FIREFLY: ENERGY EFFICIENCY BENEFITS FOR UK POWER NETWORKS

ENERGY EFFICIENCY POTENTIAL MODELLING

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UK Power Networks

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OVERVIEW AND APPROACH

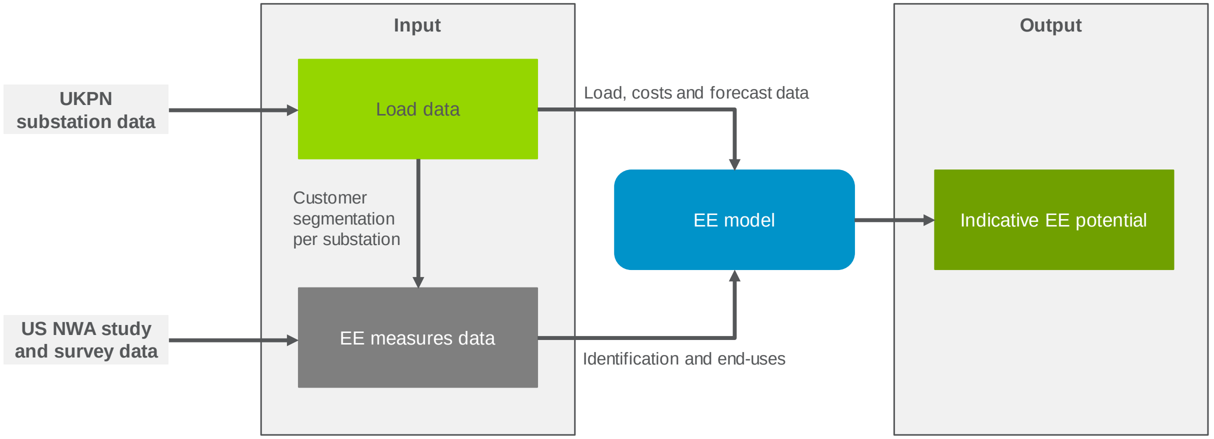
The goal of energy efficiency (EE) potential modelling is to provide a proof of concept to obtain a first indication of EE potential to defer substation investments. We have analysed reinforcement at 6 UKPN substations, using UKPN substation data and leveraging our extensive US experience with EE measures.

- Energy efficiency (EE) potential modelling provides:
  - Better understanding of customer loads at primary substations and applicable EE measures; and
  - Better understanding of the costs and benefits of deploying various EE measures for selected UKPN substations.
- In this document, we describe the methodology and assumptions used in the EE potential modelling and present the results for the 6 UKPN primary substations selected as case studies.
- This document should be considered alongside the Excel analysis tool developed for the Firefly project.

OVERVIEW AND APPROACH

The EE potential modelling approach consists of several steps to obtain an indication for the deferral potential of EE measures for selected substations.

- **First**, UKPN selected **substation case studies** giving a dataset of load profiles, planned substation investments, firm capacities and load forecasts to serve as inputs to the EE model.
- **Second**, we developed a set of **applicable EE measures** with respective hourly savings profiles, costs and adoption rates. The applicability of measures is related to the customer segmentation at each substation and leverages Navigant's extensive work and database of EE measures covering North American service areas. We used a dataset from a region of Washington state with very similar climate to UKPN's territory.
- **Finally**, the substation data, processed load profiles and data of applicable EE measures were fed into the **EE model** to assess the indicative potential for EE measures at each of the selected UKPN substations.



Overview steps for obtaining an indication for the potential of energy efficiency measures to defer investments for selected UKPN substations. (Source: Navigant)

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CASE STUDIES: SELECTED UKPN SUBSTATIONS

UKPN selected six primary substations in their service area as case studies for the assessment of EE potential to defer planned upgrades: Lithos Road, Nelson Street, Carnaby Street (all in LPN), Kenardington, Guildford (both in SPN) and West Horndon (EPN).

- For each of the substations, UKPN provided half-hourly substation load for 2018, together with winter and summer “firm” capacity values, yearly peak load forecast values and an indication of the customer segments following the Elexon profile classes[1].
- The following slides summarise the winter and summer load forecasts per substation and indicate the current peak load and the firm capacities of each substation.
- All substations, except for Lithos, are currently already at or over their 2018 winter firm capacities. In addition, all substations have planned upgrades over the next few years.

[1] https://www.elexon.co.uk/knowledgebase/profile-classes/

CASE STUDIES: SELECTED UKPN SUBSTATIONS

Winter and summer peak load forecasts for the selected UKPN substations.

Load Forecast (MW) - Winter												
	2018	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Lithos	56.1	56.5	57.1	58.0	59.2	60.5	62.1	63.9	65.9	68.1	70.5	73.0
Nelson	36.7	36.9	37.2	37.6	38.2	38.9	39.6	40.4	41.2	42.2	43.2	44.4
Carnaby	67.6	68.0	68.6	69.7	71.3	72.7	74.3	76.0	77.8	79.7	81.8	84.0
Kenardington	3.5	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.9	4.0	4.1	4.2
Guildford	23.0	23.0	23.0	23.1	23.2	23.2	23.3	23.4	23.5	23.7	23.8	24.0
West Horndon	5.7	5.7	5.7	5.7	5.7	5.7	5.8	5.8	5.9	6.0	6.0	6.1
Load Forecast (MW) - Summer												
	2018	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Lithos	40.2	40.54	40.9	41.4	42.3	43.3	44.4	45.7	47.1	48.7	50.4	52.1
Nelson	23.8	24	24.2	24.4	24.8	25.2	25.7	26.2	26.7	27.3	28	28.7
Carnaby	71.6	72	72.7	73.9	75.5	77.1	78.7	80.5	82.5	84.6	86.8	89.2
Kenardington	1.8	1.8	1.8	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1
Guildford	22.0	22.0	22.0	22.1	22.2	22.2	22.3	22.4	22.5	22.6	22.8	22.9
West Horndon	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.8	3.8

Data provided by UKPN.

CASE STUDIES: SELECTED UKPN SUBSTATIONS

Firm capacity versus 2018 peak load for the selected UKPN substations.

Substation	Firm capacity (MW) - Winter	Peak load 2018 (MW) - Winter
Lithos Road	56.7	56.1
Nelson Street	34.9	36.7
Carnaby Street	66.5	67.6
Kenardington	3.3	3.5
Guildford A	22.1	23.0
West Horndon	4.8	5.7
Substation	**Firm capacity (MW) - Summer**	**Peak load 2018 (MW) - Summer**
Lithos Road	42.3	40.2
Nelson Street	29.1	23.8
Carnaby Street	63.5	71.6
Kenardington	3.4	1.8
Guildford A	15.9	22
West Horndon	4.8	3.5

Data provided by UKPN.

CASE STUDIES: SELECTED UKPN SUBSTATIONS

Characteristics of planned substation upgrades for the selected UKPN substations.

Substation	Completion of upgrade	Cost of upgrade (£M)	Summer capacity increase (MW)	Winter capacity increase (MW)
Carnaby St	Q3 2024	29.4	57.5	58.3
Lithos Rd	Q3 2023	10	50.8	39.3
Nelson St	Q3 2023	8	35.5	49.1
Guildford A	Q3 2020	6.8	11.7	16.3
Kenardington	Q3 2022	2 *(estimated)*	3.7	4.1
West Horndon	Q3 2020	2.2	6.7	9.6

Data provided by UKPN.

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LOAD PROFILE ANALYSIS (TASK 1B)

In this project, we assume that residential and small industrial and commercial (I&C) customers at each selected UKPN substation can adopt EE measures to decrease and change their hourly electricity demand behaviour to ease peak loading at each substation.

- We analysed the hourly UKPN substation load data at each substation to understand the load profile and customer segmentation.
- The goal of the load profile analysis at each substation is to:
  1. Examine the (peak) load behaviour at each substation to identify the need for load savings at each substation (**substation peak loading analysis**); and
  2. Identify the share of annual substation load per customer type (**residential and small I&C customer segmentation**) that can adopt EE measures.
- The next slides detail the above steps.
- UKPN provided half-hourly load profiles for 2018 together with the distribution of customers per Elexon[1] profile class for the six selected substations. We disaggregated total substation load into customer segments in order to calculate the potential savings from EE measures. The following sections describe the methodology in more detail.

[1] https://www.elexon.co.uk/knowledgebase/profile-classes/

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LOAD PROFILE ANALYSIS (TASK 1B) – SUBSTATION PEAK LOADING ANALYSIS

1. Substation peak loading analysis - we examined the total hourly substation load through heat maps to identify the need for (peak) load savings in each hour, day, month and season.

- Heat maps help to visualise the peak periods when capacity savings are most needed based on hourly substation load, the substation load forecast, and a substation capacity threshold. This allows a sense-check of the substation loads to identify outliers and anomalies, and ensure that the EE measures would properly address all excess load in the season in which load reduction would be needed.
- Below is an example heat map illustrating the load above the substation capacity threshold for the worst days in the year 2026 for UKPN's Lithos Road substation. The shading indicates the need for savings in each hour for that day.

Excess Load on Peak Days for Lithos in 2026 (Without EE)

Consecutive Dates	Number of Hours → Dates with Excess ↓	Max Consecutive Hours with Peak	Hour Ending → Excess Load (MW) ↓	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	####	####	####	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	####	####	####
1	February 27	1																					1.9				
2	February 28	2																					0.6	1.6			
3	March 1	5													2.4	3.2	3.7	3.8	1.3				2.8	2.8			
4	March 2	3															0.3	0.2					5.4	4.3	0.8		
1	March 18	1																						0.1			
2	March 19	1																						1.3			
1	May 1	2																						0.2	1.4		
2	May 2	5												0.3	2.9	3.2	3.2	0.5				0.3	2.1	0.3			
1	September 24	1																					0.7				
1	September 30	1																					0.3				

Example of a heat map (Lithos Road, 2026) indicating the days in the hourly profile where load exceeds the capacity threshold for a certain number of hours as well as the capacity need in each of these hours. (Source: Navigant analysis)

LOAD PROFILE ANALYSIS (TASK 1B) – SUBSTATION PEAK LOADING ANALYSIS

1. Substation peak loading analysis - Heat maps help to visualise the peak periods when capacity savings are most needed for each substation.

The figure on the right shows a different heat map view, indicating the number of days in each month of 2026 exceeding the substation capacity threshold for the Lithos Road substation.

 # Days above Threshold by Month and Hour for Lithos in 2026 (Without EE)

Summer Firm Cap MW: 42.30 | Winter Firm Cap MW: 60.50 | Top: 29 Hours; >= 90.2% of Peak Load

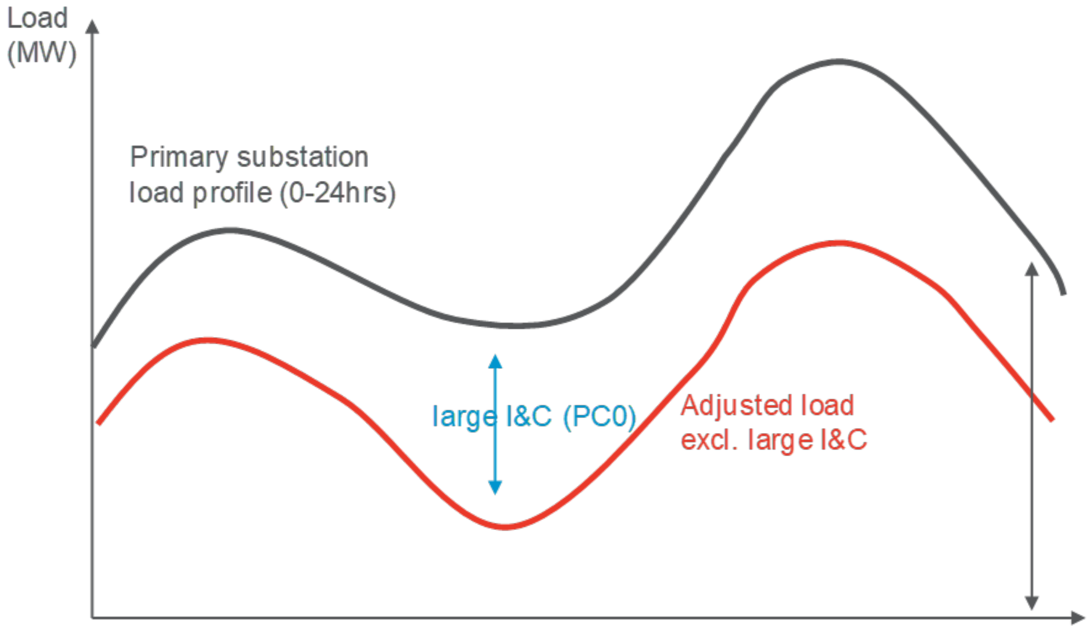
Hour Ending	January	February	March	April	May	June	July	August	September	October	November	December
1:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
2:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
3:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
4:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
5:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
6:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
7:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
8:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
9:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
10:00 AM	-	-	-	-	-	-	-	-	-	-	-	-
11:00 AM	-	-	-	-	1	-	-	-	-	-	-	-
12:00 PM	-	-	1	-	1	-	-	-	-	-	-	-
1:00 PM	-	-	1	-	1	-	-	-	-	-	-	-
2:00 PM	-	-	2	-	1	-	-	-	-	-	-	-
3:00 PM	-	-	2	-	1	-	-	-	-	-	-	-
4:00 PM	-	-	1	-	-	-	-	-	-	-	-	-
5:00 PM	-	-	-	-	-	-	-	-	-	-	-	-
6:00 PM	-	-	-	-	-	-	-	-	-	-	-	-
7:00 PM	-	-	-	-	1	-	-	-	-	-	-	-
8:00 PM	-	2	2	-	1	-	-	-	2	-	-	-
9:00 PM	-	1	4	-	2	-	-	-	-	-	-	-
10:00 PM	-	-	1	-	1	-	-	-	-	-	-	-
11:00 PM	-	-	-	-	-	-	-	-	-	-	-	-
12:00 AM	-	-	-	-	-	-	-	-	-	-	-	-

Illustrative example of the number of days in each month the hourly load exceeds the threshold (Source: Navigant analysis)

LOAD PROFILE ANALYSIS (TASK 1B) – CUSTOMER SEGMENTATION

2. Customer segmentation - To analyse the savings potential of specific EE measures, we must disaggregate annual substation demand into residential and small I&C customer segments. This disaggregation is achieved through customer segmentation of the substation half-hourly load.

- **The first step** in the customer segmentation process involves separating large I&C load from the total substation load, using the large I&C half-hourly substation profiles (kWh/HH) (Profile Class 0 – C&E measurement classes only) provided by UKPN. This is done because the EE measures in our model are assumed not to be applicable to large I&C customers. The residual hourly substation load profile for 2018 then represents the customer segments considered for EE measure adoption and can be used to identify the annual load share per customer segment (residential and small I&C) per substation as input to the EE potential model.



Illustrative example of separating total customer load (source: Navigant)

LOAD PROFILE ANALYSIS (TASK 1B) – CUSTOMER SEGMENTATION

2. Customer segmentation - To analyse the savings potential of specific EE measures, we must disaggregate annual substation demand into residential and small I&C customer segments. This disaggregation is achieved through customer segmentation of the substation half-hourly load.

- **The second step** in the customer segmentation process involves identifying the share of annual adjusted substation load per residential and small I&C profile class (% and MWh/year). We allocated the annual adjusted substation load to the different classes of end-consumers using the average annual load per Elexon profile class. The number of customers per profile class per UKPN substation, as provided by UKPN, are used as weights for the allocation.

The customer segmentation results in an annual demand (MWh/yr) per customer segment considered for the adoption of EE measures (residential and small I&C) per substation. This annual demand disaggregation per customer segment is then used to scale the EE savings per customer segment, using Navigant's database of EE measure characteristics with savings values calibrated to the UK climate (as explained in the next section).

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ENERGY EFFICIENCY MEASURES (TASK 1A) – EE MEASURES

This project leverages our extensive North American database of EE measures and their characteristics to develop a first indication of the potential for EE measures to defer UKPN's network investments at the six selected substations.

- Navigant has conducted extensive research on "non-wires alternatives" (NWA) in North America through detailed site surveys and other activities to identify energy efficiency (EE) measures and quantify their potential. This research has resulted in a long-list of EE measures applicable to different service areas and customer segments, their cost and potential, as well as their hourly savings shapes and deployment rates. This UKPN EE project leverages our extensive North American database of EE measures and their characteristics to develop a first indication of the potential for EE measures to defer UKPN's network investments at the six selected substations.
- From this North American database of EE measures, we identified a representative set of measures to feed into the EE potential model for the selected UKPN substations. Only EE measures applicable to residential and small I&C customers are considered (i.e. not large I&C customers). The long-list of residential and small I&C EE measures covers various end-uses as summarised on the next slide.

ENERGY EFFICIENCY MEASURES (TASK 1A) – END-USES OF EE MEASURES

Long-list of end-uses of residential and small I&C EE measures considered in the EE potential model.

	End-use	Description
	Electronics and Office Equipment	Efficient electronic devices, such as servers and televisions
	Space Cooling	Cooling generation units and appliances, such as air-cooled chillers
	Non-Res Refrigeration	Non-residential refrigeration units
	Whole Building/House	Energy management systems, process optimisation
	Lighting*	Efficient lighting, such as LED and occupancy sensors
	Appliances	Energy efficient appliances, such as clothes dryers and washing machines
	Space Heating and Cooling	Measures that reduce space heating and cooling requirements of buildings, such as insulation, air sealing and smart and controllable thermostats
	Non-Res Cooking	Non-residential cooking units, for example electrical cooking units and ovens and efficient commercial dish washers
	Hot Water	Efficient measures for hot water provision, e.g. low-flow shower heads or solar hot water
	Fans, Blowers, Motors, Drives and Pumps	System optimisation
	Compressed Air	Efficient compressed air generation
	Space Heating	Heating generation units and appliances, such as heat pumps

*Due to the significant adoption of efficient lighting in the UK, lighting measures were only included as a sensitivity (see Appendix B)

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ENERGY EFFICIENCY MEASURES (TASK 1A) – APPLICATION TO UKPN AREA

To identify applicable measures for the UKPN service areas, we used a database of results from a similar climatic area in North America and scaled these results to the applicable customer base at each of the six selected substations.

The EE measure selection process for the UKPN substations consists of the following steps:

- **Step 1: Matching EE measures based on weather data**. For a given service area, only a selected list of EE measures is applicable based on the substation load profile and the peaking behaviour of the local customers. This peaking behaviour is highly dependent on the local climate and resulting heating and cooling needs of buildings. The first step in determining applicable measures for each of the six selected UKPN substation involves selecting measures applicable to the service area of UKPN based on matching climate data with a North American area. The selected list of EE measures for this area is then used for assessment of the UKPN service area.
- **Step 2: Scaling measures to applicable customer base** at each of the six selected substation. The savings potential of each EE measure depends on the customer segmentation (share of residential, small I&C customers) at each of the six selected UKPN substations. The selected measures from Step 1 are therefore tailored in Step 2 to each individual UKPN substation based on a scaling of the savings potential with the customer segmentation at each substation.

The next slides detail each step.

ENERGY EFFICIENCY MEASURES (TASK 1A) – APPLICATION TO UKPN AREA

Step 1: Matching EE measures based on weather data - To select applicable EE measures for the UKPN service area, we matched the climate in London with a similar weather region in North America based on the Heating (HDD) and Cooling Degree Day (CDD) method.[1]

Heating and cooling degree days are determined based on the difference between the outside air temperature and a comfortable indoor baseline temperature level. This determines the extent to which a building requires heating or cooling, respectively, to keep the indoor building temperature to a comfortable baseline level.

Using this Degree Day comparison, we found that the climate in UKPN's service territory is very similar to that in the north-western region of Washington state in the US. We therefore used a Navigant database of EE measure characteristics from that region to select 139 unique EE measures for our analysis of the six selected UKPN substations.

The long list of selected EE measures and their descriptions is presented in Appendix A.

[1] European Environment Agency, 2019. Heating and cooling degree days. https://www.eea.europa.eu/data-and-maps/indicators/heating-degree-days-2/assessment

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ENERGY EFFICIENCY MEASURES (TASK 1A) – APPLICATION TO UKPN AREA

Step 2: Scaling measures to applicable customer base - After selecting applicable measures through a climatic match, we scaled the savings potential of each measure according to the customer base at each UKPN substation.

The savings potential of EE measures depends greatly on the mix of customers at each substation, as individual measures are only applicable to a particular customer segment (residential or small I&C). To select applicable high-impact EE measures for each UKPN substation:

- First, we performed a substation load analysis to identify whether the substation is winter-peaking, summer-peaking, or both, and to analyse the customer segmentation at each substation.
- Secondly, we applied energy savings percentages for applicable EE measures to the six selected UKPN substation loads based on the customer segmentation at each substation.

These savings percentages come from Navigant's extensive database of sector energy savings [kWh] (residential, small I&C) per measure per year, developed through our work in north-west Washington state.

For example, if a UKPN substation predominately serves small commercial customers, the model will use commercial measures scaled appropriately to the share of commercial load on the substation. In addition, supposing for example that insulation saves 5% of residential energy consumption in north-west Washington state, this will result in 50 MWh/year energy savings from insulation at a UKPN substation if its residential load is 1000 MWh per year.

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ENERGY EFFICIENCY MEASURES (TASK 1A) – APPLICATION TO UKPN AREA

Step 2: Scaling measures to applicable customer base - This matching and scaling of the UKPN service area to a highly similar North American area is a pragmatic simplification. The model is still able to serve as a proof-of-concept for using EE measures to defer network reinforcement for UKPN.

This matching and scaling approach of the UKPN service area to a highly similar North American area is a pragmatic simplification as it does not require extensive UK customer or building stock data and it does not require a mature energy efficiency evaluation ecosystem for measure characterisation in the UK. The model is still able to serve as a proof-of-concept for using EE measures to defer network reinforcement for UKPN.

A drawback of this methodology is that some measures may not be directly applicable to the UK context. There is less certainty on the implementation details, such as adoption rates and deployment costs of measures in the UK.

Note that a "kW" of savings is defined based on the single peak hour at each substation. The capacity reduction (MW) of EE measures is subsequently applied following an hourly savings profile based on the specific hourly load shape at each substation interacting with the EE savings shape for each applicable measure per customer type. This approach is adopted to ensure the adopted EE measures are not just "pushing the peak" to a new hour but are applying the hourly savings profiles of all measures across the hourly substation load.

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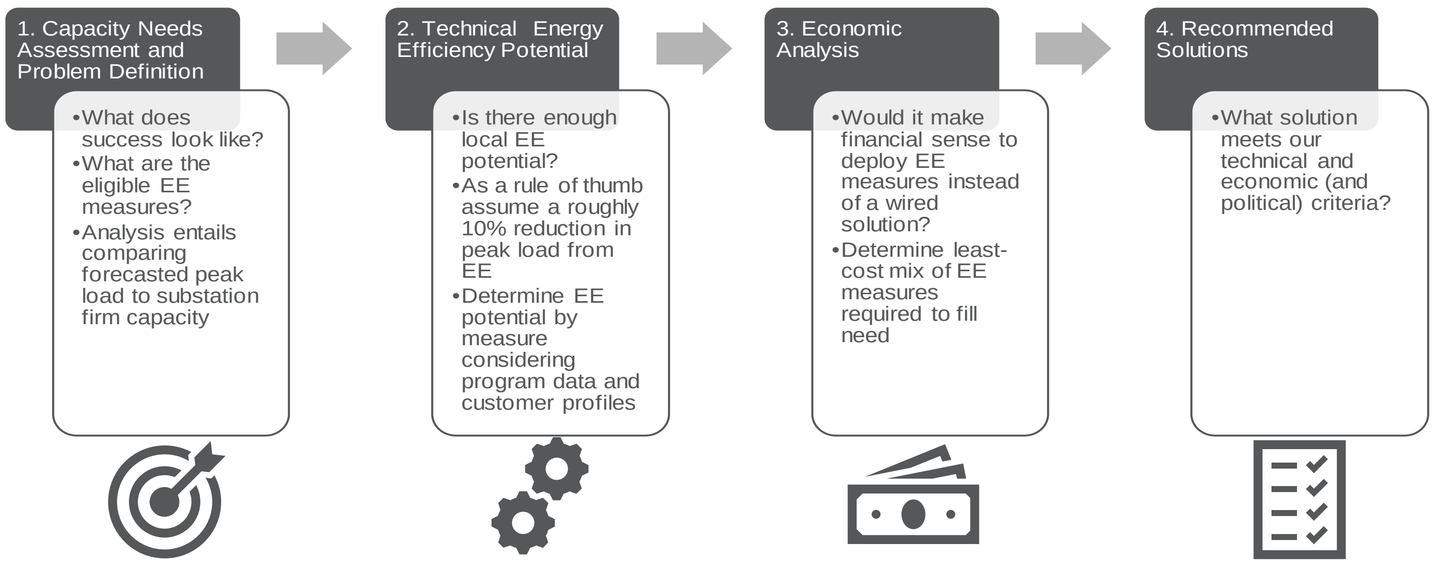
ENERGY EFFICIENCY POTENTIAL MODEL

The optimal portfolio of energy efficiency measures is determined by understanding the capacity need for each substation and the potential for measures to fill that local need. The model follows 4 steps to assess the EE potential for a substation.

- **Step 1:** locational capacity needs assessment and problem definition. This includes determining the definition of "success";
- **Step 2:** achievable technical EE potential analysis for each substation based on the deployment of all technically suited EE measures to reduce peak load;
- **Step 3:** economic EE potential analysis for each substation based on the deployment of the most cost-effective of the technically suited EE measures to reduce the peak load (technical potential > economic potential);
- **Step 4:** cost-benefit analysis to recommend a suitable solution for each substation.



ENERGY EFFICIENCY POTENTIAL MODEL – STEP 1

Step 1: locational capacity needs assessment and problem definition.

The assessment of locational capacity needs at a substation requires the following data;

- at least one year of hourly substation customer load (substation load profile),
- an accompanying forecast of annual (and hourly) load at the substation,
- the development of substation firm capacity over time, and
- characteristics of any planned substation upgrades (firm capacity additions, costs and timing).

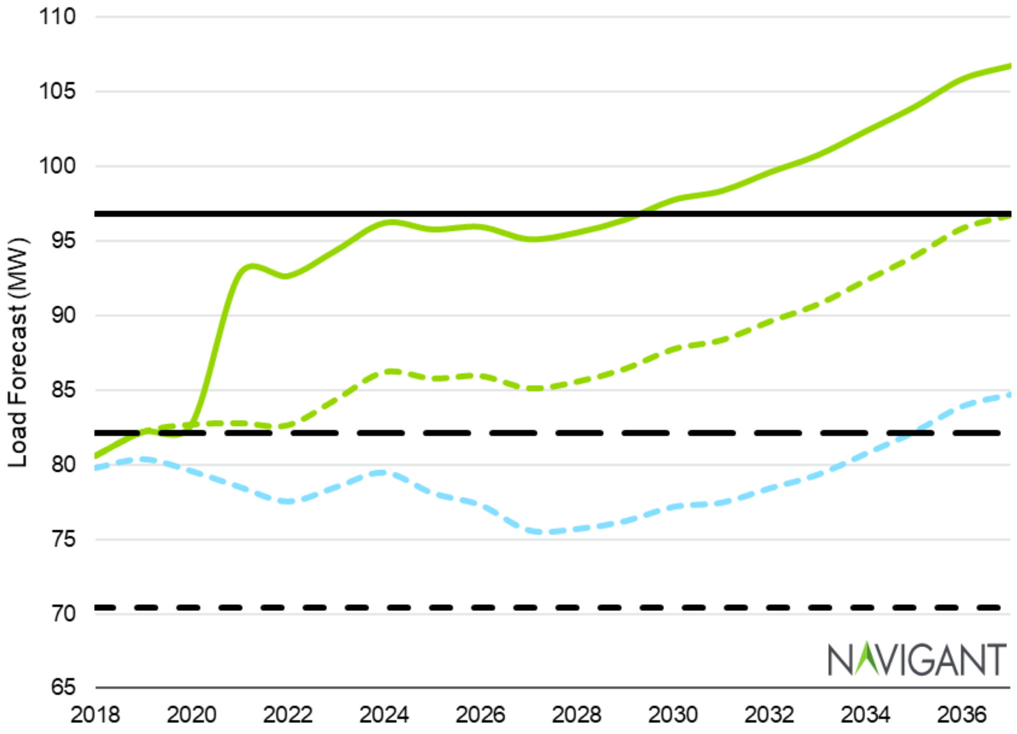
Load forecasting to assess the EE potential at a substation requires a focus on peak demand (MW) rather than yearly energy (MWh). Forecasters must also consider the (hourly) shape of the substation load profile when formulating a peak capacity forecast to, for example, capture seasonal shifts in local peak load or asymmetric load additions.

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 1

Step 1: locational capacity needs assessment and problem definition.

We assessed the local capacity needs at each substation on two levels.

- **First,** we compare the **yearly** substation peak load to the substation capacity threshold to understand the overall capacity need. The figure on the right illustrates this comparison. Note that the capacity need is expected to increase over time, due to a constant substation capacity threshold but growing load on the substation.



Illustrative example of load growth with (blue dotted (best case/green dashed) and without (green full) EE measures vs capacity thresholds for various situations, e.g. with reinforcement N-0 (black full line) and without reinforcement N-1 (bottom black dashed line). Source: Navigant Analysis

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 1

Step 1: locational capacity needs assessment and problem definition.

- **Second**, the comparison between the forecasted peak load and the substation capacity threshold on an **hourly basis** helps to understand the timing and size of the capacity need along with what would be reasonably achieved by EE measures. This hourly comparison provides more insight through visualising the substation peak periods in heatmaps (see section 3). The heatmap method helps planners to develop an intuitive sense for the peak load and the eligibility and contribution of certain EE measures to impact that hourly peak load. It provides an understanding of the local substation peak period which allows calculation of the coincidence of hourly savings profiles of EE measures with hourly local capacity needs.
- A heat map can also analyse the number of days in each month that the hourly substation load exceeds the substation capacity threshold. This analysis allows to identify the local substation peak period. Depending on the peak period (summer/winter, day/evening) certain EE measures will be better suited to bring the peak below the capacity threshold.

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 1

Step 1: locational capacity needs assessment and problem definition.

UKPN provided an hourly load profile per substation for one year (2018), as well as the development of forecasted peak load for both winter and summer. The EE potential model requires, however, not only the 2018 hourly load profile for each substation but also the hourly load profile for future years (forecasted hourly load profiles). Hence, we made some assumptions to align the hourly and peak load values provided by UKPN.

- As all selected substations are already exceeding (or close to exceeding) their winter firm capacity, the winter peak load forecast serves as basis for the development of the forecasted hourly load profiles. The EE potential analysis requires not only a peak load forecast but also an hourly load profile forecast. The 2018 hourly load profiles are therefore scaled with the annual winter peak forecast for each substation respectively.
- This scaling results in respective future summer peak loads (that might differ from the forecast provided by UKPN) aligned with the hourly load profiles and growing at the same rate as the winter peak load forecasts. These calculated summer peak load values are therefore used throughout the model instead of the summer peak forecasts provided by UKPN.
- This approach does not affect the results of the analysis given that most of the analysed substations are already at capacity (especially in winter) but still operational, implying a capacity threshold equal to the peak load in the year of planned substation upgrade.

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ENERGY EFFICIENCY POTENTIAL MODEL – STEP 1

“Definition of success”.

In determining the local capacity needs, it is important to set the “definition of success”. This includes a decision on the minimum deferral time (years) of substation investments through the deployment of EE measures. In addition, the outcomes of the model also depend on the definition of substation capacity threshold as this will affect the deferral timeline significantly.

- The maximal peak that the substation can accommodate before substation reinforcement is required (or EE deployment needs to be established) is the **capacity threshold** of the substation. The firm capacity of the selected UKPN substations serves as a first indication of these capacity thresholds. However, as highlighted in the case study data, all substations except for Lithos, are currently already at or over their 2018 winter firm capacities. In addition, all substations have planned upgrades over the next few years. Therefore, the Winter Load Forecast in the upgrade year is taken to be the capacity threshold for assessing deferral opportunities from energy efficiency.
- Based on the above capacity thresholds for the selected UKPN substations, success means deferring the year of the planned upgrade by at least a couple of years.

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 2

Step 2: achievable technical EE potential - mobilising EE measures to keep the peak load forecast below the capacity threshold.

The substation capacity needs identified in Step 1 are used to determine the achievable technical potential for EE measures. This potential includes all EE measures that are suited in terms of their savings shape, regardless of the cost of their deployment. This technical potential shows whether enough EE potential can be mobilised by the target year (year of planned deferral) to reduce the peak load below the threshold.

We estimate the technical EE potential by calculating the hourly achievable potential for various EE measures over time (specific to the peak period), which is then compared to the hourly need. The technical potential at a substation is determined for each EE measure by considering the EE program data and hourly savings shapes of each measure, the substation customer segmentation and the hourly substation load profiles.

The charts on the next slide illustrates one such comparison between the technical achievable potential of an EE measure in the target year and the yearly capacity need as determined in Step 1.

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 2

Step 2: achievable technical EE potential - Hourly capacity savings are a function of the coincidence of the EE measure savings shapes with local capacity peaks at the substation.

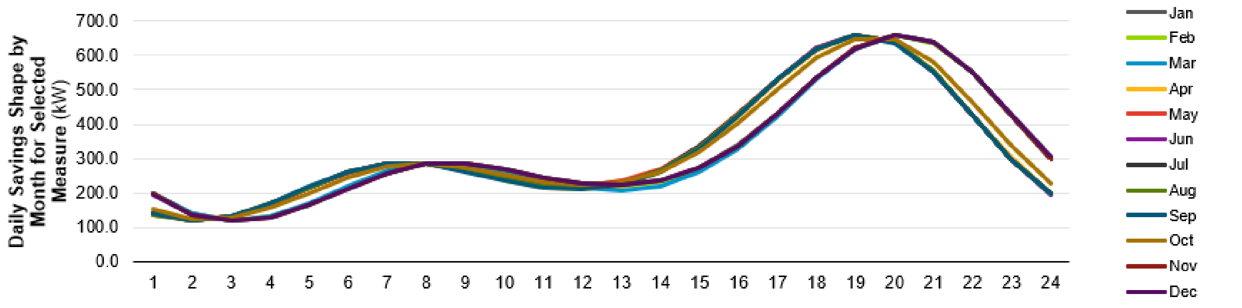
Max Load (MW) above Threshold by Month and Hour for Lithos in 2026 (Without EE)

Summer Firm Cap MW: 42.30 | Winter Firm Cap MW: 60.50 | Top: 29 Hours; >= 90.2% of Peak Load

Hour Ending	January	February	March	April	May	June	July	August	September	October
1:00 AM	-	-	-	-	-	-	-	-	-	-
2:00 AM	-	-	-	-	-	-	-	-	-	-
3:00 AM	-	-	-	-	-	-	-	-	-	-
4:00 AM	-	-	-	-	-	-	-	-	-	-
5:00 AM	-	-	-	-	-	-	-	-	-	-
6:00 AM	-	-	-	-	-	-	-	-	-	-
7:00 AM	-	-	-	-	-	-	-	-	-	-
8:00 AM	-	-	-	-	-	-	-	-	-	-
9:00 AM	-	-	-	-	-	-	-	-	-	-
10:00 AM	-	-	-	-	-	-	-	-	-	-
11:00 AM	-	-	-	-	0.28	-	-	-	-	-
12:00 PM	-	-	2.36	-	2.86	-	-	-	-	-
1:00 PM	-	-	3.23	-	3.25	-	-	-	-	
2:00 PM	-	-	3.75	-	3.20	-	-	-	-	
3:00 PM	-	-	3.76	-	0.51	-	-	-	-	
4:00 PM	-	-	1.27	-	-	-	-	-	-	
5:00 PM	-	-	-	-	-	-	-	-	-	
6:00 PM	-	-	-	-	-	-	-	-	-	
7:00 PM	-	-	-	-	0.26	-	-	-	-	
8:00 PM	-	1.92	5.40	-	2.07	-	-	-	0.66	
9:00 PM	-	1.59	4.31	-	0.30	-	-	-	-	
10:00 PM	-	-	0.79	-	1.42	-	-	-	-	
11:00 PM	-	-	-	-	-	-	-	-	-	
12:00 AM	-	-	-	-	-	-	-	-	-	

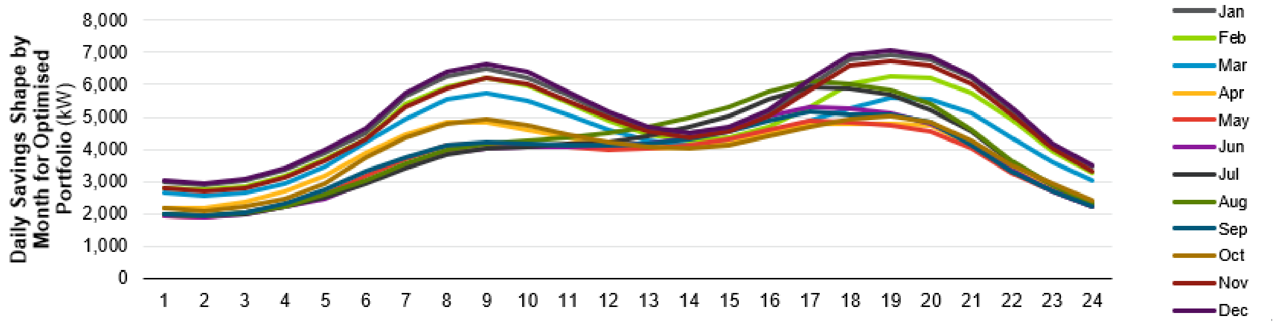
Savings Shape of Selected Measure in Target Year

Selected Measure:	Res | LED (General Service Lamps) | ROB
Day Type:	Weekday
Measure End Use:	Lighting
Included in Optimised Portfolio:	TRUE



Savings Shape of Optimised Portfolio in Target Year

Day Type:	Weekday



Illustrative example of heat map analysis and hourly profiles of EE measures. Source: Navigant Analysis

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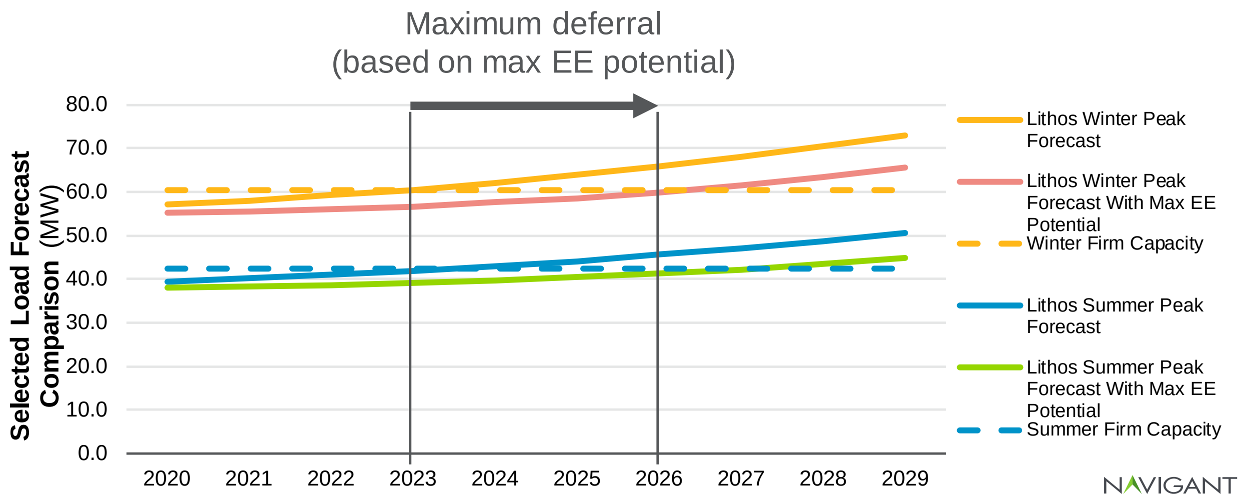
ENERGY EFFICIENCY POTENTIAL MODEL – STEP 2

Step 2: achievable technical EE potential

We estimate the maximum technical EE potential in each year in order to produce a chart per substation such as the figure on the right.

As a rough rule of thumb, technical achievable EE potential can typically achieve a reduction of roughly 10% of the peak load. This figure comes from Navigant's extensive experience with EE potential assessment in North America.



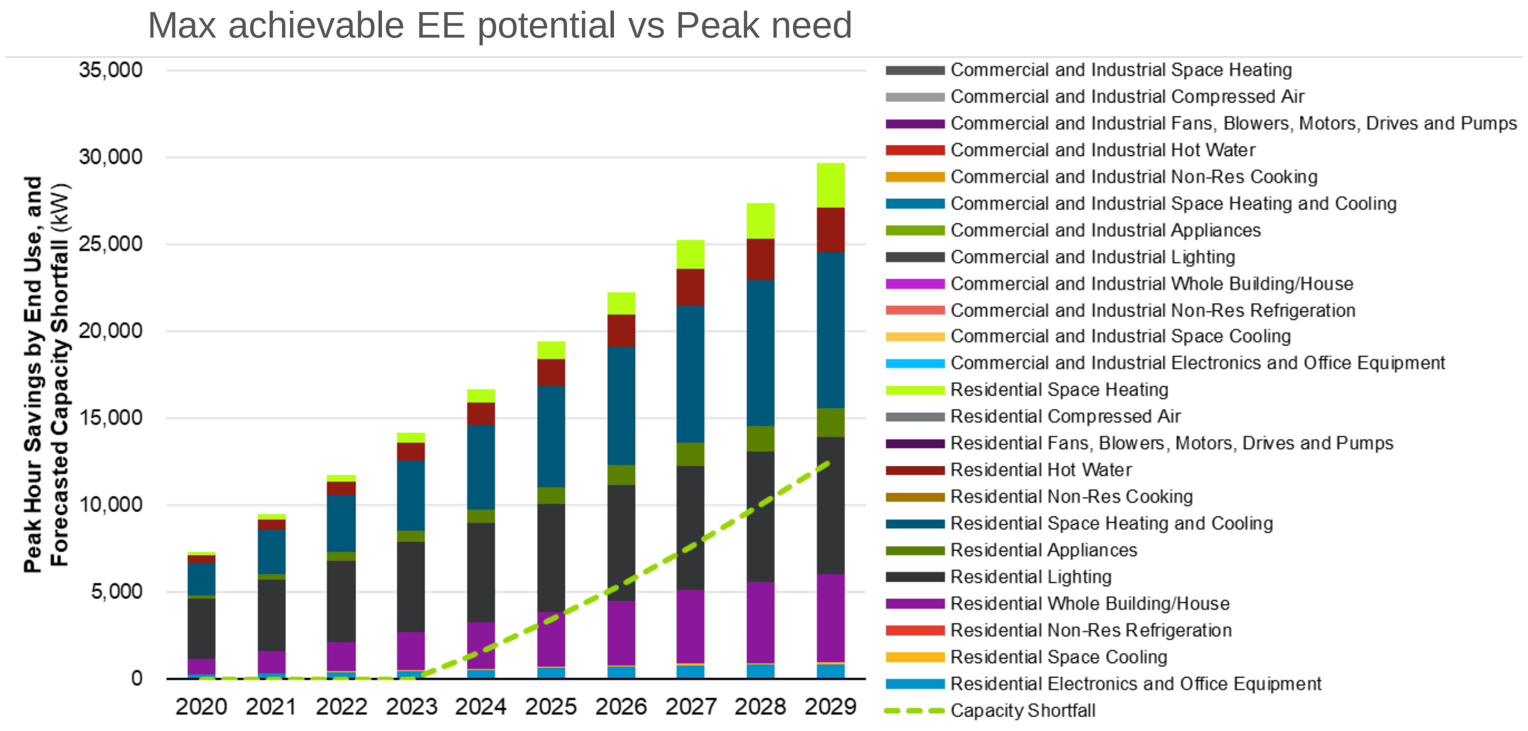
Illustrative example of max achievable technical potential of EE measures to reduce yearly peak demand below the substation capacity threshold. (Source: Navigant analysis)

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 2

Step 2: achievable technical EE potential - We can represent the need as a "capacity shortfall" and show how the achievable technical potential of EE measures can alleviate that shortfall.

The capacity need from Step 1 is matched with maximally achievable technical potential of the considered EE measures.

Note that each type of EE measure has a different adoption and uptake rate, resulting in a growing potential of each EE measures over time until saturation of this measure occurs in the local customer base as more and more customers adopt the measures. In addition, the local uptake of each EE measure shows a different growth rate depending on its ease of implementation, customer engagement and cost of the measure. Adoption and uptake processes and rates for each measure are based on Navigant's extensive North American database.



Illustrative example of max achievable technical EE potential by year and EE measure vs capacity need at a substation (capacity shortfall). Source: Navigant Analysis

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 3

Step 3: economic EE potential

After determining the achievable technical EE potential at each substation, the next step seeks to optimise this potential to a least-cost portfolio of EE measures in terms of peak demand savings to fill the capacity need at each substation.

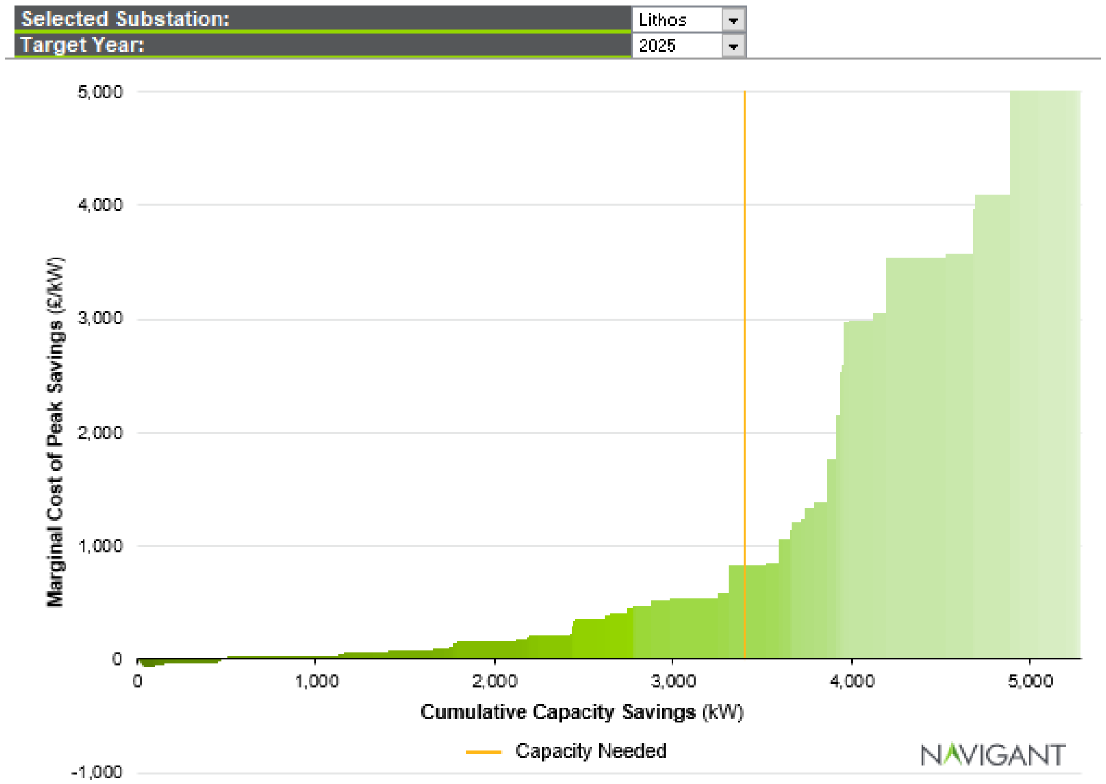
The savings potential of each EE measure (from hourly load analysis) is combined with the cost of the deployment of this measure to form a supply curve of EE measures per year per substation, as illustrated in the next slide. A supply curve (or merit order) of EE measures ranks the measures based on ascending costs to ensure that the cheapest measures are deployed first in meeting the capacity need. The cost of each measure is determined by its levelised cost of capacity.

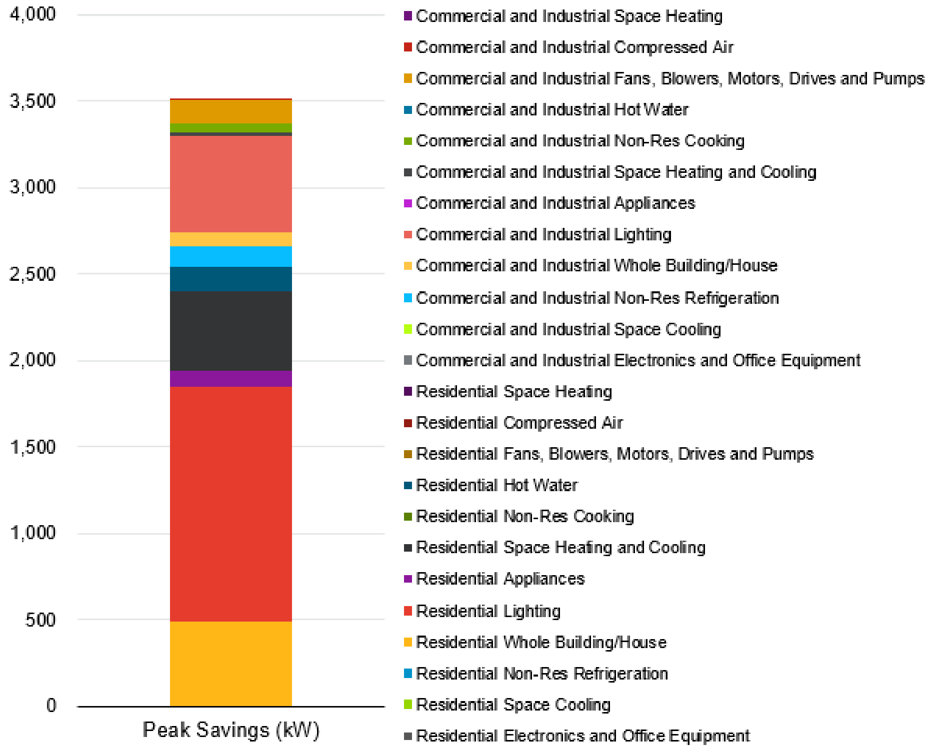
Note that the order and potential of the individual measures changes year by year as deployment and uptake rates of measures differ; some measures may take longer to break through but could be taken up more quickly than others.

The cost-optimised EE portfolio will be smaller than the achievable technical EE potential, given the latter could include measures that are not cost-effective to deploy in certain years.

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 3

Step 3: economic EE potential - By ordering the measures from least to highest cost, we determine an optimal portfolio of EE measures that meets the capacity need.





Illustrative example of a supply curve (or merit order) of EE measures for one year for a substation plotted against the capacity need in that year (left, Lithos Road, 2024) and the portfolio of measures that meets the need (right) (Source: Navigant analysis)

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ENERGY EFFICIENCY POTENTIAL MODEL – STEP 3

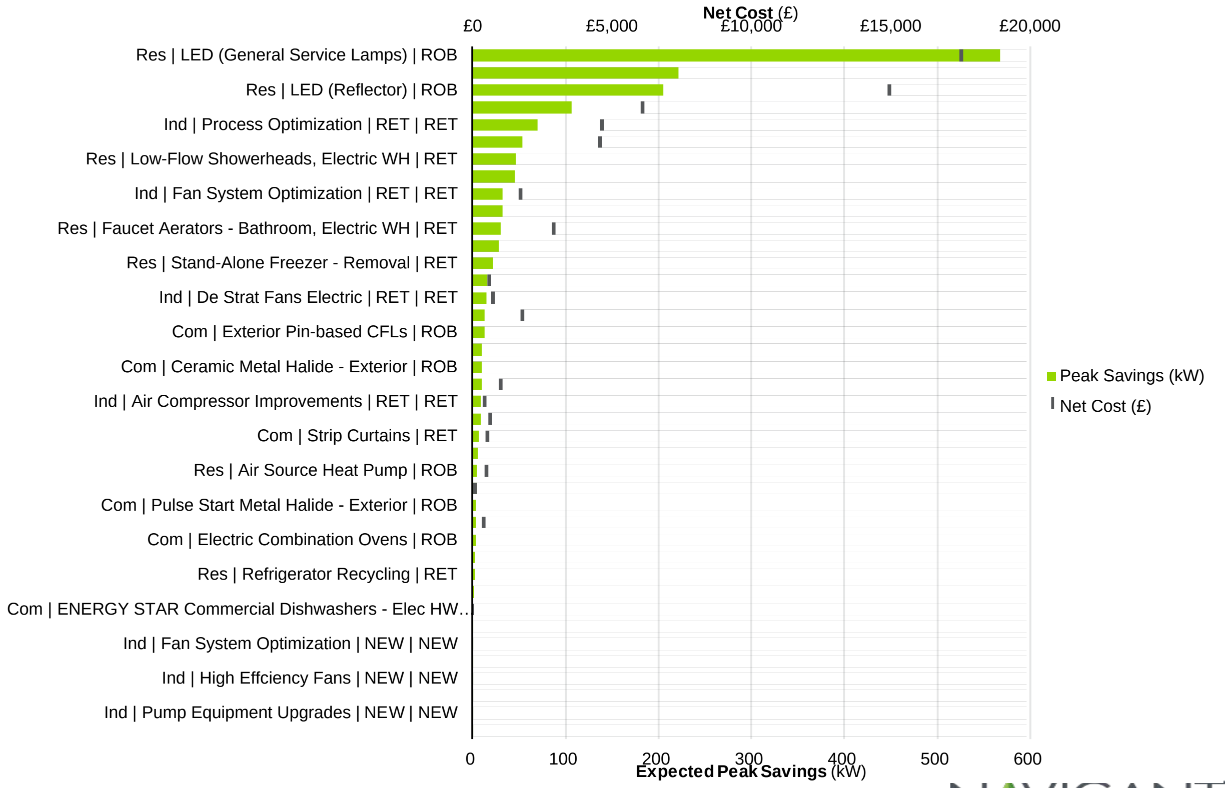
Step 3: economic EE potential - The measures comprising an optimal portfolio can be ranked by cost or peak savings.

Top EE Measures ranked by cost (increasing)

Top 40 Cost Effective Measures and Cumulative Savings in Target Year

Rank	Measure	End Use	Cumulative Savings (kW)
1	Com | Exterior LED Area and Wall Lights | ROB	Lighting	32
2	Ind | Centrifugal Fan | NEW | NEW	Fans, Blowers, Motors, Drives and Pumps	32
3	Ind | Centrifugal Fan | RET | RET	Fans, Blowers, Motors, Drives and Pumps	77
4	Com | Screw-In LED - Interior | ROB	Lighting	83
5	Res | Refrigerator Recycling | RET	Appliances	86
6	Res | Stand-Alone Freezer - Removal | RET	Appliances	108
7	Com | LED Fixture - Interior | ROB	Lighting	136
8	Com | Electric Pressureless Steamer | ROB	Non-Res Cooking	139
9	Res | Low-Flow Showerheads, Electric WH | RET	Hot Water	185
10	Res | LED (Specialty, Non-Reflector) | ROB	Lighting	406
11	Com | Ceramic Metal Halide - Exterior | ROB	Lighting	416
12	Com | Pulse Start Metal Halide - Exterior | ROB	Lighting	420
13	Ind | Ultra High Efficiency Motors | NEW | NEW	Fans, Blowers, Motors, Drives and Pumps	420
14	Ind | Ultra High Efficiency Motors | RET | RET	Fans, Blowers, Motors, Drives and Pumps	420
15	Com | Exterior Pin-based CFLs | ROB	Lighting	432
16	Com | Electric Combination Ovens | ROB	Non-Res Cooking	436
17	Res | Water Heater Temperature Setback, Electric WH, RET | RET	Hot Water	446
18	Res | Water Heater Temperature Setback, Electric WH, NEW | NEW	Hot Water	448
19	Res | LED (General Service Lamps) | ROB	Lighting	1,016
20	Ind | Effcient Conveyor Belts | NEW | NEW	Fans, Blowers, Motors, Drives and Pumps	1,016

Top EE Measures ranked by peak savings (decreasing)



Illustrative example of top EE measures from a cost (left) and peak savings (right) perspective. Source: Navigant analysis. Example shown: Lithos 2024

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 4

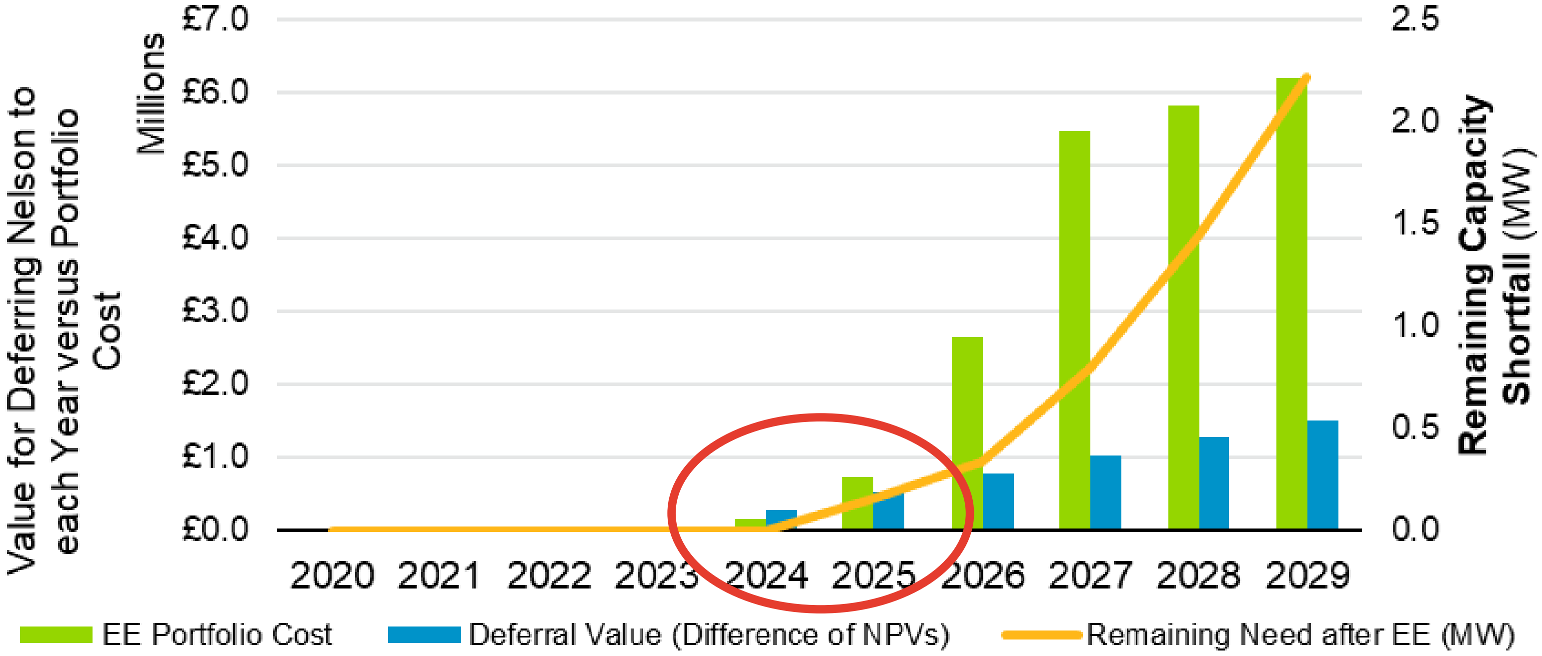
Step 4: cost-benefit analysis for deferral of substation upgrade

After determining the cost-optimised EE portfolio, we conduct a cost-benefit analysis (CBA). The purpose of the CBA is to assess the deferral potential for each substation, by comparing the yearly cost of the optimised EE portfolio required to meet the capacity need versus the NPV benefit of deferring the substation upgrade. The CBA checks whether it would make financial sense to start deploying a portfolio of EE measures today in order to postpone the cost of a traditional "wired" solution.

- We calculate the benefit of deferring the substation upgrade as a difference of net present values (NPV). Comparing the upgrade cost in the planned upgrade year versus the upgrade cost in a later year, there is a "time value of money" benefit which can be expressed in NPV terms.
- There is potential in using EE to defer the substation upgrade if two conditions are met in a year after the planned upgrade year:
    1. There is enough technical EE potential to meet the capacity shortfall; and
    2. The cost of the EE portfolio needed to meet the capacity shortfall is less than the benefit of deferring the substation upgrade.
- This logic is illustrated on the next slide.

ENERGY EFFICIENCY POTENTIAL MODEL – STEP 4

Step 4: cost-benefit analysis for deferral of substation upgrade - Upgrade can be deferred if (1) there is enough technical EE potential to meet the capacity shortfall, and (2) the EE portfolio cost (green bar) is less than the deferral benefit of the substation upgrade (blue bar).



Example CBA for Nelson. The traditional substation upgrade can be deferred from the planned year (2023) to 2024. However, it cannot be deferred to 2025 as neither condition is met: there is not enough technical EE potential and the EE portfolio would be more expensive. (Source: Navigant analysis)

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ENERGY EFFICIENCY POTENTIAL MODEL – KEY ASSUMPTIONS (I)

The key assumptions in the methodology are summarised below.

- Six primary substations as selected by UKPN are modelled with their respective load and cost data.
- EE potential is modelled on a standalone basis without consideration for other DER (e.g. storage).
- The capacity threshold for each substation is assumed to be the load forecast in the scheduled year of upgrade, because most of the selected substations are already loaded at their firm capacity.
- The analysis uses historic hourly loads and the load forecast, both provided by UKPN, to project future hourly energy saving needs.
- EE savings potential is only modelled for residential and small I&C customer segments. The database of EE measures in our model is assumed not to be applicable to large I&C customers (i.e. Profile Class 0), which typically require bespoke, custom measures.
- Substation load is disaggregated into different customer segments using average annual load per Elexon profile class.

ENERGY EFFICIENCY POTENTIAL MODEL – KEY ASSUMPTIONS (II)

The key assumptions in the methodology are summarised below.

- The database of EE measures for the analysis is selected based on climate-matching between London and Washington state, US. This is a pragmatic simplification as it does not require extensive UK customer or building stock data and it does not require a mature energy efficiency evaluation ecosystem for measure characterisation in the UK.
- The savings potential of each EE measure is scaled according to the customer base at each UKPN substation. Scaling is adjusted for the customer classes (e.g. residential, commercial) specific to each substation.
- Lighting measures are excluded from the modelling because UKPN's load forecasts already assume a high degree of lighting efficiency (see UKPN notes below). Results for a sensitivity with lighting measures are presented in Appendix B.

Domestic sector:
We indeed assume only very marginal increase in domestic lighting efficiency in future years. There has been a significant decrease in demand from lighting over the last ten years (we assumed about 25% demand reduction in lighting due to efficiency increase in those scenarios). The savings potential has almost fully been realised by 2019, and we only assume a further reduction by 2% until 2022 (no further efficiency increase post 2022).
Note however, that we further assume an increase in stock (number of lighting applications per household). For this reason, there is actually an increase in domestic lighting energy consumption per household from 2023 onwards. By the year 2045, we predict that the same energy intensity (electricity demand for lighting per household) of 2013 will be reached again.

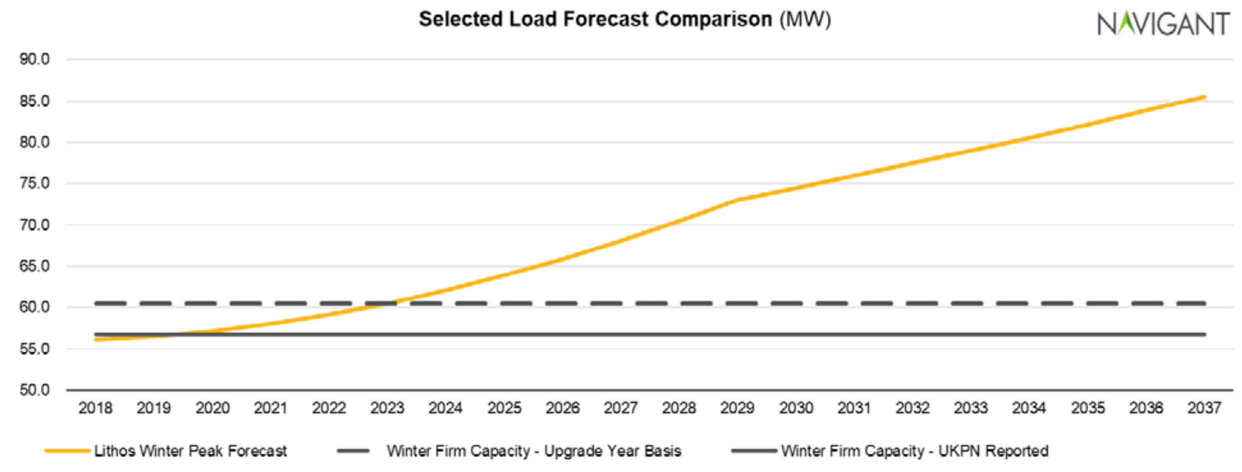
Industrial & Commercial sector:
We considered a range of efficiency measures, e.g. the use of timers for lighting applications, motion detectors, change to more efficiency lighting technology, etc. therefore it is more difficult for us to extract exactly what proportion of the observed efficiency savings is due solely to the switch to LEDs. The total potential energy efficiency saving from lighting remains higher in the I&C sector (see graph below), but as outlined above, that is from a combination of lighting efficiency measures.

CONTENTS

SUMMARY – STEP 1

Step 1: capacity needs and definition of success for UKPN substations.

- All substations (except Lithos) are already operating at or above Winter firm capacity. All substations have planned upgrades within the next few years, and can operate above Winter firm capacity in the intervening period. Therefore we take the Winter Load Forecast in the upgrade year for each substation and use that as the capacity threshold for assessing deferral opportunities from EE for each substation.

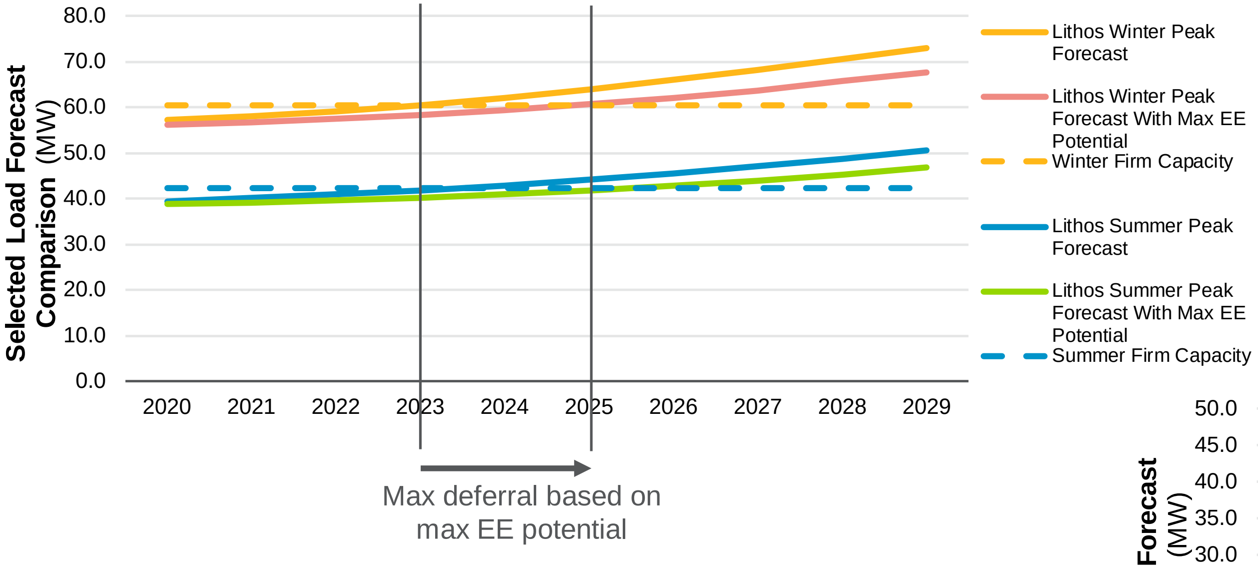


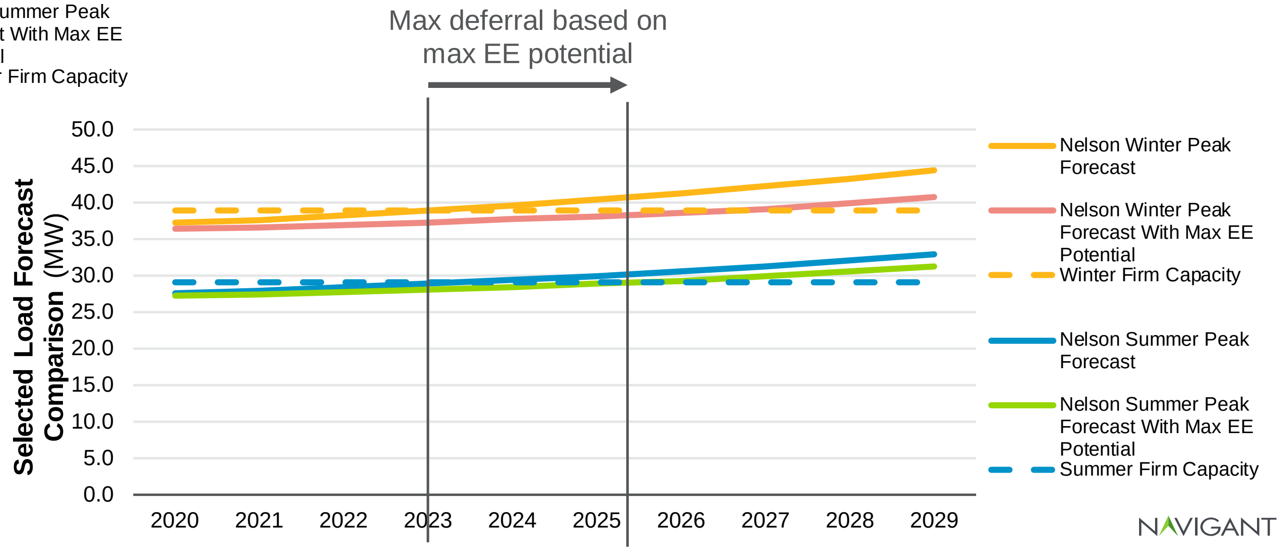
Planned upgrade year is 2023, so we take the capacity threshold as 60.5MW, not 56.7MW

Example of capacity threshold assumption due to already exceeded firm capacity and planned upgrades. Source: Navigant analysis.

SUMMARY – STEP 2

Step 2: achievable technical EE potential - With maximally deployed EE measures, there is an achievable technical potential of EE measures at most substations to defer planned substation investments.

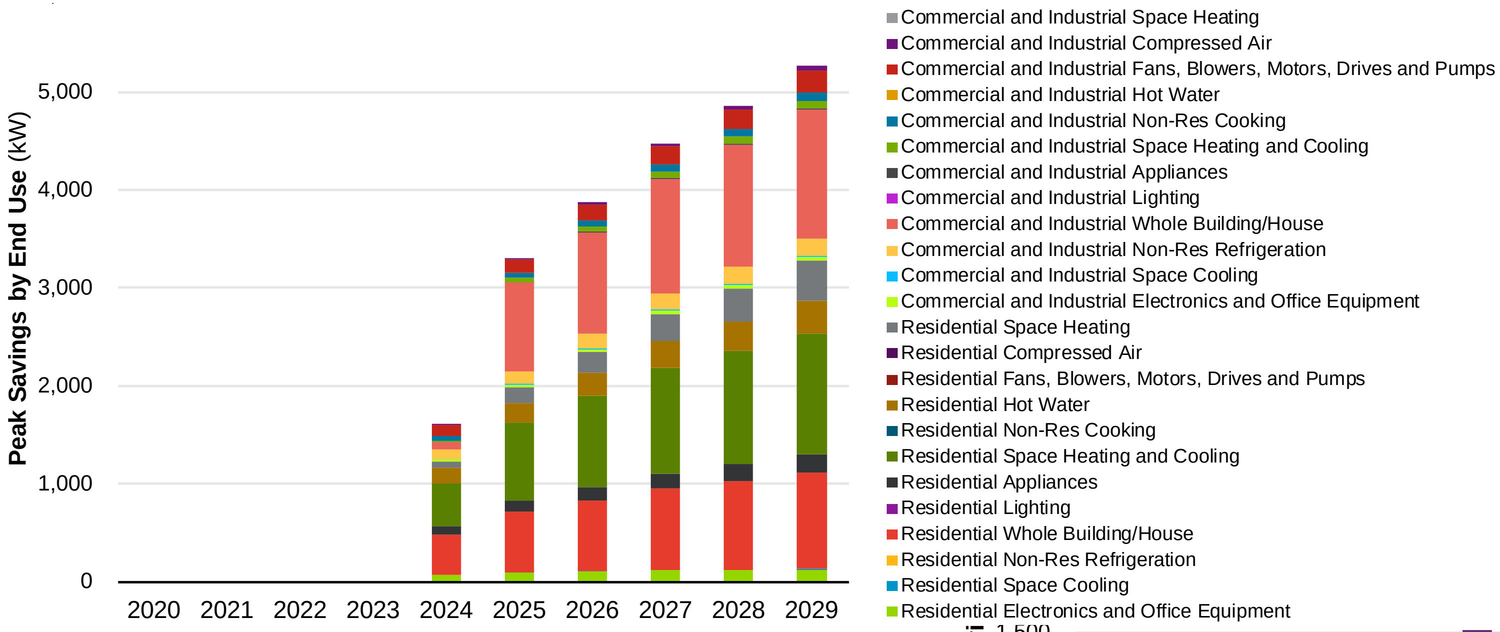


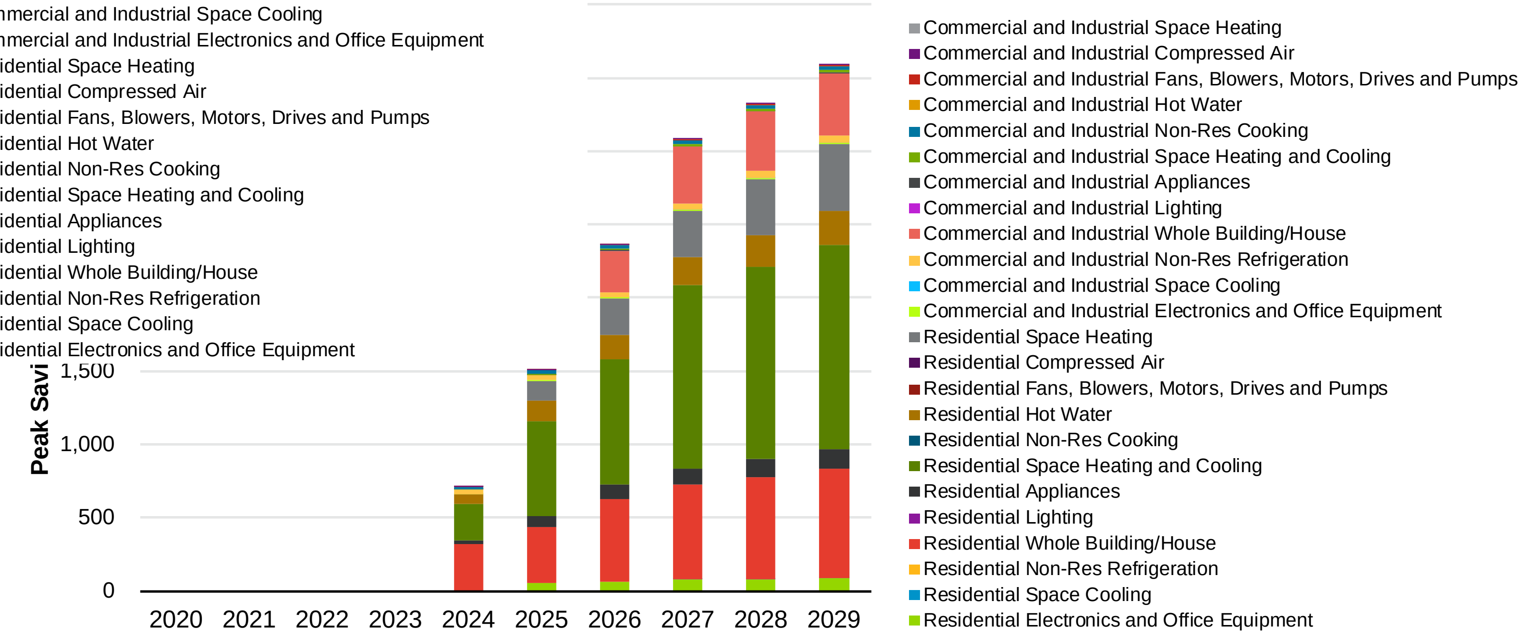


Example of max deferral potential for Lithos and Nelson. Source: Navigant analysis.

SUMMARY – STEP 2

Step 2: achievable technical EE potential - potential per measure per year, including uptake rates. Differences between substations due to varying customer mix.





Example of max achievable technical EE potential per year and measure for Lithos (top left) and Nelson (bottom right). Source: Navigant analysis.

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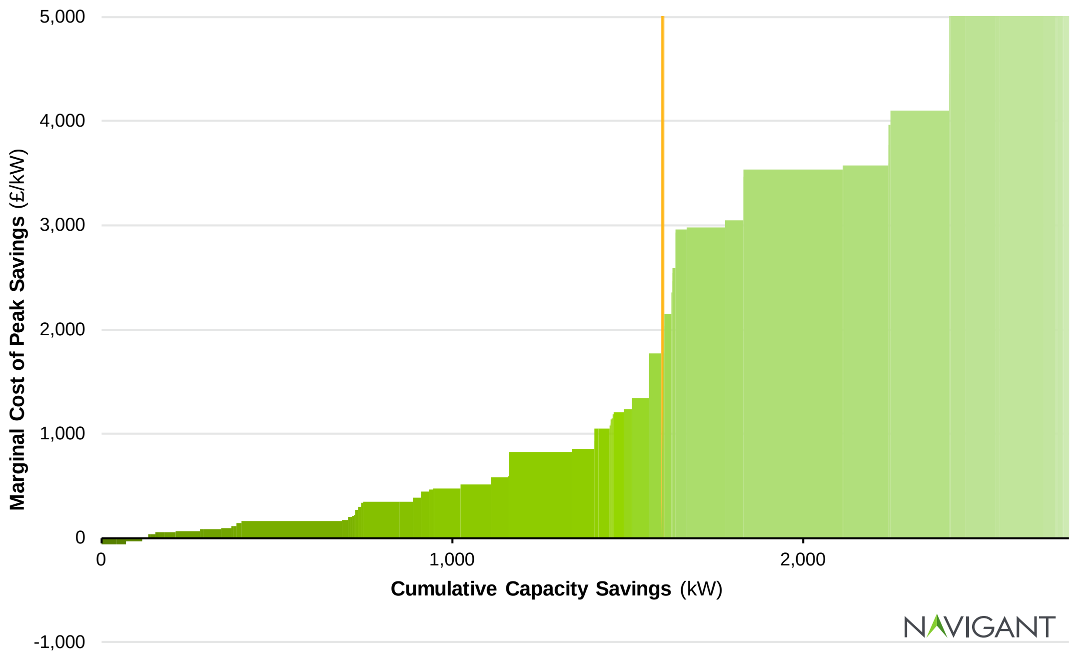
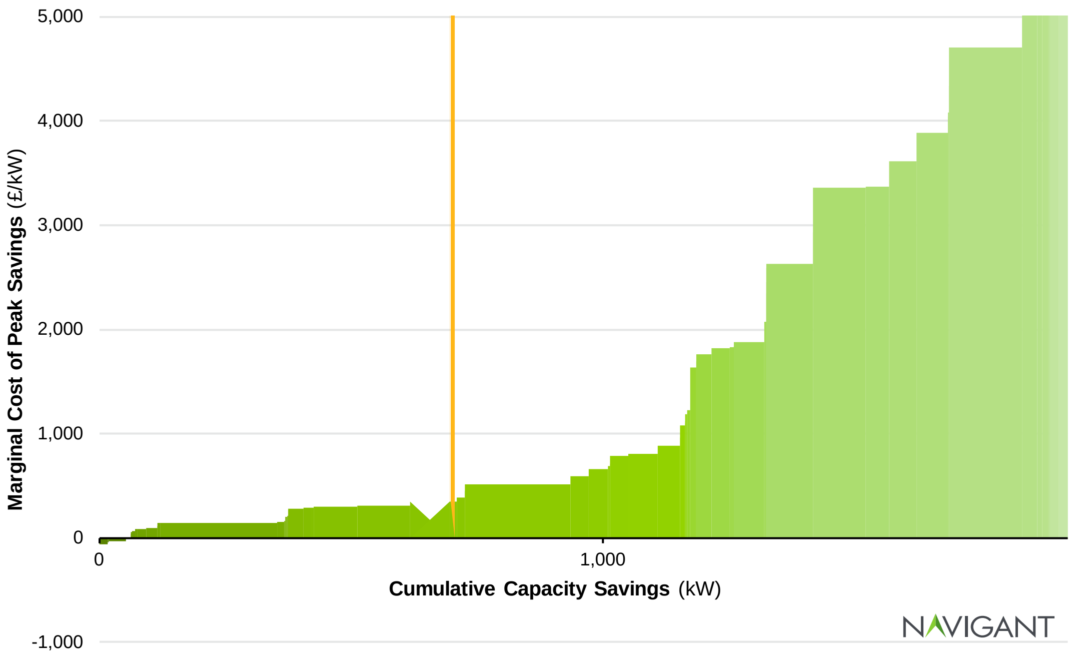
SUMMARY – STEP 3

Step 3: economic EE potential - supply curves of cost-ranked EE measures to meet the capacity need. Differences between substations due to varying customer mix.





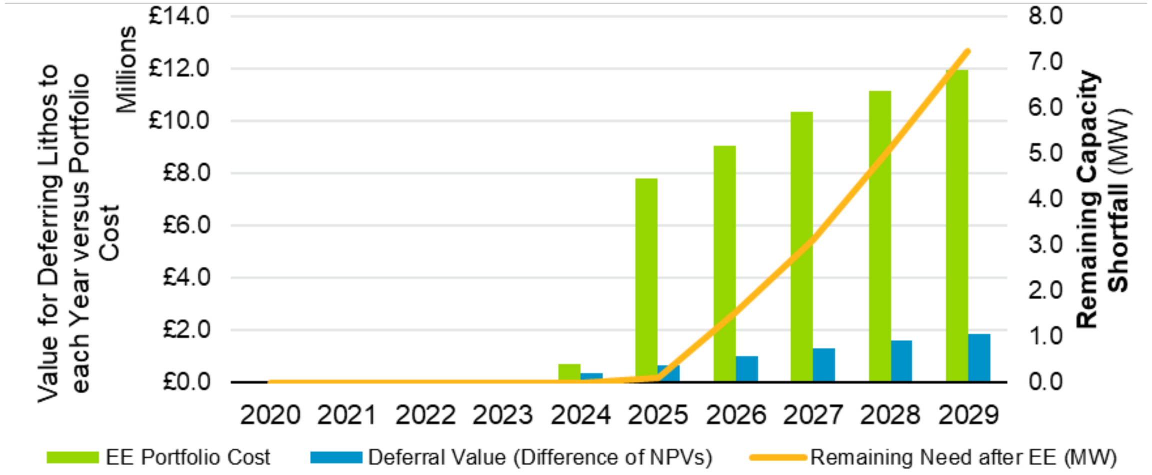
Example of supply curve of optimised EE potential per year for Lithos (left) and Nelson (right) in 2024. Yellow line is capacity need in 2024. Lithos would need to deploy more expensive measures to meet its need than Nelson. Note that some measures have negative costs. Source: Navigant analysis.

CBA PER SUBSTATION – STEP 4

Lithos has limited potential for upgrade deferral due to high cost of EE portfolio. Nelson shows some potential for EE measures to cost-effectively defer an upgrade by ~1 year.

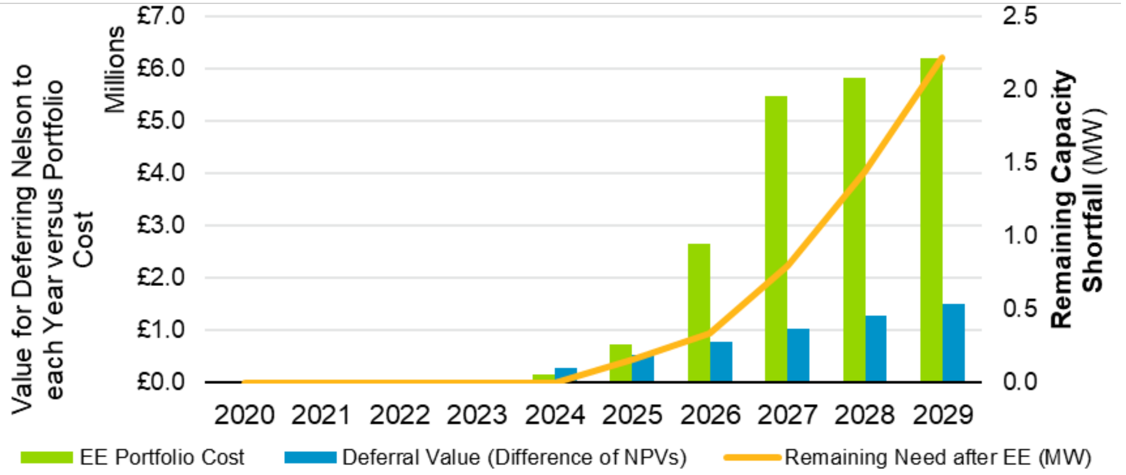
Lithos

UKPN Planned Upgrade Year:	2023
Upgrade Year with Cost-Effective EE:	2023



Nelson

UKPN Planned Upgrade Year:	2023
Upgrade Year with Cost-Effective EE:	2024



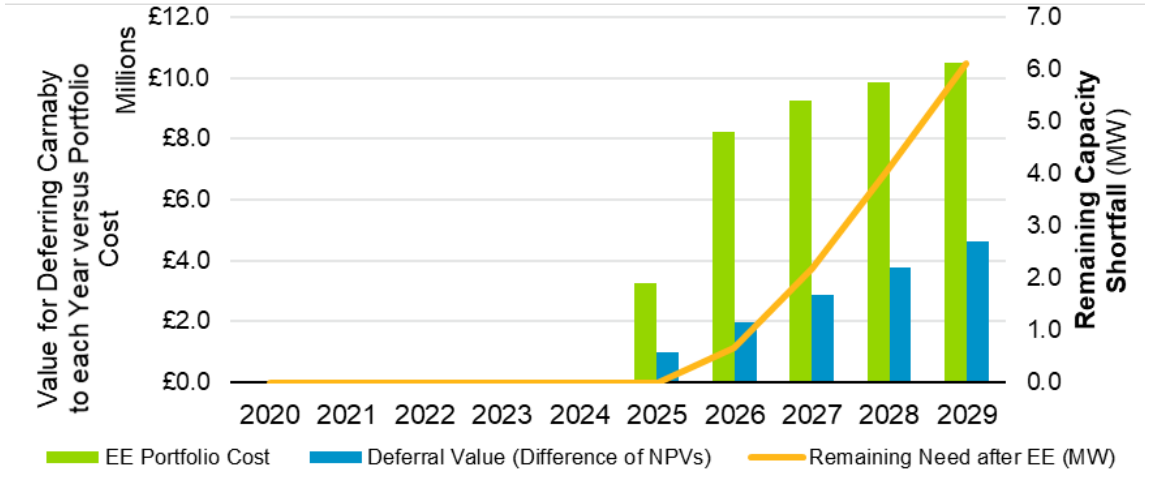
Source: Navigant analysis.

CBA PER SUBSTATION – STEP 4

Guildford and Carnaby have little potential for upgrade deferral due to high capacity needs and low EE potential, alongside a high EE portfolio cost for Carnaby.

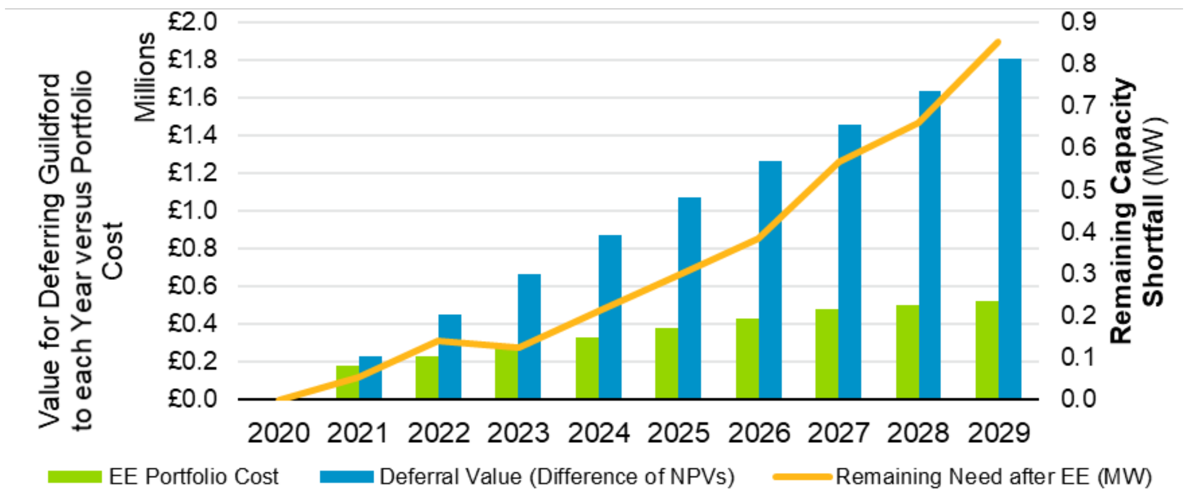
Carnaby

UKPN Planned Upgrade Year:	2024
Upgrade Year with Cost-Effective EE:	2024



Guildford

UKPN Planned Upgrade Year:	2020
Upgrade Year with Cost-Effective EE:	2020



Source: Navigant analysis.

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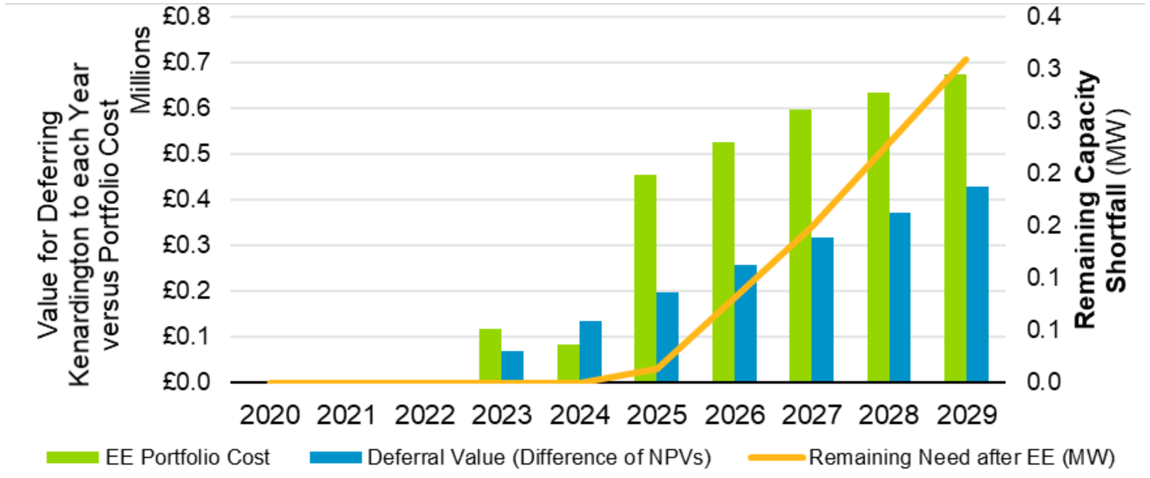
CBA PER SUBSTATION – STEP 4

Kenardington and West Horndon show some potential for EE measures to cost-effectively defer an upgrade by ~2 years and ~3 years respectively.

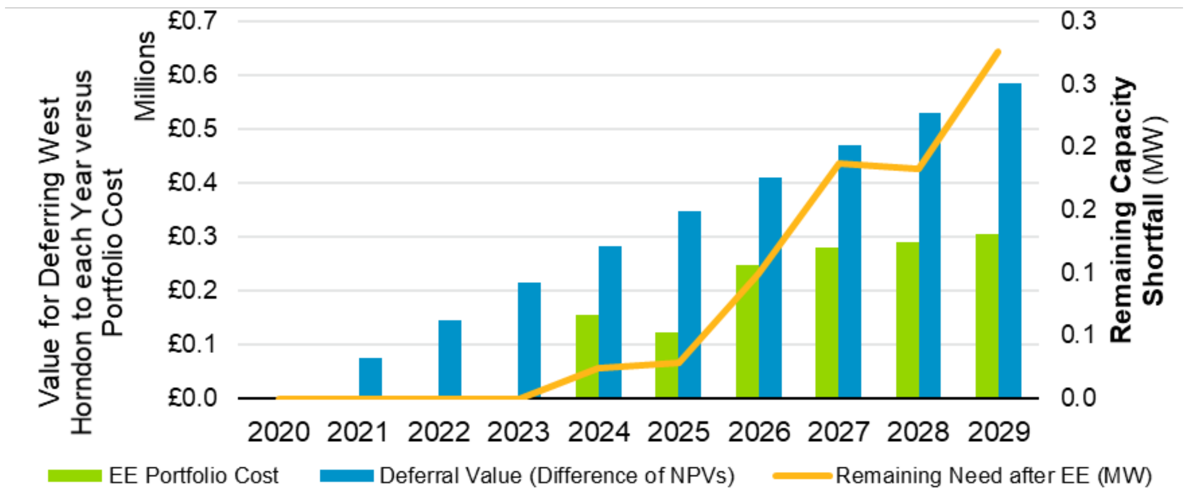
Kenardington

UKPN Planned Upgrade Year:	2022
Upgrade Year with Cost-Effective EE:	2024



West Horndon

UKPN Planned Upgrade Year:	2020
Upgrade Year with Cost-Effective EE:	2023



West Horndon has no forecasted load growth until 2024, so strictly speaking this is not a true deferral.

Source: Navigant analysis.

SUMMARY – STEP 4

- The table on the right summarises the deferral potential for each substation and the reason that no further deferral is possible
- For the substations showing deferral potential, we have estimated the annual emission savings due to lower electricity consumption (based on the average carbon intensity of UK generation)
- We excluded lighting measures from the main analysis because UKPN's load forecasts already assume a high degree of lighting efficiency. However, we modelled a sensitivity including lighting measures (see results in Appendix B). The table shows that the exclusion of lighting measures significantly reduces deferral opportunities.

Substation	Planned Upgrade Year	Deferral without Lighting measures			Deferral with Lighting measures	
		Year of deferral	Reason for no further deferral	Annual emission savings (tCO_2e)	Year of deferral	Reason for no further deferral
Lithos	2023	2023	Too costly EE portfolio		2024	Too costly EE portfolio
Nelson	2023	2024	Insufficient technical EE potential	880 tCO_2e in 2024	2026	Insufficient technical EE potential
Carnaby	2024	2024	Too costly EE portfolio		2025	Too costly EE portfolio
Kenardington	2022	2024	Insufficient technical EE potential	164 tCO_2e in 2024	2026	Too costly EE portfolio
Guildford	2020	2020	Insufficient technical EE potential		2020	Insufficient technical EE potential
West Horndon	2020	2023*	Insufficient technical EE potential	110 tCO_2e in 2024	2023*	Insufficient technical EE potential

** West Horndon has no forecasted load growth until 2024, so strictly speaking this is not a true deferral.*

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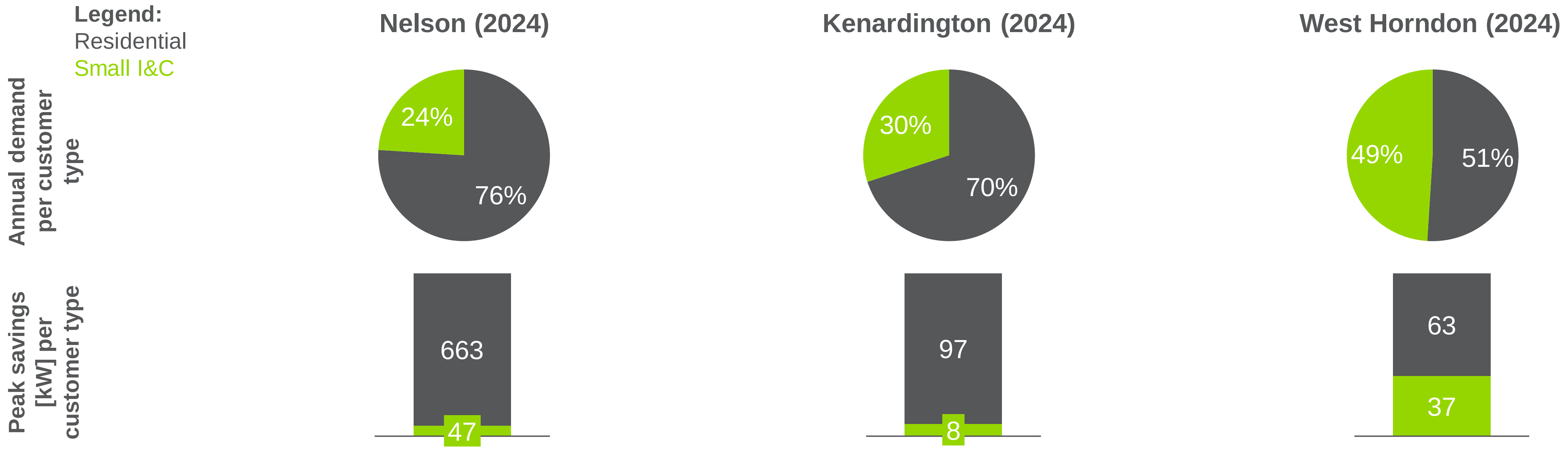
TOP EE MEASURES – MOST COST-EFFICIENT

The most cost-efficient EE measures are similar across all substations, although their relative contributions to peak savings depend on the customer mix.



Lowest-cost measures

Residential EE measures

- space heating and cooling
- whole building/house efficiency
- efficient appliances
- low-flow shower heads

Small commercial EE measures

- whole building/house efficiency
- non-residential cooking
- non-residential refrigeration
- space heating and cooling

Small industrial EE measures

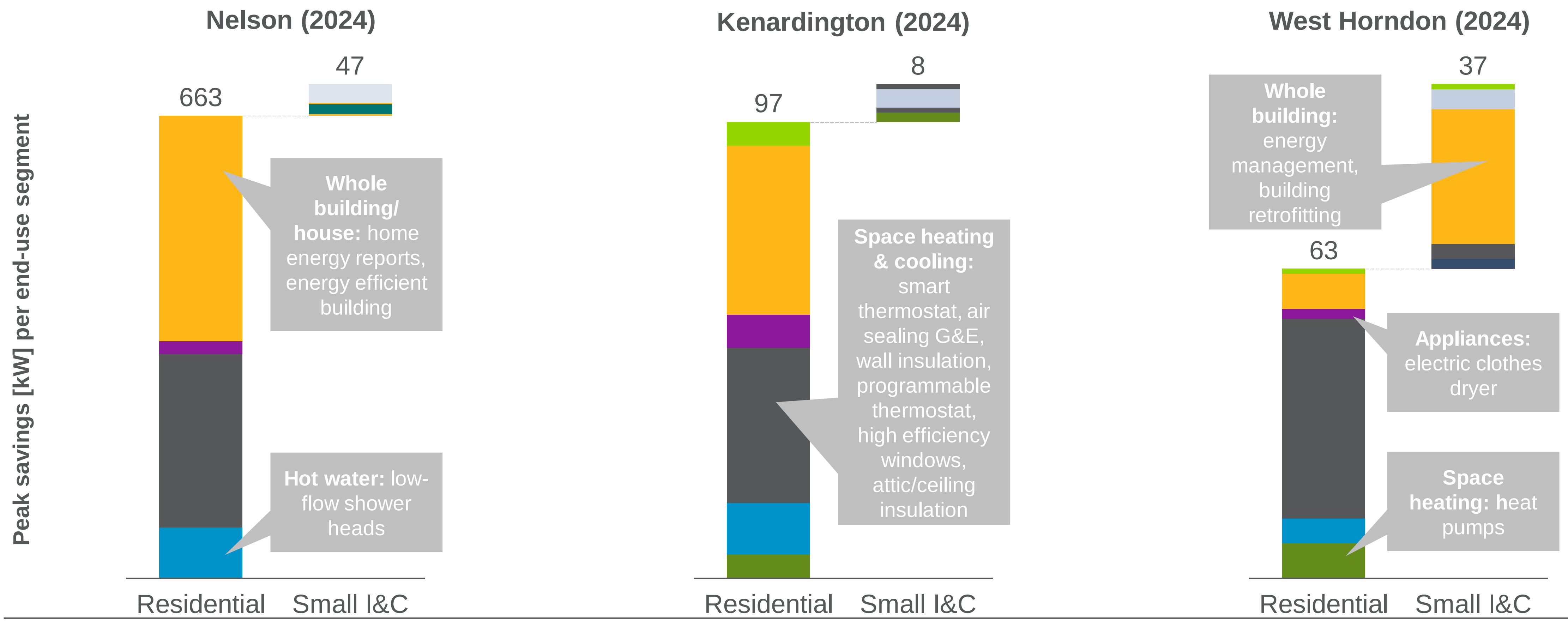
- Not in top 20 measures

Source: Navigant analysis.

TOP EE MEASURES – LARGEST PEAK SAVINGS

Legend: whole building/house Appliances Space heating & cooling Hot water Space heating/space cooling non-res refrigeration non-res cooking electronics and office equipment

The EE measures offering the largest peak savings vary significantly across the substations according to the customer mix at each.



Source: Navigant analysis.

CONTENTS

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IMPLICATIONS FOR UK POWER NETWORKS

- Our analysis indicates that EE has the potential to defer reinforcement cost-effectively at 2 out of the 6 UKPN primary substations under study. These are indicative results due to uncertainty around EE adoption rates and deployment costs in UKPN’s service area.

- We find that the EE measures offering the largest peak savings vary significantly across the substations depending on the customer mix. To achieve impact through EE, UKPN will need to better understand customers and target EE programmes accordingly, including a different focus for business customers.

- Further research and trials are required to better understand the potential and costs of EE in UKPN’s licence areas. EE programmes in the US have much greater scale, maturity and track record so their characteristics cannot be taken for granted in Great Britain.
  - In the next three slides, we have recommended further work to improve this understanding
  - Further research is particularly needed to understand the prevalence and potential of efficient lighting, which is typically cost-effective and high-impact

- The EE potential model is a proof of concept that can help UKPN in its regulatory engagement.

RECOMMENDED FURTHER WORK (I)

Based on our key modelling assumptions, we have suggested further activities to improve the understanding of EE potential and costs in UKPN's licence areas.

Modelling Assumption	Limitation of this Approach	Recommended Further Work
Six primary substations are modelled as selected by UKPN.	• The six selected substations may not be representative of EE potential to defer network reinforcement across UKPN's licence areas	• **Detailed EE evaluation study across a larger sample of UKPN substations**
EE potential is modelled on a standalone basis.	• EE does not typically defer network reinforcement on its own. It is more effective when combined with DER, voltage control, etc.	• **Broader assessment including interactions/synergies with other NWAs**
Capacity threshold for each substation is assumed to be the load forecast in the scheduled year of upgrade	• A reasonable proxy for the threshold for substation reinforcement • Dependent on assumptions implicit within the load forecasts	• **Consider revisiting load forecast assumptions**
The analysis uses historic hourly loads and the load forecast to project future hourly energy saving needs	• This assumes that future loads will follow the same shapes of historic loads on each substation and does not account for long-term shifts in the overall shape of the substation load	• **This is a standard assumption for all load forecasting and doesn't necessarily require rework unless the team has reason to believe that the load shape will shift in the future**

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RECOMMENDED FURTHER WORK (II)

Based on our key modelling assumptions, we have suggested further activities to improve the understanding of EE potential and costs in UKPN's licence areas.

Modelling Assumption	Limitation of this Approach	Recommended Further Work
EE savings potential is only modelled for residential and small I&C customer segments. The database of EE measures in our model is assumed not to be applicable to large I&C customers (i.e. Profile Class 0), which typically require bespoke, custom measures.	• EE savings potential from the large I&C segment may be sizeable. It may also be accessible through a relatively small number of customers with block loads.	• **Detailed study of the large I&C segment to assess EE savings potential** • **Engagement with large I&C customers to identify their specific electricity end-uses and understand the custom measures required**
Substation load is disaggregated into different customer segments using average annual load per Elexon profile class.	• Elexon's average customer profiles may not be representative of customers in UKPN's licence areas.	• **Further research into UKPN's customer segmentation**
Database of EE measures is selected based on climate-matching between London and Washington state, US. This is a pragmatic simplification as it does not require extensive UK customer or building stock data and it does not require a mature energy efficiency evaluation ecosystem for measure characterisation in the UK.	• Some EE measures may not be directly applicable to the UK context • Less certainty on the implementation details, such as adoption rates and deployment costs of measures in the UK	• **Detailed assessment of EE measures and customer behaviour in the UK** • **Detailed assessment of differences between UK regions** • **Seek partnerships with EE programme implementers currently operating in the UK to leverage their data and experience**

RECOMMENDED FURTHER WORK (III)

Based on our key modelling assumptions, we have suggested further activities to improve the understanding of EE potential and costs in UKPN's licence areas.

Modelling Assumption	Limitation of this Approach	Recommended Further Work
Savings potential of each EE measure is scaled according to the customer base at each UKPN substation. Scaling is adjusted for the customer classes (e.g. residential, commercial) specific to each substation.	• Some EE measures may not be directly applicable to UKPN's service area • Less certainty on the implementation details, such as adoption rates and deployment costs of measures in UKPN's service area	• **Detailed assessment of EE measures and customer behaviour in UKPN's service area** • **Analysis of building stock in UKPN's service area (e.g. using EPC data)**
Lighting measures are excluded from the modelling because UKPN's load forecasts already assume a high degree of lighting efficiency.	• Lighting measures represent valuable savings as they are typically low-cost, high impact, and relatively quick to implement. • Given the urgent deferral timeframes of the 6 substations we examined, there is limited opportunity to defer network reinforcement without lighting savings.	• **Detailed assessment of EE measures in UKPN's service area to confirm the prevalence of efficient lighting** • **Consider re-assessing the load forecast assumptions based on lighting baseline study**

CONTENTS

APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (I)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Electronics and Office Equipment	Com | Advanced Power Strips	Advanced power strip that turns off equipment plugged into it when not in use	ROB
Space Cooling	Com | Air Cooled Chillers	Air-cooled chiller with an efficiency of 11.5 EER and 15.5 SEER	ROB
Non-Res Refrigeration	Com | Anti-Sweat Heater Controls	Control that regulates the operation of anti-sweat heaters on glass doors of commercial refrigerators and walk-ins based on the ambient humidity.	RET
Whole Building/House	Com | Building Automation Systems - kWh	Building Energy Management System that monitors and controls the building's energy use.	RET
Space Cooling	Com | Centrifugal Chillers	Centrifugal chiller with an efficiency of 0.60 Full Load Value (FLV) and 0.54 Integrated Part Load Value (IPLV)	ROB
Lighting	Com | Ceramic Metal Halide - Exterior	Install ceramic metal halide instead of high-pressure sodium lamp	ROB
Space Cooling	Com | Chiller-Water Side Economizer	Water-side economizer with a new plate and frame exchanger	NEW
Space Cooling	Com | Chiller-Water Side Economizer	Water-side economizer with a new plate and frame exchanger	ROB
Appliances	Com | Clothes Washer_Edry,EDHW	Clothes washer with Modified Energy Factor of 2.2 or greater	ROB
Appliances	Com | Clothes Washer_Gdry,EDHW	Clothes washer with Modified Energy Factor of 2.2 or greater	ROB
Non-Res Refrigeration	Com | Commercial Ice Makers	Cube or nugget type ice machine that meets CEE Tier 2 efficiency level	ROB
Whole Building/House	Com | Comprehensive Retrocommissioning, kWh	Comprehensive process of checking and fixing building systems to bring them back to efficient operation if they have deteriorated over time	RET
Space Cooling	Com | Direct Evaporative Pre-Cooling	Evaporative pre-cooling of air-cooled condensers on direct expansion HVAC units	NEW
Space Cooling	Com | Direct Evaporative Pre-Cooling	Evaporative pre-cooling of air-cooled condensers on direct expansion HVAC units	ROB
Space Heating and Cooling	Com | Ductless Mini-Split Heat Pumps	Ductless mini-split heat pump with SEER rating of 15 and HSPF of 8.5	ROB
Non-Res Refrigeration	Com | ECM Fan Motor System on Walk-in/Reach-in Refrigeration	Replace PSC or shaded pole motors in walk-in and reach-in refrigeration systems with more efficient ECM motors	RET
Appliances	Com | Efficient Dryer_Electric	Electric dryer with Combined Efficiency Factor of 3.8	ROB
Appliances	Com | Efficient Dryer_Gas	Gas dryer with Combined Efficiency Factor of 3.48	ROB
Non-Res Cooking	Com | Electric Combination Ovens	Electric combination ovens that meet ENERGY STAR specifications	ROB
Non-Res Cooking	Com | Electric Convection Ovens	Electric convection ovens that meet ENERGY STAR specifications	ROB
Non-Res Cooking	Com | Electric Exhaust Hood	Commercial cooking equipment exhaust hood with demand-controlled ventilation that operates only as much as needed	RET
Non-Res Cooking	Com | Electric Fryer	Electric fryer that meets ENERGY STAR specification	ROB
Non-Res Cooking	Com | Electric Griddles	Electric griddle with 70% cooking efficiency	ROB
Non-Res Cooking	Com | Electric Pressureless Steamer	Electric pressureless steamer that meets ENERGY STAR specification	ROB

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APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (II)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Non-Res Cooking	Com | ENERGY STAR Commercial Dishwashers - Elec HW	Commercial dishwasher that meets ENERGY STAR specification	ROB
Non-Res Cooking	Com | ENERGY STAR Commercial Dishwashers - Gas HW	Commercial dishwasher that meets ENERGY STAR specification	ROB
Non-Res Refrigeration	Com | Evaporator Fan Controls	Control that regulates the operation of evaporator fans in commercial refrigeration	RET
Lighting	Com | Exterior LED Area and Wall Lights	Install LED instead of metal halide or high pressure sodium in an exterior location	ROB
Lighting	Com | Exterior Pin-based CFLs	Install high-wattage, pin-based CFL fixture that will only accept CFLs instead of an incandescent lamp	ROB
Lighting	Com | Fixture Mounted Occupancy Sensor	Sensor on a light fixture that turns off the light when no movement is detected for a period of time (indicating that a room is not occupied)	RET
Non-Res Refrigeration	Com | Floating-Head Pressure Controls	Controls that adjust operating pressure of a commercial refrigeration system based on ambient temperature conditions	RET
Space Heating and Cooling	Com | Heat Pump, Air Source	Air Source Heat Pump with an efficiency of 16 SEER	ROB
Lighting	Com | High Bay T8/T5 HO - Interior	Install T8 or T5 high bay fixtures instead of metal halide or high pressure sodium	ROB
Whole Building/House	Com | High Efficiency Comprehensive New Construction - 10% Better - kWh	Commercial new construction that uses 10% less electricity than current design practices	NEW
Whole Building/House	Com | High Efficiency Comprehensive New Construction - 25% Better - kWh	Commercial new construction that uses 25% less electricity than current design practices	NEW
Non-Res Cooking	Com | Hot Food Holding Cabinets	Gas hot food holding cabinet that meets ENERGY STAR specification	ROB
Lighting	Com | LED Exit Signs	Use LED bulbs in exit signs	RET
Lighting	Com | LED Fixture - Interior	Install LED interior fixture instead of incandescent or halogen fixture	ROB
Non-Res Refrigeration	Com | LED Refrigeration Case Lighting - Strip	Use LEDs in refrigerated cases instead of T8 or T12	ROB
Hot Water	Com | Low-Flow Pre-Rinse Spray Valves (Electric)	Low-flow spray valves for rinsing dishes in a commercial kitchen	ROB
Non-Res Refrigeration	Com | New Display Case with Doors (Medium Temperature)	Install a display case with doors instead of an open display case	ROB
Non-Res Refrigeration	Com | Night Curtains on Low and Medium Temperature Vertical Display Case	Adding curtains to refrigerated display cases that can be closed during hours when the building is unoccupied to keep cold air from escaping.	RET
Appliances	Com | Ozone Laundry	Add ozone to wash water so that lower water temperature can be used	RET
Space Cooling	Com | Packaged Terminal AC (PTAC) Equipment	PTAC condensing units with efficiency of 13.4 SEER and 11.4 EER	ROB

APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (III)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Lighting	Com | Photocell	Sensor that detects ambient light and modulates lighting accordingly	RET
Lighting	Com | Pulse Start Metal Halide - Exterior	Install pulse-start metal halide lamp instead of standard metal halide or high pressure sodium lamp	ROB
Non-Res Refrigeration	Com | Refrigeration Recommissioning	Recommission refrigeration system (maintenance that comprehensively improves operation of system)	RET
Lighting	Com | Screw-In LED - Interior	Install LED lamp instead of incandescent or halogen lamp	ROB
Space Cooling	Com | Scroll/Screw Chillers	Advanced Efficiency Standard Chiller rated at 0.50 kW/Ton at full load	ROB
Space Cooling	Com | SEER Rated Split or Rooftop AC	Direct expansion AC unit with efficiency of 14.4 SEER or greater	ROB
Electronics and Office Equipment	Com | Server - High Efficiency	Computer server that meets ENERGY STAR specification	ROB
Electronics and Office Equipment	Com | Server Virtualization	Consolidate server functions into minimal hardware that is shared by users instead of having separate servers	ROB
Space Heating and Cooling	Com | Smart Thermostats (Small Commercial) - kWh	Smart thermostat that adapts to user behavior	RET
Whole Building/House	Com | Strategic Energy Management - kWh	Method for continuously improving operation of equipment and processes	RET
Non-Res Refrigeration	Com | Strip Curtains	Adding strip curtains to walk-in refrigerator doors to reduce air infiltration	RET
Lighting	Com | Troffer LED	Replace T8 or T12 fluorescent fixtures with T5 fixtures with electronic ballasts	RET
Space Cooling	Com |Occupancy-Based PTAC Controls	Controls that adjust operation of a PTAC based on whether the room is occupied	RET
Space Heating and Cooling	Com |VFD on HVAC Fans/Pumps	Install variable frequency drive (VFD) on HVAC fans and pumps	RET
Fans, Blowers, Motors, Drives and Pumps	Ind | Ag Pump Controls | RET	Install variable frequency drive (VFD) controls on agricultural pumps	RET
Compressed Air	Ind | Air Compressor Improvements | NEW	Improving air compressor operation by fixing leaks and adding or repairing control systems and filter dryers.	NEW
Compressed Air	Ind | Air Compressor Improvements | RET	Improving air compressor operation by fixing leaks and adding or repairing control systems and filter dryers.	RET
Fans, Blowers, Motors, Drives and Pumps	Ind | Centrifugal Fan | NEW	Upgrade to more efficient fan systems including fan blades and dampers	NEW

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APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (IV)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Fans, Blowers, Motors, Drives and Pumps	Ind | Centrifugal Fan | RET	Upgrade to more efficient fan systems including fan blades and dampers	RET
Space Heating and Cooling	Ind | De Strat Fans Electric | NEW	Install de-stratification fans to improve air circulation	NEW
Space Heating and Cooling	Ind | De Strat Fans Electric | RET	Install de-stratification fans to improve air circulation	RET
Fans, Blowers, Motors, Drives and Pumps	Ind | Effcient Conveyor Belts | NEW	Upgrading to more efficient conveyor belts	NEW
Fans, Blowers, Motors, Drives and Pumps	Ind | Effcient Conveyor Belts | RET	Upgrading to more efficient conveyor belts	RET
Fans, Blowers, Motors, Drives and Pumps	Ind | Fan System Optimization | NEW	Install VFD and on/off controls on fans	NEW
Fans, Blowers, Motors, Drives and Pumps	Ind | Fan System Optimization | RET	Install VFD and on/off controls on fans	RET
Fans, Blowers, Motors, Drives and Pumps	Ind | High Effciency Fans | NEW	Install premium efficiency fan motor	NEW
Fans, Blowers, Motors, Drives and Pumps	Ind | High Effciency Fans | RET	Install premium efficiency fan motor	RET
Lighting	Ind | LED Street Lighting	Install LED street lighting instead of HID lighting	ROB
Lighting	Ind | Lighting Improvements | NEW	Add or upgrade lighting controls	NEW
Lighting	Ind | Lighting Improvements | RET	Add or upgrade lighting controls	RET
Whole Building/House	Ind | Process Optimization | RET	Low cost/no cost process operation and maintenance improvements	RET

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APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (V)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Fans, Blowers, Motors, Drives and Pumps	Ind | Pump Equipment Upgrades | NEW	Upgrade to VFD pump and properly size pump for the intended use	NEW
Fans, Blowers, Motors, Drives and Pumps	Ind | Pump Equipment Upgrades | RET	Upgrade to VFD pump and properly size pump for the intended use	RET
Non-Res Refrigeration	Ind | Refrigeration Equipment VFD | NEW	Use VFD fans in refrigeration evaporators and condensers	NEW
Non-Res Refrigeration	Ind | Refrigeration Equipment VFD | RET	Use VFD fans in refrigeration evaporators and condensers	RET
Non-Res Refrigeration	Ind | Refrigeration System Upgrades | NEW	Upgrade refrigeration equipment by installing better doors and controls; conduct maintenance of equipment	NEW
Non-Res Refrigeration	Ind | Refrigeration System Upgrades | RET	Upgrade refrigeration equipment by installing better doors and controls; conduct maintenance of equipment	RET
Fans, Blowers, Motors, Drives and Pumps	Ind | Ultra High Efficiency Motors | NEW	Install motors with greater than NEMA efficiency	NEW
Fans, Blowers, Motors, Drives and Pumps	Ind | Ultra High Efficiency Motors | RET	Install motors with greater than NEMA efficiency	RET
Electronics and Office Equipment	Res | Advanced Power Strips, Elec	Advanced power strip that turns off equipment plugged into it when not in use	RET
Electronics and Office Equipment	Res | Air Cleaner	High efficiency room air cleaner	ROB
Space Heating and Cooling	Res | Air Sealing - Gas and Electric	Seal air leaks to reduce air changes per hour (ACH) from 0.6 to 0.36	RET
Space Heating and Cooling	Res | Air Source Heat Pump	Air Source Heat Pump with efficiency of 14.5 SEER and 9 HSPF	ROB
Space Heating and Cooling	Res | Attic Insulation/Ceiling Insulation - Gas and Electric	Adding attic and ceiling insulation	RET
Space Cooling	Res | Central AC Quality Installation Verification	Improving the operation of central AC units by commissioning them, adding controls, and ensuring they are the right size for the application	NEW
Space Cooling	Res | Central Air Conditioner Replacement	Replacing existing AC with an 18 SEER AC	ROB

APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (VI)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Space Cooling	Res | Central Air Conditioner Tune up	Tune up and maintenance of central AC	RET
Appliances	Res | Clothes Washer | Electric DHW	Clothes washer that meets ENERGY STAR specification	ROB
Appliances	Res | Dishwasher | Electric HW	Dishwasher that meets ENERGY STAR specification	ROB
Appliances	Res | Dishwasher | Gas HW	Dishwasher that meets ENERGY STAR specification	ROB
Space Heating and Cooling	Res | Duct Insulation - Gas and Electric	Insulating HVAC air ducts	RET
Space Heating and Cooling	Res | Duct Sealing - Gas and Electric	Sealing HVAC air ducts	RET
Space Heating	Res | Ductless Mini-Split Heat Pumps	Install efficient mini-split ductless heat pump with electric zonal Heat	ROB
Space Heating	Res | Ductless Mini-Split Heat Pumps - SF	Install efficient mini-split ductless heat pump with electric zonal Heat	ROB
Space Heating	Res | ECM Motor MH	Use ECM fan motor instead of PSC or Shaded Pole Motor in furnace in manufactured housing	ROB
Space Heating	Res | ECM Motor SF MF	Use ECM fan motor instead of PSC or Shaded Pole Motor in furnace in single family or multi family housing	ROB
Appliances	Res | Electric Clothes Dryer	Electric clothes dryer that meets ENERGY STAR specification	ROB
Hot Water	Res | Electric Storage Water Heater	Electric storage water heater with 0.95 energy factor	ROB
Whole Building/House	Res | Energy Efficient Building - Electric & Gas ST	Multi-family building that consumes 30% less energy than a code-compliant building (Electric and Gas Service Territory)	NEW
Whole Building/House	Res | Energy Star Home, Electric & Gas ST	Multi-family building that consumes 30% less energy than a code-compliant building (Gas-Only Service Territory)	NEW
Electronics and Office Equipment	Res | Energy Star Television, Elec	Television that meets ENERGY STAR specification	ROB
Hot Water	Res | Faucet Aerators - Bathroom, Electric WH	Aerators on bathroom faucets that reduce flow to 0.5 gallons per minute	RET
Hot Water	Res | Faucet Aerators - Kitchen, Electric WH	Aerators on kitchen faucets that reduce flow to 1.5 gallons per minute	RET
Space Heating	Res | Floor Insulation - Gas and Electric	Install floor insulation up to R-30	RET
Space Heating and Cooling	Res | Ground Source Heat Pump	Ground source heat pump that meets ENERGY STAR specification	ROB

APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (VII)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Appliances	Res | Heat Pump Clothes Dryer	High efficiency heat pump clothes dryer with UCEF of 3.4 or greater	ROB
Hot Water	Res | Heat Pump Water Heater	Heat pump water heater with an Efficiency Factor of 2.0 or greater	ROB
Appliances	Res | High Efficiency Freezer	Freezer that meets ENERGY STAR specification	ROB
Appliances	Res | High Efficiency Refrigerator	Refrigerator that meets ENERGY STAR specification	ROB
Space Heating and Cooling	Res | High Efficiency Windows - Gas and Electric	Windows with a U-value of 0.22	ROB
Whole Building/House	Res | Home Energy Reports, Electric Only ST, NEW	Send home energy reports to household occupants to inform them of their energy use and suggest ways to reduce energy use	NEW
Whole Building/House	Res | Home Energy Reports, Electric Only ST, RET	Send home energy reports to household occupants to inform them of their energy use and suggest ways to reduce energy use	RET
Lighting	Res | Indoor Fixture (hard wired, pin-based)	Use pin-based fixture that is compatible with fluorescent bulbs only (to prevent installation of incandescent bulbs)	ROB
Lighting	Res | Indoor Fluorescents T8	Replace T12 fluorescent bulbs with T8 bulbs	RET
Lighting	Res | LED (General Service Lamps)	Install LED bulb instead of incandescent bulb	ROB
Lighting	Res | LED (Reflector)	Install LED reflector bulb instead of incandescent or halogen bulb	ROB
Lighting	Res | LED (Specialty, Non-Reflector)	Install LED specialty bulb instead of incandescent bulb	ROB
Lighting	Res | LED Exit Signs (Multi-Family only)	Use LEDs in exit signs instead of incandescent bulbs	ROB
Hot Water	Res | Low-Flow Showerheads, Electric WH	Showerhead that restricts flow to 1.5 gallons per minute	RET
Lighting	Res | Outdoor Fixture (hard wired, pin-based)	Use pin-based exterior fixture that is compatible with fluorescent bulbs only (to prevent installation of incandescent bulbs)	ROB
Space Heating and Cooling	Res | Programmable Thermostat - NEW	Thermostat that can be programmed by the user to change temperature settings according to a schedule	NEW
Space Heating and Cooling	Res | Programmable Thermostat - RET	Thermostat that can be programmed by the user to change temperature settings according to a schedule	RET
Appliances	Res | Refrigerator Recycling	Removing and recycling second refrigerator	RET
Space Cooling	Res | Room AC Replacement	Room air conditioner that meets ENERGY STAR specification	ROB
Space Heating and Cooling	Res | Smart Thermostat - NEW, Manual Baseline	Smart thermostat that adapts to user behavior and can be controlled by wifi	NEW

APPENDIX – LONG-LIST OF ENERGY EFFICIENCY MEASURES (VIII)

End Use	Selected Measures: Com=commercial, Ind=industrial, Res=residential	Description	Replacement Type*
Space Heating and Cooling	Res | Smart Thermostat - NEW, Programmable Baseline	Smart thermostat that adapts to user behavior and can be controlled by wifi	NEW
Space Heating and Cooling	Res | Smart Thermostat - RET, Manual Baseline	Smart thermostat that adapts to user behavior and can be controlled by wifi	RET
Space Heating and Cooling	Res | Smart Thermostat - RET, Programmable Baseline	Smart thermostat that adapts to user behavior and can be controlled by wifi	RET
Hot Water	Res | Solar Water Heater	Water heater that uses solar thermal energy to provide supplemental heat	ROB
Appliances	Res | Stand-Alone Freezer - Removal	Removing and recycling extra stand-alone freezer	RET
Space Heating and Cooling	Res | Wall Insulation - Gas and Electric	Upgrade wall insulation to R-21 insulating value, with R-5 sheathing	RET
Hot Water	Res | Water Heater Tank Blanket/Insulation, Electric WH	Wrap water heater tank in R-10 insulation	RET
Hot Water	Res | Water Heater Temperature Setback, Electric WH, NEW	Wrap water heater tank in R-10 insulation	NEW
Hot Water	Res | Water Heater Temperature Setback, Electric WH, RET	Set water heater temperature to 120 F instead of a higher temperature	RET
Space Heating and Cooling	Res | Window Film - Gas and Electric	Adding solar film to existing single or double pane windows	RET

*ROB=replace on burn-out, NEW=newly installed, RET=retrofitted

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APPENDIX B – SENSITIVITY WITH LIGHTING MEASURES

Excluding lighting measures from the EE potential modelling significantly reduces deferral opportunities. In most cases, there isn't enough technical potential from non-lighting measures to meet the need, regardless of whether the EE portfolio is cost-effective.

Substation	Planned Upgrade Year	Deferral without Lighting measures			Deferral with Lighting measures	
		Year of deferral	Reason for no further deferral	Annual emission savings (tCO_2e)	Year of deferral	Reason for no further deferral
Lithos	2023	2023	**Too costly EE portfolio**		2024	**Too costly EE portfolio**
Nelson	2023	2024	**Insufficient technical EE potential**	880 tCO_2e in 2024	2026	**Insufficient technical EE potential**
Carnaby	2024	2024	**Too costly EE portfolio**		2025	**Too costly EE portfolio**
Kenardington	2022	2024	**Insufficient technical EE potential**	164 tCO_2e in 2024	2026	**Too costly EE portfolio**
Guildford	2020	2020	**Insufficient technical EE potential**		2020	**Insufficient technical EE potential**
West Horndon	2020	2023*	**Insufficient technical EE potential**	110 tCO_2e in 2024	2023*	**Insufficient technical EE potential**

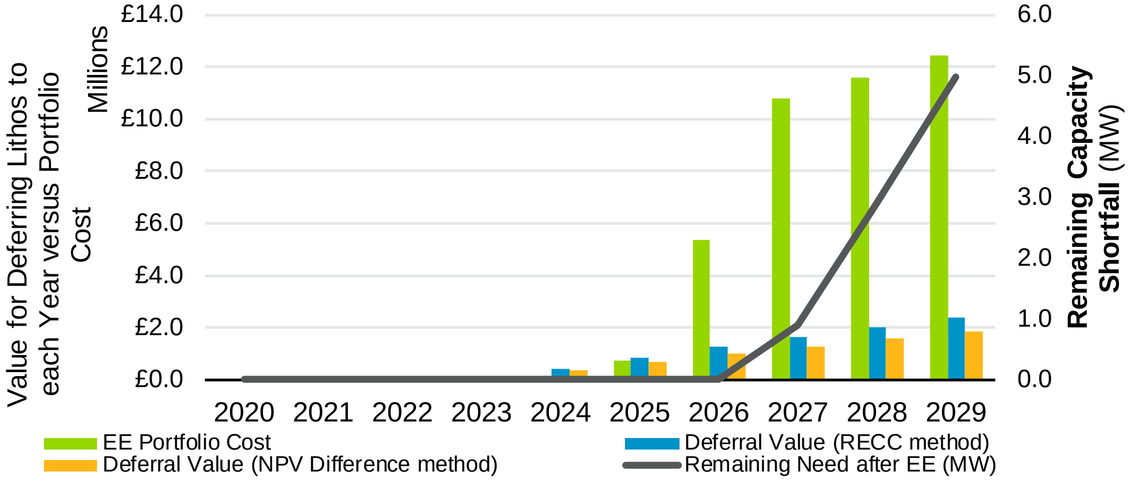
** West Horndon has no forecasted load growth until 2024, so strictly speaking this is not a true deferral.*

CBA PER SUBSTATION

Lithos and Nelson show some potential for EE measures to cost-effectively defer a network upgrade.

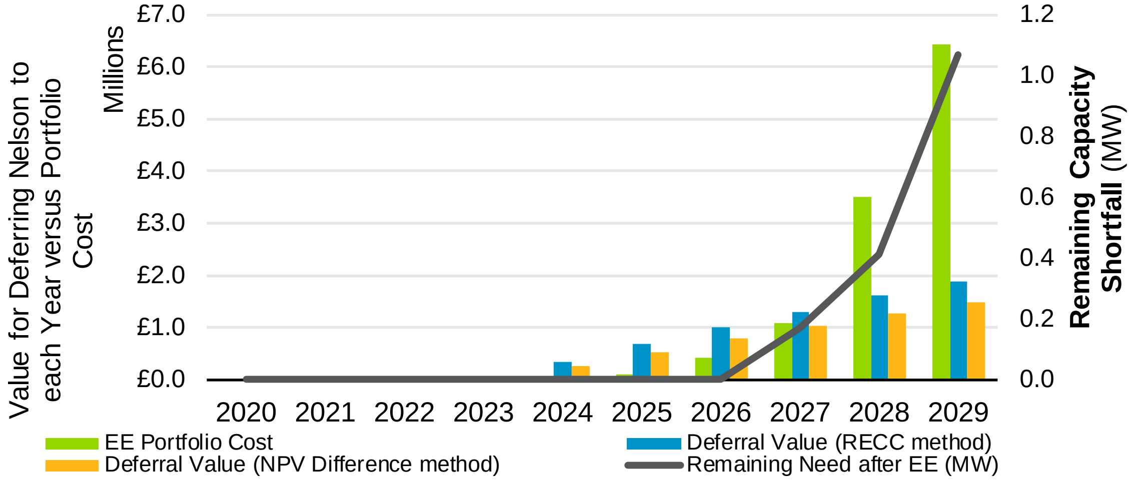
CBA Lithos

UKPN Planned Upgrade Year:	2023
Upgrade Year with Cost-Effective EE - RECC	2025
Upgrade Year with Cost-Effective EE - Difference of NPV	2024



CBA Nelson

UKPN Planned Upgrade Year:	2023
Upgrade Year with Cost-Effective EE - RECC	2026
Upgrade Year with Cost-Effective EE - Difference of NPV	2026



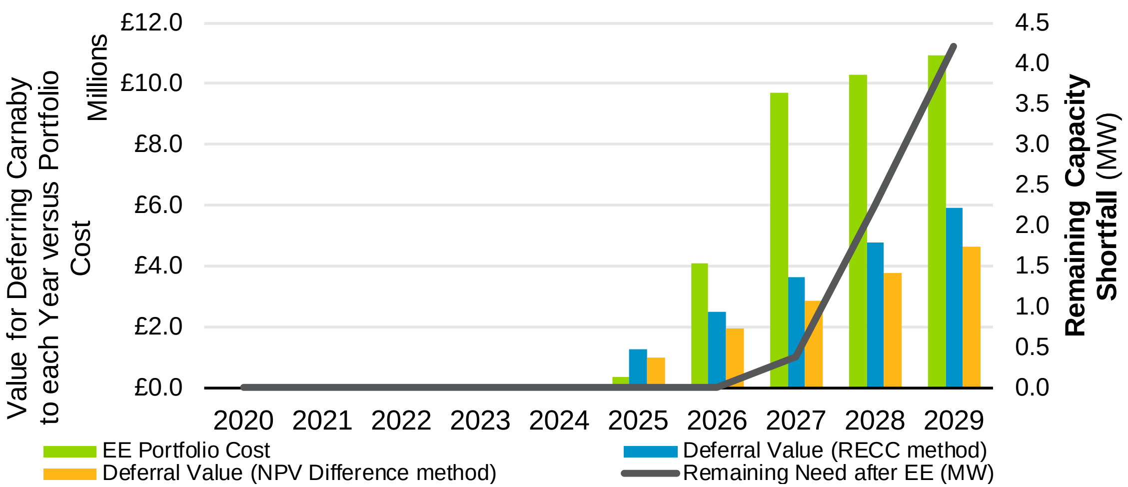
Source: Navigant analysis.

CBA PER SUBSTATION

Guildford and Carnaby have little potential for network deferral due to high capacity needs and low EE potential.

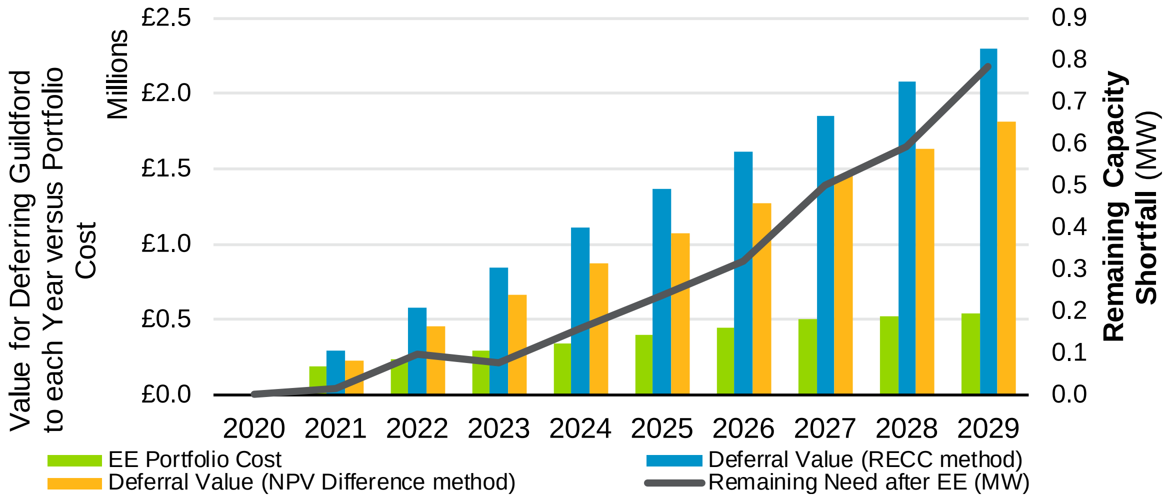
CBA Carnaby

UKPN Planned Upgrade Year:	2024
Upgrade Year with Cost-Effective EE - RECC	2025
Upgrade Year with Cost-Effective EE - Difference of NPV	2025



CBA Guildford

UKPN Planned Upgrade Year:	2020
Upgrade Year with Cost-Effective EE - RECC	2020
Upgrade Year with Cost-Effective EE - Difference of NPV	2020



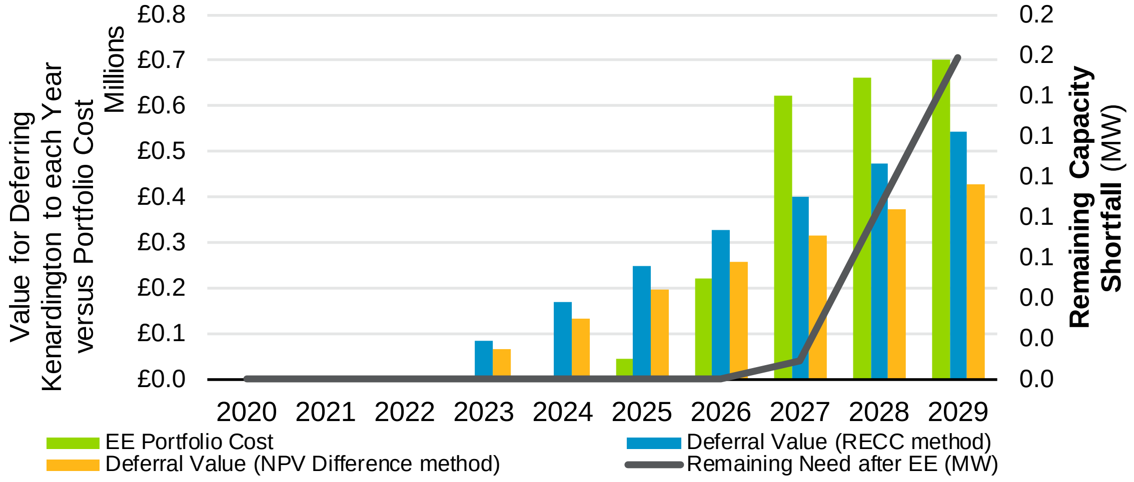
Source: Navigant analysis.

CBA PER SUBSTATION

Kenardington and West Horndon show potential for EE measures to cost-effectively defer upgrades.

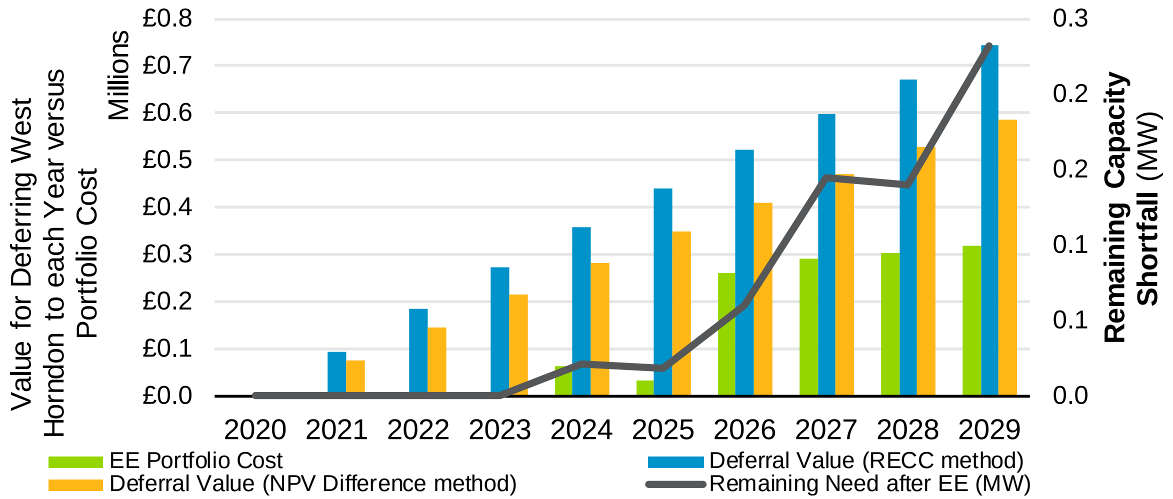
CBA Kenardington

UKPN Planned Upgrade Year:	2022
Upgrade Year with Cost-Effective EE - RECC	2026
Upgrade Year with Cost-Effective EE - Difference of NPV	2026



CBA West Horndon

UKPN Planned Upgrade Year:	2020
Upgrade Year with Cost-Effective EE - RECC	2023
Upgrade Year with Cost-Effective EE - Difference of NPV	2023



West Horndon has no forecasted load growth until 2024, so strictly speaking this is not a true deferral.

Source: Navigant analysis.

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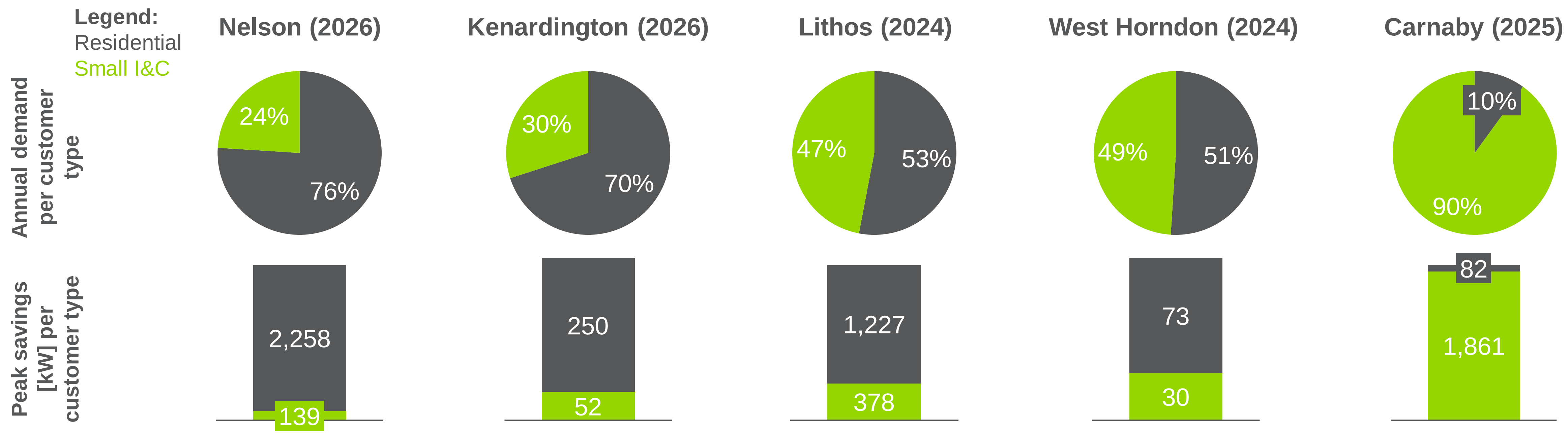
TOP EE MEASURES – MOST COST-EFFICIENT

The most cost-efficient EE measures are similar across all substations, although their relative contributions to peak savings depend on the customer mix.



Lowest-cost measures

Residential EE measures
- LED lighting
- efficient refrigeration appliances
- low-flow shower heads

Small commercial EE measures
- LED lighting
- Non-res cooking: electric pressure less steamer

Small industrial EE measures
- Centrifugal fans

Source: Navigant analysis.

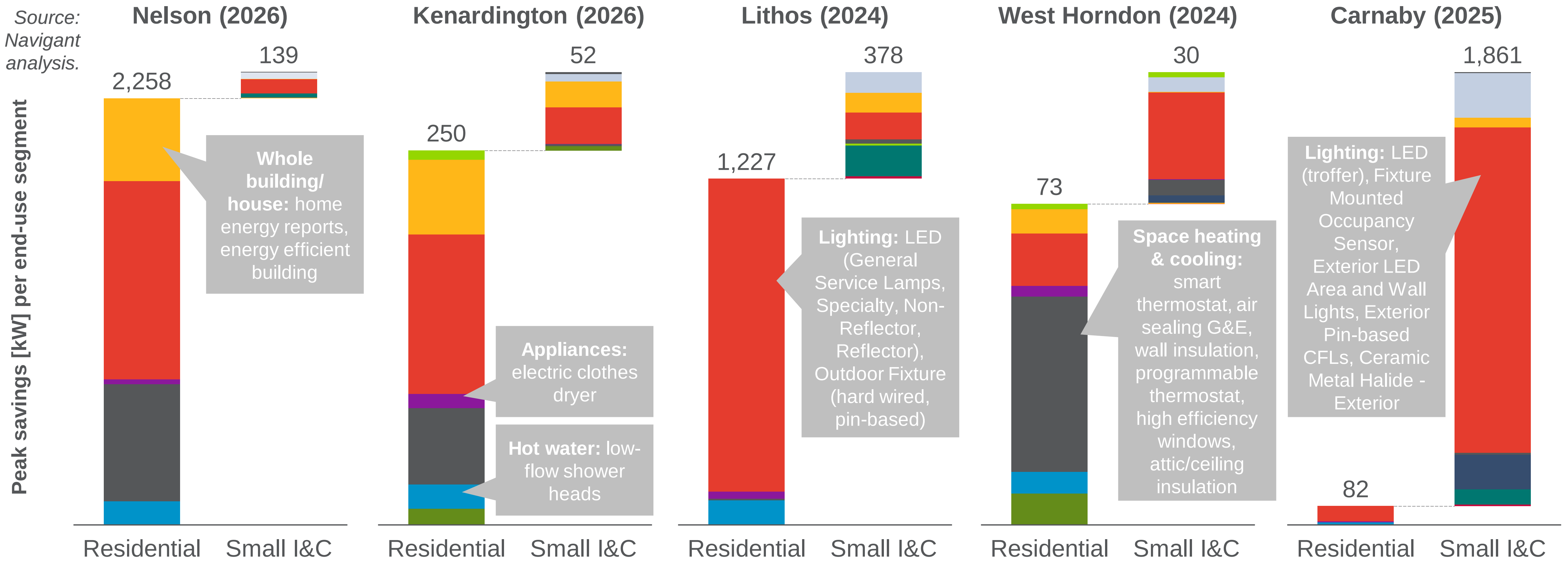
EE POTENTIAL MODELLING

TOP EE MEASURES – LARGEST PEAK SAVINGS

Legend: whole building/house Lighting Appliances Space heating & cooling Hot water Space heating/space cooling non-res refrigeration non-res cooking fans, motors, blowers, pumps compressed air electronics and office equipment

The EE measures offering the largest peak savings vary significantly across the substations according to the customer mix at each.

Source: Navigant analysis.



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