioritized. In other words, strategically placing DCFC stations in both densely and sparsely populated areas, as well as in DACs, can encourage EV adoption and alleviate range anxiety for drivers.

Table A36. Five-Priority Assessment of the Charlottesville MSA

	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
County	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Nelson	87	4.7	40	546	917	1,486				13	2	45	7
Greene	67	4.5	49	420	706	1,145				7	3	55	0
Fluvanna	111	4.0	31	697	1,170	1,897				2	2	42	12
Charlottesville	497	11.8	28	3,119	5,239	8,492	5	4		44	9	87	1
Albemarle	1,521	11.5	55	9,544	16,033	25,988	12	9	1	23	13	75	31

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

An analysis of individual localities revealed varying needs for DCFC stations, as shown in Table A37. For example, Albemarle County could see a significant increase in EV adoption and consequently require a substantial expansion of its charging infrastructure by 2030. In contrast, the rural counties of Nelson, Greene, and Fluvanna, identified as priority locations in the five-priority assessment, may need a few DCFC stations due to lower population density and EV adoption rates. The City of Charlottesville may also require two or three DCFC stations to accommodate projected EV growth.

Table A37. Projected DCFC Stations by Locality in the Charlottesville MSA by 2030

	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
County	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Nelson	0	0.5	0.8	1.3	0.5	0.8	1.3
Greene	0	0.4	0.6	1	0.4	0.6	1
Fluvanna	0	0.6	1	1.6	0.6	1	1.6
Charlottesville	5	2.7	4.5	7.2			2.2
Albemarle	7	8.1	13.6	22.1	1.1	6.6	15.1

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Lynchburg District and Lynchburg MSA

The Lynchburg District and Lynchburg MSA exhibit overlapping geographic boundaries, as illustrated in Figure A14. Both regions include the urban core of Lynchburg and its surrounding, more rural counties. The Lynchburg MSA comprises five localities, two of which lacked DCFC stations. The situation was even more pronounced within VDOT's Lynchburg District, where half of the twelve localities lacked DCFC options as of 2023. The following sections provide in-depth details on BEV adoption, DCFC stations, and socioeconomic disparities.

VDOT's Lynchburg District

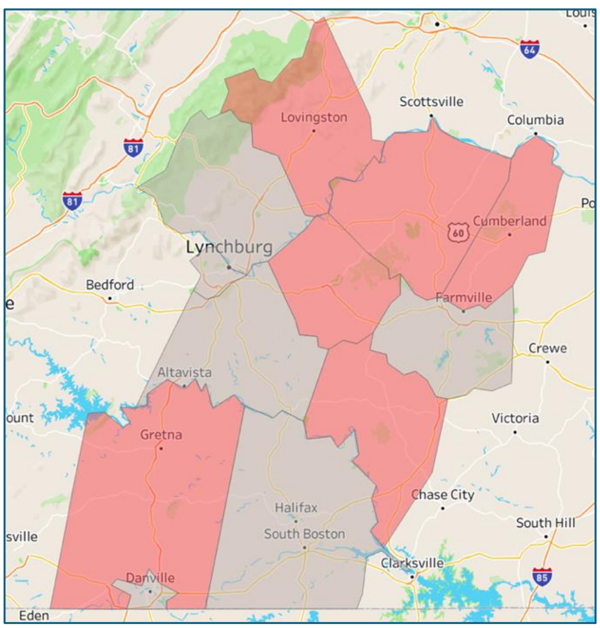
In addition to the geographic overview presented in Figure A14, Table A38 provides detailed data on BEVs and DCFC infrastructure within the Lynchburg District. While Lynchburg City showed a little more BEV adoption than surrounding areas with 197 vehicles as of 2023, the remaining localities exhibited considerably lower numbers. This trend was reflected in the overall BEV percentage for the whole district. Despite some localities experiencing growth rates exceeding 50%, the low absolute number of BEVs suggested that while interest in BEVs was evident, widespread adoption has yet to materialize. A notable deficiency existed in DCFC stations, with no such facilities available even in many DACs.

The Lynchburg District is not included in the state's AFC network due to the absence of interstate highways. While other rural regions have concentrated on developing DCFC infrastructure along AFCs, the Lynchburg District's unique needs require a different approach that does not prioritize AFCs. Instead, the focus should be on supporting daily commutes within the district to ensure adequate access to DCFC infrastructure.

Table A38. Summary of the Lynchburg District

County	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster AC	Cluster Inter	Cluster DAC
Amherst	25	44	51	15.9	0.8	1		1	8			8
Appomattox	3	3	10	233.3	0.4							
Buckingham	7	13	21	61.5	0.9							
Campbell	43	68	99	45.6	0.8	2	1	1	8		8	
Charlotte	5	5	8	60	0.4							
Cumberland	1	5	4	-20	0.2							
Danville	25	40	47	17.5	0.4	5	4	1	1			1
Halifax	14	24	41	70.8	0.5	4	3	1	4		4	
Lynchburg	88	139	197	41.7	1.4	7	6	1	2			2
Nelson	55	62	87	40.3	2.4	2	1					
Pittsylvania	17	34	32	-5.9	0.2							
Prince Edward	16	21	33	57.1	1.1	4	3	1	8		8	

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.



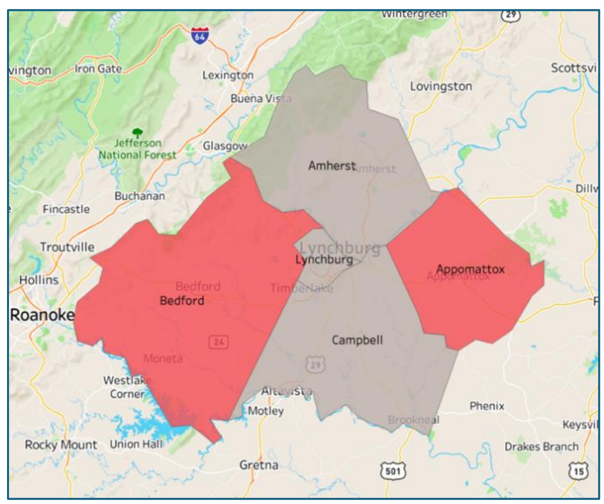


Figure A14. VDOT's Lynchburg District (left) and Lynchburg MSA (right)

Figure A15 provides a visual representation of the six DCFC stations located within VDOT's Lynchburg District, while Table A39 quantifies the geographical distances between these stations. Together, this information shows the distribution of DCFC infrastructure across the region. Note that some localities used proxy locations due to the lack of DCFC stations.

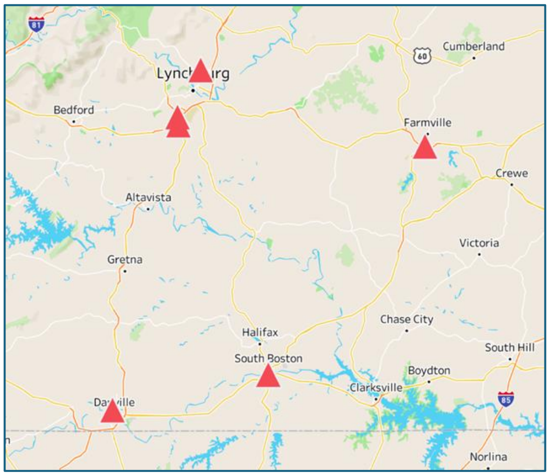


Figure A15. Direct Current Fast Charging Stations in the Lynchburg District

Table A39. Proximity of Each Pair of DCFC Stations in the Lynchburg District

Locality	Min	Median	Mean	Max	Proxy Location
Amherst	9.2	35.6	35.6	62	
Appomattox	17.4	22.1	31.5	61.1	County Administration Building
Buckingham	21	38.1	45.4	80.8	County Administration Building
Campbell	1.5	43.6	30.8	51.6	
Charlotte	20	36.1	35.5	52.7	County Administration Building
Cumberland	17.7	53.1	54.6	89.1	County Administration Building
Danville	0.8	52.8	44.9	72.4	City Hall
Halifax	28.5	48.2	43.9	55.1	
Lynchburg	1.5	26.5	25.9	53	
Nelson	24.4	38.6	49.1	85.4	County Administration Building
Pittsylvania	16	36.9	38.2	63.2	County Administration Building
Prince Edward	41.7	46.3	51.7	72.3	

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Lynchburg MSA

As illustrated in Figure A14, the Lynchburg MSA centers on Lynchburg City and incorporates surrounding rural regions. Overall, the Lynchburg MSA reported 624 BEVs as of 2023, representing a 2.9% share of new BEV registrations for that year, as detailed in Table A40. These figures indicated a relatively slow pace of BEV adoption within the MSA. While the region possessed three DCFC stations and eighteen DCFC EVSE ports, a significant gap existed in charging infrastructure. Significantly, none of the advantaged communities had DCFC stations, while ten (56%) were situated in DACs. The average physical distance between DCFC chargers within the MSA is approximately 7.1 miles.

Table A40. Overview of the Lynchburg MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster			Min	Median	Mean	Max
						AC	Inter	DAC				
624	2.9%	16	13	3	18	0 (0%)	8 (44%)	10 (56%) †	1.5	9.2	7.1	10.5

AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal 100% exactly due to rounding adjustments.

The Lynchburg MSA is projected to experience growth in BEV adoption by 2030, with estimates ranging from 2,236 to 10,662 BEVs across various growth rate scenarios (Table A41). While a 40% increase in BEV ownership is anticipated to be manageable given the current low adoption rate, a more aggressive growth trajectory of 50% could strain the existing charging infrastructure. To accommodate the potential surge in EVs, the MSA may require an additional two DCFC stations by 2030.

Table A41. Projected BEVs and Needed Charging Infrastructure in the Lynchburg MSA by 2030

	20%	30%	40%	50%
BEVs	2,236	3,916	6,578	10,662
Public DC Fast Charging Ports †		9	12	26
Number of Additional Stations with 8 EVSE Needed				1
Number of Additional Stations with 4 EVSE Needed				2

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

Table A42. Summary of the Lynchburg MSA

Locality	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Amherst	51	15.9	1	156.9	8			8.3	1.8	34.1	9	0
Appomattox	10	233.3						4.7	0.7	45.9	5.5	0
Bedford County	267	59.9						7.6	4.1	40.4	5.3	0
Campbell	99	45.6	1	80.8			8	11.4	2.5	31.1	4.6	0
Lynchburg	197	41.7	1	10.2	2			34.6	7.3	12.3	4.3	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Table A42 provides a detailed breakdown of BEV data within this MSA. Lynchburg City and Bedford County demonstrated relatively higher BEV numbers and growth rates. While other localities displayed more rapid growth, their overall BEV counts remained modest. Given the absence of interstate DVMT within the MSA, as indicated by the zero value, it can be inferred that travel primarily occurs within local areas. Therefore, infrastructure development should focus on supporting daily commuting needs within the Lynchburg MSA.

Five-Priority Assessment of Lynchburg MSA

The five-priority assessment identified Bedford County as the highest priority area for DCFC station installation within the Lynchburg MSA, followed closely by Lynchburg City (Table A43). It is crucial to note that the MSA currently lacks DCFC infrastructure in advantaged communities. Consequently, addressing this gap should be a consideration when deploying new charging stations. Table A44 provides a detailed overview of DCFC needs for each locality within the MSA. These data-driven insights will be instrumental in developing strategic plans and making informed decisions to accommodate the anticipated growth in electric vehicle adoption by 2030.

Table A43. Five-Priority Assessment of the Lynchburg MSA

County	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Bedford	267	3.6	60	1,675	2,815	4,562				8	4	60	0
Lynchburg	197	3.3	42	1,236	2,077	3,366			2	35	7	88	0
Campbell	99	2.1	46	621	1,044	1,692		8		11	2	69	0
Amherst	51	1.4	16	320	538	871			8	8	2	66	0
Appomattox	10	1.1	233	63	105	171				5	1	54	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Table A44. Projected DCFC Stations by Locality in the Lynchburg MSA by 2030

County	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Bedford County	0	1.4	2.4	3.9	1.4	2.4	3.9
Lynchburg	1	1.1	1.8	2.9	0.1	0.8	1.9
Campbell	1	0.5	0.9	1.4			0.4
Amherst	1	0.3	0.5	0.7			
Appomattox	0	0.1	0.1	0.1	0.1	0.1	0.1

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Salem District, Blacksburg–Christiansburg MSA, and Roanoke MSA

Salem District shares geographic boundaries with the Blacksburg-Christiansburg and Roanoke MSAs, as depicted in Figures A16 and A17. Characterized by a rural landscape featuring mountains, valleys, and plateaus, this region exhibits a lower population density compared to other parts of Virginia. As of 2023, urban areas within the district and the MSAs had some DCFC infrastructure, but the surrounding rural areas faced a substantial shortage of this crucial facility for BEVs. A detailed analysis of BEV adoptions, DCFC infrastructure, and socioeconomic disparities is presented in the following sections.

Salem District

Similar to other primarily rural districts, the adoption rate of BEVs within the Salem District remained relatively low, as evidenced by Table A45, although there was higher growth in BEV adoption between 2022 and 2023. Eleven of the seventeen localities within the district lacked DCFC stations as of 2023. Many of these localities were classified as intermediate communities, and even advantaged communities within the district had no access to DCFC stations. Furthermore, the distribution of DCFC stations across the district was sparse, as shown in Table A46. Due to the scarcity of DCFC stations in numerous localities, proxy locations were used for analysis purposes in Table A46.

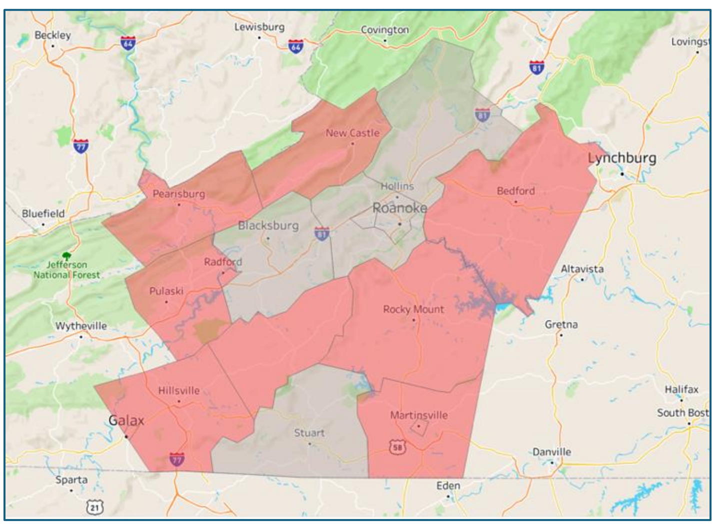


Figure A16. VDOT's Salem District

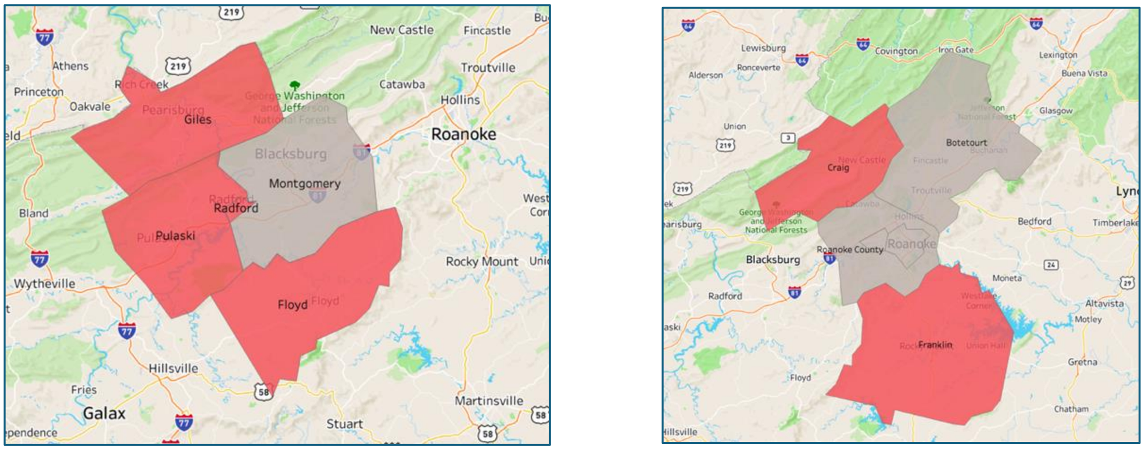


Figure A17. Blacksburg-Christiansburg MSA (left) and Roanoke MSA (right)

Table A45. Summary of the Salem District

County	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster		
										AC	Inter	DAC
Bedford	112	167	267	59.9	1.2	6	6					
Botetourt	38	63	88	39.7	0.8	2	1	1	4		4	
Carroll	19	34	40	17.6	0.4							
Craig	1	3	6	100.0	0.7							
Floyd	14	26	36	38.5	1.1	2	2					
Franklin	59	90	107	18.9	0.7	1	1					
Galax	2	6	6	0.0	0.7							
Giles	6	10	12	20.0	0.3	1	1					
Henry	24	36	38	5.6	0.3	2	2					
Martinsville	6	14	28	100.0	0.9	2	2					
Montgomery	182	315	443	40.6	2.0	32	30	2	6		2	4
Patrick	1	5	10	100.0	0.3	10	3	6	6		6	
Pulaski	21	35	49	40.0	0.7	1	1					
Radford	10	18	18	0.0	0.9	2	2					
Roanoke City	108	158	269	70.3	0.8	19	11	8	18		14	4
Roanoke County	139	242	381	57.4	1.4	9	8	2	5		5	
Salem	37	58	79	36.2	1.2	10	7	3	17		17	

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.

Table A46. Proximity of Each Pair of DCFC Stations in the Salem District

Locality	Min	Median	Mean	Max	Proxy Location
Bedford	19.1	27.8	37.9	63.9	County Administration Building
Botetourt	11.2	17.3	32.1	58.8	
Carroll	18.4	52.7	43.6	68.7	County Administration Building
Craig	13.6	19.4	28.7	55.5	County Administration Building
Floyd	13.1	30.1	26.1	45.9	County Administration Building
Franklin	17.8	23.0	25.3	32.9	County Administration Building
Galax	29.2	65.4	55.7	81.3	City Hall
Giles	20.2	43.5	41.1	50.3	County Administration Building

Locality	Min	Median	Mean	Max	Proxy Location
Henry	28.5	35.3	35.8	49.3	County Administration Building
Martinsville	28.5	35.3	35.8	49.3	County Administration Building
Montgomery	3.6	26.7	27.0	32.9	
Patrick	0.002	42.3	26.4	48.2	
Pulaski	21.4	44.9	40.9	59.3	County Administration Building
Radford	9.0	32.5	31.5	46.9	City Hall
Roanoke City	0.0	7.0	21.4	45.9	
Roanoke County	3.0	7.7	20.3	48.8	
Salem	1.8	8.9	21.0	44.0	

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

A concentration of DCFC stations was found in and around the Roanoke area, as shown in Figure A18. The Salem District is served by two AFCs along I-81 and I-77, as detailed in Table A47. However, many DCFC stations were located beyond a two-mile radius from these AFC exit points. To support long-distance travel and adhere to corridor-based development strategies in rural areas, it is crucial that the density of DCFC stations is increased along these major routes.

Table A47. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles		> 10 Miles	
		#	%	#	%	#	%	#	%
I-81	43	12	28%	31	72%	25	58%	16	37%
I-77	10	0	0%	10	100%	10	100%	8	80%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

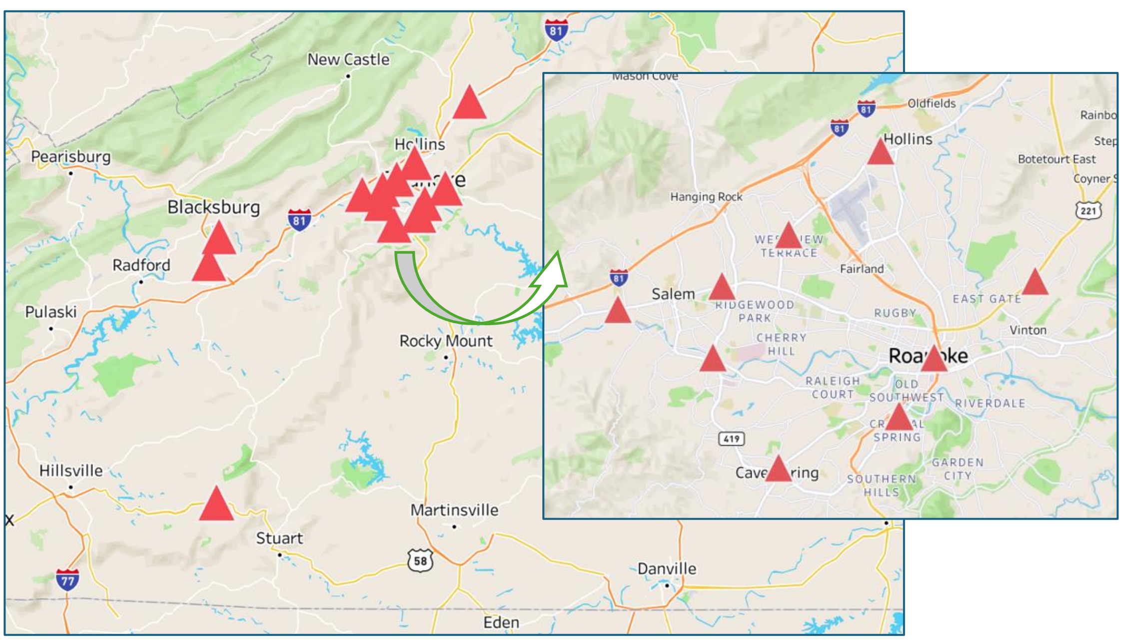


Figure A18. Direct Current Fast Charging Stations in the Salem District

Blacksburg-Christiansburg MSA

In the Blacksburg-Christiansburg MSA, as shown in Table A48, the adoption rate rose to 3.5% in 2023, but the total number of BEVs on the road was modest, with only 558 vehicles. Disadvantaged communities had a charging network with four DCFC EVSEs as of 2023. No advantaged communities had any DCFC stations.

Table A48. Overview of the Blacksburg-Christiansburg MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster			Min	Median	Mean	Max
						AC	Inter	DAC				
558	3.5%	38	36	2	6	0 (0%)	2 (33%)	4 (67%) †	3.6	3.6	3.6	3.6

AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal 100% exactly due to rounding adjustments.

Due to the slower adoption of BEVs, projected BEV numbers for this MSA have been estimated with caution. As outlined in Table A49, the current charging infrastructure can easily support a 20% increase in BEVs. However, if the MSA sees a more significant growth of 30% to 40%, one or two additional DCFC stations may be needed to meet market demand. A 50% increase in BEV adoption would require installing three new DCFC stations to provide adequate charging infrastructure.

Table A49. Projected BEVs and Charging Infrastructure in the Blacksburg-Christiansburg MSA by 2030

	20%	30%	40%	50%
BEVs	1,999	3,501	5,882	9,534
Public DC Fast Charging Ports †	7	9	15	18
Number of Additional Stations with 8 EVSE Needed		0.38	1.13	1.50
Number of Additional Stations with 4 EVSE Needed		0.75	2.25	3

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

Table A50 provides a comprehensive overview of the BEV landscape in the Blacksburg-Christiansburg MSA as of 2023. Although year-over-year growth within localities in the MSA is encouraging, a significant increase in BEV numbers is still required. In terms of charging infrastructure, Montgomery County led with two DCFC stations, while advantaged communities lacked any, creating a significant barrier to EV adoption in these areas.

Table A50. Summary of the Blacksburg-Christiansburg MSA

	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
County	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Floyd	36	38.5						2.3	0.4	56.4	16.9	0
Giles	12	20.0						8.3	0.7	49.3	6.1	0
Montgomery	443	40.6	2	13.5	4		2	30.9	6.4	16.5	2.9	43.1
Pulaski	49	40.0						13.3	2.6	31.2	7.3	53.3
Radford	18	0.0						43.2	3.7	17.1	0.8	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Blacksburg-Christiansburg MSA

The five-priority assessment, as outlined in Table A51, identified Montgomery County as the top priority for installing additional DCFC stations. Following closely behind were Radford, Pulaski, Giles, and Floyd. When planning and implementing DCFC infrastructure, both advantaged communities and DACs should be given equal consideration to ensure equitable access to these essential charging facilities in this MSA. Table A51 prioritizes areas for DCFC development, while Table A52 outlines specific infrastructure requirements and scenarios for each locality. Montgomery County, for example, may need to invest in four or five more DCFC stations to accommodate a 50% increase in BEVS by 2030. In contrast, other localities may require only one DCFC station, even with similar growth, due to their slower BEV adoption rates.

Table A51. Five-Priority Assessment of the Blacksburg-Christiansburg MSA

Locality	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Montgomery	443	4.8	41	2,780	4,670	7,569		2	4	31	6	83	43
Radford	18	2.4	0	113	190	308				43	4	83	0
Pulaski	49	1.8	40	307	517	837				13	3	69	53
Giles	12	0.8	20	75	126	205				8	1	51	0
Floyd	36	2.0	39	226	379	615				2	0	44	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Table A52. Projected DCFC Stations by Locality in the Blacksburg-Christiansburg MSA by 2030

Locality	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Montgomery	2	2.4	4	6.4	0.4	2	4.4
Radford	0	0.1	0.2	0.3	0.1	0.2	0.3
Pulaski	0	0.3	0.4	0.7	0.3	0.4	0.7
Giles	0	0.1	0.1	0.2	0.1	0.1	0.2
Floyd	0	0.2	0.3	0.5	0.2	0.3	0.5

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Roanoke MSA

The Roanoke MSA, located in southwestern Virginia and centered around Roanoke City, is known for its natural beauty, surrounded by national forests, parks, and waterways, as shown in Figure A17. In 2023, Roanoke MSA had a relatively low BEV adoption rate of 2.8%, with just under 3,000 BEVs on the road, as shown in Table A53. To support this fleet, the MSA had 14 DCFC stations, with approximately 9% of the DCFC EVSEs located in DACs. Given the slow adoption rate, BEV growth in the MSA is expected to continue at a steady pace, as shown in Table A54. To accommodate a 40% increase in BEVs, the MSA would need to add about five more DCFC stations. For a 50% increase, an additional eight DCFC stations would be required to meet the growing demand.

Table A53. Overview of the Roanoke MSA

BEVs		Number of Charging Stations			Number of DCFC EVSE				Proximity of Each Pair of MSA Stations (Miles)			
# BEVs as of 2023	% BEVs in 2023	All	L2	DCFC	All	Cluster			Min	Median	Mean	Max
						AC	Inter	DAC				
2,953	2.8%	41	28	14	44	0 (0%)	40 (91%)	4 (9%) †	0	5.2	5.9	17.9

AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community, BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment. # BEVs as of 2023: Cumulative number of BEVs in the MSA as of 2023 (Source: Virginia Clean Cities (2024)). % BEVs in 2023: Percentage of new vehicle registrations that were BEVs in 2023 (Source: S&P Global Mobility (2024)). The distances between MSA stations were calculated using the Vincenty ellipsoid formula as of 2023. This geodetic method accounts for the Earth's curvature to determine the shortest surface distance between two points based on their latitude and longitude coordinates (Source: AFDC (2024b)). † The total of the percentages may not equal exactly 100% due to rounding adjustments.

Table A54. Projected BEVs and Needed Charging Infrastructure in the Roanoke MSA by 2030

	20%	30%	40%	50%
BEV Prediction	10,581	18,530	31,129	50,455
Public DC Fast Charging Ports †	24	44	63	73
Number of Additional Stations with 8 EVSE Needed			2.38	3.63
Number of Additional Stations with 4 EVSE Needed			4.75	7.25

BEV = Battery Electric Vehicle, DC = Direct Current, EVSE = Electric Vehicle Supply Equipment. † Data on public DC Fast charging ports was obtained from EVI-Pro Lite (2024a).

As outlined in Table A55, Roanoke City and Roanoke County had relatively higher numbers of BEVs as compared to nearby localities, but BEV adoption in other localities was low as of 2023. Two localities lacked DCFC infrastructure, and there were no DCFC stations in advantaged communities. Roanoke City had eight DCFC stations, with four of these DCFC EVSEs located in DACs. Similar to other relatively rural areas, discussing socioeconomic disparities is premature due to the slow adoption of BEVs. In the future, as BEV adoption increases and DCFC stations are installed, socioeconomic factors should be considered.

Table A55. Summary of the Roanoke MSA

Locality	BEVs		Number of DCFC		Number of DCFC EVSE					Travel to Work		
	2023	Growth Rate	#	Per 1,000	DAC	AC	Int	% APT	% SFA	% > 30 min.	% > 60 min.	% IR
Botetourt	88	39.7	1	45.5			4	4.7	2.3	35	5.3	58
Craig	6	100.0						2.8	0	66.4	4.4	0
Franklin	107	18.9						7.2	2	52.5	8.8	0
Roanoke City	269	70.3	8	66.9	4		14	32.9	4.7	25.8	3.4	17.6
Roanoke County	381	57.4	2	13.1			5	18.9	4.8	28.1	3.5	41.5
Salem	79	36.2	3	215.2			17	22.3	4.2	18.6	2.8	5.4

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. The number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. The DCFC represents the number of DCFC stations. The rate was calculated by dividing the number of DCFC EVSE by the number of BEVs, then multiplying by 1,000. Blank cells indicate zero, enhancing the readability of the results. % APT (percentage of apartments) and % SFA (percentage of single-family attached) metrics are based on housing data from the 2022 ACS. Commute time information (over 30 minutes and over 60 minutes) is also sourced from the ACS. % IR: The interstate DVMT metric represents the proportion of interstate travel within the overall DVMT, which includes secondary, primary, and interstate roads, as determined by VDOT datasets as of 2022.

Five-Priority Assessment of Roanoke MSA

Based on the five-priority assessment outlined in Tables A56 and A57, Franklin County was identified as the highest priority for expanding DCFC infrastructure within this MSA. Improved access to the DCFC network would greatly benefit this region by promoting BEV adoption and reducing range anxiety. Roanoke County, which was also a close contender, similarly requires strategic investment in DCFC infrastructure to enhance BEV adoption rates and alleviate range concerns.

Considering individual localities and a projected 50% increase in BEV adoption by 2030, Franklin County would need approximately two additional DCFC stations to meet the expected demand. Roanoke County, in contrast, would require about four more DCFC stations to accommodate this growth. Roanoke City's current DCFC network is expected to be robust enough to support a 50% increase in BEV adoption by 2030. The other localities within the MSA have lower BEV adoption rates at present, indicating that their immediate need for expanded DCFC infrastructure is less critical. However, it is advisable to monitor their adoption trends and reassess their future needs as necessary. Strategically allocating resources for DCFC infrastructure expansion is crucial for promoting widespread BEV adoption and addressing range anxiety within the MSA.

Table A56. Five-Priority Assessment of the Roanoke MSA

Locality	BEV			Projected Growth of BEVs by 2030			DCFC EVSE as of 2023			Demographics			
	#	%	GR	30%	40%	50%	AC	Int	DAC	% APT	% SFA	% < 30	% IR
Franklin	107	1.2	19	671	1,128	1,828				7	2	47	0
Roanoke County	381	3.9	57	2,391	4,016	6,510		5		19	5	72	42
Roanoke City	269	2.5	70	1,688	2,836	4,596		14	4	33	5	74	18
Salem	79	3.6	36	496	833	1,350		17		22	4	81	5
Botetourt	88	2.0	40	552	928	1,504		4		5	2	65	58
Craig	6	4.2	100	38	63	103				3	0	34	0

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. #: Number of BEVs as of 2023 (source: Virginia Clean Cities (2024)); %: Percentage of new BEV registrations in 2023 (source: S&P Global Mobility (2024)); GR: growth rate between 2022 and 2023 (source: Virginia Clean Cities (2024)); % APT: percentage of apartment units; % SFA: percentage of single-family attached units; % < 30: percentage of commutes under 30 minutes as of 2022 ACS; % IR: interstate share of DVMT in 2022.

Table A57. Projected DCFC Stations by Locality in the Roanoke MSA by 2030

Locality	DCFC	Minimum Number of DCFC Stations Needed by 2030 †			Additional DCFC Stations Needed by 2030 ††		
	# DCFC as of 2023	30%	40%	50%	30%	40%	50%
Franklin	0	0.6	1	1.6	0.6	1	1.6
Roanoke County	2	2	3.4	5.5		1.4	3.5
Roanoke City	8	1.4	2.4	3.9			
Salem	3	0.4	0.7	1.1			
Botetourt	1	0.5	0.8	1.3			0.3
Craig	0	0	0.1	0.1		0.1	0.1

DCFC = Direct Current Fast Charging. † The minimum number of DCFC stations required by 2030 was determined using the projected number of BEVs and a guideline of 3.4 DCFC ports per 1,000 BEVs, assuming each station has 4 DCFC ports. †† To calculate the additional DCFC stations needed by 2030, the minimum required number was subtracted from the existing number of DCFC ports in 2023, again assuming 4 DCFC ports per station. ††† Blank cells represent negative values, enhancing clarity and comprehension.

Bristol District

Previously, VDOT districts and their respective MSAs were analyzed together to forecast future BEV adoption. However, an in-depth look at the Bristol District revealed a very low BEV adoption as of 2023, which led to a similarly low projected BEV population for 2030. Due to this limited data, the EVI-Pro Lite tool could not generate adequate estimates for the required charging infrastructure. Consequently, this section concentrated exclusively on the Bristol District, excluding its associated MSA.

Figure A19 illustrates the Bristol District, and Table A58 provides detailed information on BEVs, DCFC infrastructure, and socioeconomic disparities in the region. Together, these analyses offer a thorough overview of the current state of BEV adoption and related factors in the Bristol District. As of 2023, ten out of fourteen counties in the Bristol District lacked DCFC stations, reflecting the region's generally low BEV adoption, which is common in many rural areas. The absence of DCFC infrastructure in advantaged communities within the Bristol District highlights an additional challenge for these areas in transitioning to BEVs. Given the current low BEV adoption, a detailed analysis of socioeconomic disparities related to BEV access and usage may not be necessary at this stage. However, as BEV adoption grows in the region, it will be crucial to evaluate and address any emerging disparities.

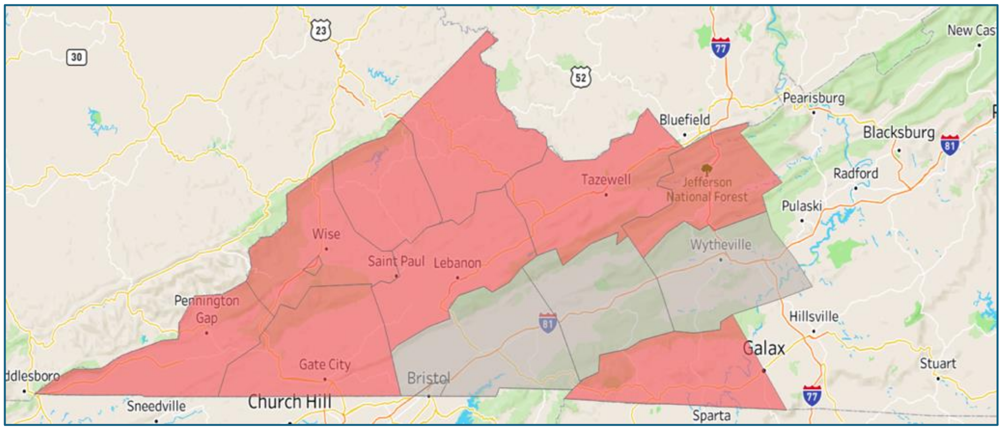


Figure A19. VDOT's Bristol District

Table A58. Summary of the Bristol District

Locality	Number of BEVs					Number of Charging Stations			Number of DCFC EVSE			
	2021	2022	2023	GR	% BEVs	All	L2	DCFC	All	Cluster		
										AC	Inter	DAC
Bland	3	4	3	-25	0.2							
Bristol	9	18	21	16.7	0.4	2		2	16		8	8
Buchanan	2	1	1	0	0.0							
Dickenson	2	6	5	-16.7	0.1							
Grayson	5	9	13	44.4	0.4							
Lee	7	9	18	100	0.4							
Norton	0	0	3		0.1							
Russell	5	7	10	42.9	0.2							
Scott	2	8	14	75	0.2							
Smyth	6	13	18	38.5	0.3	2	1	1	8		8	
Tazewell	10	12	20	66.7	0.2							
Washington	49	80	117	46.2	0.7	8	6	2	5		4	1
Wise	7	19	27	42.1	0.2	1	1					
Wythe	20	21	30	42.9	0.5	5	1	3	14		4	10

BEV = Battery Electric Vehicle, DCFC = Direct Current Fast Charging, EVSE = Electric Vehicle Supply Equipment, AC = Advantaged Community, Inter = Intermediate Community, DAC = Disadvantaged Community. Number of BEVs is from Virginia Clean Cities (2024), with growth rates calculated between 2022 and 2023. GR indicates the growth rate between 2022 and 2023. "% BEVs" represents the percentage of BEVs among all new vehicle registrations as of 2023, according to data from S&P Global Mobility (2024). Blank cells indicate zero, enhancing the readability of the results.

To better understand the distribution of DCFC stations in the Bristol District, Table A59 shows the physical distances between each pair of DCFC stations. The table indicates a pattern of widely spaced DCFC stations throughout the district. Additionally, because many localities lack actual DCFC stations, proxy locations were used to estimate the potential availability and accessibility of charging infrastructure.

Table A59. Proximity of Each Pair of DCFC Stations in the Bristol District

Locality	Min	Median	Mean	Max	Proxy Location
Bland	9.8	39.4	39.1	68.7	County Administration Building
Bristol	2.99	26.9	31.7	70	
Buchanan	40.9	47.6	51.3	65.4	County Administration Building
Dickenson	39	49.4	56.6	83.4	County Administration Building
Grayson	22.7	35.6	38.4	57.7	County Administration Building
Lee	51.5	78.4	83.4	121.2	County Administration Building
Norton	33.5	52.9	59.2	93	City Hall
Russell	14.4	28.7	35.3	62	County Administration Building
Scott	21.5	49.3	54.1	92.5	County Administration Building
Smyth	27.3	32.2	35.1	45.8	
Tazewell	18	35.8	36.3	51.3	County Administration Building
Washington	1.3	27.7	32.5	68.7	
Wise	33.7	51.1	57.7	90.3	County Administration Building
Wythe	2.4	53.9	43.1	72.8	

With the exception of proxy locations, all values are current as of December 31, 2023. Distances between DCFC stations were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.

Figure A20 shows that the existing DCFC stations in the Bristol District are primarily located near I-81, reflecting a corridor-based approach often used in areas with relatively low BEV adoption rates. Given the limited number of BEVs in the district, a community-based approach to DCFC infrastructure may not be the most feasible at this time. However, Table A60 reveals a potential issue: many DCFC stations are situated more than two miles from highway exits. Considering the district's low BEV adoption rate and the current concentration of DCFC stations along I-81, future development should focus on optimizing station locations to better meet the needs of BEV users.

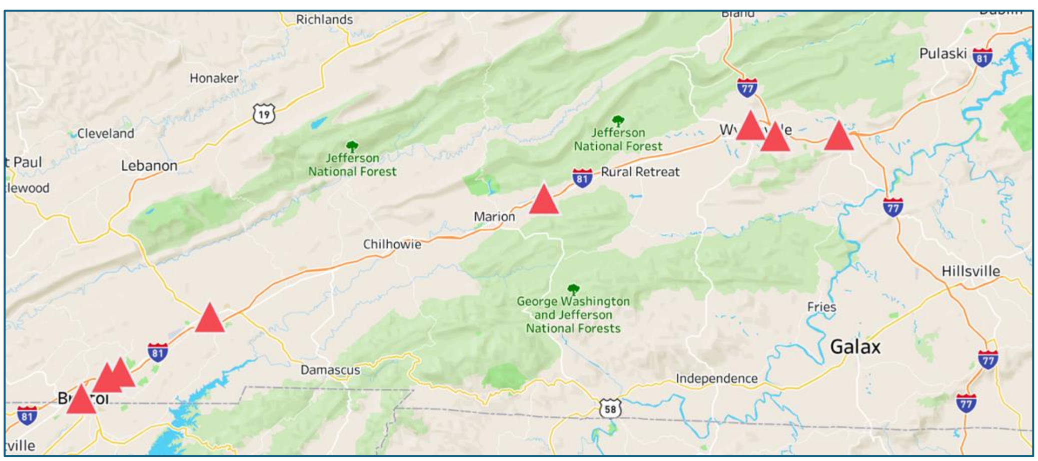


Figure A20. Direct Current Fast Charging Stations in the Bristol District

Table A60. Number of AFC Exits with DCFC Stations Located Within or More than Two Miles from the Exit

AFC	Total Number of Exits	Less than 2 Miles		> 2 Miles		> 5 Miles		> 10 Miles	
		#	%	#	%	#	%	#	%
I-81	66	28	42%	38	58%	20	30%	8	12%
I-77	14	3	21%	11	79%	9	64%	7	50%

AFC = Alternative Fuels Corridor. Distances between the exit and the DCFC station were determined using the Vincenty ellipsoid formula, a geodetic method that accounts for the Earth's curvature to accurately calculate the shortest distance between two points based on their latitude and longitude coordinates.