Modeling the "Where and When" Grid Impacts of Seattle's Building Emissions Performance Standard: A Generalized Modeling Study & Load Impact Analysis

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ABSTRACT

The City of Seattle's ambitious Buildings Emissions Performance Standard (BEPS) is expected to lower greenhouse gas emissions from buildings by 27% by 2050. The most technologically feasible and cost-effective route to achieve these emissions reductions is for building owners to electrify fossil fuel end-uses, given Seattle City Light's status as a carbon-neutral utility. Replacing natural gas and steam end uses with electric substitutes inherently increases electrical load and may require transmission and distribution infrastructure upgrades to satisfy the higher amperage loads. To understand how this electrification impacts the electrical grid, this study applies the modeled outcomes of several efficiency and decarbonization measures to commercial building benchmarking data for 2055 buildings. A multi-step approach is undertaken, wherein (1) the sample stock is characterized based on typology, vintage, and heating fuel; (2) end-use makeup is estimated based on EnergyPlus prototypes developed for a prior study conducted by EPRI; (3) the obtained end-use makeups are scaled based on benchmarking data, yielding a unique composite for every building in the set; (4) efficient electrification measures are applied to the composite benchmarks based on outcomes identified in EnergyPlus, from which (5) impacts to electric infrastructure and emissions are assessed. This study is vital for understanding the geographic and system-wide load impacts to inform short- and long-term planning at the electric utility. This generalized modeling methodology is widely applicable to other jurisdictions that have building performance standards, climate action plans, and/or energy benchmarking data.

Introduction

This study is a continuation of previous work by this research team, which resulted in a modeling-based building electrification roadmap for common building types in Seattle (Sheng, Sankaranarayanan, and Kostic, 2023). Building upon the models used for the roadmap, the intent of this paper is to showcase a methodology for applying results from building energy modeling to broader benchmarking data, using a dataset provided by Seattle City Light, to predict building stock level increases in peak load and draw conclusions regarding the volume of customer and grid-side service upgrades required between now and 2050.

Policy Background

Emissions from buildings contribute to over one-third of Seattle's core greenhouse gas emissions and have remained relatively steady over time (as seen in Figure 1). In December 2023, the City of Seattle adopted the Building Emissions Performance Standard (BEPS), which establishes carbon-emissions targets that existing buildings over 20,000 square feet (residential and nonresidential) must meet over time. BEPS requires all covered buildings to achieve net-zero emissions by 2050 or sooner, depending on building size and type. The Seattle BEPS complements the Washington Clean Buildings Performance Standard (WA CBPS), which is an energy use intensity performance standard. While the State Standard is important for energy efficiency, its current energy targets would reduce Seattle building emissions nominally whereas BEPS is projected to reduce building emissions by 27% by 2050 (City of Seattle, 2023).

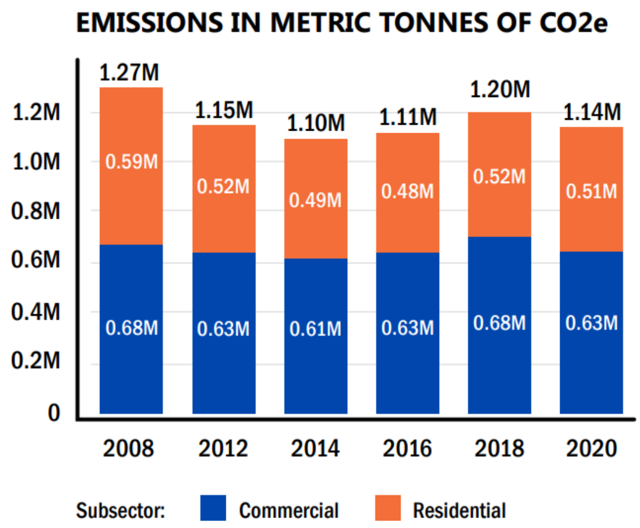

Figure 1 GHG Emissions by building subsector for a selection of years in Seattle, 2008-2020 (Seattle Office of Sustainability & Environment, 2022)

Compliance for 2027-2030 starts with verification and reporting requirements to encourage owners to prepare, develop plans and, if not already below targets, start actions to meet 2031-2035 emissions targets (Seattle Office of Sustainability & Environment, 2024). In each subsequent interval, buildings are required to meet progressively lower emissions targets. BEPS specifies greenhouse gas intensity targets (GHGITs) for 21 building activity types (e.g., office, retail, multifamily) for each compliance interval to net-zero emissions (Figure 2).

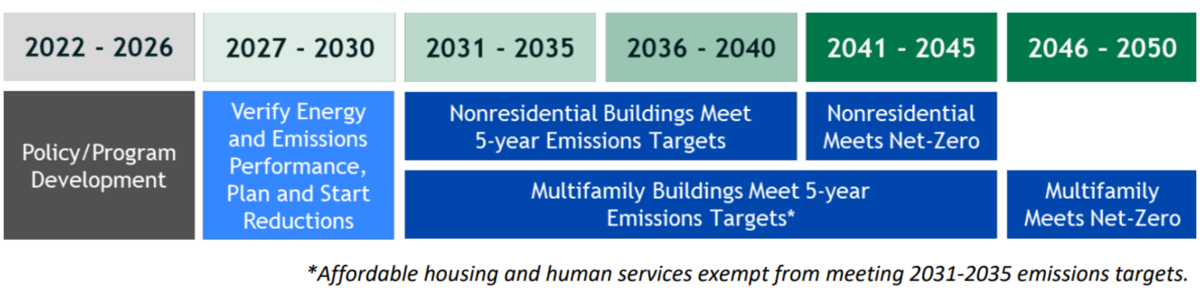

Figure 2 Seattle BEPS Compliance Timeline (Seattle Office of Sustainability & Environment, 2024)

The Potential Grid Impacts of Decarbonization

Electrification is the most cost-effective and technologically feasible pathway for buildings to achieve the emissions reductions required by BEPS and Seattle City Light is well positioned to support this effort because it is a carbon-neutral utility (Seattle City Light, 2024). While well-positioned, there will be impacts on Seattle City Light because electrification of space conditioning, water heating, and cooking will cause increases in electricity consumption and, in many cases, result in increases in electric service sizes (Blonsky et al., 2019).

Cumulative service upgrades, as anticipated by BEPS, will increase workloads for customer service and engineering staff and could lead to more significant distribution and other system upgrades. For the customer, electric service upgrades translate into higher electrification project costs and typically longer construction timelines. For the utility, individual customer service upgrades may require distribution system upgrades.

BEPS combined with Seattle's energy benchmarking data enable the utility to precisely project where and when building electrification will occur. The study results inform near- and long-term resource and staffing needs of the utility in order to support customer compliance with BEPS. Likewise, this study signals the importance for the utility to adopt and expand upon strategies that mitigate the grid impacts of BEPS, such as energy efficiency, load flexibility, technical assistance, and trade ally engagement.

Methodology

Datasets

The data set used for this case study consists of benchmarking data collected over three years (2019-2021) for 3,730 commercial and multifamily residential buildings located in Seattle. This benchmarking data is the result of Seattle's Energy Benchmarking Law that has required owners of non-residential and multifamily buildings 20,000 square feet or larger to track energy performance and annually report to the City of Seattle since 2014 (Seattle Office of Sustainability & Environment, 2024). The buildings in the sample represent 68 different building types as defined by the U.S. Environmental Protection Agency. This initial data set was then reduced to only include buildings with a mixed-fuel energy profile i.e., those buildings that used electricity and district heat and/or natural gas, as all-electric buildings are exempted from the emissions reduction requirements. The reduced data set included 2,379 buildings. Finally, buildings with no documented peak load were removed from the dataset, for a final count of 2,055. Characteristics of this dataset are shown in Table 1.

The benchmarking dataset included the following key data points for each building:

- Location (both address and neighborhood)
- Type (e.g., office building, restaurant)
- Age
- Floor area
- Aggregate electricity, natural gas, and steam use over the 2019-2021 period

City Light provided supplemental data on current annual peak loads for each building in the dataset based on metered energy consumption. City Light also provided a dataset indicating which buildings have permitted gas boilers. Since benchmarking data only indicates the amount of annual consumption for each fuel type (electricity, steam, or gas) used on-site and not the end-uses (e.g., space heating, water heating, etc.), the permitted boilers dataset enabled the team to confirm assumptions around existing end-uses.

It was assumed, given the designs of the DOE Building Prototypes, that centralized water heating systems would be the dominant systems in the given buildings (Especially for hotels and multifamily buildings). The City of Seattle defines any water heater exceeding a capacity of 120 gallons as a boiler requiring permitting (Seattle Department of Construction and Inspections, 2020). Thus, for buildings that did not have a permitted boiler but had recorded natural gas use, it was assumed that space heating is provided by some other system (such as gas furnaces for residential buildings and hotels) and that water heating was electrified.

Table 1 2019 to 2021 Benchmarked Buildings in Seattle Meeting Study Criteria

Number of Buildings	2,055
Most Represented Building Types	Residential Multifamily, Office, K-12 School, Mixed Use Property
Median Age of Buildings in Set	50 (Corresponding to 1974)
Mixed Electricity-Steam Buildings (percentage)	47 (2.28%)
Mixed Electricity-Natural Gas Buildings (percentage)	1,940 (94.40%)
Mixed Electricity-Natural Gas-Steam Buildings (percentage)	64 (3.32%)

EnergyPlus Models

To model all-electric end-use makeups, the team adopted commercial reference buildings released by Department of Energy (Deru et al., 2011). These prototype buildings use EnergyPlus simulation software to provide complete descriptions for whole building energy analysis. The models employed for this study, and its predecessor, represents existing buildings constructed in or after 1980 (“post 1980”). The types of commercial buildings we modeled include hospital, large hotel, large office, restaurant, secondary school , strip mall and supermarket.

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Table 2 Summary of electrification measures applied for each of the DOE commercial building prototypes under consideration.

DOE Building Prototype	Baseline Heating	Modeled Electrification Heating
Hospital	Chiller/boiler system	Hydronic heat pump (HP) HVAC

Hotel	Packaged terminal air conditioners (PTAC)/gas furnaces for guest rooms, packaged AC/gas furnaces for common area	Packaged terminal heat pumps (PTHP) for guest rooms, packaged HP for common area
K-12 School	Packaged single-zone air conditioner (PSZ-AC) for auditorium, gym, cafeteria and kitchen; variable air volume (VAV) reheat with chiller boiler for other areas	Packaged single-zone heat pump (PSZ-HP) for auditorium, gym, cafeteria and kitchen; VAV reheat with HPWH for other areas
Multifamily Residential	Gas furnace	PTHP
Large Office	Chiller/boiler system	Hydronic HP HVAC
Restaurant	PSZ-AC and gas furnace	PSZ-HP
Supermarket/Grocery Store	PTAC and gas furnace	PTHP

In general, the rule of the end uses replacement is to replace the original gas or steam equipment with the most similar and most efficient electric option with minimum change to the existing system. For example, if the original air conditioning is provided by packaged single-zone air conditioning (PSZ-AC), the all-electric replacement would be packaged single-zone heat pump (PSZ-HP); if the original equipment is packaged terminal air conditioning (PTAC), the replacement would be packaged terminal heat pump (PTHP); if the original equipment is boiler, the replacement would be heat pump water heater. All gas water heaters were replaced by heat pump water heaters. The end-use makeups of different commercial buildings are summarized in Table 2

For all DOE building prototypes, the baseline water heating technology was assumed to be gas boilers a**nd the modeled electrification heat pump water heaters (HPWHs).**

Model Results

Table 3 Decrease in greenhouse gas emissions by building type and electrification measure.

	Decrease in GHG Emissions by Electrifying Measure		
DOE Building Prototype	**Water Heating**	**Space Heating**	**Cooking**
Hospital	5%	95%	0%
Hotel	69%	31%	0%
K-12 School	31%	69%	0%
Multifamily Residential	46%	47%	7%
Large Office	5%	95%	0%
Restaurant	37%	16%	46%
Supermarket/Grocery Store	99%	1%	0%

Table 3 shows the resultant estimated GHG reduction for each electrification measure by building type. For all building types except for restaurants and residential multifamily, it was assumed that cooking and other fossil fuel end-uses were negligible (although it may be interesting to explore the impact of cooking in hospitals, schools, and hotels as this model continues to be refined). Therefore, electrification of both space and water heating was assumed to result in full decarbonization, i.e. compliance with the last BEPS cycle (2046-2050). **Large office buildings** have dominant HVAC loads. As such, this type of upgrade tends to provide significant reductions in GHG emission. For **hospitals**, electrification of space heating provides the most substantial decreases in emissions. **Large hotels** tend to have high hot water usage due to laundry needs and thus seem to benefit from electrifying their service water heater loads with heat pumps. **Schools** (used as a proxy for educational buildings) appear to benefit more from space heating electrification for decarbonization purposes. The result for **restaurants** suggests that adoption of induction cooktops is a critical step in complying with BEPS, particularly during the farthest compliance cycles.

Table 4 shows the peak load exacerbation for each building type based on the DOE prototypes and a prior study by this team. The largest peak load exacerbations are observed in K-12 schools (representing all educational institutions), multifamily residential buildings, and restaurants. However, relative increase is not the only relevant factor when determining load impacts, so it is important to consider the initial peak loads of the most affected buildings in the dataset.

Table 4 Peak load exacerbation by building type and electrification measure.

DOE Building Prototype	**Percent Peak Load Exacerbation from Water Heating Electrification**	**Percent Peak Load Exacerbation from Space Heating Electrification**	**Percent Peak Load Exacerbation from Space and Water Heating Electrification**	**Percent Peak Load Exacerbation from Full Electrification, including cooking end uses**
Hospital	0%	2%	2%	
Hotel	0%	2%	2%	
K-12 School	4%	66%	70%	
Multifamily Residential	33%	39%	48%	49%
Large Office	0%	1%	2%	
Restaurant	6%	17%	23%	46%
Supermarket/Grocery Store	0%	0%	0%	

Model Generalization

Table 5, Model Generalization Heuristic

DOE Building Prototype	Represented Building Types
Hospital	Hospital (General Medical & Surgical), Other/Specialty Hospital, Residential Care Facility

Hotel	Hotel
K-12 School	Library, College/University, Other-Education
Multifamily Residential	Mixed Use Property, Other – Lodging/Residential, Residence Hall/Dormitory, Multifamily HR (10+), Multifamily MR (5-9), Multifamily LR (1-4)
Large Office	Office, Mixed Use Property, Courthouse, Financial Office, Miscellaneous
Restaurant	Restaurant, Other – Restaurant/Bar
Supermarket/Grocery Store	Supermarket/Grocery Store, Retail Store

As noted in the introduction, there are a total of 68 building types, as defined by the U.S. Environmental Protection Agency, represented in the dataset provided by City Light. Given this large diversity of building types and the highly generalized nature of the seven DOE Building Prototypes, it was necessary to pair each building type with an appropriate proxy from the modeled building types . This process of proxy assignment is summarized in Table 5.

Buildings that were not assigned a specific proxy, from those listed in Table 5, were modeled based on the large office prototype. While this generalization may seem sweeping, the number of buildings ultimately modeled as small offices come out to 130, representing a small percentage of the total number of buildings in the sample discussed in this paper. As this is a study of the building stock rather than any specific building within the stock, the broad representation of those miscellaneous building types is not significantly harmful to the study.

Formulating a Compliance Narrative

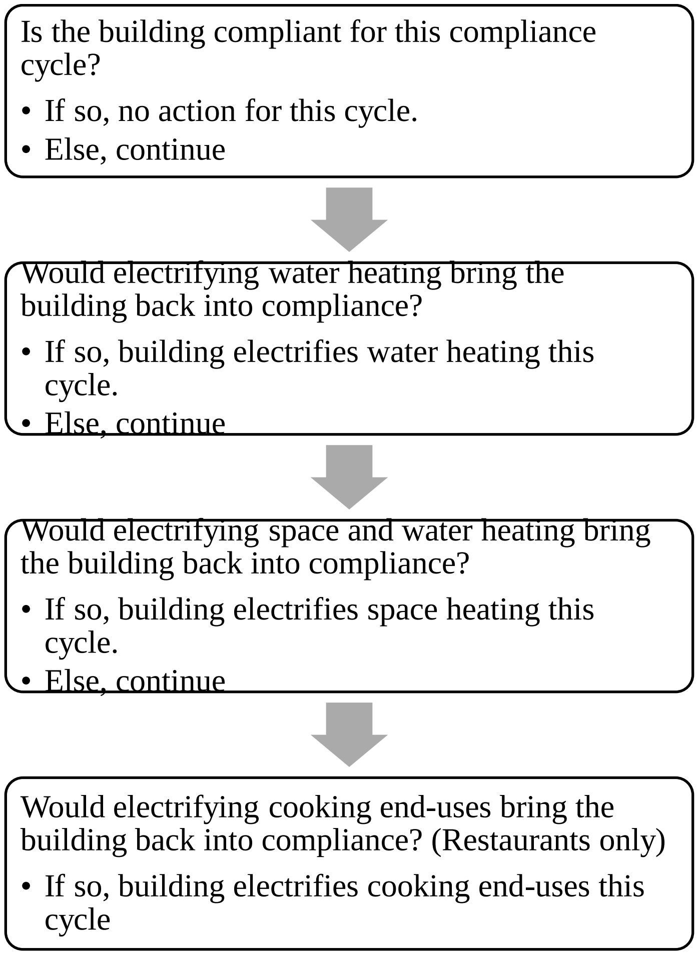

Figure 3 Compliance decision-making process employed in this study.

The project team made several assumptions in order to arrive at the most realistic compliance narratives. For the purposes of this study, the analysis assumes that all covered buildings will comply with BEPS. BEPS has significant penalties (Seattle Office of Sustainability & Environment, 2024) for noncompliance ($2.50/square foot for low-income housing/low-rent multifamily buildings, $7.50/square foot for other multifamily and $10.00/square foot for nonresidential buildings). In addition, BEPS allows for flexible compliance alternatives and exceptions during the earlier compliance periods, but the ultimate 2050 net-zero emissions target is not anticipated to move back. Finally, it is assumed that all covered buildings will electrify existing natural gas and steam end-uses, as opposed to other possible decarbonization pathways (e.g., emissions-free thermal energy networks).

When the business-as-usual scenario (namely, the building taking no action) fails to meet the compliance threshold for a given year, measures are tested for compliance starting with (1) heat pump water heater adoption, followed by (2) heat pump adoption (for space heating), then (3) a combination of those two measures. This order of operations is based on first costs- the previous study indicated that water heating retrofits had generally lower first costs than space heating retrofits. This analysis does not account for differences in operating costs. Rather, it assumes that first costs are the most important determinant of which electrification measure is chosen first. For restaurants, induction cooktops are considered as a final step, with the main argument for that being high first cost of cooking equipment electrification. The compliance thresholds are based on the GHGITs for each compliance period, as defined by the City of Seattle.

Table 6 Greenhouse Gas Intensity Target (KGCO2e/SF/YR) by compliance interval for a selection of building types

Building Type	2031-2035	2036-2040	2041-2045	2046-2050
Multifamily	0.89	0.63	0.37	0
Hotel	2.06	1.2	0	0
Office	0.81	0.47	0	0
Restaurant	5.73	3.34	0	0
Hospital	4.68	2.73	0	0
College/University	2.69	1.57	0	0

Table 6 shows the GHGITs for some of the most common building types, broken out by each compliance period. As a building progresses through the steps of its compliance narrative, its greenhouse gas emissions intensity (GHGI) and peak load are modified to estimate the impacts of measures taken to comply with BEPS. The building's GHGI is reduced by the appropriate factor seen in Table 3, while the building's peak load is increased by the appropriate factor from Table 4. For example, a restaurant that electrifies its water heating will be assigned a new GHGI that is reduced by 37% from the prior compliance cycle (or the baseline if in the first compliance cycle), and a new peak load that is increased by 6%, per tables 3 and 4.

Results and Discussion

Table 7 shows predicted average relative increases in peak load for the most common building types impacted by the Seattle BEPS under a full electrification scenario, as required by the 2046-2050 compliance phase. Building types with relatively large baseline electrical loads, such as office buildings and grocery stores, which have high ventilation (the former) and refrigeration (the latter) are much less susceptible to high peak load exacerbation than building types with minimal baseline electrical loads.

Table 7 Peak Loads for selected building types within sample dataset

Building Type	Number of Buildings	Average % increase in peak (2045 over baseline)	Average Baseline Peak Load (kW)	Average 2045 Peak Load (kW)
Multifamily MR (5-9)	521	49%	102.27	179.20
Multifamily LR (1-4)	453	49%	44.63	66.50
Office	298	2%	729.87	742.01
K-12 School	134	69%	213.93	361.37
Mixed Use Property	110	1%	772.05	783.14
Multifamily HR (10+)	103	49%	338.35	504.15
Hotel	75	10%	559.56	621.79
Total	**2,055**	**35%**	**346.54**	**404.01**

Beyond total and relative increases in peak load, another consideration for City Light is service size threshold. City Light's Requirements for Electrical Service Connection have single-phase and three-phase service voltage thresholds that determine whether the service is primary or secondary. For larger electrical services where the aggregate service entrance capacity exceeds the allowed maximum secondary service size, City Light requires the building to provide a vault or pad on private property for City Light transformer(s) and associated service equipment. It is likely that a building with an annual peak of 500 kW or above will fall above that threshold. Table 8 examines the evolution of the number of BEPS-covered buildings that have a peak load greater or equal to 500 kW. This is an important consideration because the requirement to provide a vault or pad to host City Light transformers on private property can significantly impact first cost of an electrification project. Compliance with the BEPS appears to only add 59 buildings to the 241 buildings within the sample that currently experience peak loads of 500 kW and above. The small growth of this group of interest suggests that most service upgrades resulting from BEPS compliance may not require transformers to be hosted on premise.

Table 8 Evolution of the number of buildings with peak loads exceeding 500 kW, by neighborhood.

Building Type	**Baseline (2021)**	**2030**	**2035**	**2040**	**2045**	**Increase from 2021 to 2045**
Multifamily HR (10+)	25	29	33	37	40	15
Multifamily MR (5-9)	11	13	14	17	22	11
K-12 School	15	17	18	25	25	10
Senior Living Community	5	10	10	14	14	9
Office	100	100	101	103	103	3
Hotel	15	15	16	17	17	2
College/University	10	10	10	11	11	1
Total	**281**	**294**	**303**	**325**	**335**	**54**

Figure 4 presents the total increase in peak load by neighborhood (as defined within the benchmarking dataset), grouped and color coded by compliance period. The increases seen here do not represent system peak, as the sums presented do not consider whether the peak loads are coincident or not. Instead, the increase represents the total increase in individual building peak loads due to the Seattle BEPS. Essentially, this calculation quantifies the impact of BEPS by neighborhood. The most impacted areas are Downtown and the University District.

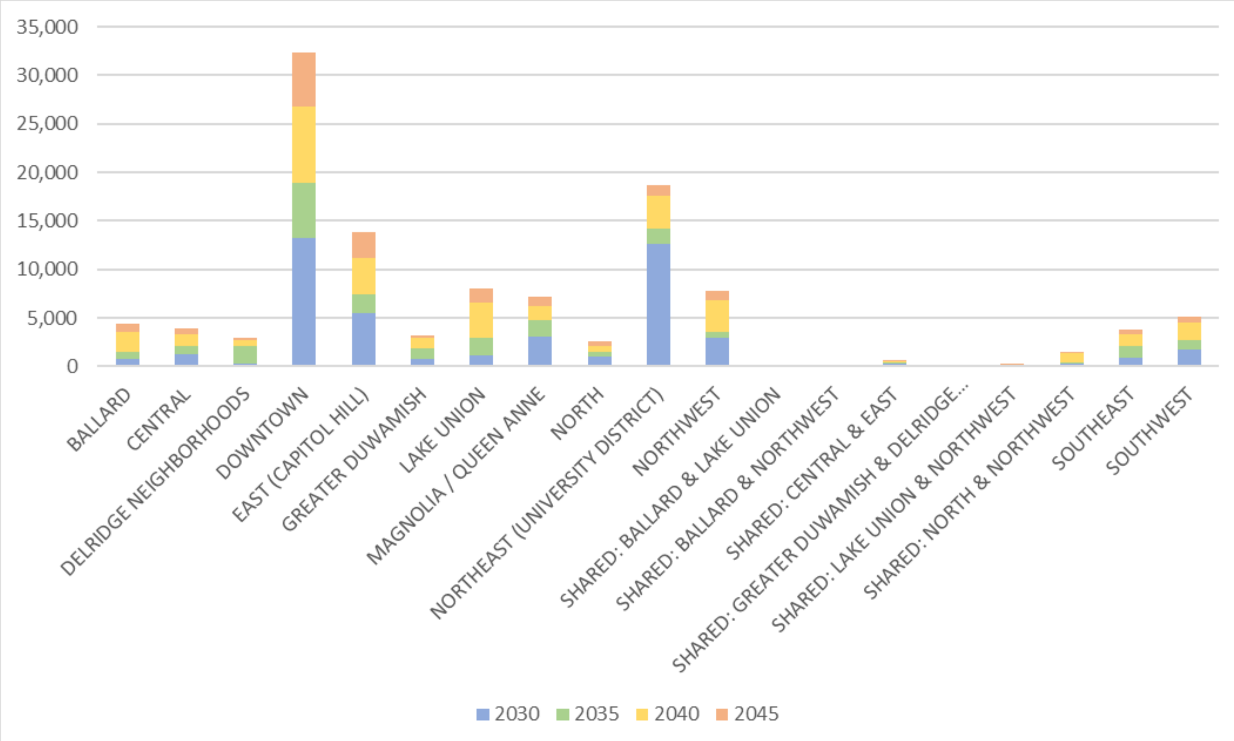

Figure 4 Cumulative peak load increase by neighborhood, grouped by estimated year of increase. Y-axis represents the cumulative increase in kW.

Conclusion

Impacts for Utility Operations

Over the course of the Seattle BEPS's compliance horizon, our modeling methodology estimates that compliance will result in an increase of individual covered buildings' peak loads amounting to a cumulative 116 MW (Figure 5). As buildings electrify their space heating, water heating, and appliance loads, the utility can expect an increased volume of increasingly complex customer service upgrades due to (a) significant increases in individual buildings' peak loads, and (b) increases in the number of buildings with a peak load exceeding 500 kW (an important complexity threshold for service upgrades). Furthermore, widespread customer electrification can be expected to lead to grid-side distribution upgrades to meet increased electrical loads, particularly in the most impacted areas of Seattle shown in Figure 4. The increased volume of customer and grid-side upgrades suggests a progressive need for increased material procurement and staffing during the 2030-2050 period.

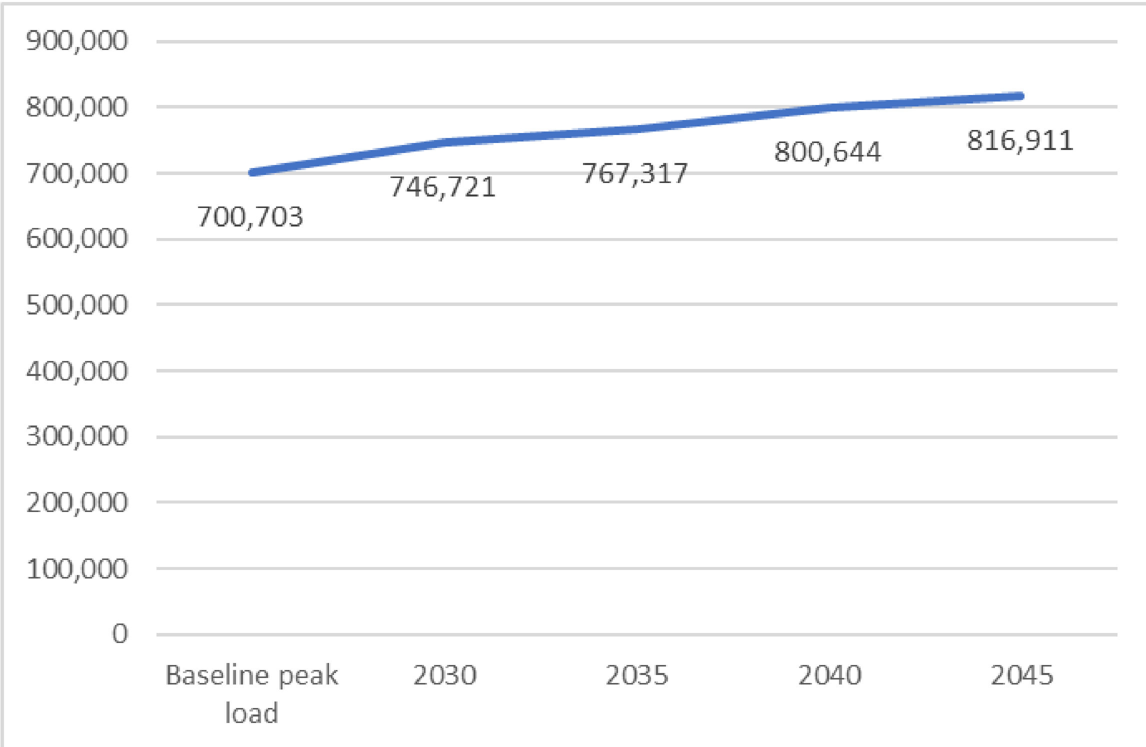

Figure **5** Cumulative (not coincident) peak load (kW) growth from BEPS compliance over time

Limitations and Next Steps

This paper presents preliminary results from the case study, rather than the final assessment to be adopted by Seattle City Light and is as such more focused on the methodology in its current state. Several limitations, with steps to eventually address them, are noted at this time:

- **Need for more building models:** More building types and vintages (e.g., pre-1980 DOE prototypes) would allow for a more accurate representation of the building stock. This case study repurposed models from a prior building electrification roadmap developed by EPRI at the request of Seattle City Light. As such, it does not make exhaustive use of the DOE building prototypes at this time. We recommend that future studies employing this methodology cast a wide net in establishing reference models used in formulating a compliance narrative.
- **Gaps in data requiring assumptions:** As described in the body of this paper, the benchmarking data leveraged in this study did not include any information on the actual mechanical systems serving the building's space and water heating needs. As such, assumptions needed to be made to formulate compliance narratives for buildings that, from benchmarking data, seemed to deviate substantially from the reference EnergyPlus models. More data regarding the systems in the building, such as data from property tax records, would make this approach of generalizing individual building energy models more robust.
- **Cost Assumptions:** As costs and customer programs change, it is reasonable to debate whether the order of operations assumed in this study is accurate. The individual

circumstances surrounding every building, in addition to potential rebate programs, further complicate these assumptions.

- **Exemptions and evolving rulemaking:** While we assume most building owners will delay compliance as much as possible, modeling for these nuances introduces too much complexity.
- **Inclusion of other measures:** Other energy conservation measures, such as weatherization, load flexibility, and renewables integration, may potentially change the projections of the present study. The exploration of the impact of these measures, especially given that the corresponding state building performance standard is based on energy use rather than emissions, is highly pertinent.
- **Model calibration:** It would be beneficial to calibrate the models here against actual building and retrofit performance observed in Seattle.

This methodology is a work in progress, as currently described, and is currently being fine-tuned. Potential next steps include the incorporation of more measures, the investigation of co-compliance with Washington Clean Buildings Performance Standard, and the inclusion of more building models.

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