EPIC HV NAT Evaluation and Learning Report

For: Western Power Distribution
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Document History

Revision	Date	Description of changes
0	19-05-2022	Initial Issue
1	03-08-2022	Incorporating WPD comments on the initial issue

Revision	Date	Author	Peer Review	Approved
0	19-05-2022	Mahmoud Elkazaz	Shahab Khan	Shahab Khan
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Contents

Figures

Tables

1. Glossary of Terms

Acronym	Definition
BU	Bottom Up
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CHI	Capacity Headroom Index
CI	Customer Interruptions
CML	Customer Minutes Lost
DFES	Distribution Future Energy Scenarios
DNO	Distribution Network Operator
EE	Energy Efficiency
EPIC	Energy Planning Integrated with Councils
EV	Electric Vehicle
FFF	Fit-For-Future
FS	Flexible Services
HH	Half Hourly / customers with Half Hourly electricity metering
HISTAN	Historical Analogue
HV	High Voltage (6.6 and 11 kV)
HV NAT	High Voltage Network Analysis Tool
JIT	Just-in-Time
LV	Low Voltage (0.4 kV)
NI	Network Investment
NIFT	Network Investment Forecasting Tool
OHL	Over-Head Line
OPEX	Operational Expenditure
PSC	Power Systems Consultants
PSS®SINCAL	Power System Simulator for Siemens Network Calculation
SCADA	Supervisory Control and Data Acquisition
SPA	Strategic Planning Area
TD	Top Down
TS	Time Series
WPD	Western Power Distribution

2. Introduction

2.1. Introduction to the EPIC Project

The aim of the Energy Planning Integrated with Councils (EPIC) project is to develop a process that considers the impacts on both the electricity and gas networks and reflects the strategic ambitions of the local authority to enable better investment outcomes. This approach may result in lower overall cost to the consumer, improved risk management and also enable local partners to realise their own strategic outcomes including net zero decarbonisation, economic growth, industrial strategy and wider societal benefits.

2.2. Purpose of this Document

The purpose of this document is to present a summary of the learning obtained throughout the project EPIC from the point of view of HV Network Analysis Tool (HV NAT) specification, tool development and analysis carried out. This report complements the assessment work carried out by Regen using the CBA tool by capturing the learning relating to the HV NAT tool development and use and also to carry out some analysis and evaluation which does not require the CBA tool. This learning report covers:

- Overview of the EPIC Process with relevance to the HV Network Analysis
- HV Network Analysis Tool overview
- Evaluation of HV NAT analysis results and some key use-case findings
- Lessons learned in dealing with SCADA data, DFES data, network modeling in SINCAL, and LCT profile modeling

3. Overview of the EPIC Process

The starting point for the EPIC process is to use the existing Distribution Future Energy Scenarios (DFES), and other sources of network data, to create a strawman or “best view” plan that is disaggregated to a lower level of granularity on the High Voltage (HV) and the Low Voltage (LV) networks. This “best view” plan is then used as a starting point to engage with local authority partners, and to incorporate local authority planning data and other inputs to create a Strategic Planning Area (SPA) energy requirements plan. The SPA requirement plan, including any sensitivities and scenarios, is then subject to network analysis, using a new set of automated analysis tools and use of the Electricity Network Association (ENA)’s whole system Cost Benefit Analysis (CBA) tool, to conduct an options appraisal exercise and to create a network investment plan.

There are six core EPIC process stages as illustrated below:

I. Opportunity identification and area selection
II. Data Collection
III. Local Energy (requirements) Planning
IV. Network analysis
V. Investment and options appraisal
VI. Local Energy Planning (completion)

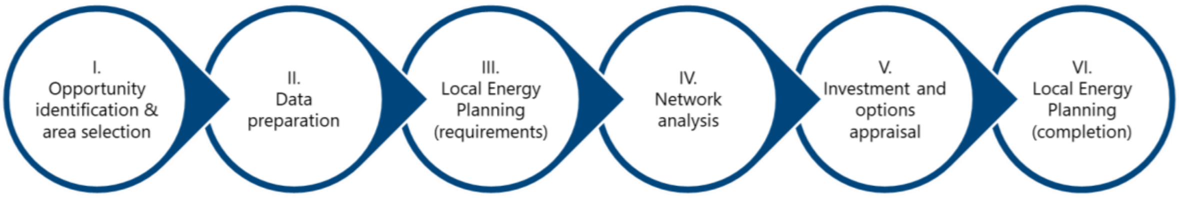

Figure 3-1: Overview of EPIC Process

The HV NAT relates to the activities taking place during the network analysis (IV stage) and the following section provides some further detail around the sub-process steps within this stage.

3.1. Network Analysis

PSC has developed the HV Network Assessment Tool (HV NAT) associated with carrying out the power system analysis and network reinforcement requirements associated with the HV system as part of the EPIC project. This section provides some further details into how that tool was developed.

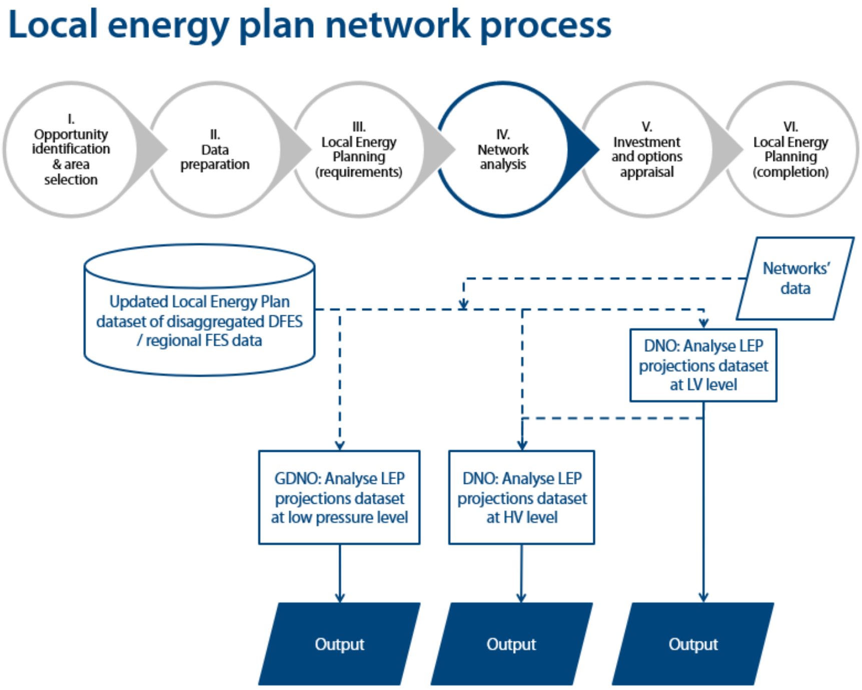

Figure 3-2: Overview of Network Analysis Stage

3.2. HV Network Analysis Tool Overview

The HV Network Analysis Tool has a number of different stages and decision points throughout its analysis. The specific details of each of these phases will depend on the condition of the input data, reinforcement requirements and necessary outputs. The following figure provides a high level overview of the HV NAT process with further details provided in the EPIC HV Network Analysis Tool Specification document [1].

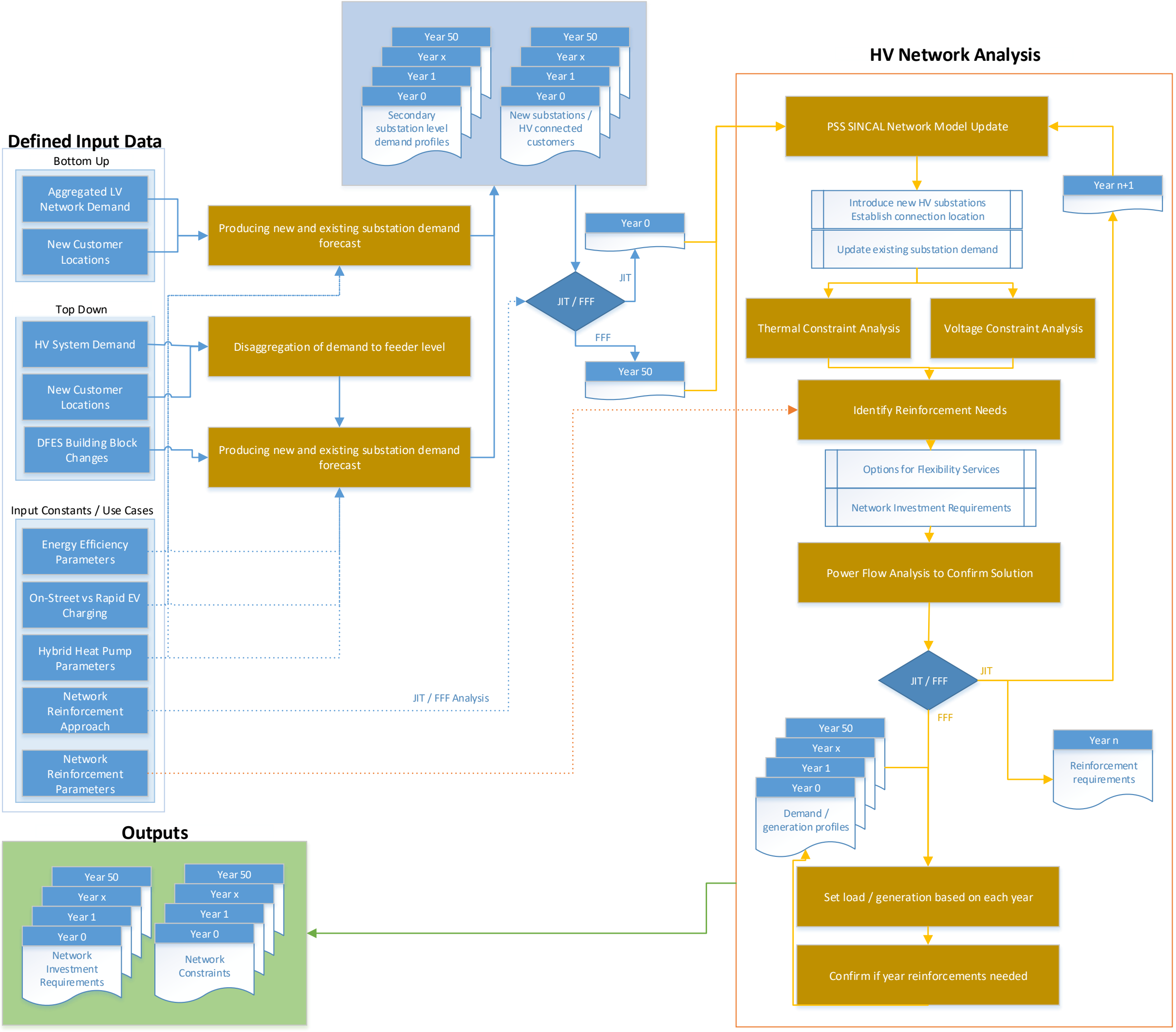

Figure 3-3: HV NAT High Level Process

3.2.1. Top Down vs Bottom Up analysis

The requirement for both Top Down (TD) and Bottom Up (BU) analysis reflects the different sources of data available and different approaches to planning for both HV and LV networks. Primary substations typically have monitoring installed at the 11kV feeder circuit breakers but most distribution substations are not monitored. Therefore while the total feeder load is known the loads at different distribution substations are estimated by pro-rating the total load, typically by transformer rating. Thus loads are allocated in a “Top- Down” method when modelling the HV networks. While this method has the advantage that the sum of the distribution substation loads will equal the monitored load for the feeder, it has the disadvantage that shape of the profiles at the distribution substations are all the same, rather than reflecting the particular mix of customers on that substation.

However, when modelling LV networks estimated loads would be built up from knowledge of the connected customers for that substation and profiles for typical customer types. Adding expected customer loads would provide profiles at the distribution substation level that should be more accurate in terms of profile shape but may not sum together along the feeder to equal the observed load at the source circuit breaker. Currently there are advantages and disadvantages for both top-down and bottom-up approaches but over time, as more distribution substations are monitored and smart meter data informs the estimated load profiles at distribution substations, it is likely that the bottom-up approach will become more accurate and will inform HV modelling.

4. HV NAT Analysis Results Evaluation

There are five use-cases defined by the project EPIC stakeholders, in EPIC Trial planning process document [2], which represent the planned approach to sensitivity testing and investment options appraisal in the Project EPIC trial. Also, there are three additional SPA specific use cases which were agreed amongst the project EPIC stakeholders and selection of those additional use-cases is defined in Local Energy Plan Addendum 1: Primary Selection for Network Analysis and Additional Use-Cases [3].

For each of the different scenarios , for the different use-cases and for each year the HV NAT provides insights as outputs in data in .csv file format. The results evaluation for difference between basecase run (Run 1 and Run2) and other runs (description of all runs is provided in Appendix A) corresponding to different use-cases is carried out in the CBA tool. Therefore, except for section 4.5, where most expensive and least expensive runs have been identified, all other subsequent sections base the analysis on results from the basecase run for different primaries.

4.1. Investment Levels in Different Primaries

For all three different primaries, and for years out to 2050 the HV NAT identifies the network equipment requiring reinforcement and flexible services needs which are as follows.

- Upgrading Cables / Transformers / Overhead Lines (OHL)s in units of kms
- Replacing OHL with underground cable where OHL circuit capacity cannot be increased beyond ampacity provided by highest size OHL conductor
- Creating a new feeder in a case of new connections which is not small enough to be accommodated on the existing infrastructure
- Feeder split
- Flexible services requirement

Investment level reported in this section accounts for both the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) outputs from HV NAT.

Figure 4-1 and Figure 4-2 indicates investment level for all three primaries over the period of analysis under the two different load allocation methods (TD and BU). While these show similar levels of investment overall, the TD analysis suggests an earlier increase in investment levels compared to the BU analysis. Investment level reported in this section accounts for both CAPEX and OPEX outputs.

Dorchester St. has the highest estimated annual demand followed by Nailsea and Cribbs Causeway as can be seen from Figure 4-3. Table 4-1 indicates the number of the distribution transformers corresponding to each primary. Number of distribution transformers in each primary when seen in conjunction with the annual estimated demand clearly indicates that the investment level would be highest in Dorchester St. followed by Nailsea and Cribbs Causeway.

Also, Dorchester St. being the 6.6 kV system experiences more frequent upgrades, as the 6.6 kV and 11 kV lines would have same thermal rating but as power is the product of voltage and current, the same levels of current on the 6.6kV network can carry less power than on the 11kV network. This is seen in the results with more feeder split interventions occurring at Dorchester St. out of all three primaries assessed as described in section 4.7.

The level of investment, on a high level, can be seen in Figure 4-1 and Figure 4-2 to be steadily increasing over the period of analysis for both the TD and BU approach. For TD analysis year 2040 onwards there is a reduction in investment levels as there is a reduction in EV numbers because of more reliance on public transport.

Table 4-1: Number of Distribution transformers per Primary

Primary	Number of Distribution transformers
Cribbs Causeway	61 transformers
Nailsea	164 transformers
Dorchester St. New	132 transformers

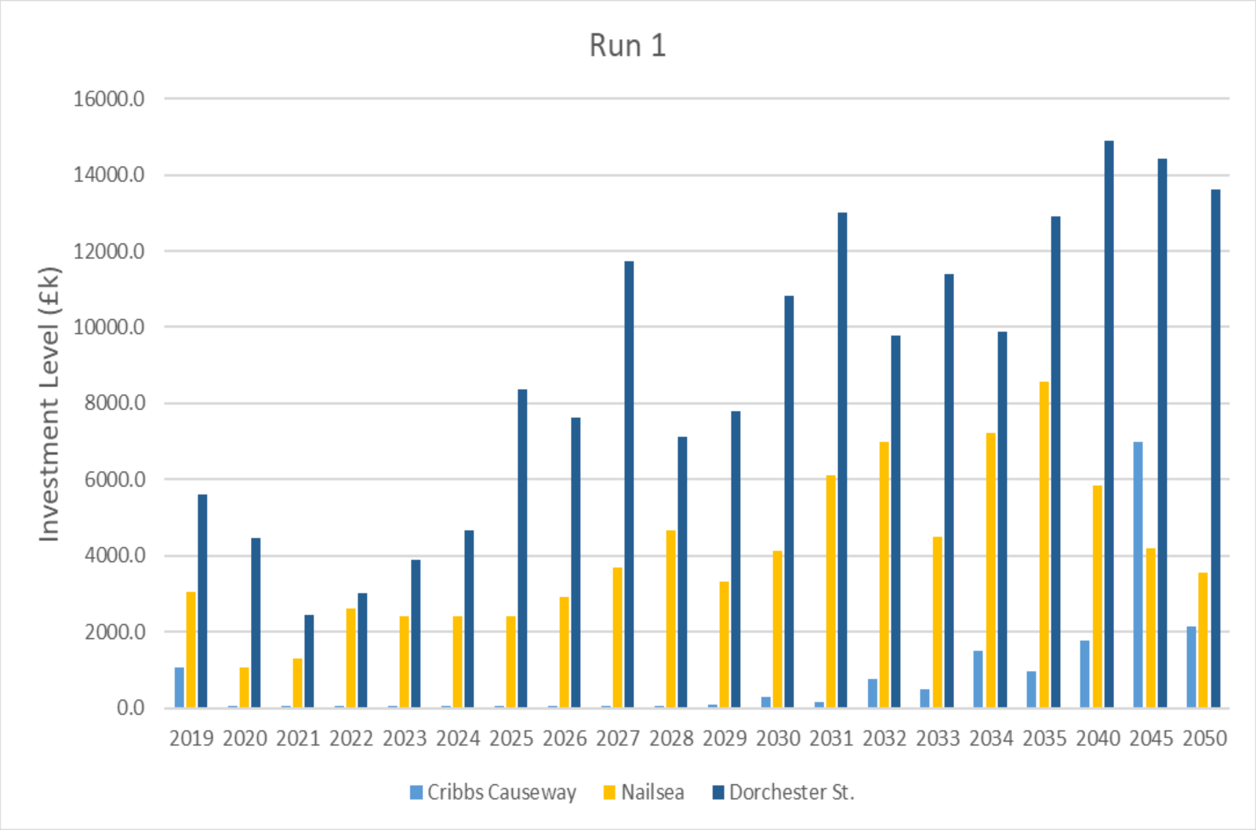

Figure 4-1: Investment Level For three Primaries - TD Approach (Run 1)

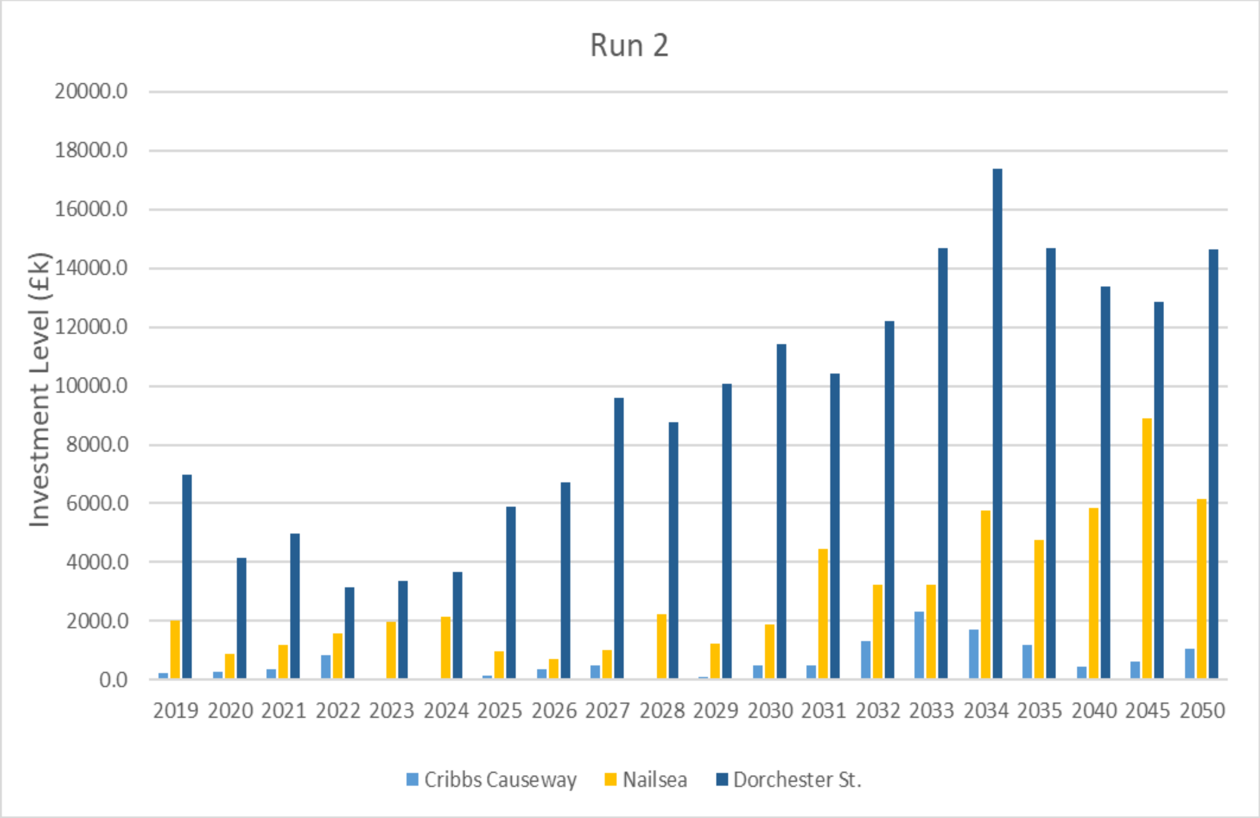

Figure 4-2: Investment Level For three Primaries - BU Approach (Run 2)

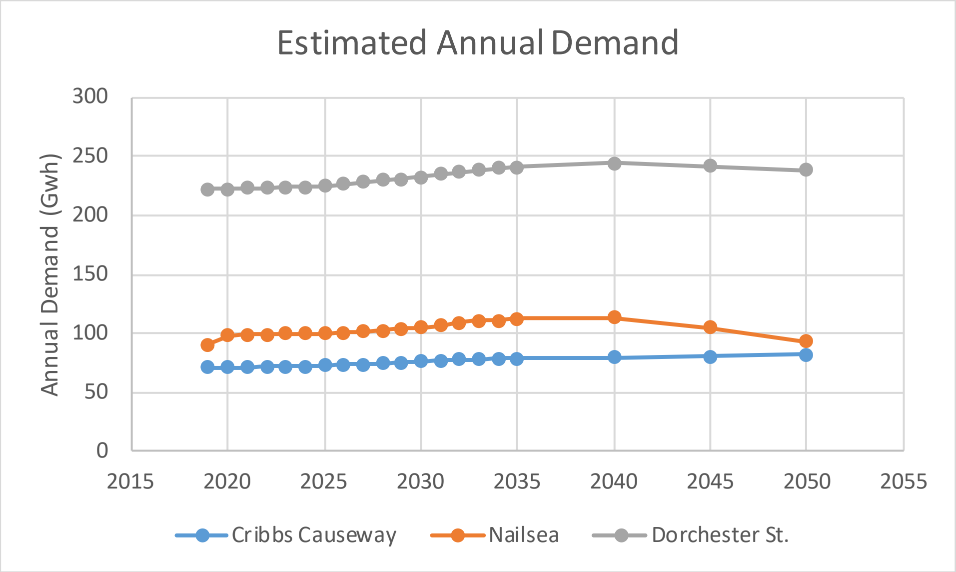

Figure 4-3: Estimated Annual Demand for Primaries – Base case run

4.2. Investment Types in Different Primaries

In order to understand where the investment is targeted network equipment wise, and whether there is any consistent pattern across different primaries, ratio of length (in km) of upgraded cable to number of upgraded transformers is worked out and shown in Figure 4-4 and Figure 4-5. This indicates for every transformer upgrade in the Dorchester St. there is more investment in cable replacement when compared to Nailsea and Cribbs Causeway. In other words, investment targeted in cables is highest in Dorchester St, followed by Nailsea and Cribbs Causeway.

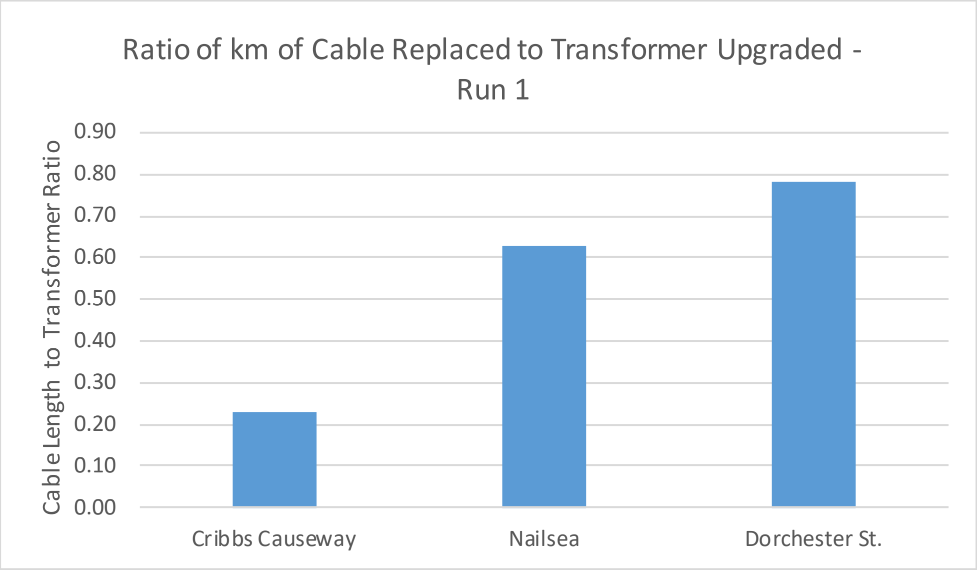

Figure 4-4: Investment Types in Primaries – TD Approach (Run 1)

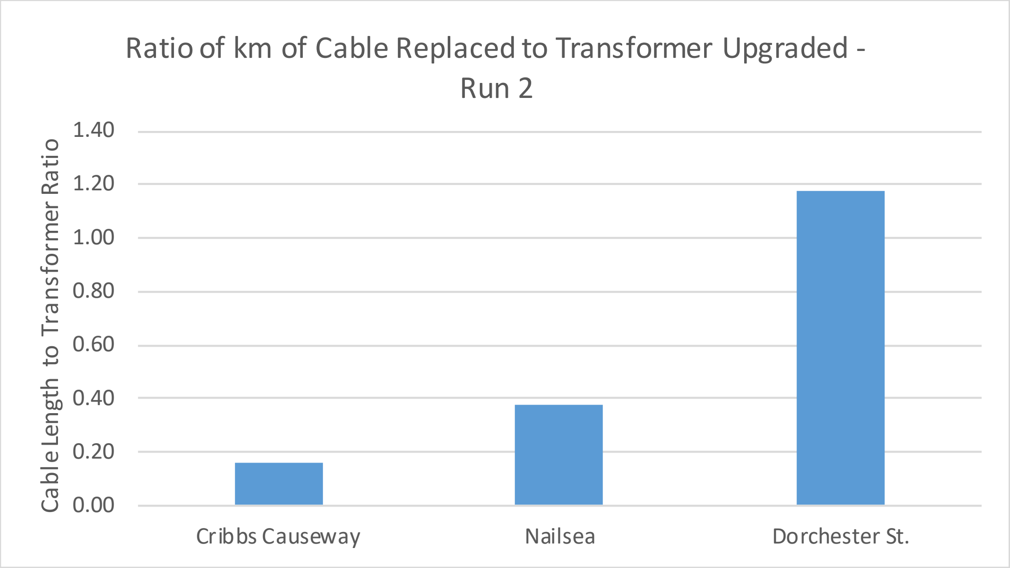

Figure 4-5: Investment Types in Primaries – BU Approach (Run 2)

4.3. Transformers replaced by 2050

In this section the proportion of transformers that gets replaced by 2050 is worked out by determining the ratio of number of transformers replaced by 2050 to total number of the transformers. Table 4-2 gives the number of primary and distribution transformers in each of the three primaries.

As can be seen from the results shown in Figure 4-6 to Figure 4-9, over the period of analysis, 100% of the primary transformers are replaced by the year 2050. This is the same for both TD and BU versions and is expected given the significant increases in load predicted from the uptake of LCTs in previous studies[1]. In terms of distribution transformers, Dorchester St. has the highest proportion of transformers replaced by 2050 followed by Cribbs Causeway and Nailsea. This trend is also consistent between TD and BU analysis. Averaging at around 25%, this suggests a significant reinforcement workload even when spread over thirty years. The majority of transformer replacements currently are driven by asset age/condition rather than capacity so where there is high confidence in the need for future assets to increase capacity this should be integrated with the condition related replacement programme in rather than replacing aging assets with new assets of the same capacity.

In the TD approach HV DFES also gets disaggregated to the distribution substation level whereas for the BU approach HV DFES gets disaggregated to three HV dummy sites on a feeder. These dummy HV sites (three of them per HV feeder with a 2 MVA transformer rating) are artificially introduced in the model to account for impact of HV DFES. Due to the difference between the TD and BU approach of how the HV DFES is dealt with, it is expected that the BU approach would lead to less distribution transformers replaced by 2050, for all three primaries, in comparison to TD approach as can be seen in Figure 4-9 and Figure 4-7 respectively. The expected pattern of results is seen with fewer transformer replacements under the bottom up approach.

Table 4-2: Number of Distribution and Primary transformers in each Primary

Primary	Number of transformers	
	Distribution	Primary
Cribbs Causeway	58	2
Nailsea	161	2
Dorchester St. New	131	4

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[1] Accelerated electrification and the GB electricity system, Imperial College & Vivid Economics. https://www.researchgate.net/publication/340062374

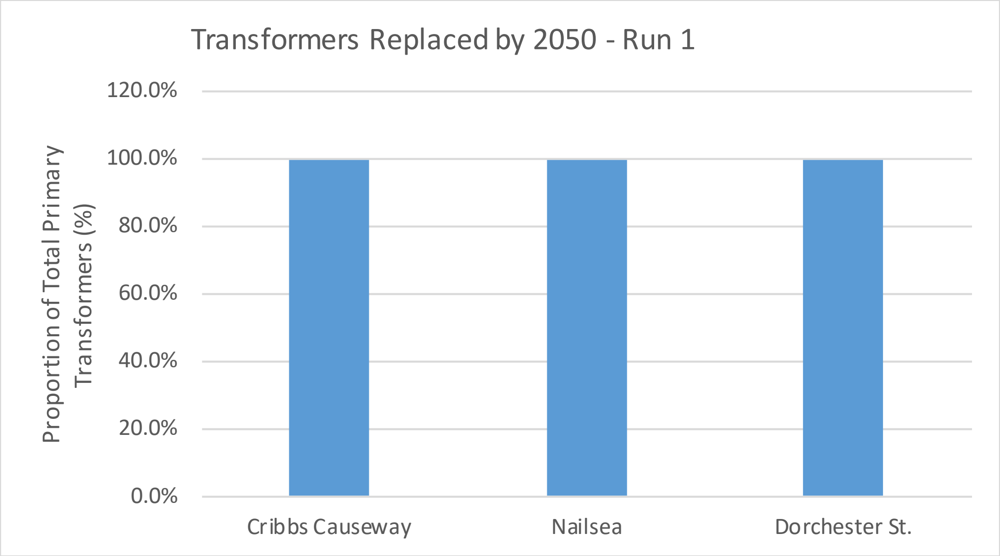


Figure 4-6: Proportion of Primary Transformers replaced by 2050 – TD Approach (Run 1)

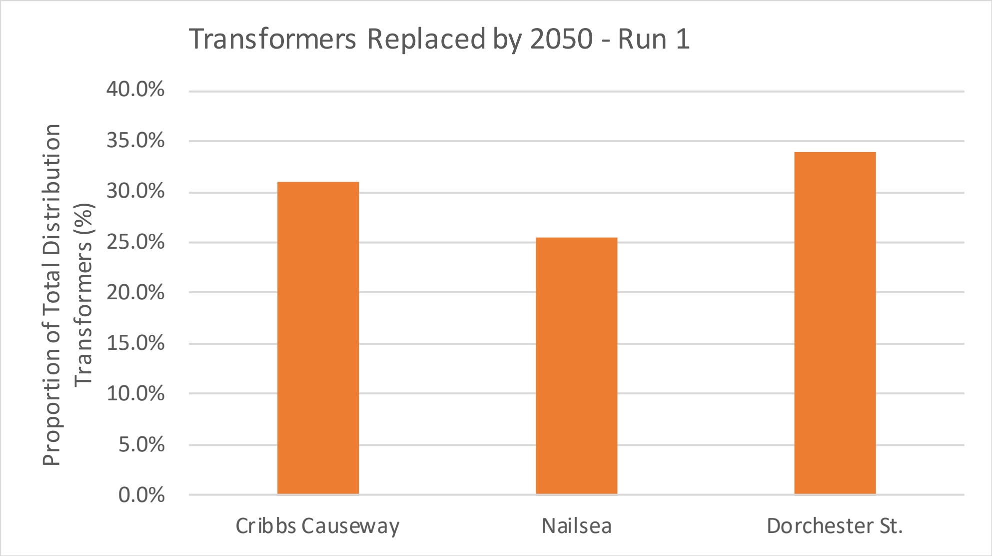


Figure 4-7: Proportion of Distribution Transformers replaced by 2050 – TD Approach (Run 1)

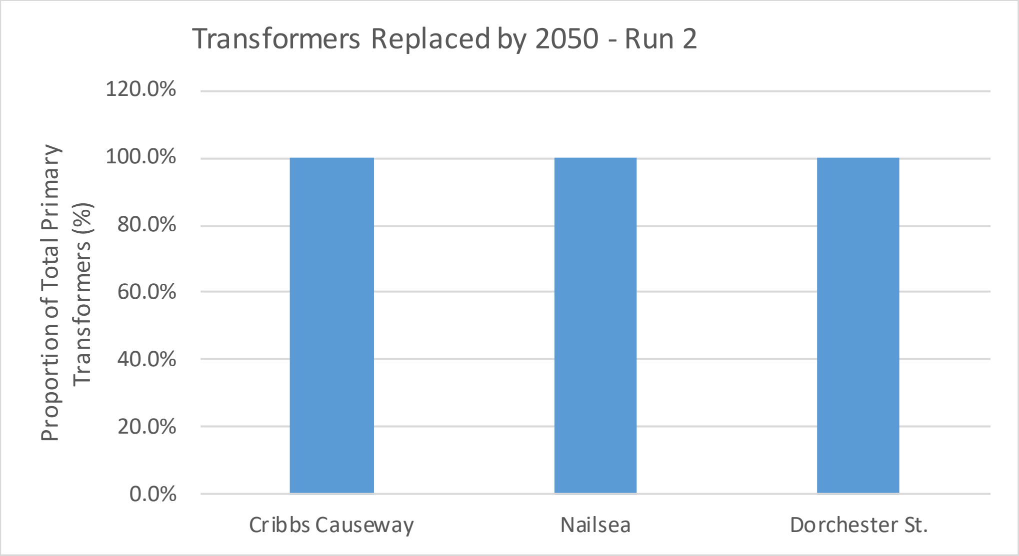


Figure 4-8: Proportion of Primary Transformers replaced by 2050 – BU Approach (Run 2)

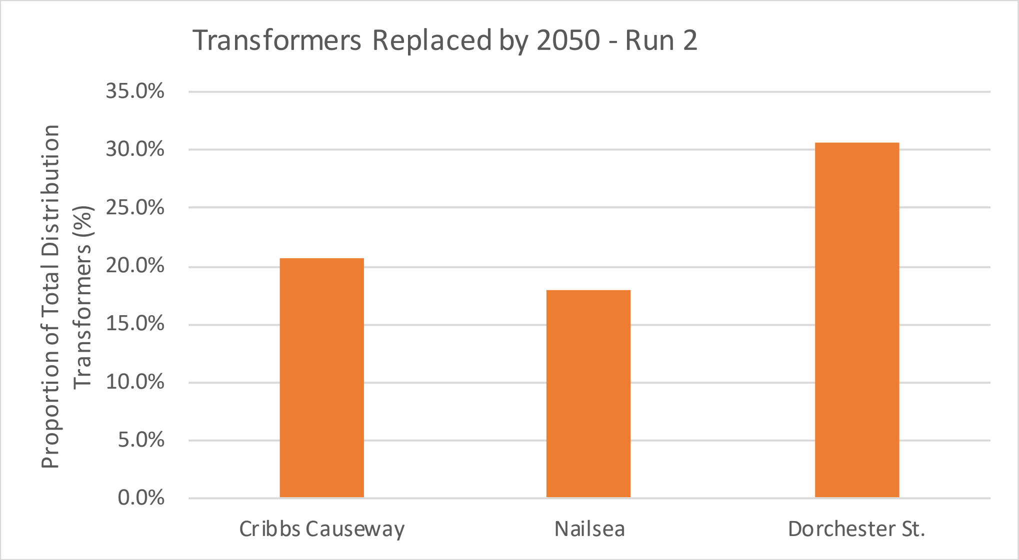


Figure 4-9: Proportion of Distribution Transformers replaced by 2050 – BU Approach (Run 2)

4.4. Transformer Upgraded more than once by 2050

There are some network assets which were upgraded more than once over the period of analysis i.e. if a particular transformer is upgraded in year 2019 and then upgraded again in year 2025, then this counts as transformer replaced more than once by 2050. The instances of all such transformers are shown below. Figure 4-10 and Figure 4-12 shows the proportion of primary transformers replaced more than once by 2050, while Figure 4-11 and Figure 4-13 shows the proportion of distribution transformers replaced more than once by 2050. The average percentage of distribution transformers being replaced twice from figure 4-11 is around 5% with the TD numbers being considerably higher than the BU values.

The higher the proportion of transformers replaced more than once by 2050, the more is the CAPEX savings when FFF approach is adopted. Given the very high cost of primary transformer replacement, and the limited resources available for such work, it strongly suggests upgrading the transformers at Nailsea to the largest size required over the period to 2050 when the first upgrade is required.

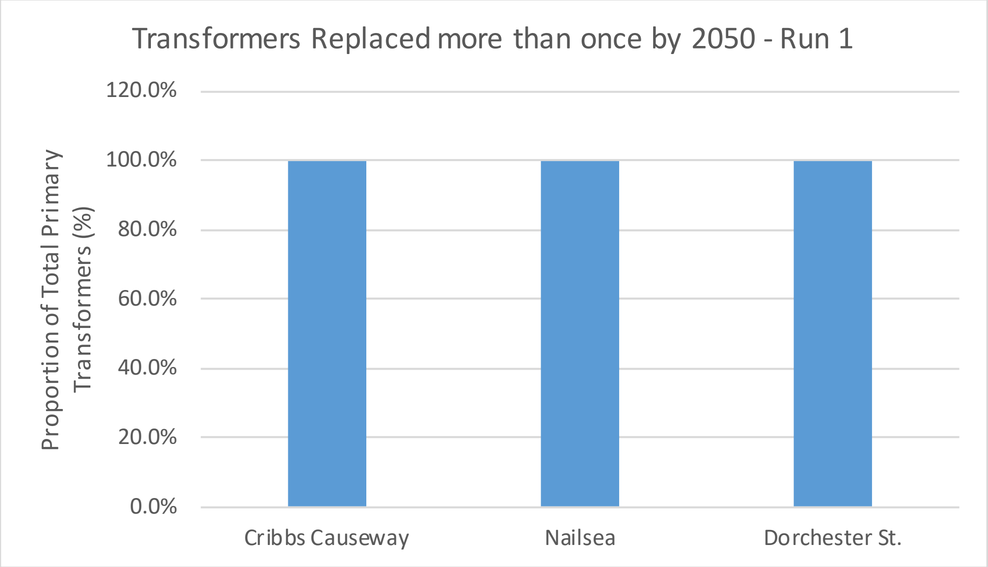


Figure 4-10: Proportion of Primary Transformers replaced more than once by 2050 – TD Approach (Run 1)

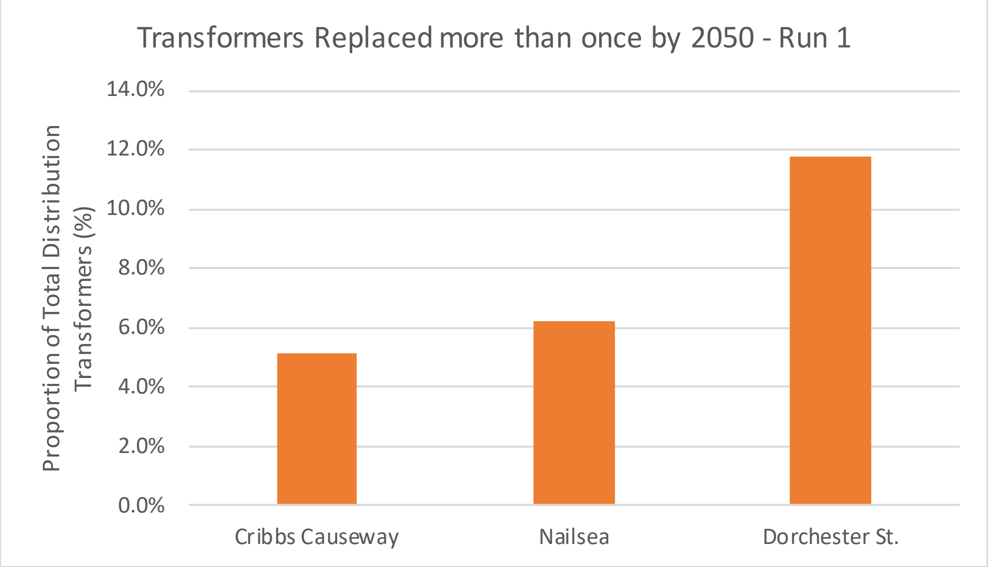


Figure 4-11: Proportion of Distribution Transformers replaced more than once by 2050 – TD Approach (Run 1)

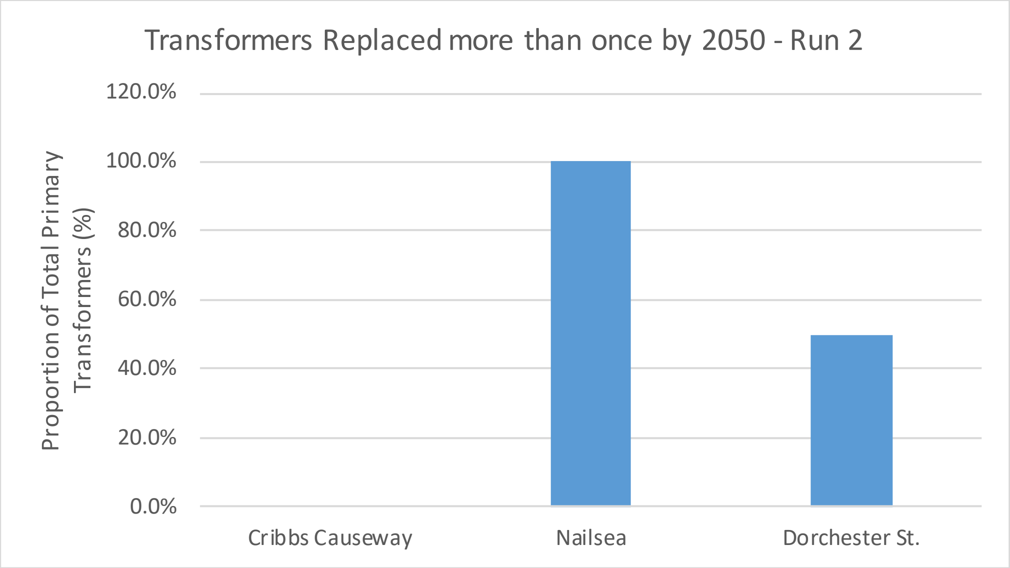


Figure 4-12: Proportion of Primary Transformers replaced more than once by 2050 – BU Approach (Run 2)

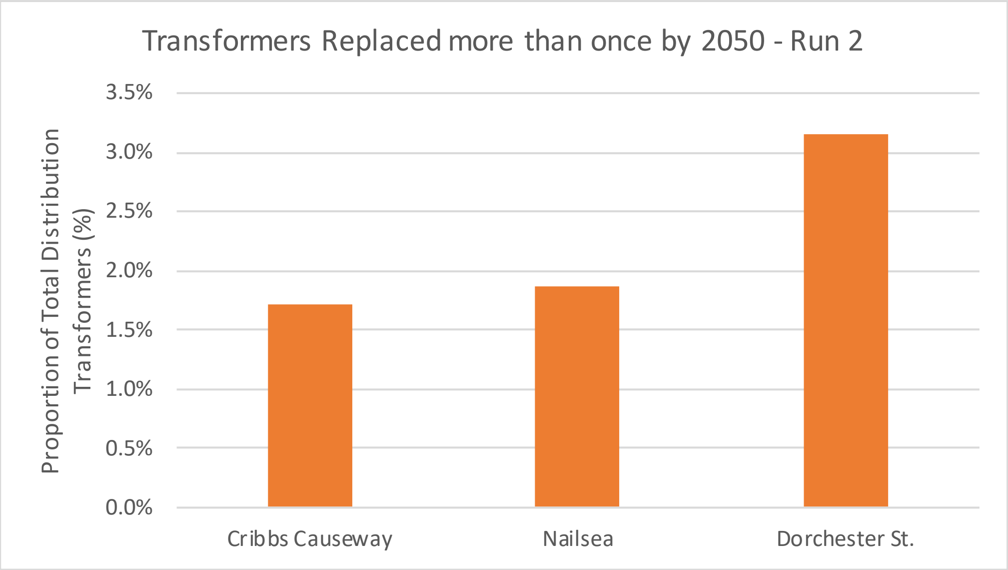


Figure 4-13: Proportion of Distribution Transformers replaced more than once by 2050 – BU Approach (Run 2)

4.5. High/Low Investment Runs

Total investment is worked out for all the runs by summing up the CAPEX and OPEX to identify the highest and lowest investment runs. In order to convert the flexibility services in MWh to a monetary value a conversion factor of £300/MWh is used. This reflects the values paid for existing flexibility services by WPD, though it is hoped that as flexibility markets develop further these values will eventually fall.

Figure 4-14 to Figure 4-19 indicate the level of total investment in relation to other runs and also highlight the highest and lowest investment run. One high level observation from the below figures can be drawn in terms of investment saving in FFF approach. For all the three primaries FFF approach runs (run 20 and 21) can be seen to be amongst the lowest investment runs.

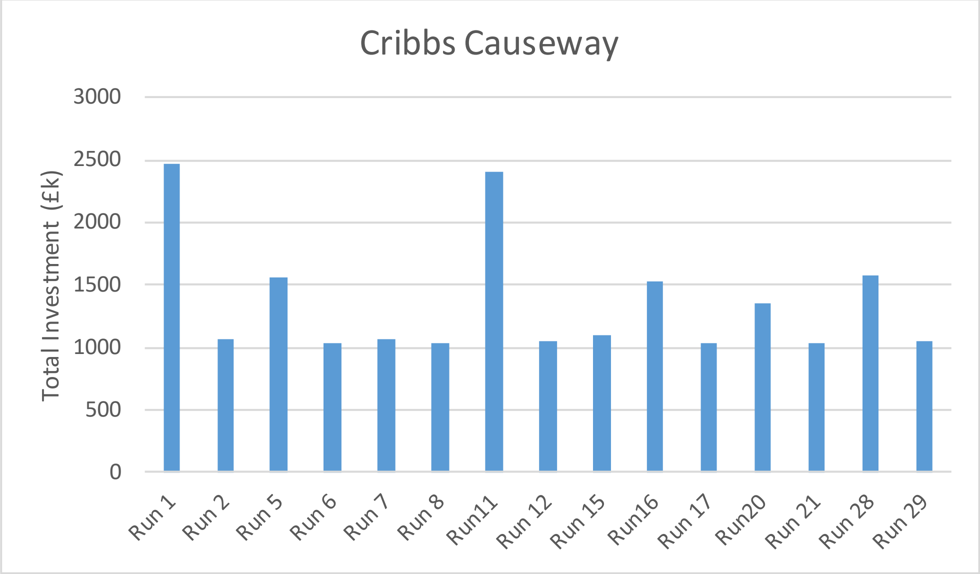


Figure 4-14: Total Investment for all runs – Cribbs Causeway primary

Run Number	CAPEX (£k)	Flex (MWh)	Flex cost (£k)	Total Investment (£k)
Run 1	2455.761901	47.16133325	14.14839998	2469.910301
Run 2	1047.957927	38.17246475	11.45173942	1059.409666
Run 5	1559.035136	30.35159546	9.105478638	1568.140615
Run 6	1020.923956	31.98685454	9.596056363	1030.520013
Run 7	1047.957927	40.07433973	12.02230192	1059.980229
Run 8	1020.923956	32.62013691	9.786041073	1030.709997
Run11	2393.199214	29.70132515	8.910397544	2402.109612
Run 12	1035.088035	38.21553542	11.46466063	1046.552695
Run 15	1084.560129	48.91822337	14.67546701	1099.235596
Run16	1527.035136	16.78901596	5.036704787	1532.071841
Run 17	1020.923956	30.95014672	9.285044015	1030.209
Run20	1354.837945	6.245472752	1.873641826	1356.711587
Run 21	1033.793848	4.008158136	1.202447441	1034.996295
Run 28	1573.199215	25.55593237	7.666779711	1580.865994
Run 29	1035.088035	34.86879023	10.46063707	1045.548672

Figure 4-15: Highest and lowest Investment run – Cribbs Causeway primary

Note: Run1 is the baseline case. Run 17 corresponds to the heat pumps use case with more hybrid heat pumps compared to non-hybrid heat pumps. Description for all runs is provided in Appendix A.

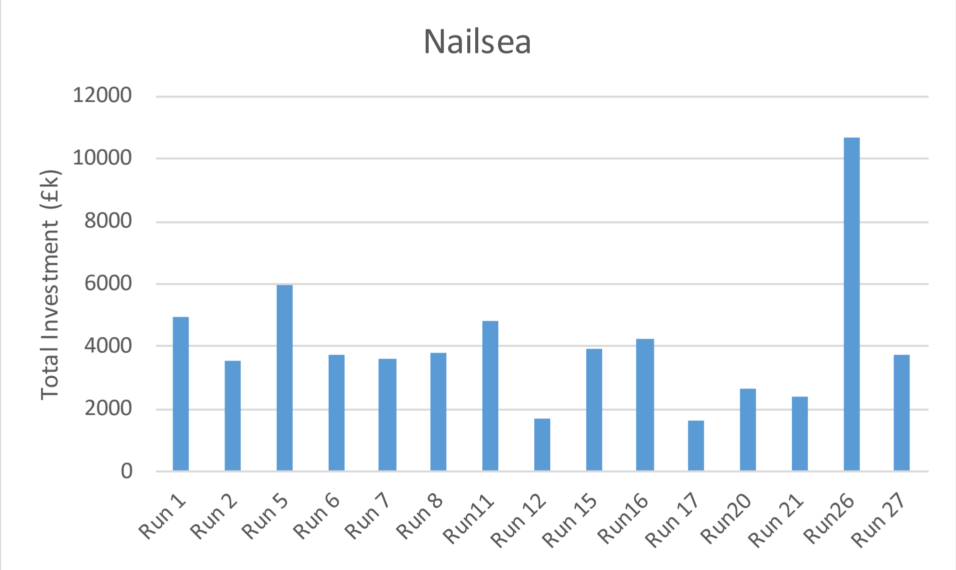


Figure 4-16: Total Investment for all runs – Nailsea primary

Run Number	CAPEX (£k)	Flex (MWh)	Flex cost (£k)	Total Investment (£k)
Run 1	4879.762559	253.3926393	76.0177918	4955.780351
Run 2	3501.35704	189.0154821	56.70464464	3558.061685
Run 5	5873.070424	231.5066799	69.45200398	5942.522428
Run 6	3690.135012	192.3936091	57.71808273	3747.853094
Run 7	3545.67028	180.0786196	54.02358589	3599.693866
Run 8	3702.685483	183.0597039	54.91791118	3757.603394
Run11	4734.364813	233.0019923	69.90059769	4804.26541
Run 12	1660.945979	148.0203	44.40609001	1705.352069
Run 15	3835.975289	166.3422835	49.90268505	3885.877975
Run16	4148.220773	219.5724064	65.87172193	4214.092495
Run 17	1545.812025	133.5973412	40.07920237	1585.891227
Run20	2663.843145	1.85482835	0.556448505	2664.399594
Run 21	2359.511481	11.60857819	3.482573457	2362.994054
Run26	10611.5428	222.7174276	66.81522829	10678.35803
Run 27	3683.917677	167.3404053	50.2021216	3734.119798

Figure 4-17: Highest and lowest Investment run – Nailsea primary

Note: Run 26 includes accelerated and increased growth of ground mounted solar. Description for all runs is provided in Appendix A.

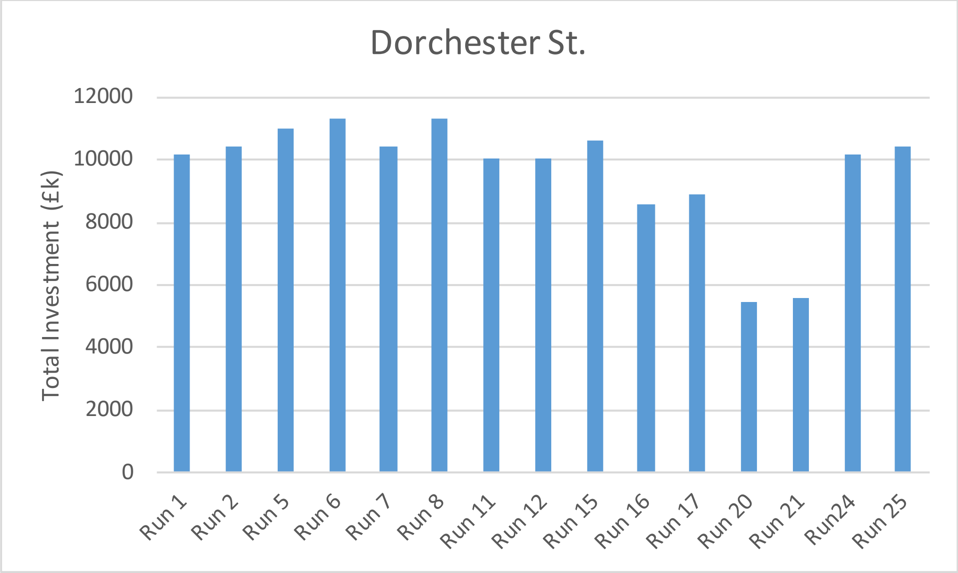


Figure 4-18: Total Investment for all runs – Dorchester St. primary

Run Number	CAPEX (£k)	Flex (MWh)	Flex cost (£k)	Total Investment (£k)
Run 1	10001.93396	558.3042996	167.4912899	10169.42525
Run 2	10254.70787	595.6918604	178.7075581	10433.41543
Run 5	10873.24959	545.2250001	163.5675	11036.81709
Run 6	11130.43656	582.6242231	174.7872669	11305.22383
Run 7	10254.70787	615.6768045	184.7030414	10439.41092
Run 8	11138.87081	591.531178	177.4593534	11316.33016
Run 11	9879.907701	528.6577924	158.5973377	10038.50504
Run 12	9881.132678	571.1681903	171.3504571	10052.48313
Run 15	10470.18074	586.1441919	175.8432576	10646.024
Run 16	8400.508483	524.6704053	157.4011216	8557.909605
Run 17	8751.083407	566.3573611	169.9072083	8920.990615
Run 20	5432.023269	9.149264257	2.744779277	5434.768048
Run 21	5586.075301	14.23254727	4.269764181	5590.345065
Run24	10001.9478	558.2813706	167.4844112	10169.43221
Run 25	10254.72171	595.513848	178.6541544	10433.37587

Figure 4-19: Highest and lowest Investment run – Dorchester St. primary

Note: Run 8 corresponds to the EV use case with low on street charging with sensitivity of managed charging. Run 20 corresponds to the investment strategy use case considering FFF approach. Description for all runs is provided in Appendix A.

4.6. Investment Level Grouped by Representative Day

In order to ensure assessment for a range of future likely most onerous cases, the following five representative days have been analysed:

- Winter Peak Demand, with minimum coincident generation – an assessment of the network's capability to meet peak demand conditions.

- Summer Peak Demand with minimum coincident generation – an assessment of the network's capability to meet maintenance period demand conditions
- Intermediate Warm Peak Demand with minimum coincident generation - an assessment of the network's capability to meet maintenance period demand conditions
- Intermediate Cool Peak Demand with minimum coincident generation
- Summer Peak Generation, with minimum coincident demand – an assessment of the network's capability to handle generation output

Figure 4-20 and Figure 4-21 shows the Investment Grouped by Representative Day for the basecase runs (run 1 and run 2) of the TD runs (Run 1) by year 2050. Investment is in terms of number of transformers (primary and distribution transformer) upgraded in response to constraints occurring on a particular representative day.

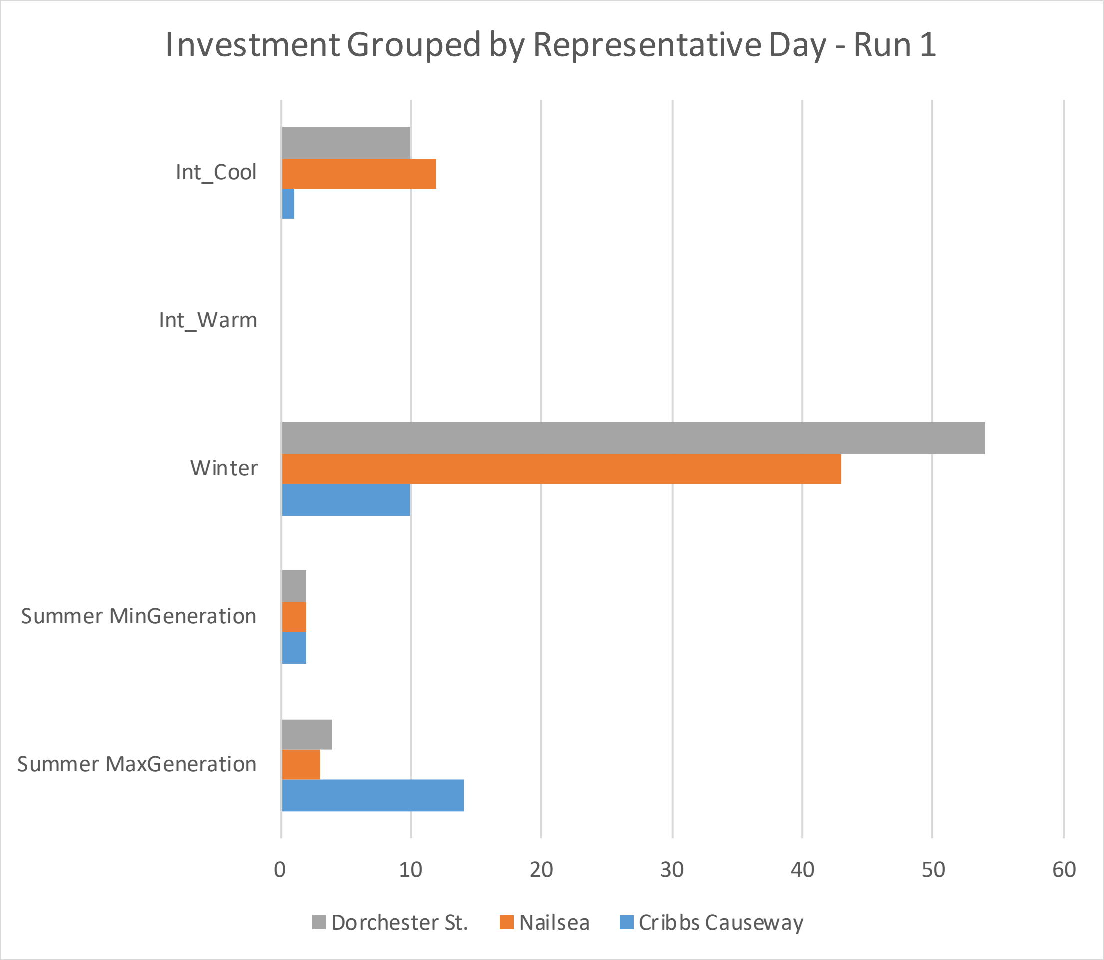


Figure 4-20: Investment Grouped by Representative Day For three Primaries - TD Approach (Run1)

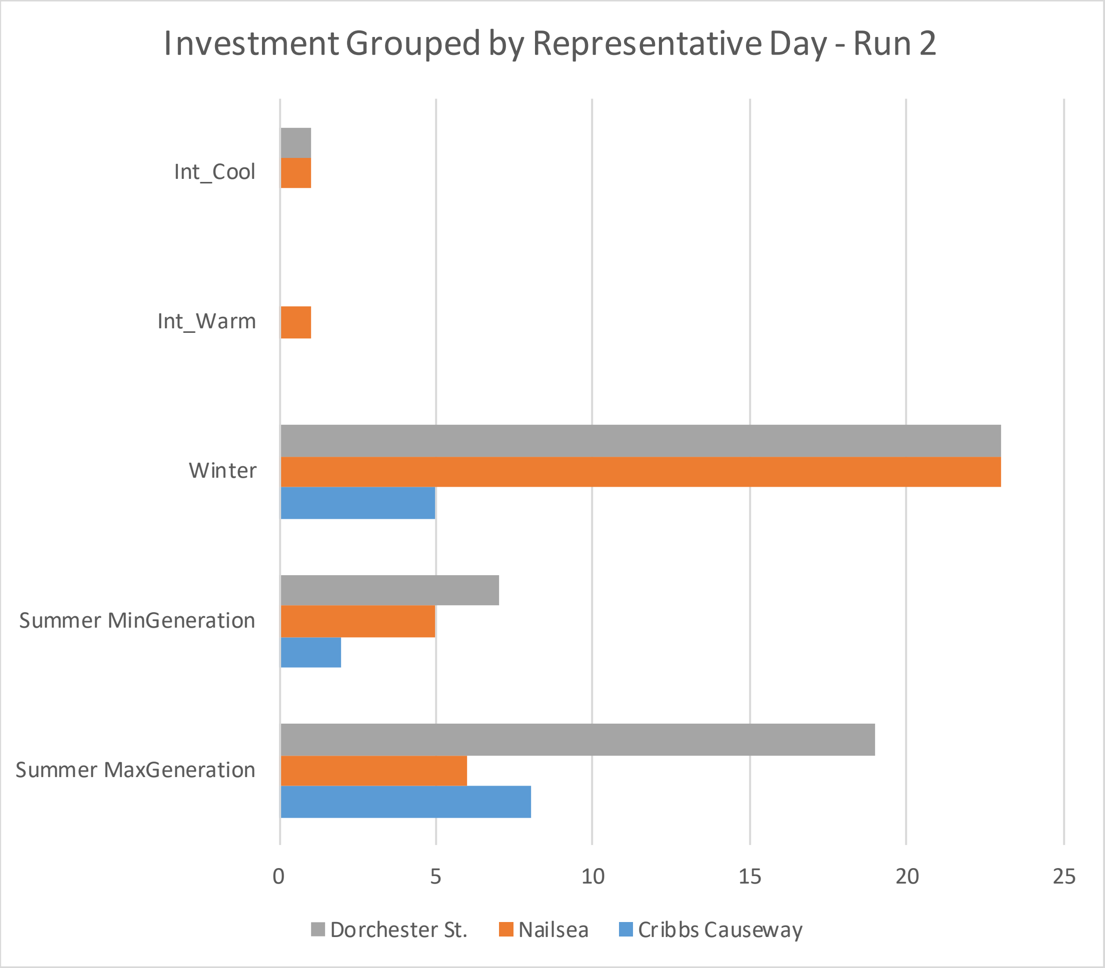


Figure 4-21: Investment Grouped by Representative Day For three Primaries - BU Approach (Run2)

The following observations are concluded from the Figure 4-20 and Figure 4-21.

- Most of the investment occurs during the Winter representative day. This is obvious because of the increase in the load demand in this period compared to the other representative days in the year.
- Some investments occur during the ‘Summer maximum generation’ representative day, and the reason is a large amount of generation- with low load demand- starts to trigger the asset upgrade option.
- ‘’Int warm’’ and ‘’Summer Min generation’’ representative days have the least number of investments, compared to the others representative days.
- It is worth mentioning that the sequence of the representative days in the load flow analysis has an effect on the number of investments in each representative day. For example, in this analysis, the ’Int_warm’ representative day come after the ‘winter’ representative day, which makes all the assets that need upgrade trigger during the “Winter” representative day , leaving no assets that require an upgrade in the ‘Int Warm’ representative day.
- ‘Summer Max generation’ representative day is an important representative day for the investment identification because it counts for the case when the system has maximum generation which may trigger the asset upgrade.

Also, it is worth mentioning that some assets are upgraded after their total cumulative peak energy (MWh) exceeded a certain threshold value (1 MWh for cables, 0.133 MWh for transformers). This criteria can be the reason for why we are seeing some investment in some representative days which have lower demand compared to the 'Winter' representative day.

4.7. Impact on Dorchester St. 6.6 kV System

Dorchester St. primary has 6.6 kV system unlike the Cribbs Causeway and Nailsea primary which have 11 kV network. Due to this 6.6 kV system, current loading at 6.6 kV level would be higher and lesser capacity headroom would be available for the equipment to begin with. Therefore, with the increment in load over the period of analysis there will be more frequent upgrades and that's one of the reasons why more feeder split cases are observed in Dorchester St. primary as cable upgrade options are exhausted quickly due to the loading on the 6.6 kV system. This can be seen from Figure 4-22 where there are three instances of feeder split Dorchester St. primary while no feeder split is observed on Nailsea and Cribbs Causeway.

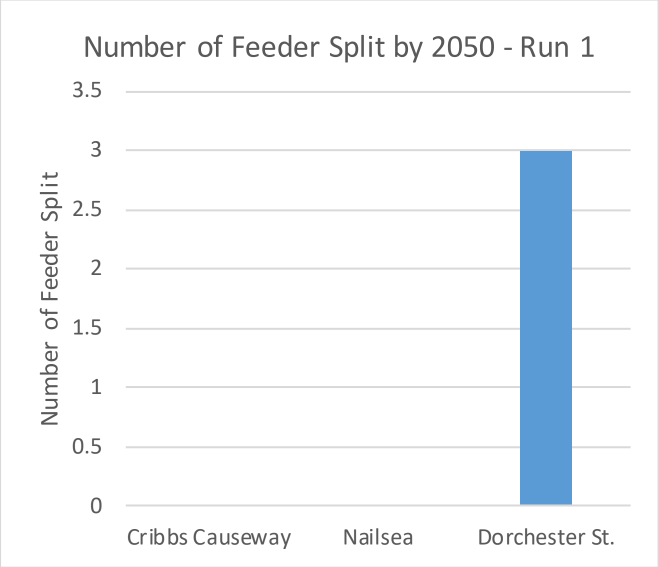


Figure 4-22: Number of Feeder Split in each Primary by 2050 - Run 1

4.8. Network Investment Visualisation

Figure 4-23 to Figure 4-25 shows the network investment (indicating transformer upgrades) for all three primaries by the year 2050. The red dots represent a transformer upgrade. This is best presented in a video format where in user can interact and select a specific study year and results will show where geographically in the primary investment need is triggered. Also this is a good way of getting insight into whether investment is targeted in certain pockets (confined area of the primary network) or evenly spread across the network.

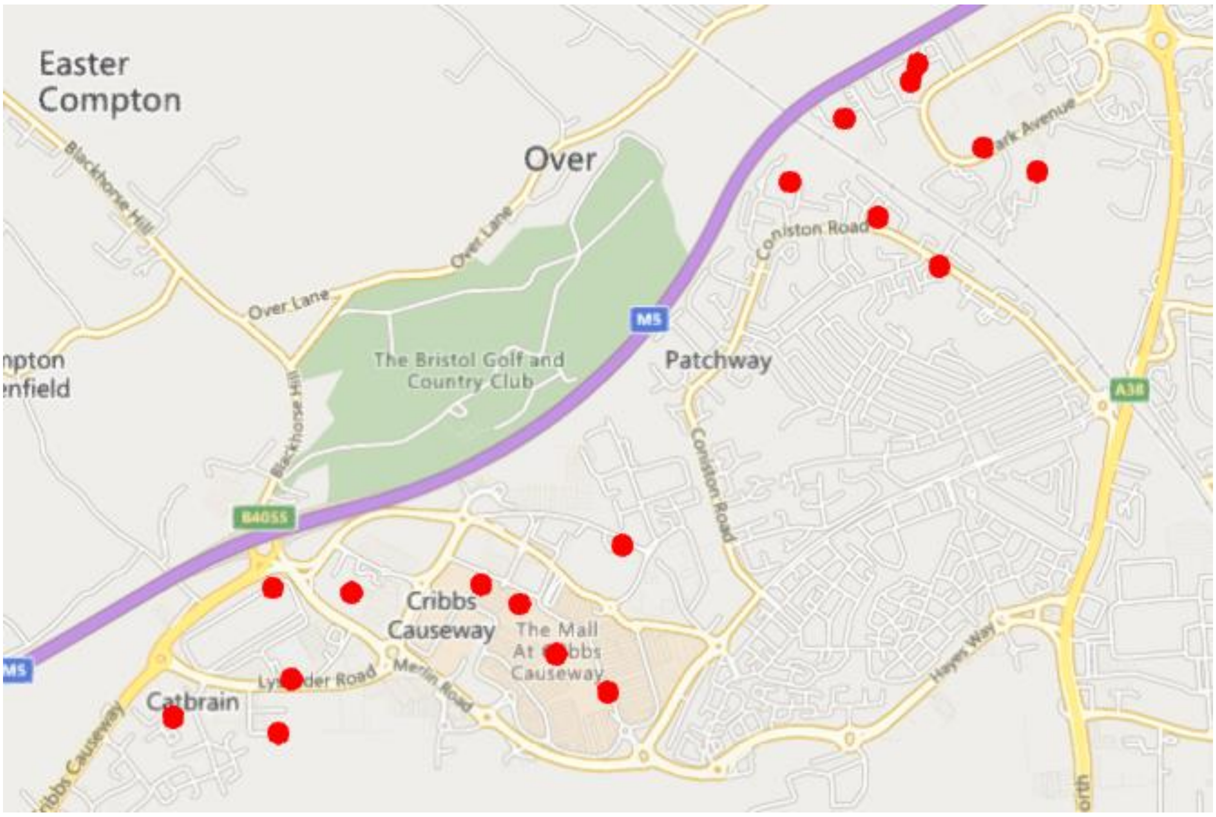


Figure 4-23: Network Investment Visualisation for year 2050 - Run 1 – Cribbs Causeway

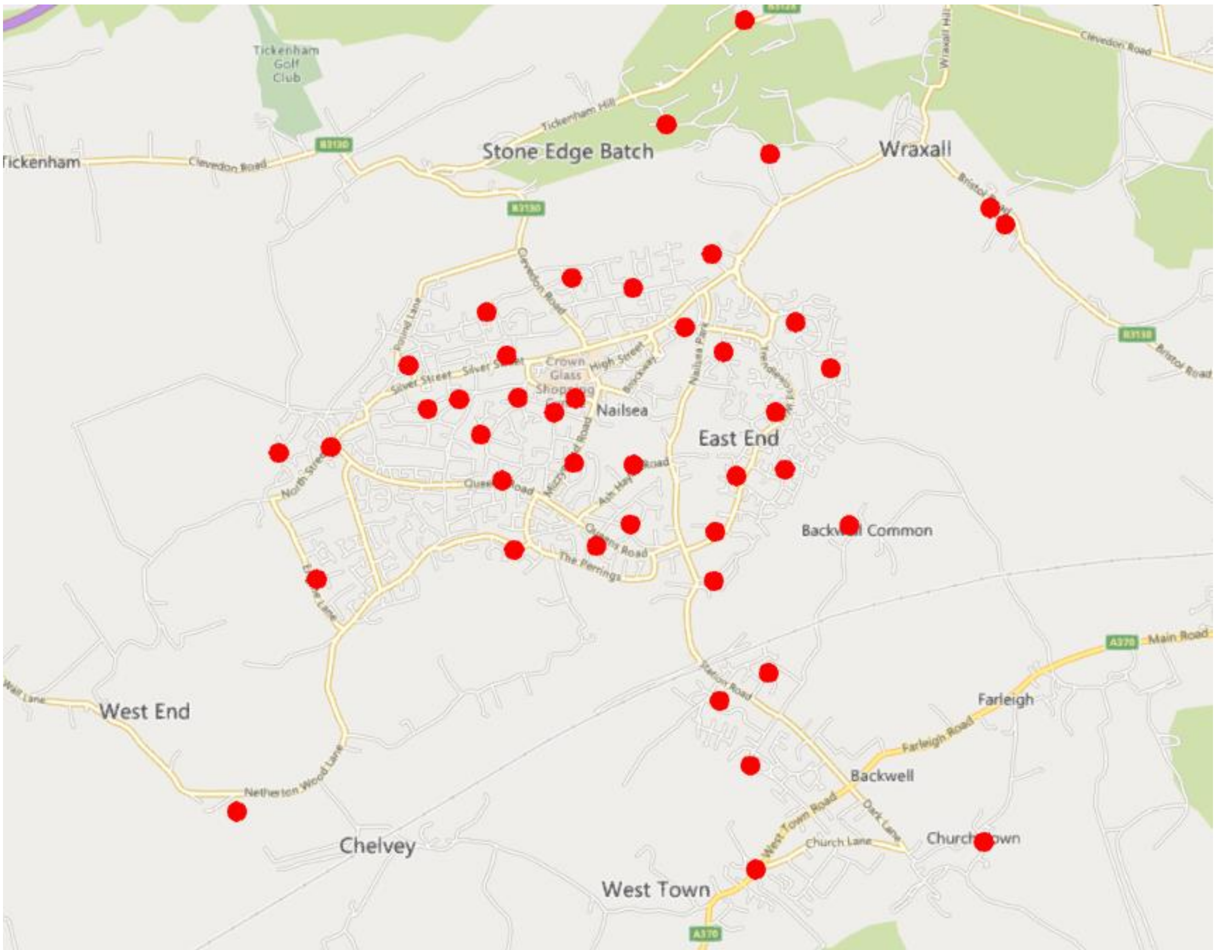


Figure 4-24: Network Investment Visualisation for year 2050 - Run 1 – Nailsea

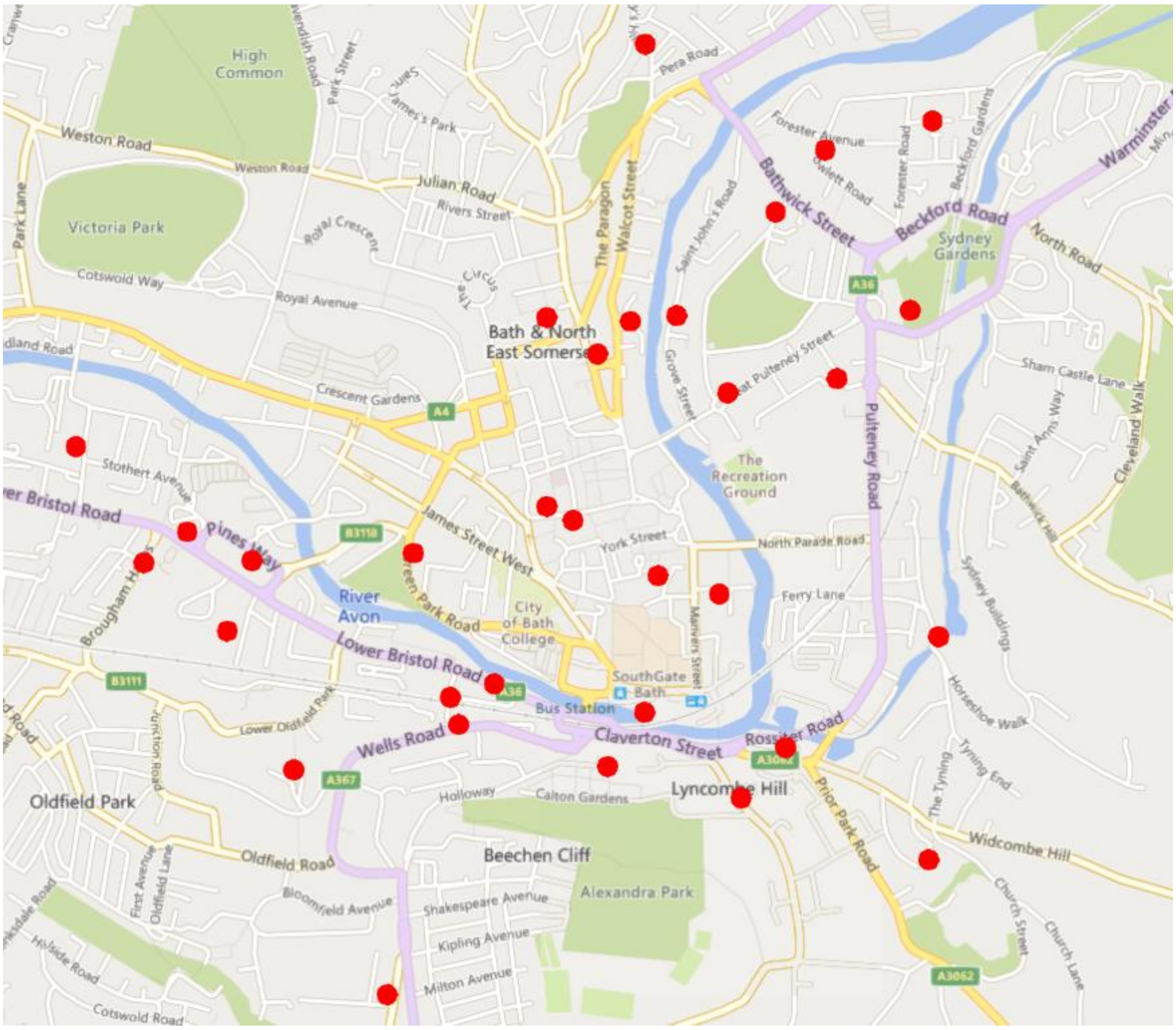


Figure 4-25: Network Investment Visualisation for year 2050 - Run 1 – Dorchester St.

4.9. Key Use-Case Specific Findings

4.9.1. Peak Shift with Managed Charging

There are two different types of profiles used in customer behaviour modeling in HV Network Analysis Tool Specification [4] namely unabated and flexed profiles. The expectation with flexed profiles is that it shall level out the load profile so that peaks in the load profile can at least be minimized if not completely removed. The BU approach based basecase run (run 2) utilises the unabated profile for non-hybrid heat pumps. However, in run 15 flexed profile is used for non-hybrid heat pumps.

It can be seen from Figure 4-26 and Figure 4-27, that the sensitivity of managed charging affects the demand profile by marginally shifting the winter peak demand by few Half Hour (HH) time steps and introduces trough at HH 130 timestep. Also the winter peak demand with managed charging is slightly increased in value as well. In Figure 4-26, the peak of 0.625 MW is observed at HH 138 timestep. While in Figure 4-27, the peak of 0.646 MW is observed at HH 141 timestep. On this basis one can conclude that the managed charging sensitivity affects the demand profile and the peak demand, which therefore affects the upgrade of assets and also the flexibility requirement.

Table 4-3: Runs for Peak Shifting Observation

Run number	Use-case	Sensitivity	TD/BU Approach
2	Basecase	Not applicable	BU
15	Heat Pumps use case	Sensitivity value of managed charging	BU

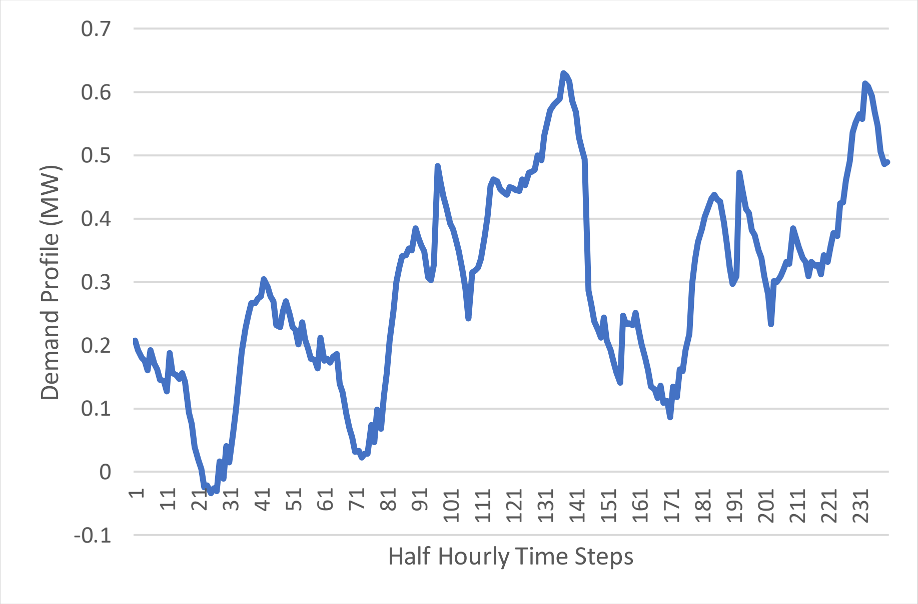


Figure 4-26: Demand profile for Distribution Substation 112150 (Cribbs Causeway primary) - Run 2

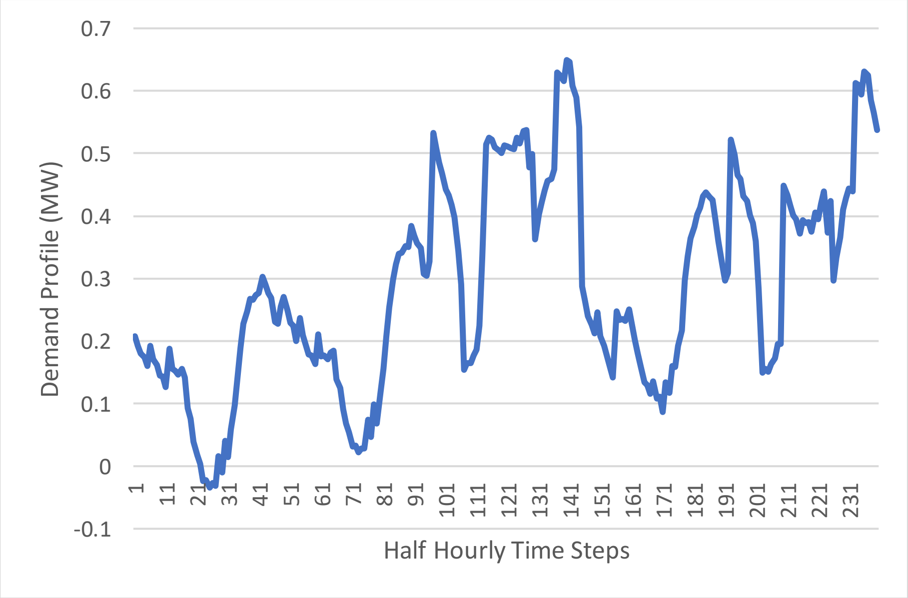


Figure 4-27: Demand profile for distribution Substation 112150 (Cribbs Causeway primary) - Run 15

The above shown change in demand profile reflects in increased CAPEX and OPEX in run 15 as can be seen from below Figure 4-28 and Figure 4-29.

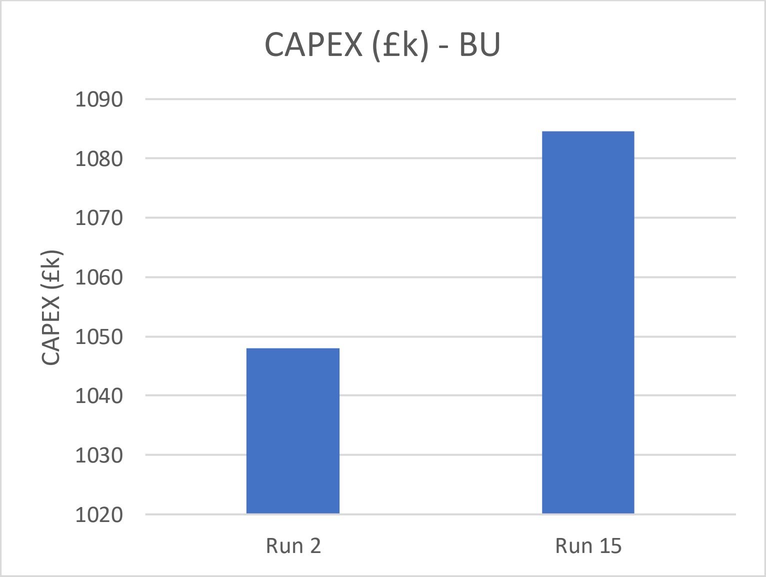


Figure 4-28: CAPEX for Cribbs Causeway Primary – Run 2 and 15 comparison

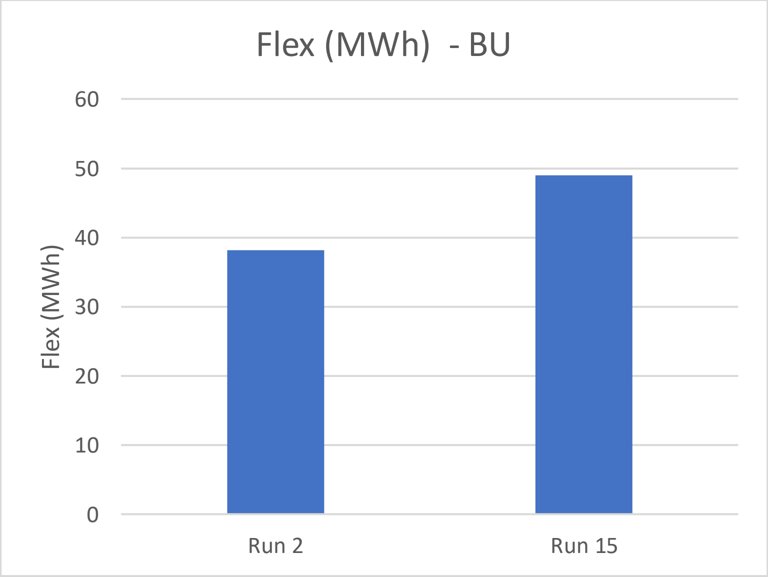


Figure 4-29: OPEX for Cribbs Causeway Primary - Run 2 and 15 comparison

These results are counter intuitive as we would expect the greater use of managed profiles to reduce peak loads and therefore reduce the requirements for reinforcements. The issue appears to lie with the profile for managed heat pump use which is creating alternative peaks rather than smoothing peaks. This in turn reflects that there is little data currently to inform the assumed profiles for managed heat pumps and further data on real installations would be useful to refine and improve the assumed operation.

4.9.2. Energy Efficiency Improvements

This use-case explores the impact of energy efficiency (EE) to reduce network (peak) demand and delay network upgrades. Reduction in the peak electricity demand, from domestic, commercial and industrial properties, resulting due to energy efficiency improvements is considered.

For this use-case, there will be reduction in peak demand applied by varying the degree of energy efficiency from low, medium to high. These different energy efficiency degrees are taken from Regen's document showing expected energy usage reductions at substations [5].

Table 4-4: Runs for Energy Efficiency Improvement Observation

Run number	Use-case	Sensitivity	TD/BU Approach
1	Basecase	Not applicable	TD
11	Energy Efficiency use case	Sensitivity value of medium energy efficiency	TD
28	Energy Efficiency use case	Sensitivity value of high energy efficiency	TD

In order to demonstrate the EE improvement, demand profile for one of the distribution substation (# 112149) is shown in Figure 4-30 wherein slight reduction in demand profile can be seen for varying degree of EE improvements. Figure 4-31 provides a zoomed in view around the winter peak demand where reduction in demand can be clearly seen.

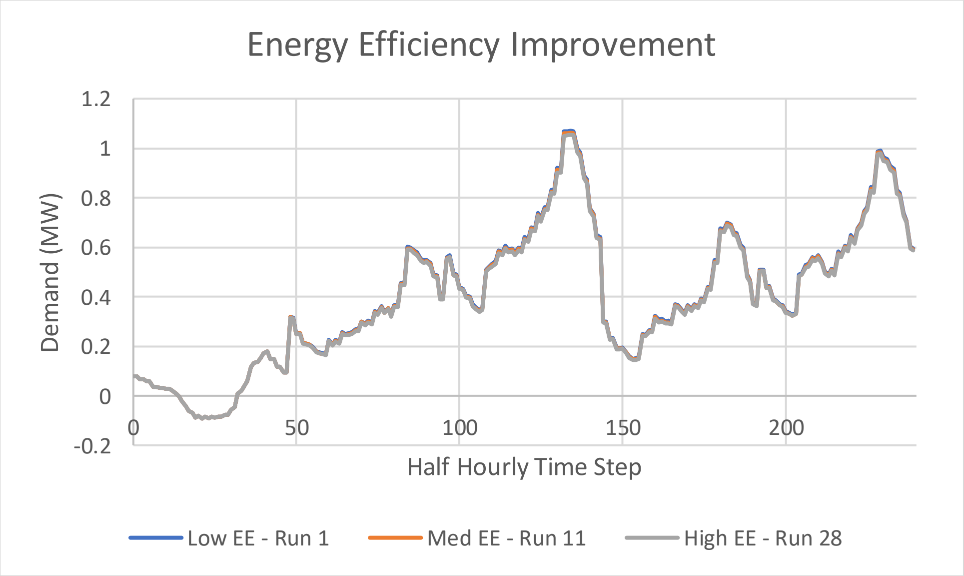


Figure 4-30: Demand profile for distribution Substation 112149 (Cribbs Causeway primary) – EE Improvement

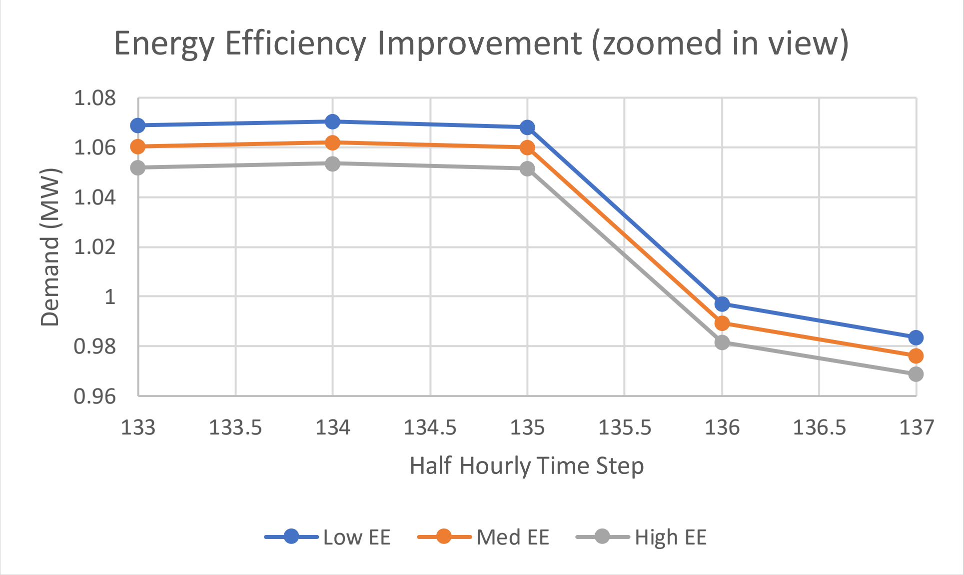


Figure 4-31: Demand profile for distribution Substation 112149 (Cribbs Causeway primary) – EE Improvement (zoomed in view)

The differences between the scenarios are not extreme but can result in different investment requirements if the load at the distribution substation is close to the threshold value.

5. Lessons Learned

5.1. SCADA Data

5.1.1. Missing HV Feeder

In the SCADA data received for some feeders there was no data and zero loading appeared against all HH time stamps. In this situation HV schematics have been referred to cross check if one of the following is applicable to this feeder

- Feeder has just a spare circuit breaker
- Feeder has a short length of cable connected but no actual substations connected to it

In both of the above cases zero loading makes sense.

If an entire HV feeder is missing from the data then following methods of obtaining HH data should be checked.

1. HISTAN file
2. TSDS viewer
3. Datalogger spreadsheet

5.1.2. Bad Quality Primary Transformer Data

Out of the six shortlisted primaries, it is observed that for some primaries like Filton DC, the primary transformer data was of bad quality which led to exclusion of such primaries from HV NAT analysis. As can be seen from Figure 5-1 to Figure 5-4, which shows the load profile for all four primary transformer at Filton DC for year 2018 to 2021, apparently some load switching event has taken place in the year 2019 resulting part of the load transferred to/from Filton DC. This inference is based on the load profile being very different and with no similarity when compared with load profile for the previous year i.e. 2018.

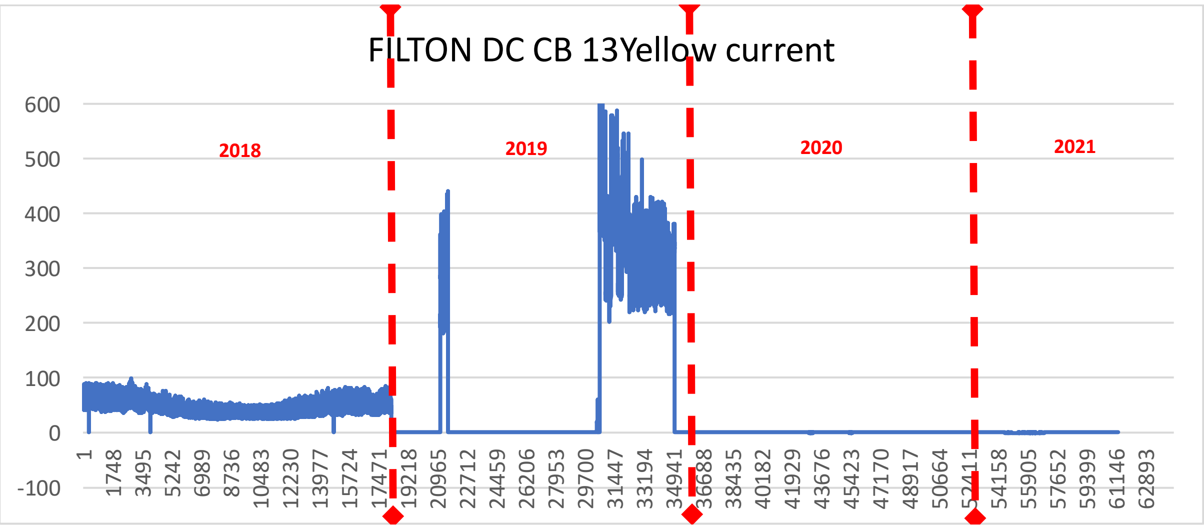


Figure 5-1: Filton DC Feeder Transformer T1 (CB 13) Data

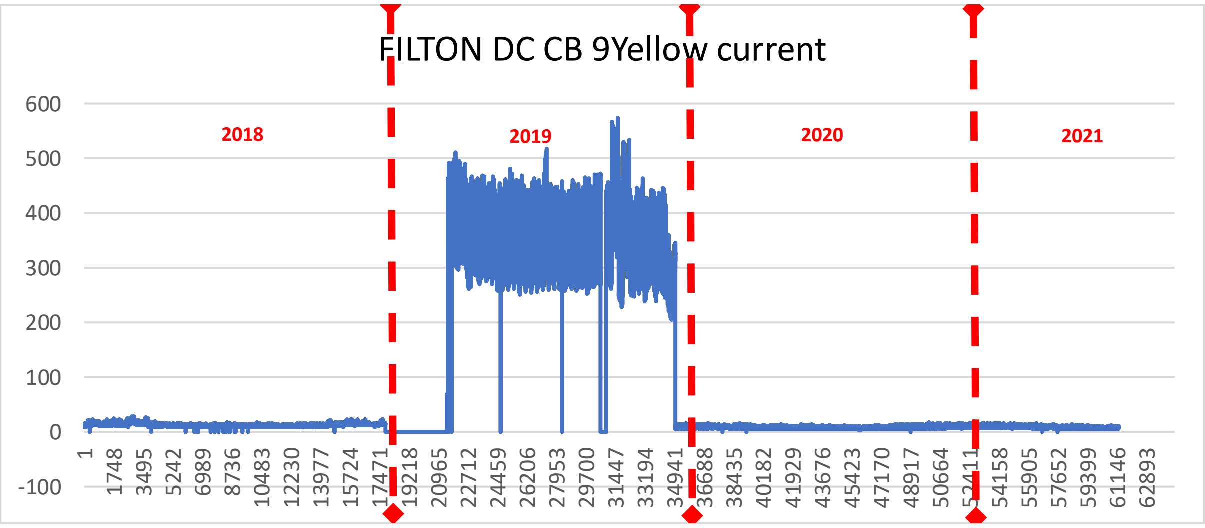


Figure 5-2: Filton DC Feeder Transformer T2 (CB 9) Data

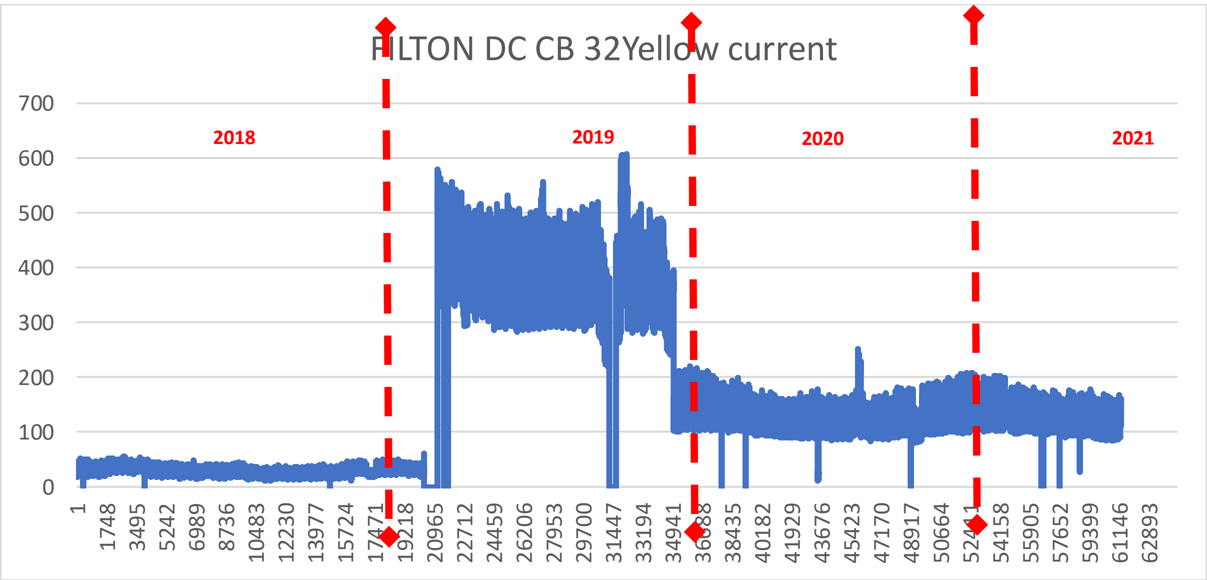


Figure 5-3: Filton DC Feeder Transformer T3 (CB 32) Data

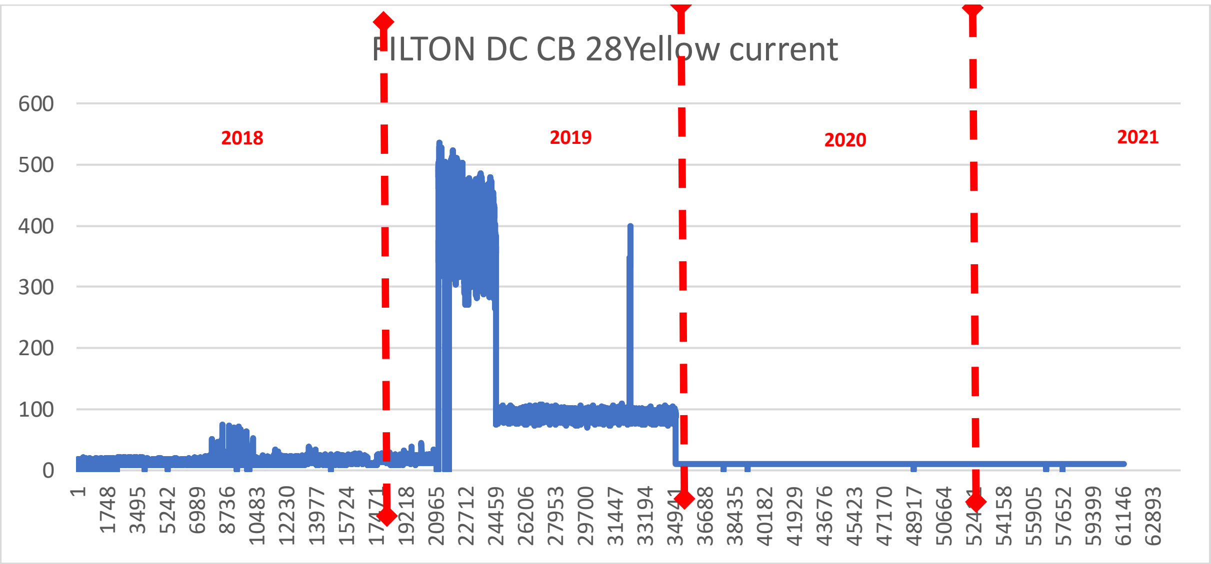
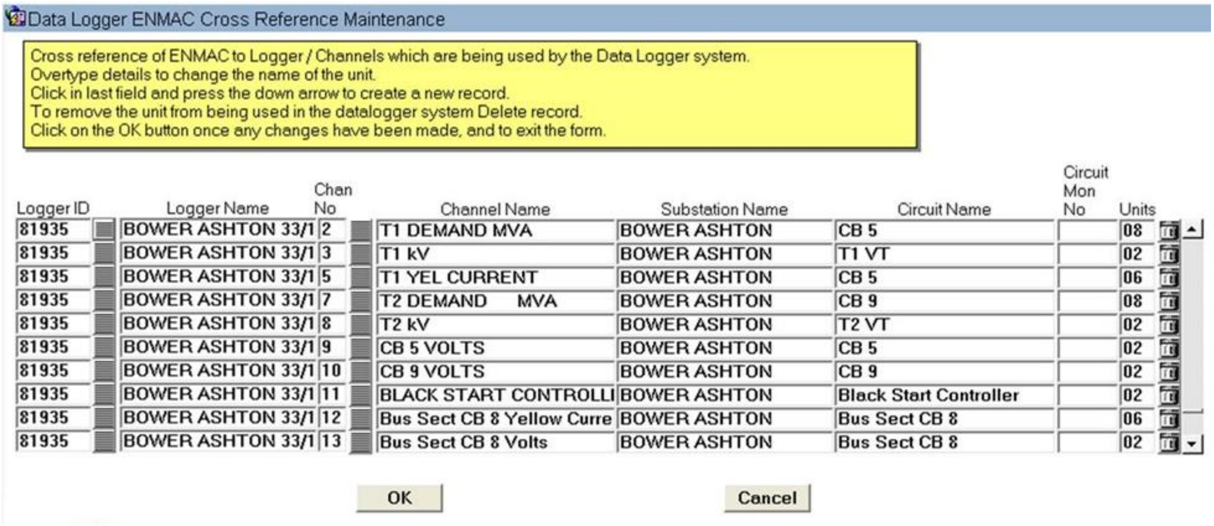


Figure 5-4: Filton DC Feeder Transformer T4 (CB 28) Data

5.1.3. Missing Primary Transformer Data

As part of the data quality assessment of the SCADA measurement for different primaries, issues such as missing data, abnormally high/low values indicating the network may be running abnormally or fault events were identified. During this sanity checking, for Bower Ashton primary, power flow into the primary busbar and power flow out of the primary busbar was compared. It was found that the values were more mismatched than usual and eventually it was found that this was because the circuit breaker references on the schematic diagram from EMU (GIS) do not match the identifiers for the half hourly data as recorded in data logger, which is then reflected in the HISTAN files.

The Data logger, as shown in Figure 5-5, appears to suggest that T1 feeds into the busbar via CB 5, T2 feeds into the busbar via CB 9 and that there is a CB1 which has an associated outgoing feeder and that CB 8 is also associated with an outgoing HV feeder but also a separate line suggests (correctly) it is the bus section.



Cross reference of ENMAC to Logger / Channels which are being used by the Data Logger system.
Overtype details to change the name of the unit.
Click in last field and press the down arrow to create a new record.
To remove the unit from being used in the datalogger system Delete record.
Click on the OK button once any changes have been made, and to exit the form.

Logger ID	Logger Name	Chan No	Channel Name	Substation Name	Circuit Name	Circuit Mon No	Units
81935	BOWER ASHTON 33/1	2	T1 DEMAND MVA	BOWER ASHTON	CB 5		08
81935	BOWER ASHTON 33/1	3	T1 kV	BOWER ASHTON	T1 VT		02
81935	BOWER ASHTON 33/1	5	T1 YEL CURRENT	BOWER ASHTON	CB 5		06
81935	BOWER ASHTON 33/1	7	T2 DEMAND MVA	BOWER ASHTON	CB 9		08
81935	BOWER ASHTON 33/1	8	T2 kV	BOWER ASHTON	T2 VT		02
81935	BOWER ASHTON 33/1	9	CB 5 VOLTS	BOWER ASHTON	CB 5		02
81935	BOWER ASHTON 33/1	10	CB 9 VOLTS	BOWER ASHTON	CB 9		02
81935	BOWER ASHTON 33/1	11	BLACK START CONTROLLI	BOWER ASHTON	Black Start Controller		02
81935	BOWER ASHTON 33/1	12	Bus Sect CB 8 Yellow Curre	BOWER ASHTON	Bus Sect CB 8		06
81935	BOWER ASHTON 33/1	13	Bus Sect CB 8 Volts	BOWER ASHTON	Bus Sect CB 8		02

Figure 5-5: Data Logger for Bower Ashton Primary

Both CROWN and GIS agree in suggesting that T1 feeds into the busbar by CB 6 (not CB 5) that T2 feeds into the busbar via CB 10 (not 9). Also there is no CB 1. This can be seen in the Bower Ashton HV schematic shown in Figure 5-6.

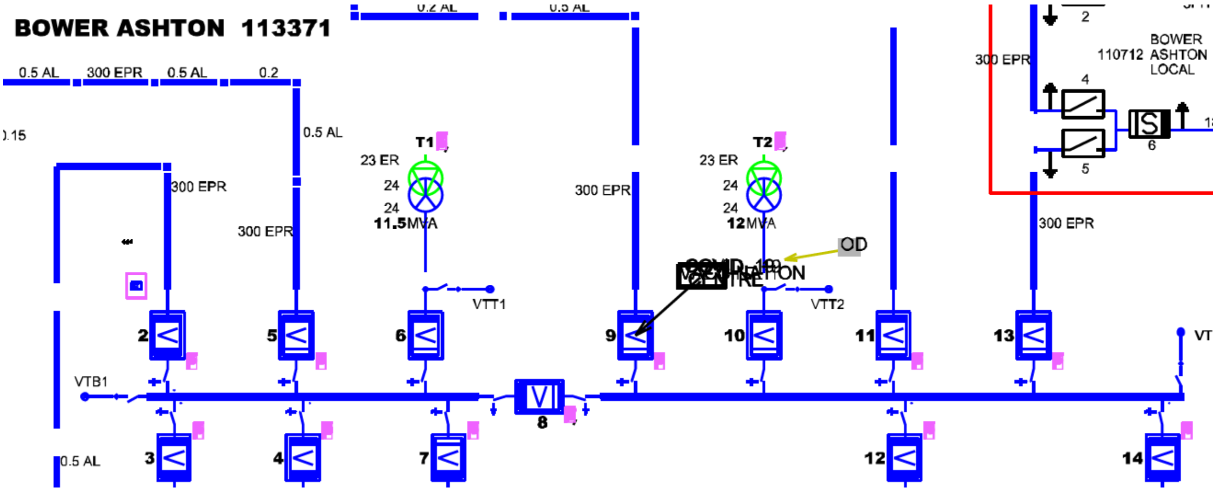


Figure 5-6: Bower Ashton HV Schematic

After some investigation, WPD advised that the circuit re-arrangement has taken place at Bower Ashton resulting into the renumbering of the CB labels .

5.1.4. Primary Baseline Loading and Generation

As part of analysis, the annual energy demand was estimated based on the trapezoidal approximation on the HH power flow data for the primary transformers for the three primaries. Figure 5-7 shows the starting energy demand for the three primaries and it is evident from it that the most heavily loaded primary out of the three is Dorchester St. followed by Nailsea and Cribbs Causeway.

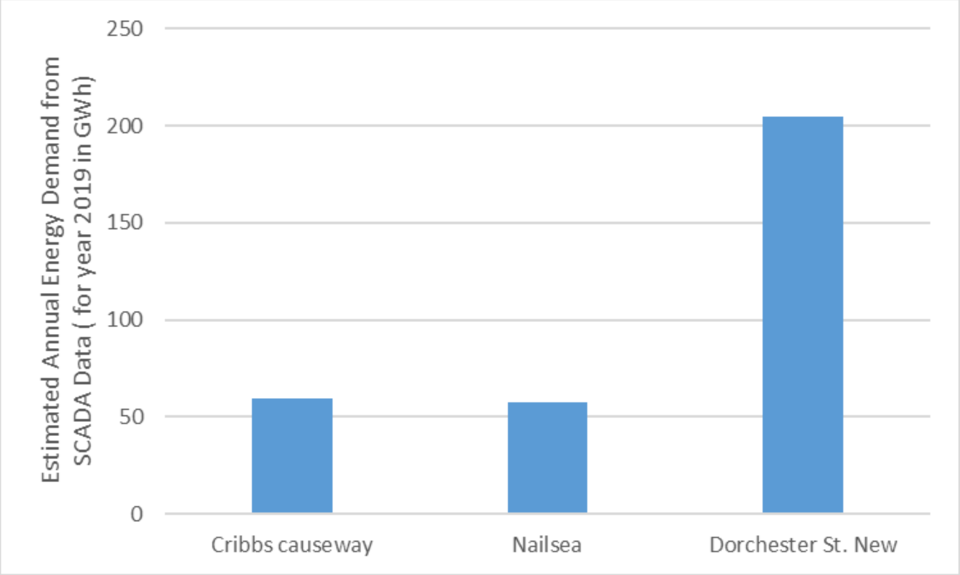


Figure 5-7: Annual Estimated Demand for Primaries

Although Nailsea and Cribbs Causeway appears to be having similar annual energy demand it must be noted that Nailsea primary has significant amount solar PV embedded, as can be seen from data from WPD presented in Table 5-1, in its network which masks the energy demand seen at the primary level due to local generation with in the network. Table 5-2 shows the high level comparative insight into the three primaries in terms of number of primary transformers, feeders, customers, distribution substations etc.

Table 5-1: Existing Generation at Primaries

	Number of units installed	Combined capacity of units in KVA
Cribbs Causeway (113983)	33	1,126
Fossil (Oil) - Engine (Combustion / Reciprocating)	1	800
Micro CHP (Domestic)	1	6
Photovoltaic	30	317
Stored Energy - Storage - Electrochemical Classic Batteries - Lithium Ion (Li-ion)	1	4
Dorchester St (164170)	92	4,681
Micro CHP (Domestic)	2	21
Other Generation	4	3,606
Photovoltaic	86	1,054
Nailsea (181000)	1015	3,568
Other Generation	1	4
Photovoltaic	1010	3,427
Storage (Battery)	3	70
Stored Energy - Storage - Other	1	67
Grand Total	1140	9,374

Table 5-2: High level Primary information

Characteristic	Dorchester St	Nailsea	Cribbs Causeway
Primary Transformers	4 x 12/24 MVA	2 x 12/24 MVA	2 x 12/24 MVA
HV network voltage	6.6kV	11kV	11kV
Number of HV feeders	24	7	7
Number of Distribution Substations	137	169	66
Combined capacity of distribution transformers	76.1MVA	51.0MVA	39.9MVA
Total number of customers	8,984	10,369	1,925
Number of domestic customers (PC 1 & 2)	6,496	9,562	1,478
EV charge points registered	14	73	2
HPs	1	6	0
Energy Storage	0	4	0

5.2. DFES Data

5.2.1. Solar Generation

There is high allocation of the solar generation for Nailsea primary which leads to significant reverse power flow in the summer maximum generation representative day. Figure 5-8 shows the demand for one of the distribution substation (180641) at ten yearly intervals for five representative days. The first representative day (HH time step of 1 to 48) is the summer maximum generation case . The records in CROWN suggest this particular substation has around 135 domestic customers. LV DFES numbers, as shown in Figure 5-9, indicate that 117 out of 135 properties were allocated domestic rooftop installations for the year 2050. This does not seem realistic due to the constraints on orientation and building type. While there are sense checks that are applied at the primary substation level these may not work where the data has been disaggregated.

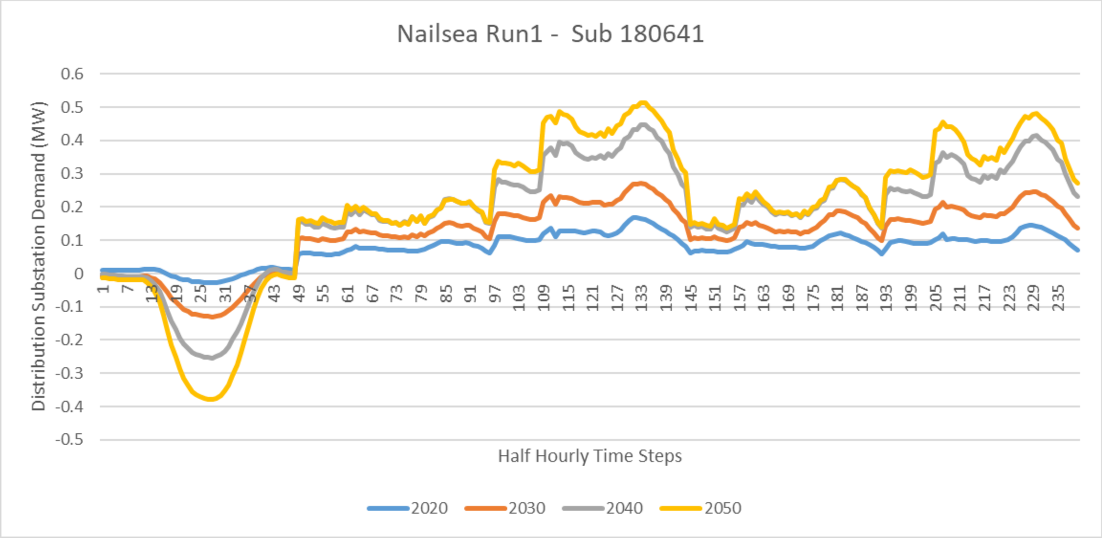
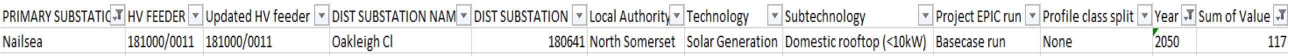


Figure 5-8: Significant Generation in Summer Maximum Generation Representative Day



PRIMARY SUBSTATIC	HV FEEDER	Updated HV feeder	DIST SUBSTATION NAM	DIST SUBSTATION	Local Authority	Technology	Subtechnology	Project EPIC run	Profile class split	Year	Sum of Value
Nailsea	181000/0011	181000/0011	Oakleigh Cl	180641	North Somerset	Solar Generation	Domestic rooftop (<10kW)	Basecase run	None	2050	117

Figure 5-9: High Volume of Domestic Rooftop Installation for Distribution Substation (180641) in Nailsea Primary [6]

5.2.2. EV Volume Reduction in 2050

For the Nailsea and Dorchester St primary, the contribution to the demand by EVs reduces in year 2050 when compared to the contribution for year 2040 as can be seen in Figure 5-10. For the year 2050 there is a reduced volume of EVs as can be seen from the below figure. This is on the basis of the assumption that there will be more utilisation of the public transport and hence less usage of EVs.

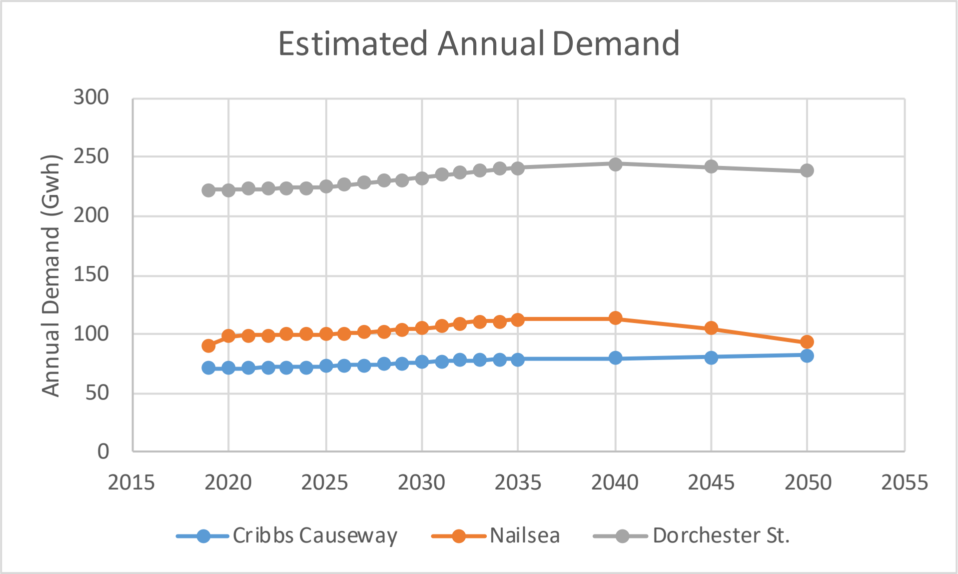
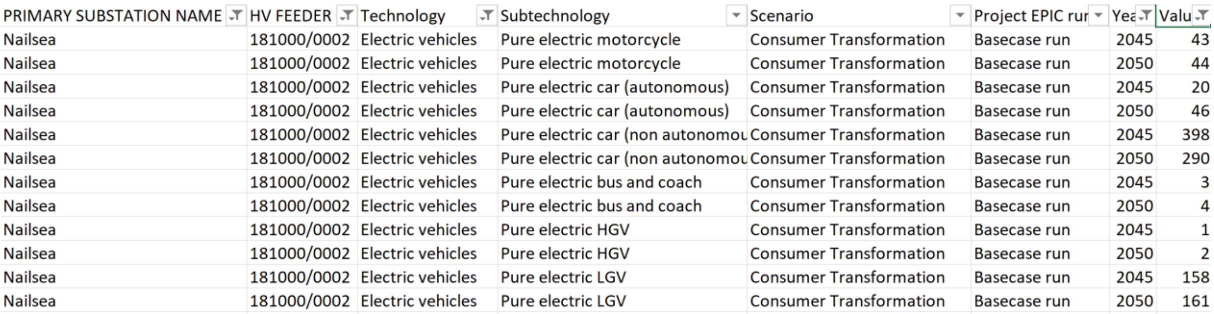
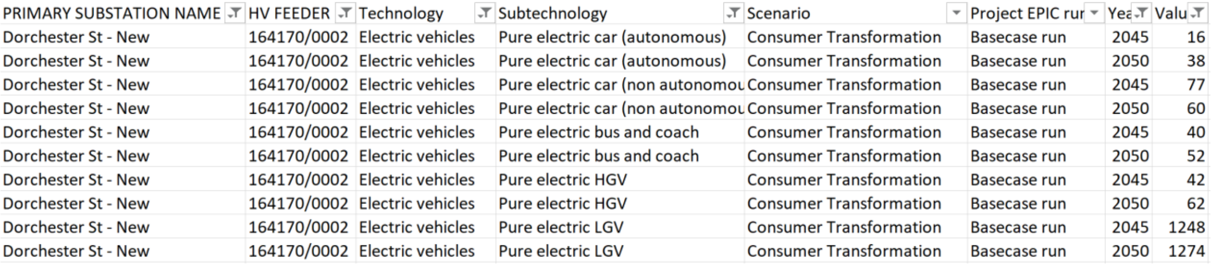


Figure 5-10: Reduction in Estimated Annual Demand for Nailsea and Dorchester St. in 2050 – Base case run



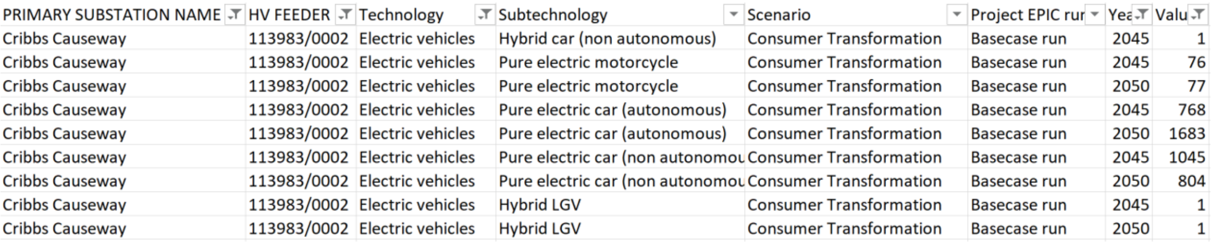
PRIMARY SUBSTATION NAME	HV FEEDER	Technology	Subtechnology	Scenario	Project EPIC rur	Yea	Valu
Nailsea	181000/0002	Electric vehicles	Pure electric motorcycle	Consumer Transformation	Basecase run	2045	43
Nailsea	181000/0002	Electric vehicles	Pure electric motorcycle	Consumer Transformation	Basecase run	2050	44
Nailsea	181000/0002	Electric vehicles	Pure electric car (autonomous)	Consumer Transformation	Basecase run	2045	20
Nailsea	181000/0002	Electric vehicles	Pure electric car (autonomous)	Consumer Transformation	Basecase run	2050	46
Nailsea	181000/0002	Electric vehicles	Pure electric car (non autonomou	Consumer Transformation	Basecase run	2045	398
Nailsea	181000/0002	Electric vehicles	Pure electric car (non autonomou	Consumer Transformation	Basecase run	2050	290
Nailsea	181000/0002	Electric vehicles	Pure electric bus and coach	Consumer Transformation	Basecase run	2045	3
Nailsea	181000/0002	Electric vehicles	Pure electric bus and coach	Consumer Transformation	Basecase run	2050	4
Nailsea	181000/0002	Electric vehicles	Pure electric HGV	Consumer Transformation	Basecase run	2045	1
Nailsea	181000/0002	Electric vehicles	Pure electric HGV	Consumer Transformation	Basecase run	2050	2
Nailsea	181000/0002	Electric vehicles	Pure electric LGV	Consumer Transformation	Basecase run	2045	158
Nailsea	181000/0002	Electric vehicles	Pure electric LGV	Consumer Transformation	Basecase run	2050	161

Figure 5-11: EV Volume disaggregated to HV Feeder (181000/0002) - Nailsea Primary



PRIMARY SUBSTATION NAME	HV FEEDER	Technology	Subtechnology	Scenario	Project EPIC rur	Yea	Valu
Dorchester St - New	164170/0002	Electric vehicles	Pure electric car (autonomous)	Consumer Transformation	Basecase run	2045	16
Dorchester St - New	164170/0002	Electric vehicles	Pure electric car (autonomous)	Consumer Transformation	Basecase run	2050	38
Dorchester St - New	164170/0002	Electric vehicles	Pure electric car (non autonomou	Consumer Transformation	Basecase run	2045	77
Dorchester St - New	164170/0002	Electric vehicles	Pure electric car (non autonomou	Consumer Transformation	Basecase run	2050	60
Dorchester St - New	164170/0002	Electric vehicles	Pure electric bus and coach	Consumer Transformation	Basecase run	2045	40
Dorchester St - New	164170/0002	Electric vehicles	Pure electric bus and coach	Consumer Transformation	Basecase run	2050	52
Dorchester St - New	164170/0002	Electric vehicles	Pure electric HGV	Consumer Transformation	Basecase run	2045	42
Dorchester St - New	164170/0002	Electric vehicles	Pure electric HGV	Consumer Transformation	Basecase run	2050	62
Dorchester St - New	164170/0002	Electric vehicles	Pure electric LGV	Consumer Transformation	Basecase run	2045	1248
Dorchester St - New	164170/0002	Electric vehicles	Pure electric LGV	Consumer Transformation	Basecase run	2050	1274

Figure 5-12: EV Volume disaggregated to HV Feeder (113983/0002) – Dorchester St. Primary



PRIMARY SUBSTATION NAME	HV FEEDER	Technology	Subtechnology	Scenario	Project EPIC rur	Yea	Valu
Cribbs Causeway	113983/0002	Electric vehicles	Hybrid car (non autonomous)	Consumer Transformation	Basecase run	2045	1
Cribbs Causeway	113983/0002	Electric vehicles	Pure electric motorcycle	Consumer Transformation	Basecase run	2045	76
Cribbs Causeway	113983/0002	Electric vehicles	Pure electric motorcycle	Consumer Transformation	Basecase run	2050	77
Cribbs Causeway	113983/0002	Electric vehicles	Pure electric car (autonomous)	Consumer Transformation	Basecase run	2045	768
Cribbs Causeway	113983/0002	Electric vehicles	Pure electric car (autonomous)	Consumer Transformation	Basecase run	2050	1683
Cribbs Causeway	113983/0002	Electric vehicles	Pure electric car (non autonomou	Consumer Transformation	Basecase run	2045	1045
Cribbs Causeway	113983/0002	Electric vehicles	Pure electric car (non autonomou	Consumer Transformation	Basecase run	2050	804
Cribbs Causeway	113983/0002	Electric vehicles	Hybrid LGV	Consumer Transformation	Basecase run	2045	1
Cribbs Causeway	113983/0002	Electric vehicles	Hybrid LGV	Consumer Transformation	Basecase run	2050	1

Figure 5-13: EV Volume disaggregated to HV Feeder (113983/0002) – Cribbs Causeway Primary

5.2.3. Extra distribution substations in DFES Data

LV DFES data has certain distribution s/s for each primary. Some of the substation in this DFES data does not appear in the SINCAL model and also not in the distribution s/s to primary mapping spreadsheet, and due to their absence in this spreadsheet there is no load disaggregation that goes onto these subs. This is caused by the data for the NIFT modelling being extracted many months ago in order to support modelling work for the upcoming ED2 price control business plan and the degree of work associated with refreshing this data to be in line with the more recent extracts for the HV NAT is prohibitive. The development of the HV and LV Integrated Network Models should result in frequent publications of network data being available and reducing the effort required to extract and cleanse data will make it easier to refresh datasets in the future.

5.3. SINCAL Modelling

5.3.1. Associating Line Segments to Feeder for Feeder Split

It was intended to carry out the feeder split in the network in the event of voltage limits violation and unavailability of higher upgrade options to satisfy equipment loading. However, in the network model provided by WPD a HV feeder has got several segments comprising of cable and/or OHL. Earlier in the project, the understanding was that it is not possible to associate the individual segments to a particular HV feeder. Therefore, a typical value of cost (£648k), advised by WPD, associated with feeder split has been utilised considering a certain length of new cable lay back to the primary and a new circuit breaker at the primary. The ongoing work to enable the Integrated Network Model to be the source of data for network modelling should result in this data being available in the future.

5.3.2. CI/CML Figures

It was intended to include CI/CML figures as one of the HV NAT output, however, as PSS SINCAL doesn't provide CI/CML figures from any of the standard functions in the software, and therefore these figures have been dropped from the list of outputs from HV NAT.

5.3.3. Upgrading of 6.6 kV Cables to 11 kV Cables

Upgrading of 6.6 kV cables to 11 kV cables was intended to be captured in HV NAT, however, it has been decided not to consider this upgradation programmatically but to consider it as one off. Hence it is not considered in HV NAT.

5.3.4. OPEX Costs for Modelled Reinforcement

OPEX costs associated with modelled reinforcement are not considered as part of the HV NAT due to the challenges in correctly identifying these in an automated fashion to impact the overall investment decision.

5.3.5. Runtime for Project EPIC Runs

High HV NAT processing run times are due to the large number of elements (Overhead lines, cables, transformers) in the HV network model provided by WPD. HV NAT has to interface with SINCAL for these elements during the processing many times.

From the initial runs carried out for Cribbs Causeway primary, it has been observed that significant reduction in simulation runtime can be achieved, by working on 120HH time steps rather than 240HH time steps, without affecting outputs from HV NAT much. Reduction in runtime for runs far outweighs the overall negligible output accuracy reduction by adopting to lower HH time step resolution. The default resolution in the HV NAT will be 240HH time steps in a year but user can switch to 120HH time steps in order to reduce the total processing time.

Also calculating Capacity Health Index (CHI) in the same power flow analysis routine, in which NI and FS calculations were carried out, saved time rather than carrying out the same powerflow multiple times.

5.3.6. Other Key Learning

- The SINCAL model generates dummy transformers of 100kVA capacity at the locations of HV connected customers. These would have been likely to create investment upgrades on non-existent transformers. This would have introduced an impedance which is not correct for network modelling. For transformer at all the HV sites, 2 MVA transformer has been assumed so that reasonable disaggregated load can be attributed the HV sites.
- The SINCAL model contains cables with no thermal rating information as this has been sourced from the GIS data. Using a value of 99 Amps allowed us to prevent HV NAT from over-reporting the required investment upgrades.
- Originally it was planned to calculate the diversity factor between HV feeders and the primary transformer because the way in which the primary transformer replacement is calculated is to assume overload if the total profiles exceed 50% of rating but this is a bit pessimistic as not all HV feeders experience their most onerous conditions concurrently. This could be adjusted for by altering the point at which assets are considered overloaded.
- In the distribution substation to primary mapping data there are certain distribution substations which appear twice in it but with different distribution transformer rating at the same site. This duplication was removed to ensure HV NAT reads the correct value of transformer rating at the concerned site. The HV connected sites had no transformer rating data with all of them reading zero. Therefore, transformers for HV connected sites was assumed to be 2MVA so that they get disaggregated load in the top down approach.
- The LV DFES data has got profile class (PC) information only for non hybrid heat pumps i.e. a distribution substation had heat pumps allocated for PC1 and PC2. This profile class split information is used by EA Technology. As PC information is not needed in HV NAT this PC split was seen by HV NAT as duplication of HP volume allocation and only PC2 volume was getting picked up in the analysis thereby underestimating the demand due to HPs. In order to account for the demand associated with missing PC non hybrid heat pumps, HV NAT was amended to pick up volume of the both the PC.
- In order to account for HV DFES for BU approach three dummy sites with assumed 2 MVA transformer rating, to enable load disaggregation, are artificially introduced in the model for each HV feeder to account for impact of HV DFES. Location (latitude & longitude) for the dummy HV sites is advised by WPD. In TD approach HV DFES also gets disaggregated to the distribution substation level whereas for the BU approach HV DFES gets disaggregated to three HV dummy sites on a HV feeder. Due to the difference between the TD and BU approach of how the HV DFES is dealt with, it is expected that BU approach would lead to less distribution transformers replacement over the period of analysis, for all three primaries.

5.4. *Flexible Services Cost*

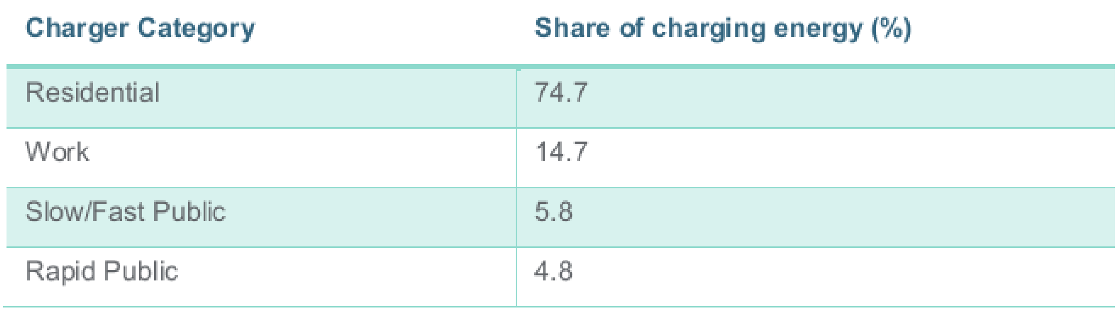
It was intended to work out the FS cost on an annual basis by extrapolating the FS cost from five representative days to an annual estimated figure. However, considering the challenges and complexities in this approach an assumption has been made that we would only use flex services on HV networks to support the Restore service and therefore modelling a year's worth of data is not required, but modelling the peak days gives us indicative values of the service capacity requirements, including the worst case. With this analysis insights will be obtained about potential flexibility requirements to inform future policy developments.

5.5. *EV Demand Apportioning*

There are two methods for profiling the impact of electric vehicles on the network. These methods, as per DFES Customer Behaviour Assumptions Report [4], are based on the following two profiles:

- EV Profile
- Charger Profile

Due to certain limitations in assessing EV and chargers independently, it was decided to consider a model that accounts for scenario and year dependent energy requirement and the chargers that are available to deliver this energy. The Element Energy project work detailed in [4] grouped all chargers into four categories to determine each representative day energy requirement, the total vehicle stock energy is apportioned to each charger type as shown in Table 4-1 :



Charger Category	Share of charging energy (%)
Residential	74.7
Work	14.7
Slow/Fast Public	5.8
Rapid Public	4.8

Figure 5-14: Share of Charging Demand across Charger Categories [4]

Representative day profiles for residential, work and Slow/Fast public EV charge point were utilised from DFES Customer Behaviour Assumptions Report [4] to determine demand associated with different EV charge points for each year. The approach is to calculate annual charging demand using the number of vehicles (from DFES data) and annual demand per vehicle for different vehicle types from [4].

To obtain an hourly profile for each charge category for all representative days the equation below has been used to apportion the energy across each charger category.

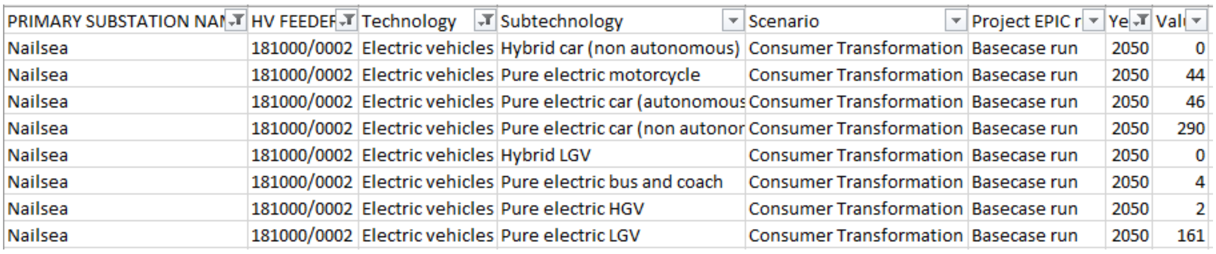
$$Charger\ profile\ (units\ of\ kW\ per\ charger) = \frac{Normalised\ profile\ \left(\frac{kW}{kWh}\right) * share\ of\ charging\ demand(\%) * Total\ EV\ energy(kWh)}{Number\ of\ chargers\ connected}$$

The Element Energy work grouped all chargers into one of four categories as shown in Table 4-2:

Table 5-3:Mapping of WPD EV charge point subtechnologies to corresponding Element Energy categorisations [4]

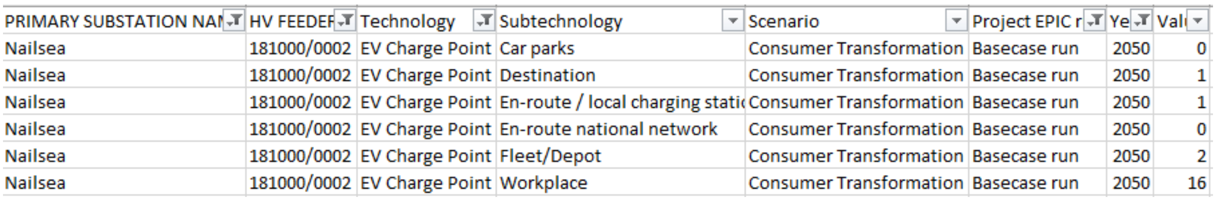
Charger Grouping	WPD Charger Sub-technology	Type of Profile (unabated/flexed)
Residential	Domestic off-street	Residential (unabated) - Figure 43 Residential managed charging (flexed) - Figure 44
	Domestic on-street	
Work	Fleet/Depot	Work (unabated) - Figure 45
	Workplace	
Slow/Fast Public	En-route / local charging stations	Slow/Fast (unabated) - Figure 46
	Car parks	
	Destination	
Rapid Public	En-route national network	*

The DFES numbers from Regen provided the volumes of EVs and different sub-technology chargepoints (Domestic off-street, Fleet/Depot, Car parks etc.) disaggregated down to HV feeders and distribution substations [7] [6]. Figure 5-15 and Figure 5-16 shows the volume of EVs and charge points disaggregated down to HV feeder level (HV Feeder – 181000/0002).



PRIMARY SUBSTATION NAI	HV FEEDEF	Technology	Subtechnology	Scenario	Project EPIC r	Ye	Val
Nailsea	181000/0002	Electric vehicles	Hybrid car (non autonomous)	Consumer Transformation	Basecase run	2050	0
Nailsea	181000/0002	Electric vehicles	Pure electric motorcycle	Consumer Transformation	Basecase run	2050	44
Nailsea	181000/0002	Electric vehicles	Pure electric car (autonomous	Consumer Transformation	Basecase run	2050	46
Nailsea	181000/0002	Electric vehicles	Pure electric car (non autonor	Consumer Transformation	Basecase run	2050	290
Nailsea	181000/0002	Electric vehicles	Hybrid LGV	Consumer Transformation	Basecase run	2050	0
Nailsea	181000/0002	Electric vehicles	Pure electric bus and coach	Consumer Transformation	Basecase run	2050	4
Nailsea	181000/0002	Electric vehicles	Pure electric HGV	Consumer Transformation	Basecase run	2050	2
Nailsea	181000/0002	Electric vehicles	Pure electric LGV	Consumer Transformation	Basecase run	2050	161

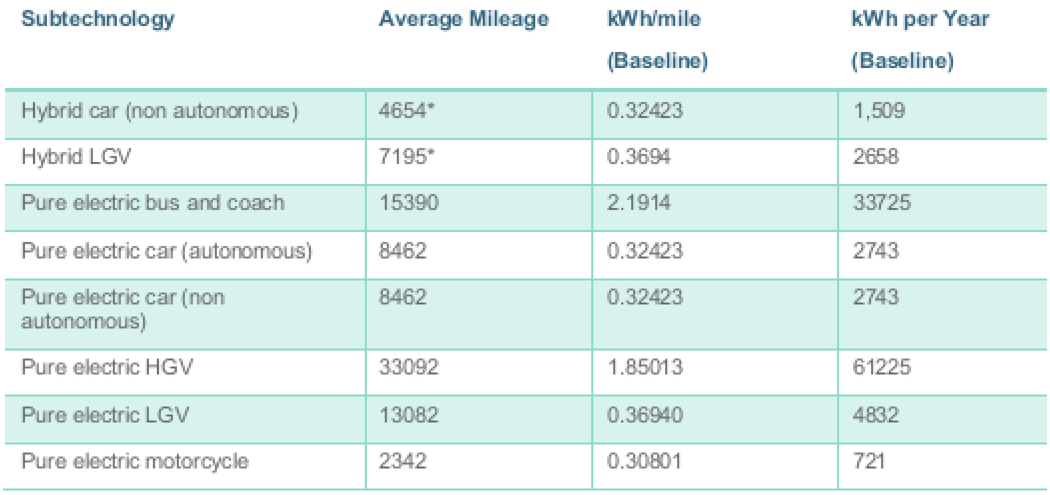
Figure 5-15: DFES Data Showing Nailsea Primary EV volume (disaggregated to HV feeder 181000/0002) for year 2050 [7]



PRIMARY SUBSTATION NAI	HV FEEDEF	Technology	Subtechnology	Scenario	Project EPIC r	Ye	Val
Nailsea	181000/0002	EV Charge Point	Car parks	Consumer Transformation	Basecase run	2050	0
Nailsea	181000/0002	EV Charge Point	Destination	Consumer Transformation	Basecase run	2050	1
Nailsea	181000/0002	EV Charge Point	En-route / local charging stati	Consumer Transformation	Basecase run	2050	1
Nailsea	181000/0002	EV Charge Point	En-route national network	Consumer Transformation	Basecase run	2050	0
Nailsea	181000/0002	EV Charge Point	Fleet/Depot	Consumer Transformation	Basecase run	2050	2
Nailsea	181000/0002	EV Charge Point	Workplace	Consumer Transformation	Basecase run	2050	16

Figure 5-16: DFES Data Showing Nailsea Primary EV Charge Point volume (disaggregated to HV feeder 181000/0002) for year 2050 [7]

Firstly, total EV energy is worked out utilising the annual energy consumption values from [4] which are as shown in Figure 5-17. EV volume is from Figure 5-15 and the per vehicle annual consumption is from Figure 5-17. However, as the charger profile is to be obtained for total number of charge points in a particular charger grouping (residential, work, Slow/Fast public, Rapid Public), therefore the number of charge points variation does not alter the EV demand apportioning. For example, for "work" charger grouping, "Fleet/Depot" and "Workplace" sub-technology is counted together.

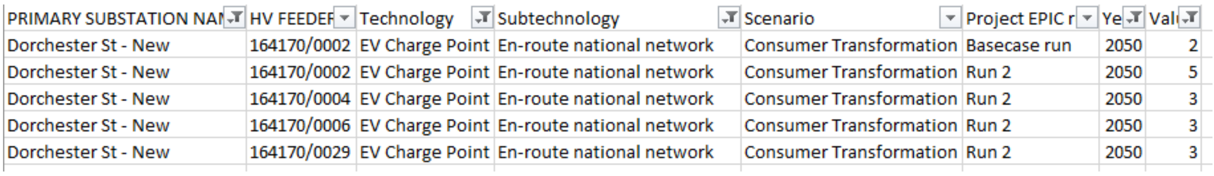


Subtechnology	Average Mileage	kWh/mile (Baseline)	kWh per Year (Baseline)
Hybrid car (non autonomous)	4654*	0.32423	1,509
Hybrid LGV	7195*	0.3694	2658
Pure electric bus and coach	15390	2.1914	33725
Pure electric car (autonomous)	8462	0.32423	2743
Pure electric car (non autonomous)	8462	0.32423	2743
Pure electric HGV	33092	1.85013	61225
Pure electric LGV	13082	0.36940	4832
Pure electric motorcycle	2342	0.30801	721

Figure 5-17: Baseline Energy Assumptions per vehicle category [4]

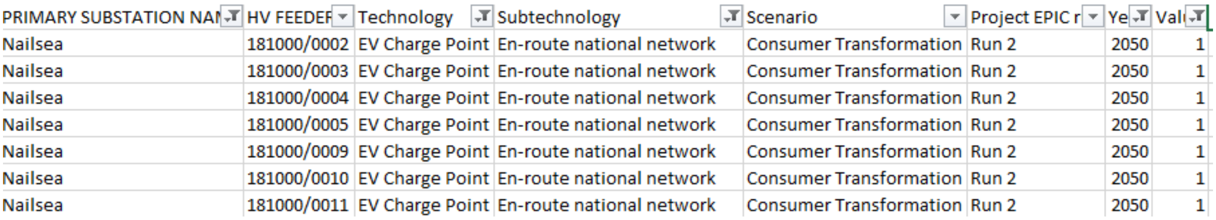
For the "Rapid Public" charger category (or "En-route national network" charger subtechnology) the profile is modelled at a constant 350 kW for all demand representative days. Due to this reason the variation in number of "En-route national network" charge points the EV demand gets impacted whereas for other three charger grouping (residential, work, Slow/Fast public) EV demand apportioning is not affected by variation in charge point volume.

This subtechnology appears in DFES numbers for Nailsea and Dorchester St. but not for Cribbs Causeway i.e. zero for Cribbs Causeway. More volume of this subtechnology appears for Dorchester St than volume for Nailsea as can be seen from Figure 5-18 and Figure 5-19



PRIMARY SUBSTATION NAI	HV FEEDEF	Technology	Subtechnology	Scenario	Project EPIC r	Ye	Val
Dorchester St - New	164170/0002	EV Charge Point	En-route national network	Consumer Transformation	Basecase run	2050	2
Dorchester St - New	164170/0002	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	5
Dorchester St - New	164170/0004	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	3
Dorchester St - New	164170/0006	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	3
Dorchester St - New	164170/0029	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	3

Figure 5-18: EV Charge Point volume (for En-route national network) Subtechnology for Dorchester St Primary [7]



PRIMARY SUBSTATION NAI	HV FEEDEF	Technology	Subtechnology	Scenario	Project EPIC r	Ye	Val
Nailsea	181000/0002	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1
Nailsea	181000/0003	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1
Nailsea	181000/0004	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1
Nailsea	181000/0005	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1
Nailsea	181000/0009	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1
Nailsea	181000/0010	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1
Nailsea	181000/0011	EV Charge Point	En-route national network	Consumer Transformation	Run 2	2050	1

Figure 5-19: EV Charge Point volume (for En-route national network) Subtechnology for Nailsea Primary [7]

It is observed from above that the above approach for EV demand apportioning would not work for assessment at the primary level. In this case working with typical capacity of different EV chargepoints and their corresponding demand profile (without any link to number of EVs) could be used as the objective is to observe the difference in network investment due to variation in volume of EV charge points.

The customer behaviour document [4] that includes the approach to modelling all the types of LCT reflects the best available profiles but is looking to improve these as more data becomes available from innovation projects, pilot programmes and other data on customer usage. There should be a thorough review of the available data and process used as part of the next iteration of the customer behaviours document to ensure that the profiles and assumptions used for EV charging continue to improve over time.

6. Conclusion

Following are key observations from the analysis carried out in HV NAT for three primaries and learning captured while developing HV NAT specification and the tool itself

- The investment level is observed to be highest in Dorchester St. followed by Nailsea and Cribbs Causeway. Dorchester St. being the 6.6 kV system experiences more frequent upgrades, as the 6.6 kV and 11 kV lines would have same rating, and more feeder split (second biggest CAPEX driver after primary transformer replacement) out of all three primaries assessed as described in section 4.7
- For every transformer upgrade in the Dorchester St. there is more investment in cable replacement when compared to Nailsea and Cribbs Causeway as described in section 4.2.
- Dorchester St. has the highest proportion of transformers replaced by 2050 followed by Cribbs Causeway and Nailsea
- Number of representative days in this kind of analysis, with study time horizon upto 2050, can be reduced from five to three. The “Int_Warm” and “Summer MinGeneration” representative day as shown in section 4.6 captured the least level of investment and hence dropping this representative day from the analysis would not result in losing any significant finding. It would in fact lead to lesser computational effort as the number of HH time steps reduces by a one fourth of the processing time.
- Reduction in runtime for runs, by halving the HH timestep from 240 to 120 as described in section 5.3.5, far outweighs the overall negligible output accuracy reduction by adopting lower HH time step resolution in the analysis. Sensitivity of managed charging affects the demand profile, as shown in section 4.9.1, by marginally shifting the winter peak demand by few HH time steps and introduces another downward peak at HH 130 timestep.
- Approach for EV demand apportioning in [4] would require a change to make it work at the primary level. In this case working with typical capacity of different EV chargepoints and their corresponding demand profile (without any link to number of EVs) could be used as the objective is to observe the difference in network investment due to variation in volume of EV charge points.
- Dorchester St. primary, being a 6.6kV level network, would have higher current loading and lesser capacity headroom available for the equipment to begin with. Therefore, with building block changes over the period of analysis there will be more frequent upgrades resulting in more feeder split cases.
- There is high allocation of the solar PV generation for Nailsea primary in [6], indicating that 117 out of 135 properties were allocated domestic rooftop installations for the year 2050. This does not seem realistic due to the constraints on orientation and building type. While there are sense checks that are applied at the primary substation level these may not work where the data has been disaggregated to distribution substation.
- It is recommended to have the start of load flow analysis with the “Winter” representative day followed by the ‘summer max generation’ representative day followed by all other representative days.
- Both TD and BU approach results, as shown in section 4.4, suggests upgrading the primary transformers at Nailsea to the largest size required over the period to 2050 when the first upgrade is required.
- Fit for Future approach as opposed to JIT results in generally large savings in CAPEX/OPEX savings, for all primaries, due to the higher proportion of network assets replaced more than once by 2050 as seen in section 4.5.

- Counter-intuitive results are observed with greater use of managed profiles for heat pump as instead of smoothing peaks, creation of alternative peaks and load peak shifting is observed. This suggests further data on real installations would be useful to refine and improve the assumed managed charging profile.
- More number of hybrid heat pumps compared to non-hybrid heat pumps results in both CAPEX/OPEX saving which is expected because for non-hybrid heat pumps all energy is provided by electricity network.
- With energy efficiency improvements reduction in CAPEX is observed but with no significant difference in demand profile. However, based on existing distribution substation loading with respect to threshold value for upgrade may result different investment requirements.

7. References

[1] PSC, “JK9398-1-2 EPIC HV Network Analysis Tool Specification,” 2021.

[2] Regen, “EPIC Trial Planning Process,” 2021.

[3] Regen, “Local Energy Plan Addendum 1: Primary Selection for Network Analysis and Additional Use-Cases,” 2021.

[4] Western Power Distribution, “Distribution Future Energy Scenarios 2020: Customer behaviour profiles and assumptions report,” Western Power Distribution, Bristol, UK, 2021.

[5] Regen, “WP5 D1 - Project EPIC_Energy consumption statistics over time_v2,” 2021.

[6] Regen, “WP5 D1 - Project EPIC_LV input data disagg_v6,” 2021.

[7] Regen, “WP5 D1 - Project EPIC_HV input data disagg_v2,” 2021.

Appendix A Description of Runs

Run number	Baseline / use case	Use case scenario	Sensitivity variant	top down/ bottom up
1	Baseline	n/a	Default balance of managed and unmanaged charging	TD
2	Baseline	n/a	Default balance of managed and unmanaged charging	BU
3	Use Case 1 - EV	High on street charging	Default balance of managed and unmanaged charging	TD
4	Use Case 1 - EV	High on street charging	Default balance of managed and unmanaged charging	BU
5	Use Case 1 - EV	Low on street charging	Default balance of managed and unmanaged charging	TD
6	Use Case 1 - EV	Low on street charging	Default balance of managed and unmanaged charging	BU
7	Use Case 1 - EV	High on street charging	Sensitivity value of managed charging	BU
8	Use Case 1 - EV	Low on street charging	Sensitivity value of managed charging	BU
9	Use case 2 - Energy Efficiency	Baseline (eg. low) energy efficiency	N/A	TD
10	Use case 2 - Energy Efficiency	Baseline (eg. low) energy efficiency	N/A	BU
11	Use case 2 - Energy Efficiency	Medium energy efficiency	N/A	TD
12	Use case 2 - Energy Efficiency	Medium energy efficiency	N/A	BU
13	Use Case 3 - Heat Pumps	Baseline HP allocation	N/A	TD
14	Use Case 3 - Heat Pumps	Baseline HP allocation	N/A	BU
15	Use Case 3 - Heat Pumps	Baseline HP allocation	Sensitivity value of managed charging	BU
16	Use Case 3 - Heat Pumps	Hybrid Heat Pumps	N/A	TD
17	Use Case 3 - Heat Pumps	Hybrid Heat Pumps	N/A	BU
18	Use Case 4 - Investment Strategy	Baseline Just In Time	N/A	TD

19	Use Case 4 - Investment Strategy	Baseline Just In Time	N/A	BU
20	Use Case 4 - Investment Strategy	Fit for the Future	N/A	TD
21	Use Case 4 - Investment Strategy	Fit for the Future	N/A	BU
22	Use Case 5 – Flexibility Solution	High flexibility threshold	N/A	TD
23	Use Case 5 – Flexibility Solution	High flexibility threshold	Note: At present, flexibility services are considered as an alternative to reinforcement for issues that affect primary substations, EHV and 132kV networks and are not deployed to resolve issues on HV feeders, distribution substations or LV networks. Therefore, this run will not be modelled in the NIFT but remains in this table for clarification and to retain the agreed run numbers.	BU
24	Additional use case for BEZ SPA	Heat pumps vs heat network connected new developments	N/A	TD
25	Additional use case for BEZ SPA	Heat pumps vs heat network connected new developments	N/A	BU
26	Additional use case for SW Bristol	Accelerated and increased growth of ground mounted solar vs baseline trajectory	N/A	TD
27	Additional use case for SW Bristol	Accelerated and increased growth of ground mounted solar vs baseline trajectory	Note: Ground mounted solar connects at HV level so this run will not be modelled in the NIFT but remains in this table for clarification and to retain the agreed run numbers.	BU
28	Additional use case for N Fringe	High energy efficiency for domestic and commercial heat demand.	This will be compared to the baseline (eg low) energy efficiency (run 9).	TD
29	Additional use case for N Fringe	High energy efficiency for domestic and commercial heat demand.	This will be compared to the baseline (eg low) energy efficiency (run 10).	BU