DEFENDER

WP1.4 Case Study Report

National Grid Electricity Distribution

19 April 2023

→ **The Power of Commitment**

Project name	Household Energy Retrofit Support
Document title	DEFENDER | WP1.4 Case Study Report
Project number	12564539
File name	2023-04-19 - Case Study Report F1 Issue.docx

Status Code	Revision	Author	Reviewer		Approved for issue		
			Name	Signature	Name	Signature	Date
S3	D0	N Edwards D Thorn	D Thorn	DT	N Murdoch	NM	23/02/23
S4	F0	N Edwards D Thorn	D Thorn		D Hardman		12/04/23
S4	F1	N Edwards D Thorn	D Thorn		D Hardman		19/04/23

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The Power of Commitment

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1. Introduction

To meet net zero targets, individual households and business premises will need to play a part through implementation of decarbonisation measures. These measures are expected to consist of a combination of energy efficiency and behavioural changes, which will require an increased understanding of the changing demand profiles and energy saving measures on the part of Distribution Network Operators (DNOs).

The Demand Forecasting Encapsulating Domestic Efficiency Retrofits (DEFENDER) project aims to investigate and create tools capable of working towards this goal.

As part of the project, GHD has completed the following activities:

– A scoping exercise completed as part of WP0 in conjunction with the Carbon Trust and Hildebrand (relating to subsequent work on WP1) and Frontier Economics (relating to WP2). This concluded in a GHD Scoping Document that was finalised in June 2022 [1], which included details of the process used to identify suitable trial network areas. Three case study network areas were selected by agreement between NGED, the Carbon Trust and GHD, comprising of a single 11kV feeder in each of three primary substation networks, as follows:
    - Mackworth 33/11kV substation, 11kV feeder: 870038/0010;
    - Withycombe Raleigh 33/11kV substation, 11kV feeder: 310037/0024; and
    - Axbridge 33/11kV substation, 11kV feeder: 180017/0001.
– At the outset of WP1.4, a literature review of the existing and prospective alternative approaches to modelling the impact of energy efficiency measures as part of DNO demand forecasting processes (DFES). The results from this review have been captured in a Literature Review Report finalised 5 July 2022 [2];
– Subsequently in WP1.4, a network model validation exercise, which comprised preparation of network models in PSS[1] SINCAL for the three trial areas that were selected for the project, and confirmation of the suitability of these. The results of this activity were captured in a Network Model Validation Report, also completed in July 2022 [3]; and
– As part of our role to support the other activities in WP1, provision of comments on the User Acceptance Testing (UAT) plan and UAT findings for the testing of the tool developed by Hildebrand.

This case study analysis report presents the results of network modelling to show the impact of the derived demand profiles on the selected distribution network areas. It follows the development and application of a tool by the Carbon Trust and Hildebrand to prepare the relevant demand profiles, and a period of consultation between GHD and the other partners to support the validation of the profiles and agree a format that can be imported into a half-hourly time series database for use in PSS SINCAL.

1.1 Scope

The GHD scope of work for WP1.4 was to undertake power flow studies using network models in the PSS SINCAL 11kV network planning tool, incorporating bespoke demand profiles developed by the Carbon Trust using a tool developed by Hildebrand as part of the project. The profiles were prepared for different scenarios based on analysis of the behaviour of each house archetype making up the case study network areas. GHD was requested to provide limited support for the validation of the output demand profiles.

The network studies employed time series analysis to apply half-hourly After Diversity Maximum Demand (ADMD) low voltage profiles to each 11/0.415 kV substation on the selected HV feeders. It was requested that the range of profiles prepared by the Carbon Trust and Hildebrand should be applied in the network analysis, covering a range of energy efficiency scenarios, selected years between now and 2050, and representative days in each year accounting for seasonal variations.

The results from the network modelling looked to establish the asset overloads to inform the reinforcement requirements for the subsequent Cost Benefit Analysis (CBA) to be carried out by the Carbon Trust. The approach to use scenarios was adopted to enable the difference in asset loading resulting from different levels of uptake of

[1] PSS is a registered trademark for the Siemens power system simulation and modelling software. GHD undertook modelling in the project using the ‘PSS®SINCAL’ software package, henceforth referred to as ‘PSS SINCAL’. In addition, references to the PSS®E transmission planning and analysis software adopted by NGED are henceforth ‘PSS/E’.

energy efficiency measures to be observed. In addition to identifying required investment for network reinforcements, this report looks to:

– Discuss the planning criteria for HV network reinforcements;
– Identify broader issues relating to accommodation of HPs by DNOs;
– Compare the analysis with alternative approaches identified in literature review; and
– How to integrate the analysis with existing BAU processes, e.g. for preparation of the DFES.

1.2 Assumptions

Several assumptions have been identified in relation to the case study analysis, as follows:

– **Network models -** The network models are based on the latest PSS SINCAL models, which have been prepared using NGED's GIS data. The models have been adopted as described in the Network Model Validation Report [3], including being streamlined to include only the selected HV feeders. This ensures that the results are easier to interpret and mitigates possible interference from adjacent HV network feeders that are not part of the trial area;
– **Demand profiles for validation** – A summary of the observations provided by GHD to the Carbon Trust and Hildebrand about the initial profiles, for consideration for the validation of the profiles, is provided in Section 3.1 and Appendix A-1. No further manipulation or validation of the profiles has been undertaken by GHD. The bespoke demand profiles provided by the Carbon Trust and Hildebrand for the individual distribution substations have been applied directly within the PSS SINCAL models via time series database files;
– **EE interventions** - the demand profiles developed by the Carbon Trust and Hildebrand for the project analysis exclusively represent the impact of energy efficiency interventions in combination with HP installations, in line with the rate of HP uptake from the DFES Consumer Transformation scenario;
– **Reactive power** - The Carbon Trust and Hildebrand provided half-hourly profiles for the real power demand on each distribution substation across the case study areas. No profiles were prepared for reactive power demand, and unity power factor has been assumed for all loads.
– **Diversity** – It is assumed that the demand profile data provided by the Carbon Trust corresponds to After Diversity Maximum Demand (ADMD) profiles which account for the impact of diversity at the appropriate network level;
– **Asset ratings** – The network models have been developed using asset ratings from the NGED CROWN Enterprise Asset Management system. In the case of the transformers, these correspond to continuous nameplate ratings;
– **Nature of network studies** – The network studies have been limited to load flow studies only. Any other considerations, e.g. fault level constraints, have not been investigated as part of the project; and
– **Outcomes from the project -** The study is not showing the impact of uptake of HPs per se, since the scenarios have been developed by the Carbon Trust and Hildebrand to show the incremental impact of energy efficiency measures for a given level of HP uptake (based on the Consumer Transformation DFES scenario).

2. Modelling methodology

The modelling undertaken by GHD in WP1.4 of the project, which is the subject of this report, comprised load flow studies using network models in NGED's 11kV planning tool (PSS SINCAL). These studies were completed for each half-hour time step for selected days, years and scenarios to fully understand the impact of EE measures on the network. Demand profiles from the tool developed by the Carbon Trust and Hildebrand were imported as inputs to the network modelling for these days.

This section presents details of the modelling methodology adopted, comprising details of the:

- Nature of the input half-hourly demand profiles:
  - Scenarios in section 2.1;
  - Representative days in section 2.2;
  - Case study areas in section 2.3;
- Network model input data and settings:
  - Input Data in section 2.4; and
  - Study settings in section 2.5.

2.1 Scenarios

The Scenarios Methodology [4] report produced by the Carbon Trust and Hildebrand describes how the energy efficiency scenarios were derived for use in the project analysis. The scenarios are based on the Climate Change Committee's (CCC) Balanced Pathway, as detailed in its 6th Carbon Budget, which corresponds to the Medium Energy Efficiency scenario for the project analysis. Two other EE scenarios, Low and High, were derived to represent the extremes of uptake in fabric measures to upgrade thermal efficiency of properties. These fabric measures were modelled, according to the scenario assumptions, in combination with the heat pump (HP) installation projection from the DFES Consumer Transformation scenario.

The methodology adopted by the Carbon Trust and Hildebrand, as described in the Scenarios Methodology report, developed a building stock database for each of the case study areas selected for the project. These were selected following discussions between the project team based on an initial shortlist presented in the GHD Scoping Document [1], as well as consideration of factors including: proportion of domestic buildings; projected HP uptake from DFES; and coverage of EPC data. Several datapoints were extracted from the EPCs to allow the houses to be categorised into archetypes and sub-archetypes, which were then categorised as having high, medium or low thermal efficiency.

Once the building stock was characterised into the three levels of thermal efficiency, the different types of EE improvement as well as the rate of EE improvements could be calculated. The rate of energy efficiency interventions was based on the rate of HP installations, available from DFES at a primary substation or Electricity Supply Area (ESA) level. It was assumed that HP uptake will be the principal driver for energy efficiency interventions. As such, the demand profiles developed by the Carbon Trust and Hildebrand for the project analysis exclusively represent the impact of energy efficiency interventions in combination with HP installations.

It should be noted that the number of HP installations in DFES varies by scenario. However, this Case Study Report only focusses on profiles developed for the Consumer Transformation scenario. Figure 2.1 provides an illustration of the DFES scenario assumptions for the uptake of domestic non-hybrid air source heat pumps (ASHPs) in the Mackworth primary substation area. Further work would likely include a comparison with the Falling Short scenario, to expand the analysis to cover the upper and lower bounds of heat electrification.

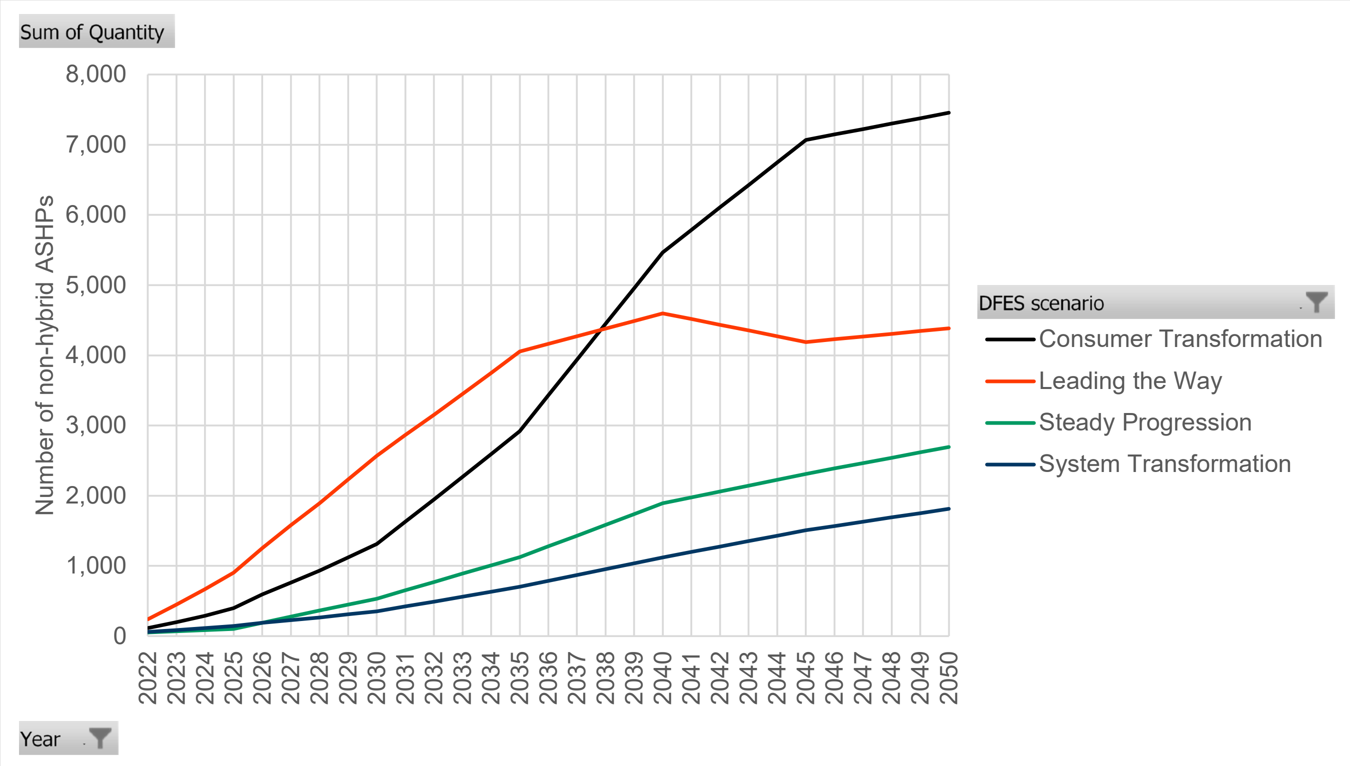


Figure 2.1 Illustration of DFES 2021 assumptions for uptake of domestic non-hybrid ASHPs in the Mackworth primary substation area (points interpolated between 2035, 2040, 2045 and 2050)

HP installations in an ESA are split evenly across all properties, i.e. there is no weighting towards more efficient homes. Table 2.1 indicates the level of EE interventions applied to the different property categories under each project EE scenario. This is based on the assumed principles that:

– Buildings with low efficiency must be increased to medium or high before HPs could be installed, as high-temperature HPs were excluded from the study due to running costs;
– Medium efficiency buildings would either remain as medium or increase to high efficiency following the installation EE measures;
– High efficiency buildings were already placed in the top category where they would remain, and no further measures would be installed.

Table 2.1 Application of EE measures

	Level of EE intervention		
Property efficiency category	**Low EE scenario**	**Medium EE scenario**	**High EE scenario**
Low	All properties will upgrade to Medium efficiency	68% of properties will upgrade to Medium efficiency 32% of properties will upgrade to High efficiency	All properties will upgrade to High efficiency
Medium	All properties will remain at Medium efficiency	34% of properties will remain at Medium efficiency 66% of properties will upgrade to High efficiency	All properties will upgrade to High efficiency
High	All properties will remain at High efficiency	All properties will remain at High efficiency	All properties will remain at High efficiency

2.2 Representative days

For each energy efficiency scenario it was agreed that half-hourly profiles would be provided for three representative days for the years 2030 and 2050 by the Carbon Trust and Hildebrand. This enabled GHD to determine the impact of seasonal variations in temperature on the loading of the distribution network assets. The days for which the profiles have been prepared comprise:

– Intermediate (average autumn/spring conditions);
– Winter (average winter conditions); and
– Extreme (1-in-20 winter conditions).

The dates for each of the representative days are shown in Table 2.2 and were provided in the distribution profiles. It should be noted that the dates are used in both 2030 and 2050 (i.e. for Winter profiles, 10/01/2030 and 10/01/2050 are both valid dates).

For all three case study areas, the Winter, Extreme and Intermediate days are set to 10 January, 28 February and 10 October respectively.

Table 2.2 Dates chosen for representative days

Case Study Area	Representative Day	Date
Axbridge	Winter	10 January
Axbridge	Intermediate	10 October
Axbridge	Extreme	28 February
Mackworth	Winter	10 January
Mackworth	Intermediate	10 October
Mackworth	Extreme	28 February
Withycombe Raleigh	Winter	10 January
Withycombe Raleigh	Intermediate	10 October
Withycombe Raleigh	Extreme	28 February

In addition to the demand profiles for the future scenarios, baseline demand profiles corresponding to recent historical average winter day conditions were provided by the Carbon Trust and Hildebrand for comparison. These were also used by them for validation purposes, as described in their project reports.

2.3 Case study areas

The case study feeders chosen for analysis are 180017/0001 Axbridge (South West), 870038/0010 Mackworth (East Midlands) and 310037/0024 Withycombe Raleigh (South West). Figure 2.2 shows the locations of the sites within a map of the NGED distribution network.

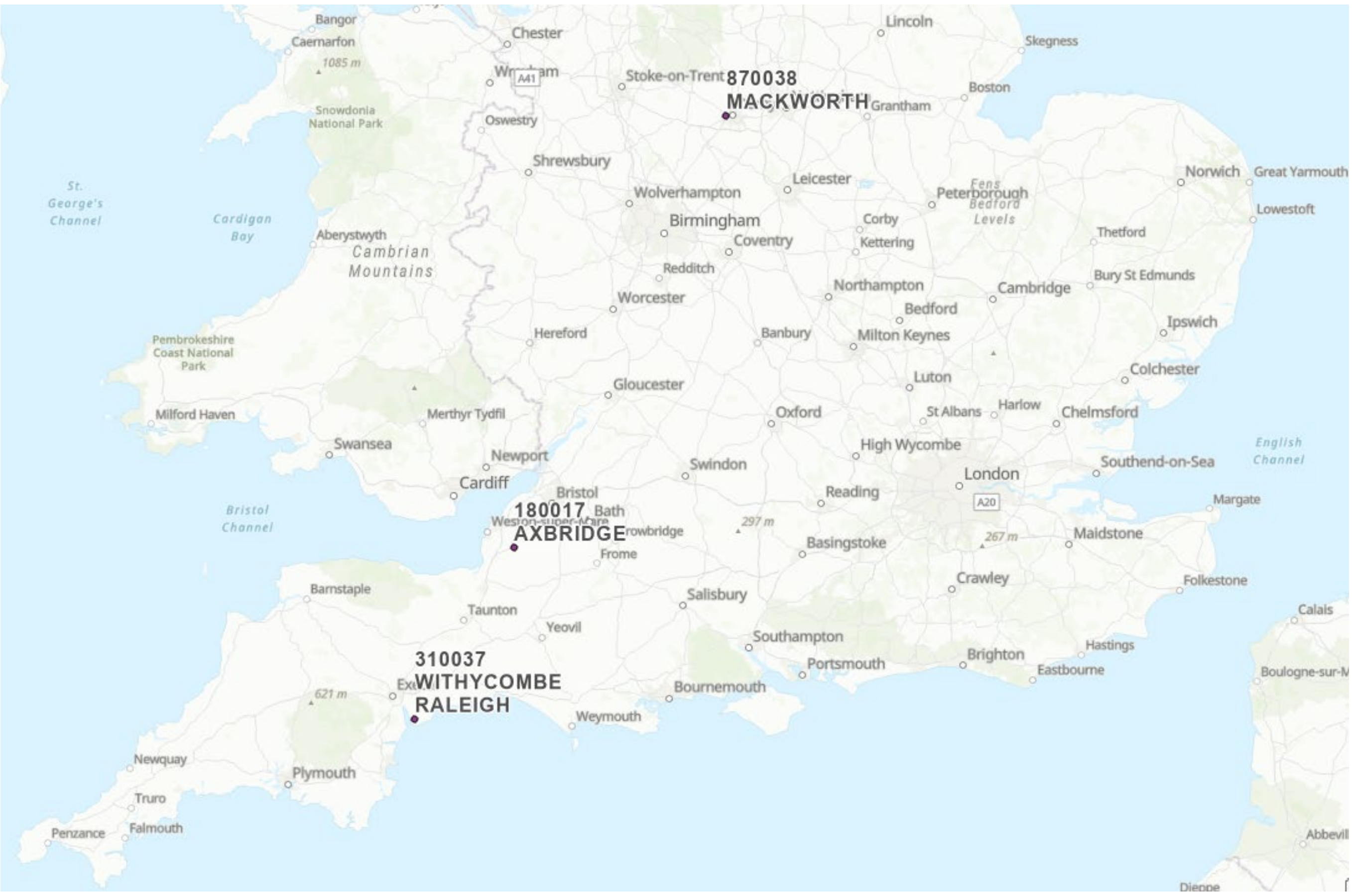


Figure 2.2 *Map showing location of case study sites within the NGED distribution network*

Figure 2.3, Figure 2.4 and Figure 2.5 show screenshots of the individual feeders, as represented in the PSS SINCAL models. The locations of the primary substations are indicated by black circles, and the different conductor types are highlighted in different colours (with labels showing asset ID, conductor type and Amp rating). In addition, Single Line Diagrams (SLDs) with the selected feeders highlighted are presented in Appendix C-1, and Table 2.3, Table 2.4 and Table 2.5 show the numbers of houses per distribution substation on each of the feeders.

Figure 2.3 PSS SINCAL view of Axbridge feeder 1

Table 2.3 Axbridge house numbers per distribution substation

Primary Name	Primary No/HV Feeder No	Sub Number	Distribution Substation Name	Total Houses
Axbridge	180017/0001	180292	Cheddar St	100
Axbridge	180017/0001	181960	Hippisley Drive	152

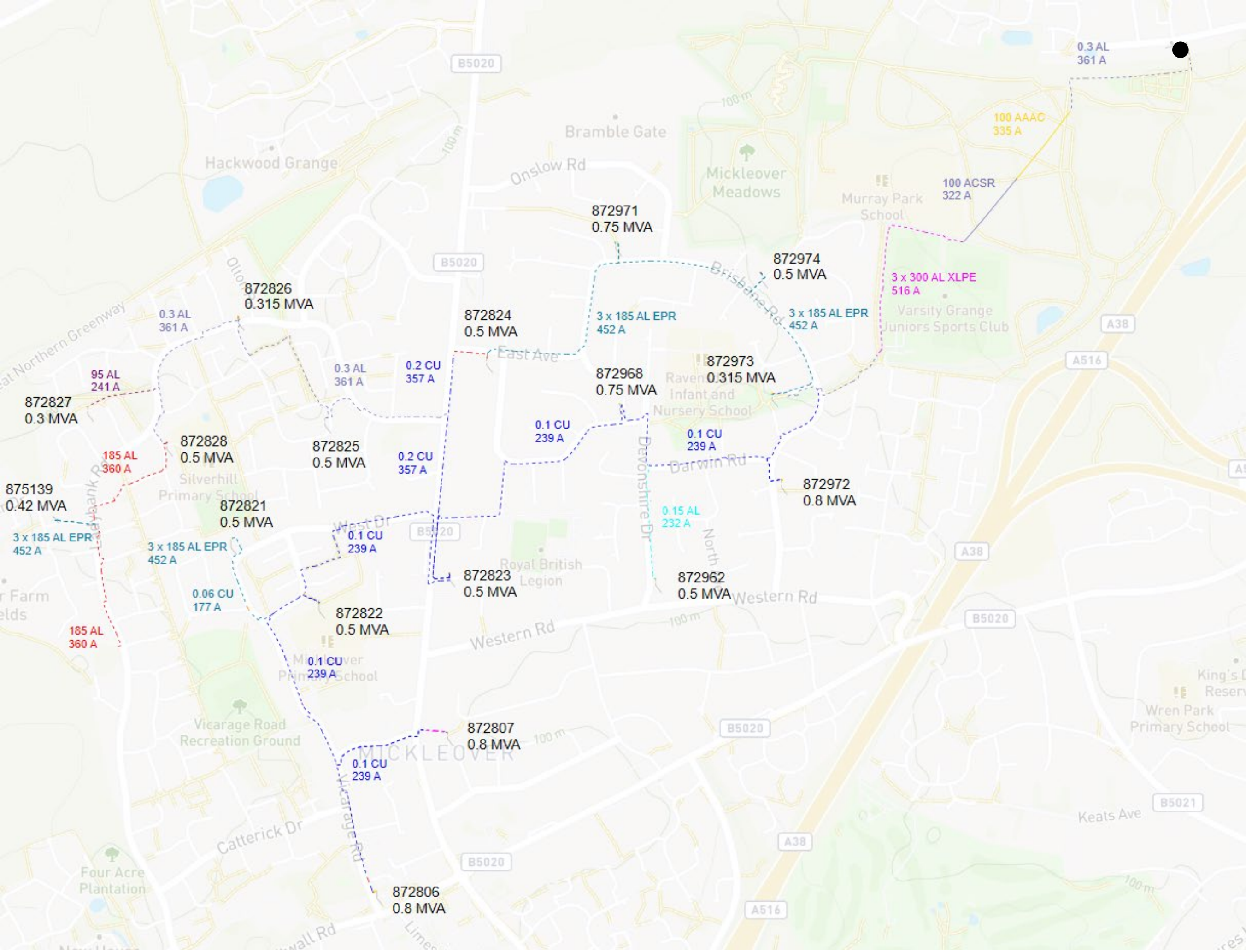


Figure 2.4 PSS SINCAL view of Mackworth feeder 10

Table 2.4 Mackworth house numbers per distribution substation

Primary Name	Primary No/HV Feeder No	Sub Number	Distribution Substation Name	Total Houses
Mackworth	870038/0010	872806	Vicarage Road Mickleover	313
Mackworth	870038/0010	872807	Portland Close, Mickleover	283
Mackworth	870038/0010	872821	West Drive, Mickleover	166
Mackworth	870038/0010	872822	Farneworth Road	224
Mackworth	870038/0010	872823	Edale Avenue	208
Mackworth	870038/0010	872824	East Avenue	113
Mackworth	870038/0010	872825	Chilson Drive, Mickleover	227
Mackworth	870038/0010	872826	Ladybank Road, Mickleover	203
Mackworth	870038/0010	872827	Brampton Close, Mickleover	170
Mackworth	870038/0010	872828	Draycott Drive, Mickleover	215
Mackworth	870038/0010	872962	Devonshire Drive	245
Mackworth	870038/0010	872968	Chestnut Avenue Mickleover	246
Mackworth	870038/0010	872971	Brisbane Road No.2, Mickleover	232
Mackworth	870038/0010	872972	Brisbane Road No.1	193

Primary Name	Primary No/HV Feeder No	Sub Number	Distribution Substation Name	Total Houses
Mackworth	870038/0010	872973	Sydney Close	100
Mackworth	870038/0010	872974	Murray Road, Mickleover	224
Mackworth	870038/0010	875139	Swayfield Close	165[2]

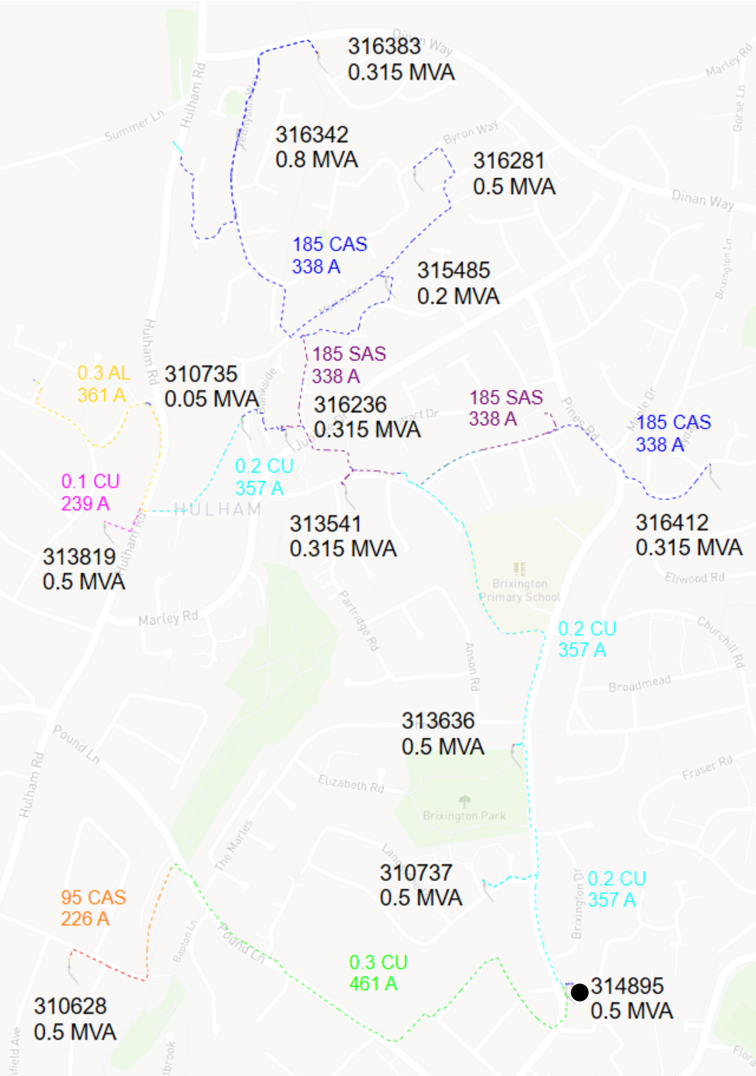


Figure 2.5 *PSS SINCAL view of Withycombe Raleigh feeder 24*

Table 2.5 *Withycombe Raleigh house numbers per distribution substation*

Primary Name	Primary No/HV Feeder No	Sub Number	Distribution Substation Name	Total Houses
Withycombe Raleigh	310037/0024	310628	Bapton Lane	217
Withycombe Raleigh	310037/0024	310735	Symonds Farm	4
Withycombe Raleigh	310037/0024	310737	Parsons Close	163
Withycombe Raleigh	310037/0024	313541	Partridge Road	174
Withycombe Raleigh	310037/0024	313636	The Marles Rear of No 130	171
Withycombe Raleigh	310037/0024	313819	Westleigh	180
Withycombe Raleigh	310037/0024	314895	Withycombe Raleigh Local	213

[2] Swayfield Close is an HV connection to a new housing development, which will be supplied by an IDNO. This housing development is not yet connected and does not have a Baseline profile, but the houses have been modelled in the future scenario profiles.

Primary Name	Primary No/HV Feeder No	Sub Number	Distribution Substation Name	Total Houses
Withycombe Raleigh	310037/0024	315485	Hollymount Close	121
Withycombe Raleigh	310037/0024	316236	Priddis Close	47
Withycombe Raleigh	310037/0024	316281	Byron Way	216
Withycombe Raleigh	310037/0024	316342	Lovering Farm Estate	179
Withycombe Raleigh	310037/0024	316383	Dinan Tower	76
Withycombe Raleigh	310037/0024	316412	Ivydale	82

2.4 Input Data

2.4.1 Circuit Data

Table 2.6, Table 2.7 and Table 2.8 show impedance and rating data for the circuit elements that make up the selected HV feeders in Axbridge, Mackworth and Withycombe Raleigh primary substation areas, respectively. This data has been extracted from the PSS SINCAL models. Both the Winter and Intermediate ratings are shown for the circuit elements, as the loading results for the Intermediate representative days are compared with the separate, lower Intermediate rating. The Winter rating is used for assessment of the results for both the Winter and Extreme representative days.

Table 2.6 Axbridge feeder 1 circuit elements

				Thermal Rating (kA)
Type Name	**Circuit Type**	**Total Length (m)**	**X (Ohm/km)**	**Intermediate**
0.1 CU	Cable	144.9	0.089	0.227
95 AL	Cable	148.9	0.091	0.228
185 SAS	Cable	165.5	0.080	0.320
0.3 AL	Cable	175.0	0.078	0.342
3 x 185 1c TxAL EPR	Cable	7.0	0.107	0.424

				Thermal Rating (kA)
Type Name	Circuit Type	Total Length (m)	X (Ohm/km)	Intermediate

Table 2.7 Mackworth feeder 10 circuit elements

					Thermal Rating (kA)	
Type Name	Circuit Type	Total Length (m)	R (Ohm/km)	X (Ohm/km)	Winter	Intermediate
0.06 CU	Cable	153.4	0.463	0.096	0.177	0.169
0.15 AL	Cable	248.7	0.312	0.084	0.232	0.221
0.1 CU	Cable	3,278.1	0.276	0.089	0.239	0.227
95 AL	Cable	179.6	0.321	0.091	0.241	0.228
3 x 70 1c Al XLPE	Cable	11.4	0.443	0.123	0.256	0.242
0.15 CU	Cable	88.6	0.188	0.084	0.299	0.284
95 CU	Cable	4.9	0.194	0.091	0.310	0.294
3w 100 ACSR	Overhead line	177.0	0.305	0.381	0.322	0.299
3w 100 AAAC	Overhead line	183.4	0.277	0.358	0.335	0.310
0.2 CU	Cable	672.9	0.142	0.081	0.357	0.339
185 AL	Cable	681.1	0.165	0.083	0.360	0.340
0.3 AL	Cable	1,799.2	0.153	0.078	0.361	0.342
3 x 185 1c Al XLPE Ducted	Cable	31.5	0.164	0.104	0.402	0.389
3 x 185 1c Al XLPE	Cable	58.8	0.164	0.104	0.452	0.426
3 x 185 1c TxAL EPR	Cable	1,573.2	0.165	0.107	0.452	0.424
3 x 300 1c Al XLPE Ducted	Cable	445.6	0.100	0.097	0.516	0.499
3 x 185 1c XLPE	Cable	7.2	0.104	0.127	0.595	0.561

Table 2.8 Withycombe Raleigh feeder 24 circuit elements

					Thermal Rating (kA)	
Type Name	Circuit Type	Total Length (m)	R (Ohm/km)	X (Ohm/km)	Winter	Intermediate
0.1 AL	Cable	3.3	0.456	0.090	0.185	0.176
95 CAS	Cable	155.9	0.321	0.087	0.226	0.215
0.1 CU	Cable	85.6	0.276	0.089	0.239	0.227
3w 0.1 AL AL	Overhead line	21.8	0.277	0.358	0.335	0.310
185 SAS	Cable	545.9	0.165	0.080	0.338	0.320
185 CAS	Cable	2218.3	0.165	0.080	0.338	0.320
0.2 CU	Cable	1,308.9	0.142	0.081	0.357	0.339
185 AL	Cable	107.7	0.165	0.083	0.360	0.340

					Thermal Rating (kA)	
Type Name	Circuit Type	Total Length (m)	R (Ohm/km)	X (Ohm/km)	Winter	Intermediate
0.3 AL	Cable	423.9	0.153	0.078	0.361	0.342
3 x 185 1c TxAL EPR	Cable	9.9	0.165	0.107	0.452	0.424
0.3 CU	Cable	841.1	0.092	0.078	0.461	0.437
3 x 300 1c TxAL EPR	Cable	14.3	0.102	0.100	0.598	0.561
0.75 1c CU	Cable	28.7	0.037	0.090	0.904	0.845

2.4.2 Transformer Data

Table 2.9, Table 2.10 and Table 2.11 show the impedance and rating data for the HV/LV transformers connected to the selected HV feeders in the Axbridge, Mackworth and Withycombe Raleigh primary substation areas, respectively. Additionally, the assumed vector group of the transformers is shown, with all assets being assigned vector group DYN11 except for 310735_TX0 in the Withycombe Raleigh primary substation area.

Table 2.9 Axbridge transformers

Name	Primary Voltage (kV)	Secondary Voltage (kV)	Rated Apparent Power (MVA)	R (%)	X (%)	Vector Group
180292_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
181960_TX0	11	0.433	0.5	1.35741	4.56027	DYN11

Table 2.10 Mackworth transformers

Name	Primary Voltage (kV)	Secondary Voltage (kV)	Rated Apparent Power (MVA)	R (%)	X (%)	Vector Group
872806_TX00	11	0.433	0.8	1.24167	4.56560	DYN11
872807_TX0	11	0.433	0.8	1.24167	4.56560	DYN11
872821_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872822_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872823_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872824_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872825_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872826_TX0	11	0.433	0.315	1.51377	4.50266	DYN11
872827_TX0	11	0.433	0.3	1.51689	4.49626	DYN11
872828_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872962_TX0	11	0.433	0.5	1.35741	4.56027	DYN11
872968_TX0	11	0.433	0.75	1.25207	4.60027	DYN11
872971_TX0	11	0.433	0.75	1.25207	4.60027	DYN11
872972_TX0	11	0.433	0.8	1.24167	4.56560	DYN11
872973_TX0	11	0.433	0.315	1.51377	4.50266	DYN11
872974_TX0	11	0.433	0.5	1.35741	4.56027	DYN11

875139_L0 is also present in the model, with an ASC of 0.42MVA; however, it is an HV-metered customer, so it has no transformer.

Table 2.11 Withycombe Raleigh transformers

Name	Primary Voltage (kV)	Secondary Voltage (kV)	Rated Apparent Power (MVA)	R (%)	X (%)	Vector Group
310037_TX0	11	0.433	0.500	1.35741	4.56027	DYN11
310628_TX0	11	0.433	0.500	1.35741	4.56027	DYN11
310735_TX0	11	0.250	0.050	1.68543	4.33092	Y0
310737_TX0	11	0.433	0.500	1.35741	4.56027	DYN11
313541_TX0	11	0.433	0.315	1.51377	4.50266	DYN11
313636_TX0	11	0.433	0.500	1.35741	4.56027	DYN11
313819_TX0	11	0.433	0.500	1.35741	4.56027	DYN11
315485_TX0	11	0.433	0.200	1.68543	4.33092	DYN11
316236_TX0	11	0.433	0.315	1.51377	4.50266	DYN11
316281_TX0	11	0.433	0.500	1.35741	4.56027	DYN11
316342_TX0	11	0.433	0.800	1.24167	4.56560	DYN11
316383_TX0	11	0.433	0.315	1.51377	4.50266	DYN11
316412_TX0	11	0.433	0.315	1.51377	4.50266	DYN11

2.5 Study settings

Figure 2.6 and Figure 2.7 outline the processes followed to produce the PSS SINCAL models and run the studies, from which the results presented in this document have been derived.

The initial stage involved creating the PSS SINCAL substation models for each of the three case study areas (selected HV feeders in Axbridge, Mackworth and Withycombe Raleigh primary substation areas), using a process developed in FME Workbench. Given that, in each case, only a single feeder was being studied, any additional 11kV feeders at the primary substation were removed in order to simplify the models. A comparison was then undertaken between the PSS SINCAL models and data from NGED’s EMU schematics and CROWN feeder reports, as described in the GHD Network Model Validation Report [3]. That report provides greater detail about the validation process, which resulted in quality assured models.

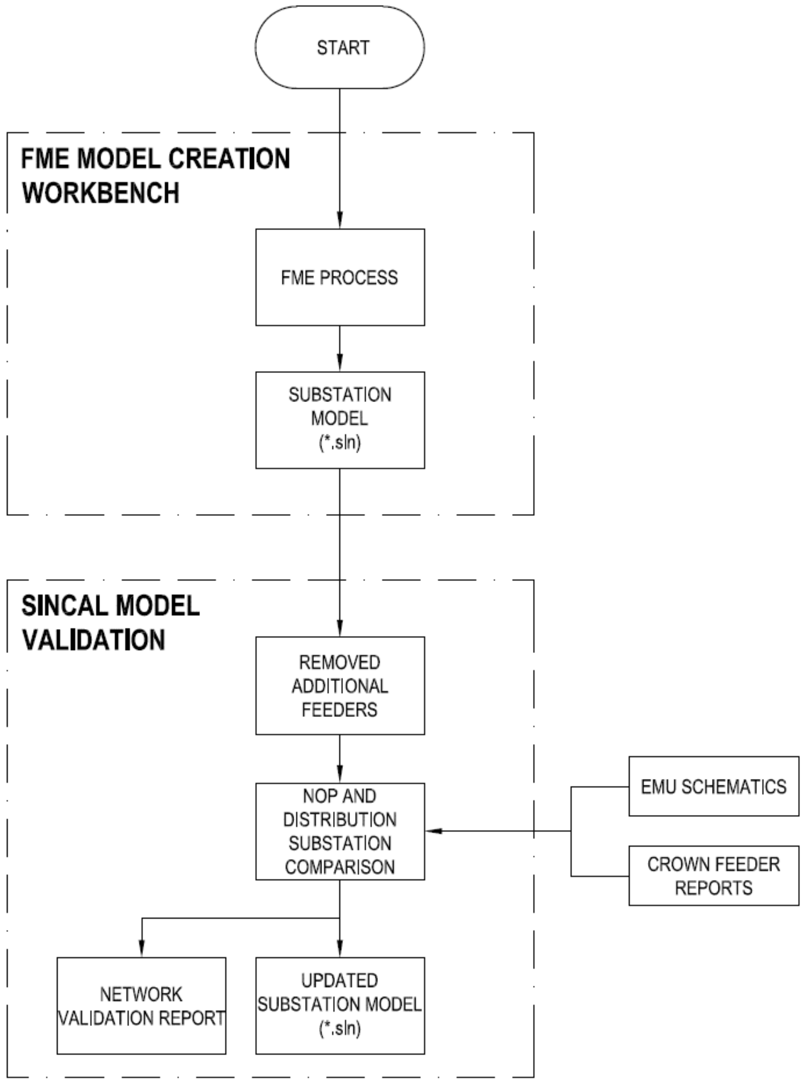


Figure 2.6 PSS SINCAL Network Model Validation Process Diagram

Following the validation process, load profile data was received from the Carbon Trust and Hildebrand for each distribution substation across the case study areas. It should be noted that no profiles were provided for reactive power demand, and unity power factor has been assumed for all loads. This was deemed to be reasonable by the project team as it is:

1. Due to the lack of a strong evidence base to support assumptions for the average HP power factor; and
2. Consistent with NGED's current forecasting approach.

A 2022 base profile was received from the Carbon Trust and Hildebrand for each case study area, which was processed and imported into an SQLite database, allowing it to be ingested into the corresponding PSS SINCAL model. Each Load element in the PSS SINCAL models was assigned a unique identifier, a Master Resource ID (MRID), which was mapped to a record in the Topology table of the SQLite database.

A time series power flow study was undertaken for each of the representative days in the 2022 profile and the initial results were extracted for analysis. Further profiles were received for 2030 and 2050, in line with the project EE scenarios described in Section 2.1 for the representative days and case study areas described in Sections 2.2 and 2.3, respectively. The process for creating and populating the SQLite database was repeated, with three databases being produced for each case study area, representing the low, medium and high energy efficiency scenarios.

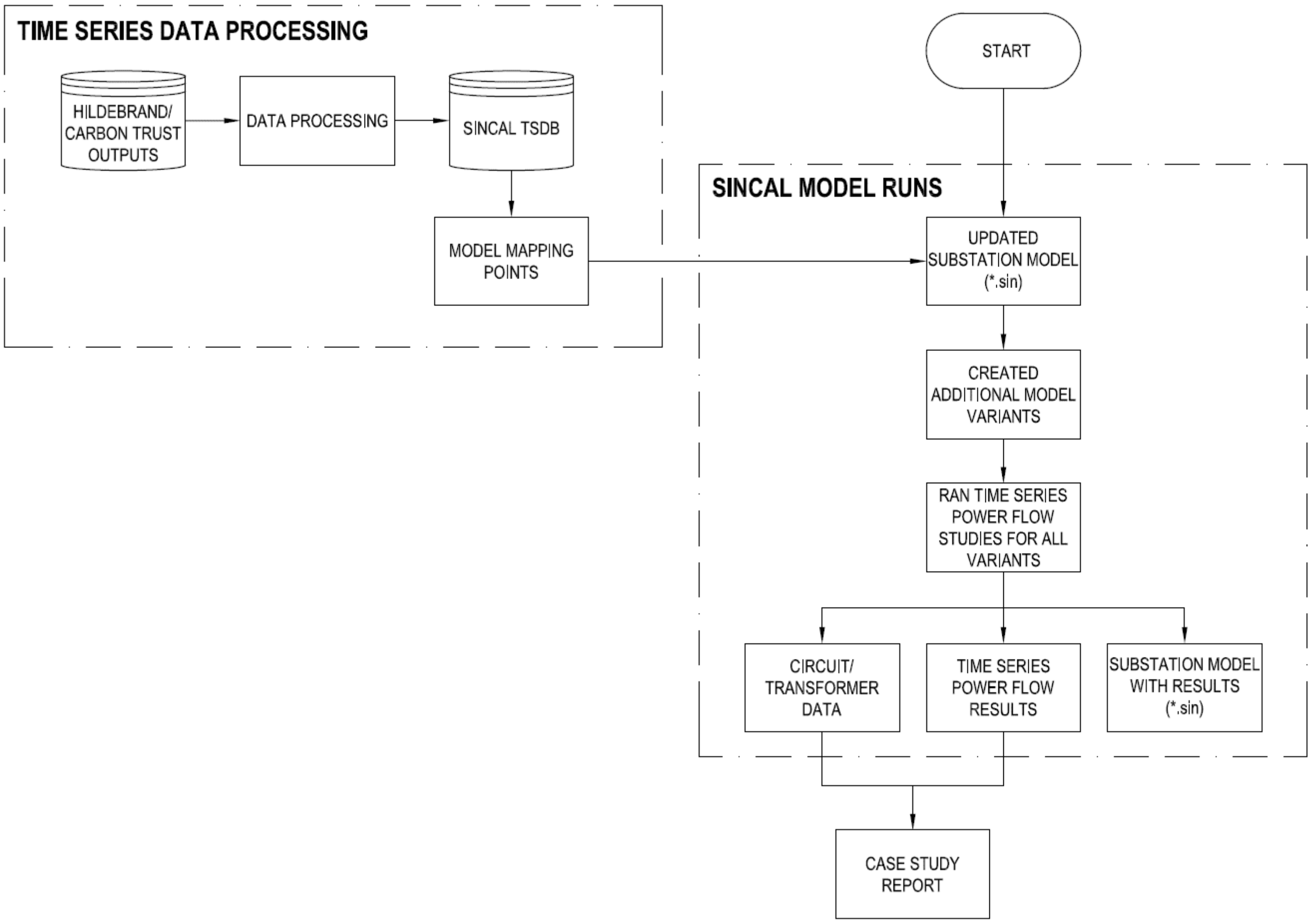


Figure 2.7 Time Series Study Process Diagram

Within the PSS SINCAL models, variants and sub-variants were created for each study year, energy efficiency scenario and representative day, as per the structure shown in Figure 2.8. This structure allows calculation settings to be passed down to sub-variants. As a result, the appropriate SQLite database was selected at the third variant level (energy efficiency measures), and the calculation dates were selected at the fourth variant level (representative day). The calculation settings of the first two variant levels (base and study years) were left as defaults.

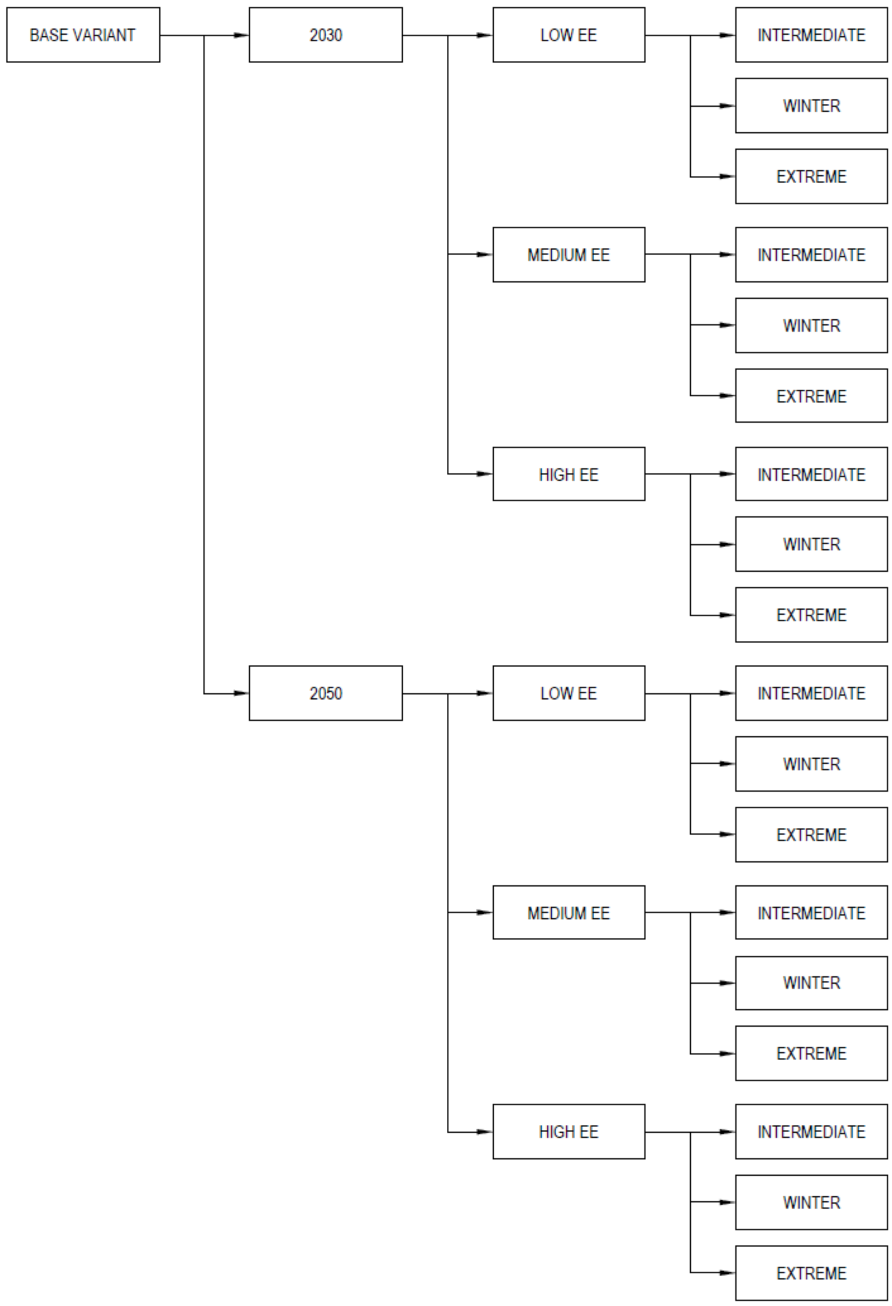


Figure 2.8 PSS SINCAL model variant structure

2.5.1 Scope changes

During the course of the project a number of minor changes to the scope of the network modelling have been agreed through discussions with the project team and NGED. Largely these have been necessary to maintain consistency with the modelling activities being undertaken by the Carbon Trust and Hildebrand, noting that the network modelling relies on the half-hourly demand profiles provided as inputs from those activities. Table 2.12 provides a summary to confirm the key points related to the scope of the network modelling.

Table 2.12 Summary of network modelling scope

Scope category	GHD Scoping Document	Outcome	Nature of change
Case study areas	11kV network models for three case study network areas, corresponding to three HV feeders	11kV network models for three case study network areas, corresponding to three HV feeders	No change (specific areas selected in consultation with the project team)
Number of scenarios	2019 baseline plus three future EE scenarios (definitions referenced from the Carbon Trust and Hildebrand Scoping Document [5]): – Baseline – electrification at lowest capex; – Scenario 1 – combination of EE measures that results in lowest peak load on the network; and – Scenario 2 – combination of EE measures that results in lowest cost for the homeowner	2019 baseline plus three future EE scenarios: – Low; – Medium; and – High	No change (scenario definitions clarified by the Carbon Trust and Hildebrand)
Number of years	2019 baseline plus three future scenario years: – 2030; – 2040; and – 2050	Baseline plus two future scenario years: – 2030; and – 2050	Intermediate future scenario year not provided based on recommendation by the Carbon Trust and Hildebrand to reduce the volume of data for analysis
Number of representative days	Three, to be selected from the five adopted by NGED DSO team in DFES: – Winter peak demand; – Intermediate cool peak demand; – Intermediate warm peak demand; – Summer peak demand; and – Summer peak generation	Three: – Intermediate; – Winter (average winter conditions); and – Extreme (1-in-20 winter conditions) NB. Demand profiles have only been provided for the three representative days for the future scenario years. The baseline profiles received for each distribution substation are limited to the average winter conditions only.	No change (representative day definitions clarified by the Carbon Trust and Hildebrand)
Half-hourly demand profiles	Real (P) and reactive (Q) power demand profiles	Only P profiles provided from the Carbon Trust and Hildebrand tool	No Q profiles provided so zero value input tables prepared and applied (assumed unity power factor for all distribution substation demands)
Adjustments to network models	GHD to implement adjustments to network models for: – Exclusion of other HV feeders from the case study network models; – Addition of non-domestic demand assumptions for selected feeders; and – Adjustment of models to account for anticipated developments to the network implemented prior to future study years.	Adjustments implemented, where required	No change

2.5.2 Limitations

In addition, a number of limitations have been identified during the course of the analysis, summarised as follows:

- The project scope was limited to:
  - Investigation of the incremental impact of energy efficiency measures for a given level of HP uptake (based on the Consumer Transformation DFES scenario). This means that alternative scenarios for the level of HP uptake were not explored, or those for uptake of HPs in combination with any other low carbon technologies (LCTs);
  - Investigation of the impact of energy efficiency measures on selected single HV feeders through application of demand profiles to the individual distribution substations connected to them;
  - The Carbon Trust and Hildebrand advised that due to rounding 'the number of houses in the scenario model, the 2030 Medium scenario has slightly fewer heat pumps than the 2030 high and low scenarios, which makes it not directly comparable. The High and Low scenarios for 2030 do have the same number of heat pumps, and all scenarios in 2050 have the same number of heat pumps, so these are comparable';
- The Carbon Trust and Hildebrand advised that the baseline profiles presented in the later sections of this report are based on 'more broad parameters for night storage… which the initial validation with real data highlighted as being wrong'. Changes to these parameters were adopted for the future scenarios, but the baseline profiles are not entirely consistent with these; and
- Finally, the Carbon Trust and Hildebrand advised that the future scenario profiles for the selected HV feeder in the Mackworth primary substation area are based on input data with 'a few discrepancies in the number of heat pumps vs fossil fuel systems in some of the substations'.

3. Comparison of profiles

This section presents a comparison of the demand profiles provided by the Carbon Trust and Hildebrand for use in the network modelling activity. It provides details from an offline assessment of the profiles to confirm the validity of them and obtain insights about the overall impact of household energy retrofit solutions on the demand seen by the network.

This section is divided into four parts, as follows:

– Support for validation of demand profiles output from tool developed by the Carbon Trust and Hildebrand, discussed in Section 3.1;
– Feeder level comparison of half-hourly demand profiles provided for analysis, presented in Section 3.2;
– High level analysis of distribution substation demand, presented in Section 3.3; and
– Detailed comparison of selected distribution substation profiles, presented in Section 3.4.

3.1 Validation of profiles

GHD supported the validation of the demand profile outputs from the tool developed by the Carbon Trust and Hildebrand. This was done at the HV feeder level, with reference to datalogger measurements for the kVA demand on each feeder. Appendix A-1 presents details of the observations that were provided to the Carbon Trust and Hildebrand by email. This assessment was based on comparison of the baseline profiles (the sum of the individual distribution substation profiles) provided for each HV feeder with the corresponding historical measured half-hourly demand, averaged over the period 4-8 January 2022.

Subsequently, GHD provided historical kVA datalogger measurements for the selected HV feeders for the full year period 01/03/2019 to 28/02/2022 to the Carbon Trust and Hildebrand for their own internal investigation. It is understood that the findings from this validation exercise will be described in the project reports prepared by the Carbon Trust and Hildebrand, and that the profiles that have been provided to GHD for use in the network models include the improvements identified during this validation exercise (except in the case of the baseline profiles, as stated in Section 2.5.1).

3.2 Feeder level profiles

This section presents details of the feeder level comparison of the half-hourly demand profiles provided for analysis from the tool developed by the Carbon Trust and Hildebrand following the profile validation activities described in Section 3.1.

This section is divided into sub-sections for each of the three case study areas, as follows:

– Axbridge feeder 1 presented in Section 3.2.1;
– Mackworth feeder 10 presented in Section 3.2.2; and
– Withycombe Raleigh feeder 24 presented in Section 3.2.3.

The sub-sections for each of the case study areas each present three sets of charts for the comparisons, as shown in Table 3.1:

Table 3.1 Summary of comparison charts for the feeder level profiles

Group	Group of figures	Purpose
1	Half-hourly demand profiles for the baseline, 2030 and 2050 winter days for the three energy efficiency scenarios (low, medium and high EE)	Shows the impact of the different EE scenarios on the winter day profiles
2	Half-hourly demand profiles for the baseline, 2030 and 2050 winter, intermediate and extreme days under the medium EE scenario	Shows the differences between the demand profiles provided from the Carbon Trust/Hildebrand tool for the different representative days
3	Load duration curves for the baseline, 2030 and 2050 winter day profiles for the medium EE scenario	Provides a useful indication of the changes to the shape ("peakiness") of the winter day demand profiles in 2030 and 2050

3.2.1 Axbridge

Figure 3.1 provides the group 1 comparison of the winter day profiles for the aggregate Axbridge feeder 1 demand across the different study years and EE scenarios. Additionally, the 2022 base profile is plotted for reference.

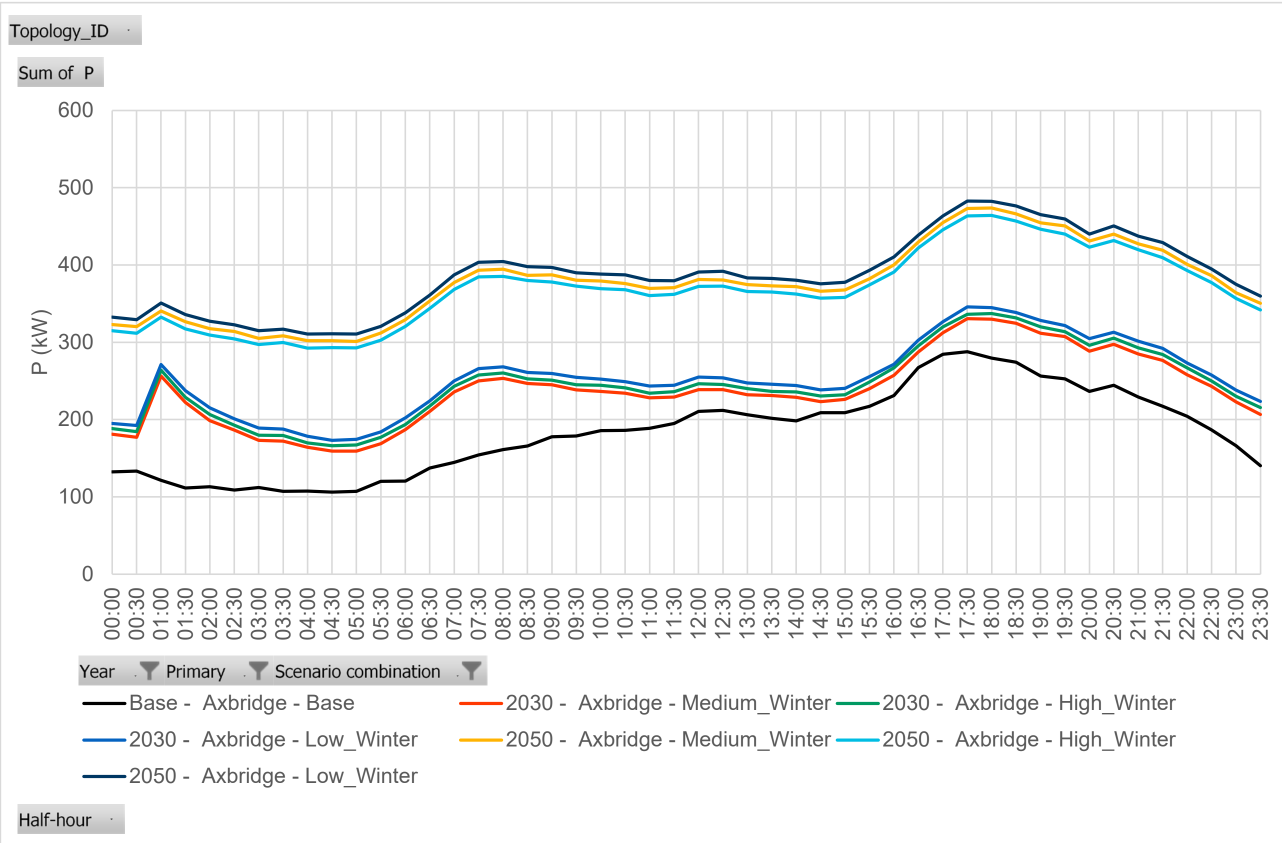


Figure 3.1 Group 1 comparison: Axbridge feeder 1 half-hourly demand profiles (winter day EE scenario comparison)

As expected, the Low EE scenario consistently has the highest demand at any given time for the 2030 and 2050 profiles. The High EE scenario corresponds to the lowest demand for the 2050 profile; however, in the 2030 profiles, the Medium EE scenario has a consistently lower demand than the High EE scenario.

As indicated in Section 2.5.2, it was advised by the Carbon Trust and Hildebrand that the medium EE scenario demand profiles presented for 2030 are depressed due to the predicted number of HP installations being fewer than both the low and high scenarios due to a rounding error. The scenario model output statistics shared by the Carbon Trust showed that in 2030 the number of HP installations in the medium scenario is 37, whereas the low and high scenarios are predicted to have 43 installations. However, due to the computation time and the low impact on the overall conclusions, the Carbon Trust and Hildebrand decided to forgo the correction and use the 2050 results to compare all three scenarios (consistent approach between the Case Study and CBA reports).

Table 3.2 presents details of the maximum difference between the medium EE scenario winter half-hourly demand values presented in Figure 3.1 and the corresponding low and high EE scenario demand values, for 2030 and 2050.

Table 3.2 Maximum difference from medium EE scenario winter day demand values: Axbridge feeder 1

	2030	2050
Absolute difference (kW)	16.8 (23:30)	11.3 (10:30)
Percentage difference (%)	9.7% (05:00)	3.3% (03:00)

From Figure 3.1 and Table 3.2 it can be seen that the demand profiles for the three EE scenarios follow the same pattern, and the greatest difference from the 2050 medium EE scenario demand value in any half-hour is 3.3%. Based on this, and noting that the number of HP installations assumed for the 2050 analysis appears to be consistent, it is deemed to be reasonable to adopt the medium EE scenario for subsequent detailed investigation.

Figure 3.2 and Figure 3.3 provide the group 2 comparison of the range of 2030 and 2050 daily profiles, respectively, for the aggregate Axbridge feeder 1 demand under the medium EE scenario. Additionally, the 2022 base profile is plotted for reference (corresponding to the baseline winter day profile).

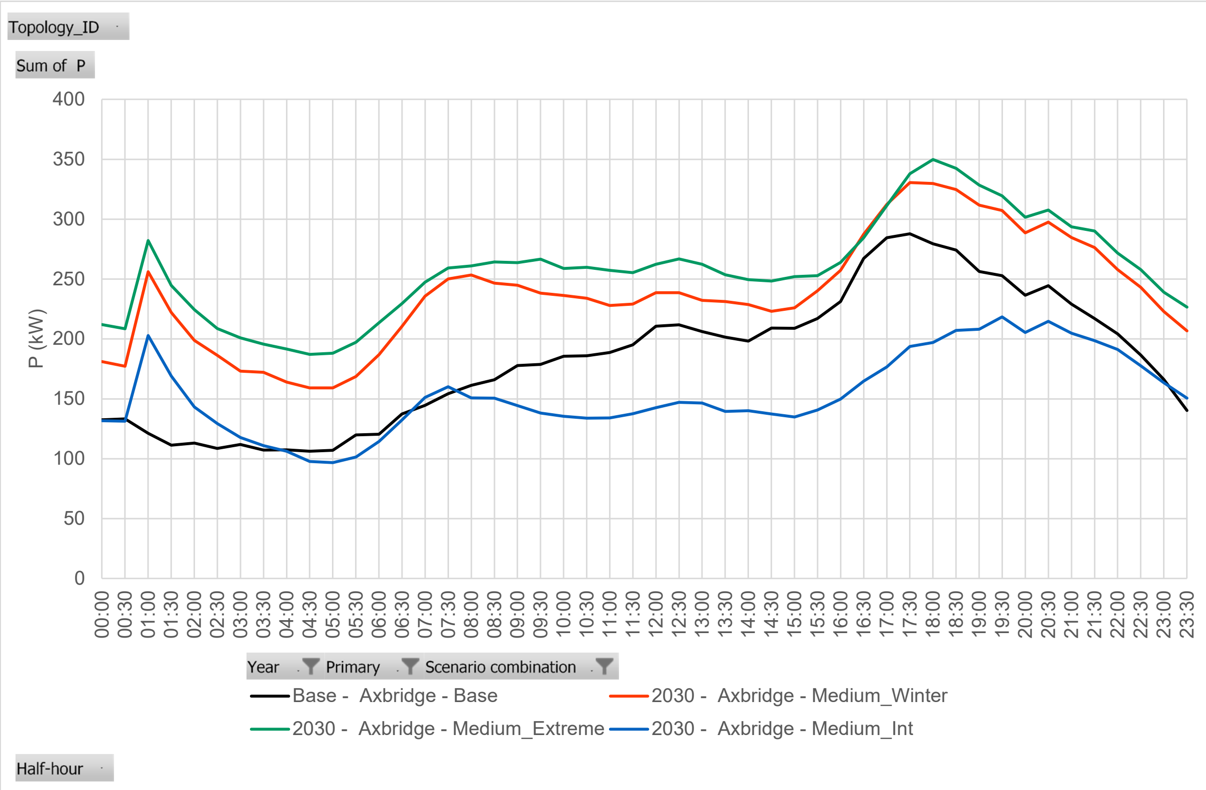


Figure 3.2 Group 2 comparison: Axbridge feeder 1 half-hourly demand profiles (2030 medium EE scenario representative day comparison)

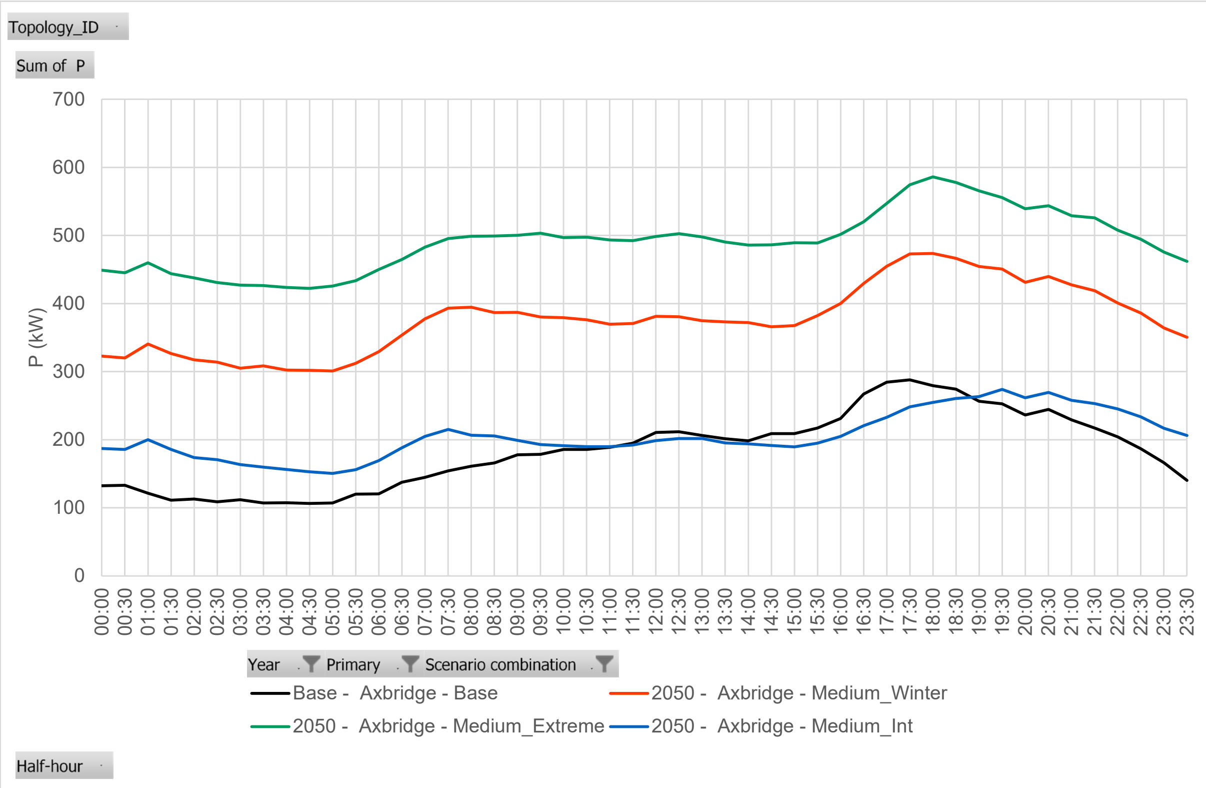


Figure 3.3 ***Group 2 comparison: Axbridge feeder 1 half-hourly demand profiles (2050 medium EE scenario representative day comparison)***

Figure 3.2 and Figure 3.3 illustrate the medium EE scenario profiles provided from the Carbon Trust and Hildebrand tool for the winter, extreme and intermediate representative days in 2030 and 2050, respectively. In 2030, substantial peaks can be observed in all three representative days at 01:00 hours, corresponding to modelled overnight storage demand. As indicated in Section 2.5.2, the Carbon Trust and Hildebrand advised that the baseline profiles do not fully reflect the modelling parameters that were applied for night storage in the future scenario profiles, which result in the introduction of the 01:00 hours demand spike. The magnitude of the spike was highlighted by GHD in the observations provided for the profile validation activity described in Section 3.1. This may be an area that should be considered for further investigation in future.

Figure 3.4 and Table 3.3 present the group 3 comparisons of the load duration curves and load factors for the 2030 and 2050 aggregate Axbridge feeder 1 winter day demand under the medium EE scenario. The Load Duration Curve (LDC) presents the half-hourly demand values in decreasing order, i.e. no longer chronological. In this case, the LDCs are normalised to the maximum daily demand in each year. The load factor corresponds to the average demand value over the whole day.

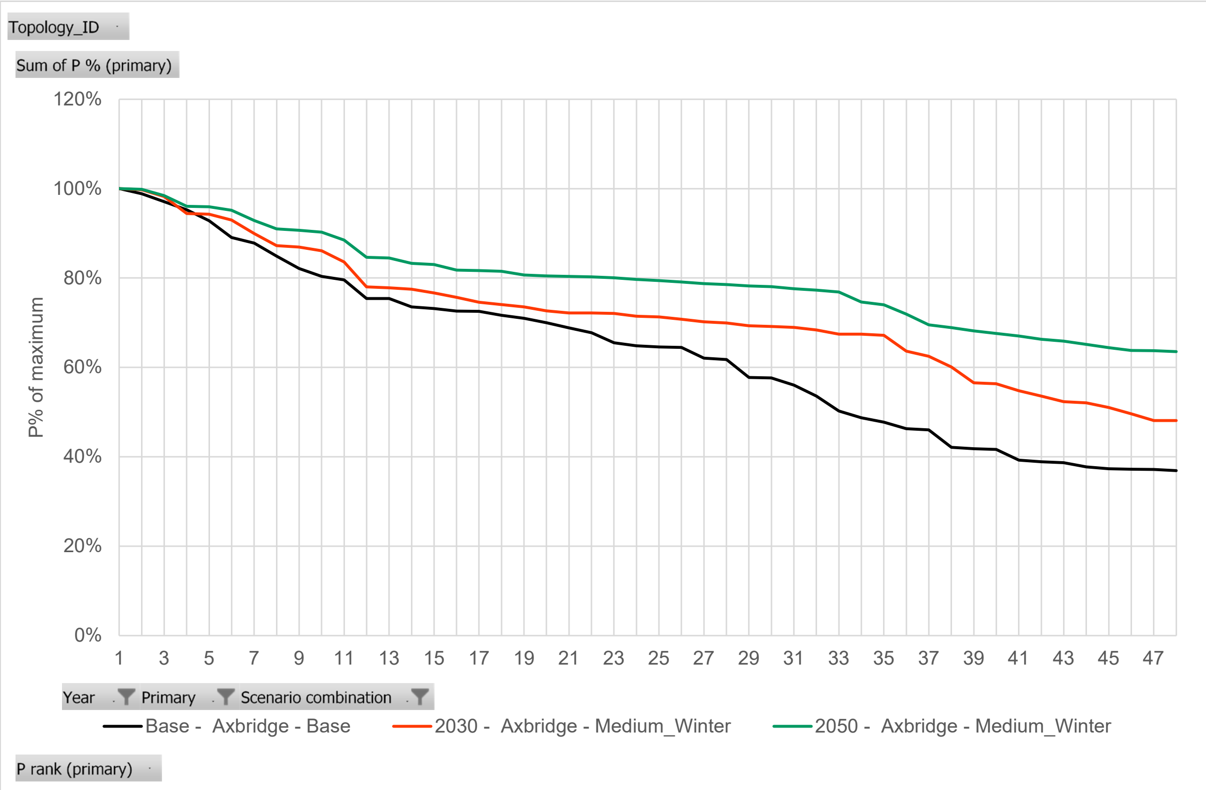


Figure 3.4 Group 3 comparison: Axbridge feeder 1 load duration curves (winter day, medium EE scenario year comparison)

Table 3.3 Group 3 comparison: Axbridge feeder 1 load factors (winter day, medium EE scenario year comparison)

Year	Load factor (%)
Base	63.7%
2030	71.9%
2050	79.6%

Figure 3.4 and Table 3.3 illustrate that the medium EE scenario winter day demand profiles align with the expectation that the load factor will increase (as well as the magnitude of the demand increasing, as seen in Figure 3.1). The increase in load factor corresponds to a flattening of the demand curve, i.e. a reduction in the “peakiness” of the profiles, as greater numbers of HPs are installed, which have a largely continuous demand.

3.2.2 Mackworth

Figure 3.5 provides the group 1 comparison of the winter day profiles for the aggregate Mackworth feeder 10 demand across the different study years and EE scenarios. Additionally, the 2022 base profile is plotted for reference.

Figure 3.5 shows that, in 2030, the Low EE scenario consistently has the highest demand. It also shows that the High EE scenario is mostly lower than the Medium EE scenario; however, there is very little difference across all three profiles as indicated in Table 3.4.

In 2050, the High EE scenario is consistently the lowest of the three scenarios, with the Low and Medium scenarios having very little difference between them. Generally, the Low EE scenario has a higher demand, but not in all cases.

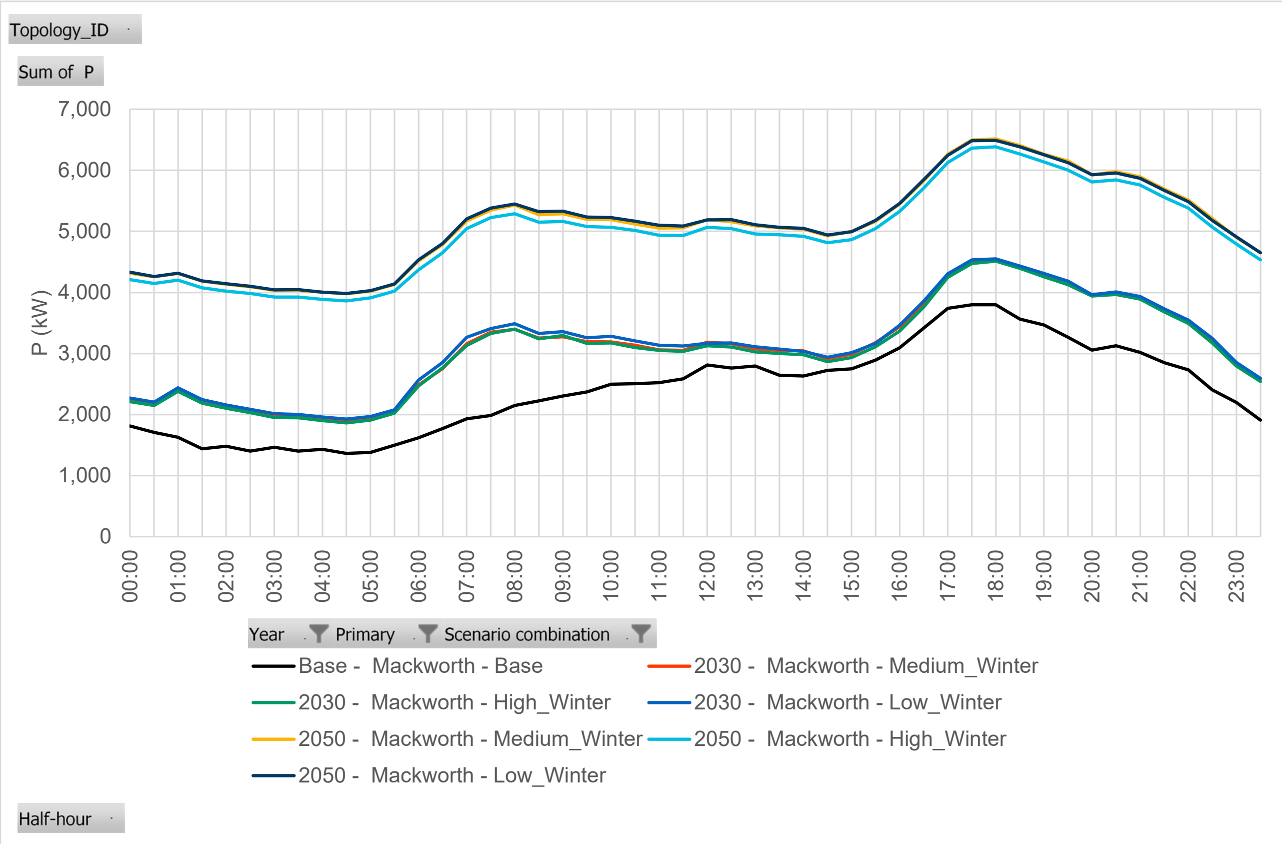


Figure 3.5 Group 1 comparison: Mackworth feeder 10 half-hourly demand profiles (winter day EE scenario comparison)

Once again, as described in Section 2.5.2, there was some discrepancy in the number of HP installations in 2030 with the Medium EE scenario having 437 installations and the other scenarios having 443 installations. In addition, it is recommended that the 'number of heat pumps vs fossil fuel systems' modelled for each substation should be reviewed for discrepancies as part of future investigations. The impact of these is modest given the higher demand and overall number of installations in the Mackworth case study area.

Table 3.4 presents details of the maximum difference between the medium EE scenario winter half-hourly demand values presented in Figure 3.5 and the corresponding low and high EE scenario demand values, for 2030 and 2050.

Table 3.4 Maximum difference from medium EE scenario winter day demand values: Mackworth feeder 10

	2030	2050
Absolute difference (kW)	107.7 (07:00)	48.6 (08:30)
Percentage difference (%)	3.7% (06:30)	0.9% (08:30)

From Figure 3.5 and Table 3.4 it can be seen that the demand profiles for the three EE scenarios follow the same pattern, and the greatest difference from the 2030 and 2050 medium EE scenario demand values in any half-hour was 3.7% and 0.9%, respectively. Based on this, and noting that the number of HP installations assumed for the 2050 analysis appears to be consistent, it is deemed to be reasonable to adopt the medium EE scenario for subsequent detailed investigation.

Figure 3.6 and Figure 3.7 provide the group 2 comparison of the range of 2030 and 2050 daily profiles, respectively, for the aggregate Mackworth feeder 10 demand under the medium EE scenario. Additionally, the 2022 base profile is plotted for reference (corresponding to the baseline winter day profile).

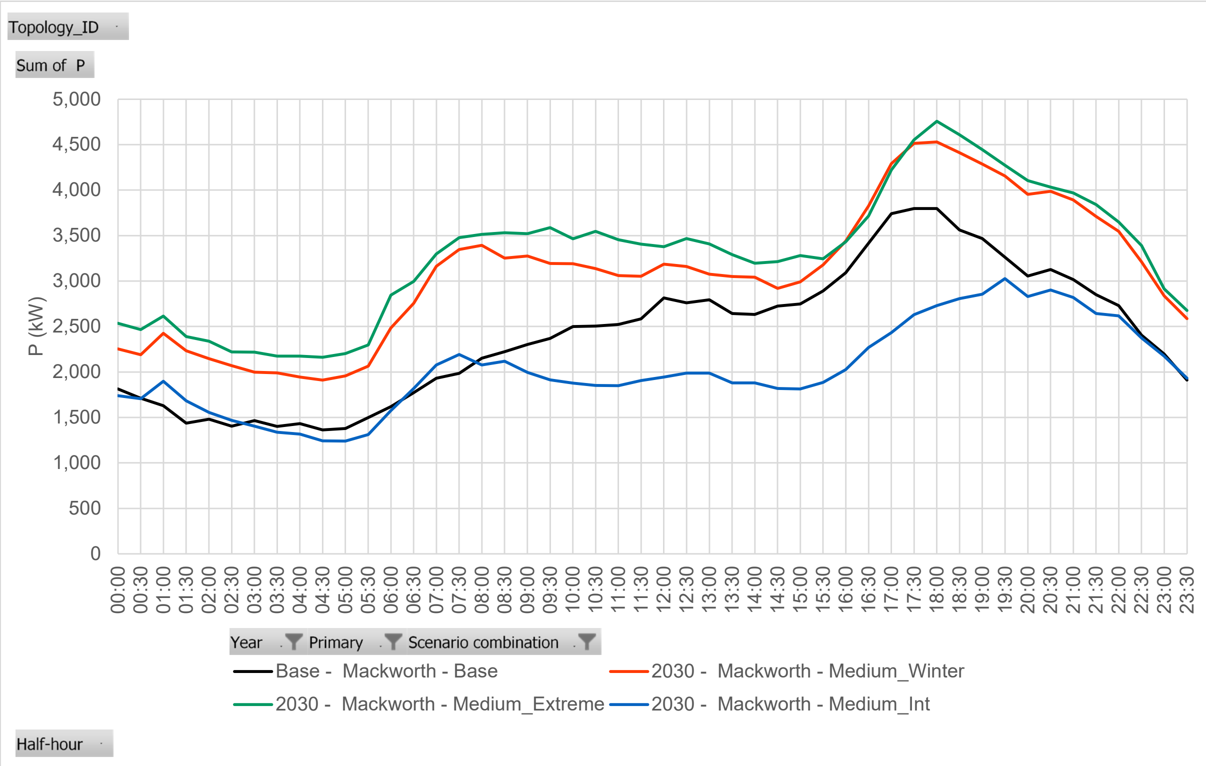


Figure 3.6 ***Group 2 comparison: Mackworth feeder 10 half-hourly demand profiles (2030 medium EE scenario representative day comparison)***

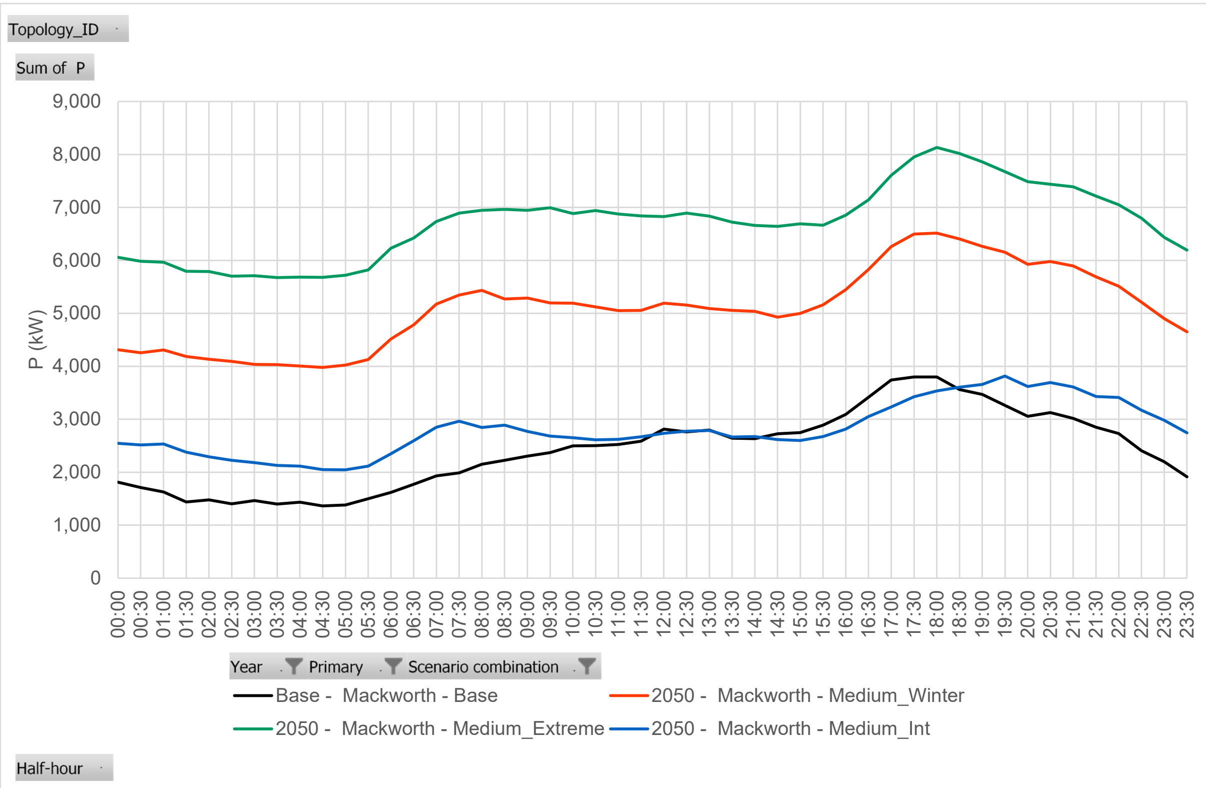


Figure 3.7 ***Group 2 comparison: Mackworth feeder 10 half-hourly demand profiles (2050 medium EE scenario representative day comparison)***

Figure 3.6 and Figure 3.7 illustrate the medium EE scenario profiles provided from the Carbon Trust and Hildebrand tool for the winter, extreme and intermediate representative days in 2030 and 2050, respectively. In 2030, modest peaks can be observed in all three representative days at 01:00 hours, corresponding to modelled overnight storage demand, and this may be an area that should be considered for further investigation in future.

Figure 3.8 and Table 3.5 present the group 3 comparisons of the load duration curves and load factors for the 2030 and 2050 aggregate Mackworth feeder 10 winter day demand under the medium EE scenario.

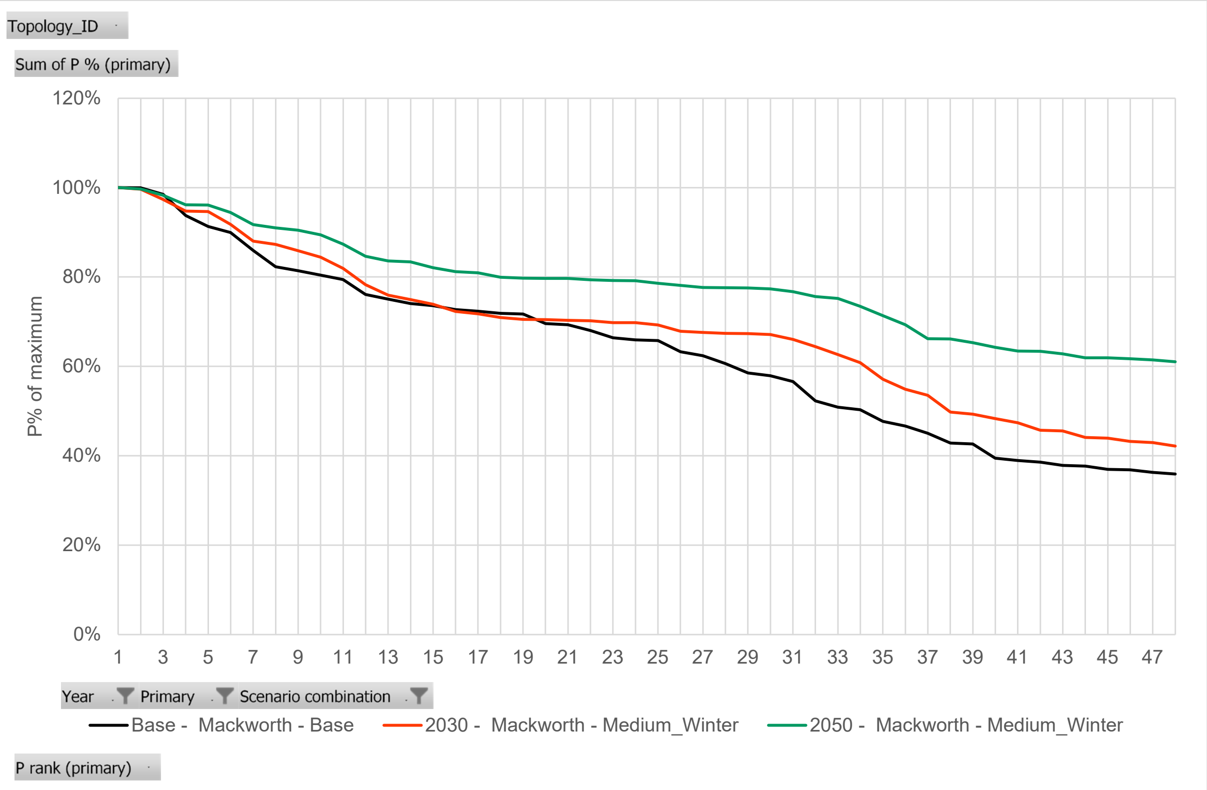


Figure 3.8 ***Group 3 comparison: Mackworth feeder 10 load duration curves (winter day, medium EE scenario year comparison)***

Table 3.5 ***Group 3 comparison: Mackworth feeder 10 load factors (winter day, medium EE scenario year comparison)***

Year	Load factor (%)
Base	63.6%
2030	68.2%
2050	78.2%

Figure 3.8 and Table 3.5 illustrate that the medium EE scenario winter day demand profiles align with the expectation that the load factor will increase (as well as the magnitude of the demand increasing, as seen in Figure 3.5). The increase in load factor corresponds to a flattening of the demand curve, i.e. a reduction in the "peakiness" of the profiles, as greater numbers of HPs are installed, which have a largely continuous demand.

3.2.3 Withycombe Raleigh

Figure 3.9 provides the group 1 comparison of the winter day profiles for the aggregate Withycombe Raleigh feeder 24 demand across the different study years and EE scenarios. Additionally, the 2022 base profile is plotted for reference.

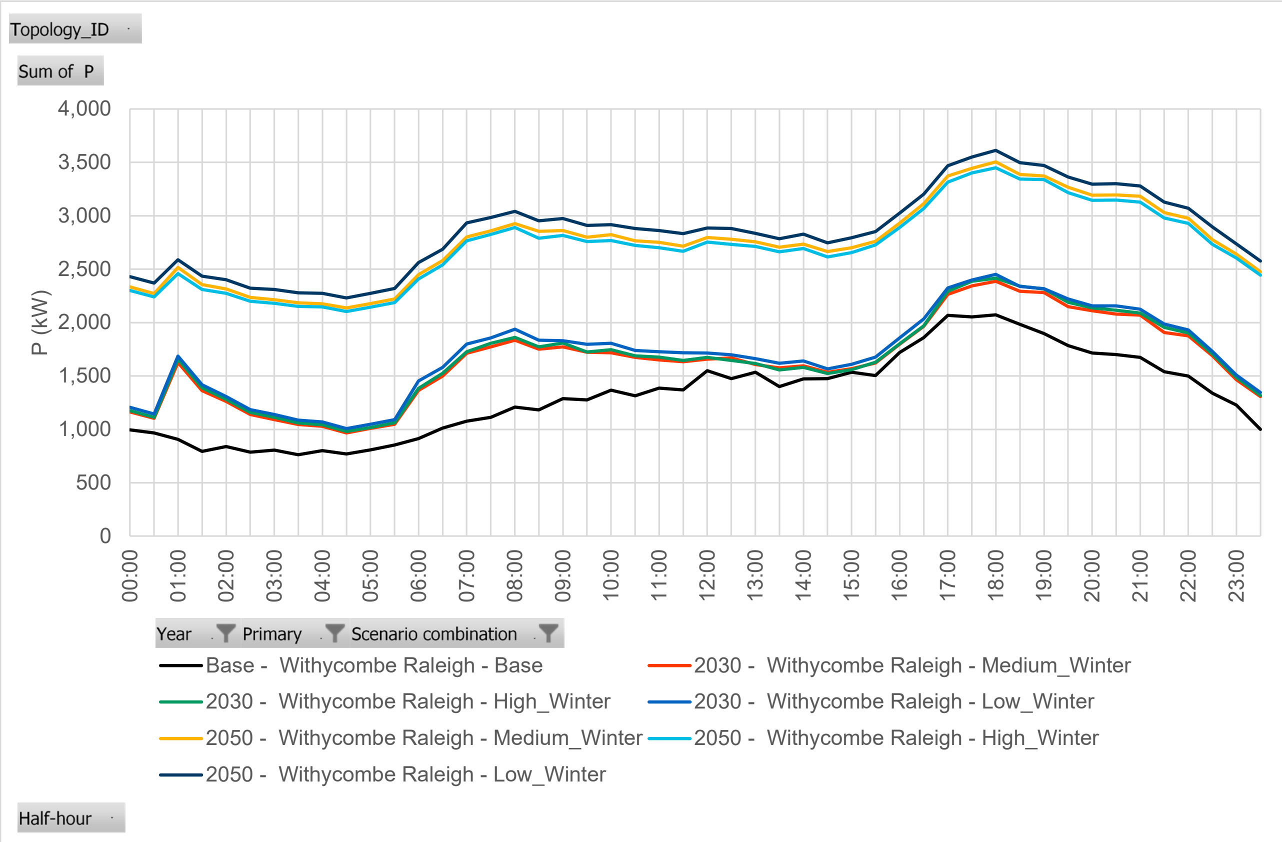


Figure 3.9 ***Group 1 comparison: Withycombe Raleigh feeder 24 half-hourly demand profiles (winter day EE scenario comparison)***

Figure 3.9 shows that, in 2030, the Low EE scenario consistently has the highest demand. It also shows that the demand in the High EE scenario is mostly greater than the Medium EE scenario; however, there is little difference between the profiles. In 2050, the demand in the Low EE scenario is consistently higher than the other scenarios. Additionally, unlike in 2030, the demand in the Medium EE scenario is consistently higher than the High EE scenario.

Once again, as described in Section 2.5.2, it was advised by the Carbon Trust and Hildebrand that the Medium EE scenario demand profile may be reduced due to the number of predicted HP installations in 2030, with the Medium EE scenario having an estimated 218 installations and the other EE scenarios having 227 installations.

Table 3.6 presents details of the maximum difference between the medium EE scenario winter half-hourly demand values presented in Figure 3.9 and the corresponding low and high EE scenario demand values, for 2030 and 2050.

Table 3.6 ***Maximum difference from medium EE scenario winter day demand values: Withycombe Raleigh feeder 24***

	2030	2050
Absolute difference (kW)	101.9 (08:00)	132.0 (07:00)
Percentage difference (%)	6.4% (06:00)	4.7% (07:00)

From Figure 3.9 and Table 3.4 it can be seen that the demand profiles for the three EE scenarios follow the same pattern, and the greatest difference from the 2030 and 2050 medium EE scenario demand values in any half-hour was 6.4% and 4.7%, respectively. Based on this, and noting that the number of HP installations assumed for the

2050 analysis appears to be consistent, it is deemed to be reasonable to adopt the medium EE scenario for subsequent detailed investigation.

Figure 3.10 and Figure 3.11 provide the group 2 comparison of the range of 2030 and 2050 daily profiles, respectively, for the aggregate Withycombe Raleigh feeder 24 demand under the medium EE scenario. Additionally, the 2022 base profile is plotted for reference (corresponding to the baseline winter day profile).

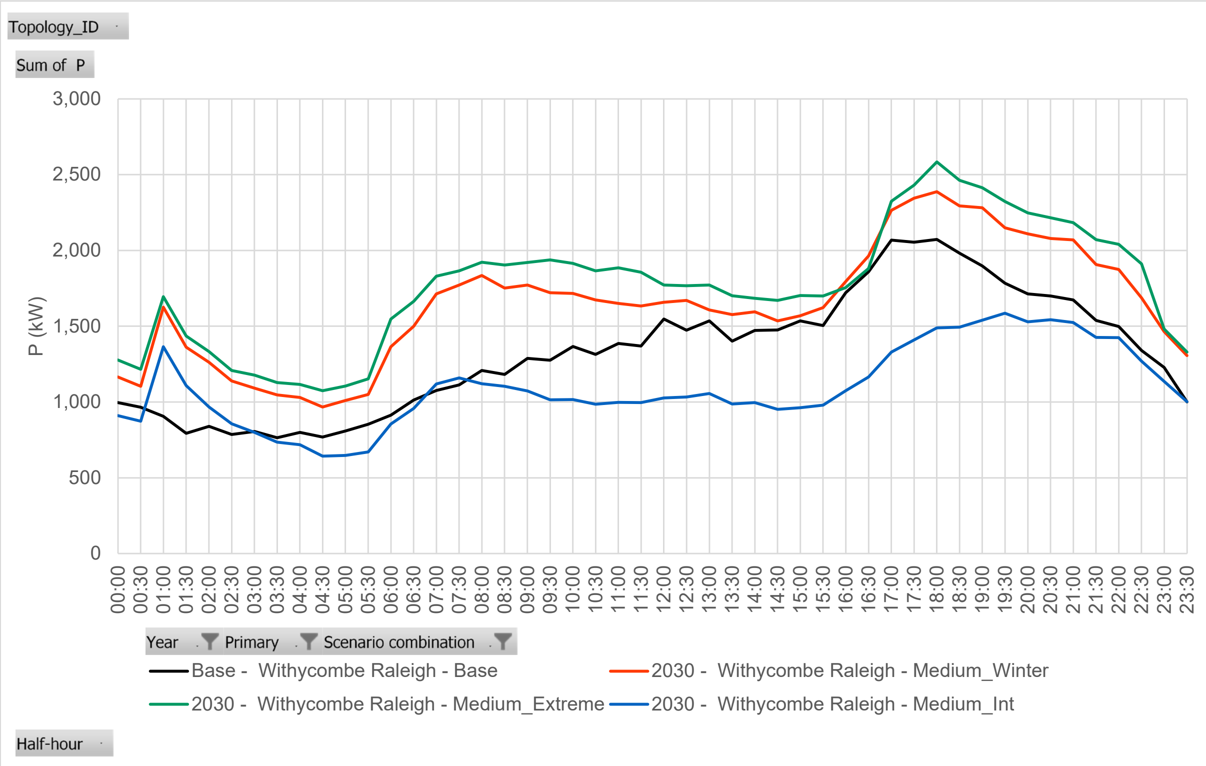


Figure 3.10 ***Group 2 comparison: Withycombe Raleigh feeder 24 half-hourly demand profiles (2030 medium EE scenario representative day comparison)***

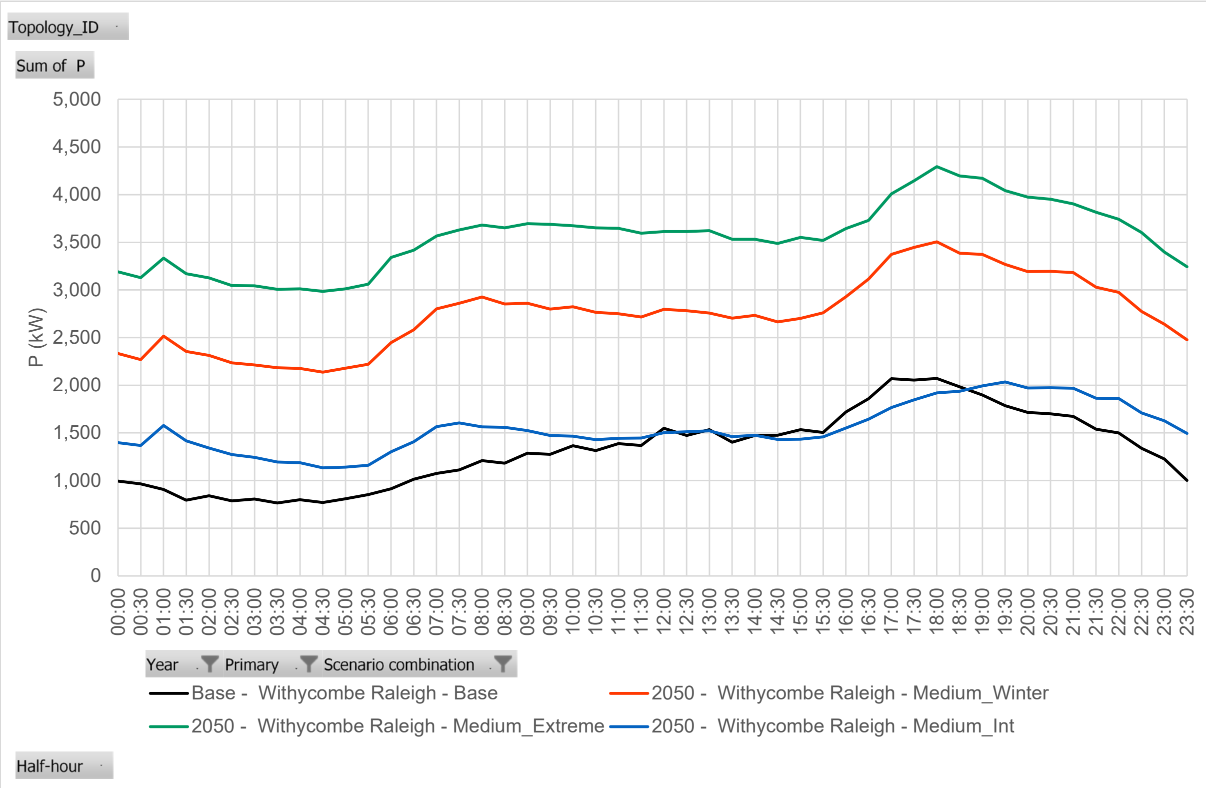


Figure 3.11 ***Group 2 comparison: Withycombe Raleigh feeder 24 half-hourly demand profiles (2050 medium EE scenario representative day comparison)***

Figure 3.10 and Figure 3.11 illustrate the medium EE scenario profiles provided from the Carbon Trust and Hildebrand tool for the winter, extreme and intermediate representative days in 2030 and 2050, respectively. In the 2030 and 2050 profiles peaks can be observed in all three representative days at 01:00 hours, corresponding to modelled overnight storage demand, and this may be an area that should be considered for further investigation in future.

Figure 3.12 and Table 3.7 present the group 3 comparisons of the load duration curves and load factors for the 2030 and 2050 aggregate Withycombe Raleigh feeder 24 winter day demand under the medium EE scenario.

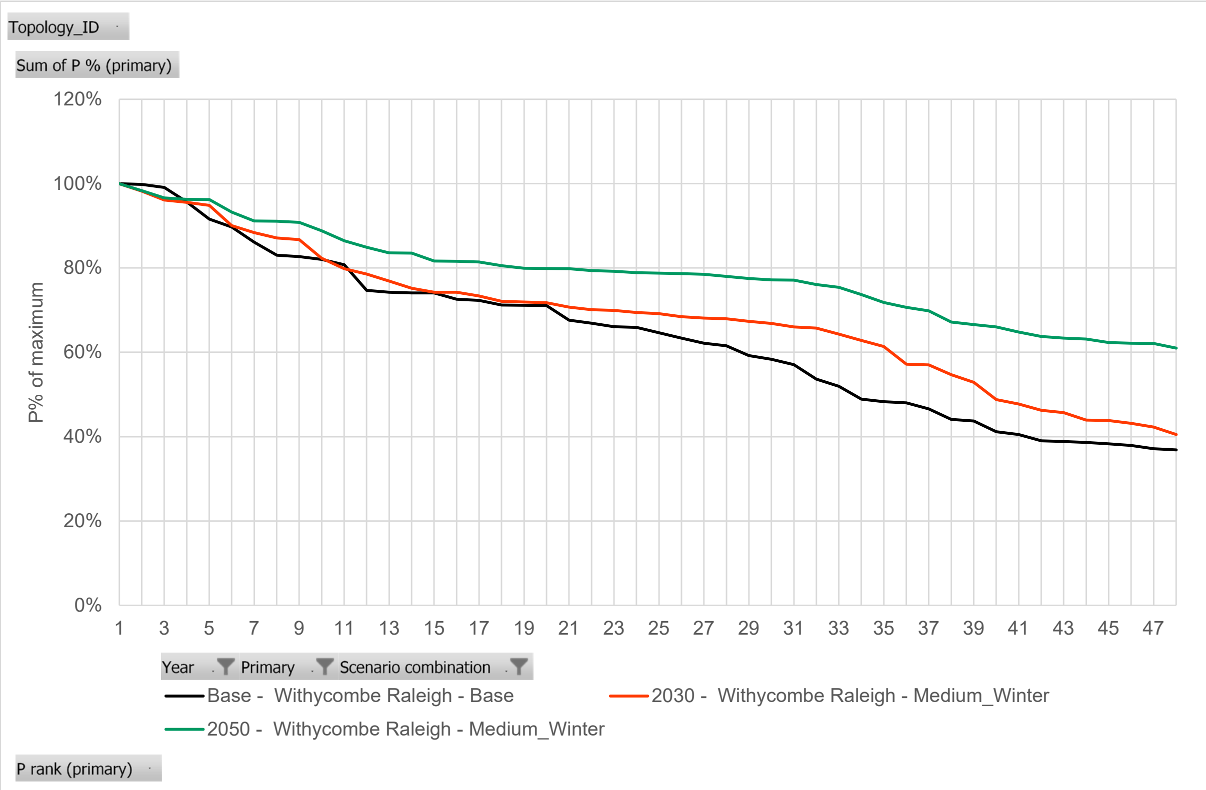


Figure 3.12 ***Group 3 comparison: Withycombe Raleigh feeder 24 load duration curves (winter day, medium EE scenario year comparison)***

Table 3.7 ***Group 3 comparison: Axbridge feeder 1 load factors (winter day, medium EE scenario year comparison)***

Year	Load factor (%)
Base	64.0%
2030	68.7%
2050	78.5%

Figure 3.12 and Table 3.7 illustrate that the medium EE scenario winter day demand profiles align with the expectation that the load factor will increase (as well as the magnitude of the demand increasing, as seen in Figure 3.9). The increase in load factor corresponds to a flattening of the demand curve, i.e. a reduction in the “peakiness” of the profiles, as greater numbers of HPs are installed, which have a largely continuous demand.

3.3 High level analysis of distribution substation demand

Figure 3.13 presents a plot of the load factor calculated for each distribution substation winter day demand profile under the medium EE scenario against the corresponding daily peak demand, for the baseline, 2030 and 2050 profiles. This figure looks to highlight the nature of the changes to the profiles in terms of both absolute peak demand values and flattening of the demand profiles represented by the load factor.

Figure 3.13 also highlights some distribution substations with labels to identify them, and a selection of dotted lines is presented on the chart to show the nature of the changes from the current baseline through to 2050 by joining the black, red and green points for particular distribution substations.

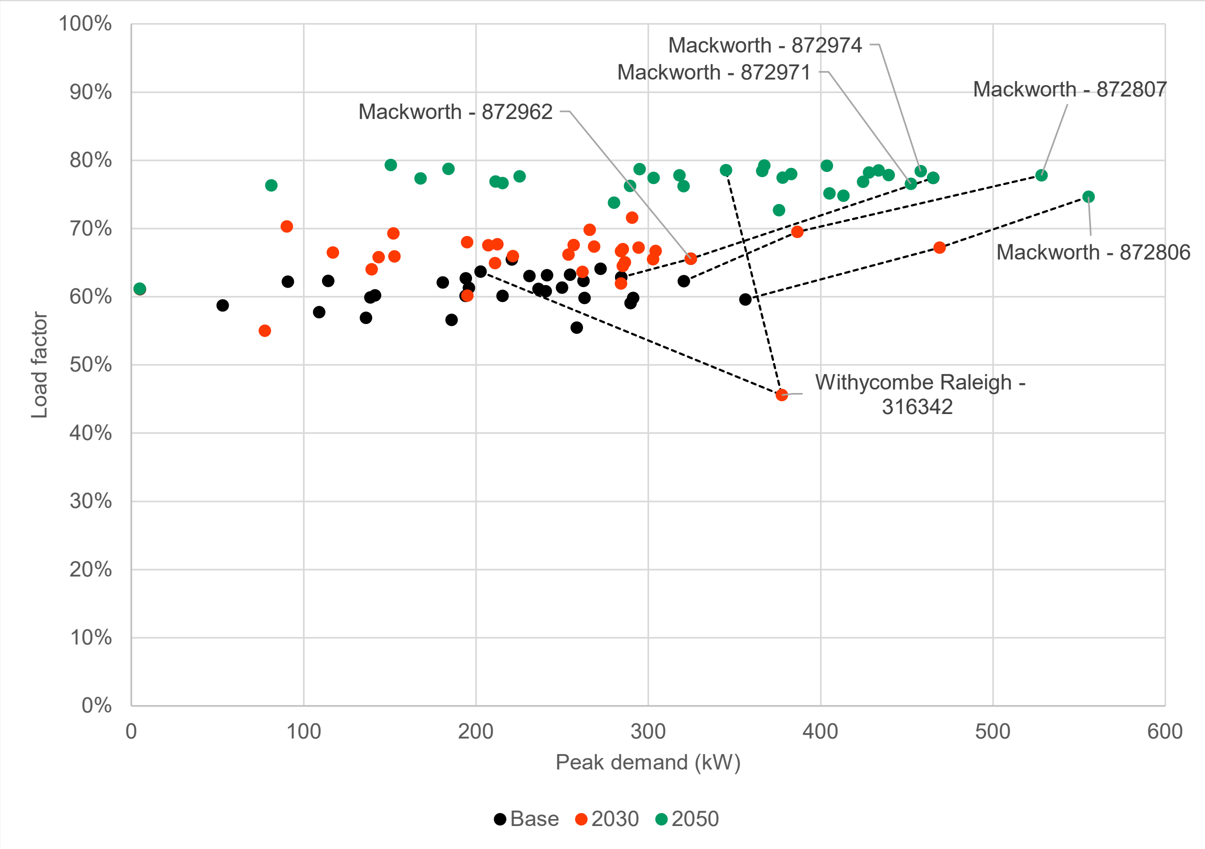


Figure 3.13 Load factor plotted against peak demand on each secondary substation (medium EE scenario, winter day profiles in 2030 and 2050)

Figure 3.13 indicates the following general trends, which are quantified in average terms in Table 3.8:

– The absolute peak demand on each distribution substation to increase in the future; and

– The demand profile of each distribution substation will flatten in future, represented by an increase in load factor.

Table 3.8 Change in the average winter day peak demand and load factor across all distribution substations considered (medium EE scenario)

Average	Baseline	2030 (%increase vs baseline)	2050 (%increase vs baseline)
Peak demand (kW)	207.3	237.4 (14.5%)	333.3 (60.8%)
Load factor (%)	60.9%	65.3% (7.2%)	76.7% (25.9%)

During the course of the analysis it was observed that in some cases the profiles provided from the Carbon Trust and Hildebrand tool exhibited shifts from the peak demand occurring in the late afternoon to the early hours of the morning. To investigate this issue, Figure 3.14 presents the winter daily peak demand on each distribution substation plotted against the half-hour period in which that peak demand occurred.

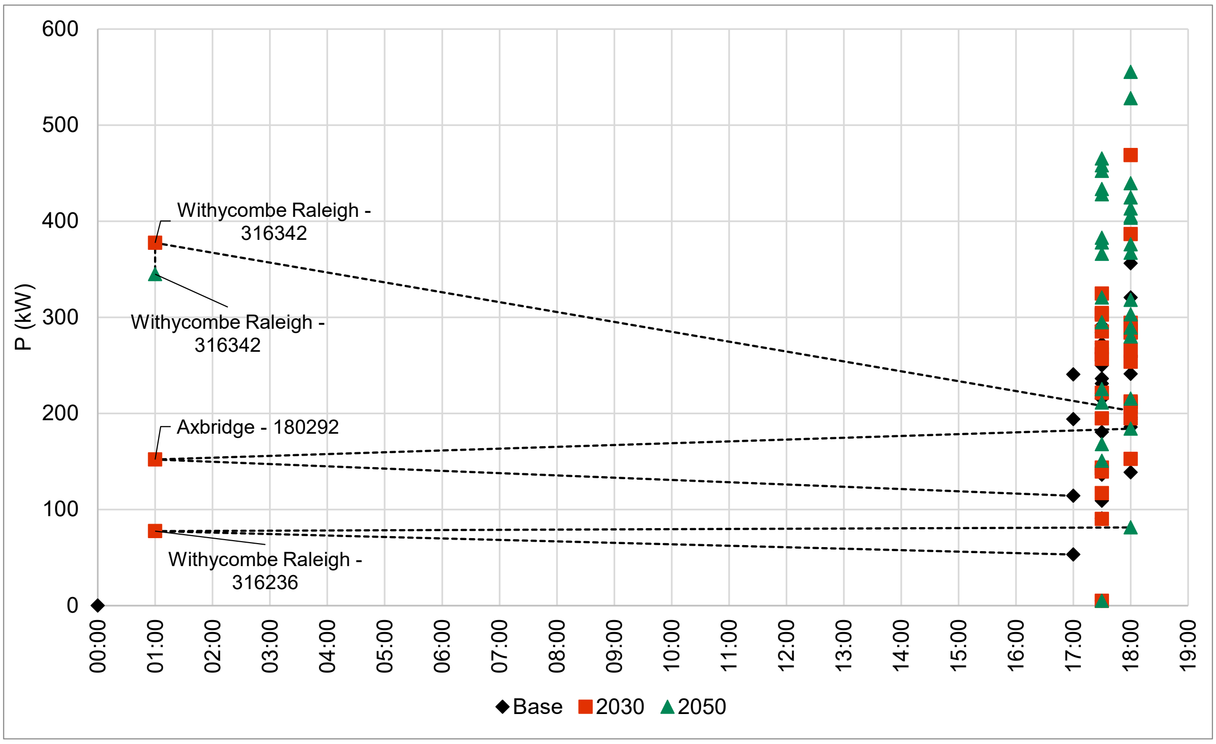


Figure 3.14 ***Peak demand on each secondary substation plotted against time of peak demand (Base and Medium-Winter day profiles in 2030 and 2050)***

Based on Figure 3.13 and Figure 3.14, the following distribution substations have been highlighted for further investigation in Section 3.4. These have been selected due to them having relatively high peak demand values and/or substantial changes observed between the baseline, 2030 and 2050 profiles, including shifts in the time of the peak demand period and a reduction in the demand between the baseline and 2030 profiles (in the case of 316342).

– Axbridge feeder 1:
  - 180292 – Cheddar St;
– Mackworth feeder 10:
  - 872806 – Vicarage Road Mickleover;
  - 872807 – Portland Close, Mickleover;
  - 872962 – Devonshire Drive;
  - 872971 – Brisbane Road No.2, Mickleover; and
  - 872974 – Murray Road, Mickleover;
– Withycombe Raleigh feeder 24:
  - 316236 – Priddis Close; and
  - 316342 – Lovering Farm Estate.

3.4 Distribution substation profiles

3.4.1 Axbridge

Figure 3.15 presents the 2030 winter day half-hourly demand profile, stacked to show each distribution substation connected to Axbridge feeder 1.

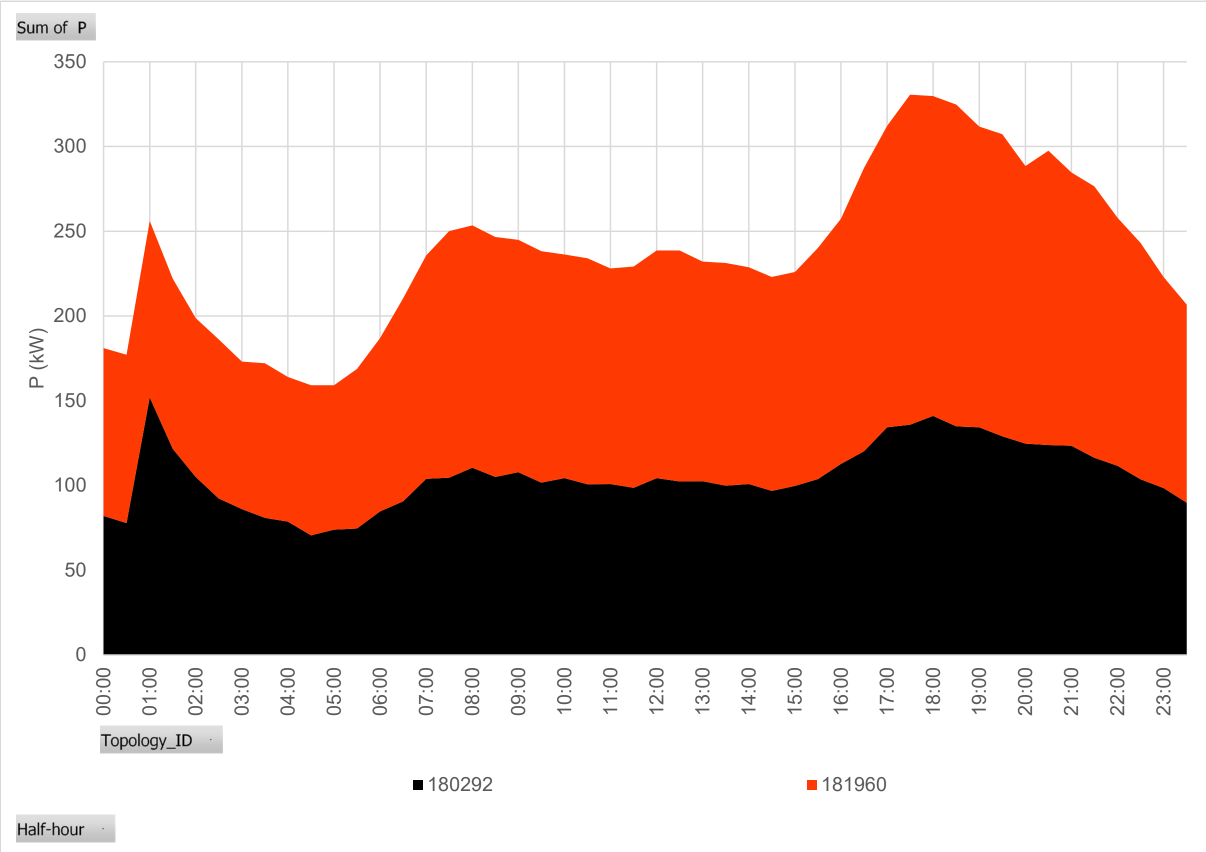


Figure 3.15 ***Axbridge feeder 1 half-hourly stacked demand profiles for each distribution substation (medium EE scenario 2030 winter day profiles)***

Figure 3.16 presents the winter day half-hourly demand profiles for distribution substation 180292 (Cheddar St), which was highlighted for investigation in Section 3.3.

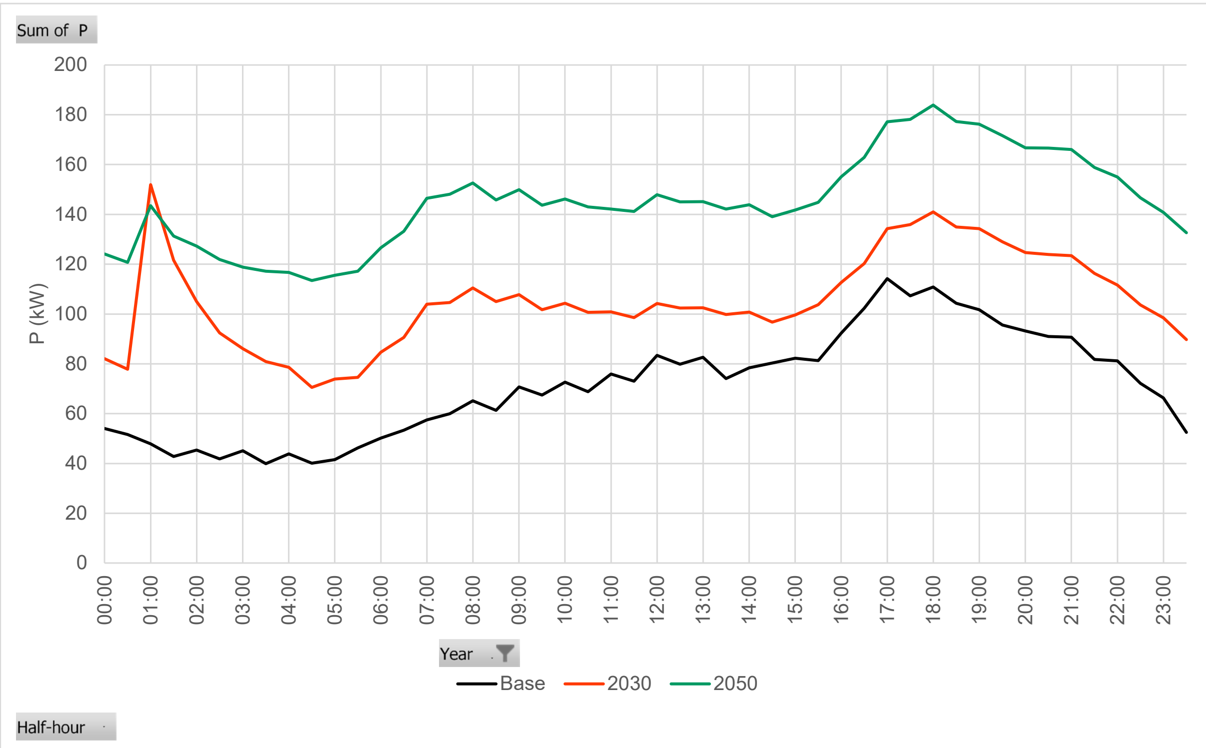


Figure 3.16 ***180292 – Cheddar St (Axbridge feeder 1): winter day half-hourly demand profiles (medium EE scenario, 2030 and 2050)***

Figure 3.16 shows the large spike in the 2030 demand profile at 01:00, corresponding to modelling of overnight storage demand, results in this spike overtaking the late afternoon peak demand. It also represents a substantial change from the baseline profile, which does not appear to be consistent with the changes throughout the rest of the day. GHD recommends that the Carbon Trust and Hildebrand may wish to investigate this issue, if it is not already discussed in the project reports under preparation by them.

3.4.2 Mackworth

Figure 3.17 presents the 2030 winter day half-hourly demand profile, stacked to show each distribution substation connected to Mackworth feeder 10.

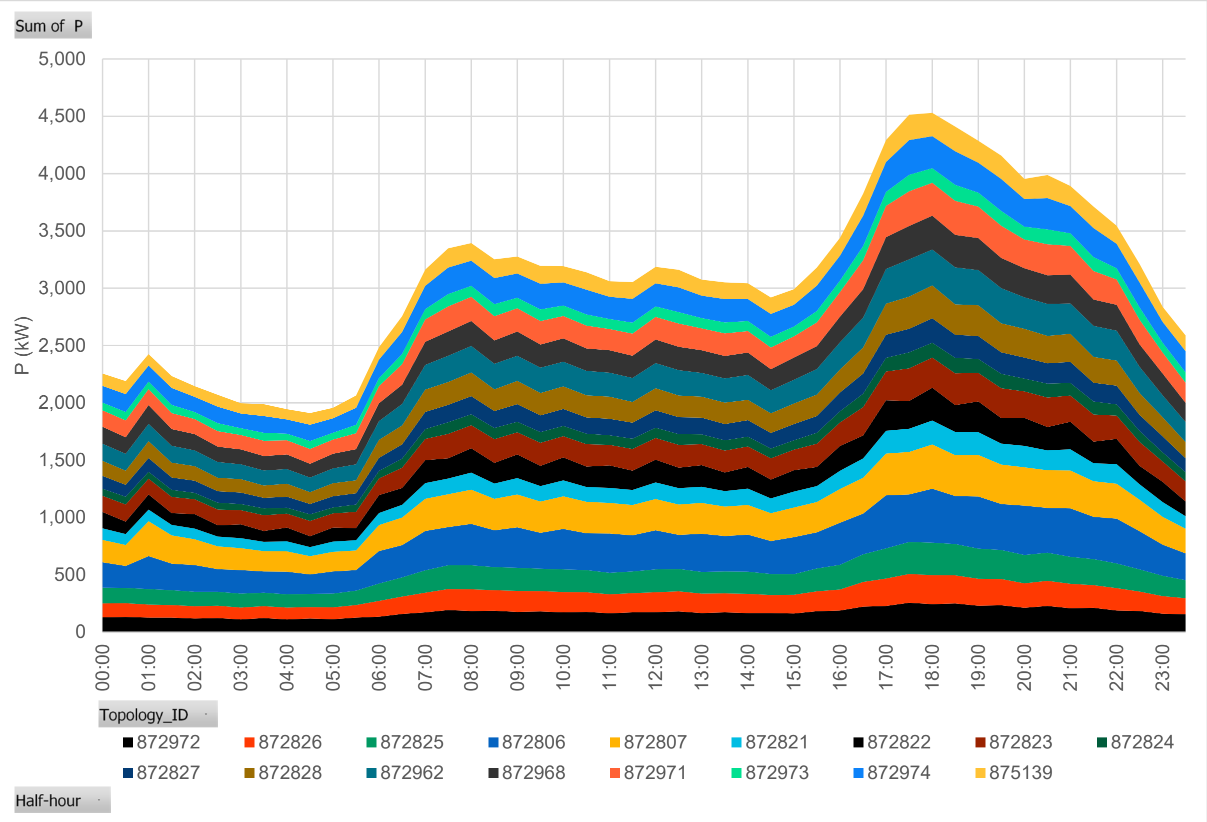


Figure 3.17 ***Mackworth feeder 10 half-hourly stacked demand profiles for each distribution substation (medium EE scenario 2030 winter day profiles)***

Figure 3.18 to Figure 3.22 present the winter day half-hourly demand profiles for the distribution substations highlighted for investigation in Section 3.3, as follows:

- 872806 – Vicarage Road Mickleover;
- 872807 – Portland Close, Mickleover;
- 872962 – Devonshire Drive;
- 872971 – Brisbane Road No.2, Mickleover; and
- 872974 – Murray Road, Mickleover.

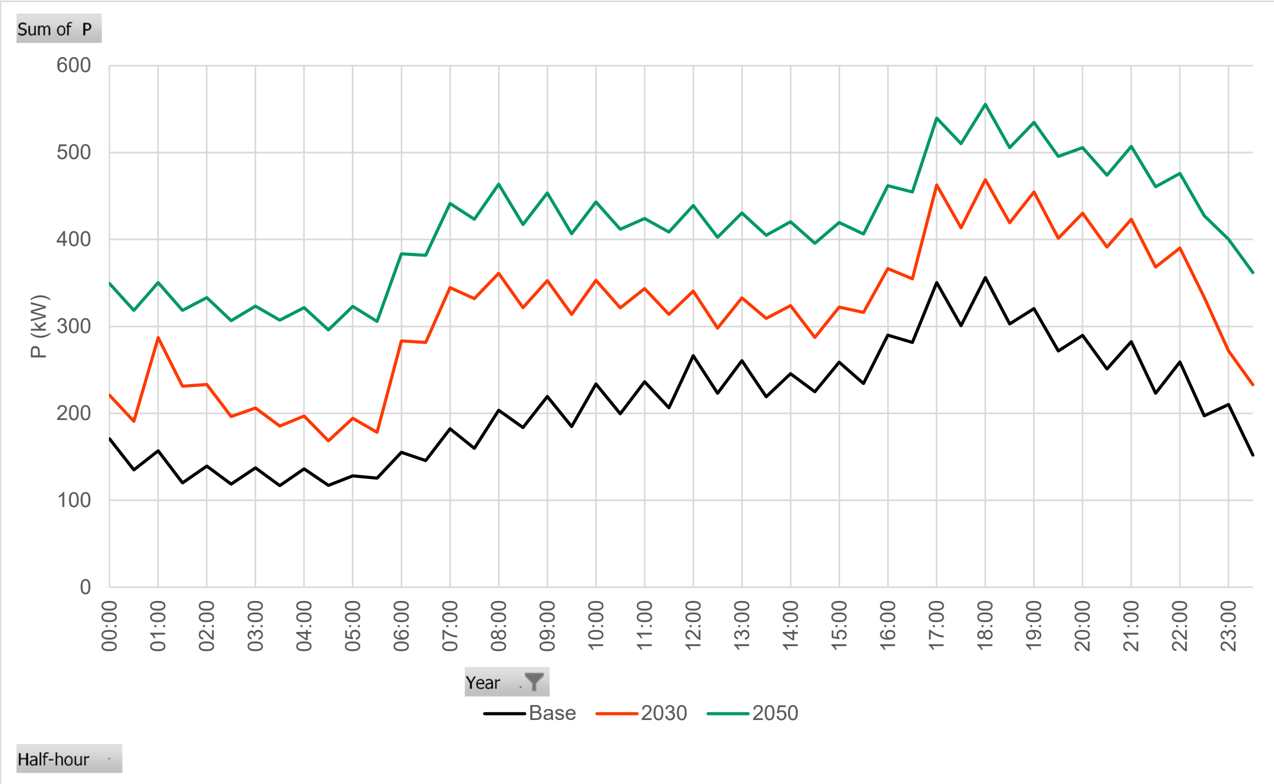


Figure 3.18 *872806 – Vicarage Road Mickleover (Mackworth feeder 10): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)*

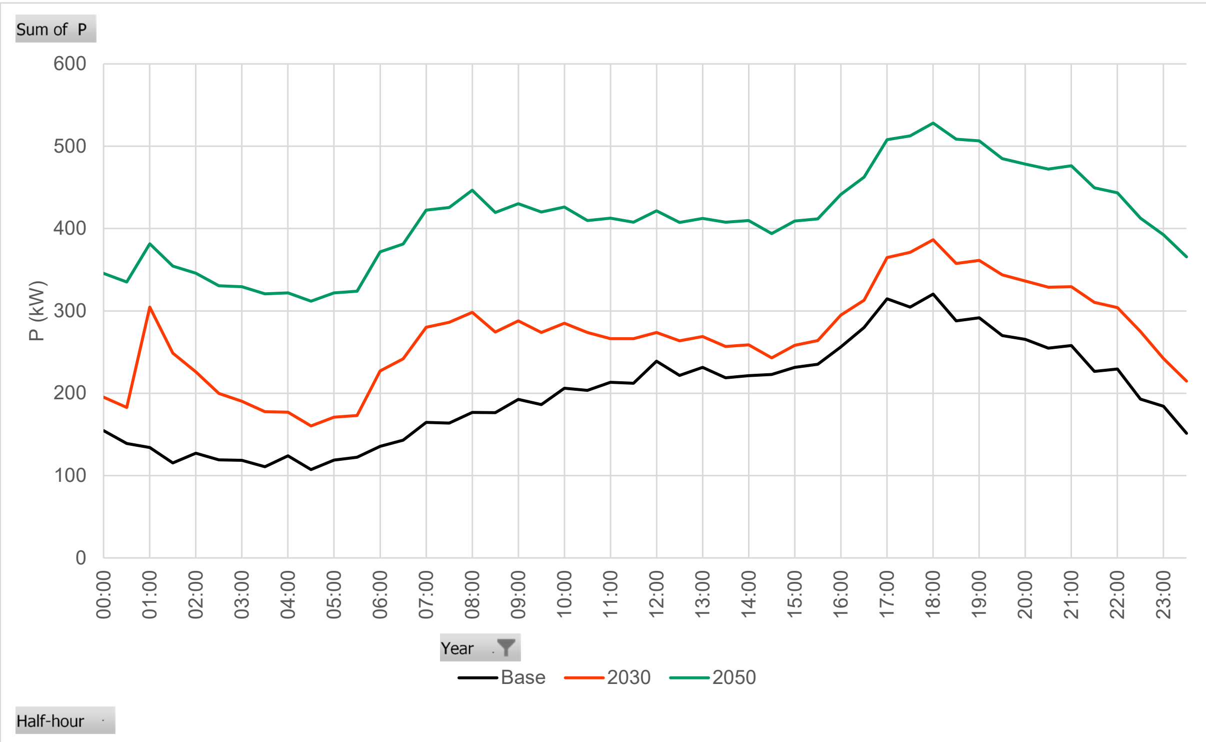


Figure 3.19 *872807 – Chestnut Avenue (Mackworth feeder 10): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)*

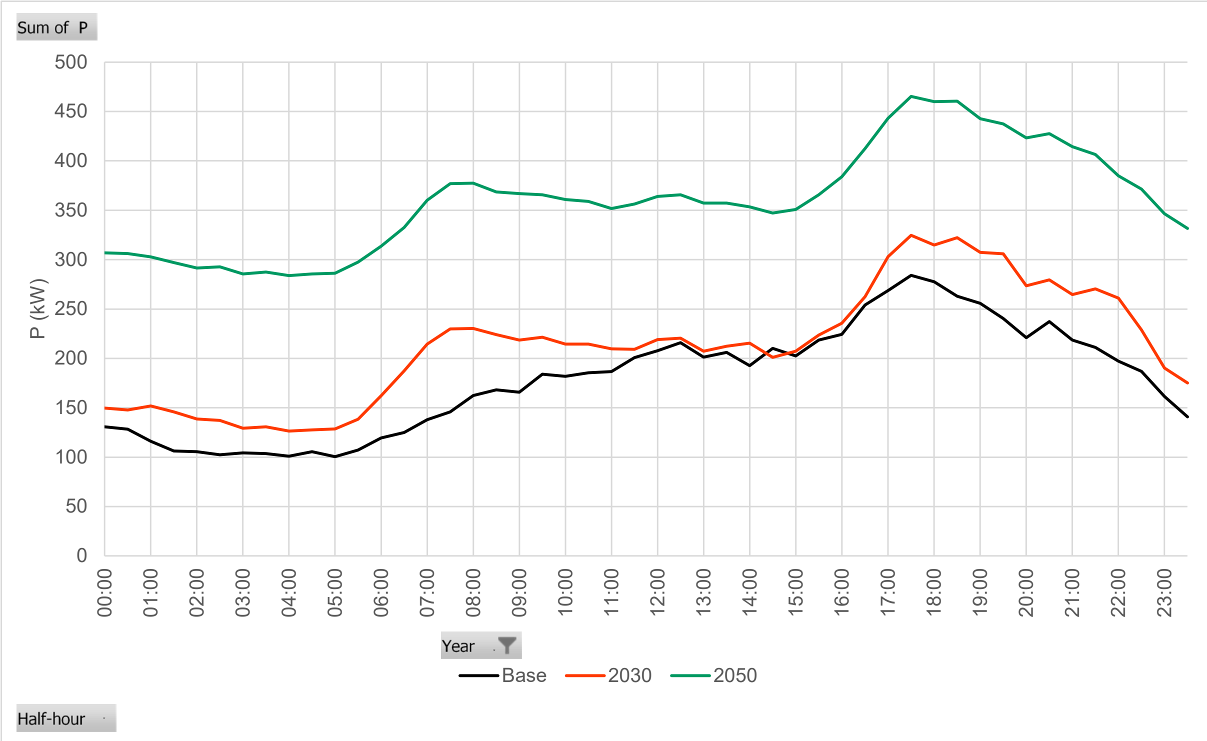


Figure 3.20 ***872962 – Devonshire Drive (Mackworth feeder 10): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)***

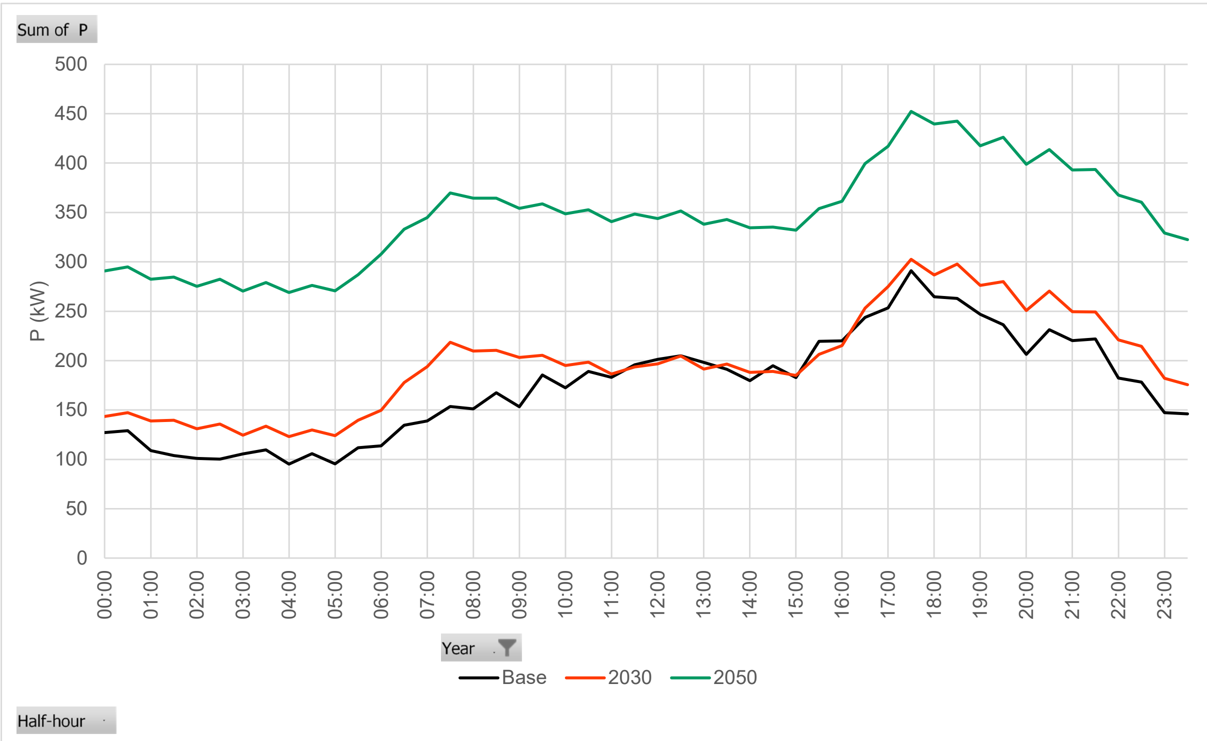


Figure 3.21 ***872971 – Brisbane Road No.2, Mickleover (Mackworth feeder 10): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)***

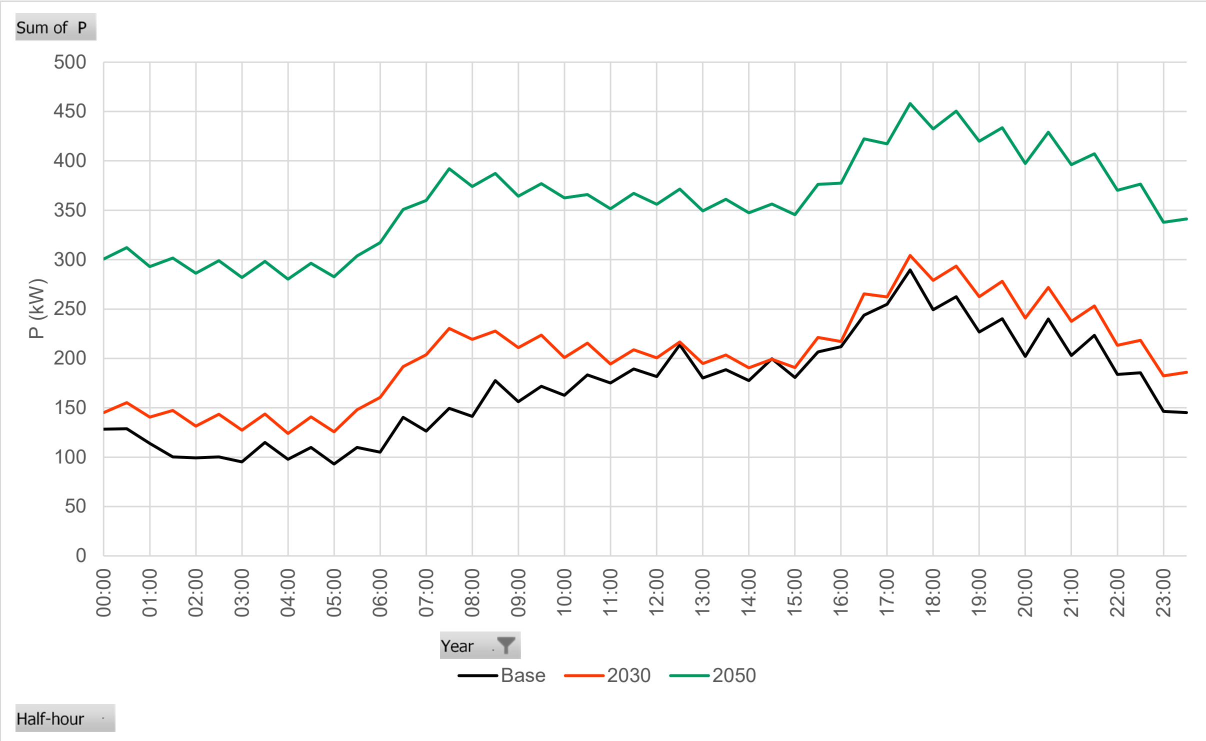


Figure 3.22 872974 – Murray Road, Mickleover (Mackworth feeder 10): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)

The features of the above figures may be summarised, as follows:

– The profiles for 872806 (Vicarage Road Mickleover) and 872974 (Murray Road, Mickleover) exhibit a sawtooth profile with up and down oscillations in each half-hour;

– The profiles for 872962 (Devonshire Drive), 872971 (Brisbane Road No.2, Mickleover) and 872974 (Murray Road, Mickleover) show a relatively small change between the baseline and 2030 profiles, and a more substantial change between the 2030 and 2050 profiles; and

– The profiles for 872806 (Vicarage Road Mickleover) and 872807 (Chestnut Avenue) exhibit, to varying degrees, the peak demand at 01:00 hours associated with overnight storage heating. However, this characteristic is not observed in the other profiles highlighted for investigation.

GHD recommends that the Carbon Trust and Hildebrand may wish to investigate the above issues relating to the sawtooth profiles and spikes in demand at 01:00 hours, if they are not already discussed in the project reports under preparation by them.

3.4.3 Withycombe Raleigh

Figure 3.23 presents the 2030 winter day half-hourly demand profile, stacked to show each distribution substation connected to Withycombe Raleigh feeder 24.

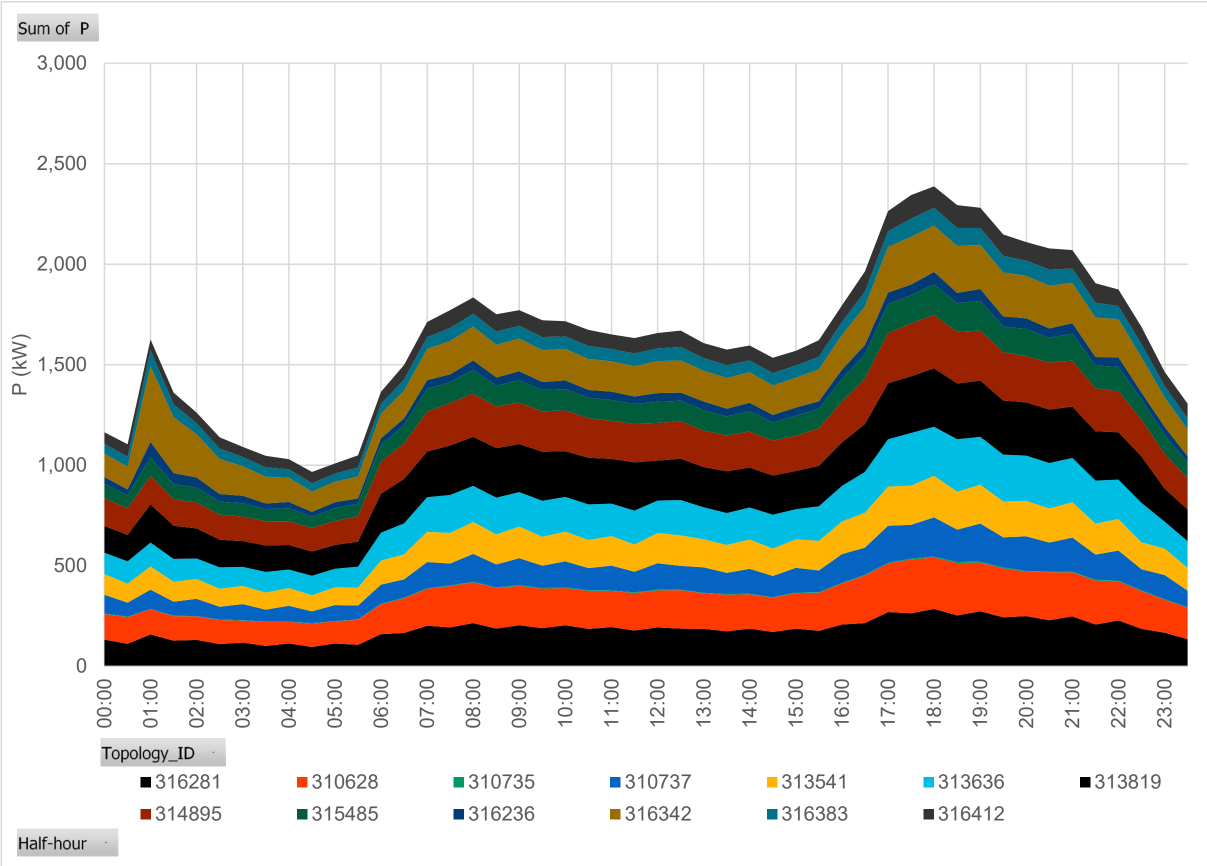


Figure 3.23 Withycombe Raleigh feeder 24 half-hourly stacked demand profiles for each distribution substation (medium EE scenario 2030 winter day profiles)

Figure 3.24 and Figure 3.25 present the winter day half-hourly demand profiles for the distribution substations highlighted for investigation in Section 3.3, as follows:

– 316236 – Priddis Close; and

– 316342 – Lovering Farm Estate.

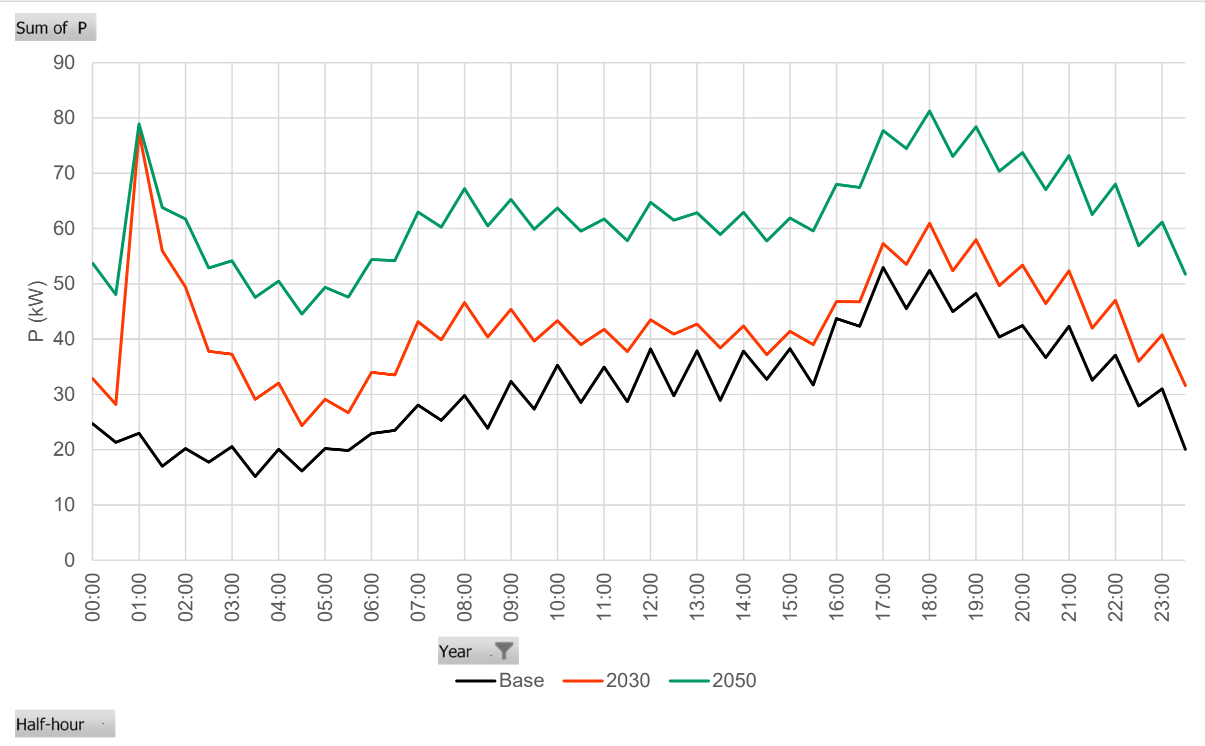


Figure 3.24 316236 – Priddis Close (Withycombe Raleigh feeder 24): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)

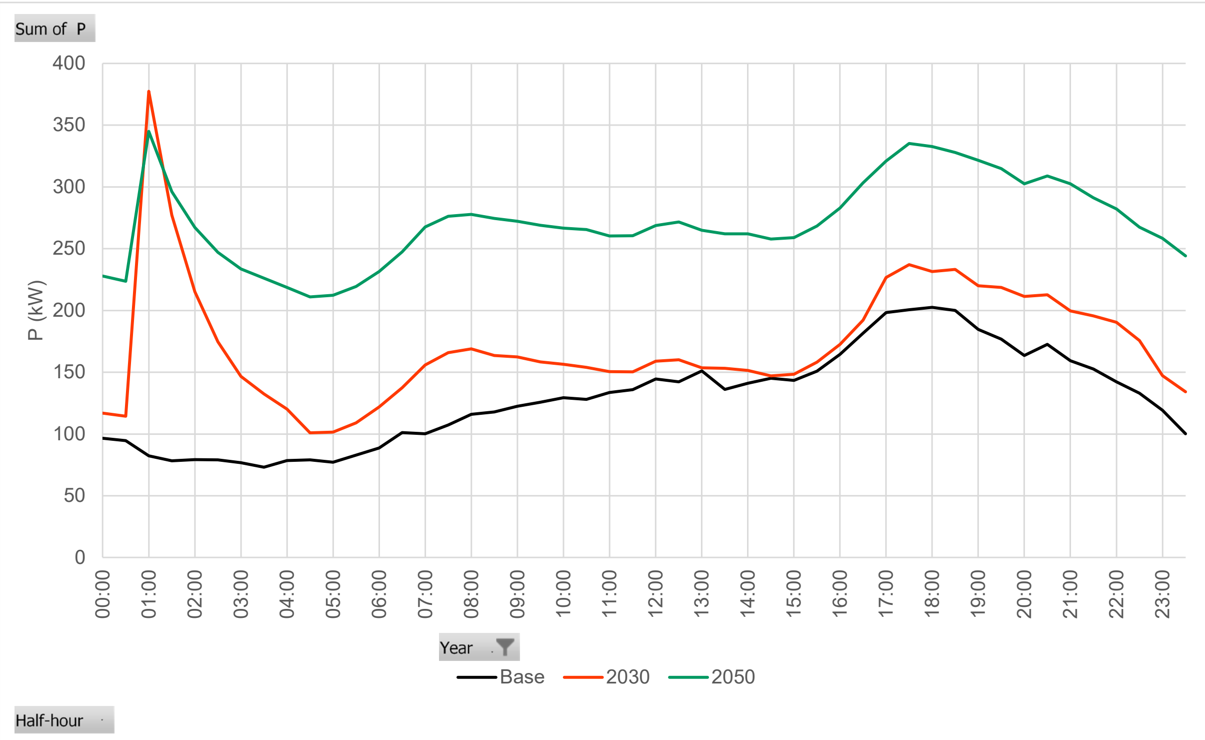


*Figure 3.25 316342 – **Lovering Farm Estate** (Withycombe Raleigh feeder 24): winter day half-hourly demand profiles (baseline and medium EE scenario, 2030 and 2050)*

The features of the above figures may be summarised, as follows:

– The profile for 316236 (Priddis Close) exhibits the sawtooth profile with up and down oscillations in each half-hour, as highlighted for some of the distribution substations in the Mackworth case study area; and

– Both profiles investigated exhibit substantial peak demand values at 01:00 hours associated with overnight storage heating.

As stated previously, GHD recommends that the Carbon Trust and Hildebrand should investigate the above issues relating to the sawtooth profiles and spikes in demand at 01:00 hours, if they are not already discussed in the project reports under preparation by them.

3.5 Summary

The findings from the comparison of the input demand profiles provided from the tool developed by the Carbon Trust and Hildebrand are summarised, as follows:

– The impact of additional demand from HPs is not the focus of the study, which looks to demonstrate the incremental impact of installation of retrofit EE measures (under low, medium and high EE scenarios) alongside HPs. As such, the input demand profiles are based on the HP uptake from the Consumer Transformation DFES scenario. However, the impact of increasing HP numbers may be observed by comparison between the baseline, 2030 and 2050 profiles, as follows:
  - The average peak demand for all distribution substations considered increases by 60.8% from 207.3 kW under the baseline profiles to 333.3 kW under the 2050 profiles;
  - The average load factor for all distribution substations considered increases by 25.9% from 60.9% under the baseline profiles to 76.7% under the 2050 profiles. This increase, corresponding to flattening of the profile shape, should be noted as it represents a loss of cyclic capability; and
  - The above points should not be considered in isolation. In assessing upgrade options, the increase in the peak demand may be the dominant factor, but the suitability of the cyclic ratings specified in NGED standards should be reviewed in light of the reduced time for transformers to recover from overload periods;

– The difference between the demand profiles for the low, medium and high EE scenarios is small in 2030 and 2050 (less than 10% in all cases and less than 4% in 2050, which was unaffected by the discrepancy in the number of HPs described below). Given this, it is deemed to be reasonable to adopt the medium EE scenario for subsequent detailed investigation;

– The impact of overnight storage heating reduces in 2050 from a peak in 2030. In the case of some distribution substations the overnight storage peak demand at 01:00 hours appears to be very high in 2030 and may warrant further investigation by the Carbon Trust and Hildebrand;

– In the case of some distribution substations in the Mackworth and Withycombe Raleigh case study areas, sawtooth profile shapes were observed with up and down oscillations in each half-hour. This is an area that should considered for further investigation, to confirm whether these profiles are accurately modelled;

– In the case of some distribution substations in the Mackworth and Withycombe Raleigh case study areas, a relatively small change between the baseline and 2030 profiles was observed, and a more substantial change between the 2030 and 2050 profiles. This is an area that should considered for further investigation, to confirm the reason for this, which may be due to the particularly housing stock and associated assumptions;

– It is understood that the baseline demand profile for each distribution substation has been used to calibrate the future scenario profiles, and details of this activity are presented in the Carbon Trust and Hildebrand project reports [4, 6]. The baseline profile corresponds to the current winter demand, based on selected days in January 2022 or January 2021 (based on available data), and is presented on the figures for comparison; and

– GHD recommends that the Carbon Trust and Hildebrand should investigate the issues identified relating to the consistency of the number of HP installations modelled, sawtooth profiles and spikes in demand at 01:00 hours, if they are not already discussed in the project reports under preparation by them.

4. Study results

The following sections show the results of the PSS SINCAL studies across the three case study areas. In order to assess whether interventions are likely to be required across the network, some thresholds have been adopted for replacing assets:

– Circuits
  - 50% loading - N-1 threshold (allowing for backfeed of an adjacent HV feeder)

– Transformers
  - 80% loading – Pro-active replacement threshold
  - 100% loading – Nameplate rating threshold
  - 130% loading – Cyclic rating threshold

Where an asset exceeds a threshold in a future profile (2030 or 2050), a proposed replacement year has been derived using linear interpolation of the results with the previous profile. In reality, it is unlikely that demand will increase linearly, so it should be noted that the replacement year is simply indicative.

It should be noted that the following results focus on the Medium EE scenario, as it was highlighted in Section 3.5 that the difference in demand between the scenarios was minimal. The PSS SINCAL studies have been completed for all three EE scenarios, and additional details can be found in Appendix B-1.

4.1 Demand Profiles

The figures in Appendix A-3 show the overall demand profiles as seen at the primary substation 11kV busbar in each of the three case study areas under the different energy efficiency scenarios. The overall demand corresponds to the sum of the load profiles at the distribution substations as well as any losses from the assets (albeit these are relatively small as only a single feeder is being studied in each case). The base profile (2022) has been shown on the figures to allow a comparison to be drawn, but it should be noted that some improvements in the modelling in relation to overnight storage are not fully reflected in these base profiles as discussed in Section 3.5.

No reactive power profiles have been derived for the distribution substations, as mentioned in Section 2.5, so the loads are assumed to be at unity power factor. As a result, only the reactive power profiles are plotted on the figures.

The results below show asset loading as a percentage of their nominal rating (either in A or MVA) and will, therefore, include any reactive power contributed by the circuits and transformers.

4.2 Axbridge

4.2.1 Circuit Loading

Figure 4.1 and Figure 4.2 show the maximum percentage circuit loading plotted against current rating (kA) and length (m), respectively, for each distribution substation under the medium EE scenario for the winter representative day in 2030 and 2050, as well as the baseline 2022 profile. Additionally, a reference point of 50% loading has been shown on the figures, signifying the threshold at which circuits should be upgraded. It should be noted that the plots only present the maximum circuit loading of each circuit element on the winter representative day under the medium energy efficiency scenario, which allows for comparison between the baseline, 2030 and 2050 profiles. It is deemed to be reasonable to use the average winter profile for the purpose of planning, since it would not be economically justified to upgrade all of the network assets to provide resilience in the more extreme (1-in-20) conditions. However, there may be justification for additional upgrades in strategic locations.

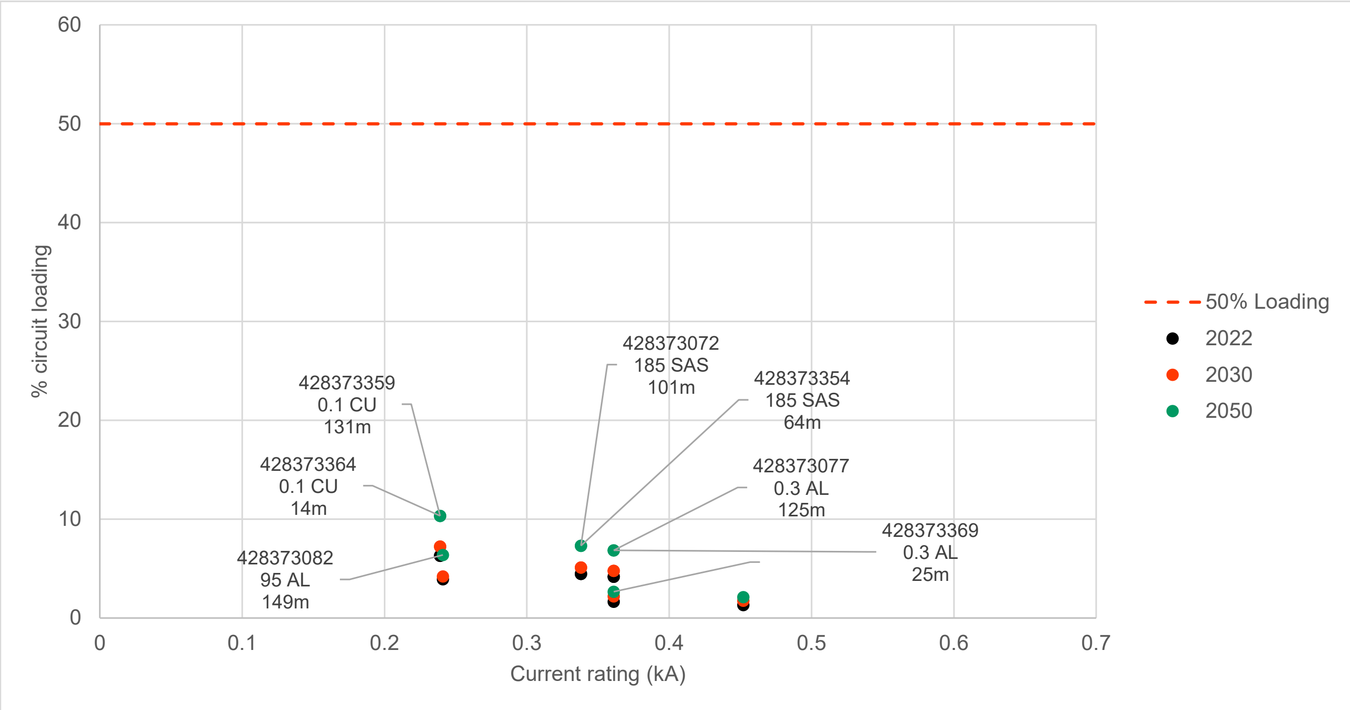


Figure 4.1 ***Axbridge circuit loading against current rating***

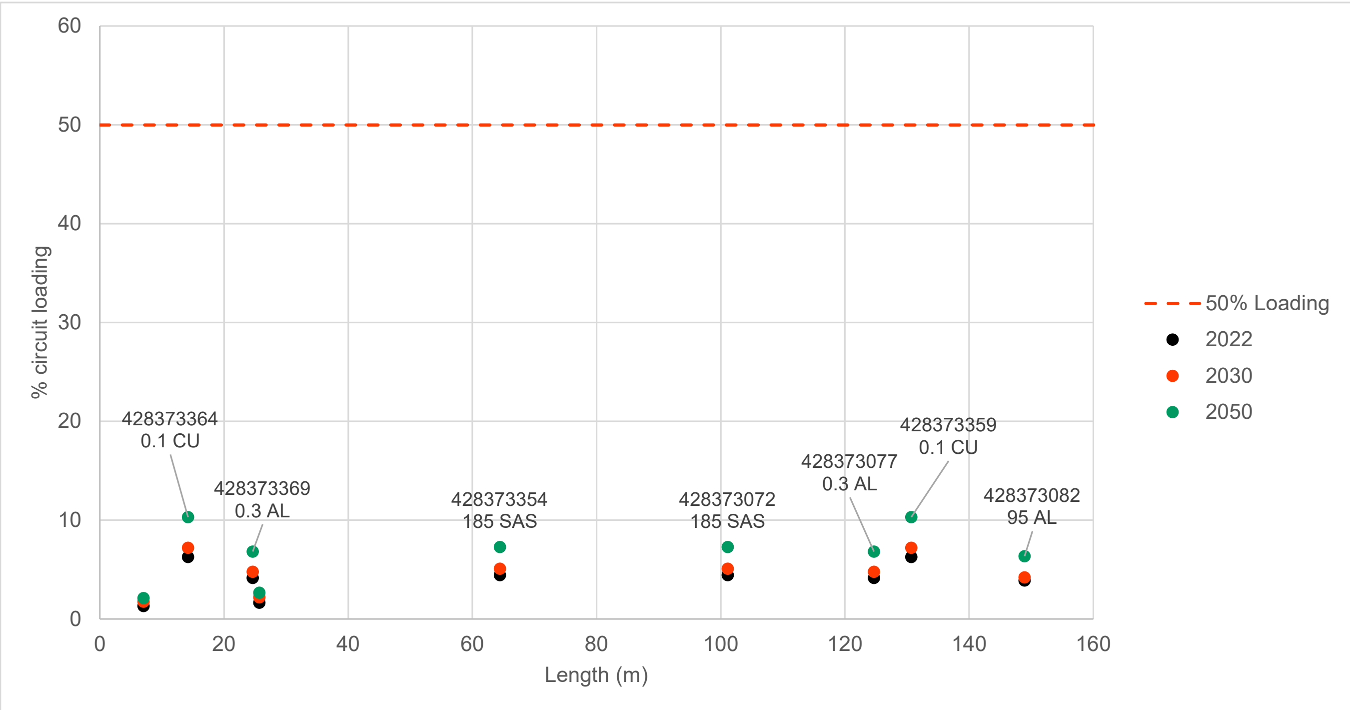


Figure 4.2 ***Axbridge circuit loading against length***

In all cases, the circuit loading is significantly below the replacement threshold of 50%, suggesting that none of the circuit elements would require any intervention as a result of additional demand due to HP installations under the Consumer Transformation DFES assumptions, and associated EE measures.

Table 4.1 shows the highest circuit loading values recorded in Axbridge across all representative days for the medium EE scenario.

Table 4.1 Axbridge medium EE scenario highest circuit loadings in each representative day and year

				Asset loading (%)						
				Winter			Extreme		Intermediate	
Asset ID	Line type	Length (m)	Asset rating (kA)	Baseline	2030	2050	2030	2050	2030	2050
428373364	0.1 CU	14.2	0.239	6.30	7.23	10.33	7.65	12.75	5.04	6.31
428373359	0.1 CU	130.7	0.239	6.30	7.23	10.33	7.65	12.76	5.04	6.31
428373072	185 SAS	101.1	0.338	4.45	5.11	7.30	5.41	9.02	3.57	4.47
428373354	185 SAS	64.4	0.338	4.45	5.11	7.30	5.41	9.02	3.57	4.47
428373369	0.3 AL	24.6	0.361	4.17	4.79	6.84	5.06	8.44	3.35	4.19
428373077	0.3 AL	124.7	0.361	4.17	4.78	6.84	5.06	8.45	3.34	4.19
428373082	95 AL	148.9	0.241	3.91	4.22	6.37	4.22	7.77	3.00	3.88
428373240	0.3 AL	25.7	0.361	1.65	2.20	2.66	2.43	3.26	1.85	1.60
428373245	3 x 185 1c TxAL EPR	7.0	0.452	1.32	1.76	2.12	1.94	2.60	1.49	1.29

It can be seen from Table 4.1, that the maximum loadings occur in the Extreme 2050 day. It can also be seen that none of the circuits reach the 50% replacement threshold, suggesting that it is unlikely that any interventions will be required on the HV feeder due to HPs in isolation, but these should be considered alongside other technology uptake for a full picture.

4.2.2 Transformer Loading

Figure 4.3 shows the maximum percentage transformer loading plotted against the apparent power rating for each distribution substation under the medium EE scenario for the winter representative day in 2030 and 2050, as well as the baseline 2022 profile. As previously stated, three thresholds for transformer loading have been applied, which are shown on Figure 4.3.

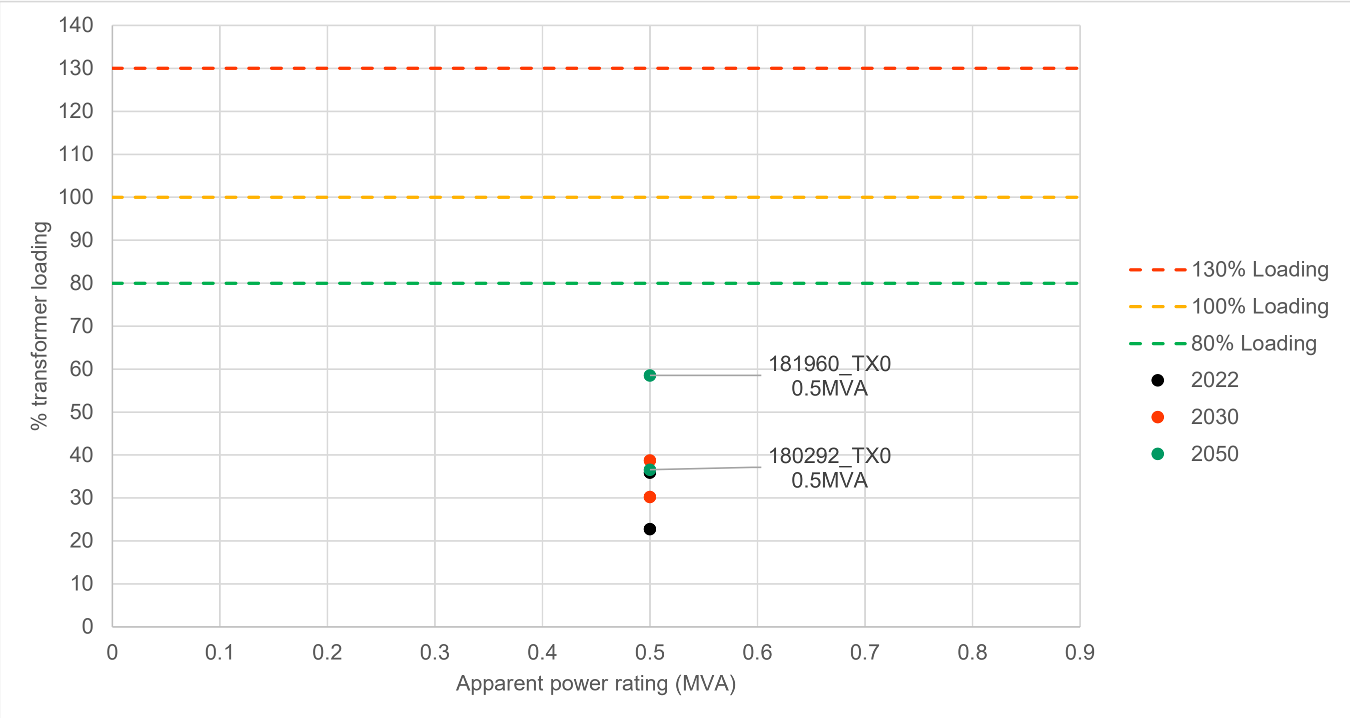


Figure 4.3 Axbridge transformer loading against apparent power rating

It can be seen from Figure 4.3 that there are only two transformers on the feeder, both of which have a rating of 0.5MVA. Neither of the transformers exceeds the pro-active replacement threshold of 80%; therefore, it is unlikely that the case study area would benefit from the addition of energy efficiency measures in order to avoid or delay interventions.

Table 4.2 shows the highest transformer loading values in Axbridge across all representative days for the medium EE scenario.

Table 4.2 Axbridge medium EE scenario ten highest loaded transformers across all rep. days

		Asset loading (%)						
		Winter			Extreme		Intermediate	
Asset ID	Asset rating (MVA)	Baseline	2030	2050	2030	2050	2030	2050
181960_TX0	0.500	35.9	38.7	58.5	38.7	71.4	26.1	33.8
180292_TX0	0.500	22.8	30.3	36.6	33.5	44.8	24.1	20.8

It can be seen from Table 4.2 that, in all instances, the highest loading values occur in the Extreme 2050 day. It can also be seen that none of the values reach the 80% pro-active upgrade threshold; therefore, it is unlikely that any transformers on the feeder will require intervention.

4.3 Mackworth

4.3.1 Circuit Loading

Figure 4.4 and Figure 4.5 show the maximum percentage circuit loading plotted against current rating (kA) and length (m), respectively, for each distribution substation under the medium EE scenario for the winter representative day in 2030 and 2050, as well as the baseline 2022 profile.

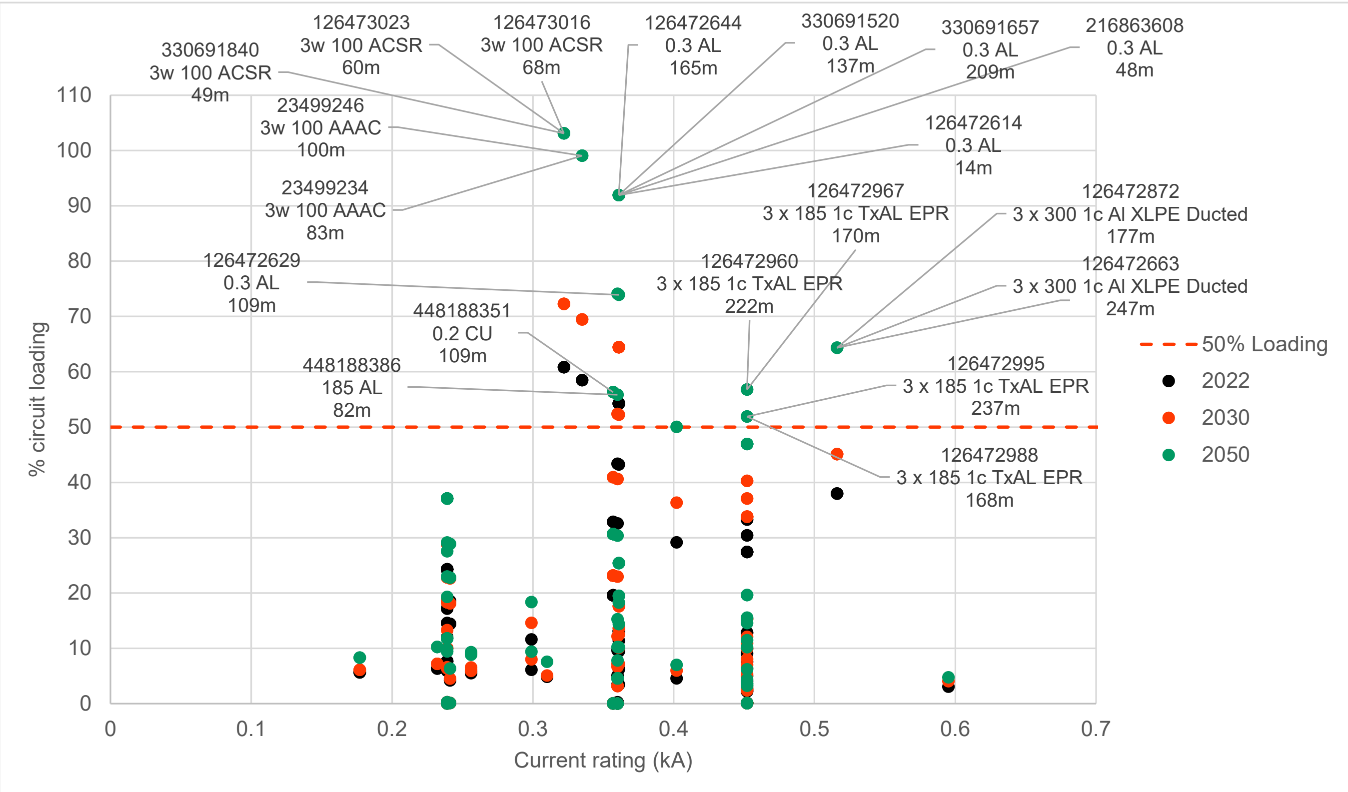


Figure 4.4 Mackworth circuit loading against current rating

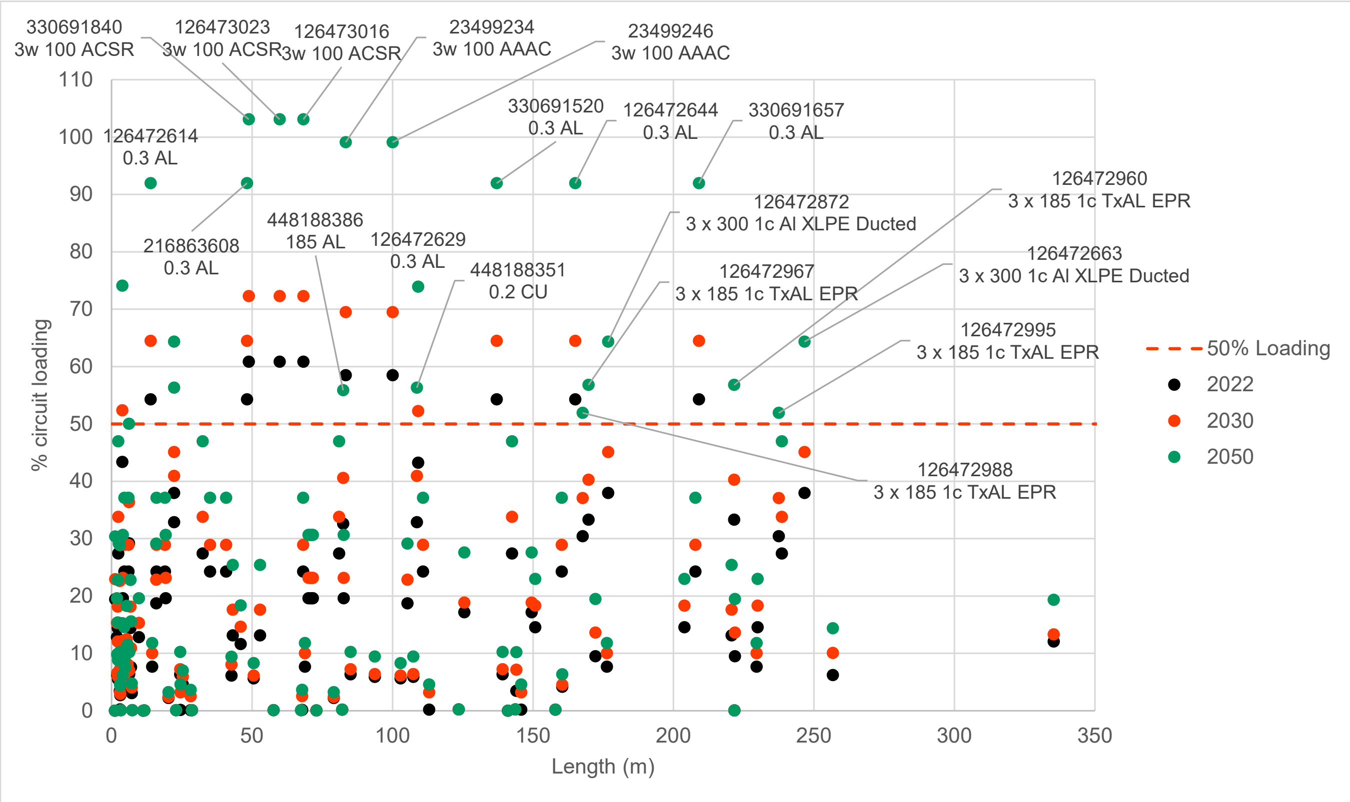


Figure 4.5 ***Mackworth circuit loading against length***

The following can be seen from Figure 4.4 and Figure 4.5:

- Some circuits are already exceeding the 50% replacement threshold under the baseline profile. It is likely that this is based on the assumption that load can be transferred elsewhere following an N-1 event;
- Some circuits exceed 90% of their rating in 2050, which represents quite a significant "overload". It should be noted that in these cases the replacement circuit would need to have a rating of circa 700A to achieve the 50% requirement. As this exceeds the standard 630A circuit breaker (CB) rating, and it is unlikely that it would be possible to procure a large enough conductor, a new feeder would need to be created and the network split up; and
- A number of the circuits identified as requiring upgrades are overhead lines. It may only be possible to replace these with underground cable, which is more expensive and harder to implement.

It was noted that all of these circuits are located between the 11kV busbar of the primary substation and distribution substation 872825, which can be seen on Figure 4.6. This suggests that a large section of the northern portion of the feeder is not suitably rated at present.

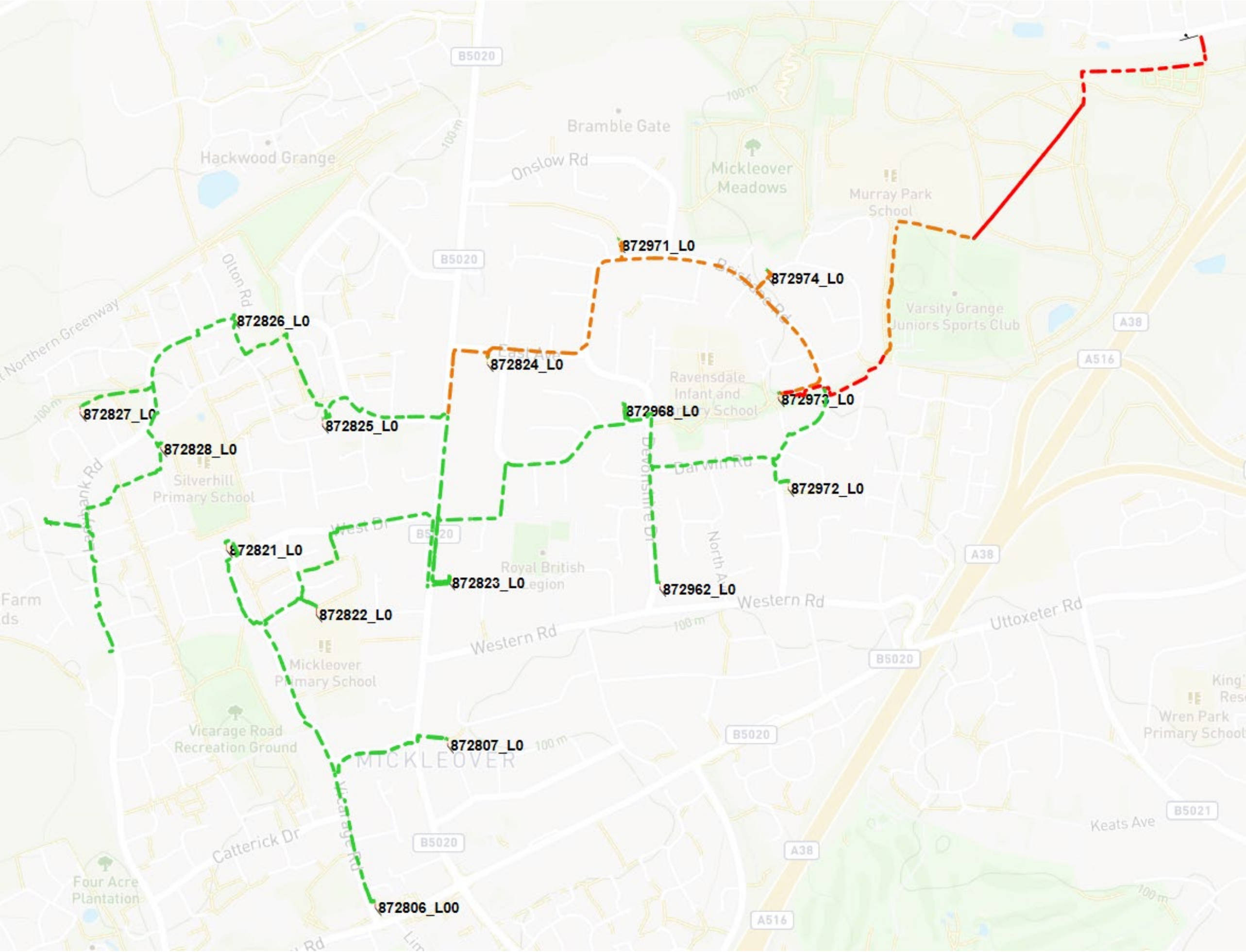


Figure 4.6 Mackworth case study area 2050 line loading (medium EE scenario)

Table 4.3 shows the highest circuit loading values recorded in Mackworth across all representative days for the medium EE scenario, along with the upgrade years determined by interpolation based on the winter day loading values in baseline, 2030 and 2050.

Table 4.3 Mackworth medium EE scenario highest circuit loadings in each representative day and year

				Asset loading (%)							
				Winter			Extreme		Intermediate		
Asset ID	Line type	Length (m)	Asset rating (kA)	Baseline	2030	2050	2030	2050	2030	2050	Upgrade Year
126473023	3w 100 ACSR	59.85	0.299	60.8	72.3	103.1	75.8	127.8	52.4	65.8	2022
126473016	3w 100 ACSR	68.26	0.299	60.8	72.3	103.1	75.8	127.8	52.4	65.8	2022
330691840	3w 100 ACSR	48.84	0.299	60.8	72.3	103.1	75.8	127.8	52.4	65.8	2022
23499246	3w 100 AAAC	100.05	0.310	58.5	69.5	99.1	72.8	122.8	50.6	63.5	2022
23499234	3w 100 AAAC	83.33	0.310	58.5	69.5	99.1	72.8	122.8	50.6	63.5	2022
126472614	0.3 AL	13.92	0.342	54.2	64.4	91.9	67.6	114.0	45.8	57.5	2022
126472644	0.3 AL	164.98	0.342	54.2	64.4	91.9	67.6	114.0	45.8	57.5	2022
330691657	0.3 AL	209.07	0.342	54.3	64.5	91.9	67.6	114.0	45.8	57.5	2022
330691520	0.3 AL	137.07	0.342	54.3	64.5	91.9	67.6	114.0	45.8	57.5	2022
216863608	0.3 AL	48.19	0.342	54.3	64.5	91.9	67.6	114.0	45.8	57.5	2022

				Asset loading (%)							
				Winter			Extreme		Intermediate		
Asset ID	Line type	Length (m)	Asset rating (kA)	Baseline	2030	2050	2030	2050	2030	2050	Upgrade Year
126472924	185 AL	3.85	0.340	43.4	52.4	74.1	55.4	92.1	37.0	46.4	2028
126472629	0.3 AL	109.07	0.342	43.2	52.2	73.9	55.2	91.8	36.7	46.1	2028
126472649	3 x 300 1c Al XLPE Ducted	22.24	0.499	38.0	45.1	64.3	47.3	79.8	31.4	39.4	2035
126472663	3 x 300 1c Al XLPE Ducted	246.66	0.499	38.0	45.1	64.3	47.3	79.8	31.4	39.4	2035
126472872	3 x 300 1c Al XLPE Ducted	176.69	0.499	38.0	45.1	64.3	47.3	79.8	31.4	39.4	2035
126472960	3 x 185 1c TxAL EPR	221.57	0.424	33.3	40.3	56.8	42.6	70.5	28.5	35.7	2042
126472967	3 x 185 1c TxAL EPR	169.74	0.424	33.3	40.3	56.8	42.6	70.5	28.5	35.7	2042
448188351	0.2 CU	108.62	0.339	32.8	40.9	56.3	43.6	69.7	27.9	34.6	2042
448188381	0.2 CU	22.24	0.339	32.8	40.9	56.3	43.6	69.7	27.9	34.6	2042
448188386	185 AL	82.45	0.340	32.6	40.6	55.9	43.2	69.1	27.8	34.5	2042
126472995	3 x 185 1c TxAL EPR	237.42	0.424	30.4	37.1	51.9	39.2	64.3	25.9	32.4	2047
126472988	3 x 185 1c TxAL EPR	167.68	0.424	30.4	37.1	51.9	39.2	64.3	25.9	32.4	2047
448188478	3 x 185 1c Al XLPE Ducted	6.15	0.389	29.2	36.3	50.0	38.7	61.9	24.3	30.1	2050

It can be seen from Table 4.3, that the maximum loadings occur in the Extreme 2050 day. It can also be seen that all of the 23 circuits shown reach the 50% upgrade threshold under the winter day profile at some point up to 2050. Of the 23 required upgrades, a total of 10 circuits exceed the upgrade threshold in the 2022 base scenario. These 10 circuits are all located between the 11kV busbar at Mackworth and substation 872973, which can be seen on Figure 2.4. 872973 is the first substation out on the feeder.

4.3.2 Transformer Loading

Figure 4.7 shows the maximum percentage transformer loading plotted against the apparent power rating for each distribution substation under the medium EE scenario for the winter representative day in 2030 and 2050, as well as the baseline 2022 profile.

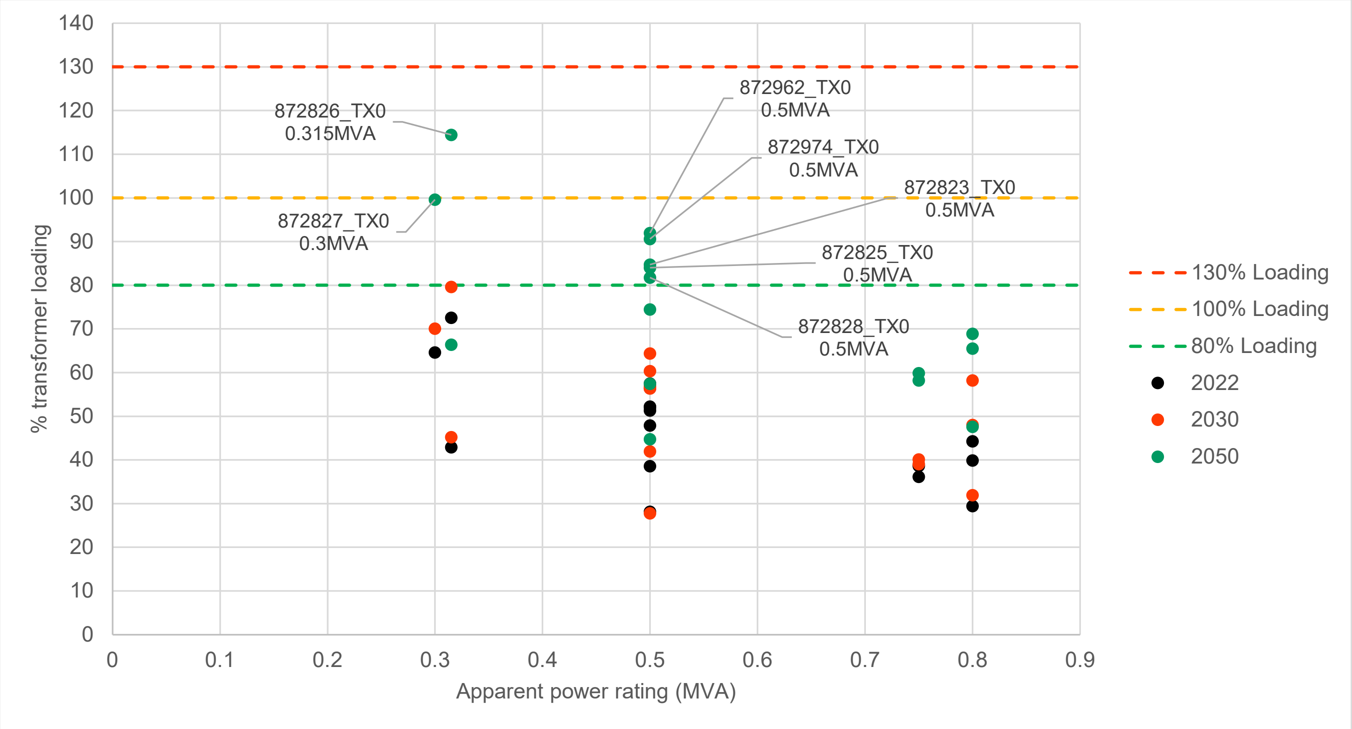


Figure 4.7 ***Mackworth transformer loading against apparent power rating***

From Figure 4.7 it can be seen that there are a number of transformers whose 2050 peak loading exceeds the 80% pro-active replacement threshold and even the 100% nameplate rating threshold, suggesting that some intervention is likely to be required before 2050. The percentage loading of the transformers is illustrated in Figure 4.8.

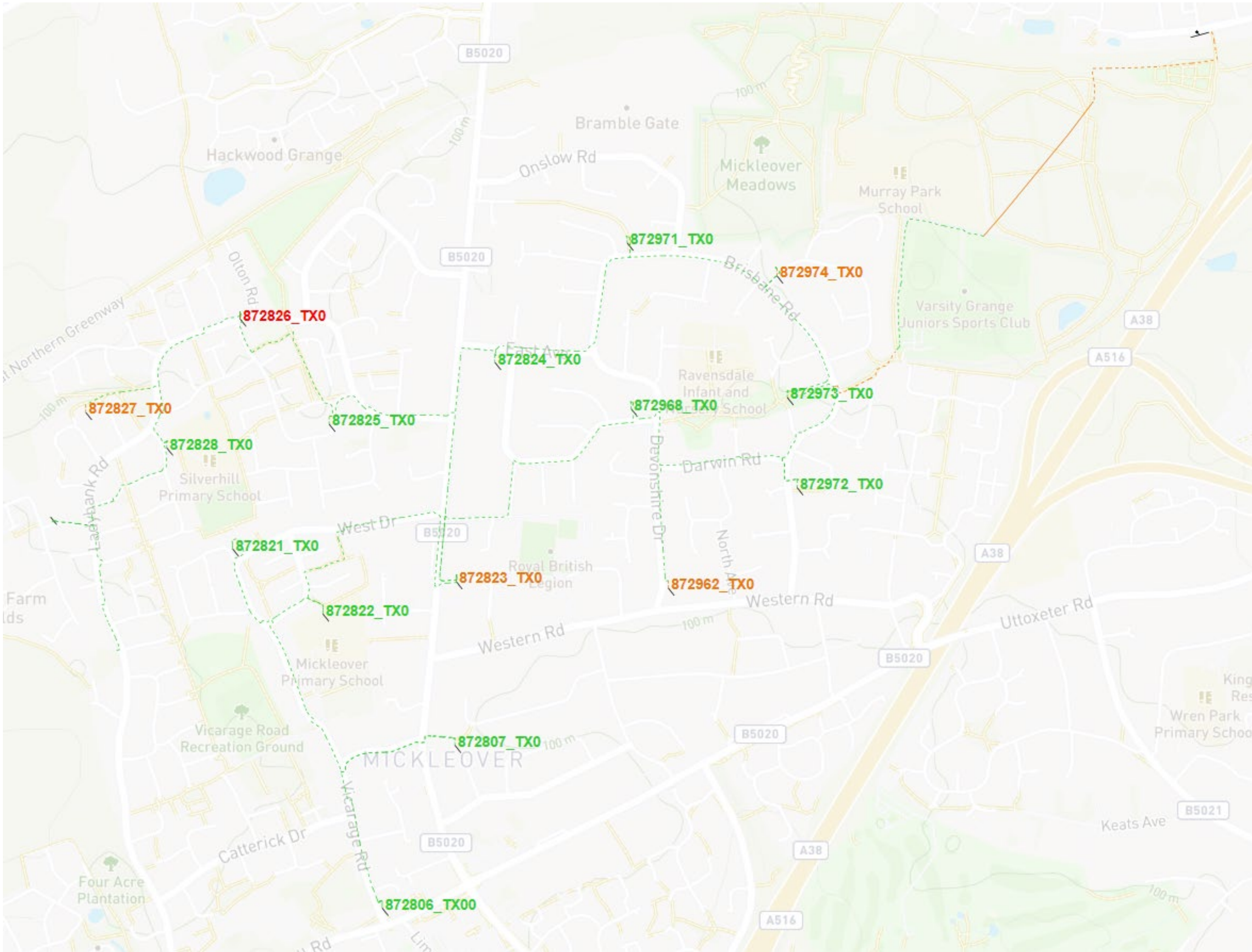


Figure 4.8 Mackworth case study area 2050 transformer loading (medium EE scenario)

Table 4.4 shows the highest transformer loading values in Mackworth across all representative days for the medium EE scenario, as well as the required upgrade years. The transformer upgrade years have been determined using the maximum loadings from the winter day profiles under the medium EE scenario, compared against the 80% pro-active replacement threshold and interpolated to provide an indicative year.

Table 4.4 Mackworth medium EE scenario highest loaded transformers across all representative days

		Asset loading (%)							
		Winter			Extreme		Intermediate		
Asset ID	Asset rating (MVA)	Baseline	2030	2050	2030	2050	2030	2050	Upgrade year
872826_TX0	0.315	72.6	79.6	114.4	80.2	145.1	54.4	69.4	2030
872827_TX0	0.300	64.7	70.1	99.6	71.5	122.2	46.8	58.7	2037
872962_TX0	0.500	56.4	64.4	92.0	62.5	111.4	44.2	54.5	2041
872974_TX0	0.500	57.5	60.4	90.6	62.1	112.3	42.4	54.3	2043
872823_TX0	0.500	52.2	56.6	84.7	57.3	105.7	38.1	49.4	2047
872825_TX0	0.500	52.1	56.4	84.0	59.2	107.0	38.5	49.1	2047
872828_TX0	0.500	47.9	56.8	81.8	59.3	96.9	37.3	47.0	2049

Table 4.4 shows that the highest loading occurs in the Extreme 2050 day and all seven transformers shown reach the 80% pro-active replacement threshold by 2050, based on the winter day profiles. One transformer also reaches the 100% nameplate rating threshold, but the 130% cyclic rating threshold is not reached except when

considering the extreme day profiles. It should be noted that all of the transformers are rated at 315 or 500kVA, so upgrades to 800/1,000kVA should be able to be implemented on the existing substation site, but may require additional low voltage cabling to be installed. Should a 1,000kVA transformer require upgrade then this would trigger the need for a new substation to be installed and associated 11kV and low voltage upgrades.

4.4 Withycombe Raleigh

4.4.1 Circuit Loading

Figure 4.9 and Figure 4.10 show the maximum percentage circuit loading plotted against current rating (kA) and length (m), respectively, for each distribution substation under the medium EE scenario for the winter representative day in 2030 and 2050, as well as the baseline 2022 profile.

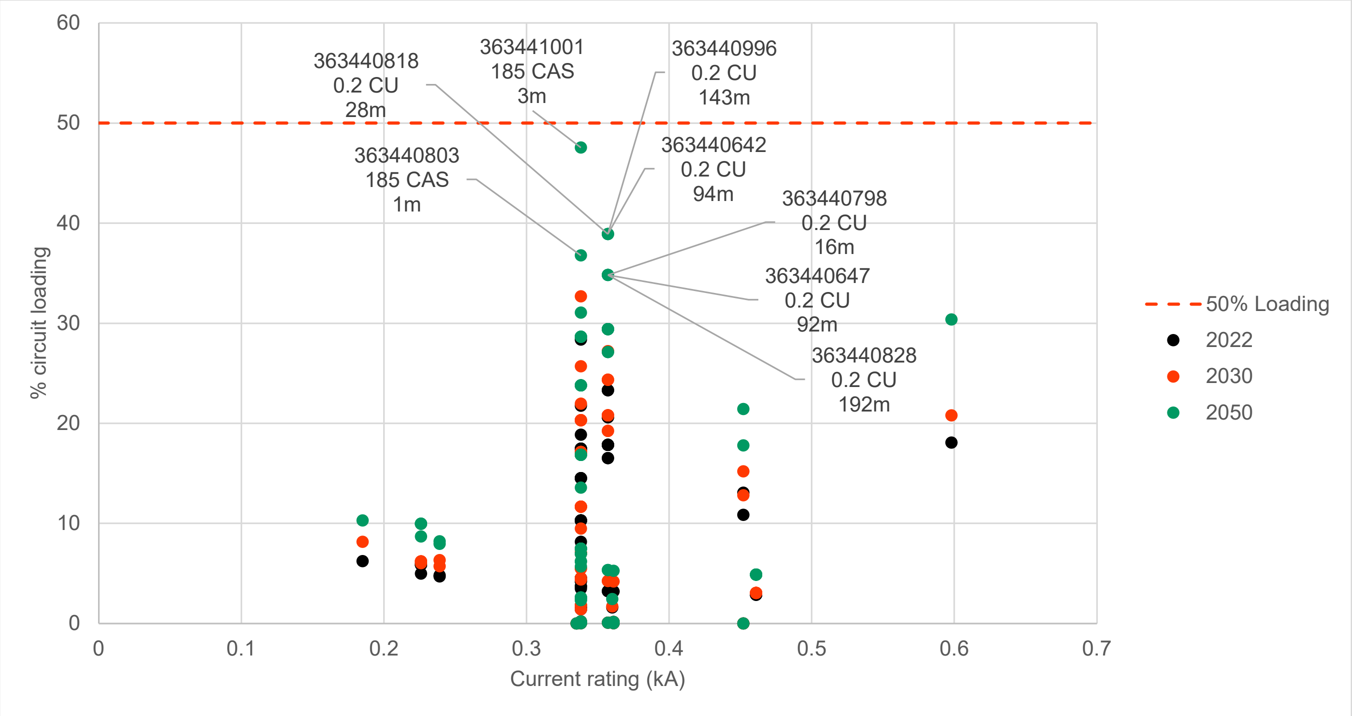


Figure 4.9 Withycombe Raleigh circuit loading against current rating

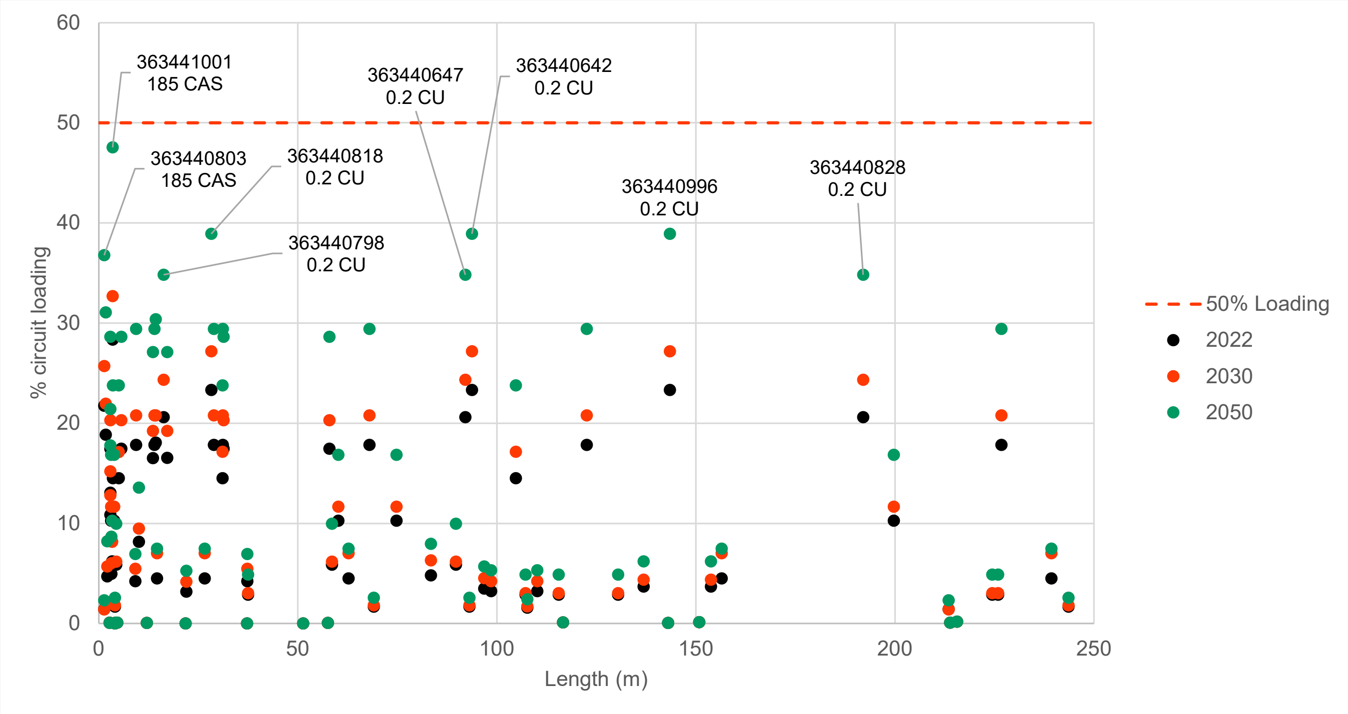


Figure 4.10 Withycombe Raleigh circuit loading against length

Figure 4.9 and Figure 4.10 show that, while no circuits exceed the 50% threshold, circuit 363441001 is relatively close by 2050. It should be noted that this circuit is very short (approximately 3m) and is located near to the primary, so higher loading is expected. This suggests that the circuits are suitably rated at present.

Table 4.5 shows the highest circuit loading values recorded in Withycombe Raleigh across all representative days for the medium EE scenario.

Table 4.5 Withycombe Raleigh medium EE scenario highest circuit loadings in each representative day and year

				Asset loading (%)							
				Winter			Extreme		Intermediate		
Asset ID	Line type	Length (m)	Asset rating (kA)	Baseline	2030	2050	2030	2050	2030	2050	Upgrade Year
363441001	185 CAS	3.5	0.338	28.4	32.7	47.5	35.3	58.1	22.9	29.3	-
363440996	0.2 CU	143.5	0.357	23.3	27.2	38.9	29.4	47.5	18.7	23.7	-
363440642	0.2 CU	93.7	0.357	23.3	27.2	38.9	29.4	47.5	18.7	23.7	-
363440818	0.2 CU	28.3	0.357	23.3	27.2	38.9	29.4	47.5	18.7	23.7	-
363440803	185 CAS	1.4	0.338	21.8	25.7	36.8	27.9	45.0	17.9	22.6	-
363440647	0.2 CU	92.1	0.357	20.6	24.3	34.8	26.5	42.6	16.9	21.4	-
363440828	0.2 CU	192.0	0.357	20.6	24.3	34.8	26.5	42.6	16.9	21.3	-
363440798	0.2 CU	16.3	0.357	20.6	24.3	34.8	26.5	42.6	16.9	21.3	-
363440813	185 CAS	1.7	0.338	18.8	22.0	31.1	23.4	37.7	16.1	19.2	-

It can be seen from Table 4.5, that the maximum loadings occur in the Extreme 2050 day. It can also be seen that none of the nine circuits shown reach the 50% upgrade threshold under the winter day profile at any point up to 2050. Furthermore, only one circuit reaches the upgrade threshold when the extreme day profile is considered.

4.4.2 Transformer Loading

Figure 4.11 shows the maximum percentage transformer loading plotted against the apparent power rating for each distribution substation under the medium EE scenario for the winter representative day in 2030 and 2050, as well as the baseline 2022 profile.

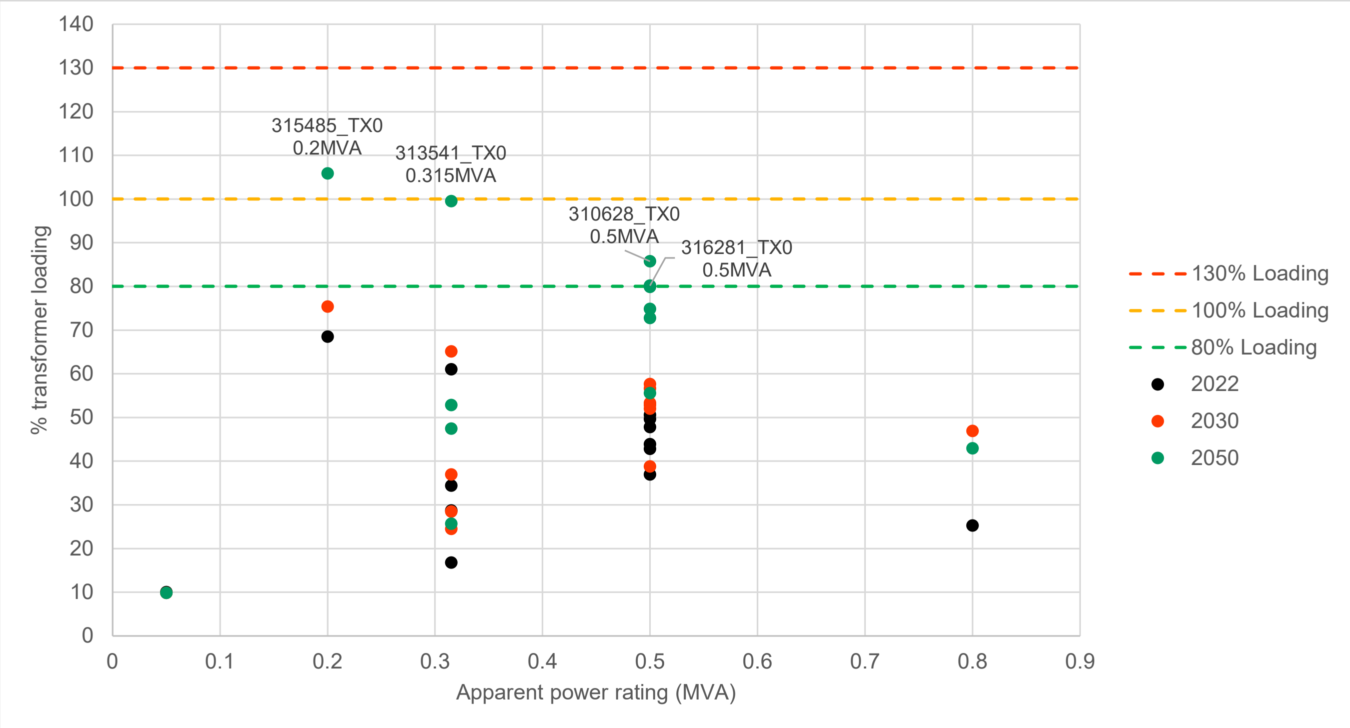


Figure 4.11 Withycombe Raleigh transformer loading against apparent power rating

Figure 4.11 shows that there are a number of transformers whose 2050 peak loading exceeds the 80% pro-active replacement threshold and even the 100% nameplate rating threshold, suggesting that some intervention is likely to be required before 2050.

Table 4.6 shows the highest transformer loading values in Withycombe Raleigh across all representative days for the medium EE scenario, as well as the required upgrade years. The transformer upgrade years have been determined using the maximum loadings from the winter day profiles under the medium EE scenario, compared against the 80% pro-active replacement threshold and interpolated to provide an indicative year.

Table 4.6 Withycombe Raleigh medium EE scenario highest loaded transformers across all representative days

		Asset loading (%)							
		Winter			Extreme		Intermediate		
Asset ID	Asset rating (MVA)	Baseline	2030	2050	2030	2050	2030	2050	Upgrade year
315485_TX0	0.200	68.5	75.4	105.8	71.5	127.3	49.3	61.7	2033
313541_TX0	0.315	61.0	65.1	99.5	74.0	120.6	43.8	57.5	2039
310628_TX0	0.500	50.6	53.3	85.8	56.6	103.3	38.0	50.4	2046
316281_TX0	0.500	47.8	56.6	80.2	57.0	96.3	36.5	46.4	2050
310037_TX0	0.500	49.7	52.8	79.9	58.2	97.8	36.7	47.3	-
313636_TX0	0.500	42.8	52.0	74.8	60.6	95.4	34.6	42.2	-
313819_TX0	0.500	43.9	57.7	72.8	68.9	88.9	36.6	41.9	-

Table 4.6 shows that the highest loading occurs in the Extreme 2050 day and all four of the seven transformers shown reach the 80% pro-active replacement threshold by 2050, based on the winter day profiles. Three

transformers also reach the 100% nameplate rating threshold when considering the extreme day profiles, but the 130% cyclic rating threshold is not reached. It should be noted that all of the transformers are rated at 500kVA or less, so upgrades to 800/1,000kVA should be able to be implemented on the existing substation site, but may require additional low voltage cabling to be installed. However, the 200kVA transformer at 315485 is likely to be a “padmount” transformer, and would need to be replaced with a larger “unit” type substation.

4.5 Summary

4.5.1 Findings

The findings from the PSS SINCAL studies undertaken for the three case study areas may be summarised, as follows:

– The results presented in this section are limited to the medium EE scenario, since the difference between the demand profiles for the alternative scenarios was shown to be small in Section 3.2;
– The PSS SINCAL studies were carried out for all three EE scenarios, and the results of the studies are summarised in Appendix B-1. Furthermore, the results for all three EE scenarios are summarised in Table 4.7 and Table 4.8 for circuit and transformer loadings, respectively;
– Table 4.7 indicates that, based on the 50% upgrade threshold:
  - Axbridge case study area: no circuits are expected to require intervention up to 2050 across all EE scenarios and representative days;
  - Mackworth case study area: 12 circuits require upgrade by 2030 based on the winter day profile under the medium EE scenario. This includes 10 circuits that appear to exceed the 80% threshold loading value in the 2022 baseline profile. The number of required upgrades rises to 23 circuits by 2050, based on the winter day profile under the medium EE scenario. Slightly different numbers are observed for the other EE scenarios and representative days;
  - Withycombe Raleigh case study area: no circuits are expected to require intervention up to 2050 based on the winter day profile under all three EE scenarios. Only one circuit requires upgrade when considering the extreme day profile in 2050;
– Table 4.8 indicates that, based on the 80% pro-active upgrade threshold:
  - Axbridge case study area: no transformers are expected to require intervention up to 2050 across all EE scenarios and representative days;
  - Mackworth case study area: no transformers are expected to require intervention up to 2030 based on the winter day profile under the medium EE scenario. This rises to one transformer requiring upgrade by 2030 when considering the extreme day profile, and the winter day profiles under the low and high EE scenarios. Seven transformers are expected to require intervention up to 2050 based on the winter day profile under the medium EE scenario. Slightly different numbers are observed for the other EE scenarios and representative days;
  - Withycombe Raleigh case study area: no transformers are expected to require intervention up to 2030 based on the winter day profile under all three EE scenarios. This rises to one transformer requiring upgrade by 2030 when considering the extreme day profile under the high EE scenario. Four transformers are expected to require intervention up to 2050 based on the winter day profile under the medium EE scenario. Slightly different numbers are observed for the other EE scenarios and representative days;

Table 4.7 shows the number of circuits whose loading exceeds the 50% upgrade threshold in each EE scenario and for each representative day. The corresponding percentage of the total number of circuits in each case study area is also presented, along with the number of half-hours during which the threshold is exceeded and the percentage of the total number of half-hours modelled for all circuits[3].

[3] Calculated by multiplying 48 half-hour periods by the number of assets. For example, in Axbridge there are a total of nine circuits. This means that, in each modelling scenario and for each representative day, there is a total of 432 results covering all circuits in each half-hour period.

Table 4.7 Number of circuits loaded greater than 50% across all days

			Axbridge				Mackworth				Withycombe Raleigh			
EE Scenario	**Rep. Day**	**Year**	**Number circuits**	**% circuits**	**Number HHs**	**% HHs**	**Number circuits**	**% circuits**	**Number HHs**	**% HHs**	**Number circuits**	**% circuits**	**Number HHs**	**% HHs**
Med	Winter	2030	0	0.0	0	0.0	12	9.8	175	3.0	0	0.0	0	0.0
Med	Extreme	2030	0	0.0	0	0.0	12	9.8	249	4.2	0	0.0	0	0.0
Med	Int	2030	0	0.0	0	0.0	5	4.1	8	0.1	0	0.0	0	0.0
High	Winter	2030	0	0.0	0	0.0	12	9.8	164	2.8	0	0.0	0	0.0
High	Extreme	2030	0	0.0	0	0.0	12	9.8	218	3.7	0	0.0	0	0.0
High	Int	2030	0	0.0	0	0.0	5	4.1	8	0.1	0	0.0	0	0.0
Low	Winter	2030	0	0.0	0	0.0	12	9.8	189	3.2	0	0.0	0	0.0
Low	Extreme	2030	0	0.0	0	0.0	12	9.8	256	4.3	0	0.0	0	0.0
Low	Int	2030	0	0.0	0	0.0	5	4.1	8	0.1	0	0.0	0	0.0
Med	Winter	2050	0	0.0	0	0.0	23	18.7	696	11.8	0	0.0	0	0.0
Med	Extreme	2050	0	0.0	0	0.0	28	22.8	1,078	18.3	1	1.2	14	0.3
Med	Int	2050	0	0.0	0	0.0	10	8.1	124	2.1	0	0.0	0	0.0
High	Winter	2050	0	0.0	0	0.0	22	17.9	666	11.3	0	0.0	0	0.0
High	Extreme	2050	0	0.0	0	0.0	28	22.8	1,037	17.6	1	1.2	10	0.2
High	Int	2050	0	0.0	0	0.0	10	8.1	121	2.0	0	0.0	0	0.0
Low	Winter	2050	0	0.0	0	0.0	22	17.9	687	11.6	0	0.0	0	0.0
Low	Extreme	2050	0	0.0	0	0.0	28	22.8	1,043	17.7	1	1.2	28	0.7
Low	Int	2050	0	0.0	0	0.0	10	8.1	124	2.1	0	0.0	0	0.0

Similarly, Table 4.8 shows the number of transformers whose loading exceeds the 80% pro-active upgrade threshold in each EE scenario and for each representative day. The corresponding percentage of the total number of transformers in each case study area is also presented, along with the number of half-hours during which the threshold is exceeded and the percentage of the total number of half-hours modelled for all transformers[4].

Table 4.8 Number of transformers loaded greater than 80% across all days

			Axbridge				Mackworth				Withycombe Raleigh			
EE Scenario	Rep. Day	Year	Number trans-formers	% trans-formers	Number HHs	% HHs	Number trans-formers	% trans-formers	Number HHs	% HHs	Number trans-formers	% trans-formers	Number HHs	% HHs
Med	Winter	2030	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Med	Extreme	2030	0	0.0	0	0.0	1	6.3	1	0.1	0	0.0	0	0.0
Med	Int	2030	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
High	Winter	2030	0	0.0	0	0.0	1	6.3	1	0.1	0	0.0	0	0.0
High	Extreme	2030	0	0.0	0	0.0	1	6.3	3	0.4	1	7.7	1	0.2
High	Int	2030	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Low	Winter	2030	0	0.0	0	0.0	1	6.3	2	0.3	0	0.0	0	0.0
Low	Extreme	2030	0	0.0	0	0.0	1	6.3	4	0.5	0	0.0	0	0.0
Low	Int	2030	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Med	Winter	2050	0	0.0	0	0.0	7	43.8	80	10.4	4	30.8	51	8.2
Med	Extreme	2050	0	0.0	0	0.0	11	68.8	302	39.3	7	53.8	217	34.8
Med	Int	2050	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
High	Winter	2050	0	0.0	0	0.0	6	37.5	70	9.1	3	23.1	47	7.5
High	Extreme	2050	0	0.0	0	0.0	10	62.5	268	34.9	7	53.8	193	30.9
High	Int	2050	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Low	Winter	2050	0	0.0	0	0.0	6	37.5	85	11.1	5	38.5	74	11.9
Low	Extreme	2050	0	0.0	0	0.0	10	62.5	293	38.2	7	53.8	242	38.8
Low	Int	2050	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

[4] Calculated by multiplying 48 half-hour periods by the number of assets. For example, in Axbridge there are a total of two transformers. This means that, in each modelling scenario and for each representative day, there is a total of 96 results covering both transformers in each half-hour period.

Table 4.9 provides a summary of the total numbers of circuits and transformers in each case study area, for reference.

Table 4.9 Numbers of circuits and transformers in each case study area

Case study area	Number of circuits	Number of transformers
Axbridge	9	2
Mackworth	123	16
Withycombe Raleigh	85	13

4.5.2 Recommendations

GHD recommends that the Carbon Trust and Hildebrand should investigate the issues identified relating to the consistency of the number of HP installations modelled, sawtooth profiles and spikes in demand at 01:00 hours, if they are not discussed in the project reports under preparation by them.

Following resolution of the issues in the demand profiles, next steps might include:

– Further development of the modelling of demand profiles to provide predicted profiles covering HP uptake combined with other LCTs, as well as the impact of changes to industrial and commercial demand connected to each distribution substation/HV metered supplies;
– Consideration of reactive as well as active power demand;
– Preparation of profiles for all of the distribution substations in a selected primary substation area (multiple HV feeders), and running network studies for the whole primary area. It is recommended that Mackworth primary would be a good candidate for further analysis in this way.

5. Conclusions

The principal conclusions from the assessment can be grouped into the following categories, which are described in the sub-sections below:

– Nature of demand profiles and considerations for accommodation of HPs;
– Planning criteria for HV network reinforcements;
– Comparison of the analysis with alternative approaches; and
– Integration with BAU.

5.1 Nature of demand profiles and considerations for accommodation of HPs

The assessment has demonstrated that demand profiles derived using the tool developed by the Carbon Trust and Hildebrand can be input into a time series database to successfully complete PSS SINCAL network model runs covering a range of scenarios, years and representative days. As discussed in Section 3, there are some known limitations in the profiles that may be considered for further investigation and improvement in future, including:

– Consistency in the number of HPs applied to each distribution substation under different scenarios;
– Modelling parameters for overnight storage heating demand profiles; and
– The reason for sawtooth profile shapes observed with up and down oscillations in each half-hour.

As stated in Section 3.5, the impact of additional demand from HPs is not the focus of the study, which looks to demonstrate the incremental impact of installation of retrofit EE measures (under low, medium and high EE scenarios) alongside HPs. However, the input demand profiles are based on the HP uptake from the Consumer Transformation DFES scenario, and the impact of increasing HP numbers may be observed by comparison between the baseline, 2030 and 2050 profiles. Increases in the magnitude of the peak demand and the load factor, corresponding to a flattening of the demand profiles, have been observed.

The difference between the demand profiles for the low, medium and high EE scenarios is small in 2030 and 2050 (less than 4% in 2050). This is a characteristic of the modest differences in the EE measures that are applied in the different scenarios. However, the project has demonstrated that a range of profiles can be applied effectively to PSS SINCAL models of individual HV feeders, and this approach could be adopted to assess the impact of different profiles that account for a broader range of technology uptake (e.g. alternative assumptions for uptake of HPs, EE measures, EVs and rooftop solar PV in combination).

The demand profiles assessed in the project can generally be characterised as having a late afternoon peak demand (with a few exceptions), and shifting upwards throughout the day in later years as higher HP uptake is manifested in additional continuous demand. As such, the details presented in this report typically focus on the daily peak demand observed for each of the representative days in each year. However, it should be noted that the demand profiles may change more substantially in future, with the uptake of other technologies, and the study results can be used to assess such changes.

5.2 Planning criteria for HV network reinforcements

Within Section 4, the following threshold loading percentages were established for HV network reinforcements:

Circuits

– 50% loading - N-1 threshold

Transformers

– 80% loading – Pro-active replacement threshold
– 100% loading – Nameplate rating threshold

– 130% loading – Cyclic rating threshold

ENA EREC P2/8 [7] defines the minimum level of security of supply that should be achieved by a DNO's distribution network. It is assumed that the feeders would be assigned to supply class B (Over 1MW and up to 12MW) and as a result, there is a requirement to restore the Group Demand minus 1MW within three hours of a circuit outage. In order to be able to backfeed during an outage, a 50% loading threshold has been proposed for all circuits.

With regards to distribution transformers, three thresholds have been applied throughout the analysis. The lowest threshold proposed (80%) is based on pro-active replacement of a transformer. It should be noted that this threshold is not set by NGED, but instead accounts for lead times of new assets for replacement before the nameplate continuous rating (100%) is reached. Finally, the highest rating provided (130%) is based on cyclic ratings of distribution transformers. In a now-withdrawn NGED Standard Technique (ST:SD8D/1), different winter cyclic ratings were provided based on whether the transformer was underground, enclosed, outdoor or pole-mounted. A rating of 130% aligns with that applied to a ground mounted transformer in a GRP enclosure. However, the increases in both peak demand and load factor mean that the suitability of the cyclic ratings specified in NGED standards should be reviewed and upgrade options considered carefully.

In reality, it may be the case that the limiting factor when determining the permissible transformer loading is the ancillary equipment associated with the substation, rather than the transformer itself. As a result, a percentage threshold is unlikely to accurately predict whether a transformer should be replaced, and the values should be taken as indicative and used as a precursor to a more detailed assessment.

5.3 Comparison of the analysis with alternative approaches

The similarities between the approach adopted in the DEFENDER project and alternatives identified in the literature review remain applicable:

– Development of long-term trends for house/customer archetypes to represent the impact on the network at a granular using building stock analysis; and
– Use of demand profiles for representative days.

Table 5.1 reproduces the summary of the findings from the literature review report [2], covering alternative approaches to modelling energy efficiency and preparing demand profiles. The commentary remains valid in that the NGED DFES approach is the baseline approach adopted at the ESA level, and the assessment undertaken in the project looks to complement the DFES analysis by providing additional detail at a greater spatial resolution (profiles for individual distribution substations based on building stock analysis that enable network modelling at the HV feeder level).

Furthermore, the other data sources identified in the literature review represent useful secondary sources for validation of the profile outputs. GHD provided limited support to the Carbon Trust and Hildebrand for the validation of the demand profile outputs from the tool developed by them in the project. Some limitations were identified in the demand profiles, which should be considered for further investigation in future alongside comparisons with third party sources such as those identified in Table 5.1.

Table 5.1 Summary of findings from literature review

Project name	Author	Energy efficiency (long-term projections)	Representative daily demand profiles	Potential use for validation of DEFENDER outputs
Distribution Future Energy Scenarios	NGED	Y	Y (aggregated profiles based on top-down analysis of underlying demand and assumed profiles for additional technologies)	Baseline NGED approach for comparison. Demand profiles for each Electricity Supply Area (ESA) may be used for comparison and potential validation of the distribution substation demand profiles by CT.
Future Energy Scenarios (FES)	NGESO	Y	Y (limited published data for demand profiles, but high-level outputs provided for winter peak and summer peak days)	Secondary source for review and comparison to achieve consistency in long term trends and understand differences winter/summer peak day.
Open Networks project	ENA	N	Y (varying levels of system implementation and forecast time periods; details of other DNO proprietary systems not published fully)	Secondary source for subsequent review of methodology (and to make approaches to other DNOs for information should this be appropriate).
Heat Street project	UKPN	Y	N	N/A (assumed long-term trends are consistent with/superseded by other sources)
FREEDOM project	NGED	Y (analysis based on long-term uptake projections from other sources, e.g. Delta-EE ASHP uptake)	Y	Source for review and validation of heat pump demand profiles by CT.
Peak Heat project	NGED	Y (illustrative long-term uptake projections broadly in line with DFES)	Y	Source for review and validation of heat pump demand profiles by CT.
Kent Active System Management (KASM) project	UKPN	N	Y (limited forecast time period)	N/A
Customer Led Network Revolution (CLNR) project	NPg	N	Y	Source for review and validation of heat pump demand profiles by CT.

5.4 Integration with BAU

PSS SINCAL is being implemented in NGED as the main planning tool for evaluating power flow and short circuit studies on the 11kV network. While PSS SINCAL is currently used by planners to determine whether new connections are viable, the work undertaken for the DEFENDER project has demonstrated its potential to be utilised for determining where reinforcement is required on the HV network. Currently in NGED, the findings from DFES (prepared by the DSO team) are used across the DSO and Primary System Design (PSD) teams with PSS/E models to identify constraints for resolution on the EHV network. However, given the availability of improved distribution substation demand profiles from the tool developed in the DEFENDER project, similar work could be undertaken to identify HV network constraints based on comprehensive analysis. The analysis undertaken by GHD and presented in this report may be considered as an example of the assessment that could be undertaken by the DSO or Engineering Design teams, or HV planners.

The tool developed by project partners the Carbon Trust and Hildebrand has been used to produce demand profiles based on information around building stock using EPC data as well as incorporating sensitivity factors based on DFES outputs. Through completion of the DEFENDER network modelling, it has been shown that these profiles can be easily integrated within NGED's systems to extract additional benefits.

6. Bibliography

[1] GHD for NGED, “DEFENDER - GHD Scoping Document,” Jun 2022.

[2] GHD for NGED, “DEFENDER - WP1.4 Literature Review,” Jul 2022.

[3] GHD for NGED, “DEFENDER - WP1.4 Network model validation,” Jul 2022.

[4] The Carbon Trust and Hildebrand for NGED, “Project DEFENDER - D1.4-2 – Forecast Scenario Methodology report,” Nov 2022.

[5] The Carbon Trust and Hildebrand for NGED, “Project DEFENDER - WP1 Scoping Document,” 2022.

[6] The Carbon Trust and Hildebrand, “Project DEFENDER: CBA Report,” 2023 (forthcoming).

[7] Energy Networks Association, “Engineering Recommendation (EREC) P2/8: Security of Supply,” Feb 2023. [Online]. Available: https://www.ena-eng.org/ENA-Docs/Index?Action=ViewDetail&EID=101433&tab=search. [Accessed 21 Feb 2023].

Appendices

Appendix A

Demand profiles

A-1 Profiles validation

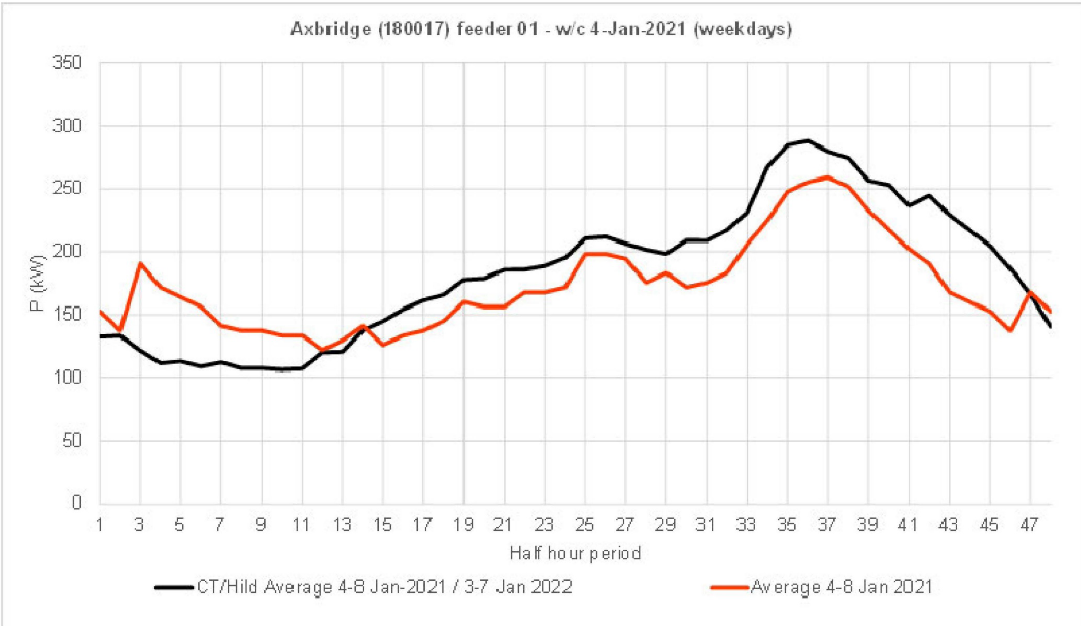
From: David Thorn
Sent: 03 November 2022 16:44
To: Joshua Cooper; Ben Robertson; Devine, Nick J.
Cc: Joshua Cooper; Jane Wilson; Laura Glover; Nicholas Edwards; Neil Murdoch
Subject: RE: EVs connected at case study feeders

Hi all

I have provided an updated chart for the validation of the baseline profile for Axbridge (based on slightly updated numbers sent through by Josh last night), along with the equivalent charts for Mackworth and Withycombe Raleigh, below. Please note that the validation is done against the historical feeder demand measured on each feeder in the period 4-8 January 2021. I note that the baseline profiles provided for each substation are labelled either 01/01/2021 or 01/01/2022, i.e. for early January 2021 or 2022.

My brief observations are as follows:

- As noted on Tuesday, there appear to be some steps associated with overnight heating demand on the Axbridge feeder;
- The CT/Hildebrand profiles appear to be slightly above the historical measured demand on each feeder ('Average 4-8 Jan 2021') for the majority of the day (but not the whole day) in each case.
- The CT/Hildebrand profiles match well with the historical feeder profiles.
- It should be noted that the historical measured demand includes any non-domestic demand, which is not included in the bottom-up assessment of housing stock by CT/Hildebrand. However, the non-domestic demand should be relatively small on the feeders that we have selected.
- In the case of Withycombe Raleigh there seems to be a more visible 'saw tooth' fluctuation effect in the middle of the day (half-hour periods 17-32). I wonder whether this might be averaged over fewer days – and the averaging has not resulted in such a smooth curve?



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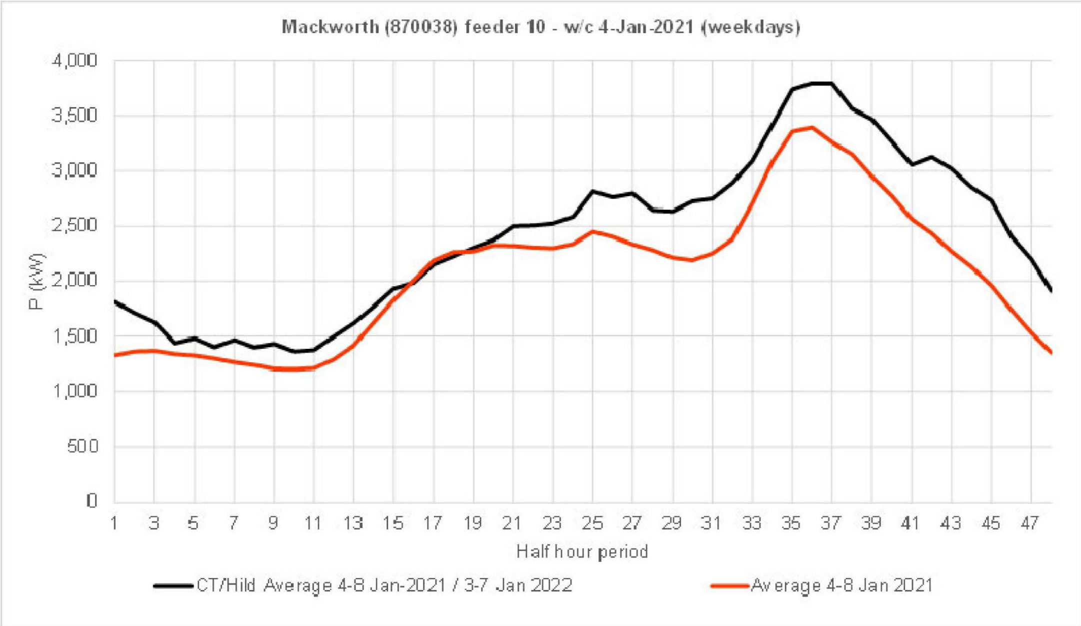

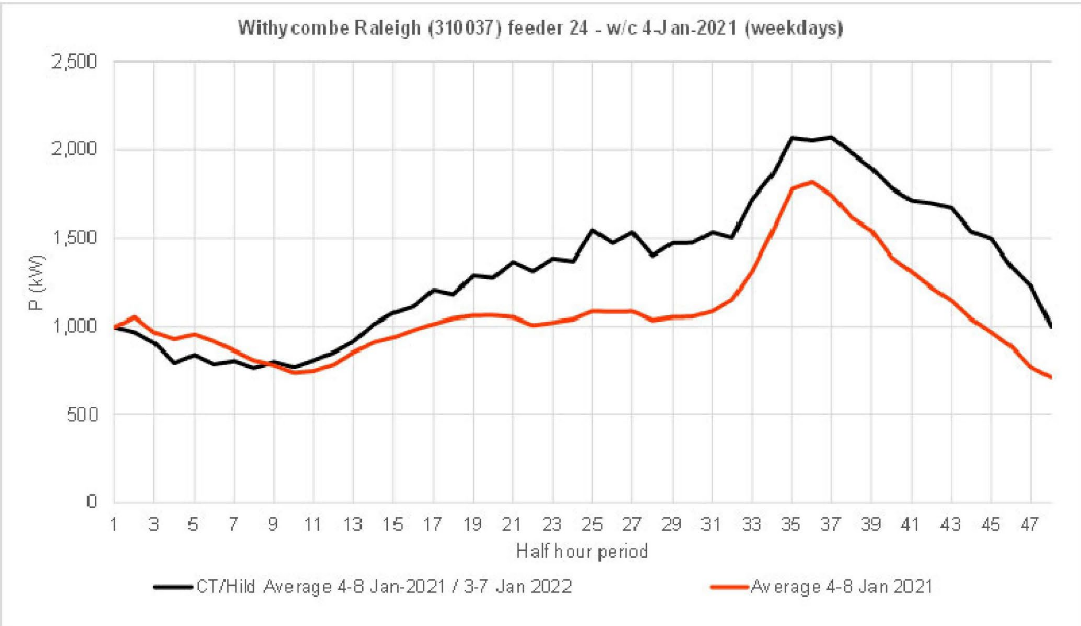

I trust that the above provides a useful starting point for discussion, but I am happy to say that the profile shapes look good!

Kind regards,
David

David Thorn
MEng MA (Cantab.) MIET
Principal Consultant

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A-2 Profiles comparison

Figure B 1 and Figure B 2 provide alternative presentation formats for the peak demand and load factor data presented in the form of scatter plots in Section 3.3.

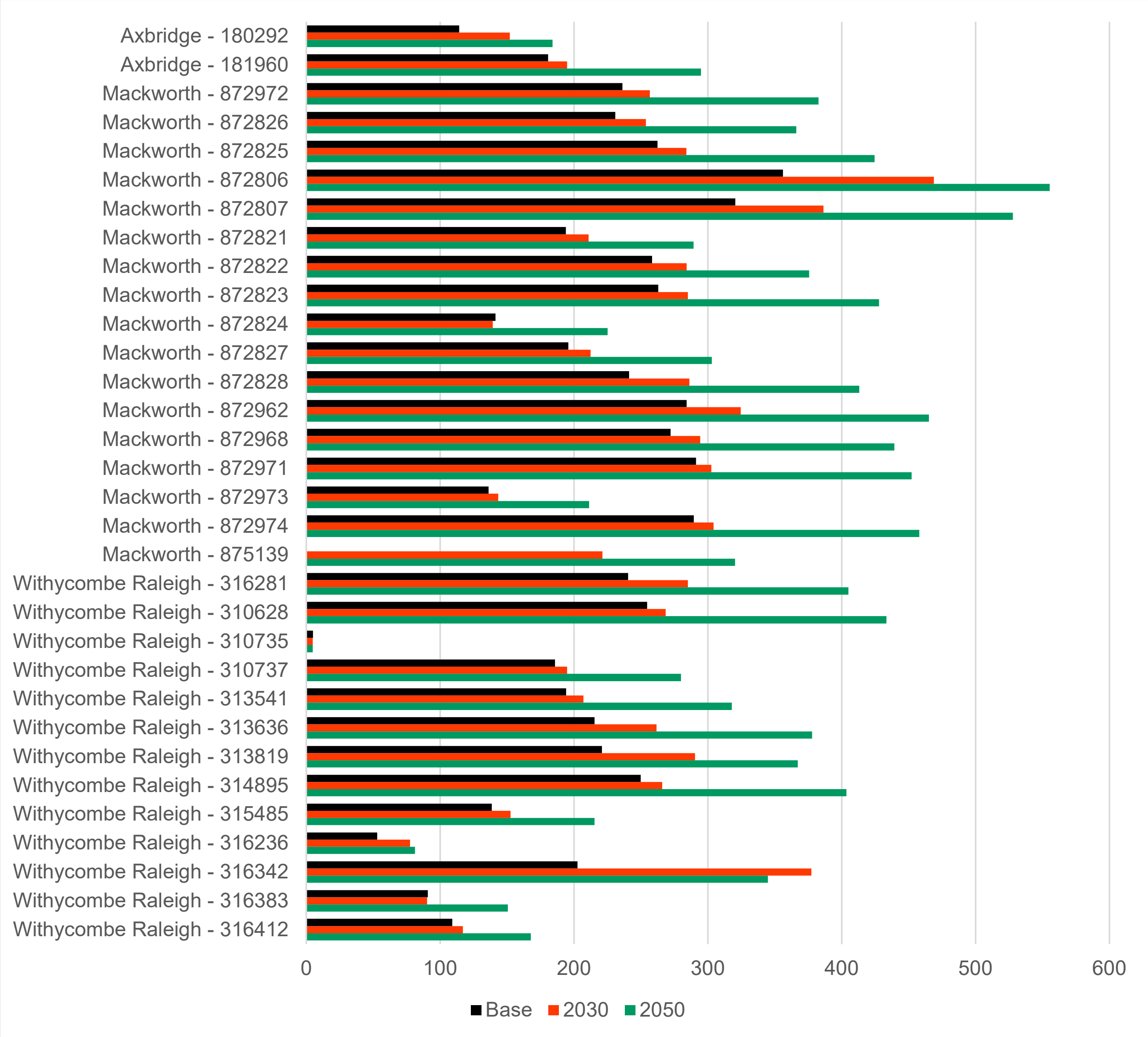


Figure B 1 ***Comparison of peak demand on each secondary substation (Base and Medium-Winter day profiles in 2030 and 2050)***

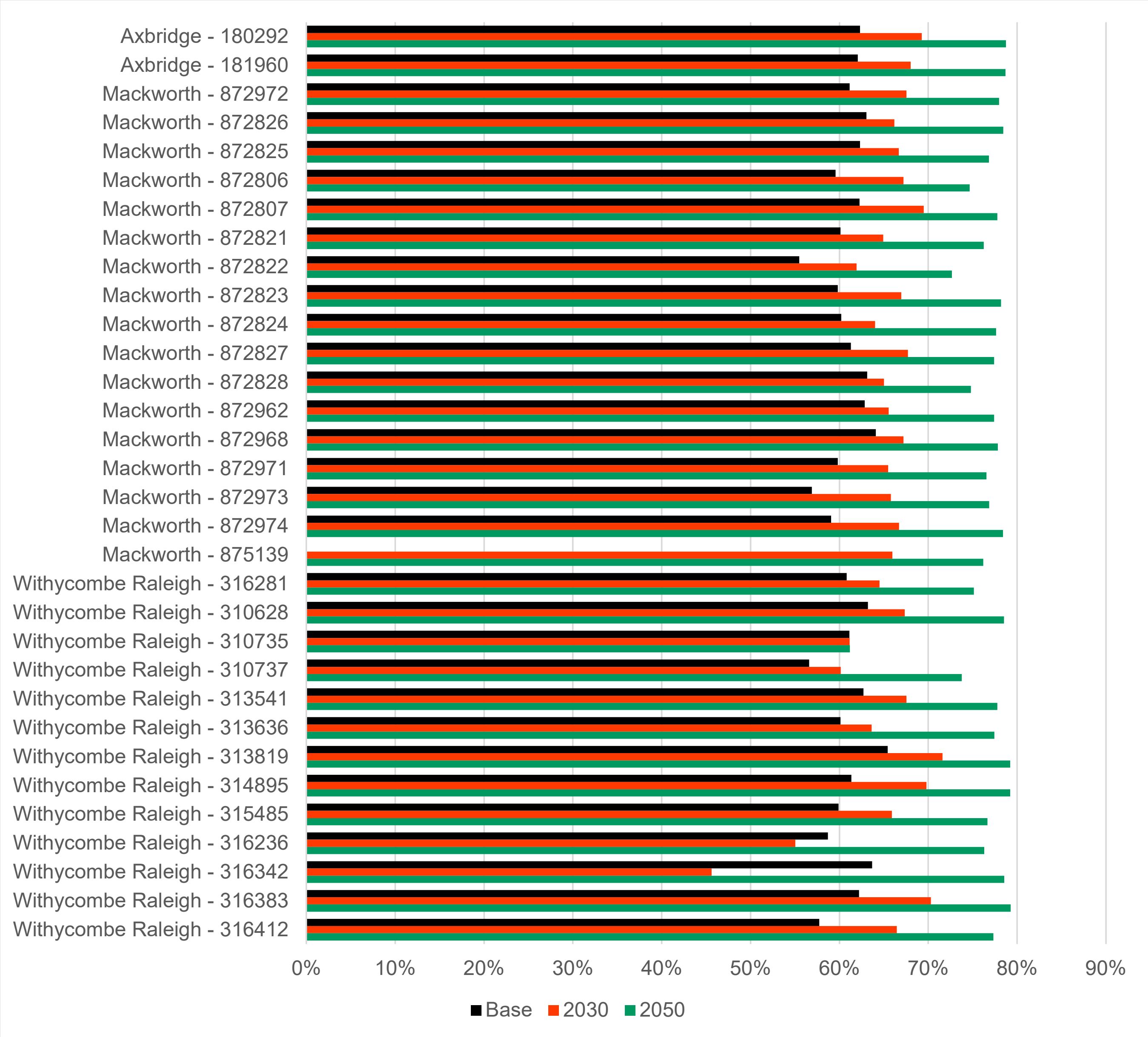


Figure B 2 ***Comparison of load factor of each secondary substation (Base and Medium-Winter day profiles in 2030 and 2050)***

A-3 Demand profiles exported from PSS SINCAL

This Appendix provides details of the HV feeder level demand profiles extracted from the PSS SINCAL model results. These profiles may be compared with those presented in Section 3.2, which correspond to the inputs to the PSS SINCAL model, but the losses are included here.

A-3-1 Axbridge

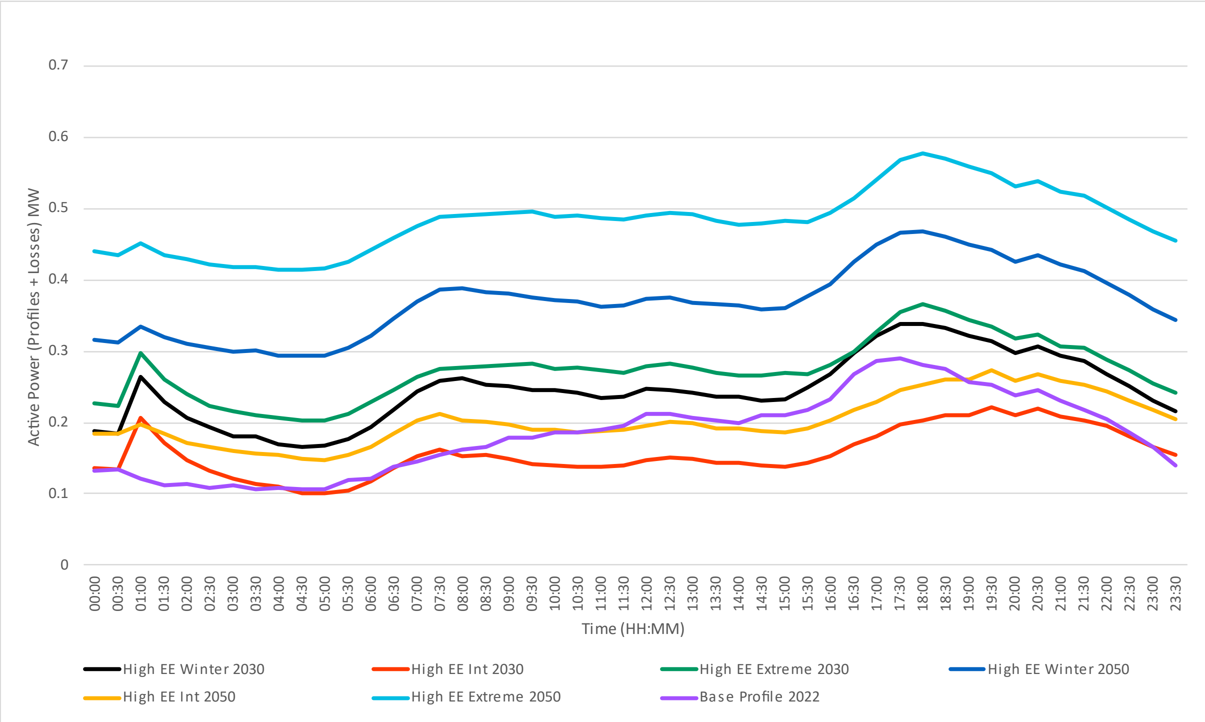


Figure B 3 Axbridge High EE demand profiles

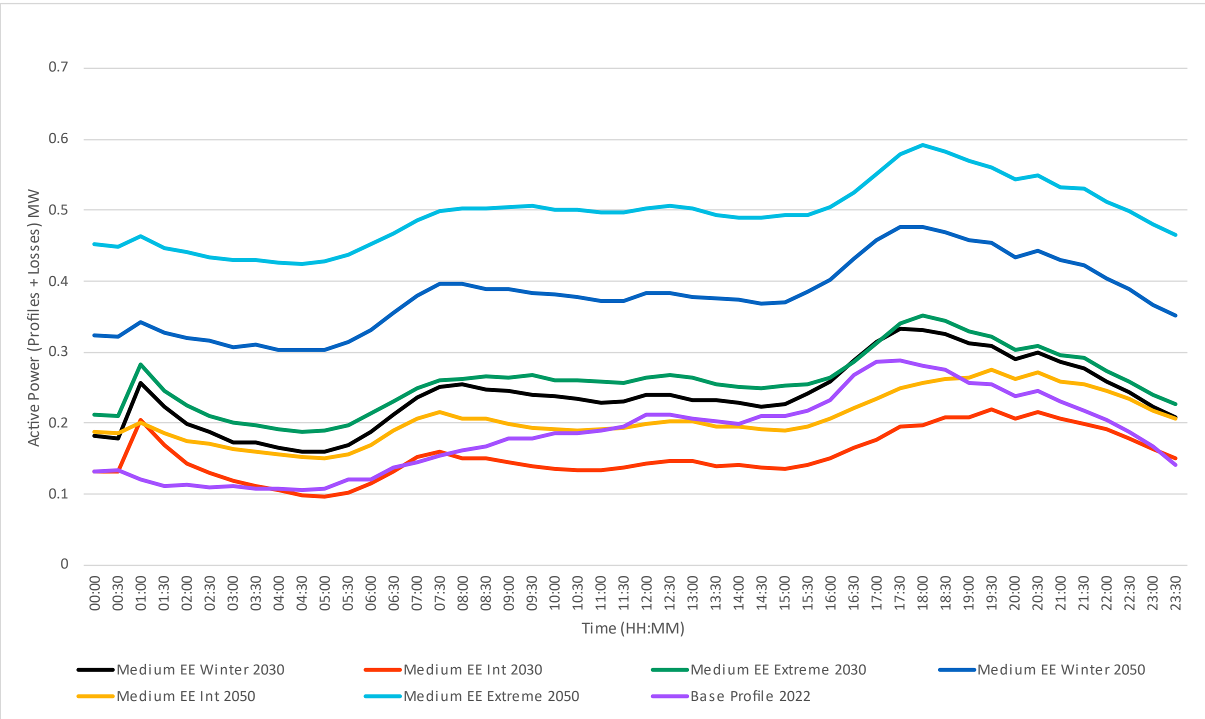


Figure B 4 Axbridge Medium EE demand profiles

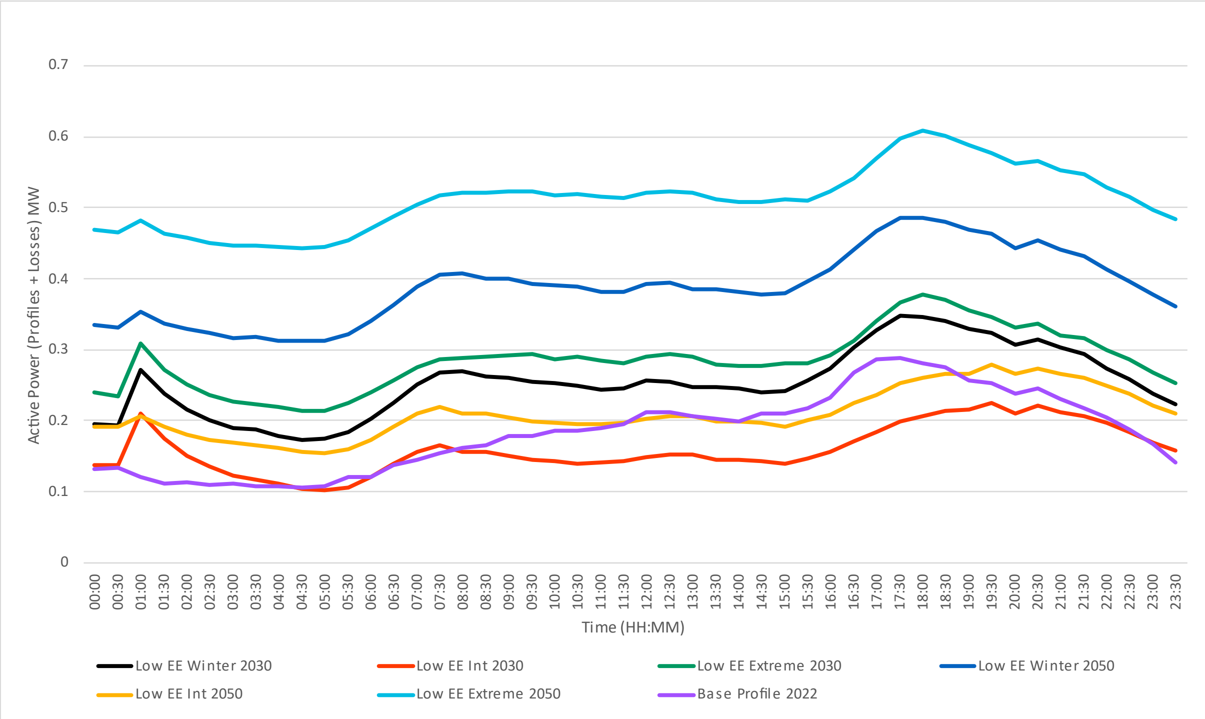


Figure B 5 Axbridge Low EE demand profiles

A-3-2 Mackworth

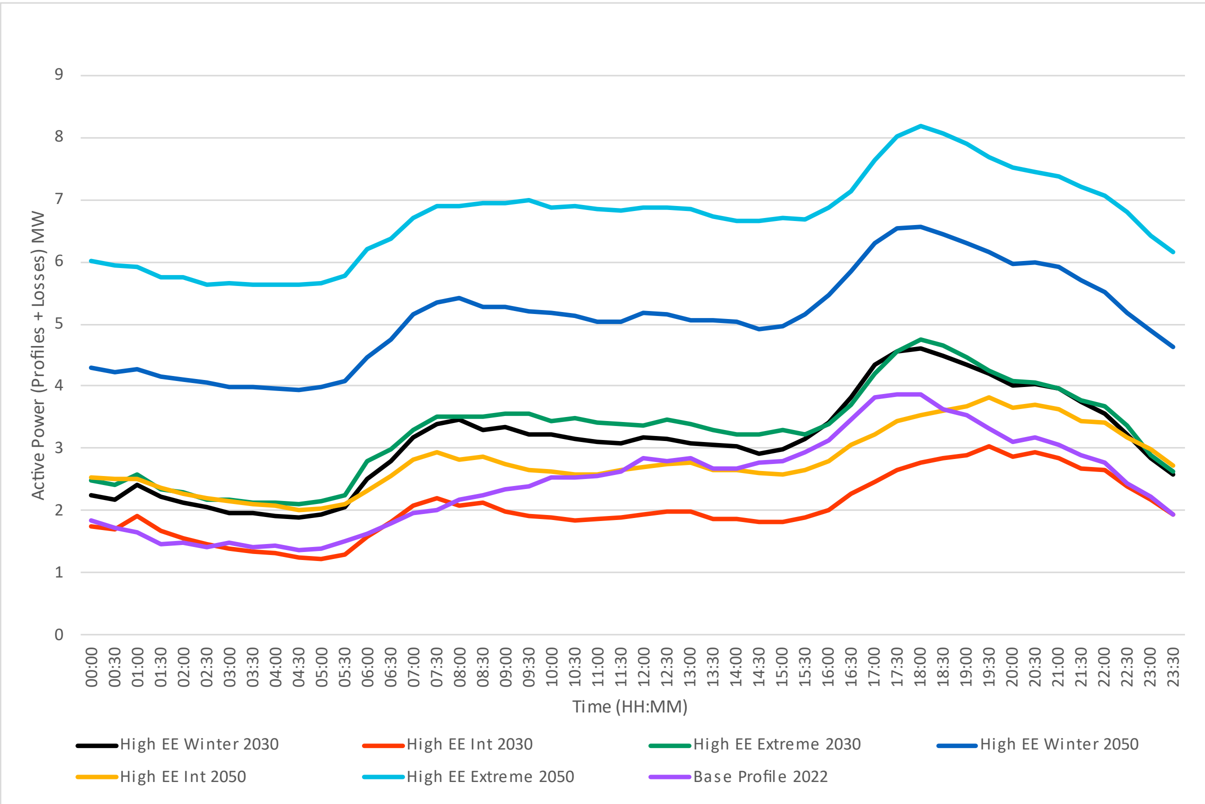


Figure B 6 Mackworth High EE demand profiles

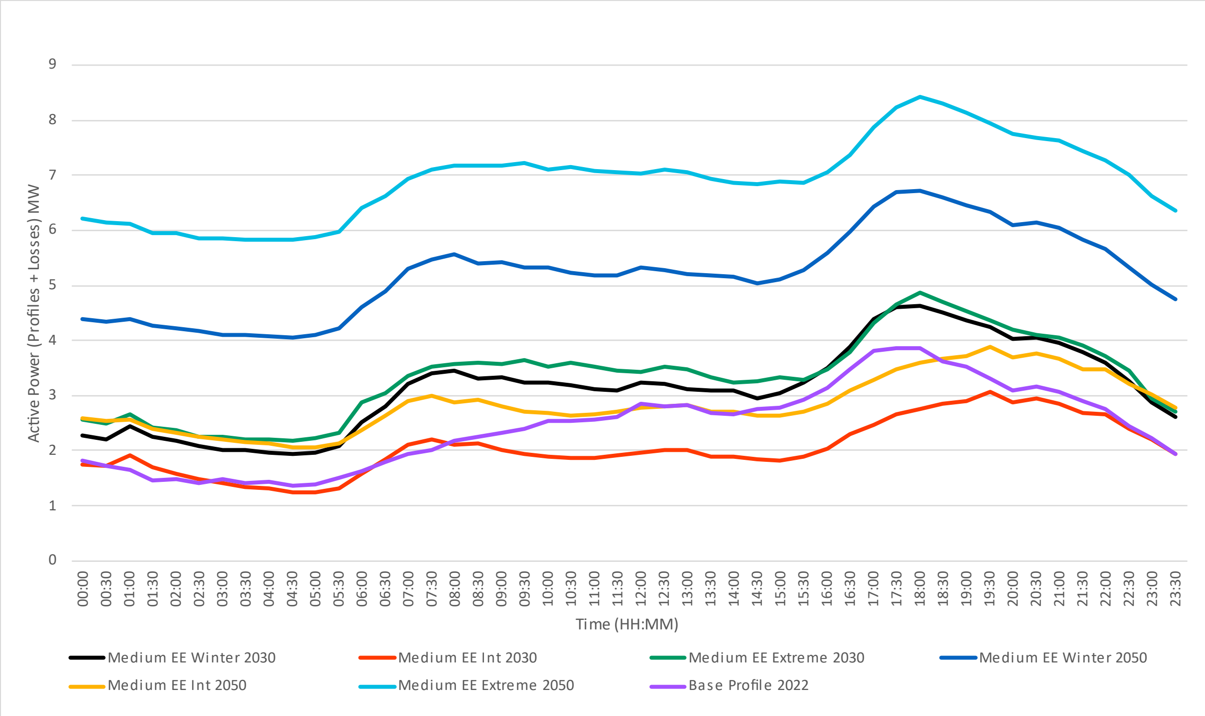


Figure B 7 ***Mackworth Medium EE demand profiles***

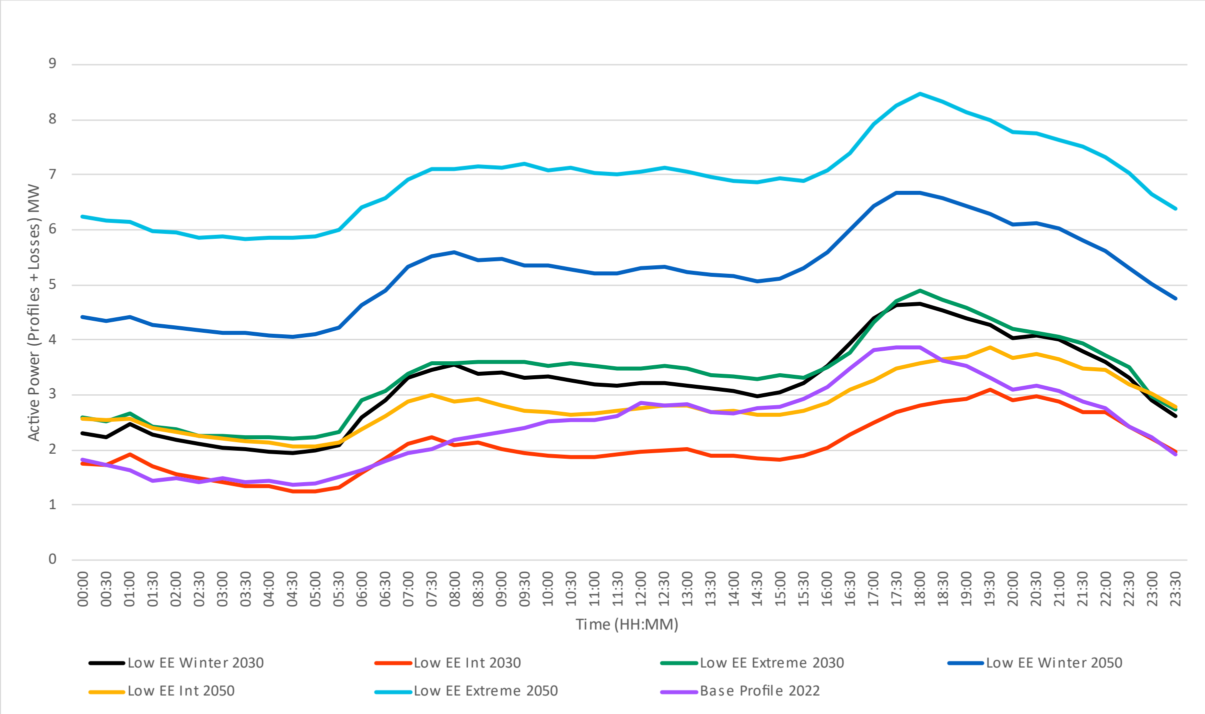


Figure B 8 ***Mackworth Low EE demand profiles***

A-3-3 Withycombe Raleigh

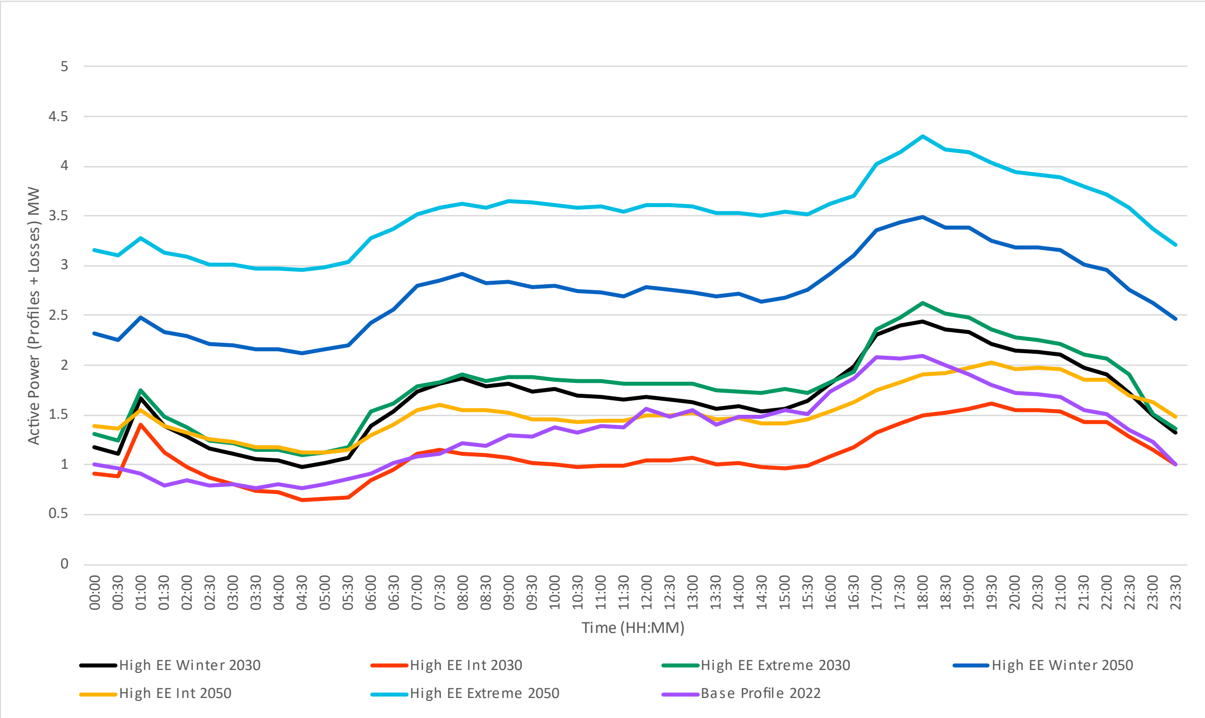


Figure B 9 Withycombe Raleigh High EE demand profiles

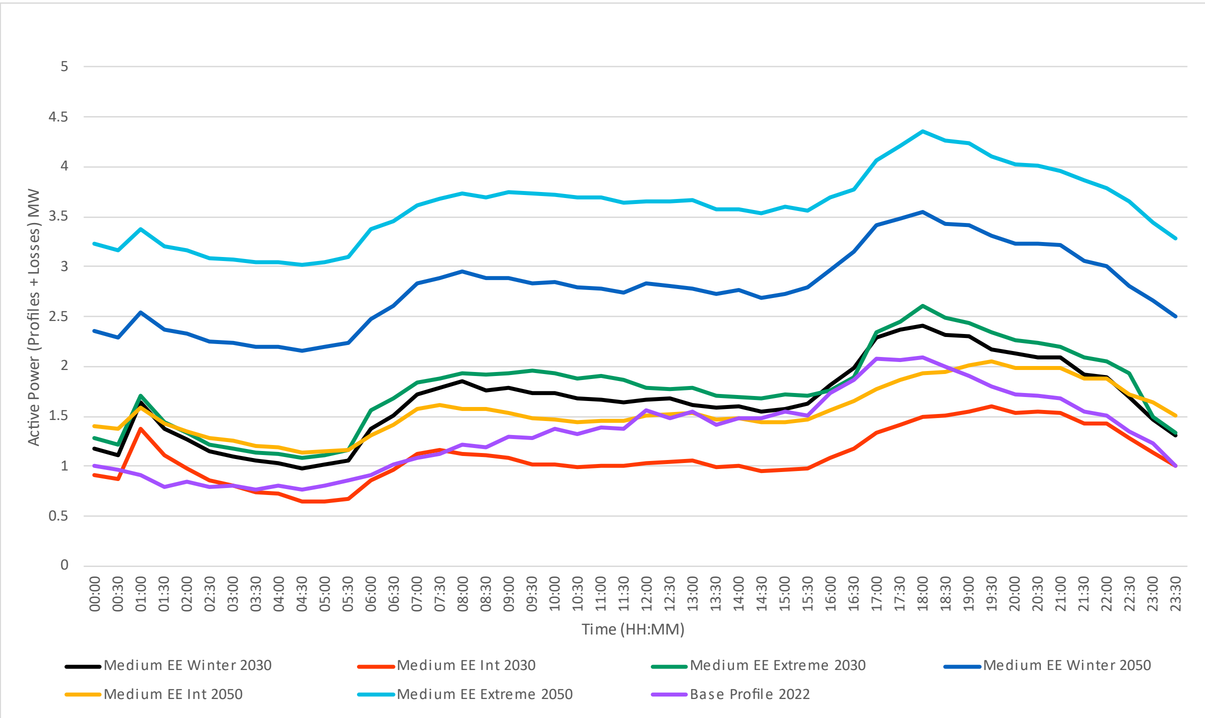


Figure B 10 Withycombe Raleigh Medium EE demand profiles

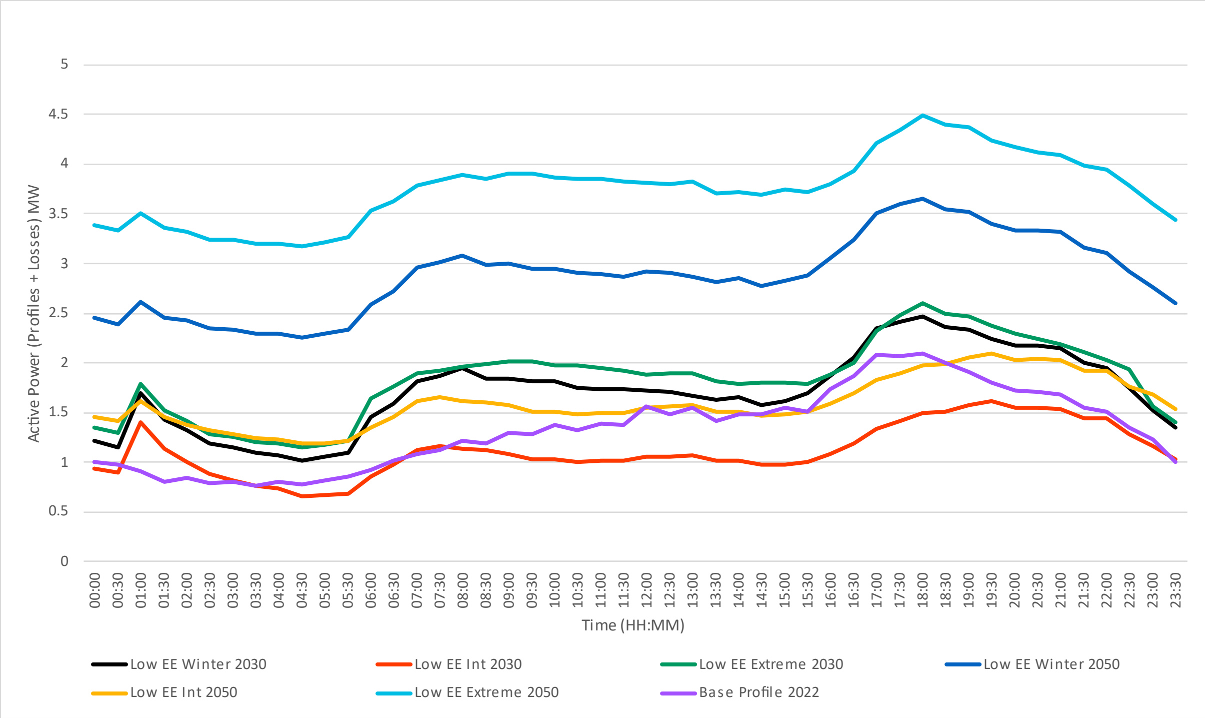


Figure B 11 ***Withycombe Raleigh Low EE demand profiles***

Appendix B

Detailed asset loadings

B-1 Detailed asset loadings

B-1-1 Axbridge

Circuit Loading

Table B 1 shows the highest loaded circuits overall within the Axbridge scenarios. It can be seen that eight of the top ten results are from the worst-case scenario (Low EE, Extreme day, 2050), with the remaining results coming from the Medium EE scenario instead.

Table B 1 Axbridge highest loaded circuits

Index	Asset ID	Line Type	Length (m)	EE Scenario	Rep. Day	Year	Time	Asset rating (kA)	Asset loading (%)
1	428373359	0.1 CU	130.7	Low	Extreme	2050	18:00	0.239	13.1
2	428373364	0.1 CU	14.2	Low	Extreme	2050	18:00	0.239	13.1
3	428373359	0.1 CU	130.7	Low	Extreme	2050	18:30	0.239	13.0
4	428373364	0.1 CU	14.2	Low	Extreme	2050	18:30	0.239	13.0
5	428373359	0.1 CU	130.7	Low	Extreme	2050	17:30	0.239	12.9
6	428373364	0.1 CU	14.2	Low	Extreme	2050	17:30	0.239	12.9
7	428373359	0.1 CU	130.7	Medium	Extreme	2050	18:00	0.239	12.8
8	428373364	0.1 CU	14.2	Medium	Extreme	2050	18:00	0.239	12.8
9	428373359	0.1 CU	130.7	Low	Extreme	2050	19:00	0.239	12.7
10	428373364	0.1 CU	14.2	Low	Extreme	2050	19:00	0.239	12.7

Table B 2 shows the highest loaded circuit in each of the days modelled. In all scenarios, the line type of the highest loaded circuit is 0.1 CU, which is the lowest rated cable type used in Axbridge, as per Table 2.6.

Table B 2 Axbridge highest loaded circuit in each day

Asset ID	Line type	Length (m)	EE Scenario	Rep. day	Year	Time	Asset rating (kA)	Asset loading (%)
428373364	0.1 CU	14.2	High	Winter	2030	18:00	0.239	7.4
428373364	0.1 CU	14.2	High	Int	2030	19:30	0.227	5.1
428373364	0.1 CU	14.2	High	Extreme	2030	18:00	0.239	7.9
428373364	0.1 CU	14.2	Medium	Winter	2030	17:30	0.239	7.2
428373364	0.1 CU	14.2	Medium	Int	2030	19:30	0.227	5.0
428373364	0.1 CU	14.2	Medium	Extreme	2030	18:00	0.239	7.6
428373364	0.1 CU	14.2	Low	Winter	2030	17:30	0.239	7.6
428373364	0.1 CU	14.2	Low	Int	2030	19:30	0.227	5.2
428373364	0.1 CU	14.2	Low	Extreme	2030	18:00	0.239	8.2
428373364	0.1 CU	14.2	High	Winter	2050	18:00	0.239	10.1
428373364	0.1 CU	14.2	High	Int	2050	19:30	0.227	6.3
428373359	0.1 CU	130.7	High	Extreme	2050	18:00	0.239	12.5
428373364	0.1 CU	14.2	Medium	Winter	2050	18:00	0.239	10.3
428373364	0.1 CU	14.2	Medium	Int	2050	19:30	0.227	6.3

Asset ID	Line type	Length (m)	EE Scenario	Rep. day	Year	Time	Asset rating (kA)	Asset loading (%)
428373359	0.1 CU	130.7	Medium	Extreme	2050	18:00	0.239	12.8
428373364	0.1 CU	14.2	Low	Winter	2050	17:30	0.239	10.5
428373364	0.1 CU	14.2	Low	Int	2050	19:30	0.227	6.4
428373359	0.1 CU	130.7	Low	Extreme	2050	18:00	0.239	13.1

From the results above, it can be seen that even in the worst-case scenario (Low EE, Extreme weather, 2050), the highest loaded circuit is still only 13.1%, which is significantly lower than the proposed threshold for intervention of 50%. As it is not anticipated that any circuits will require intervention in Axbridge, it is unlikely that applying greater EE measures would provide a benefit in this instance.

Transformer Loading

Table B 3 shows the ten highest loaded transformers across all Axbridge scenarios. It can be seen that all results come from Extreme weather days in 2050, which is expected. Additionally, all ten results come from substation 181960.

Table B 3 Axbridge highest loaded transformers

Index	Asset Name	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
1	181960_TX0	Low	Extreme	2050	18:00	0.5	73.4
2	181960_TX0	Low	Extreme	2050	17:30	0.5	73.4
3	181960_TX0	Low	Extreme	2050	18:30	0.5	73.4
4	181960_TX0	Medium	Extreme	2050	18:00	0.5	71.4
5	181960_TX0	Low	Extreme	2050	19:00	0.5	71.2
6	181960_TX0	Medium	Extreme	2050	18:30	0.5	71.1
7	181960_TX0	Medium	Extreme	2050	17:30	0.5	71.0
8	181960_TX0	Low	Extreme	2050	19:30	0.5	70.6
9	181960_TX0	High	Extreme	2050	18:00	0.5	70.1
10	181960_TX0	High	Extreme	2050	17:30	0.5	69.9

Table B 4 shows the highest loaded transformer in each of the days modelled. Similar to Table B 3, all of the results are from substation 181960.

Table B 4 Axbridge highest loaded transformer in each day

Asset name	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
181960_TX0	High	Winter	2030	17:30	0.5	40.465
181960_TX0	High	Int	2030	20:30	0.5	26.823
181960_TX0	High	Extreme	2030	18:00	0.5	41.628
181960_TX0	Medium	Winter	2030	17:30	0.5	38.745
181960_TX0	Medium	Int	2030	19:30	0.5	26.080
181960_TX0	Medium	Extreme	2030	18:00	0.5	38.749
181960_TX0	Low	Winter	2030	17:30	0.5	41.328
181960_TX0	Low	Int	2030	19:30	0.5	27.128
181960_TX0	Low	Extreme	2030	18:30	0.5	42.906

Asset name	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
181960_TX0	High	Winter	2050	17:30	0.5	57.495
181960_TX0	High	Int	2050	19:30	0.5	33.435
181960_TX0	High	Extreme	2050	18:00	0.5	70.090
181960_TX0	Medium	Winter	2050	17:30	0.5	58.517
181960_TX0	Medium	Int	2050	19:30	0.5	33.761
181960_TX0	Medium	Extreme	2050	18:00	0.5	71.426
181960_TX0	Low	Winter	2050	17:30	0.5	59.694
181960_TX0	Low	Int	2050	19:30	0.5	34.388
181960_TX0	Low	Extreme	2050	18:00	0.5	73.421

B-1-2 Mackworth

Circuit Loading

Table B 5 shows the highest loaded circuits overall within the Mackworth scenarios. It can be seen that six of the top ten results are from the worst-case scenario (Low EE, Extreme day, 2050), with the remaining results coming from the Medium EE scenario instead.

Table B 5 Mackworth highest loaded circuits

Index	Asset ID	Line Type	Length (m)	EE Scenario	Rep. Day	Year	Time	Asset rating (kA)	Asset loading (%)
1	126473023	3w 100 ACSR	59.9	Low	Extreme	2050	18:00	0.322	128.4
2	126473016	3w 100 ACSR	68.3	Low	Extreme	2050	18:00	0.322	128.4
3	330691840	3w 100 ACSR	48.8	Low	Extreme	2050	18:00	0.322	128.4
4	126473023	3w 100 ACSR	59.9	Medium	Extreme	2050	18:00	0.322	127.8
5	126473016	3w 100 ACSR	68.3	Medium	Extreme	2050	18:00	0.322	127.8
6	330691840	3w 100 ACSR	48.8	Medium	Extreme	2050	18:00	0.322	127.8
7	126473023	3w 100 ACSR	59.9	Low	Extreme	2050	18:30	0.322	126.6
8	126473016	3w 100 ACSR	68.3	Low	Extreme	2050	18:30	0.322	126.6
9	330691840	3w 100 ACSR	48.8	Low	Extreme	2050	18:30	0.322	126.6
10	126473023	3w 100 ACSR	59.9	Medium	Extreme	2050	18:30	0.322	126.1

Table B 6 shows the highest loaded circuit in each of the days modelled. In all scenarios, the line type of the highest loaded circuit is 3w 100 ACSR, which is the lowest rated overhead line type used in Mackworth, as per Table 2.7.

Table B 6 Mackworth highest loaded circuit in each day

Asset ID	Line type	Length (m)	EE Scenario	Rep. Day	Year	Time	Asset rating (kA)	Asset loading (%)
330691840	3w 100 ACSR	48.8	High	Winter	2030	18:00	0.322	72.0
330691840	3w 100 ACSR	48.8	High	Int	2030	19:30	0.299	52.0
330691840	3w 100 ACSR	48.8	High	Extreme	2030	18:00	0.322	74.2
330691840	3w 100 ACSR	48.8	Medium	Winter	2030	18:00	0.322	72.3

Asset ID	Line type	Length (m)	EE Scenario	Rep. Day	Year	Time	Asset rating (kA)	Asset loading (%)
330691840	3w 100 ACSR	48.8	Medium	Int	2030	19:30	0.299	52.4
330691840	3w 100 ACSR	48.8	Medium	Extreme	2030	18:00	0.322	75.8
330691840	3w 100 ACSR	48.8	Low	Winter	2030	18:00	0.322	72.6
330691840	3w 100 ACSR	48.8	Low	Int	2030	19:30	0.299	52.6
330691840	3w 100 ACSR	48.8	Low	Extreme	2030	18:00	0.322	76.2
126473023	3w 100 ACSR	59.9	High	Winter	2050	18:00	0.322	101.0
330691840	3w 100 ACSR	48.8	High	Int	2050	19:30	0.299	64.9
126473023	3w 100 ACSR	59.9	High	Extreme	2050	18:00	0.322	124.5
126473023	3w 100 ACSR	59.9	Medium	Winter	2050	18:00	0.322	103.1
330691840	3w 100 ACSR	48.8	Medium	Int	2050	19:30	0.299	65.8
126473023	3w 100 ACSR	59.9	Medium	Extreme	2050	18:00	0.322	127.8
126473023	3w 100 ACSR	59.9	Low	Winter	2050	17:30	0.322	102.7
330691840	3w 100 ACSR	48.8	Low	Int	2050	19:30	0.299	65.5
126473023	3w 100 ACSR	59.9	Low	Extreme	2050	18:00	0.322	128.4

Transformer Loading

Table B 7 shows the ten highest loaded transformers across all Mackworth scenarios. It can be seen that all results come from Extreme weather days in 2050, which is expected. Additionally, all ten results come from substation 872826.

Table B 7 Mackworth highest loaded transformers

Index	Asset Name	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
1	872826_TX0	Low	Extreme	2050	18:00	0.315	151.507
2	872826_TX0	Low	Extreme	2050	18:30	0.315	150.445
3	872826_TX0	Low	Extreme	2050	17:30	0.315	147.348
4	872826_TX0	Low	Extreme	2050	19:00	0.315	145.138
5	872826_TX0	Medium	Extreme	2050	18:30	0.315	145.094
6	872826_TX0	Medium	Extreme	2050	18:00	0.315	144.569
7	872826_TX0	Medium	Extreme	2050	17:30	0.315	144.078
8	872826_TX0	Low	Extreme	2050	19:30	0.315	143.870
9	872826_TX0	Medium	Extreme	2050	19:00	0.315	142.260
10	872826_TX0	Low	Extreme	2050	17:00	0.315	141.509

Table B 8 shows the highest loaded transformer in each of the days modelled. Similar to Table B 7, all of the results are from substation 872826.

Table B 8 Mackworth highest loaded transformer in each day

Asset ID	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
872826_TX0	High	Winter	2030	18:00	0.315	81.024

Asset ID	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
872826_TX0	High	Int	2030	19:30	0.315	54.137
872826_TX0	High	Extreme	2030	18:00	0.315	83.425
872826_TX0	Medium	Winter	2030	18:00	0.315	79.632
872826_TX0	Medium	Int	2030	19:30	0.315	54.423
872826_TX0	Medium	Extreme	2030	18:00	0.315	80.236
872826_TX0	Low	Winter	2030	18:00	0.315	82.434
872826_TX0	Low	Int	2030	19:30	0.315	55.527
872826_TX0	Low	Extreme	2030	18:00	0.315	87.621
872826_TX0	High	Winter	2050	17:30	0.315	116.242
872826_TX0	High	Int	2050	19:30	0.315	69.030
872826_TX0	High	Extreme	2050	18:00	0.315	139.068
872826_TX0	Medium	Winter	2050	17:30	0.315	114.435
872826_TX0	Medium	Int	2050	19:30	0.315	69.402
872826_TX0	Medium	Extreme	2050	18:30	0.315	145.094
872826_TX0	Low	Winter	2050	18:00	0.315	119.927
872826_TX0	Low	Int	2050	19:30	0.315	69.687
872826_TX0	Low	Extreme	2050	18:00	0.315	151.507

B-1-3 Withycombe Raleigh

Circuit Loading

Table B 9 shows the highest loaded circuits overall within the Withycombe Raleigh scenarios. It can be seen that six of the top ten results are from the worst-case scenario (Low EE, Extreme day, 2050), with the remaining results coming from the Medium and High EE scenarios.

Table B 9 Withycombe Raleigh highest loaded circuits

Index	Asset ID	Line Type	Length (m)	EE Scenario	Rep. Day	Year	Time	Asset rating (kA)	Asset loading (%)
1	363441001	185 CAS	3.48	Low	Extreme	2050	18:00	0.338	59.753
2	363441001	185 CAS	3.48	Low	Extreme	2050	18:30	0.338	58.435
3	363441001	185 CAS	3.48	Low	Extreme	2050	19:00	0.338	58.215
4	363441001	185 CAS	3.48	Medium	Extreme	2050	18:00	0.338	58.071
5	363441001	185 CAS	3.48	Low	Extreme	2050	17:30	0.338	57.697
6	363441001	185 CAS	3.48	High	Extreme	2050	18:00	0.338	57.323
7	363441001	185 CAS	3.48	Medium	Extreme	2050	18:30	0.338	56.737
8	363441001	185 CAS	3.48	Medium	Extreme	2050	19:00	0.338	56.482
9	363441001	185 CAS	3.48	Low	Extreme	2050	19:30	0.338	56.431
10	363441001	185 CAS	3.48	Low	Extreme	2050	17:00	0.338	56.123

Table B 10 shows the highest loaded circuit in each of the days modelled. In all scenarios, the line type of the highest loaded circuit is 185 CAS.

Table B 10 Withycombe Raleigh highest loaded circuit in each day

Asset ID	Line type	Length (m)	EE Scenario	Rep. Day	Year	Time	Asset rating (kA)	Asset loading (%)
363441001	185 CAS	3.5	High	Winter	2030	18:00	0.338	33.2
363441001	185 CAS	3.5	High	Int	2030	19:30	0.320	23.2
363441001	185 CAS	3.5	High	Extreme	2030	18:00	0.338	35.5
363441001	185 CAS	3.5	Medium	Winter	2030	18:00	0.338	32.7
363441001	185 CAS	3.5	Medium	Int	2030	19:30	0.320	22.9
363441001	185 CAS	3.5	Medium	Extreme	2030	18:00	0.338	35.3
363441001	185 CAS	3.5	Low	Winter	2030	18:00	0.338	33.4
363441001	185 CAS	3.5	Low	Int	2030	19:30	0.320	23.2
363441001	185 CAS	3.5	Low	Extreme	2030	18:00	0.338	35.3
363441001	185 CAS	3.5	High	Winter	2050	18:00	0.338	46.8
363441001	185 CAS	3.5	High	Int	2050	19:30	0.320	29.0
363441001	185 CAS	3.5	High	Extreme	2050	18:00	0.338	57.3
363441001	185 CAS	3.5	Medium	Winter	2050	18:00	0.338	47.5
363441001	185 CAS	3.5	Medium	Int	2050	19:30	0.320	29.3
363441001	185 CAS	3.5	Medium	Extreme	2050	18:00	0.338	58.1
363441001	185 CAS	3.5	Low	Winter	2050	18:00	0.338	49.0
363441001	185 CAS	3.5	Low	Int	2050	19:30	0.320	29.9
363441001	185 CAS	3.5	Low	Extreme	2050	18:00	0.338	59.8

Transformer Loading

Table B 11 shows the ten highest loaded transformers across all Withycombe Raleigh scenarios. It can be seen that all results come from Extreme weather days in 2050, which is expected. Additionally, all ten results come from substation 315485.

Table B 11 Withycombe Raleigh highest loaded transformers

Index	Asset Name	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
1	315485_TX0	Low	Extreme	2050	18:00	0.2	133.034
2	315485_TX0	Low	Extreme	2050	19:00	0.2	129.047
3	315485_TX0	Medium	Extreme	2050	18:00	0.2	127.277
4	315485_TX0	Low	Extreme	2050	18:30	0.2	127.067
5	315485_TX0	High	Extreme	2050	18:00	0.2	126.728
6	315485_TX0	Low	Extreme	2050	17:30	0.2	125.322
7	313541_TX0	Low	Extreme	2050	18:00	0.315	125.249
8	315485_TX0	Low	Extreme	2050	17:00	0.2	124.427
9	315485_TX0	Medium	Extreme	2050	19:00	0.2	123.037
10	315485_TX0	Low	Extreme	2050	20:00	0.2	122.935

Table B 12 shows the highest loaded transformer in each of the days modelled. Similar to Table B 11, all of the results are from substation 315485.

Table B 12 Withycombe Raleigh highest loaded transformer in each day

Asset ID	Scenario	Rep. Day	Year	Time	Asset rating (MVA)	Asset loading (%)
315485_TX0	High	Winter	2030	18:00	0.2	77.954
315485_TX0	High	Int	2030	20:00	0.2	50.282
315485_TX0	High	Extreme	2030	18:00	0.2	84.823
315485_TX0	Medium	Winter	2030	18:00	0.2	75.393
315485_TX0	Medium	Int	2030	19:00	0.2	49.264
313541_TX0	Medium	Extreme	2030	18:00	0.315	74.013
315485_TX0	Low	Winter	2030	18:00	0.2	75.592
315485_TX0	Low	Int	2030	19:00	0.2	50.707
315485_TX0	Low	Extreme	2030	18:00	0.2	76.371
315485_TX0	High	Winter	2050	18:00	0.2	105.537
315485_TX0	High	Int	2050	19:00	0.2	61.667
315485_TX0	High	Extreme	2050	18:00	0.2	126.728
315485_TX0	Medium	Winter	2050	18:00	0.2	105.844
315485_TX0	Medium	Int	2050	19:00	0.2	61.711
315485_TX0	Medium	Extreme	2050	18:00	0.2	127.277
315485_TX0	Low	Winter	2050	18:00	0.2	110.181
315485_TX0	Low	Int	2050	19:30	0.2	63.542
315485_TX0	Low	Extreme	2050	18:00	0.2	133.034

Appendix C

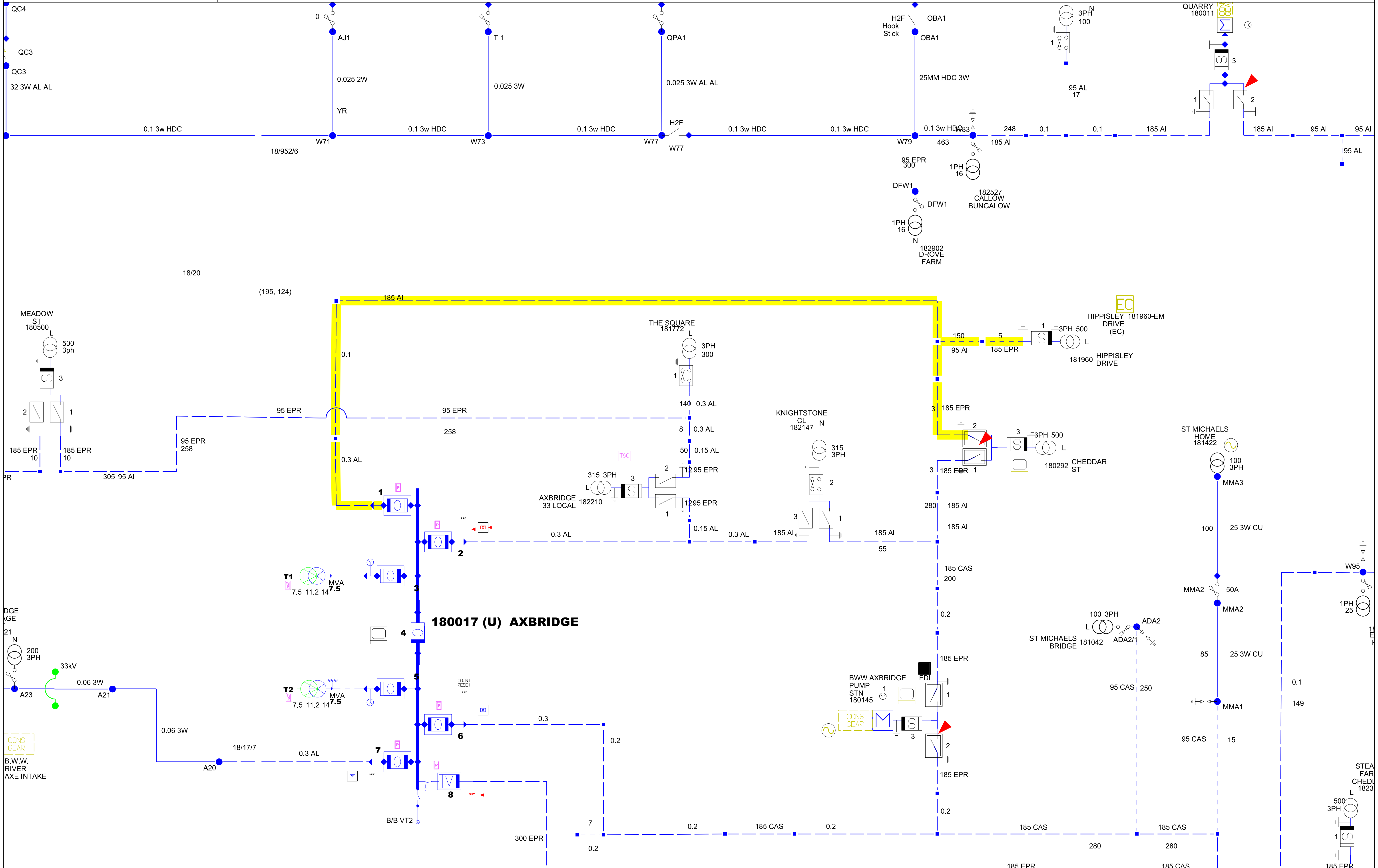
Case study area schematics

C-1 Single line diagrams (SLDs)

The following sheets provide SLDs for the Axbridge, Mackworth and Withycombe Raleigh case study areas, respectively, with the selected feeder highlighted in each case.

WARNING: This a copy of the Enmac Diagram extracted on a monthly Refresh cycle.
Please refer to the live Enmac system for all operational matters

Information is given as a guide only
and it's accuracy cannot be guaranteed.



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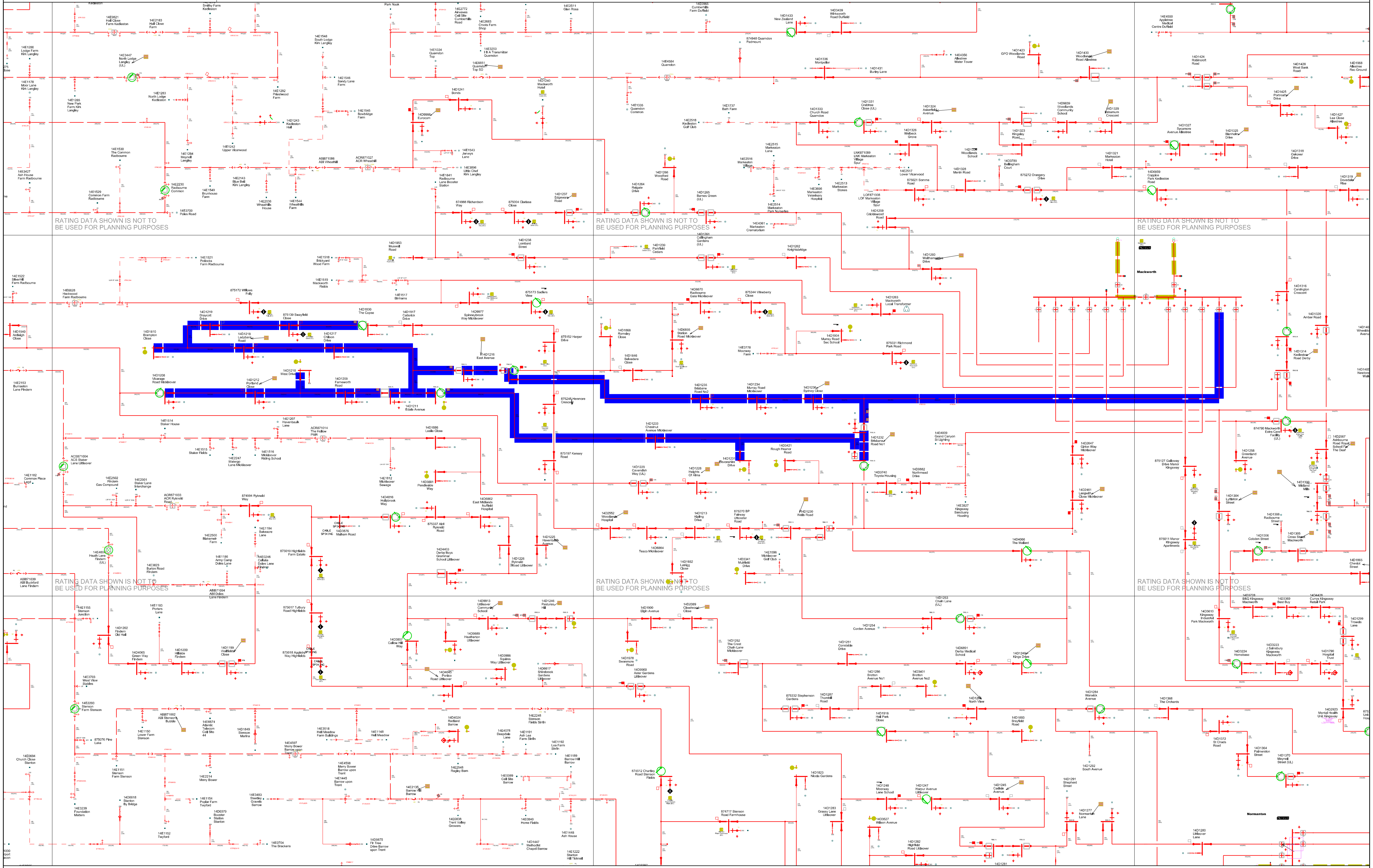

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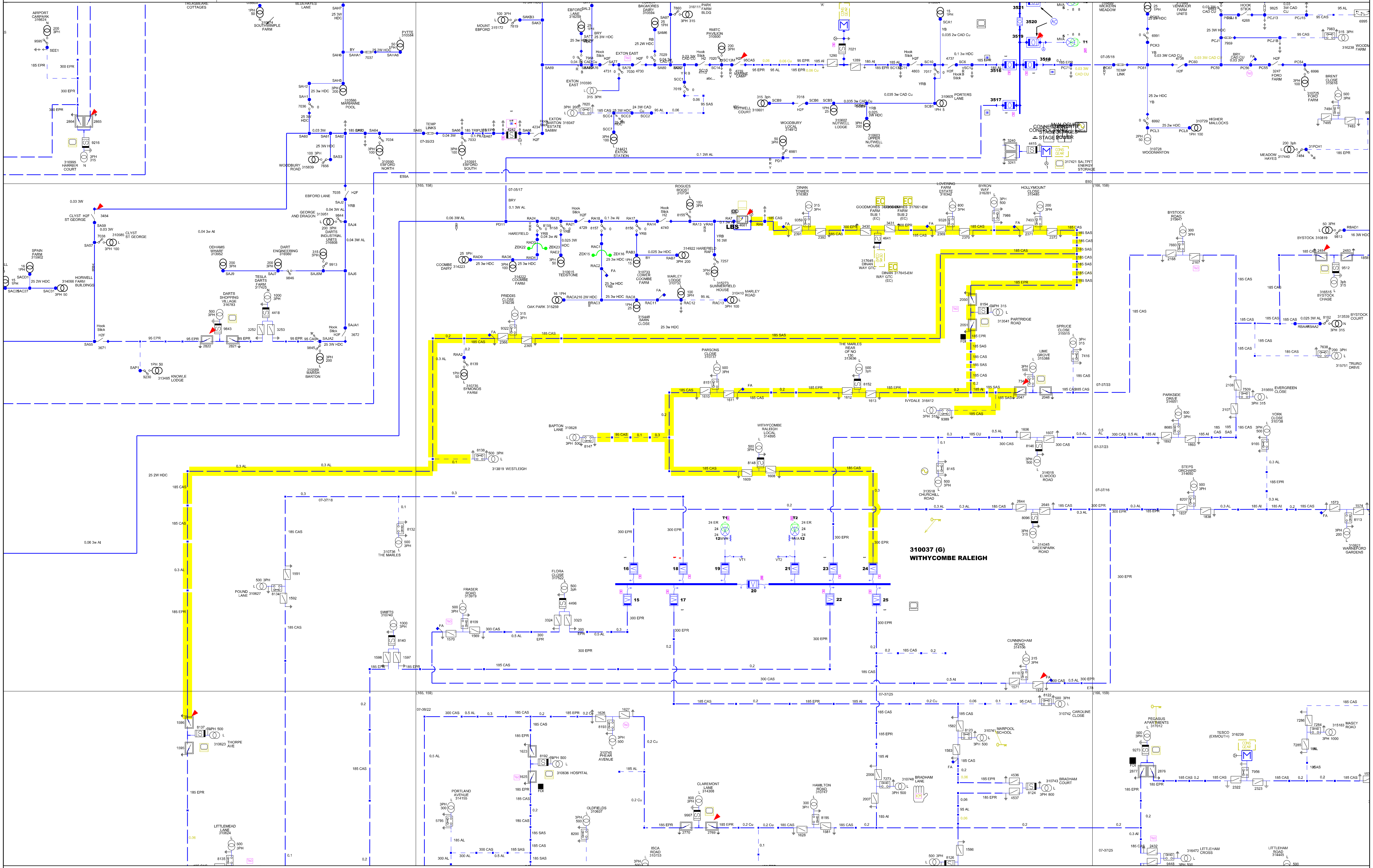

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