An Assessment of Electrification Impacts on the Pepco DC Distribution System

VOLUME I: SUMMARY REPORT

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Notice

This report was prepared by The Brattle Group for Pepco. It is intended to be read and used as a whole and not in parts. The report reflects the analyses and opinions of the authors and does not necessarily reflect those of The Brattle Group's clients or other consultants.

The authors would like to thank the Pepco team, including Lindsay North, Jacob Burlin, Eric Moberg, Lingo Haile, Brendan Timmons, Will Davis, Bill Snodgrass, and Zinn Morton, for their invaluable insight and leadership throughout this study.

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1. Summary

Introduction

The purpose of this study is to provide a granular estimate of the capacity expansion investments needed for Pepco's distribution grid to support full electrification, in line with the District's climate goals and roadmap.

The DC Public Service Commission's Order 22313[1] directed Pepco to develop a granular electrification impact study with detail on the capital expenditures needed for the electric grid to support full electrification. Further, the Order required the study to consider energy efficiency and load flexibility impacts and account for associated load reductions.

Study scope. This study is intended to inform stakeholders on the distribution grid impacts of electrification and the related value of grid flexibility. It assesses the impacts of achieving the District's electrification goals on the loading of Pepco's electric distribution system – consisting of 827 feeders and 45 substations – and identifies the cost of potential grid upgrade needs, with and without grid flexibility.

The potential role of grid flexibility. This study illustrates the ability of a portfolio of distributed energy resources, energy efficiency, and demand flexibility technologies to mitigate grid upgrades. The study refers to these technologies collectively as "grid flexibility technologies". Grid flexibility is defined as the ability to shift demand or supply to meet grid needs.

1 *Order 22313, Case Number 1167*

Interpreting the Findings

The study is focused on distribution capacity expansion investment needs driven by load growth. Other needs, such as grid modernization or replacement of aging equipment, are outside the scope of this study.

While the study provides feeder-level granularity, it is not a substitute for detailed distribution system planning and is not intended to inform the need for specific projects. It uses average feeder and substation project costs to estimate the investment needed to mitigate projected overloads. More detailed solution scoping may identify additional asset-specific issues, alternative solutions, and refined cost estimates for each specific grid need.

The study illustrates the value of grid flexibility technologies to the distribution grid. It does not assess value to the bulk system and does not include the cost of deploying these technologies. Detailed benefit-cost assessments should be done in the context of specific programs or distribution upgrade deferral opportunities.

The study assumes high electrification levels in 2040 in order to conduct the grid needs assessment in the context of achieving the District's decarbonization goals. It is not necessarily a forecast of the most likely trajectory of technology adoption or load growth.

Distribution Grid Needs to Support Electrification

Without new grid flexibility, a portion of Pepco's feeders and substations would need to be upgraded to support load growth, more than doubling distribution capex relative to the scenario without new electrification load.

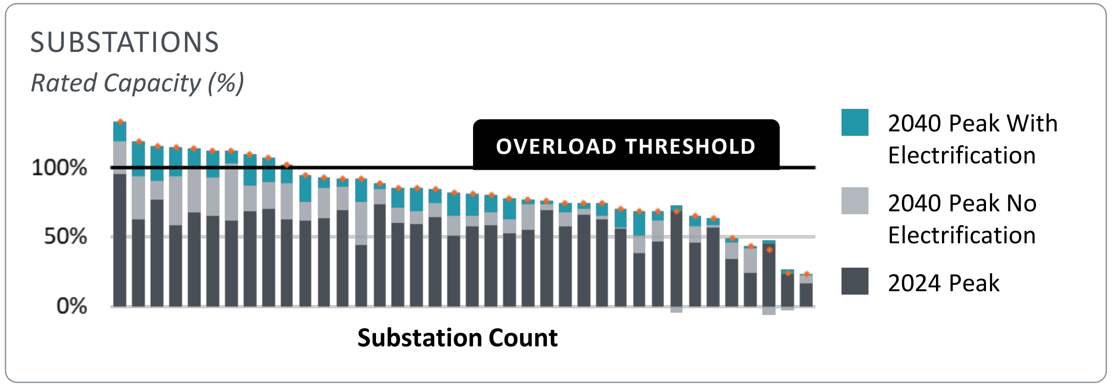
Pepco's feeders and substations currently have significant hosting capacity for load growth, especially in the winter. Due to over a decade of stagnant demand growth, most parts of Pepco's distribution system experience summer peak loads that are less than 75% of rated feeder/substation capacity. Due to the limited amount of electrified heating currently used in the District, winter peaks are significantly lower than summer peaks in most locations, meaning there is even more room for winter load growth.

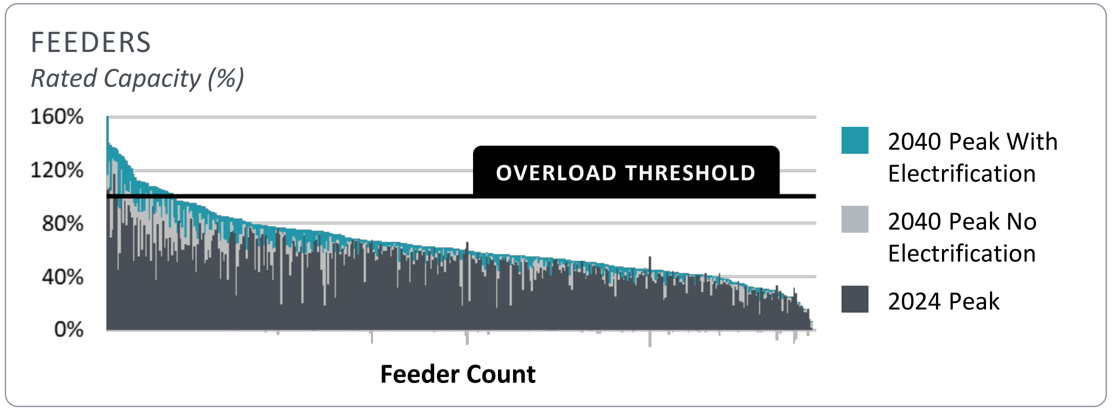
However, even in the absence of new electrification, without additional grid flexibility, Pepco's load is expected to grow 26% by 2040, requiring approximately $665 million[1] in capacity expansion investment. Pepco's distribution system planning process identifies and plans for capacity needs through 2034. Those already-planned upgrades combined with additional upgrades for needs through 2040 result in total estimated "baseline" capex of $665 million, or $44 million/year for the 15-year period from 2025 to 2040.

When accounting for the levels of electrification assumed in this study, total load growth from 2024-2040 is 52%, requiring capacity expansion investment of $1,594 million. That investment requirement represents a 140% increase over the scenario without new electrification load. As a result of electrification, our modeling identifies the need to upgrade 5 feeders and 3 substations, as well as the need to build 26 new feeders and 2 new substations. These results *do not* account for the potential impacts of grid flexibility (see next page).

1 Values throughout this study are reported in 2025 real dollars.

PROJECTED OVERLOADS BY 2040 – FULL ELECTRIFICATION, NO ADDITIONAL GRID FLEXIBILITY





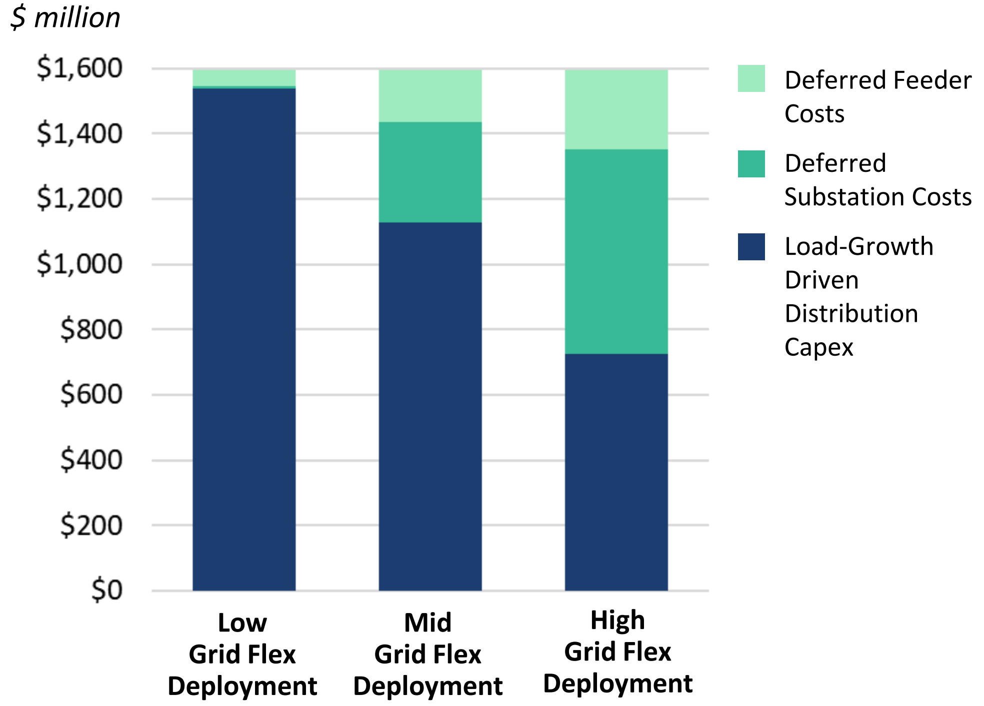
The Potential Role of Grid Flexibility

Deploying a portfolio of grid flexibility technologies could reduce the 2025-2040 capex requirement by $58-$868 million (a 4%-54% reduction). However, the costs of deploying the grid flexibility measures are not included in this analysis and should be studied for cost-effectiveness relative to traditional grid upgrades.

The results highlight that the ability of grid flexibility to defer distribution system investment depends heavily on reaching sufficient levels of grid flexibility adoption. Further, once the largest deferral opportunities are achieved, the incremental value of additional reductions declines. Investment decisions are highly project-specific and each will need to consider the relative cost of grid flexibility, which is not included in this study.

Grid Flex Case	Description	Upgrade Deferral Outcomes
Low Deployment	Representative of meaningful current-day adoption of grid flexibility programs, but with very limited increase in localized solar generation	Several new feeders are avoided, one substation upgrade avoided
Mid Deployment	Represents 2040 adoption levels of 10%-25%, depending on the technology	Many new feeders are avoided, and one high-cost substation build is avoided
High Deployment	Represents 2040 adoption levels nearing the upper limits of the modeled sample technologies' maximum achievable adoption, with levels between 20%-50%	Most electrification-driven new feeders and many substation upgrades are avoided

2025-2040 DISTRIBUTION CAPEX REQUIREMENT WITH VARYING DEPLOYMENT OF GRID FLEXIBILITY TECHNOLOGIES



Key Findings

The Pepco DC system currently has significant capacity headroom for load growth, especially in the winter. Most parts of the system can support electrification loads through 2040 without additional upgrades. However, the areas requiring upgrades due to electrification will increase the total investment need relative to recent levels.

Without grid flexibility, meeting the District's electrification goals could more than double Pepco's capacity expansion expenditures by 2040. Pepco's capacity expansion needs from 2025-2040 are estimated to cost $665 million in a scenario with no additional electrification and $1,594 in a scenario with full electrification and no grid flexibility.

Grid flexibility technologies could be a feasible solution to reduce capacity expansion expenditures. A portfolio of grid flexibility technologies - rooftop solar, batteries, weatherization, cold climate heat pumps, managed EV charging, and smart thermostats – could reduce the required capex by $58 to $868 million (4% to 54%). However, this result does not account for the cost of the grid flexibility measures; more granular cost-effectiveness analysis is an important next step.

There is significant value in targeted deployment of grid flexibility in areas where grid capacity expansion would be particularly expensive. The grid capacity expansion solutions to mitigate overloads have a wide range of costs. Grid flexibility is shown to be particularly valuable to deploy in locations where the most expensive capacity expansion projects may be needed, and where overload conditions are limited in terms of duration, magnitude, and rate of growth.

Scale is essential to achieve grid flexibility value. The distribution value of grid flexibility is highly dependent on deployment reaching significant scale in the locations where it is needed most; moderate levels of deployment are unlikely to produce meaningful distribution benefits.

Cold climate heat pumps are a particularly valuable grid flexibility technology. The efficiency-related savings of cold-climate heat pumps (relative to heat pumps with auxiliary resistive heating) tend to be coincident with the winter peak and can be a major contributor to grid flexibility portfolios that defer the need for grid upgrades.

Batteries provide unique value to the grid flexibility portfolio. Batteries are flexible from both an operational and siting perspective, with the option to take advantage of efficiencies by them at the customer's premise or to attach them to the distribution system where needed most. Batteries can act as the "glue" that enables the rest of the grid flexibility portfolio to provide benefits.

2. Introduction

The District's Decarbonization Goals

The District has adopted several laws and regulations related to the supply, delivery, and use of energy as part of climate initiatives in recent years. Electrification of various end uses in the transportation and building sectors is one of the cornerstones of the District's decarbonization strategy.

SUMMARY OF RELEVANT GOALS AND DIRECTIVES OF RECENT DISTRICT LEGISLATION

2030

- **2026**: Adopt net zero energy construction codes for new buildings[1,3,10]
- **2030:** Reduce GHG emissions by 60%[2]
- **2030:** 25%+ zero-emissions vehicle (ZEV) registrations[1]
  - 68% under ACCII[7,10]
- **2030:** 50% ZEV for public buses, commercial fleets, taxis, limos, & large private fleets[1]

2035

- **2032:** 100% renewable energy supply[1,10]
- **2032:** 100% residents can walk to facility with clean backup power[9]
- **2032:** Reduce energy use by 50%[10]
- **2035:** 100% ZEV registrations[7,10]
- **2035:** 75% ZEV for public buses, taxis, limos, commercial fleets, & large private fleets[1]
- **2035:** New and replacement heat and water 100% electric[8]

2040

- **2040:** 90% ZEV for public buses, commercial fleets, taxis, limos, & large private fleets[1]
- **2040:** 90% electric heat & water[8,10]
- **2041:** 15% local solar[4]

2045+

- **2045:** Carbon neutrality[2]
- **2045:** 100% ZEV for public buses, commercial fleets, taxis, limos, & large private fleets[1,10]
- **2045:** 100% electric heat and water[8,10]
- **2045:** Residual gross emissions of 1.25 MMTCO2 allocated 88% to electric generation, 4% to fossil gas, 4% to gasoline, 2% to diesel, and 2% to waste[8,10]

Source Legislation & Policy Documents

1. *CEDC Omnibus Amendment Act of 2018*
2. *Climate Commitment Act of 2022*
3. *Clean Energy DC Building Code Amendment Act of 2022*
4. *Local Solar Expansion Amendment Act of 2022*
5. *Healthy Homes and Residential Electrification Amendment Act of 2024*
6. *Inflation Reduction Act of 2022*
7. *Advanced Clean Cars II (ACCII) (adopted 2023)*
8. *Carbon Free DC (2023)*
9. *Sustainable DC*
10. *Clean Energy 2.0, DRAFT (2023)*

Study Purpose and Scope

The purpose of this study is to provide a granular estimate of the capacity expansion investments needed for Pepco's distribution grid to support full electrification, in line with the District's climate goals and roadmap.

On August 27, 2021, Pepco filed with the DC Public Service Commission a study analyzing the load impacts of electrification on its Washington, D.C system.[1] That study, conducted by The Brattle Group, focused on system load growth rates and the role that grid flexibility could play in mitigating load growth.

Subsequently, on October 10, 2024, the DC Public Service Commission issued Order 22313[2] directing Pepco to develop an updated electrification study. According to the Order:

> *"The updated electrification study should have sufficient detail, granularity, and explanation of capital expenditures needed to bolster the electric grid for full electrification. Pepco's updated electrification study must [include] granular energy efficiency and load flexibility impacts that indicate energy and load reductions, as a result of the revised CSP or revised CBP, and the new 15-Year Plans. The 15-Year Plan and electrification study must also provide detailed analyses regarding load-shifting projections, any capital investments, and behind-the-meter equipment investments (including end-use equipment, wiring, panel upgrades, etc.) necessary to support a winter peaking system."*

The purpose of this study is to address the Commission's request for an updated electrification study by assessing the impacts of the District's electrification goals on the loading of Pepco's electric distribution system – consisting of 827 feeders and 45 substations – and identifying the cost of potential grid upgrade needs, with and without grid flexibility. Our analysis considers load growth and distribution investments needs through 2040.

What is Grid Flexibility?

In this study, we use the term "grid flexibility" to include distributed energy resources, energy efficiency, and demand flexibility technologies that could potentially be used to mitigate grid upgrades.

The study refers to these technologies collectively as "grid flexibility technologies", and grid flexibility is defined as the ability to shift/reduce demand or supply to meet grid needs.

The technologies included in our analysis are indicative of the types of programs that are or could be introduced as part of Pepco's Climate Solutions plan. We have analyzed long-run deployment/adoption scenarios that extend beyond the scale include in Pepco's near-term plans.

1 An Assessment of the Impacts of Electrification on the Pepco DC System
2 Order 22313, Case Number 1167

Interpreting the Findings

This study should not be considered a substitute for detailed distribution system planning.

Focus on load growth. The study focuses specifically on distribution capacity expansion investment needs driven by load growth. Other needs, such as grid modernization or replacement of aging equipment, are outside the scope of this study.

Not a distribution system investment plan. While this study provides feeder-level granularity, it is not a substitute for detailed distribution system planning and is not intended to inform the need for investing in specific projects. Our study uses average feeder and substation project costs to estimate the investment needed to mitigate projected overloads. More detailed solution scoping may identify additional asset-specific issues, alternative solutions, and refined cost estimates for each specific grid need.

Grid flexibility distribution value, not cost-effectiveness. The study illustrates the distribution grid investments that may be deferred through the deployment of grid flexibility technologies. It does not assess value to the bulk system and does not include the cost of deployment of these technologies. Detailed benefit-cost assessments should be done in the context of specific programs or distribution upgrade deferral opportunities.

Policy-based assumptions. The study assumes high electrification levels in 2040 in order to conduct the grid needs assessment. It is not a forecast of electrification or adoption of certain technologies by customers.

Additional Distribution System Planning Considerations

In addition to the load shape and grid flexibility technology-related considerations described throughout this report, there are several important engineering and economic considerations that must be studied before selecting grid flexibility as the solution to mitigate a grid need. These include:

- Contingency analysis and potential upgrades that cannot be avoided due to needs in N-1 conditions
- Minimum loading conditions and potential distributed generation hosting capacity constraints
- Load flow studies to inform voltage stability and other power quality metrics
- IT and OT capabilities needed to enable the operational visibility and locational control of grid flexibility technologies in response to locational grid needs
- Sufficiency of grid flexibility technology potential in the specific location (e.g., based on customer types, saturation of end use technologies, availability of physical space for siting solar/storage)
- Cost of DER deployment relative to the grid upgrade that would be scoped for the specific grid need

3. Methodology Overview

Study Scenarios

The study evaluates distribution grid needs in three scenarios designed to provide insights into grid upgrades that could be driven by electrification, and the value grid flexibility could provide by mitigating some of the grid needs.

SCENARIO	SCENARIO DESCRIPTION	SCENARIO PURPOSE
No Additional Electrification, No Additional Grid Flexibility	This scenario holds the current (i.e., 2024) fuel mix for transportation and buildings constant through 2040 and assumes no additional DERs, energy efficiency, or demand flexibility.	Serves as the status quo baseline relative to which impacts of electrification and grid flexibility can be evaluated
Full Electrification, No Additional Grid Flexibility	This scenario assumes a 2040 fuel mix for transportation and buildings consistent with the decarbonization strategies enumerated in various District's climate initiatives.	Allows estimation of grid needs to support the District's electrification goals Serves as the basis for evaluating the potential value of grid flexibility to the distribution grid
Full Electrification with Achievable Grid Flexibility	This scenario assumes three plausible levels of deployment of grid flexibility technologies – i.e., DER, energy efficiency, and demand flexibility – by 2040.	Allows estimation of the value of mitigating grid needs using grid flexibility Highlights the relative value of various individual grid flexibility technologies

Detailed assumptions on technology penetration and capabilities in each scenario are provided in the Appendix Report.

Analytical Approach

The analytical approach for this study consists of three interrelated steps.

1 Develop a Demand Projection

- Gather 2024 hourly load for each feeder and substation to serve as baseline
- Grow non-electrification loads based on Pepco's feeder-level forecast
- Adjust loads to reflect Pepco's planned load transfers
- Model hourly demand for each electrification technology for each customer type (residential and commercial)
- Add electrification loads to each feeder based on feeder-specific customer types and counts and assumed technology penetration in the scenario

2 Model Grid Buildout

- Identify overloads based on asset rated capacity and projected hourly load in 2040
- Identify the solution set allowable in each location based on rules-of-thumb for each asset type and space constraints by ward
- Assess allowable solutions and select the lowest cost upgrade/build that would resolve the overload

3 Assess Grid Flexibility Options

- Model changes to the load shape based on the set of non-dispatchable technologies deployed at the asset
- Optimize dispatch of the demand flexibility technologies to reduce the asset's peak load
- Estimate the battery capacity that would be required to mitigate any remaining overloads and consider feasibility
- Conduct sensitivities on technology deployment levels
- Reassess grid buildout needed after accounting for grid flexibility
- *Note: Deployment costs are not factored into this approach*

A detailed description of the methodology is provided in the Appendix Report.

4. The Impacts of Electrification

Baseline: No Electrification, No Grid Flexibility Scenario

In the absence of additional electrification and grid flexibility, Pepco's system peak load is projected to grow 26% by 2040, requiring $665 million in capacity expansion investments.

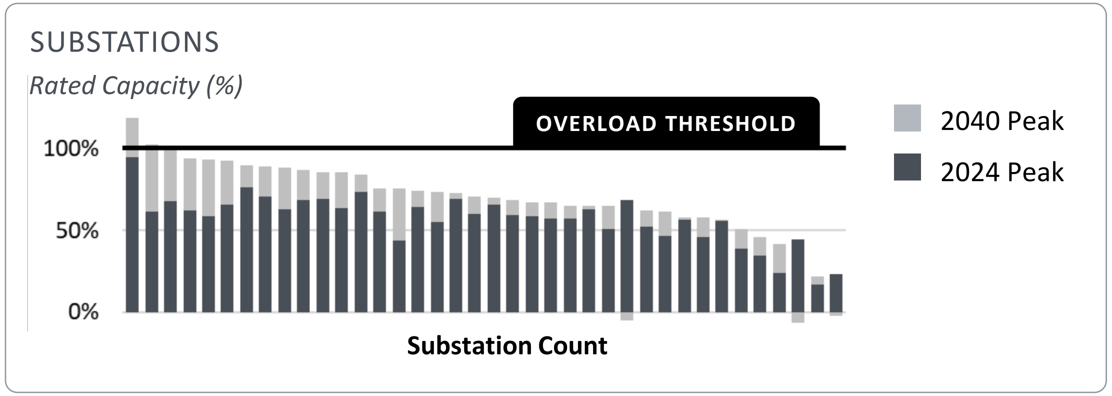
Pepco DC system peak demand grows by 557 MW (26% growth relative to 2024) by 2040 in the No Electrification, No Grid Flexibility Scenario. This is driven primarily by forecasted growth of the residential customer count by 48% and commercial customer count by 3%.

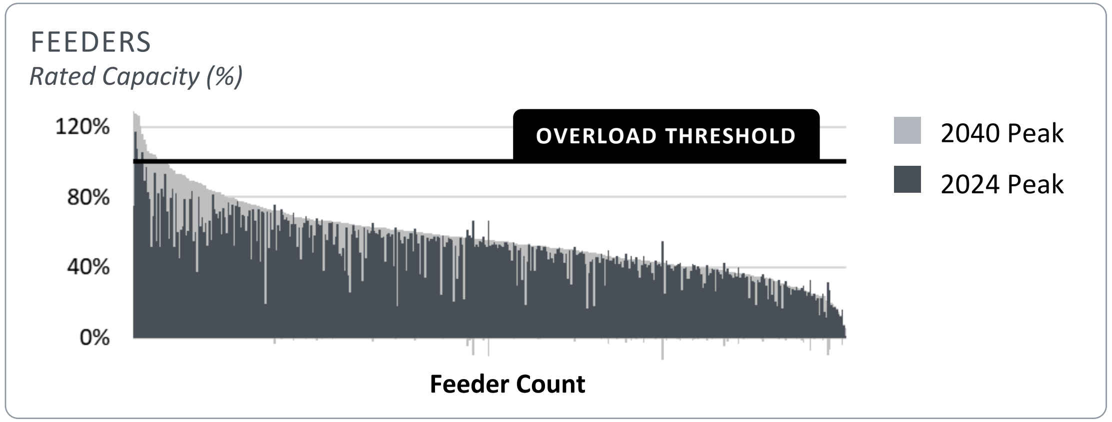
Approximately $665 million in capacity expansion investment is needed to support this Baseline load growth. Pepco's distribution system planning process identifies and plans for capacity needs through 2034. This study's No Electrification Scenario includes those already-planned upgrades and adds additional upgrades for needs through 2040. Total estimated capex is $665 million or $44 million/year for the 15-year period from 2025 to 2040[1]. All costs figures in this report are in real 2025 dollars.

Pepco's feeders and substations have significant hosting capacity for load growth, especially in the winter. Due to over a decade of stagnant demand growth, most parts of Pepco's distribution system experience summer peak loads that are less than 75% of rated feeder/substation capacity. Due to the limited amount of electrified heating currently used in the District, winter peaks are significantly lower than summer peaks in most locations, meaning there is even more room for winter load growth.

1 In order to align with the methodology used in this study for the other scenarios, we estimate the capex for Pepco's already-planned projects using the same generalized rules of thumb for feeder and substation projects costs, rather than project-specific costs. Therefore, the capex shown for this scenario is unlikely to match the figures in any of Pepco's distribution system planning filings; 2 Overload thresholds for all modeled distribution components include the capacity increases already in Pepco's existing capacity expansion plan.

PROJECTED OVERLOADS BY 2040 – NO ADDITIONAL ELECTRIFICATION SCENARIO[2]





Electric Load Growth Drivers Under The District's Climate Roadmap

Electrification is a cornerstone of the District's climate goals.

The District's Carbon Free DC strategy identifies the key actions needed to reach carbon neutrality by 2045. A significant part of the strategy is electrification of the District's transportation and building sectors, with specific goals outlined for certain technologies and a target for minimal residual fossil fuel use in 2045. We analyzed these targets to develop the 2040 electrification levels assumed in this study, as outlined in the table.

Apart from electrification, Pepco's load growth is expected to be driven primarily by residential customer growth. Over the next 15 years. Pepco forecasts the residential customer base to increase nearly 50%, while commercial growth remains roughly flat. Today, the Pepco system is heavily commercial with almost 80% of demand coming from commercial customers.

KEY SCENARIO ASSUMPTIONS DRIVING LOAD GROWTH

		Current (2024)	2040
Customer Count	Residential	318k	470k (+48%)
	Commercial	28.0k	28.9k (+3%)
Electric Space Heating	Residential	41%	90%
	Commercial	50%	90%
Electric Water Heating	Residential	52%	90%
	Commercial	73%	90%
Electric Vehicles	LDV	2.5%	73%
	MDV	0%	80%
	Bus	0.5%	90%
	HDV	0%	10%

Sources and notes: Customer count forecast is from Pepco's latest load forecast. 2024 baselines are calibrated based on data from NREL ResStock and ComStock, EIA RECS and CBECS, and Federal Highway Administration Statistics. 2040 penetration assumptions for electrified technologies are developed based on various District climate initiatives (see pg. 9). 2024 and 2040 percentages refer to the portion of customers served by each technology.

Peak Demand Impacts of Electrification

Achieving the District's electrification goals would lead to significantly higher demand growth on Pepco's system.

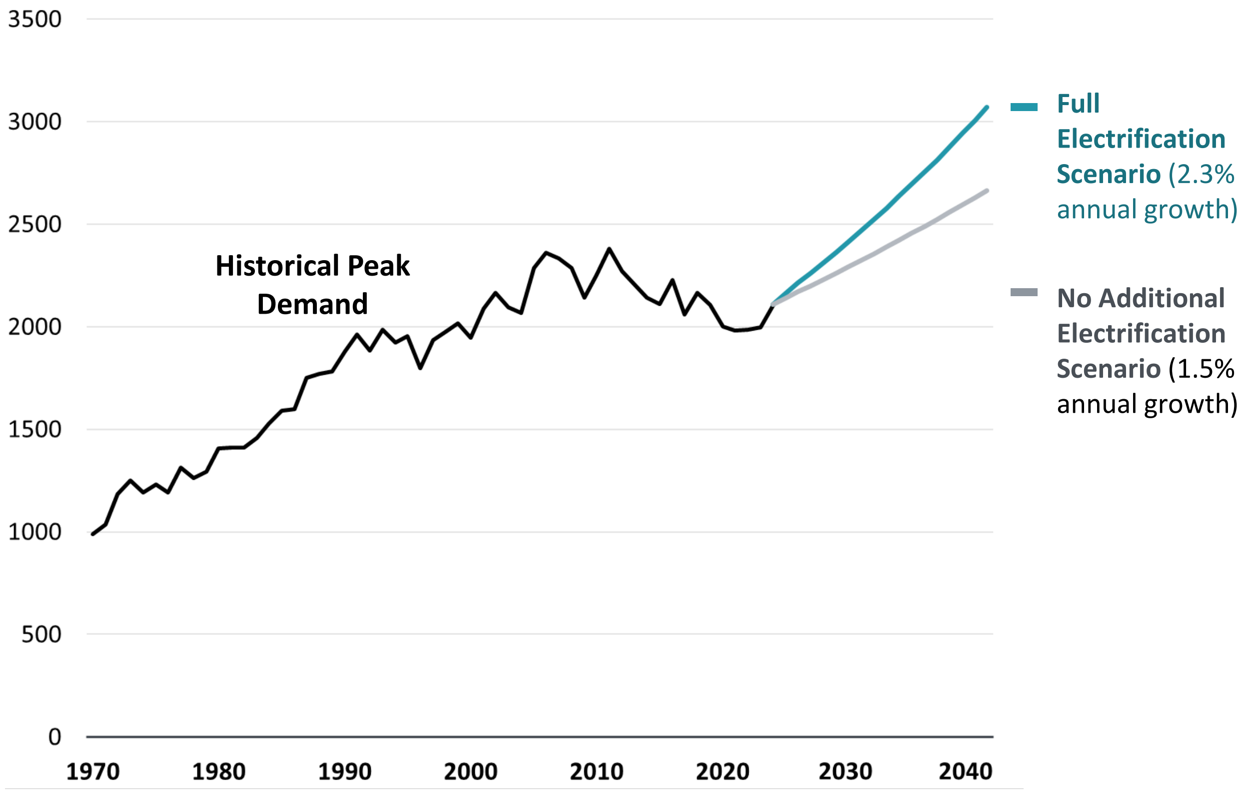
Pepco DC system peak demand grows by 1,097 MW (52% growth relative to 2024) by 2040 in the Full Electrification, No Grid Flexibility Scenario. This is 540 MW more growth than without electrification, i.e., electrification roughly doubles the projected growth. Growth is driven primarily by peak electric heating loads, which occur on cold winter mornings.

Pepco DC as a whole becomes winter-peaking. Relative to 2024 seasonal peaks, the winter peak grows 61% while the summer peak grows 41%, with electric heating driving the winter growth. Transportation electrification contributes to summer load growth but is a limited contributor to winter peaks because typical vehicle charging schedules are not very coincident with the morning heating peak.

Consistent with Pepco's 2021 Electrification Study[1], though electrification significantly increases load growth, growth rates are within historically observed ranges. Historically, Pepco experienced high load growth rates of 4.5% per year from 1970-1990, driven by the adoption of air conditioning, among other drivers. The projected load growth rate in the Full Electrification Scenario is 2.3% per year through 2040, well under the highest historical growth rates. In addition, future load growth rates can be mitigated to an extent by deploying grid flexibility measures, as discussed later in this report.

1 An Assessment of Electrification Impacts on the Pepco DC System; 2 PHI Statistical Loadbook

PEPCO DC SYSTEM PEAK DEMAND (MW)



Note: 2040 is the only year modeled in the study. A trajectory between 2024 and 2040 is shown based on the implied annual average load growth rate for illustrative purposes.

Distribution Grid Needs to Support Electrification

Several feeder and substation upgrades will be needed to support load growth in the Full Electrification Scenario, causing Pepco's capacity expansion capex to more than double relative to the scenario without electrification.

Required Incremental Grid Investments *(in 2025 dollars)*
Full Electrification, No Grid Flexibility Scenario

Feeders:

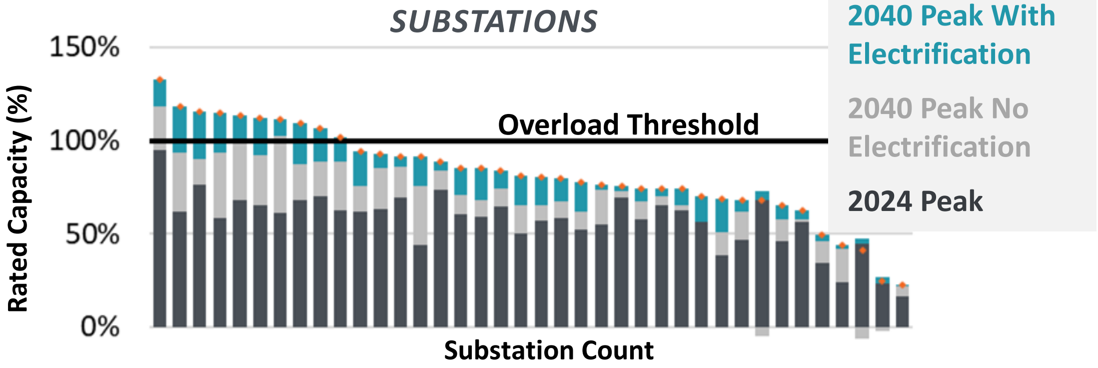
- 26 new 13 kV feeders: $286 million
- 3 feeder conversions from 4kV to 13kV: $18.6 million
- Total capex: $305 million

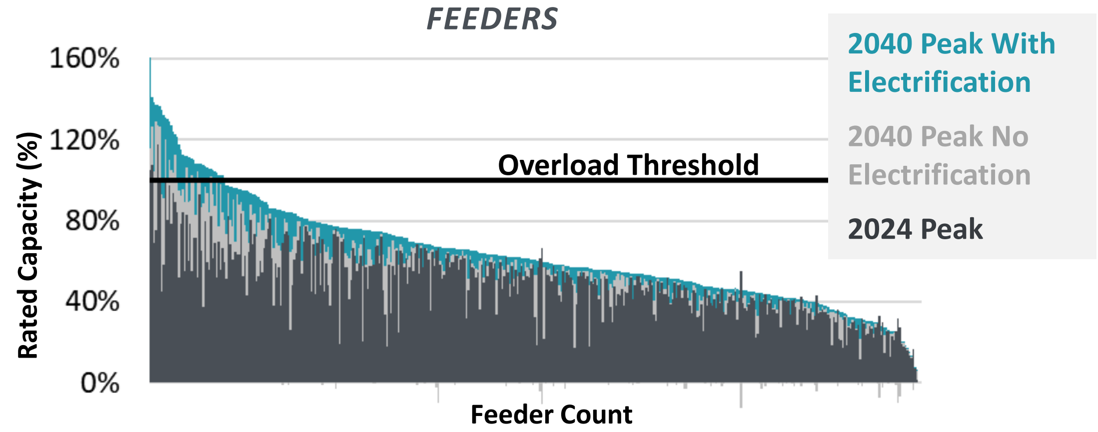
Substations:

- 2 new substation builds: $588 million
- 3 new transformer banks at existing substations: $24 million
- 2 4kV substation overloads resulting in feeder conversions: $12.4 million
- Total capex: $624.4 million

Total: $929 million incremental capex on top of the $665 million in the No Additional Electrification Scenario

PROJECTED OVERLOADS BY 2040 –
FULL ELECTRIFICATION, NO ADDITIONAL GRID FLEXIBILITY





Notes: Some substations/feeders have a negative component to their load growth to indicate Pepco's planned load transfers. These components show up as negative growth for one component and positive growth for another. The orange points represent net total loading of each component after accounting for both load growth and transfers.

5. The Potential Role of Grid Flexibility

Grid Flexibility Technologies: Potential Alternatives to Grid Upgrades

The study considers several grid flexibility measures which, under the right conditions, could be an alternative to traditional distribution system investment.

MODELED GRID FLEXIBILITY TECHNOLOGIES AND SUITABILITY AS A SOLUTION FOR DISTRIBUTION GRID NEEDS

	Technology	Assumed Deployment Rates	Modeled Operation	Suitability as a Solution For Distribution Grid Needs
Distributed Generation	**BTM Solar**	*Low:* Supplies 4% of energy *Mid:* Supplies 7.5% of energy *High:* Supplies 15% of energy	Based on a representative hourly solar profile for the Washington, D.C. area.	Solar, as a non-dispatchable resource, can serve to reduce loading on the grid if needs are consistently coincident with times of high solar generation.
	Batteries	*Low:* 0.3 MW *Mid:* 9.6 MW *High:* 16 MW	4-hour duration assets, with 85% round-trip efficiency. Dispatch is assumed to be grid-aware, i.e., optimized to reduce feeder/substation peaks.	Deployment can be either BTM or FTM, and operation can be highly targeted, flexible, and controllable. Batteries can fill gaps in the grid flexibility portfolio as needed to mitigate the grid need.
Energy Efficiency	**Weatherization**	*Low:* 5% of buildings *Mid:* 10% of buildings *High:* 20% of buildings	Refers to building envelope upgrades that are assumed to result in a 10% reduction in the building's heating demand across all hours.	Because many of the grid needs in the Full Electrification Scenario are driven by heating peaks, efficiency measures that reduce heating energy needs can be highly effective and targeted solutions even though they are non-dispatchable. Their impacts are also not duration-limited, unlike batteries and demand flexibility technologies.
	Cold Climate Heat Pumps (ccASHPs)	*Low:* 12.5% of heat pumps *Mid:* 25% of heat pumps *High:* 50% of heat pumps	Supplemental auxiliary resistive heating below 32F. Customers with ccASHPs are assumed not to need resistive heating, so their COPs are slightly higher in the coldest hours.	
Demand Flexibility	**Heating Load Control**	*Low:* 5% of customers *Mid:* 12.5% of customers *High:* 25% of customers	3-hour event, 20-40% of heating load during events is shifted into the prior two and following three hours, up to 15 events.	Heating load control with heat pumps is in the early stages of deployment but could be useful to call on for a very limited number of events to target the most constrained hours.
	EV Managed Charging	*Low:* 12.5% of LDV EVs *Mid:* 25% of LDV EVs *High:* 50% of LDV EVs	Modified average charging load shape. More charging occurring overnight rather than during the evening peak hours.	High impact in locations that remain summer peaking and require load shifting in the evening hours.

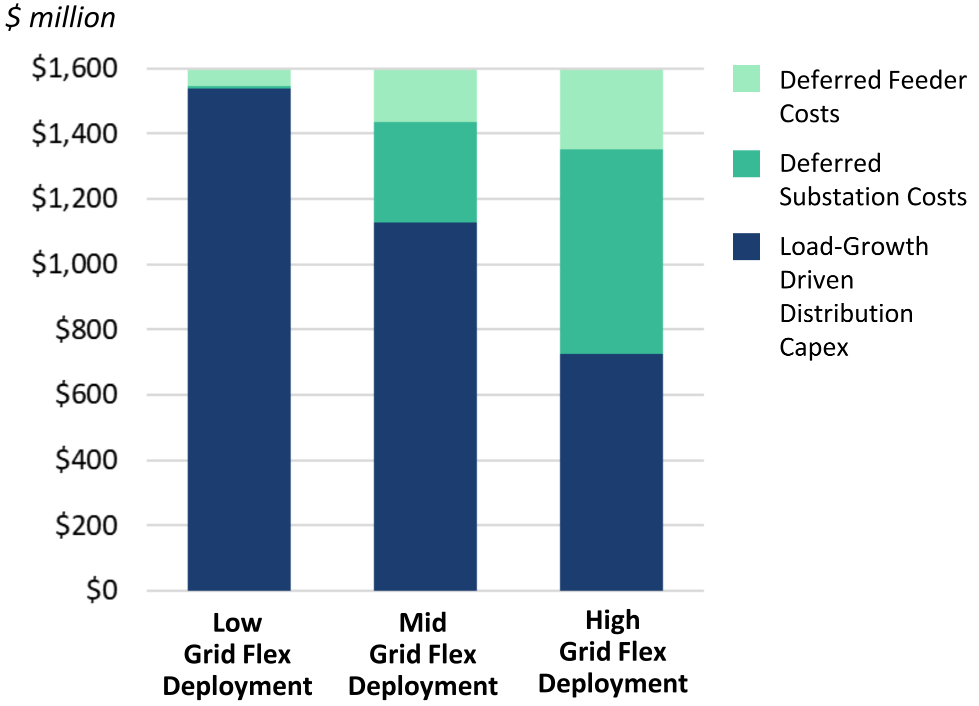
Reduced Grid Needs Through Grid Flexibility

Deploying a portfolio of grid flexibility technologies could reduce the 2025-2040 capex requirement by $58-$868 million (a 4%-54% reduction). However, the costs of deploying the grid flexibility measures are not included in this analysis and should be studied for cost-effectiveness relative to traditional grid upgrades.

The results highlight that the ability of grid flexibility to defer distribution system investment depends heavily on reaching sufficient levels of grid flexibility adoption. Further, once the largest deferral opportunities are achieved, the incremental value of additional reductions declines. Investment decisions are highly project-specific and each will need to consider the relative cost of grid flexibility, which is not included in this study.

Grid Flex Case	Description	Upgrade Deferral Outcomes
Low Deployment	Representative of meaningful current-day adoption of grid flexibility programs, but with very limited increase in localized solar generation	Several new feeders are avoided, one substation upgrade avoided
Mid Deployment	Represents 2040 adoption levels of 10%-25%, depending on the technology	Many new feeders are avoided, and one high-cost substation build is avoided
High Deployment	Represents 2040 adoption levels nearing the upper limits of the modeled sample technologies' maximum achievable adoption, with levels between 20%-50%	Most electrification-driven new feeders and many substation upgrades are avoided

2025-2040 DISTRIBUTION CAPEX REQUIREMENT WITH VARYING DEPLOYMENT OF GRID FLEXIBILITY TECHNOLOGIES

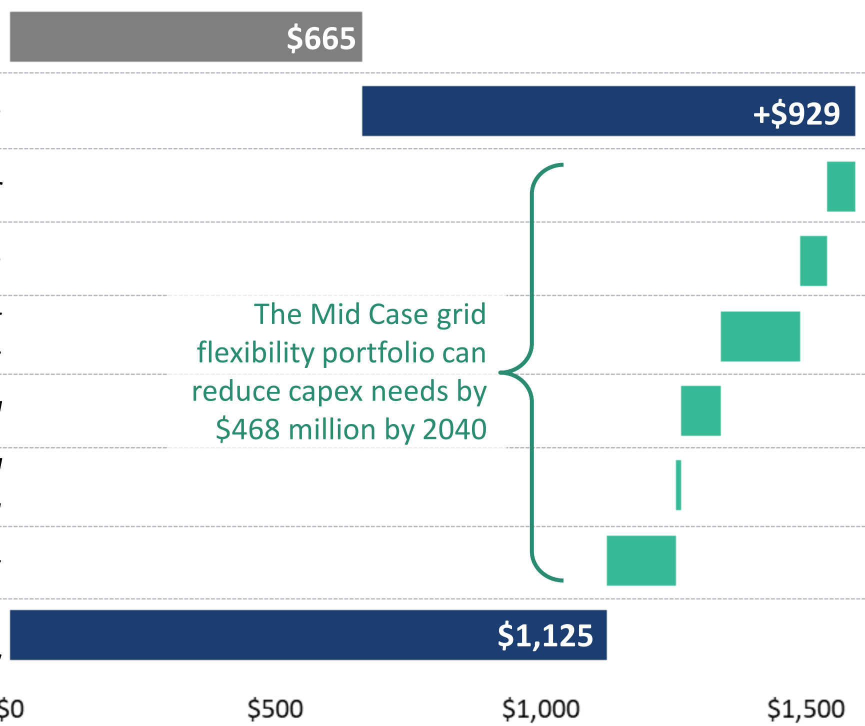


Technology-Specific Contributions: Mid Case Illustration

Each component of the grid flexibility portfolio can contribute to a reduction in grid needs. The relative contributions will vary due to differing deployment levels and technology performance characteristics.

ILLUSTRATIVE REDUCTION OF GRID NEEDS THROUGH A PORTFOLIO OF GRID FLEXIBILITY TECHNOLOGIES (MID-DEPLOYMENT CASE)

Distribution grid capex by 2040 *(2025$ million)*



	Description
No Electrification	$665 million capacity expansion capex needed by 2040 with no additional electrification or grid flexibility
Full Electrification	Incremental $929 million needed to support load growth from electrification
BTM Solar	Assuming BTM solar generation equal to 7.5% of energy demand on every feeder
Weatherization	Assuming weatherization of 10% of the District's buildings
Cold Climate Heat Pumps	Assuming 25% of heat pumps are cold climate heat pumps without auxiliary resistive heating
Heating Load Control	Assuming 13% of customers with heat pumps shift a small amount of heating load out of winter peak hours
EV Managed Charging	Assuming 25% of LDV EVs shift charging out of evening peak periods, reducing grid needs primarily in locations that remain summer-peaking
Batteries	Assuming targeted deployment and operation of around 10 MW of 4-hour storage in locations identified as feasible deferrals
Full Electrification and Grid Flexibility	The grid flexibility portfolio avoids 1 new 210 MVA substation build, 1 substation bank, 1 4kV substation overload, 1 4kv feeder conversion and 14 new 13kV feeders, reducing capex by 29%

Characteristics of Deferral Opportunities

Grid flexibility is unlikely to be a feasible solution for all grid upgrade needs. The most feasible candidates for investment deferral will have low load growth rates, a modest forecasted level of overload, and a limited duration (i.e., hours) of overload.

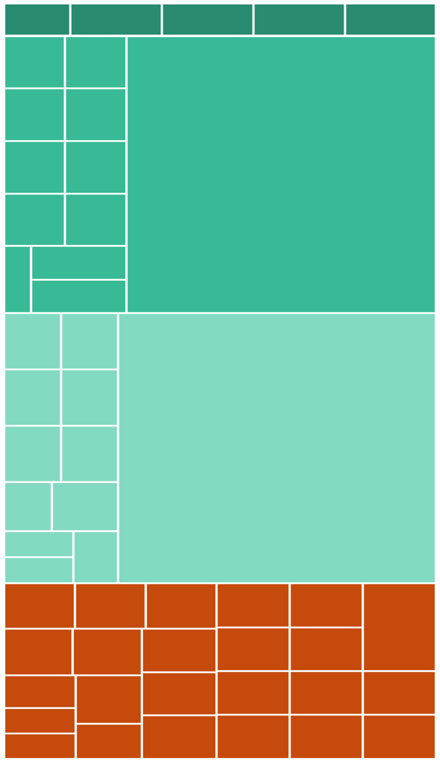
GRID NEEDS – FULL ELECTRIFICATION SCENARIO
EACH BOX IS ONE UPGRADE; BOX SIZE IS PROPORTIONAL TO UPGRADE COST

UPGRADES DEFERRED IN LOW GRID FLEX CASE
$58 million

UPGRADES DEFERRED IN MID GRID FLEX CASE
$410 million

UPGRADES DEFERRED IN HIGH GRID FLEX CASE
$399 million

UPGRADES NOT DEFERRED IN ANY GRID FLEX CASE
$259 million



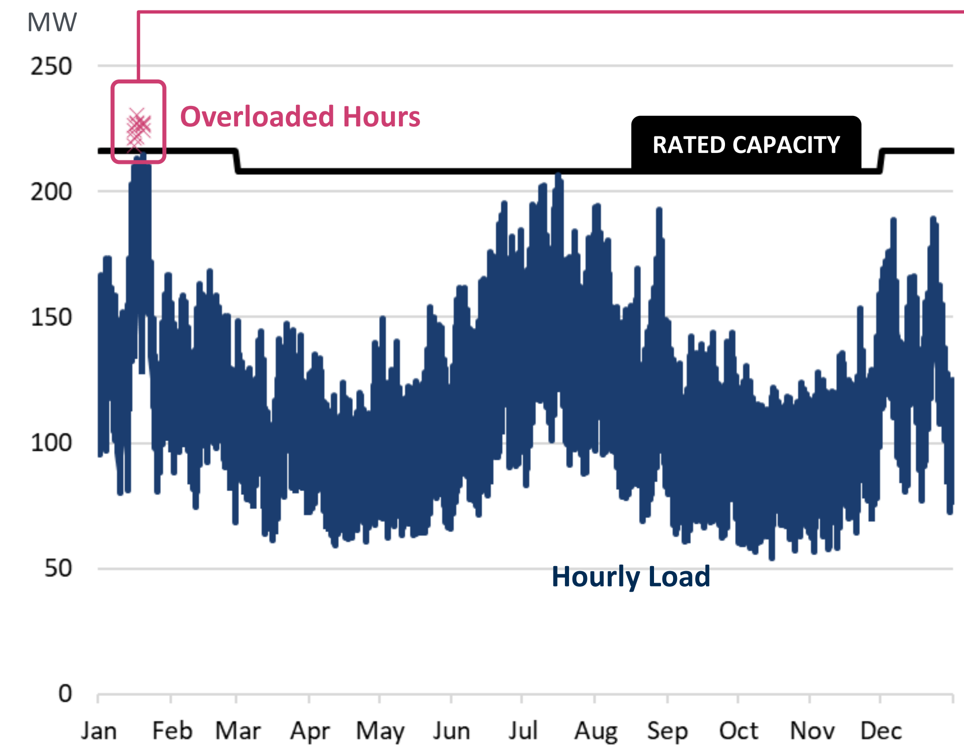
DISTRIBUTION ASSET CHARACTERISTICS RELATED TO DEFERRAL FEASIBILITY

Upgrade Deferral Status	Load Growth Rate	Magnitude of Overload	Duration of Overload	Frequency of Overload
Deferred in Low Grid Flex Case	2.4%-5.4%	0.8%-4.6%	2-3 hours/day	1-2 days/year
Deferred in Mid Grid Flex Case	3.1%-7.0%	3.8%-9.0%	2-5 hours/day	1-6 days/year
Deferred in High Grid Flex Case	2.6%-6.1%	6.7%-18.5%	4-9 hours/day	1-14 days/year
Not Deferred in Any Grid Flex Case	2.1%-7.4%	8.1%-68.6%	1-24 hours/day	2-365 days/year
Takeaway	Assets facing rapid load growth are less likely to be feasible candidates.	Assets facing larger overloads are less likely to be feasible candidates.	Assets facing frequent overloads for longer periods are less likely to be feasible candidates.	

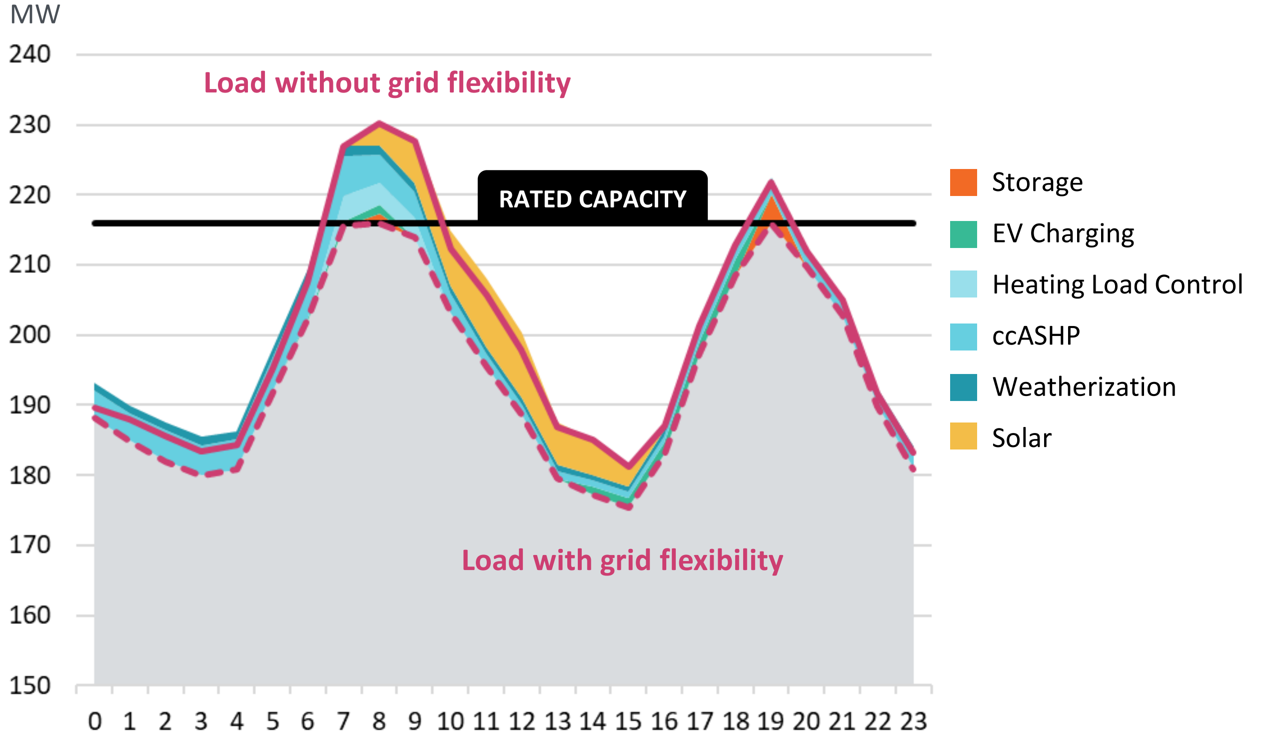
Operational Feasibility: Waterfront Substation Example

The figures below illustrate how the portfolio of grid flexibility technologies could mitigate the projected overload at the Benning Substation, avoiding the need for a new substation that could cost around $300 million.

HOURLY SUBSTATION LOAD
SUBSTATION: 7 BENNING



GRID FLEXIBILITY IMPACTS ON PEAK DAY (MID CASE)
SUBSTATION: 7 BENNING



Note: As discussed throughout this report, the analysis of this investment deferral opportunity does not consider the cost of grid flexibility relative to the cost of building the new substation. It is only an illustration of operational feasibility under assumed future adoption levels.

6. Additional Considerations

Pepco DC in the context of other utilities

The portion of Pepco's distribution system requiring upgrades is modest compared to some other jurisdictions with deep electrification goals.

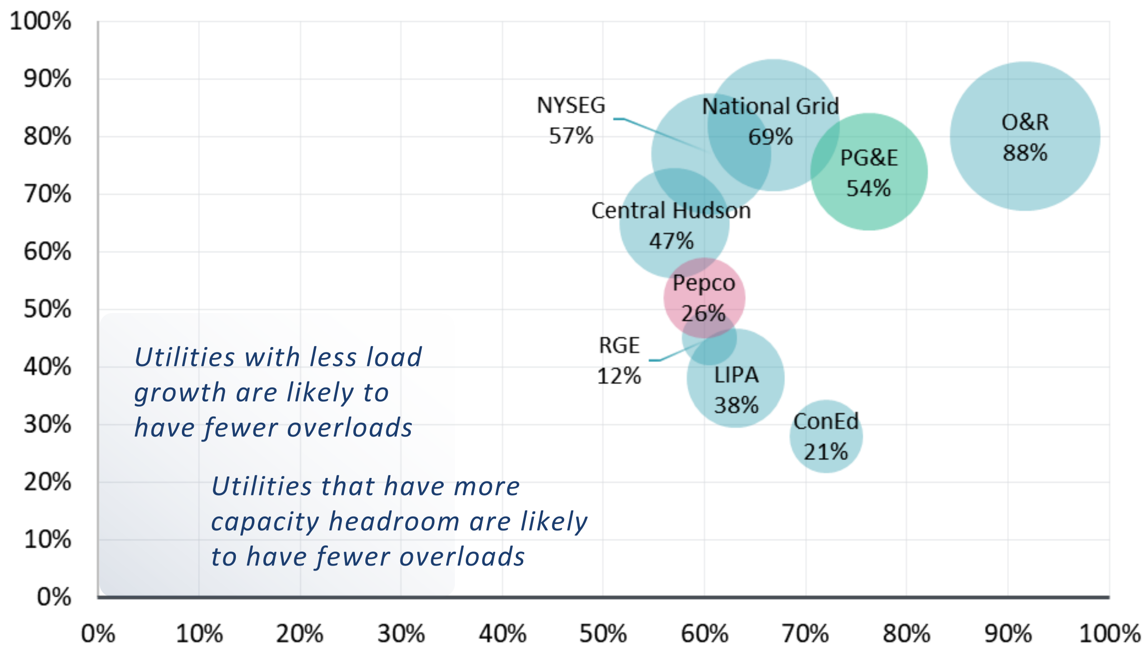
Benchmarking against two recent studies – New York's Grid Flexibility Potential Study and California's Electrification Impact Study – show that our results for Pepco fall within the range of results observed in these two studies. As the wide range of results (12%-88% of substations overloaded across utilities) shows, electrification impacts are highly utility-specific. Two important utility-specific drivers may explain some of the variation in results:

- **Average existing capacity headroom** on the system varies widely across utilities. Utilities with less headroom are likely to face more overloads, all else equal. Pepco's results are similar to Con Edison, which has a similarly large urban service territory and a networked distribution system.
- **Load growth rates** vary widely across utilities. Utilities with more load growth are likely to face more overloads, all else equal. The 52% system peak load growth for Pepco in the Full Electrification Scenario is within the 28-85% load growth range for the New York utilities in a high electrification scenario, with higher growth rates potentially being due to the colder climate in upstate New York.

COMPARISON WITH FINDINGS FROM RECENT STUDIES IN CALIFORNIA AND NEW YORK

BUBBLE SIZE INDICATES % OF OVERLOADED SUBSTATIONS

Total Utility System Peak Load Growth by End of Study Period[1]



Loading of Median Substation at Start of Study Period[2]

Sources: New York's Grid Flexibility Potential Study, The Brattle Group; CPUC Electrification Impact Study, Kevala
Notes: 1 End of study period is 2035 for the CPUC Electrification Impact Study and 2040 for the NY Grid Flexibility Study and the Pepco Electrification Impact Study (this study). 2 Start of study period is 2023 for the NY Grid Flexibility Study and 2024 for the Pepco Electrification Impact Study. Because loading at the start of the study is not available from the CPUC study report, the chart shows 2025 median loading from each California IOU's hosting capacity map.

Comparing this Study's Findings to Related Studies

Prior studies of electrification load growth and the impact on the distribution system show similar findings, highlighting Pepco's substantial headroom in winter months and the resulting moderate impact of electrification.

Pepco – An Assessment of Electrification Impacts on the Pepco DC System (August 2021) – *Link to study*

The original version of Pepco's electrification study, filed with the Commission in 2021, assessed the magnitude of load growth that could be expected due to full electrification.

SIMILAR TAKEAWAYS

- Pepco's system would remain within observed historical rates of load growth, even with full electrification by 2050.
- Pepco's system would become winter-peaking due to electrified heating loads.
- Energy efficiency and demand flexibility could reduce annual load growth rates significantly.

STUDY FRAMEWORK DIFFERENCES

Granularity: The 2021 study assessed electrification impacts on peak load at the Pepco system level, while the 2025 study assesses impacts at the feeder and substation level.

Costs: The 2021 study did not quantify the costs of supporting the estimated load growth. The 2025 study estimates capacity expansion capex through 2040.

Time horizon: The 2021 study focused on 2050, while the 2025 study focuses on 2040.

Scenario design: The 2021 study used a Reference case based on PJM's load forecast for the Pepco zone. The 2025 study developed its own "No Additional Electrification" baseline scenario, building on top of Pepco's feeder-level load forecasts, which are used for distribution system planning.

Policy changes: While both studies assume full/near-full electrification, the 2025 study incorporates goals from various District climate initiatives adopted after publication of the 2021 study.

DOEE – Strategic Electrification Roadmap for Buildings and Transportation (April 2023) – *Link to study*

The DOEE electrification study estimated electrification load impacts, identified a small number of required grid upgrades, and evaluated non-wire alternatives to mitigate grid needs.

SIMILAR TAKEAWAYS

- Pepco's system has significant winter capacity headroom, which moderates electrification-driven grid needs.
- The substations flagged in DOEE's study as approaching capacity by 2032 are some of those flagged in this study as being overloaded by 2040.
- Grid flexibility/non-wire alternatives are a feasible solution to meet some of the identified grid needs. Cost-effectiveness should be studied case-by-case.

STUDY FRAMEWORK DIFFERENCES

Granularity: The DOEE study had similar feeder/substation level granularity but focused on a subset of Pepco's feeders, not Pepco's entire system.

Costs: While both studies estimated capex costs, the cost estimated in the DOEE study was much lower primarily due to the difference in time horizon.

Time horizon: The DOEE study focused on 2032, while the 2025 Pepco study focuses on 2040.

Scenario design: The DOEE study assumes a much lower level of electrification, also driven by the difference in time horizons.

Additional electrification costs and benefits

Separate from Pepco's investment in distribution system capacity expansion, achieving the District's decarbonization goals through electrification will include other costs and associated benefits.

Secondary Distribution System Upgrades

The secondary distribution system extends from the utility's higher voltage primary system to the customer's meter; it includes the secondary transformer and the service line to the customer's premise. The secondary system is generally not part of the distribution capacity planning process; it is upgraded/replaced at the point of predicted asset failure or when customers apply for a larger service that would overload the existing system.

Many customers may require upgrades to their service to support their EV charging and heat pump demands. As multiple customers in a neighborhood electrify, secondary transformers, which serve small groups of customers, are also likely need upgrades to serve higher coincident peaks across their group of customers.

Incremental costs to upgrade the secondary system are likely to depend on the current age of the system and planned standards for routine replacement (e.g., making all replacement transformers electrification-ready now may have a lower cost than upgrades at the time of customer load request). In addition, there are emerging solutions for granular load shaping to avoid local distribution system overloads. Examples of such solutions include smart panels, meter-socket-adapters, and grid-aware active management of EV charging.

Due to the location-specificity of these needs, most electrification studies do not attempt to estimate the system-wide costs or timing of electrification-driven secondary system upgrades. One point of reference for the potential order of magnitude of these costs is Kevala's Electrification Impact Study for the CPUC. It found that secondary transformer upgrades could comprise about 30% of total distribution grid upgrade costs in a high electrification scenario.

Heating Appliances and Building Upgrades

As an approximate indicative value, we estimate that the modeled full electrification scenario involves net incremental expenditures of $1.2 billion on space and water heating appliances from 2025 to 2040. This is based on an estimated cost of $4.3 billion for new electric appliances and avoided costs of $3.1 billion for fossil fuel appliance replacement. There may be additional avoided costs of replacing cooling appliances as heat pumps can provide both heating and cooling.

Some buildings may require upgrades to their heating distribution systems, electrical panels, or wiring when electrifying. These costs are highly building-specific and should be evaluated at the time of upgrade.

These are not utility costs, so they would be borne by the electrifying customer (with offsetting incentives where applicable) and not by Pepco ratepayers as part of utility rates.

Avoided Fossil Fuel Costs

Electrifying customers would avoid the cost of fossil fuel purchases and any associated delivery or infrastructure costs. The costs and benefits of specific electrification technologies have been extensively studied in the District and elsewhere, so we do not attempt to estimate these benefits in this study.

7. Conclusion

Key Findings

The Pepco DC system currently has significant capacity headroom for load growth, especially in the winter. Most parts of the system can support electrification loads through 2040 without additional upgrades. However, the areas requiring upgrades due to electrification will increase the total investment need relative to recent levels.

Without grid flexibility, meeting the District's electrification goals could more than double Pepco's capacity expansion expenditures by 2040. Pepco's capacity expansion needs from 2025-2040 are estimated to cost $665 million in a scenario with no additional electrification and $1,594 in a scenario with full electrification and no grid flexibility.

Grid flexibility technologies could be a feasible solution to reduce capacity expansion expenditures. A portfolio of grid flexibility technologies - rooftop solar, batteries, weatherization, cold climate heat pumps, managed EV charging, and smart thermostats – could reduce the required capex by $58 to $868 million (4% to 54%). However, this result does not account for the cost of the grid flexibility measures; more granular cost-effectiveness analysis is an important next step.

There is significant value in targeted deployment of grid flexibility in areas where grid capacity expansion would be particularly expensive. The grid capacity expansion solutions to mitigate overloads have a wide range of costs. Grid flexibility is shown to be particularly valuable to deploy in locations where the most expensive capacity expansion projects may be needed, and where overload conditions are limited in terms of duration, magnitude, and rate of growth.

Scale is essential to achieve grid flexibility value. The distribution value of grid flexibility is highly dependent on deployment reaching significant scale in the locations where it is needed most; moderate levels of deployment are unlikely to produce meaningful distribution benefits.

Cold climate heat pumps are a particularly valuable grid flexibility technology. The efficiency-related savings of cold-climate heat pumps (relative to heat pumps with auxiliary resistive heating) tend to be coincident with the winter peak and can be a major contributor to grid flexibility portfolios that defer the need for grid upgrades.

Batteries provide unique value to the grid flexibility portfolio. Batteries are flexible from both an operational and siting perspective, with the option to take advantage of efficiencies by them at the customer’s premise or to attach them to the distribution system where needed most. Batteries can act as the “glue” that enables the rest of the grid flexibility portfolio to provide benefits.

Next steps

We recommend several next steps for acting on the findings in this study.

Cost-effectiveness analysis: A comprehensive assessment of the benefits and costs of grid flexibility will identify the most valuable opportunities and limitations of this resource. Such an analysis should account for additional benefits that grid flexibility can provide beyond distribution value.

Barriers assessment: A range of regulatory, technical, and market barriers may prevent grid flexibility from being achieved at the levels assumed in this study. An assessment of those barriers in the District – and options for overcoming them – will provide a guide for maximizing the potential.

Utility investment needs roadmap: Investments such as DERMS systems may be needed to enable grid flexibility benefits. A roadmap that identifies key utility capability gaps and options for mitigating them will ensure that the underlying infrastructure is in place to enable the opportunity.

Timing/scale assessment: This study focused on a 2040 end state and assumed full achievement of District policy goals. Analysis of the technology adoption trajectory to 2040 - as well as uncertainty in that trajectory - will be important to ensure robust strategies across a range of possible future outcomes.

Further Reading on Electrification and Grid Flexibility

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