Techno-Economic Analysis of High Efficiency and Connected DERs for Connected Communities: A Case Study in Seattle, WA

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ABSTRACT

Decarbonizing multifamily affordable housing communities through efficient electrification retrofits presents a unique set of challenges. These challenges arise from a wide variety of technical considerations. For example, ensuring that electrified end-use technologies are appropriate given intense capacity constraints and limited capital budgets. These complex considerations necessitate a thoughtful multi-dimensional approach that can lead to optimal outcomes for all stakeholders involved. This paper presents an approach that employs a value framework that evaluates a set of high-efficiency and connected distributed energy resources (DER) from the perspective of lifetime value generated for the customer, the grid, and society at large. The framework employs a calibrated building energy modeling approach that is augmented with an analysis of grid services potential to understand the value-add that is achievable through demand flexibility and behind-the-meter DERs. This framework is employed as part of a large-scale demonstration under the auspices of the DOE Connected Communities program involving a combination of electrified space conditioning and water heating alongside Solar PV and EV charging added to several communities in Seattle, WA. Two key results of the techno-economic analysis are highlighted - (a) The difference in the overall value that arises from choosing options that are efficiency-focused vs. options that balance efficiency against the value generated through demand flexibility and (b) value enhancements that are achievable by using a Time-of-Day (TOD) rate structure.

Introduction

The building segment accounts for more than 37% of the global annual greenhouse gas (GHG) emissions on a total carbon accounting basis (operating and embodied carbon) (UNEP, 2022). Several policy measures are carried out to help reduce the GHG emissions from buildings including tightening the building codes to be more energy efficient. The City of Seattle has taken several such code updates and as of the writing of this paper has one of the more progressive and energy-efficient building codes in the country. While this has ensured that the new building stock is energy-efficient, it doesn't cover existing buildings except when a major retrofit is planned. This leaves behind existing buildings, especially the rental segment including multifamily buildings . Amongst the multifamily rental segment, the multifamily affordable housing segment represents one of the most challenging building typologies to retrofit.

Given this backdrop, Seattle has set up an ambitious climate action plan that calls for reducing GHG emissions from buildings by 38% below 2008 levels by 2030 and achieving net

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zero carbon emissions by 2050. Seattle City Light, the municipal electric utility in Seattle has a vertically integrated electrical system with a highly decarbonized generation mix thanks to the availability of large quantities of hydro-electric power. Seattle City Light's grid is about 97% carbon-free and the last 3% is imported from regional operators such as the Bonneville Power Authority (Seattle City Light, 2023).

Seattle City Light conducted an electrification assessment study of its system alongside its building and transportation stock to understand the availability (or lack thereof) of capacity for supporting various end-use electrification scenarios. The study was conducted by the Electric Power Research Institute (EPRI) and indicated that Seattle has enough generation capacity to support a 100% electrification scenario. However, with a dense urban distribution network, the principal challenge for rapid electrification is the need to upgrade distribution infrastructure. Rapid electrification scenarios also indicated significantly exacerbated peak loads as space conditioning and water heating loads (that are currently served by natural gas provided by Puget Sound Energy) fuel switches to electricity.

Drivers for Connected Communities in Seattle, WA

Electrification of building loads in Seattle may necessitate costly distribution infrastructure upgrades and thus any mechanism that effectively helps to reduce coincident peaks at a distribution asset level (e.g., feeder/substation) can help reduce the thermal stresses on these distribution assets. This in turn may help to prolong the lifetime of these distribution assets. Seattle City Light has also identified the potential for active intervention measures such as demand response to help mitigate system peak loads and has included DR targets as part of their Integrated Resource Planning (IRP) for 2030. Finally, by deferring infrastructure upgrades, the need for cost recovery through rate increases can be deferred which benefits the over 400,000 customers that Seattle City Light serves including those who live in multifamily affordable housing. This need for efficient electrification and demand flexibility works alongside Seattle City Light's interest in grid modernization as it evaluates software solutions for better managing its distribution network.

DESIRED Project Outline

The Department of Energy (DOE) funded Connected Communities (CC) portfolio of projects is carefully curated to include a wide range of value propositions that are being evaluated in different parts of the US (from the Pacific Northwest to the SouthEast to the SouthWest to New England and in the Mid West). One of the ten Connected Communities projects led by EPRI in conjunction with Seattle City Light in Seattle, WA, is called Deep Efficiency and Smart-grid Integrated Retrofits in Disadvantaged Communities (DESIRED). The goals of the DESIRED project are threefold:

a. Investigate optimal pathways for transforming an existing stock of multifamily affordable housing communities into a Connected Community of Grid-interactive and Efficient Buildings (GEB).

b. Explore how a combination of high-efficiency and connected end-uses and community scale Distributed Energy Resources (DER) can work in concert to provide grid services at the distribution-system level.
c. Scale up the approach using lessons learned from the field demonstrations to establish a set of best practices and choose the pathways that provide value for all the stakeholders involved.

The project includes a portfolio of buildings that are owned and operated by Community Roots Housing, a progressive multifamily affordable housing provider in Seattle. A set of six communities were identified for the project (see Figure 1) to install a variety of end-uses that can help to efficiently electrify space conditioning and water heating along with community-scale DERs in the form of rooftop Solar and community-level EV charging (see Table 1 for an initial view of DERs by community).

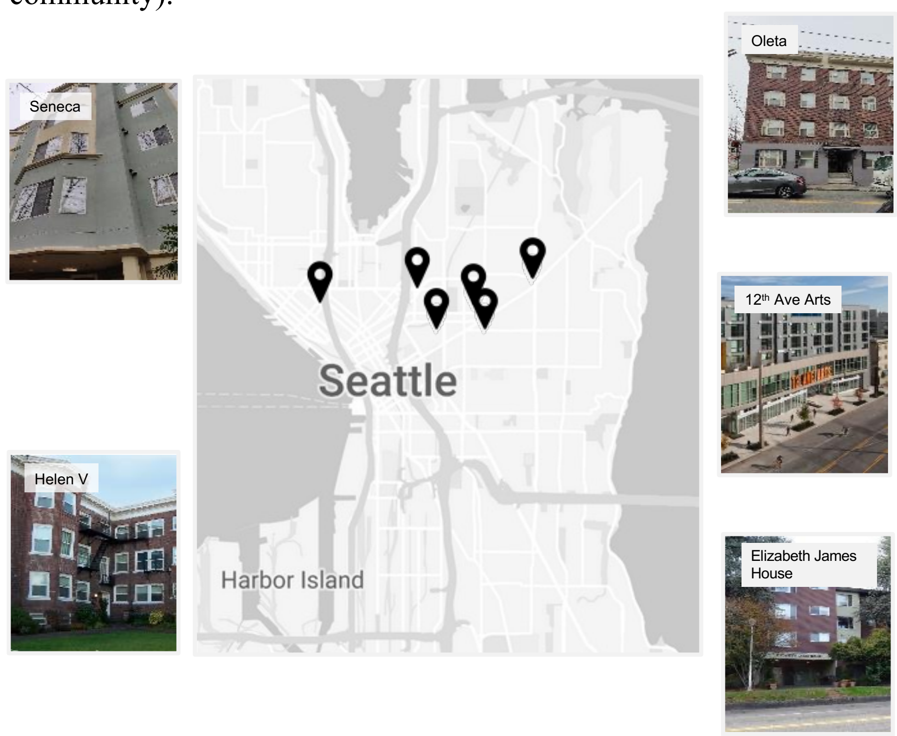

Figure 1. Sites for Seattle DESIRED project.

One of the key considerations in the choice of space conditioning was to ensure that the resulting choices didn't require a panel capacity upgrade to the community and so were restricted to the choice of 120V monoblock heat pumps which have a coefficient of performance of over 3.5 for the moderate climate in Seattle and had low maximum power draw (max of 7.5A).

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Table 1. Initial assessment of flexible loads and community scale DERs for Seattle sites.

Community	Space Conditioning	Water Heating	Solar PV	EV Charging
Oleta	120V monoblock heat pump	Centralized HPWH	Maybe (roof needs to be inspected)	No
Seneca	120V monoblock heat pump	120V Unitary HPWH	Yes	Yes
Helen V	120V monoblock heat pump	Centralized HPWH	No	No
12th Avenue Arts	No changes	No changes	Yes	No
Elizabeth James	120V monoblock heat pump	No changes	Maybe (roof needs to be inspected)	Yes
Broadway Crossing	No changes	No changes	No changes	Yes

Contribution of this Study

A key initial task in the project is to understand the cost-benefit of adding a variety of electrification and community-scale DERs for each of the communities to study two vital questions:

1. What are the achievable levels of efficiency, GHG emissions reductions, and demand flexibility[1] potential for a set of end-use technologies? What is the relative tradeoff between adding additional efficiency measures vs. adding demand flexibility?
2. What are the first costs and operating cost savings for each set of end-use technologies relative to a prior year baseline? What set of measures optimizes cost recovery for all stakeholders involved?

Methodology

The cost-benefit analysis outlined above was conducted using a building energy model-driven approach. The building energy models for each of the communities were developed using EnergyPlus™. For this, the project utilized XeroHome™, a software platform that employs publicly available data from property tax records and building permits, along with 3D geometry from GIS datasets to build an energy model. It then progressively calibrates the model in three distinct phases, for alignment with ground-truth data and smart-meter data. This produces highly

[1] Load shed was the only demand flexibility approach that was studied at the time of writing this paper

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aligned energy models that can then be used to evaluate various space conditioning and water heating end-uses alongside community scale DERs using a set of annual, counterfactual hourly load profiles.

The XeroHome approach of progressively calibrating EnergyPlus models that are first developed using public data provides a scalable approach to building energy modeling for conducting cost-benefit analysis. Demonstrating and validating this approach helps achieve the goal of scaling up implementation beyond this pilot.

Three Phases of EnergyPlus Model Development

EnergyPlus models were developed in three phases. In the first phase, the models were developed using the 3D geometry of the buildings (using Google Earth) with a set of parameter values that were “default” based on a variety of factors including the vintage and aerial views (using property tax assessment, and building permit data). In phases two and three, the models were then progressively calibrated to increase modeling accuracy. In phase two, ground-truth data collected from interviews with the building owner/operator, building plans, site-visit photographs, and nameplate data were used to replace some of the default values from phase one, and Actual Metrological Year (AMY) data was used to condition the buildings for a specific year (2022). Finally, in phase three, energy use interval data from Advanced Metering Infrastructure (AMI) from 2022 was employed to fine-tune modeling assumptions. In each step of the calibration, an error estimate (E1 for Phase 1 to Phase 2, E2 for Phase 2 to AMI calibration, and Em for final baseline calibration) was produced and this error estimate will eventually be used to understand the scaled performance of the field demonstration to estimate portfolio and utility-scale results.

In the third phase, models utilized Seattle’s Actual Metrological Year (AMY) weather files for a specific year for which AMI data was available, instead of the typical Metrological Year (TMY) weather files. This helped establish a calibrated baseline model for each building. Parameter tuning was stopped when the Coefficient of Variation of Root Mean Square Error (CVRMSE) between the model and the actual smart meter was less than 20% and Normalized Mean Bias Error (NMBE) was less than 5%. Figure 2 depicts the overall calibrated baseline model development methodology.

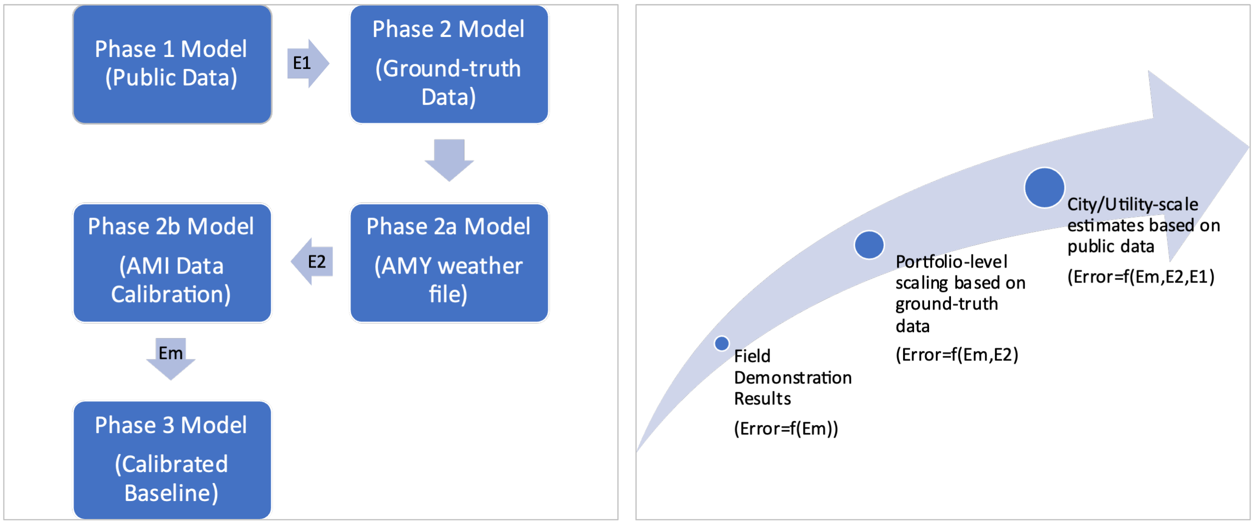

Figure 2. The progressive calibration approach used in this study (left) and method to scale results from field demonstration to city/utility scale (right).

With the baseline established, a set of counterfactual annual hourly load data was generated from the calibrated models for a set of CC technology options for each site. Both individual technologies as well as technology packages were modeled and counterfactuals[2] were generated. The counterfactual annual hourly load data was then analyzed using a cost-benefit calculator that was developed by EPRI. The cost-benefit calculator helps to compare the economic value generated for the 3 major stakeholders namely the customer (the building owner/operator and resident), the utility (electric and/or gas utility), and society (the broader community).

One of the key advantages of the progressive calibration approach is to derive quantitative insights into the quality of public data sources, e.g., from Level 1 (Public Data) to Level 2 (ground truth) if there is a 40% improvement in RMSE, then this establishes an error estimate for scaling results from the field demonstration to a city/utility-scale stock of buildings. By comparing the calibrated counterfactual modeling results to actual field demonstration data, we derive a realistic estimate of the model's prediction accuracy. This accuracy estimate then allows us to place bounds on the accuracy of the stock-level results arising from estimating stock-level performance from field demonstration results. Given that broad-scaled modeling approaches such as ResStock (NREL, ResStock, 2023) and UrbanOpt (NREL, UrbanOpt Advanced Analytics Platform, 2023) typically involve data derived from public data sources, it helps to provide an estimate of the improvement in accuracy by developing stock-level estimates based on scaling results from field demonstrations compared to these modeling approaches. The resulting broad-scaled results are much stronger as they have an average baseline from the field demonstration and an overall estimate of accuracy. Figure 2 shows the process of scaling up results from the field demonstration to a city/utility-scale footprint of buildings.

[2] Here the term counterfactuals are used to denote the performance numbers generated from "what-if" modeled scenarios. For example, the performance after replacing gas heating with heat pumps.

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Value framework for Decision Making

To analyze the options for optimizing the value of the Connected Communities technologies, a framework that employs a set of cost and benefit metrics for the stakeholders involved is used. Figure 3 shows the decision framework. The framework considers the customer's first and operating costs of energy (electricity and gas equipment and labor costs along with annual bill estimates after retrofits), the utility's impact in terms of peak-load exacerbation (that could potentially add up at the distribution feeder or higher levels to trigger a distribution asset upgrade), and total on-bill revenues (resulting from fuel-switching), and the society's impact in terms of GHG emissions reductions. The benefit is assessed as the lifetime value of the investment for the customer (over the lifetime of the technology deployed), the lifetime value of the on-bill revenues for the utility, and the lifetime value of the GHG emissions reduction expressed in monetary terms using the published value of the social cost of carbon. The decision matrix is then set up as a function of the tradeoff between the primary value dimension (lifetime values for all 3 stakeholders) and decision matrix dimensions such that solutions that provide optimal positive value for all 3 stakeholders are recommended on a site-by-site basis.

	Utility	Customer	Society
First cost parameters (-)	✓ Distribution upgrades needed to accommodate electrification ✓ Customer acquisition (incremental administrative costs) *(not included in value model)*	✓ Equipment and labor cost of electrification measure ✓ Retrofit cost to enable electrification (wiring, panel upgrade, disposal of old equipment)	✓ Federal and state incentives *(not included in value model)*
Operating cost parameters (-/+)	✓ On-Bill Revenue	✓ Increase/decrease in bills	✓ Rates for electricity and natural gas ✓ Societal cost of carbon
Primary Value Dimension	Lifetime value of Infrastructure Upgrade Investment	Lifetime value of Electrified End-Use	Projected overall reduction in GHG emissions
Decision Matrix Dimensions	Incremental peak demand, Demand flexibility potential	First cost, operating cost savings	Social cost of carbon-based benefit of GHG emissions reductions

Figure 3. Value framework for aiding decision-making for stakeholders involved in GEB retrofits

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The estimate of the first costs is based on a simplified model that estimates the customer cost as a sum of the equipment and labor costs with an additional "retrofit" cost which essentially models any residual costs such as new panels (added breakers for new loads wherever applicable without any additional capacity) and disposal of old equipment. The equipment cost assumes a national average cost that is then adjusted for cost of living adjustment based on the regional variations in average income levels. The labor cost is calculated as a function of the number of HVAC units to be installed and the capacity of centralized heat pump water heaters with similar

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cost of living adjustments as equipment costs. Weatherization and Solar PV equipment and labor costs are calculated using online calculators.

To estimate the operating costs of electricity and natural gas the counterfactual hourly load data is converted to kWh and a comparison between Seattle City Light's Tiered (Block) rate and a proposed Time-of-Day (TOD) rate is performed. Additionally, net-metering-based reduction in electricity bills is concerned. Finally, any residual natural gas is estimated at Puget Sound Energy's prevailing block rates for natural gas.

Results and Discussion

Calibrated Baseline Models

With the modeling methodology outlined above, the improvement/changes in source[3] energy use for each site as it evolved through the iterations of model calibration are shown in Figure 4. As described above, the calibration from Phase 1 to Phase 2 indicated that only one of the 5 communities was within a 10% margin of error. A majority of the models were over-estimating the energy use and this is largely attributed to better than expected R-value for roof and wall insulation and the use of NG-based central water heating boilers in many of the communities. Many of the communities also have different proportions of LED and CFL lighting compared to the Phase 1 assumption of 50% CFL/50% LED.

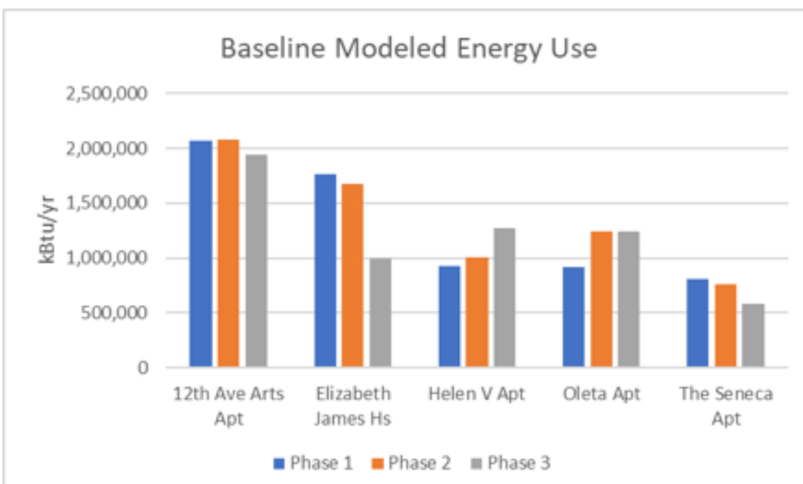

Figure 4. Results of the progressive calibration approach to develop baseline energy models

In the calibration from Phase 2 to Phase 3 (via Phase 2a, Phase 2b), we found two of the communities to be within 10% margin of error and one of the communities was within 25% of the margin of error. Table 2 shows the CVRMSE of the Phase 3 model relative to 2022 building-level aggregate AMI data. The building-level AMI data was provided by Seattle City

[3] Source energy was used as a metric for comparing the calibration accuracy across buildings normalizing the effects of individual building's end-use load characteristics. For example, some buildings already had HP HVAC whereas most buildings did not have cooling loads and one of the buildings already had HPWH while most have gas boilers.

Light consistent with the tenets of the City of Seattle's AMI ordinance which effectively identifies AMI data as part of Personally Identifiable Information (PII) and is thus not permitted for sharing with third parties. This was overcome by aggregating the individual unit-level AMI data along with the house meter data (for common area loads) to produce building-level AMI data and sharing the data under a Non-Disclosure Agreement. Natural Gas use at the community level was obtained through Energy Star Portfolio Manager access provided by Community Roots Housing for the communities under consideration.

Table 2. Calibration errors of the final baseline models for Seattle communities

Community	CVRMSE Electricity	CVRMSE Natural Gas	Major parameter tuning needed & high level reason
Oleta	15%	15%	200% increase in infiltration (Corrected an estimate of infiltration that was based on building vintage)
Seneca	9%	n/a	66% increase in infiltration; 80% reduction in peak water draw (Corrected infiltration based on building vintage and water usage from parameter tuning for WH usage)
Helen V	14%	20%	Water heater EF reduction by 13% (Corrected after site visit)
12th Avenue Arts[4]	24%	8%	First-floor commercial space AMI data couldn't be disaggregated
Elizabeth James	7%	n/a	Reducing window u-factor by 50%; 50% increase in infiltration; 60% reduction in peak water draw (Corrected after a result of site visit)

Analyzing Performance and Cost Tradeoffs

With the calibrated baseline models in hand, a consistent set of CC measures was applied to each of the communities under consideration using EnergyPlus (EnergyPlus, 2023) Building Energy Modeling software to generate the counterfactuals. These measures included (a) Improving sealing and reducing infiltration in the building envelope, (b) Addition of Ephoca 120V monoblock heat pumps, (c) Replacing natural gas boilers with SanCO2/Mitsubishi

[4] With 12th Ave Arts being a mixed-use building with the first floor and mezzanine level comprised of commercial spaces (theaters, restaurants, and office space) and without disaggregated AMI data for the commercial and residential spaces, the Phase 3 models were not particularly well-calibrated for that building.

centralized heat pump water heaters, replacing electric resistance water heaters with Rheem Proterra120V heat pump water heaters (in Seneca), (d) Addition of bi-facial solar PV, and (e) Addition of WexEnergy SolarSkin™ which is a passive internal window insert that helps to reduce the solar heat gain coefficient, (f) addition of a mobile app for inducing customer participation in energy management for bill reduction enabled through EPRI's DERMS integrated into Neuro Building Systems' NeuroEdge™, a building automation system that can help with demand flexibility (load shed) and achieve bill reduction and a relatively flat load factor. In particular, the tradeoff between envelope efficiency (measures (a) and (e) above) and demand flexibility is studied with the understanding that the demand flexibility potential represents the maximum achievable load shed.

The initial set of modeling runs focused on single measures to verify if there was a significant exacerbation of energy use, peak loads, and/or GHG emissions observed. This was necessitated by the fact that technologies that inadvertently cause exacerbation are not likely to be considered. As expected, this resulted in some measures producing a reduction in energy use whereas other measures such as heat pump HVAC caused an increase in energy use partially due to increased summer cooling use while improving resident comfort. This was then followed up with runs that focused on a package of measures such as Weatherization and HVAC, HVAC, and water heating. Table 3 summarizes the site energy reduction/increase compared to baseline. Clearly, from a site energy use perspective, the option of electrifying space conditioning and water heating produces significant energy efficiency in three of the communities. One of the challenges with 12th Ave Arts is that being a relatively new building, it already has a fairly tight envelope and has common area HVAC loads that are serviced by heat pump HVAC. While heat pump water heater helps this community, the project team is not recommending any changes to the community for now and instead use the large flat rooftop to install bifacial solar panels that can potentially cover 100% of the building loads and thus provide a community solar service and any associated virtual net-metering credits to the residents in the community.

Table 3. Site energy use reduction/increase from the use of various CC measures.

Community	Measure 1 Weath.	Measure 2 HP HVAC	Measure 3 HPWH	Measures 1+2	Measures 2+3
Oleta	-3%	-7%	-18%	-8%	-25%
Seneca	-2%	+12%	-38%	11%	-28%
Helen V	-9%	-11%	-17%	-14%	-28%
Eliz. James	-3%	-3%	0%	-4%	-3%
12th Ave Arts	-1%	+6%	-4%	6%	2%

The first costs and associated utility bill savings are shown in Table 4 and Table 5. While weatherization provides uniformly improved energy performance, the cost of weatherization is relatively high compared to other measures such as heat pumps and heat pump water heaters.

Table 4. The first cost of CC measures for Seattle communities includes equipment and labor costs.

Community	Measure 1 Weath.	Measure 2 HP HVAC	Measure 3 HPWH	Measures 1+2	Measures 2+3
Oleta	$49,410	$119,170	$98,634	$168,580	$217,804
Seneca	$56,715	$112,160	$92,832	$168,875	$204,992
Helen V	$72,147	$108,665	$89,931	$180,802	$198,586
Eliz. James	$115,373	$210,300	$0	$325,673	$210,300
12th Ave Arts	$160,705	$308,440	$255,288	$469,145	$563,728

One of the more counter-intuitive results comes in the form of operating costs which despite overall energy reduction in kBTU terms, does not directly translate to corresponding savings as seen in Table 5. The simplest explanation for this is that the energy use reduction arises from fuel switching, however, factoring in the operating efficiency of the electrified end-use relative to baseline and the rate structure employed (including the baseline allowance, off-peak, mid-peak, and peak rates) causes an actual increase in energy bills. This effectively means that additional measures, e.g., demand flexibility may need to be incorporated to switch the loads to times when off-peak and mid-peak rates are in use. Additionally, net metering may help to reduce the operating cost of energy post-retrofit.

Table 5. Annual Operating cost relative to the baseline of CC measures for Seattle communities using a TOD rate. Positive values indicate higher costs and negative indicate lower costs than the baseline

Community	Measure 1 Weath.	Measure 2 HP HVAC	Measure 3 HPWH	Measures 1+2	Measures 2+3
Oleta	-$559	+$4,599	+$7,214	+$3,946	+$11,812
Seneca	-$425	+$2,773	-$8,370	+$2,714	-$5,809
Helen V	-$4,030	-$5,060	+$6.045	-$6,359	+$987
Eliz. James	-$1,166	-$1,083	$0	-$1,409	-$1,083
12th Ave Arts	-$970	+$4,651	+$28,037	+$5,096	+$32,780

Peak loads in the community as a result of electrification is a key decision matrix dimension for the utility and exacerbations in peak loads may require replacements or upgrades to secondary transformers which is challenging in dense urban distribution networks without adequate space and safety considerations. Table 6 shows the peak load exacerbation arising from the electrification measures and follows the same convention thus far with + indicating higher peak loads and negative indicating a lower peak load. It is not surprising that weatherization and heat pumps show reduced peak loads whereas water heating adds to the peak with package measures showing similar trends. The only exception is Oleta which went from a relatively low electrical load to a significant peak load as it was the only community with a natural gas-based heating system. One of the reasons for this is the potential for coincident

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HVAC loads from all the individual living units combined with water heating loads set against the backdrop of a very low baseline peak load.

Table 6. Building-level peak loads relative to the baseline of CC measures for Seattle communities. Positive values indicate higher peak loads and negative indicate lower peak loads compared to baseline

Community	Measure 1 Weath.	Measure 2 HP HVAC	Measure 3 HPWH	Measures 1+2	Measures 2+3
Oleta	0%	+391%	+150%	+363%	+514%
Seneca	-11%	-4%	+8%	-7%	+2%
Helen V	-11%	+1%	+24%	-12%	+25%
Eliz.James	-10%	-3%	0%	-12%	-3%
12th Ave Arts	-24%	-6%	+66%	-21%	+63%

The use of electrified end-uses delivers a significant reduction to the site-level GHG emissions for the communities under consideration in Seattle. Table 7 shows the GHG reduction in Metric Tonnes of CO2e. Only one of the communities under one of the measures ends up with increased GHG emissions. This may be explained by higher than baseline summer use for cooling loads in a community that currently does not have any cooling loads. Figure 6 shows a comparison of first cost and operating cost-saving as well as first costs and peak load exacerbation. For decision-making purposes, those measures that are high on savings and low on peak-load exacerbation would be ideal candidates. These options are circled in Figure 6 and Figure 7 and represent the low-hanging fruit.

Table 7. GHG emissions are attributed to various CC technology measures. Positive values indicate higher GHG emissions and negative indicate lower GHG emissions.

Community	Measure 1 Weath.	Measure 2 HP HVAC	Measure 3 HPWH	Measures 1+2	Measures 2+3
Oleta	-2.07	-6.24	-14.59	-6.97	-20.82
Seneca	-0.47	+2.80	-9.14	+2.73	-6.56
Helen V	-4.46	-6.00	-13.27	-7.47	-19.27
Eliz.James	-1.27	-1.41	0	-1.78	-1.41
12th Ave Arts	-4.46	-6.00	-13.27	-7.47	-19.27

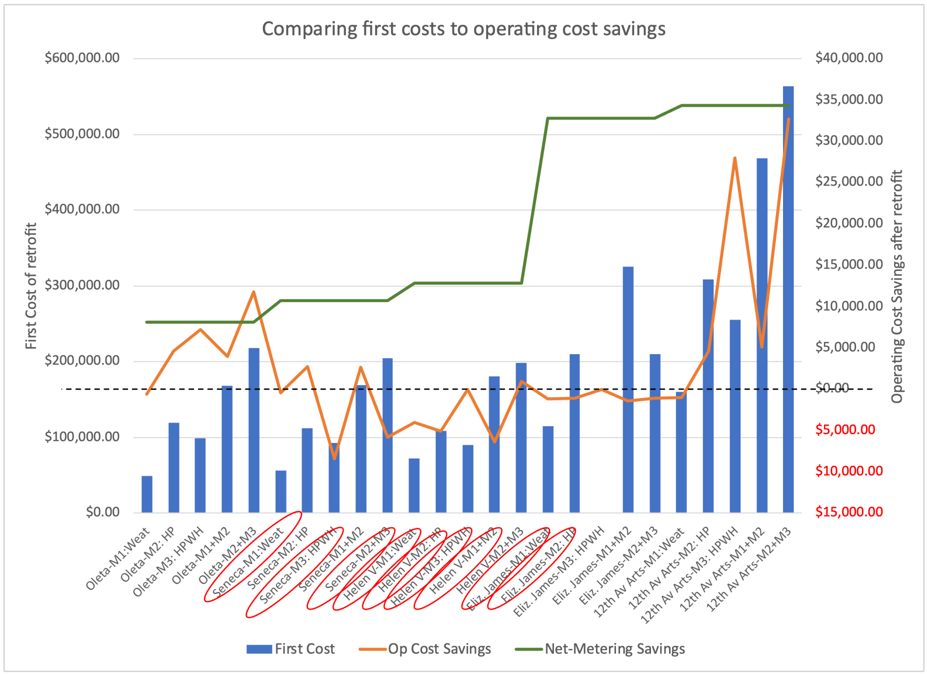

Figure 6. Comparing the first cost to operational cost savings.

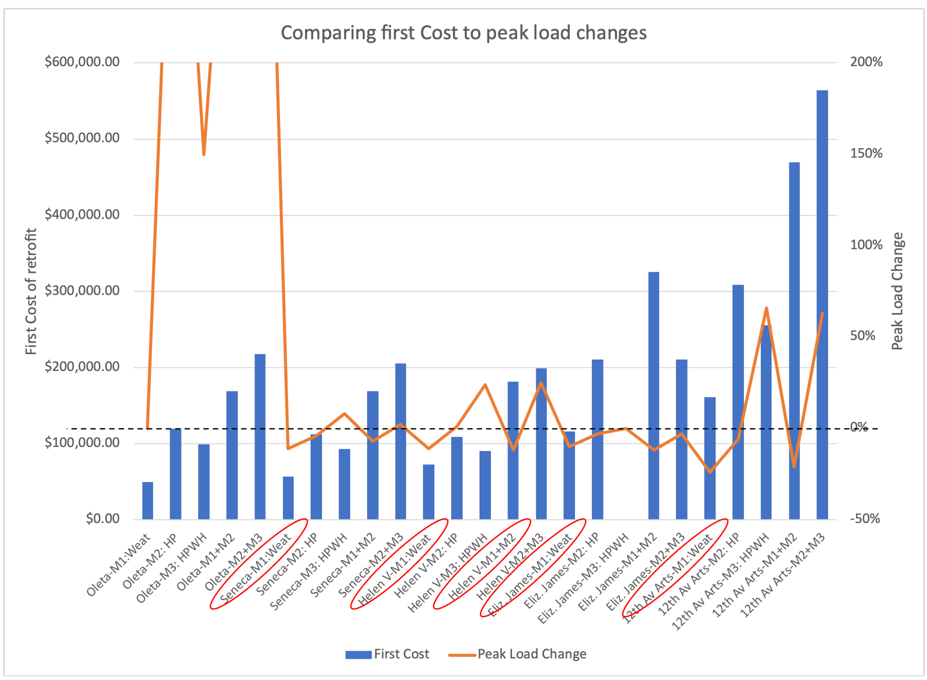

Figure 7. Comparing the first cost to peak load changes[5].

[5] The secondary axis has been deliberately truncated to preserve the details in the secondary line plot.

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The estimation of Solar PV capacity employed a simple rules-based approach wherein an attempt was made with the available flat roof space to install enough solar panels to cover a maximum of 100% of the baseline energy use. If there isn't enough space, then enough solar panels will be added to cover the available space on the rooftop. Table 8 shows a comparison of available space, % coverage of baseline load, and % coverage on a per CC measure basis. Based on the PV array size projections, a few communities are better suited to add solar PV. Table 9 shows the operating cost savings after the application of net-metering savings. Except for Oleta, all communities significantly benefit from adding Solar PV with net-metering savings. This is evident from Figure 6 where most operating cost savings (except for Oleta with HP and HPWH) are well below the net-metering savings line.

Table 8. Solar PV generation potential and coverage for each of the CC measures.

Community	% roof covered	PV Array (kW)	% baseline load covered	Measure 1 Weath.	Measure 2 HP HVAC	Measure 3 HPWH	Measures 1+2	Measures 2+3
Oleta	49%	47	62%	62%	35%	29%	37%	21%
Seneca	66%	62	45%	46%	40%	73%	40%	62%
Helen V	57%	74	42%	49%	52%	29%	56%	34%
Eliz.James	76%	189	80%	83%	83%	80%	84%	83%
12th Ave Arts	77%	198	100%	103%	88%	45%	87%	42%

Table 9. Net-metering savings in the community.

Community	Net-metering Savings
Oleta	-$8,163
Seneca	-$10,768
Helen V	-$12,852
Eliz.James	-$32,826
12th Ave Arts	-$34,389

A demand flexibility (DF) analysis was conducted in these communities to understand the load-shed potential of the flexible loads. The analysis assumed that the peak loads were controlled down to the average load level thereby flattening the load profile (reducing hourly peak loads) and improving the load factor. Table 10 and Table 11 show the community-level load shed potential for summer and winter. Given the winter-peaking nature of Seattle, there is a significantly higher load shed potential in winter compared to summer.

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Table 10. DF potential for HP and HPWH measures in Seattle communities in summer based on hourly peak load reduction. All values in kW.

Community	Measure 2 HP HVAC (summer)	Measure 3 HPWH (summer)	Measures 2+3 (summer)	Measure 2 HP HVAC (winter)	Measure 3 HPWH (winter)	Measures 2+3 (winter)
Oleta	16.4	5.0	18.1	57.4	5.3	55.3
Seneca	7.0	8.9	13.3	14.1	25.0	22.5
Helen V	16.7	34.5	17.9	53.9	41.5	54.5
Eliz.James	15.1	8.9	15.1	41.4	39.8	41.4
12th Ave Arts	14.5	6.7	15.7	33.9	38.7	33.8

As a final analysis step, the community energy consumption was subject to two different rate plans, namely, the tiered (block) rates and a proposed Time-of-Day (TOD) rate. Table 12 shows the potential for bill savings on the baseline load when switching from the Tiered rate to the TOD rate. However, the caveat is that for the TOD rate to continue to provide savings an active load management method is necessary and customers need to opt-in to the active load management.

Table 12. Bill savings in switching to TOD rate from Tiered rates.

Community	Net-metering Savings
Oleta	-$234
Seneca	-$1,095
Helen V	-$1,553
Eliz.James	-$7,151
12th Ave Arts	-$724

Final Set of Recommendations

Given the entire body of analysis that was performed, a final set of recommendations are drawn taking into account the value dimensions of lifetime operating cost savings for the customer, minimization of peak-load exacerbation for the utility, and maximization of GHG emissions reductions potential for society, Table 13 shows the recommended set of CC measures for each of the communities under consideration in Seattle. In general, the recommendations were based on the "low-hanging fruit" measures identified in Figure 6 and Figure 7. For any of the additional measures, the ability to achieve customer operating cost savings after the inclusion of solar PV for a "reasonable" increase in peak loads (which may be offset using demand flexibility) was used.

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Table 13. The final set of recommended measures in the Seattle communities.

Community	Weatherization	120V Ephoca HP	HPWH	Solar PV	EV Charging	GEB Controls
Oleta	Yes	Yes	No	Yes	No	Yes
Seneca	Yes	Yes	Yes	Yes	Yes	Yes
Helen V	Yes	Yes	Yes	Yes	No	Yes
Eliz. James	Yes	Yes	No	Yes	No	Yes
12th Ave Arts	No	No	No	Yes	No	No
Broadway Crossing	No	No	No	No	Yes	Yes

Conclusion

The paper outlines a systematic value-driven approach to developing retrofit packages for implementing the DESIRED Connected Communities approach in Seattle, WA. The approach includes the development of a novel building energy modeling methodology that includes a progressive calibration method that achieves low CVRMSE values. The calibrated baseline model was then subject to a package high high-efficiency connected flexible loads to estimate the energy efficiency potential alongside impacts to the distribution system as well as associated improvements in GHG emissions from the community. The results of the analysis indicate that with the collective set of measures energy efficiency of the order of 20% is achievable without the need for any active intervention measures. However, this energy efficiency does not automatically translate to bill savings for the customer and necessitates the addition of Solar PV net metering to achieve improved operating costs for the customer. The exacerbation in peak loads requires a GEB control solution. The GEB controls aer also required to perform active load management to help with bill reduction for those communities that do not have enough rooftop space to cover the whole building load. The resulting set of recommendations is expected to provide positive value outcomes for the customer, utility, and society. We expect to continue to explore how the post-retrofit performance compares to the cost-benefit picture laid out here.

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