REPORT

SILVERSMITH Network Study Results

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Executive Summary

Background to the Project

Great Britain is undergoing a transition to a system where Low Carbon Technologies (LCTs) are becoming increasingly prevalent. Across National Grid's[1] four distribution licence areas (East and West Midlands, South Wales and the South West) many energy customers are becoming increasingly involved in the energy system, transitioning from being simply energy consumers to instead becoming energy prosumers by installing distributed generation (DG), most commonly solar photovoltaics (PV). Other LCTs such as heat pumps, Electric Vehicles (EVs) and Battery Energy Storage Systems (BESSs) are also forecast to witness vast uptake rates over the next few decades. The uptake of LCTs will have a profound effect on the electricity network; it being carefully managed to facilitate the uptake of LCTs by resolving network constraints in the most cost effective manner.

To efficiently manage the evolution of the network, it is important to extract as much value as possible from the existing assets. To understand the network constraints that will occur as a result of LCT uptake, the EA Technology, Transform Model® was the tool used to perform scenario based network analysis. Before network analysis commenced, the Transform models for all four of National Grid's licence areas were updated based on the 2021 Distribution Future Energy Scenarios. This report outlines the assumptions and updates made to the models along with the validation process conducted to provide confidence that the model was representative of National Grid's distribution networks.

Utilising the updated models analysis is reported focussing on identifying the types of network constraint (voltage, thermal, generation or load related) forecast to be encountered across each licence area and on what time frame. This is further broken down to detail the network constraint likely to be encountered for each LV feeder archetype representing different typical characteristics of LV networks. Analysis of the wider GB Transform Model was used to compare the types of network constraints encountered across the wider GB electricity network to those encountered across National Grid's licence areas to understand where there were differences in the potential interventions necessary.

This study utilises Transform to perform a broad study of the network constraints generally experienced across National Grid's electricity distribution network. A parallel study using PowerFactory has been conducted to provide insight into specific network constraints on case study networks at particular years in the future. Findings from the two methodologies will be compared in the Technology Witnessing report later in this project.

Conclusions

This project has concluded that based on the forecast LCT uptake rates, generally voltage rise constraints due to the installation of solar PV will be the most prevalent issue facing networks. As LCT uptake continued, this will transition to become thermal constraints resulting from increased electrical load (i.e. heat pumps and electric vehicles). Therefore, there is an opportunity and need to investigate the potential for new technologies or operational practices which can both increase voltage headroom as well increasing thermal capacity at least cost and disruption to consumers. The analysis has shown that the network constraints encountered across National Grid's licence areas are also typical across Great Britain and so similar approaches to management will be applicable elsewhere.

Further analysis by LV archetype shows that under the assumption outlined in this report, there will be some variation in the type of network constraint depending on the specific feeder type. Feeder types dominated by commercial customers are forecast to witness primarily voltage rise constraints driven by PV uptake without

[1] National Grid Electricity Distribution, part of the National Grid group, were previously known as Western Power Distribution and renamed in September 2022.

the later thermal constraints being an issue. This is largely driven by the reduced number of customers but still high uptake rates associated with PV installations alongside the limited data currently available with regards to commercial EV uptake rates and profiles.

Conversely, those feeders which are dominated with residential customers although initially witnessing constraints from voltage rise associated with PV uptake this will quickly be replaced with thermal constraints as a result of heat pump and residential EV charge point uptake.

This report shows that across National Grid's four electricity distribution licence areas voltage rise constraints will be prevalent in the near term future, at relatively low frequencies of approximately 2% of feeders by 2028. The growth in prevalence of voltage rise constraints will be steady, rising to affect 7% of feeders by 2050. As LCTs continue to grow, thermal constraints will then become dominant. In 2028, thermal constraints will affect 6% of feeders, rising to 17% of feeders by 2033. By 2040 thermal constraints will affect 40% (27% transformer, 13% thermal) of feeders, rising to 60% (38% transformer, 22% thermal) of feeders by 2050.

It is therefore important when accessing the available technical solutions to consider that one solution will not be applicable in all locations and may not be necessary to resolve the same constraints. Additionally, due to the LCT uptake ratios it is likely that intermediate measures may be appropriate to temporarily resolve an initial constraint (i.e. voltage rise issues) before a more significant solution is implemented in the longer term.

Next Steps

The next phase of this project investigates the potential solutions currently available and used as standard by National Grid along with emerging technologies to resolve these constraints. The analysis is focussed on identifying which and in what locations emerging technologies have the greatest potential along with the required Functional Specification those technologies will need to meet.

The combination of this analysis will allow National Grid to understand the potential savings available from the emerging technologies along with those which should be trialled or developed to fully understand the potential. Through this process it will be possible to develop a set of criteria to enable network planning engineers to better understand the conditions within which net technologies may be favourable to traditional reinforcement options. The Functional Specification will cover both the required solution technical performance, together with the required price point at which the technology would be deployed in favour of traditional solutions.

Recommendations

Throughout the analysis and development of this report several areas of recommendation for National Grid to consider as part of their ongoing activities and investigations to facilitate the energy transition:

R1. Develop understanding of commercial heat pump profile(s) such that the effect of commercial heat pumps can be included in future network modelling.

R2. Develop understanding of BESS profile such that it represents realistic use of BESS rather than simply a worst case analysis.

R3. Solutions that cost effectively release voltage headroom capacity will see wide-scale deployment to support the forecast PV uptake, on feeders where many PV installations are clustered together. Due to the high prevalence of this network constraint type, National Grid should continue to closely monitor new technologies that offer potential voltage headroom release as these could provide high value across the electricity distribution network.

R4. Solutions that simultaneously voltage headroom and thermal capacity will also enable the continued support for forecast heat pumps and EVCPs. National Grid should closely monitor new technologies that could offer these as an option to avoid revisiting sites for subsequent capacity release.

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1. Definitions

Term	Definition
AC	Alternating Current
BESS	Battery Energy Storage Systems
DC	Direct Current
D-FACTS	Distributed Flexible Alternating Currents Transmission System
DFES	Distribution Future Energy Scenarios
DG	Distributed Generation
DNO	Distribution Network Operator
DSM	Demand Side Management
DSR	Demand Side Response
EAVC	Enhanced Automatic Voltage Control
EES	Electrical Energy Storage
EHV	Extra High Voltage
EV	Electric Vehicle
EVCP	Electric Vehicle Charging Point
GB	Great Britain
GM	Ground Mounted
GSR	Generation Side Response
HV	High Voltage
LCTs	Low Carbon Technologies
LV	Low Voltage
NG	National Grid
OH	Overhead
OLCTs	On Load Tap Changers
PM	Pole Mounted
PoC	Point of Connection
PV	(Solar) Photovoltaics
PV mode	Generator mode of operation defined to keep active power and bus voltage constant
RfI	Request for Information
RTTR	Real time thermal ratings
STATCOM	Static Synchronous Compensator
Tx	Transformer
UG	Underground

2. Background and Introduction

Great Britain is undergoing a transition to renewable and distributed energy. Many energy customers are becoming more involved in the energy system, transitioning from simply being electricity consumers to electricity prosumers. This is being led through the electrification of transport (i.e. electric vehicles) and heating (i.e. heat pumps) along with the continued growth in distributed generation, most commonly solar photovoltaics (PV). LCTs such as Electric Vehicles (EVs) and heat pumps are forecast to witness vast uptake rates over the next few decades. The combined effect of these technologies will have a profound effect on the electricity network. Large numbers of these technologies will be deployed on the Low Voltage (LV) networks, which will place significant additional demand on it, in many cases beyond which the network was designed for. National Grid[2] manage the LV network across their licence areas in the East Midlands, West Midlands, South West, and South Wales, and have commissioned this study to help increase their understanding of the challenges and opportunities for new technologies across their LV network.

As National Grid transitions towards management of an active LV network, this must be achieved in a manner which enables customers to install LCTs at the foreseeable uptake rates. This has to be achieved while minimising costs to consumers resulting from network augmentation but continuing to provide a safe and reliable supply of electricity. Additionally, network management should be fair to all electricity consumers, regardless of whether they own LCTs or not. It is therefore important to maximise value extracted from the existing LV network in order to minimise network costs arising from network reinforcement.

The purpose of this report is to present analysis identifying the types of network constraint forecast to be encountered across National Grid's licence areas. This has been delivered through use of the EA Technology, Transform Model® which enables a parametric based analysis for different LCT uptake scenarios and how they will impact the network. Before analysis of the network constraints could be conducted, National Grid's existing Transform models were updated based on the latest scenarios in DFES 2021 [1]. The report outlines the assumptions made in updating the Transform models along with the validation process that provides confidence the models are representative of National Grid's networks.

This report presents the results of analysis conducted to identify network constraints both at network level, and on a feeder archetype basis. This highlights the durations, scenarios, and timescales under which network constraints are met, and how this differs across network archetype. It is also important to understand whether the challenges faced by National Grid are unique or will also be experienced in other regions of GB and so a comparison of constraints against those forecast through the wider GB Transform Model analysis is presented.

The identification of network constraints performed in this report will feed into the next stages of the SILVERSMITH project. In the next stages of the project, a set of traditional solutions together with their associated parameters (such as Capex and Opex costs and headroom releases) will be agreed with National Grid. These solutions will then be utilised in Transform to perform a counterfactual study which will act as a baseline. Following the counterfactual study, novel and emerging solutions will be incorporated into the solution set and comparisons made to identify which of the novel solutions offer an advantage over the traditional approach. It is recognised that there may currently exist gaps in the market and this will lead to a set of functional requirements specification identifying the approaches to be used by National Grid when identifying the situations and potential conditions under which the novel solutions should be considered.

[2] National Grid Electricity Distribution, part of the National Grid group, were previously known as Western Power Distribution and renamed in September 2022.

3. Network Modelling

3.1 Low Carbon Technology Uptake Scenarios

DFES 2021[3] provides projections of future growth in load, generation and storage technologies until 2050, for a range of scenarios, which range from relatively gradual LCT uptakes (Steady Progress scenario), through to more aggressive LCT uptake rates (Leading the Way scenario). The Best View scenario is considered most likely, and this scenario can be thought of as the central position.

In all scenarios, forecasts for LCT uptake rates show significant growth. The growth in LCTs will range across generating technologies (such as solar PV), storage technologies (particularly BESSs) and loads (such as EVs and heat pumps).

The following sections set out the uptake scenarios considered and represented in the Transform Model updates for each of the scenarios.

[3] These scenarios are presented in DFES 2021 at an aggregated level, National Grid were able to provide this at a more granular level for the purpose of this study.

3.1.1 Solar Photovoltaic (PV) Uptake

Figure 1 shows the cumulative uptake rates of solar PV across National Grid's four licence areas according to the 2021 DFES.

Figure 1: Cumulative Solar PV Deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios

3.1.2 Heat Pumps

Figure 2 shows the forecast cumulative residential heat pump (without thermal storage) deployment until 2050 according to DFES 2021. Figure 3 shows the forecast cumulative residential heat pump with thermal storage until 2050 according to DFES 2021.

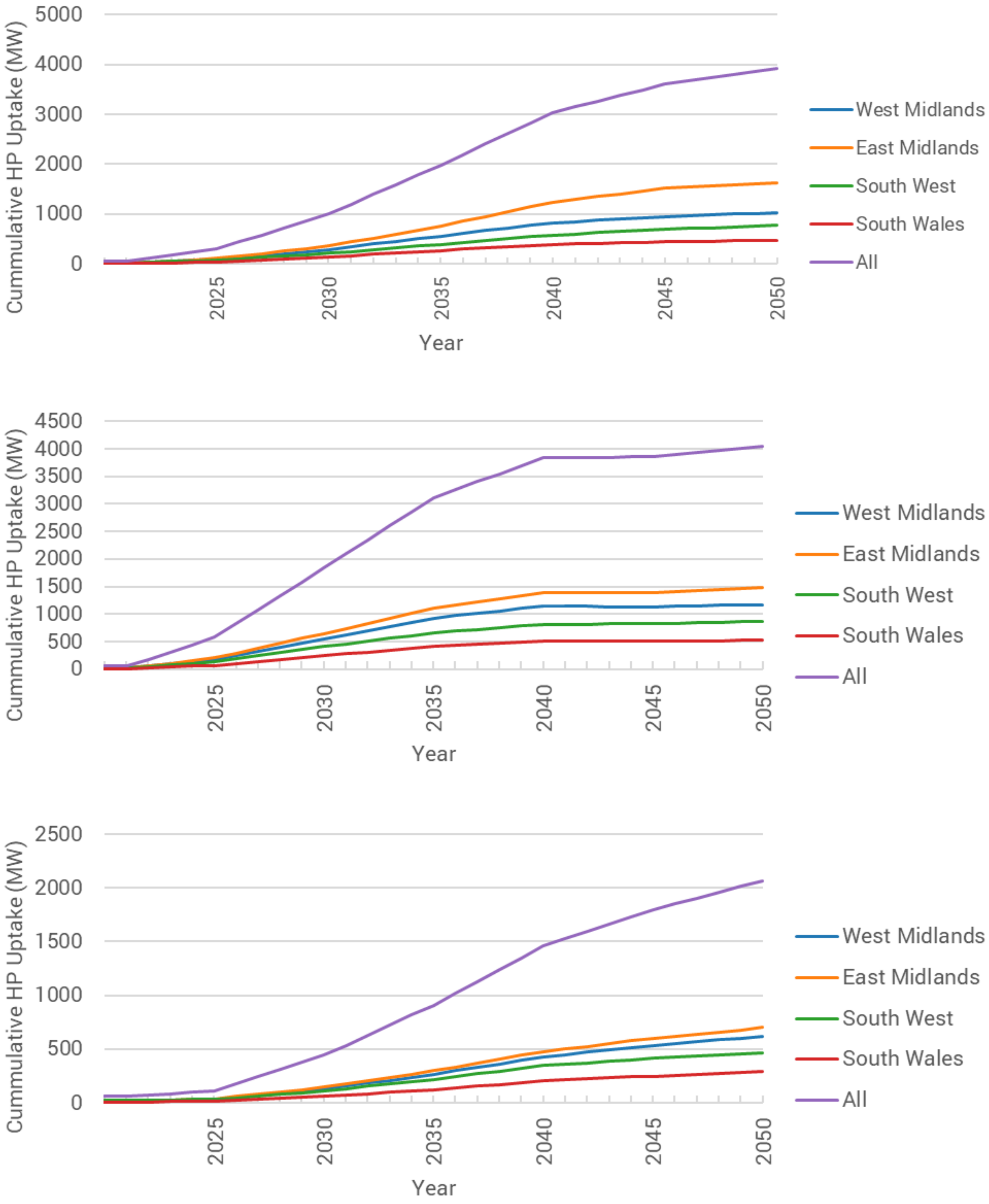

Figure 2: Cumulative Heat Pump (without thermal storage) deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

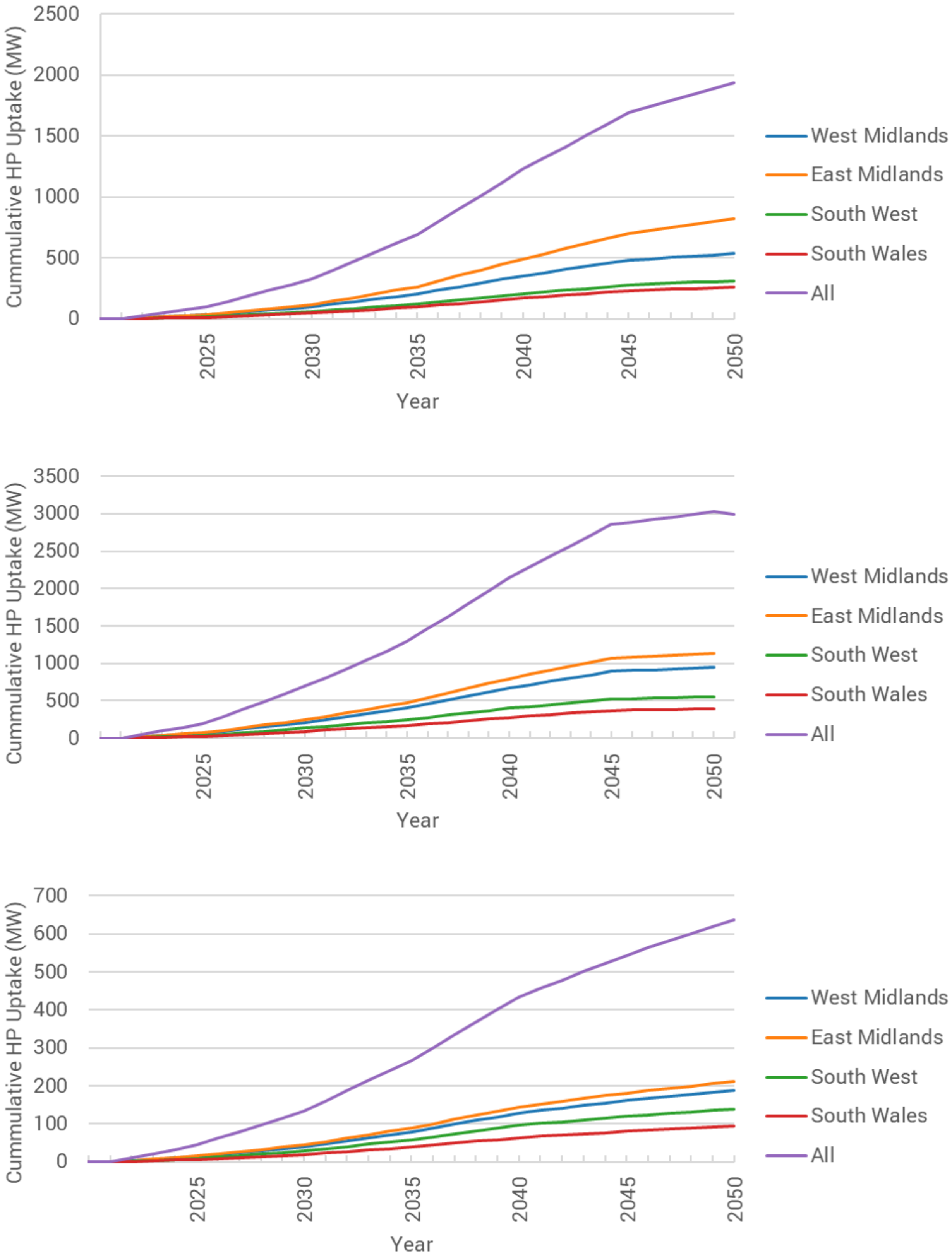

Figure 3: Cumulative Heat Pump with thermal storage deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

3.1.3 Battery Energy Storage System (BESS)

Figure 4 shows the forecast cumulative BESS deployment until 2050 according to DFES 2021.

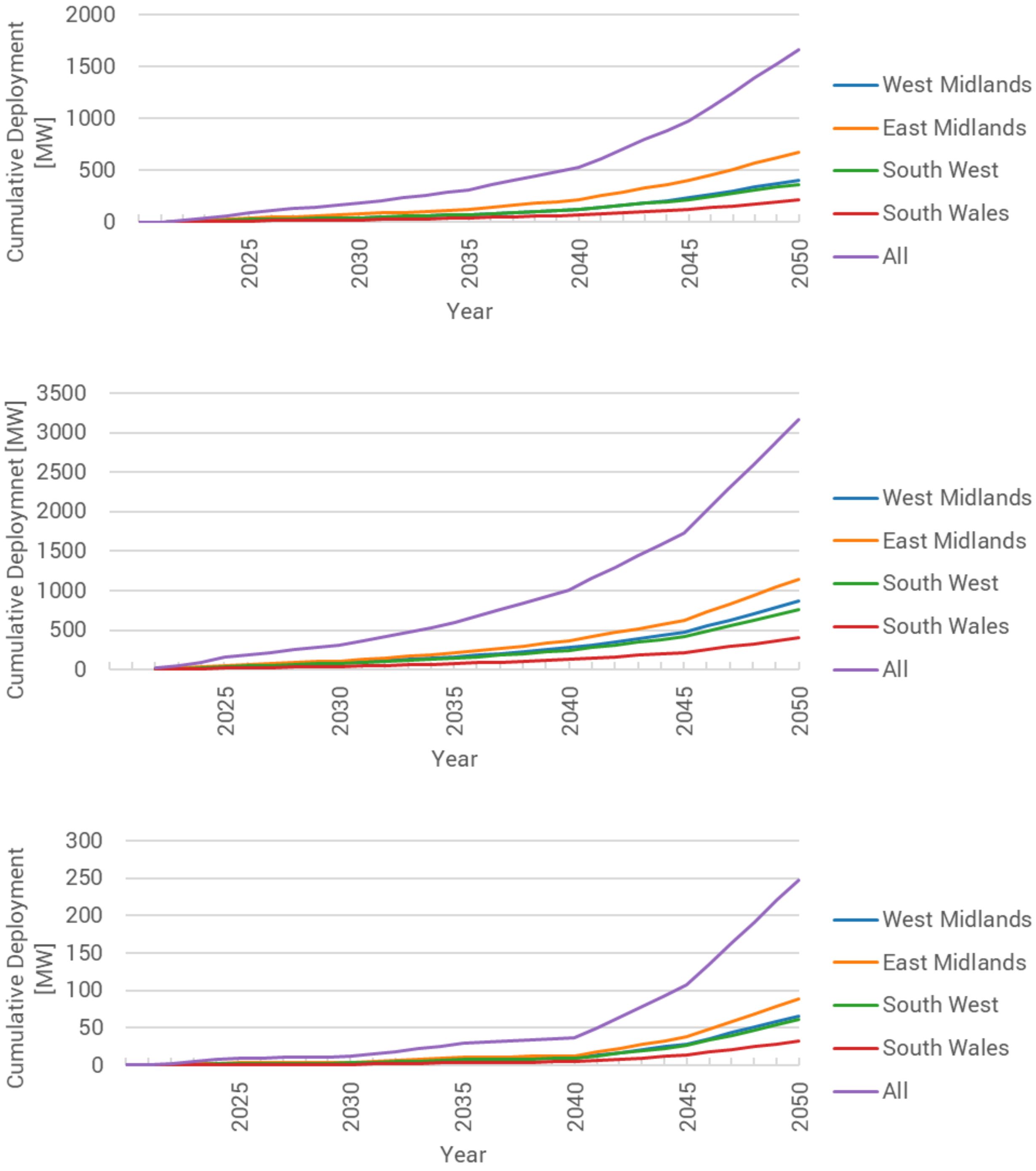

Figure 4: Cumulative BESS deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

3.1.4 Electric Vehicle Charge Points

Figure 5 shows the forecast cumulative deployment of residential EVCPs (EVCPs charged at domestic properties), combining those that charge on street and off street.

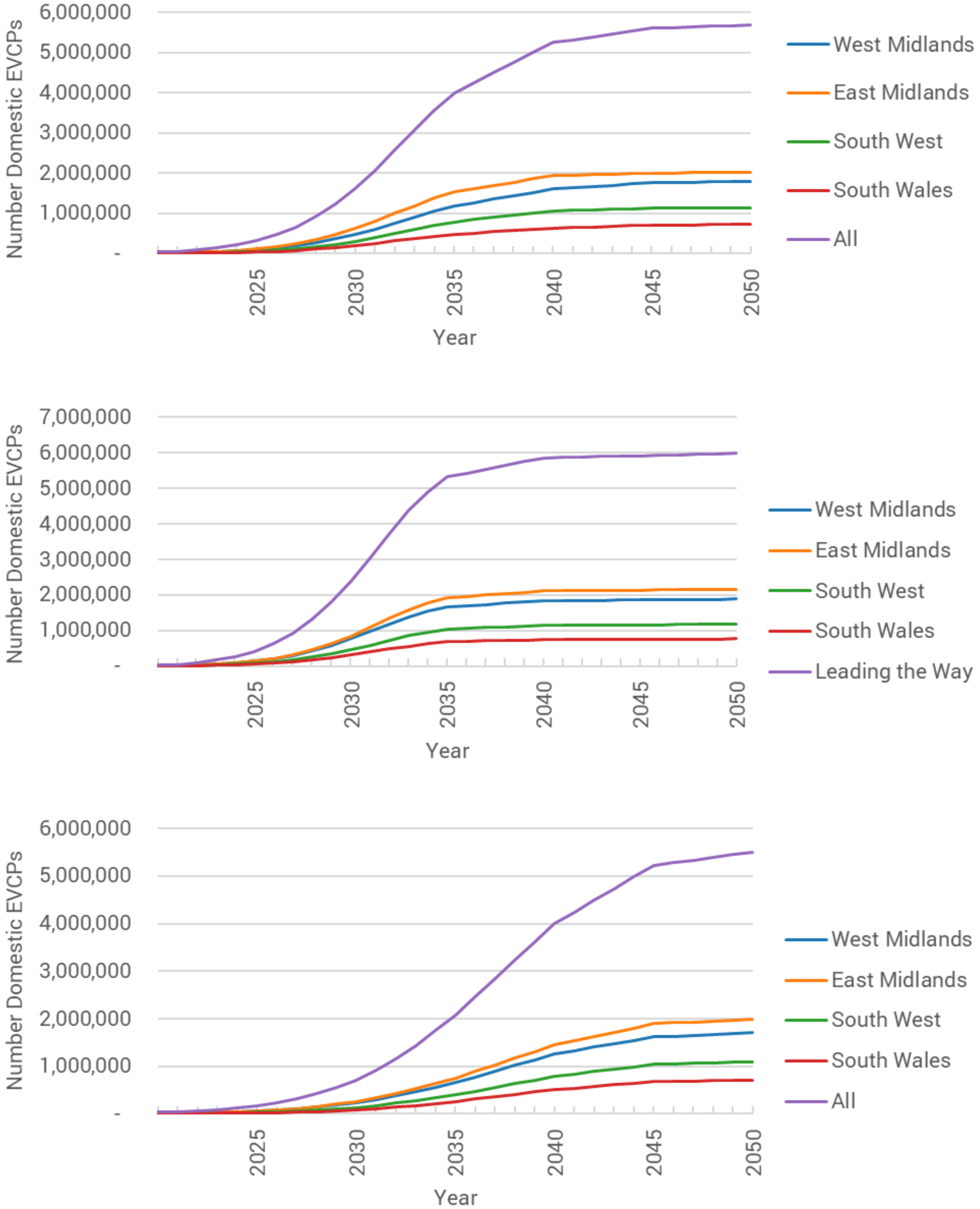

Figure 5: Cumulative residential EVCPs deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

3.2 Electricity Demand / Generation Profiles

The Transform model considers three seasons; Summer Peak Generation, Summer Peak Demand and Winter Peak Demand. Each property profile and each LCT profiles have separate profiles for each season with the seasonal profiles for LCTs displayed on the pages that follow in this report

Modelling three seasons including the extremes of peak winter load and peak summer generation allows for the full breadth of network constraints to be identified. Constraints that occur due to net import will occur first during the Winter Peak Demand season when load is highest and embedded generation lowest, whereas constraints due to net export will occur first during the Summer Peak Generation seasons where PV generation is highest and load is low. Therefore, by studying multiple seasons all constraints that occur on the network can be identified.

3.2.1 Solar Photovoltaic Profiles

For PV, each season has a different generation profile according to assumed weather conditions, outlined as follows:

1. Summer Peak Generation: Generation by PV during a sunny, clear, summer's day, representing typical peak solar generation from a UK installed PV system.
2. Summer Peak Demand: Typical Generation by PV during an overcast, summer's day, where underlying demand is at its highest for the summer months.
3. Winter Peak Demand: Generation by PV during an overcast cold winter's day where underlying demand is at its peak.

The PV profiles used in Transform differ slightly for each of the licence areas based on data and analysis carried out by National Grid. Each PV profile shows the generation expected from a PV unit on a per kilowatt peak capacity basis. In other words, the power produced by a PV system throughout the day relative to its rated peak power output. The PV profiles were sourced from DFES 2021, which along with the other LCT profiles considered in this study are available for download from the National Grid website [1]. Figure 6 shows the PV profiles from DFES 2021 for each of National Grid's four licence areas used in the Transform analysis.

Figure 6: Solar PV Profiles for National Grid's Licence areas; West Midlands (Top Left), East Midlands (Top Right), South Wales (Bottom Left), South West (Bottom Right).

3.2.2 Heat Pump Profiles

DFES 2021 has two distinct profiles for domestic heat pumps, namely standalone heat pumps (i.e. without thermal storage) and heat pumps with thermal storage. In the Summer Peak Generation season, it is assumed warm environmental conditions ensure heat pumps aren't run, thus contributing no load. The profile for standalone heat pumps is shown in Figure 7 and heat pumps with thermal storage in Figure 8.

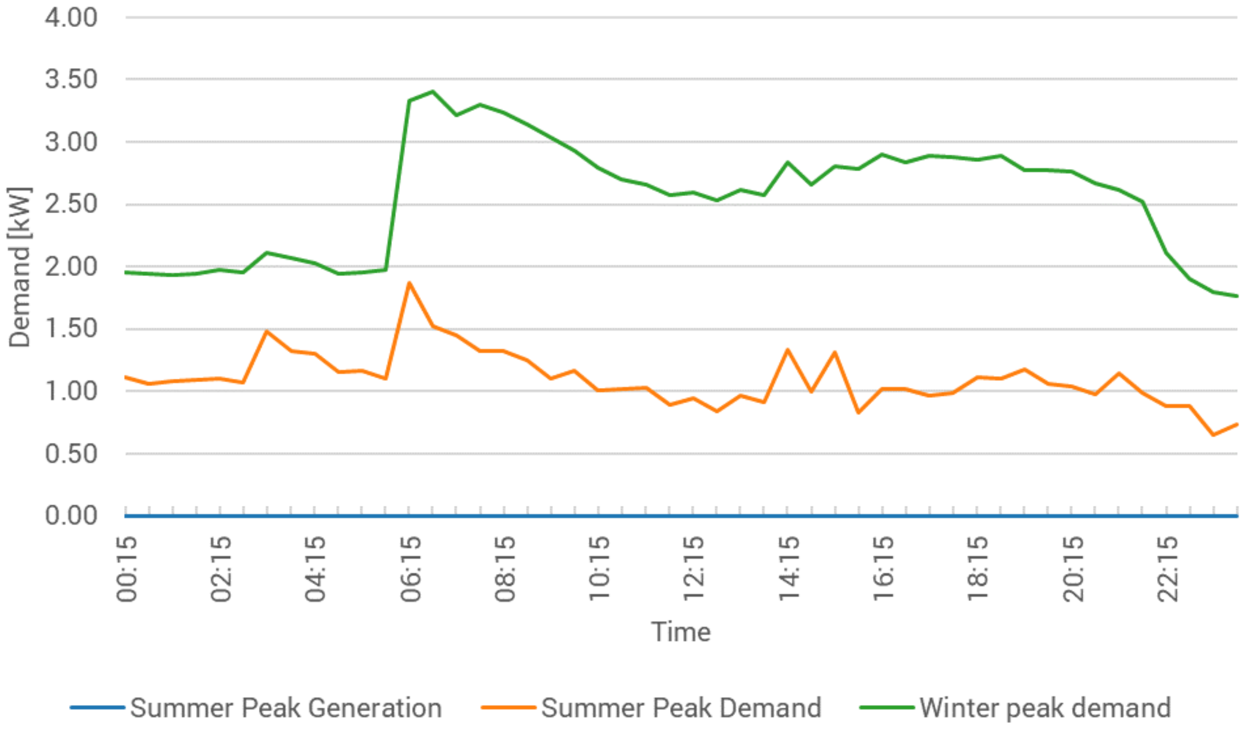

Figure 7: Domestic heat pump profile.

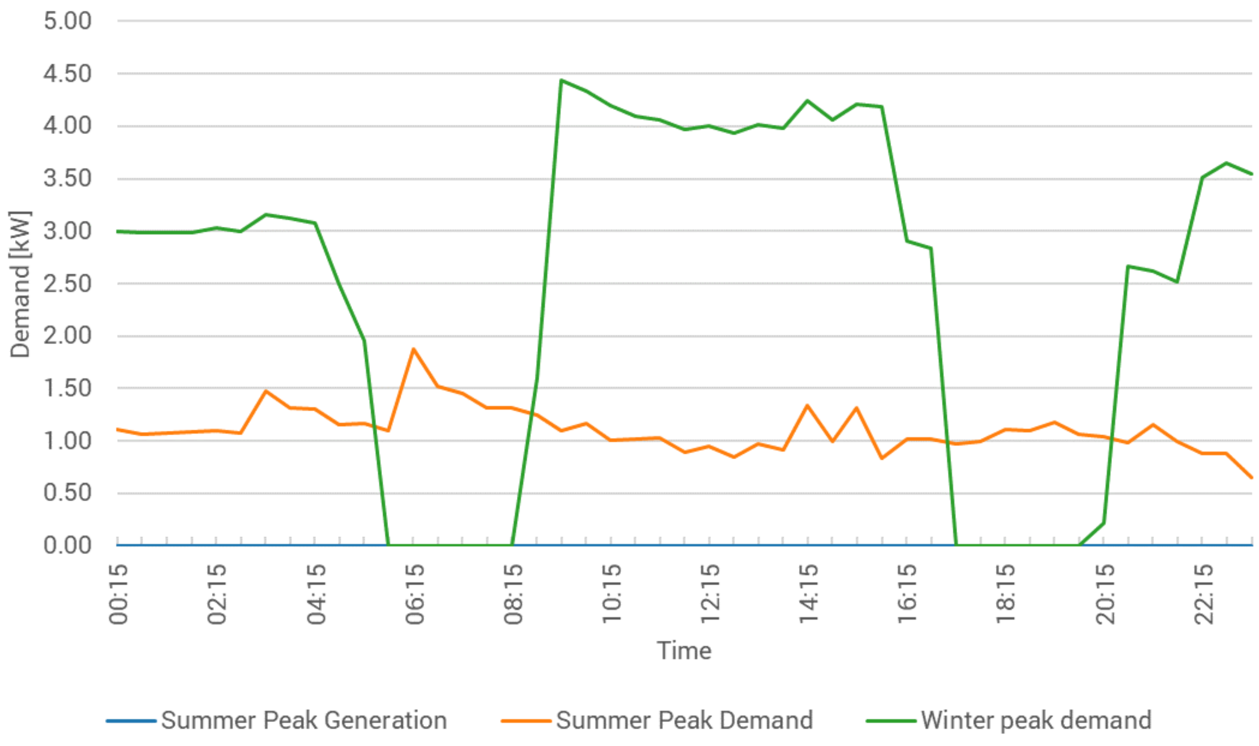

Figure 8: Domestic heat pump with thermal energy storage profile.

The domestic heat pump profiles in DFES 2021 do not vary according to property type. In reality, the heat pump profile would be expected to vary by property type due to differences in property size and energy efficiency. A new build flat would be expected to have a much smaller heat demand than an old detached house. The limitation of including only two heat pumps profiles (for stand alone heat pump and heat pump with thermal storage) is that this diversity in heat demand fails to be captured by the model. The likely consequence of this is that feeders with high levels of properties with low heat demand will have their number of constraints overestimated (and occurring earlier than in reality), whereas the opposite will be true for feeders with high levels of properties with high heat demands.

There is no standardised profile yet available for commercial heat pump installation due to the variety of different types, conditions and operating requirements. Therefore, commercial heat pumps have not been considered as part of this study and it is possible LV networks with significant numbers of commercial properties may witness network issues before this study indicates. If commercial heat pumps were added to the analysis and caused network constraints, it is most likely that these additional network constraints would be thermal due to the additional load from the heat pumps.

Since it is anticipated that there could be significant adoption of electrified heat in Commercial Properties, the following recommendation is made to support future modelling and scenario analysis:

R1.	Develop understanding of commercial heat pump profile(s) such that the effect of commercial heat pumps can be included in future network modelling.

3.2.3 Battery Energy Storage System Profiles

The process of understanding profiles for usage of BESS is at an early stage of development. DFES 2021 assumes a "worst case" profile for battery storage of maximal discharge rate during the season Summer Peak Generation, and maximal charging rate during the seasons Winter Peak Demand and Summer Peak Demand. For consistency and comparison with other work being carried out, these "worst case" DFES 2021 BESS profiles were used (Figure 9). The BESS profile is given in kilowatt per kilowatt peak. A value of 1 for maximal discharge represents batteries discharge at their maximum rate during the season Summer Peak Generation, A value of -1 for the season Winter Peak Demand and Summer Peak Demand represent batteries charging at their maximum rate. The assumed peak charging or discharging rates of residential BESS units in the Transform modelling is 4kW.

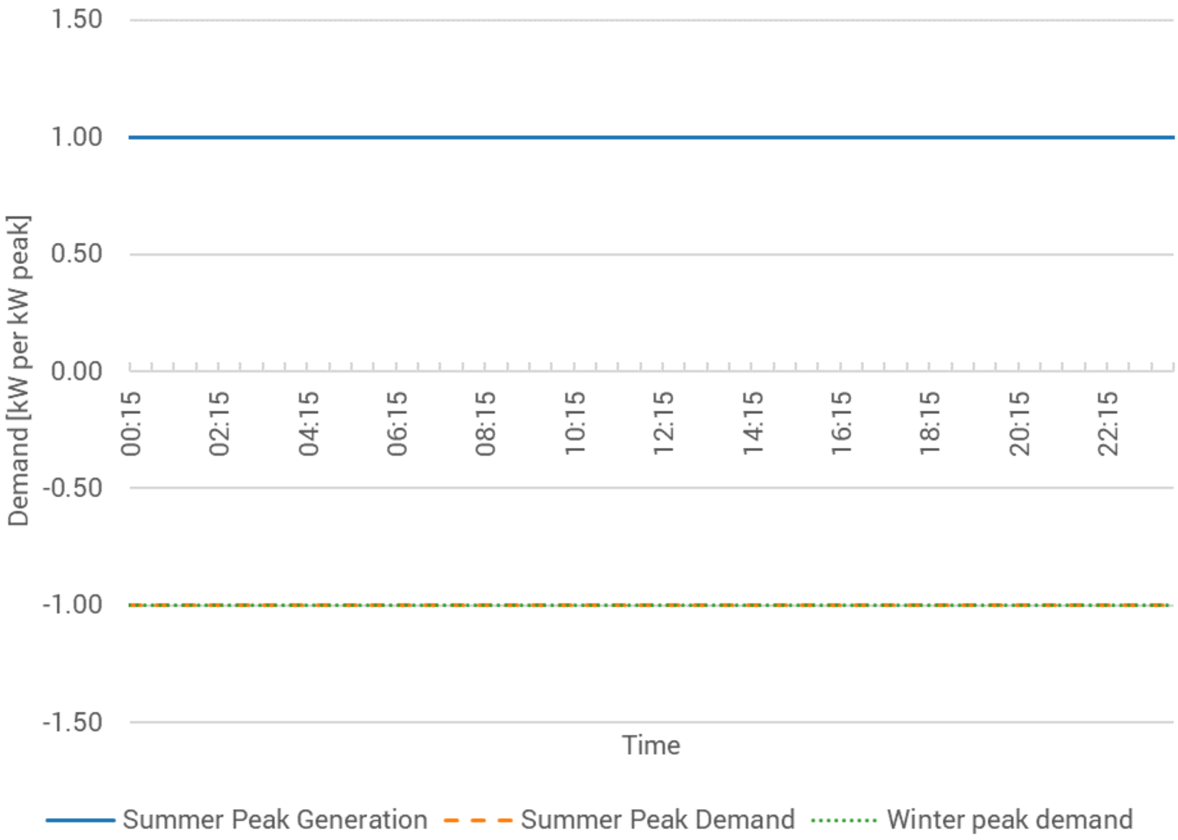

Figure 9: BESS profile.

Assuming "worst case" BESS profiles will have an impact on the results. Constraints on the LV networks will be reached earlier as these profiles assume BESSs introduce additional stress onto the distribution network. Taking this worst-case approach ensures that all possible constraints are captured but is potentially an unrealistic condition, recognising BESS is more likely to be residential then there is a greater probability they will follow energy supplier prices signals or be in place to maximise self-consumption of renewable generation. Additionally, BESSs have the potential to support the LV distribution network by charging when there is excess generation and discharging during times of peak load and supplier commercial models that encourage this are emerging. BESSs can therefore have significantly different effects on the network depending on how it is utilised. It is recommended that in preparation for future modelling National Grid:

R2. Develop understanding of BESS profile such that it represents realistic use of BESS rather than simply a worst case analysis.

3.2.4 Electric Vehicle Charge Point Profiles

DFES 2021 [1] includes forecast uptake rates for a variety of EVCP types. These include residential off-street, residential on-street, workplace, car parks, destination, en-route / local charging stations and fleet depot.

The type of EVCPs with the highest uptake rates are for residential on-street and off-street EVCPs for which the profiles are identical. While this may change in the future as understanding of charging profiles evolves, it allows residential on and off-street profiles to be combined into a single profile in this analysis. The residential EVCP profile used in the National Grid Transform models is shown in Figure 10. The Electric Nation project [2] showed that significant diversity existed for EV charging. The residential EVCP profile accounts for this diversity; since EV owners are unlikely to all charge at the same time on the same day. This leads to a peak in the EVCP profile less than the peak output of an individual residential EVCP. This profile therefore accounts for the diversity in charging behaviour across residential EVCPs across feeders.

The other EVCP types (workplace, car park, destination, en route /local charging stations and fleet depot) are also included in the Transform analysis and shown in Appendix I.

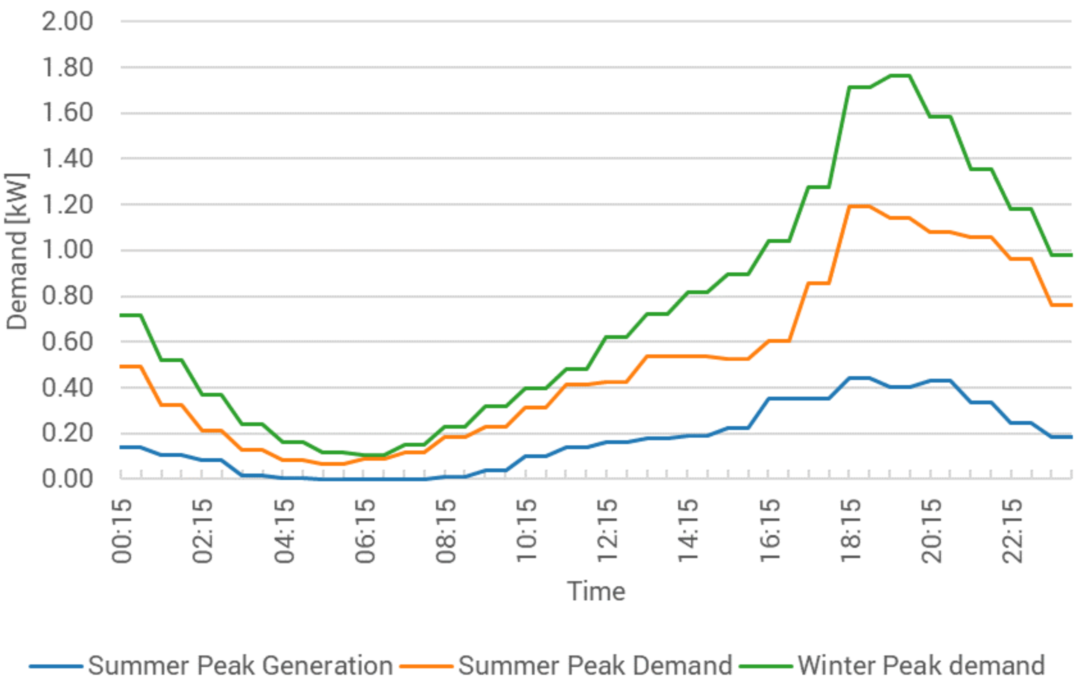

Figure 10: Residential EVCP profile.

3.3 Low Voltage Feeder Types

The Transform model for National Grid's licence areas makes use of 11 LV network archetypes representing different types of representative LV feeder. Table 1 gives a brief description of each of these and the same are used across all 4 licence areas. Additional details for each LV network archetype assumed in the Transform analysis can be found in Appendix IV.

Table 1: Description of LV Network Archetypes used in National Grid's Transform Models

Number	Network Archetype Name	Description
LV1	Central Business District	Radial underground central business district feeders supplying only commercial customers. Typically found in town and city centres.
LV2	Dense Urban (Apartments etc.)	Radial underground feeder typical of those found in areas on dense population in cities (such as where there are many apartments in close proximity). Feeder supply a range of residential property types.
LV3	Town Centres	Radial underground feeder typical of those found in town centres. These feeders supply primarily commercial customers but also have a small number of domestic customers.
LV4	Business Park	Radial underground feeder with only commercial customers representative of a typical business park.
LV5	Retail Park	Radial underground feeder with only commercial customers representative of a typical retail park.
LV6	Suburban Street (3 4 Bed Semi-detached or Detached Houses)	Radial underground feeder representative of a typical suburban area. This feeder supplies detached and semi-detached residential properties.
LV7	New Build Housing Estate	Radial underground feeder representative of a typical new build housing estate.
LV8	Terraced Street	Radial underground feeder representative of a typical feeder supplying a row of terraced houses.
LV9	Rural Village (Overhead Construction)	Radial overhead feeder supplying mostly domestic customers, typical of that found in rural villages.
LV10	Rural Village (Underground Construction)	Radial underground feeder supplying mostly domestic customers, typical of that found in rural villages.
LV11	Rural Farmsteads Small Holdings	Radial overhead feeder typically used to supply small groups of houses or small farms.

3.4 Transform Model Assumptions

The Transform Model[4] presents a parametric model of an entire electricity distribution network. This model builds on data from a number of sources, which includes:

- A range of hosting capacities from prototypical representations of different feeder categories
- A range of solutions for improving hosting capacity that a network operator may employ. (This includes network led solutions such as new transformers and non-network solutions such as tariffs or customer storage)
- Electricity consumption profiles of different customers classes
- Generation profiles of varying solar PV, battery storage and EV behaviour
- Installation rates for different DER (such as PV generation and battery storage).

As a parametric model based on representative feeders, it is not an exact replica connectivity model of National Grid's electricity distribution network. Input variation and clustering to represent socio-economic factors is used to capture additional diversity around the network. However, a parametric model based on representative feeders is by its nature unable to capture the full diversity of feeders on the physical network for which a full connectivity model would need to be developed. Instead, a balance is needed between input parameters such that the model is representative of the entire network and able to provide outputs upon which confidence and strategic decisions can be made.

To ensure that the model is representative, various verification checks have been conducted to ensure key input and output parameters in the model are in alignment with the observed values. Specific details of model verification are included in section 1 of this report. However, there is always a level of uncertainty around whether a different selection of representative feeders may have produced different outputs.

The Transform Model® overlays the anticipated future demand that will be placed upon the network from various low carbon technologies onto the existing network. In instances where network feeders are taken beyond acceptable network quality standards, the Transform Model® simulates the technical and economic choices that a network owner will have to make to maintain an acceptable service.

The following sections set out some of the assumptions made specifically with regards to this analysis.

[4] https://www.eatechnology.com/engineering-projects/the-transform-model/

3.4.1 Maximum Low Carbon Technology Deployment

To support the deployment of LCTs across the LV networks in Transform it is important to understand the maximum amount that is typical to be installed at each property. This analysis is carried out by property type (detached, semi-detached, terraced, etc.) along with domestic vs commercial properties. It has been assumed that each property type can accommodate a maximum quantity of LCTs as detailed in Table 2 below.

Table 2: Maximum LCT Deployment by Customer Type

	Domestic	Commercial
PV (kW peak)	4	40
BESS (kW peak)	4	10
Heat Pumps (number)	1[5]	1[6]
EVCPs (number)	1[7]	25[8]

3.4.2 Low Carbon Technology Clustering

In practise, it is unlikely that a completely uniform distribution of LCT uptake will occur across customers within each distribution network feeder type. Instead, there is likely to be some feeders which see a greater increase in LCTs before others as a result of socio-economic factors. To capture this uncertainty, Transform has a clustering feature that allows the proportion of LCTs deployed to be varied, allowing diversity in uptake rates of LCTs across any particular feeder type to be captured. This is achieved using 10 clustering bins and LCTs (PV, BESS, EVCPs and heat pumps) have been assumed to be deployed with variability across the clustering bins such that some clusters will see significantly higher uptake earlier than others.

The allocation of LCTs to clustering bins used a standard clustering methodology agreed by GB DNOs. These clustering assumptions cover a full variety of feeder types from feeders with very high levels of LCT penetration to feeders with very low levels of LCT penetration. This clustering approach gives a broad overview of challenges that will occur on the LV network, covering feeders with very high to feeders with very low numbers of LCTs deployed.

To investigate the impact of these clustering bins, sensitivity studies were performed using Transform with balanced clustering of LCTs across the 10 clustering bins (10% LCT deployment / cluster). The effect of this change was to delay the initial constraints (due to the removal of clusters with very high uptake rates of LCTs), and to reduce the total number of constraints witnessed across the network by 2050, as constraints on certain cluster bins occurred later. This sensitivity study showed that the types of network constraints expected across the network did not change significantly only the timing of constraints.

It has been assumed for the purposes of this study that the uptake rates of PV, BESS, EVCPs and heat pumps are correlated. In other words, those households most likely to deploy PV are also the most likely to deploy BESS EVCPs and heat pumps.

[5] Very old and old detached and semi-detached properties are assumed to have maximum heat pump deployment of 2 to account for poor insulation and high heat demand in these property types.
[6] Commercial heat pump profiles have not been developed for DFES 2021 so no profile has been included to model commercial heat pumps. However, the clustering has been set at 1 to facilitate commercial heat pump profile to be included as understanding of commercial heat pump profiles develops.
[7] Maximum of 1 residential EVCP profile per domestic property. Other types of EVCP such as workplace and destination have a maximum EVCP profile deployment of 0 on domestic properties.
[8] Number of residential EVCPs profiles that can be deployed to commercial properties is set at 0. Other EVCPs profile types such as workplace and destination are set at 25.

3.4.3 Low Voltage Constraints Only

The scope of this project is to investigate the effect of the forecast increased deployment of LCTs on the LV network. As such, the HV thermal conductor, transformer and voltage limits have been set at arbitrarily high levels that do not necessitate any investment in the network as a result of downstream investment. It is important to recognise that this report therefore only covers the necessary investment on the LV network required to facilitate the forecast uptake of LCTs. Additional data would need to be considered in order to investigate the impact of LCT deployment on solutions required to resolve HV network constraints.

3.4.4 Resolving Constraints

The Transform model resolves constraints as they occur by deploying the most cost effective solution to resolve the constraint for that year the constraint occur and the following 5-year period. It does not assume perfect knowledge of LCT uptake rates and as such it may not select the most cost effective solution to resolve all constraint until the last year of the model (2050). This frequently lead to multiple solutions being deployed on a specific LV feeder type, since the first solution deployed releases insufficient capacity to deal with additional LCT uptake later in the model.

3.5 Network Model Development and Validation

It is essential to verify the model is representative of the electricity network being modelled. In this case, the four Transform models for each of National Grid's licence areas all require verifying. Three data points from each Transform model can be compared against the network data on a licence area basis to ensure that each model is indeed representative. These data points are the number of LV feeders in each licence area, the total number of LV connected customers in each licence area (this includes both residential and commercial customers) and the peak load observed for each licence area.

As discussed in section 3.4, Transform is a parametric model that utilises representative feeders and customer data to represent an electrical network. The representative feeders and customer data must be chosen to ensure the model closely aligns with the real network. To ensure the network is representative, the number of LV feeders, the number of LV connected customers and the peak load for each licence area must all closely match their true number on the network. Exact matches across all three verification data sets are very unlikely to be achieved, since adjusting one set of input parameters will affect the other parameters. For example, increasing the number of LV feeders in the model would lead to an increase in number of customers and an increase in peak load on the modelled network. It was agreed with National Grid that each verification check should remain within 15% of the true value to be considered sufficiently representative.

It is important to remember that the primary purpose of this study is to consider what type of network constraints occur on which LV network archetypes. By modelling all 11 LV network archetypes found across National Grid's electricity network, this study provides insights into the constraints likely to be encountered and how these constraints vary across each of the different LV archetypes.

3.5.1 Number of LV Feeders

Table 3 compares the number of LV feeders in each licence area against the number of LV feeders in each Transform model. The number of LV feeders in the model is slightly short of true number of LV feeders on the network, but in all cases within the 15% tolerance agreed. The 2013 East Midlands model did not have any feeder of type LV11 (rural farmstead and small holdings). In discussion with National Grid, it was agreed that since the East Midlands does have feeder of this type, that the network topologies for rural feeder types (LV9, LV10 and LV11) for the East Midlands should be based off the West Midlands feeder topology. This was considered a more viable option than the alternative which would be to categorise National Grid's feeders into the 11 LV network archetypes, which would have been outside the scope of this project. As a consequence, it is accepted that there was likely to be a discrepancy in the number of LV feeders. Since this discrepancy fell within the accepted tolerance, this approach was considered preferable since this allowed analysis of the constraints encountered and solutions deployed across the LV11 network archetype in the East Midlands.

Table 3: Comparison of LV feeder numbers on network against in Transform model.

Region	Number of LV Feeders on Network	Number of LV Feeders in Model	% Difference
East Midlands	106,351	94,551	-12%
West Midlands	113,178	105,177	-8
South West	83,891	80,506	-4%
South Wales	61,154	58,518	-5%

3.5.2 Total Number of Customers

Table 4 compares the total number of LV connected customers (residential and commercial) in each licence area against the total number of customers in each Transform model. For all licence areas, the total number of customers in the model falls within 15% tolerance agreed of the true number of customers on the network. The slight deficit of properties in the South West model when compared to the network data is possibly due to stronger than expected rates of new build properties in the South West region.

Table 4: Comparison of total customer numbers on network against in Transform model.

Region	Total Number of Customers on Network	Total Number of Customers in Model	% Difference
East Midlands	2,683,006	2,805,754	4%
West Midlands	2,511,188	2,457,429	-2%
South West	1,646,359	1,538,112	-7%
South Wales	1,151,120	1,102,535	-4%

3.5.3 Peak Load in 2022

Table 5 compares the peak load observed for each licence area in 2022 against the peak load observed in the Transform model in 2022. The peak load in the model for all licence areas is within the 15% tolerance agreed of the observed peak load. The South West and South Wales have greater discrepancies than the East and West Midlands. This is suspected to be due to greater levels of HV and EHV connected generation in the South Wales and South West licence area netted out (essentially acting to reduce demand) in the DFES peak load. The Transform models only consider LV connected generation.

Table 5: Comparison of peak load on network against in Transform model.

Region	Peak Load on Network [MW]	Peak Load in Model [MW]	% Difference
East Midlands	4,827	4,789	-1%
West Midlands	4,313	4,456	3%
South West	2,498	2,907	14%
South Wales	1,832	2,0247	11%

3.5.4 Peak Load in 2029

Table 6 compares the peak load in the DFES scenario (provided directly from National Grid) for each licence area in 2029 against the peak load in 2029 in the Transform model, for the Best View scenario. The peak load for all licence areas is within 20% of the observed peak load. A wider tolerance of 20% was considered acceptable for the year 2029 due to uncertainty from National Grid concerning which DFES scenario the forecast peak load was derived from. In addition, greater levels of uncertainty were considered acceptable due to real world uncertainties in forecasting peak loads on the network in the future, that don't exist when measuring peak loads on the existing network.

Table 6: Comparison of peak load forecast in 2029 against load in 2029 in Transform model

Region	Peak Load Forecast [MW]	Peak Load in Model (Best View Scenario) [MW]	% Difference
East Midlands	6,551	5,874	-12%
West Midlands	5,914	4,926	-20%
South West	3,280	3,574	8%
South Wales	2,381	2,514	5%

4. Network Constraint Analysis

This section first considers the type of network constraints experienced for each combination of licence area and scenario. In section 4.3 the constraints witnessed on each network archetype are assessed.

4.1 Constraint Types

Through detailed analysis of the Transform constraint identification and output, the constraints can be categorised into six common but distinct types.

1. Voltage drop constraints occur when the voltage drop along a feeder exceeds the maximum voltage drop defined as allowed for that particular feeder.
2. Similarly, voltage rise constraints occur when the voltage rise along a feeder exceeds the maximum voltage rise defined for that particular feeder.
3. Thermal Transformer (Load) constraints occur when the maximum net import to a feeder exceeds the thermal capacity of the transformer associated with that particular feeder.
4. Thermal Transformer (Generation) constraints occur when the maximum net export from a feeder exceeds the thermal capacity of the transformer associated with that particular feeder.
5. Thermal Cable (Load) constraints occur when the maximum net import to a feeder exceeds the thermal capacity of the cable as defined in Transform for that particular feeder.
6. Thermal Cable (Generation) constraints occur when the maximum net export to a feeder exceeds the thermal capacity of the cable as defined in Transform for that particular feeder.

The following sections of the report analyse the constraints encountered on the network as forecast by the Transform model. Plots are produced detailing the constraints witnessed across the four licence areas and three scenarios on a cumulative basis.

Analysis of the Transform output results was conducted to identify for every LV network archetype, what type and in which years network constraints were encountered. While commonly a single network constraint is encountered, it is also common that multiple types of network constraints are encountered at the same time. When multiple network constraints are encountered, these are sometimes on distinct feeders, but regularly also on the same feeder. A common example would be thermal transformer and thermal cable constraints being witnessed simultaneously on a feeder.

Each time a network constraint is identified, Transform deploys the most cost effective solution to resolve that constraint over the next 5 year period. In many instances, after that 5 year period, another constraint is hit due to further deployment of LCTs, which requires another intervention. This is counted as an additional constraint for the purposes of this analysis, since an additional solution is required to be deployed. In some cases a single feeder can be subject to three of four constraints over the course of the study, requiring multiple interventions.

Due to the combined effects of multiple constraint type occurring on a single feeder simultaneously, and multiple constraints of the same type being encountered on a single feeder at different time frames, the figures displayed in this report occasionally have very high penetration of network constraints, occasionally exceeding 100%. This does not mean all feeder require interventions, but it does mean either or both of multiple constraint types being encountered by the feeders simultaneously and/or repeated constraints. Repeated constraints may occur when, due to the LCT uptake ratios, intermediate measures are required to resolve an initial constraint before a more significant solution is implemented in the longer term. When percentage figures are quoted in this report or read from the figures, this should be interpreted not as a literal percentage of feeders requiring intervention but instead an equivalent percentage of feeders requiring intervention, since some networks are likely to require intervention more than once whereas others require no interventions.

4.2 Network Wide Constraint Analysis

4.2.1 Constraints in the Best View Scenario

Figure 11, Figure 12, Figure 13, Figure 14 shows the percentage of feeders requiring intervention for each licence area in 2028, 2033, 2040 and 2050 respectively. A weighted average has been calculated to show the percentage of National Grid's feeders across all four licence areas that require intervention.

In 2028, on average across all National Grid's licence areas approximately 6% of feeders require intervention for thermal constraints under net import (approximately 4.5% transformer and 1.5% cable), and 2% of feeders require intervention for voltage rise constraints.

By 2033, voltage rise constraints are witnessed on approximately 3% of feeders, whereas thermal constraints are experienced on approximately 17% of feeders (12% transformer, 5% cable). Significant growth in frequency of thermal constraints shows that in the RIIO-ED3 regulatory period between 2028 and 2033, solutions that release thermal headroom would begin to be deployed across National Grid's LV network.

By 2040, voltage rise constraints occur on approximately 4% of feeders, whereas thermal constraints occur on approximately 40% of feeders (27% transformer, 13% cable). Therefore, over period from 2034-2040, a large number of interventions will be required to resolve thermal constraints occurring on the LV network. Solutions that release thermal headroom have the potential for widescale deployment in this period.

By 2050, voltage rise constraints occur on approximately 7% of the networks. Thermal constraints again show a large increase in frequency to approximately 60% of networks (38% transformer, 22% cable). Thermal constraints are again the most dominant network constraint type in the period 2040-2050. Solutions offering to release thermal headroom on the LV network again are likely to see widescale deployment.

Overall, voltage rise constraints will be experienced on relatively low number of feeders, but will begin to occur immediately. Thermal constraints will become the dominant network constraint type. Significant levels of interventions and thus investment will be required to alleviate thermal constraints particularly during the 2034-2040 and 2041-2050 timeframes.

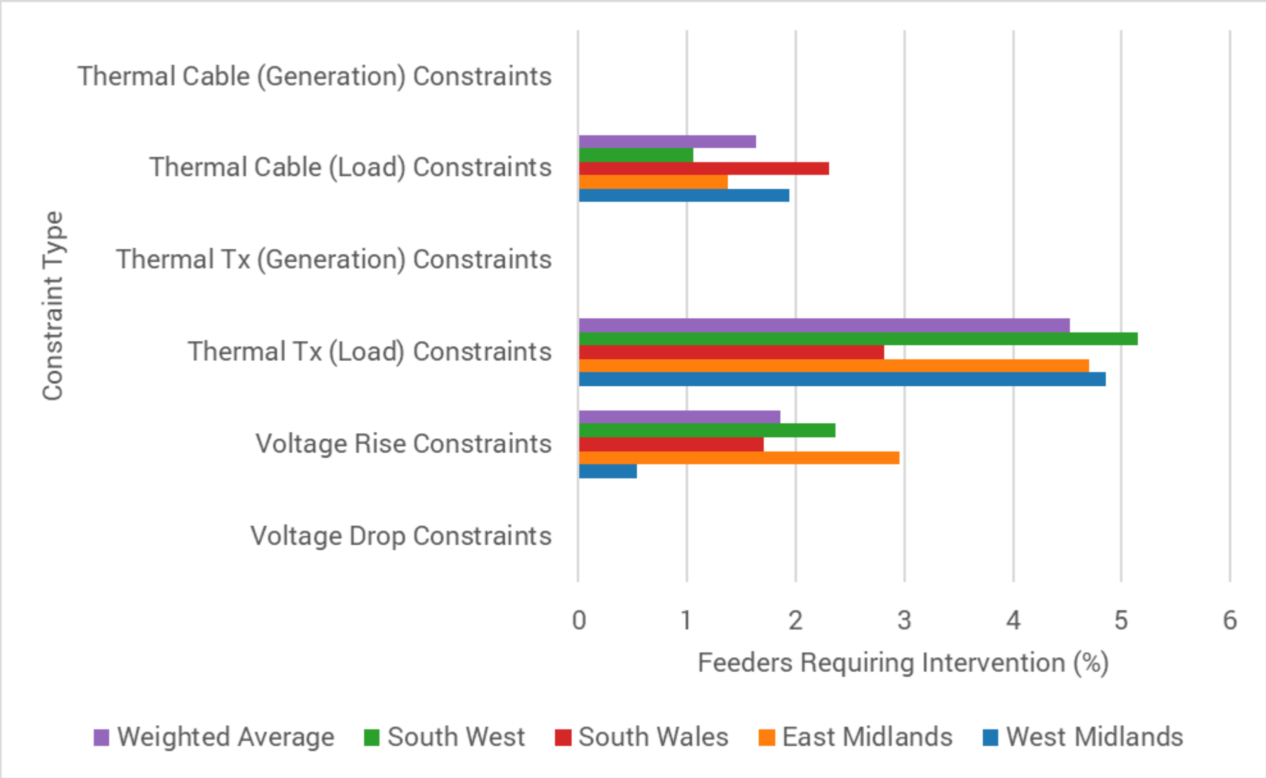

Figure 11: Cumulative percentage of feeders requiring intervention due to each network constraint type, by the year 2028 across under the Best View scenario for all licence areas.

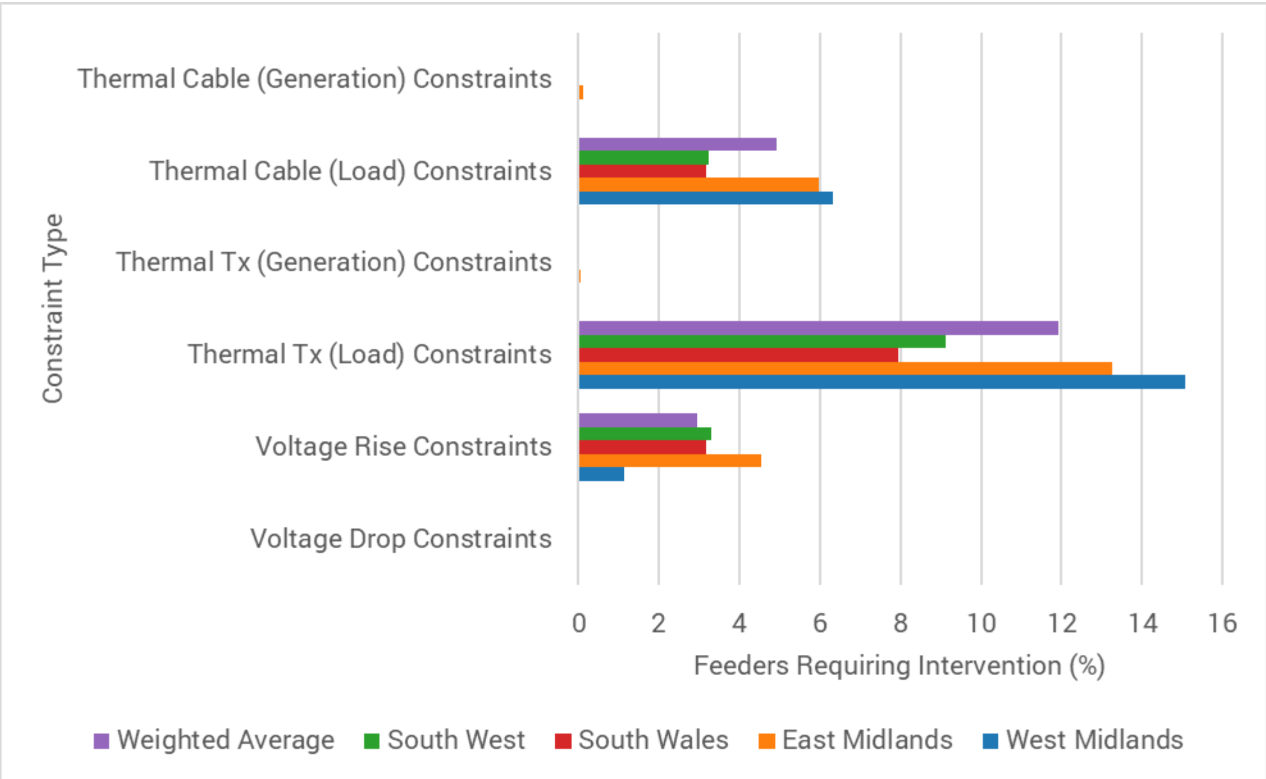

Figure 12: Cumulative percentage of feeders requiring intervention due to each network constraint type, by the year 2033 across under the Best View scenario for all licence areas.

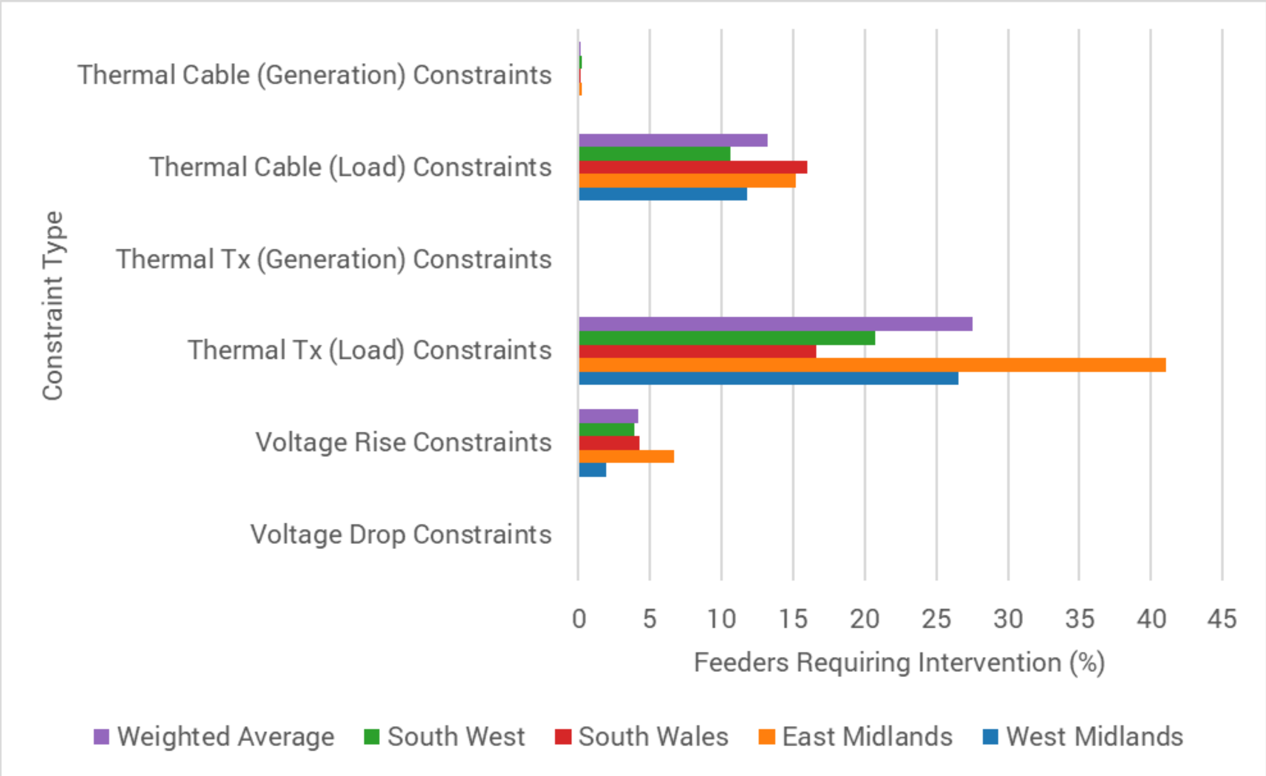

Figure 13Cumulative percentage of feeders requiring intervention due to each network constraint type, by the year 2040 across under the Best View scenario for all licence areas.

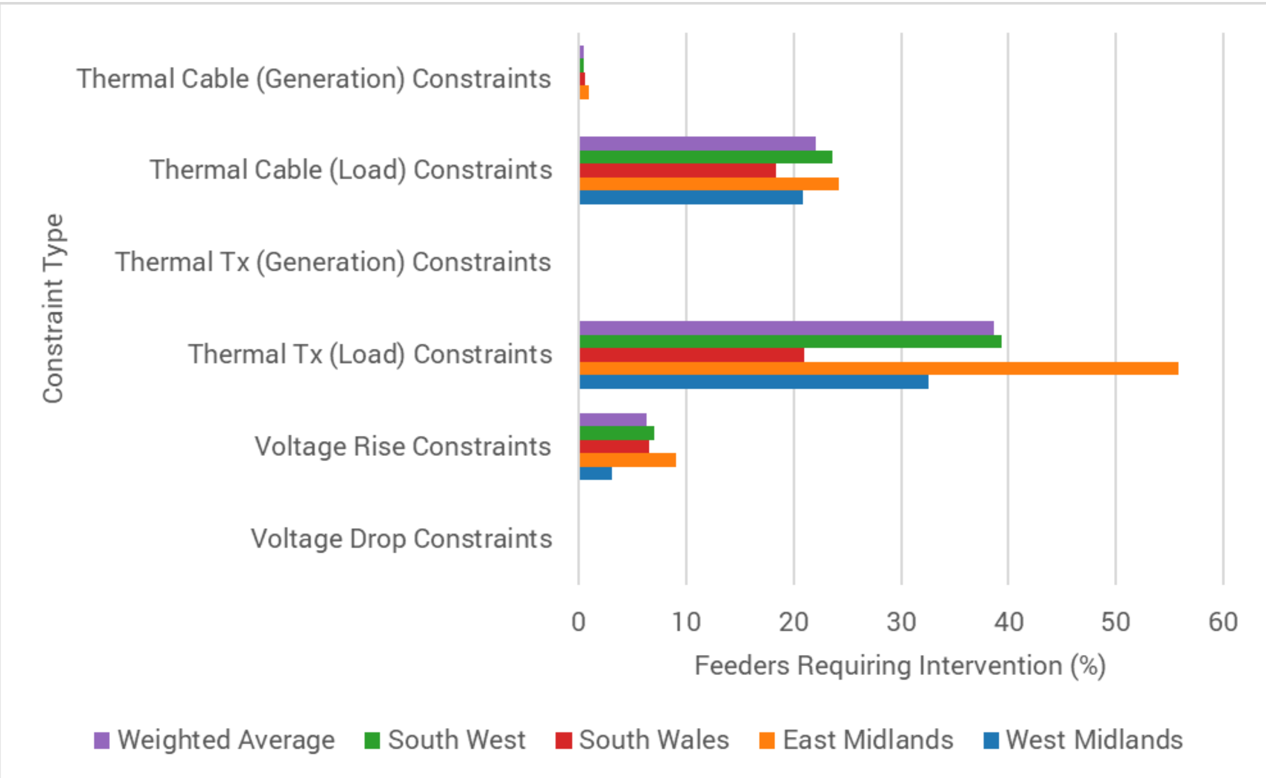

Figure 14: Cumulative percentage of feeder requiring intervention due to each network constraint type, by the year 2050 across under the Best View scenario for all licence areas.

Figure 15 to Figure 18 show the time profile of the cumulative network constraint types associated with East Midlands, West Midlands, South Wales and South West licence areas respectively for the Best View scenario. All four licence areas show a similar pattern; in the first few years of constraints are primarily Voltage Rise constraint, associated with increasing deployment of PV across the network coupled with low levels of voltage headroom available on the LV networks in the Transform model. The voltage headroom available on the LV networks is set at 1% in the original modelling assumptions, therefore small net exports (from PV deployment) are sufficient to cause voltage rise constraints. The low voltage headroom reflects that National Grid in common with other DNOs typically set their transformers towards the upper end of the statutory voltage limits, to leave more legroom for the voltage to drop along the feeder, This allows more load to connect while keeping within statutory voltage limits. From approximately 2025 onwards, both thermal transformer and thermal cable issues begin to be witnessed across the network. Load growth from primarily EVCPs and heat pumps drives the maximum import on LV networks above the limits necessitating solutions to be deployed. Previously, Figure 5 showed that residential EVCPs installations are due to grow rapidly from 2025 to approximately 2040 before largely plateauing. Similarly, Figure 2 and Figure 3 showed deployment of residential heat pumps increases rapidly, continuing to increase through to 2050. The combined increase in load from both heat pumps and EVCPs increases the maximum net import on many feeders above the thermal transformer and cable capacities, thus necessitating network reinforcements to resolve the thermal transformer (load) and thermal cable (load) constraints.

The constraints occurring as early as 2025 may in some instances seem earlier than anticipated but should be considered in combination with the uptake scenarios and clustering assumptions (section 3.4.2). The clustering may highlight issues earlier than expected for some parts of the network but also highlight a potential challenge with accommodating LCT uptake throughout the network.

West Midlands

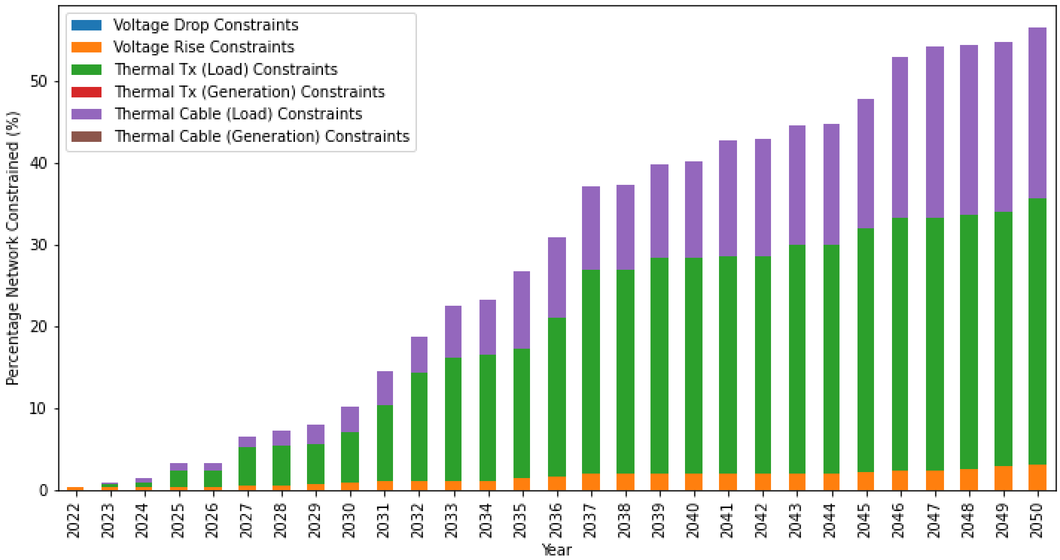

Figure 15: Cumulative network constraints across West Midlands under Best View scenario.

East Midlands

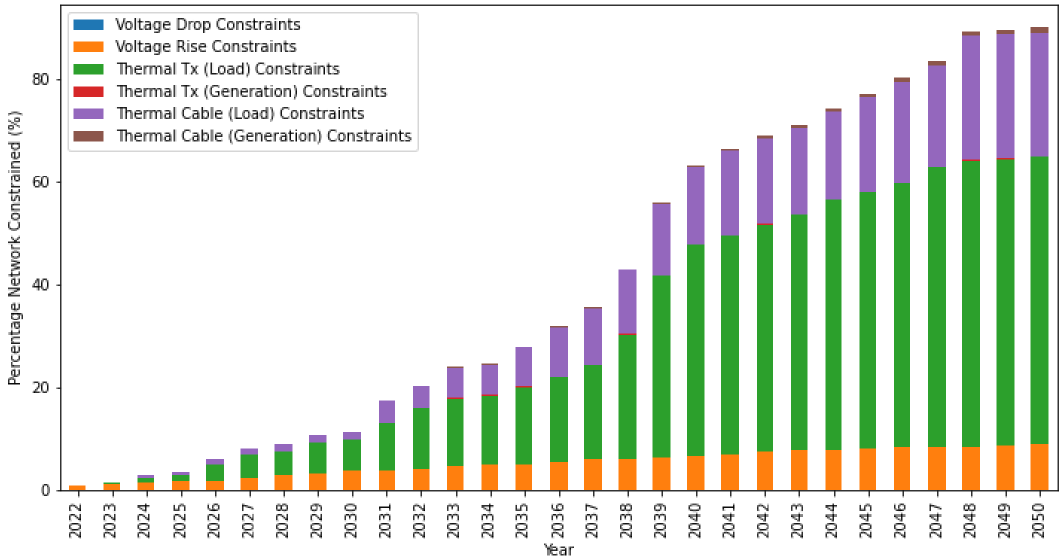

Figure 16: Cumulative network constraints across East Midlands under Best View scenario

South Wales

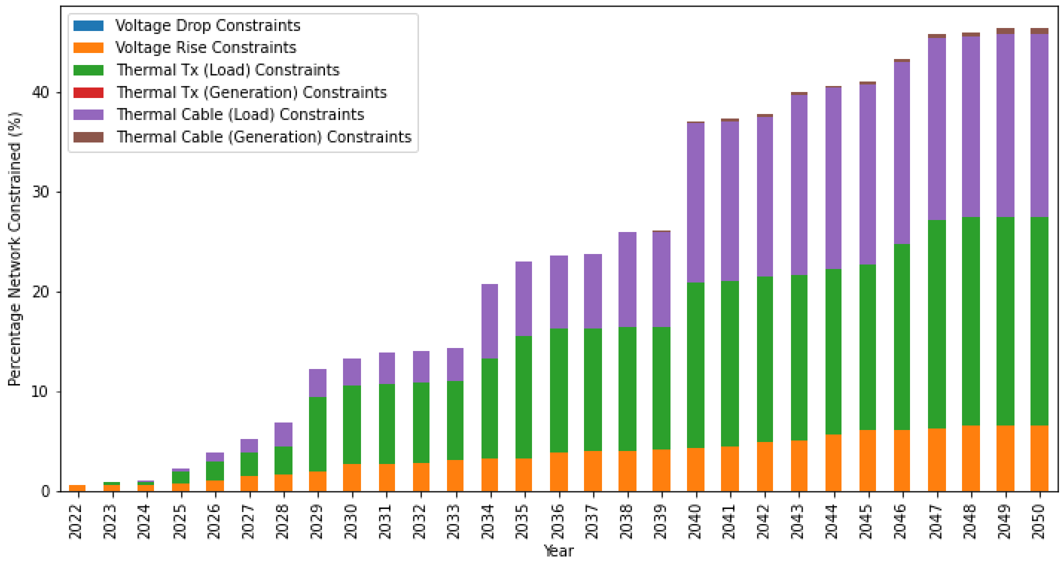

Figure 17: Cumulative network constraints across South Wales under Best View scenario

South West

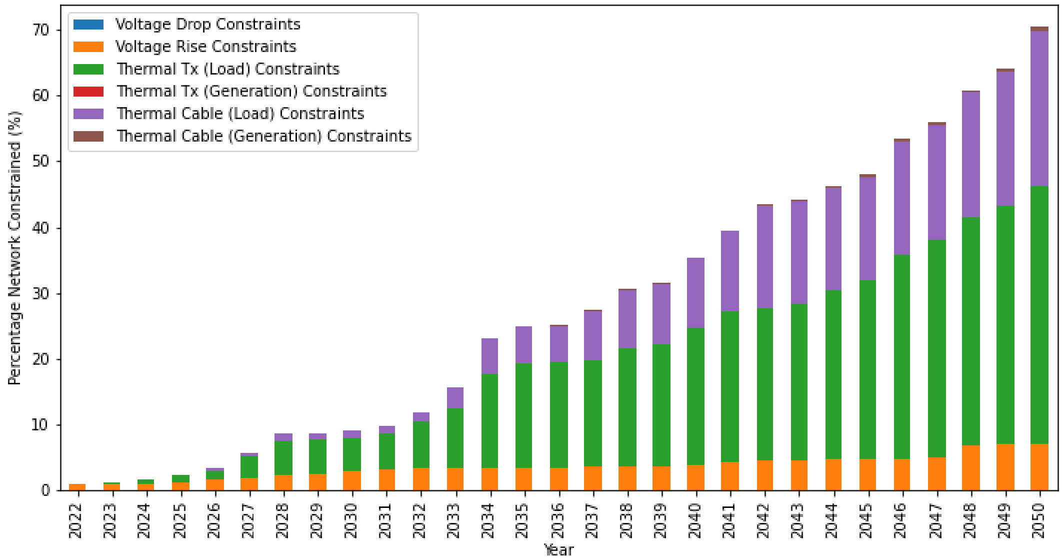

Figure 18: Cumulative network constraints across South West under Best View scenario

4.2.2 Constraints in the Best View Scenario by Period

National Grid Electricity Distribution as with other distribution network operators plan network investment around regulatory period cycles. Sensitivities should be carefully considered when examining year to year differences in the cumulative plots in section 4.2.1 as small change in assumed uptake rates, profiles or asset ratings can cause slight shifts in the timing on constraints being encountered. Averaging into regulatory periods reduces this since larger changes in the input parameters would be needed to shift investment into adjacent regulatory periods. The periods 2034-2040 and 2041-2050 are not regulatory periods, but periods selected to align with the DFES data available.

Figure 19 presents a weighted average (accounting for the fact each licence area has a different number of feeders) of the prevalence of each type of network constraint, aggregated by period. In the first regulatory period, approximately 8% of network require intervention for a combination of voltage rise and thermal constraints. By the second regulatory period, this increases to approximately 12% of networks, and becomes dominated more heavily by thermal constraints.

There is a distinct rise in prevalence of necessary new network interventions for the 2034-2040 period. In this time period 25% of network require intervention, mainly for thermal constraints. The necessary new network interventions remains high in the 2041-2050 period, although its longer time frame means the average number of interventions per year is down on the previous period. It may be necessary to relieve some of the constraints anticipated in 2034-2040 ahead of need (before 2034) due to finite staff resource, or to recruit and train additional staff by the 2034-2040 period for ensure the necessary network interventions can occur in a timely fashion.

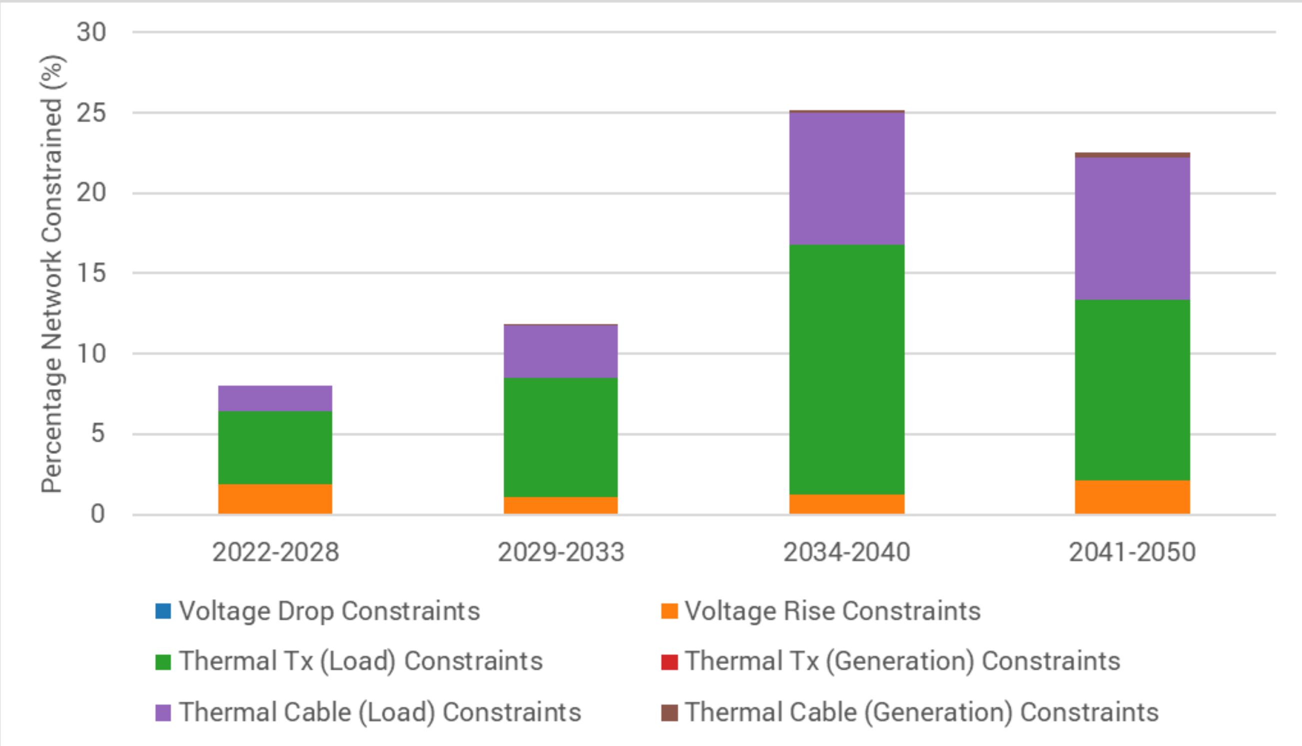

Figure 19: Weighted average of network constraints encountered by across National Grid's four licence areas under the Best View scenario. .

4.2.3 Constraints in the Leading The Way Scenario

Figure 20 to Figure 23 show the yearly and cumulative network constraint types encountered for the East Midlands, West Midlands, South Wales and South West licence areas respectively under the Leading The Way DFES scenario. The constraints encountered follow a similar pattern to the constraints encountered in the Best View scenario.

In the initial years, voltage rise constraints are highly prevalent due to high levels of PV uptake. Quickly thermal transformer (load) and thermal cable (load) constraints begin to be encountered across the network. Deployment of heat pumps and EVCPs at faster rates than in the Best View scenario (see Figure 2, Figure 3 and Figure 5) cause these constraints to occur earlier. Slightly higher forecast deployments of EVCPs and heat pump (particularly those with thermal storage) cause a modest increase in the number of LV networks encountering constraints by 2050, resulting in increased total numbers of constraints as more networks experience constraints.

West Midlands

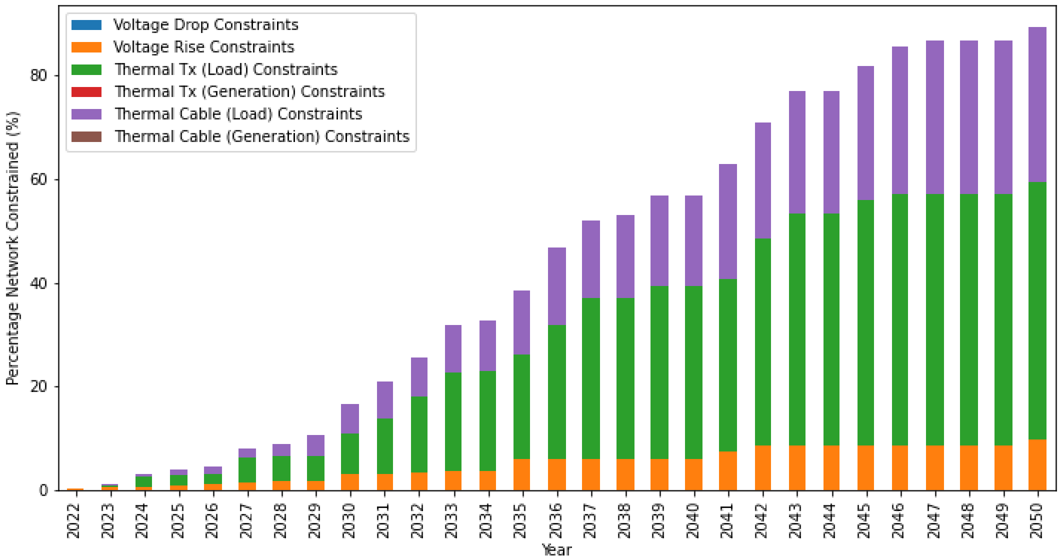

Figure 20: Cumulative network constraints across West Midlands under Leading the Way scenario

East Midlands

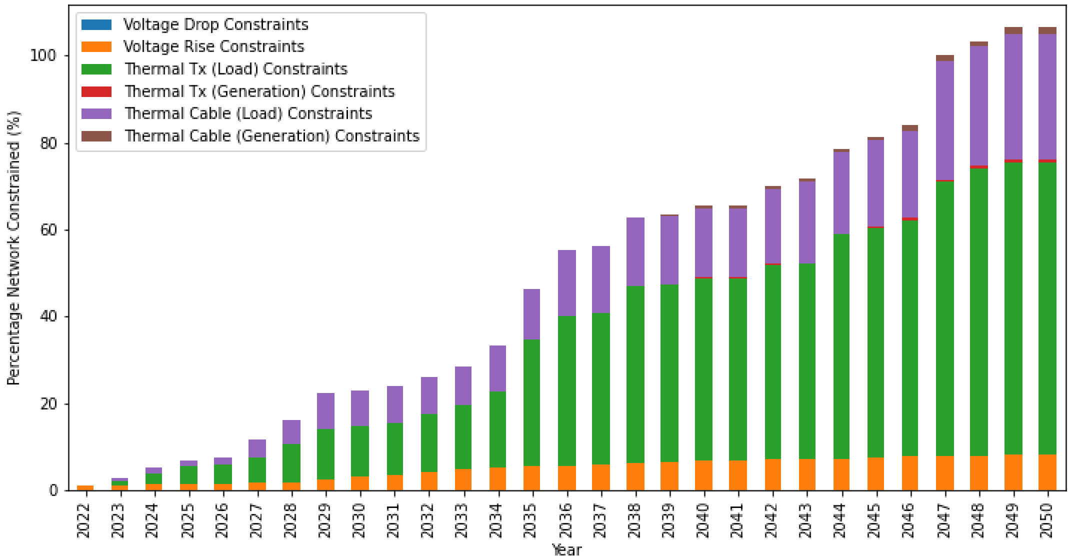

Figure 21: Cumulative network constraints across East Midlands under Leading the Way scenario

South Wales

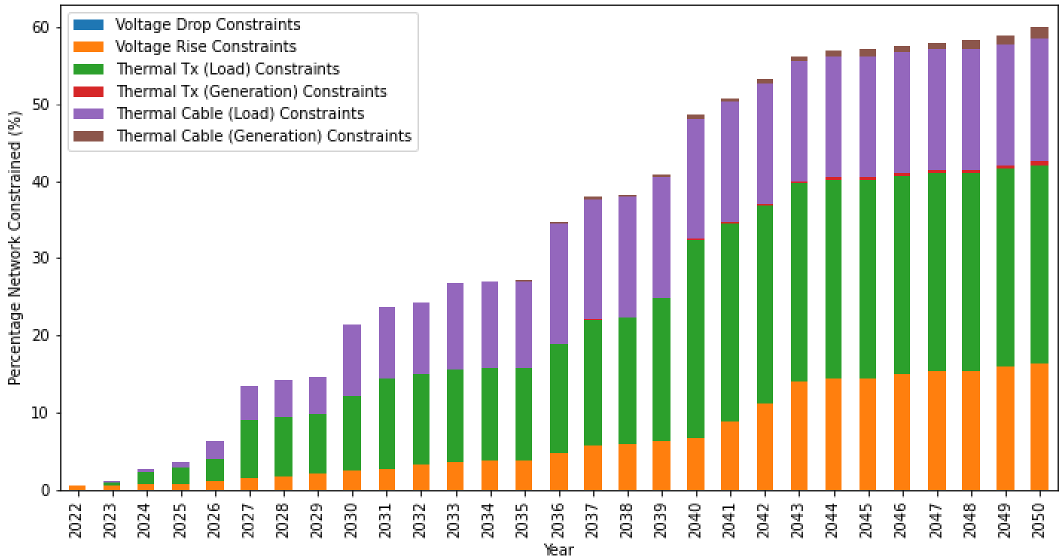

Figure 22: Cumulative network constraints across South Wales under Leading the Way scenario

South West

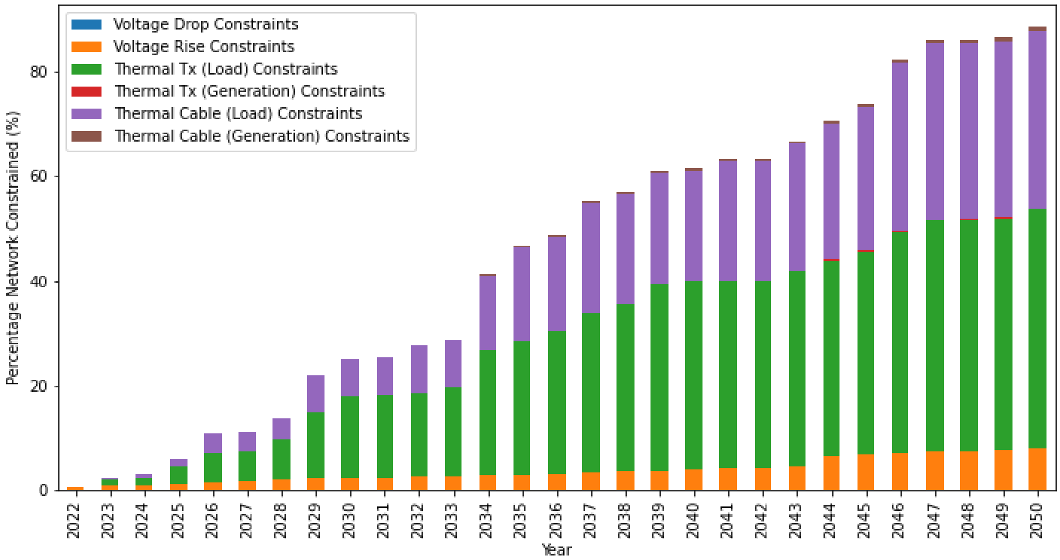

Figure 23: Cumulative network constraints across South West under Leading the Way scenario

4.2.4 Constraints in the Steady Progress Scenario

Figure 24 to Figure 27 show the cumulative network constraint types encountered for the East Midlands, West Midlands, South Wales and South West licence areas respectively, under the Steady Progress DFES scenario. Once again, the constraints encountered follow a similar pattern to the constraints encountered in the Best View and Leading The Way scenarios. Initially, the most prevalent network constraints are voltage rise constraints, once again caused by the deployment of PV across the LV network. The increasing deployment of heat pumps and EVCPs again cause thermal transformer (load) and thermal cable (load) constraints. However, the slower uptake rates of these technologies (see Figure 2, Figure 3 and Figure 5) result in these constraints occurring later than in the other two scenarios. In addition, the reduced total uptake of EVCPs and heat pumps (particularly with heat pumps) results in fewer constraints occurring, resulting in a reduced number of constraints being witnessed in the Steady Progress scenario by 2050.

West Midlands

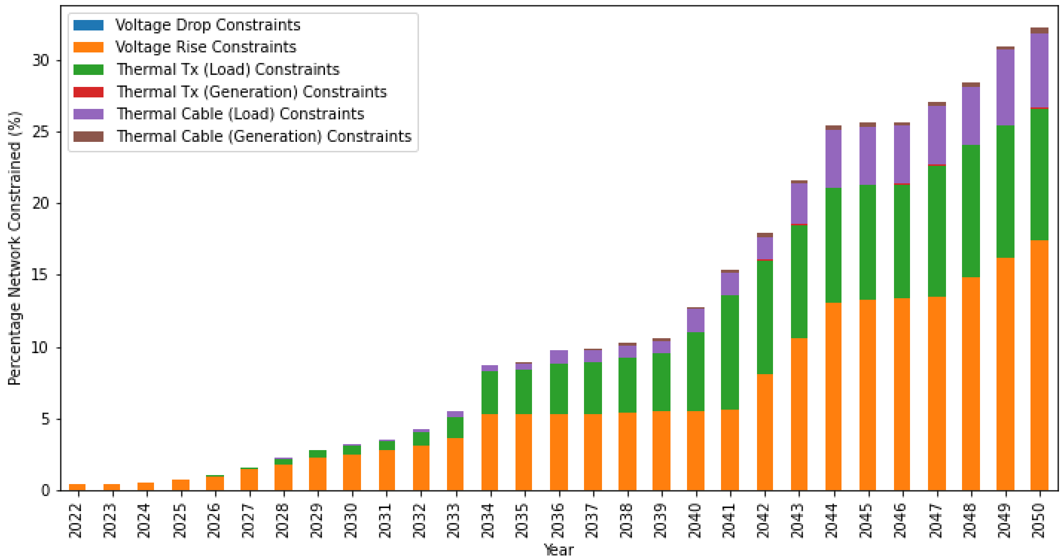

Figure 24: Cumulative network constraints across West Midlands under Steady Progress scenario

East Midlands

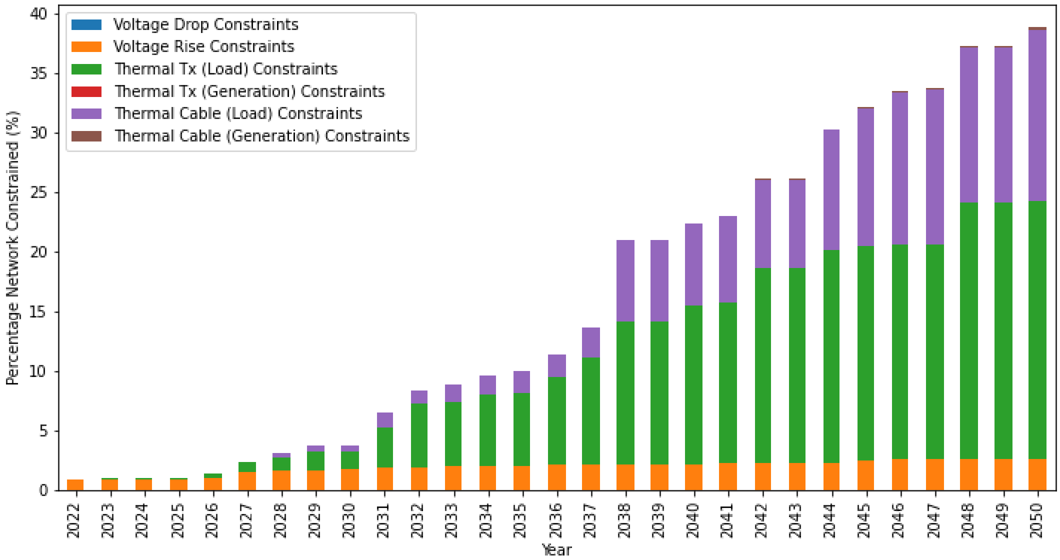

Figure 25: Cumulative network constraints across East Midlands under Leading the Way scenario

South Wales

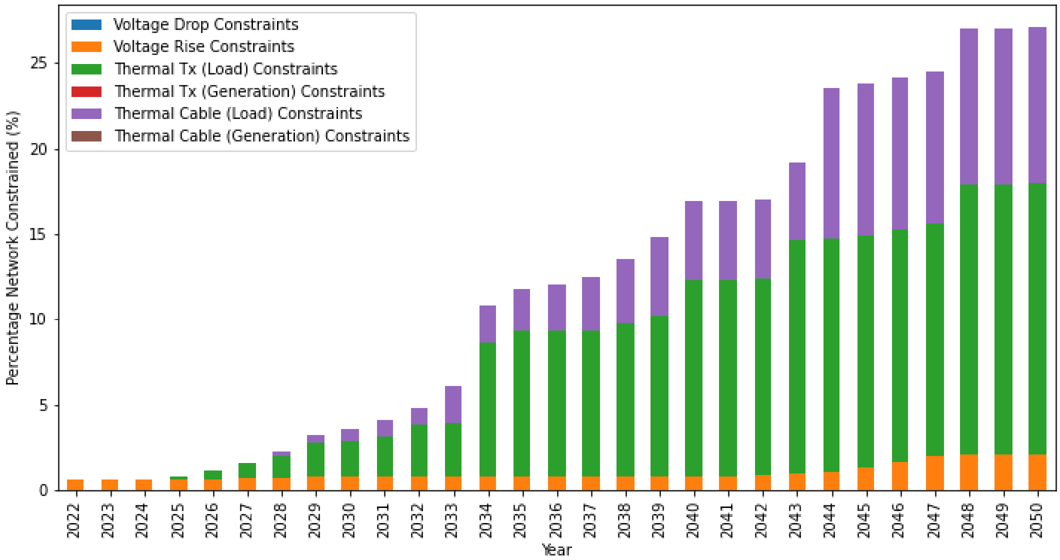

Figure 26: Cumulative network constraints across South Wales under Steady Progress scenario

South West

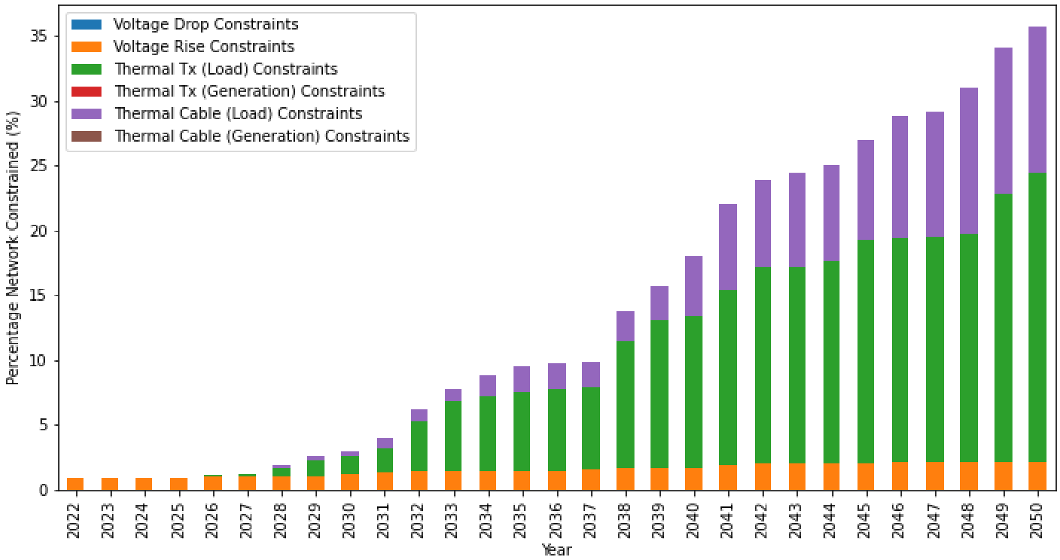

Figure 27: Cumulative network constraints across South West under Steady Progress scenario

4.2.5 Conclusions from Network Wide Constraint Analysis

The analysis presented in the previous sections with regards to constraints associated with the National Grid licence areas has shown the extent of both voltage and thermal constraints across networks between 2022 and 2050.

In summary, across National Grid's four electricity distribution licence areas voltage rise constraints will be prevalent in the near term future, at relatively low frequencies of approximately 2% of feeders by 2028. The growth in prevalence of voltage rise constraints is steady, rising to affect 7% of feeders by 2050. Thermal constraints will become the dominant form of network constraint. By 2040 thermal constraints will affect 40% (27% transformer, 13% thermal) of feeders, rising to 60% (38% transformer, 22% thermal) by 2050.

For all licence areas, comparing the network constraint types encountered in the Best View (section 4.2.2), Leading the Way (section 4.2.3) and Steady Progress (section 4.2.4) shows the constraint types encountered in each scenario are similar. The Leading the Way scenario, which has the fastest uptake rate of LCTs, witnesses constraints of all type earlier and at greater penetration than in the Steady Progress scenario, which has the slowest uptake rate of LCTs.

For the West Midlands licence area, a greater level of voltage rise constraint occurs in the Steady Progress scenario and a lower level of thermal constraint compared to the Best View and Leading The Way scenarios. Slower uptake rates of heat pumps and EVCPs is insufficient to prevent net export from the PV generation installed causing breech of voltage rise limits. This illustrates the nature of tipping points in the Transform study. A tipping point exists between the uptake rates in the Steady Progress and Best View scenarios which cause more thermal constraints and less voltage rise constraints.

The following conclusions are drawn from this analysis across the 3 scenarios.

C1. In the near term, voltage rise constraints will be prevalent arising as increasing levels of PV is installed within the network. It is witnessed early due to a combination of significant early solar PV uptake deployed in a clustered manner (therefore some networks have high levels of PV uptake from the outset in 2022), in addition to small amount of voltage rise headroom.

C2. Voltage rise issues across many LV network archetypes continue to increase in number out until 2050 due to increasing uptake solar PV. However, for most licence areas and scenarios, the total number of voltage rise constraints increase slowly (or even plateau) after the mid-2030s.

C3. From the late 2020s the most dominant forms of new network constraint are thermal cable and thermal transformer both under load. These constraints are driven by high uptake rates of both heat pumps and EVCPs.

C4. Voltage drop constraints are not expected to be a significant issue across National Grid's network. This is due to a combination of existing voltage drop legroom and in the case of many solutions[9], solutions deployed to resolve either voltage rise and thermal constraints releasing additional voltage headroom before limits are reached.

C5. Across National Grid's licence areas, a significant increase in the frequency of (largely thermal) constraints encountered is forecast for the 2034-2040 period. This may warrant investing ahead of need or training of additional staff ahead of this period. Network constraints encountered remains high for the 2041-2050 period.

[9] Note not all solutions deployed to resolve voltage rise constraints increase voltage legroom; for example adjusting tap positions to increase voltage headroom reduces legroom.

C6. For each licence area, the types of network constraints encountered in each DFES scenario is similar. The prevalence of network constraints is higher in scenarios with greater levels of LCT uptake (Leading the Way) compared to the scenario with the lowest level of LCT uptake (Steady Progress) and network constraints occur earlier.

Based on the analysis of the network constraints, the following recommendations can be made which will need to be taken into consideration when investigating the potential for novel or emerging solutions.

R3. Solutions that cost effectively release voltage headroom capacity will see wide-scale deployment to support the forecast PV uptake, on feeders where many PV installations are clustered together. Due to the high prevalence of this network constraint type, National Grid should continue to closely monitor new technologies that offer potential voltage headroom release as these could provide high value across the electricity distribution network.

R4. Solutions that simultaneously voltage headroom and thermal capacity will also enable the continued support for forecast heat pumps and EVCPs. National Grid should closely monitor new technologies that could offer these as an option to avoid revisiting sites for subsequent capacity release.

4.3 Constraint Analysis by Archetypes

This section of the report presents the types of network constraints witnessed on each LV network archetype under the Best View DFES scenario. To limit the length of this report, this section displays only the yearly and cumulative constraint plots for the Best View DFES scenario. The yearly and cumulative constraints plots on a network archetype by network archetype basis for the Leading The Way and the Steady Progress scenarios are available as detailed in Appendix VI.

Table 7 details the network constraints encountered by each LV network archetype across National Grid's four licence areas. The network constraints are ordered chronologically in each cell, such that the network constraints encountered earliest in the model appear at the top of each cell. It is clear that although generally the same LV archetypes experience the same constraints irrelevant of network region, it is not the case for all areas. This is likely to be due to different customer distributions combined with LCT uptake scenarios and profiles. Therefore, it is important that when considering recommendations for solution deployment the specific characteristics of each area are factored in to develop the associated guidance. Table 7 is colour coded to indicate the year in which network constraints first occur (on above 1% of feeders); red cells represent a constraint that occurs before the end of 2028, amber cells indicate constraints that occur after 2028 but before the end of 2040 and green cells represent constraints that occur after 2040 but before the end of 2050. Red cells therefore represent constraints that will require addressing within the next regulatory period, amber cells in the two regulatory periods that follow and green cells constraints that will require addressing by 2050.

Table 8 also displays the network constraints encountered. This table is colour coded according to the penetration of each network constraint by 2050. Red cells indicate the network constraint type occurs on greater than 20% of the feeders of that archetype in 2050, amber cells indicate the network constraint type occurs on between 5% and 20% of the feeders by 2050 and green cells indicate that the network constraint type occurs on less than 5% of the feeders by 2050. The RAG status can be used to quickly identify the network constraint types that present the biggest issues to the network operator.

Comparing the types of network constraints encountered for each LV network archetype, it is observed that broadly speaking each LV network archetype falls into one of two groups. Firstly, for LV network archetypes LV1, LV3, LV4 and LV5, that network constraints encountered on these networks are all export related. All these network archetypes witness voltage rise constraints from 2022. Later LV3, LV4 and LV5 witness thermal cable constraints (under export) in all licence areas. LV1 typically witnesses both thermal transformer and thermal cable constraints (under export), except for in South Wales where only thermal transformer constraints are encountered. The export constraints are caused by the deployment of PV.

LV1, LV3, LV4 and LV5 feeders represent central business district, town centres, business parks and retail parks. All these feeders are therefore dominated by commercial rather than residential customers. No commercial heat pump profile has been considered in this study, since there is no commercial heat pump profile available from DFES 2021. The majority of the EVCPs forecast by DFES 2021 are residential EVCPs, which can only be connected at residential properties. Other EVCP types such as destination and workplace can be connected at commercial properties, but the forecast uptake rates of these EVCP types are much smaller. With the lack of commercial heat pumps and EVCPs considered there is insufficient load growth across these network archetypes to drive load related network constraints (either voltage drop or thermal).

LV2, LV6, LV7, LV8, LV9, LV10 and LV11 all witness voltage rise constraints relatively early (across all licence areas). Again, this is due to the deployment of solar PV on these network archetypes. Later, these network typically encounter both thermal transformer and thermal cable constraints (under import). For some feeders and licence areas only one of these thermal constraints is encountered, which is typically due to a solution deployed to resolve one type of network constraint also increasing the headroom for the other type of thermal constraint. An example of this if for LV9, across all licence areas the thermal constraint encountered in thermal transformer. A common solution to this is new pole mounted transformer circuits, which release additional thermal cable capacity. Since the thermal transformer constraint is encountered first and this solution deployed, this releases additional thermal cable capacity which prevent thermal cable issues being encountered. LV9 feeders, which represent rural village feeders of an overhead construction, experience thermal transformer constraints early across all licence areas, due to low thermal capacity limits of the existing PMTs on the network (see Appendix V) coupled with strong early uptake rates of particularly EVCPs increasing demand. Continued strong uptake rates of EVCPs and residential heat pumps, coupled with the low thermal transformer headroom result in high penetration of LV9 feeders witnessing thermal transformer constraints.

Figure 28 to Figure 38 show the constraints encountered for each LV network archetype in turn, for the West Midlands licence area under the Best View Scenario. Since many of the plots for the East Midlands, South Wales and South West licence areas are similar, these can be found in Appendix VII, Appendix VIII and Appendix IX. In most cases, the differences between network constraints across licence areas is the timing of the constraints being encountered.

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Table 7: Types of network constraints encountered on each network. The constraint appearing at top of each LV archetype occurs chronologically earliest. The colour coding is as follows, red cells indicate network constraints that are encountered on the network archetype at penetrations higher than 1% by 2028, amber cells indicate this threshold is reached by 2040 and green cells indicate the threshold is reached by 2050.

LV Network Archetype	West Midlands	East Midlands	South Wales	South West
LV1	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Export)	Thermal Transformer (Export)		Thermal Cable (Export)
	Thermal Cable (Export)	Thermal Cable (Export)		
LV2	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Transformer (Import)
		Thermal Transformer (Import)		Thermal Cable (Import)
LV3	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)
LV4	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)
LV5	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)
LV6	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)
LV7	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Cable (Import)
	Thermal Transformer (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Transformer (Import)
LV8	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Cable (Import)
	Thermal Transformer (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Transformer (Import)
LV9	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
LV10	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
		Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)
LV11	Voltage Rise	Voltage Rise	Thermal Cable (Import)	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
	Thermal Cable (Import)	Thermal Cable (Import)		Thermal Cable (Import)

Table 8: Colour coded table indicating prevalence of network constraint by 2050. Green indicates network constraint penetration less than 5% by 2050, amber indicate network constraint penetration between 5% and 20% by 2050 and red indicate network constraint penetration in excess of 20% by 2050.

LV Network Archetype	West Midlands	East Midlands	South Wales	South West
LV1	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Export)	Thermal Transformer (Export)		Thermal Cable (Export)
	Thermal Cable (Export)	Thermal Cable (Export)		
LV2	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Transformer (Import)
		Thermal Transformer (Import)		Thermal Cable (Import)
LV3	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)
LV4	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)
LV5	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)	Thermal Cable (Export)
LV6	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)
LV7	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Cable (Import)
	Thermal Transformer (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Transformer (Import)
LV8	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Cable (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Cable (Import)
	Thermal Transformer (Import)	Thermal Cable (Import)	Thermal Cable (Import)	Thermal Transformer (Import)
LV9	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
LV10	Voltage Rise	Voltage Rise	Voltage Rise	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
		Thermal Cable (Import)	Thermal Cable (Import)	Thermal Cable (Import)
LV11	Voltage Rise	Voltage Rise	Thermal Cable (Import)	Voltage Rise
	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)	Thermal Transformer (Import)
	Thermal Cable (Import)	Thermal Cable (Import)		Thermal Cable (Import)

4.3.1 West Midlands Best View

The following figures present the results of LV archetypes considered for the West Midlands area under the Best View scenario. The same characteristics can be seen across all of the network regions with the exceptions of those detailed further in section 4.3.2. For completeness, full details of the LV network archetype constraints across all network regions are included in the appendices.

LV1 Central Business District

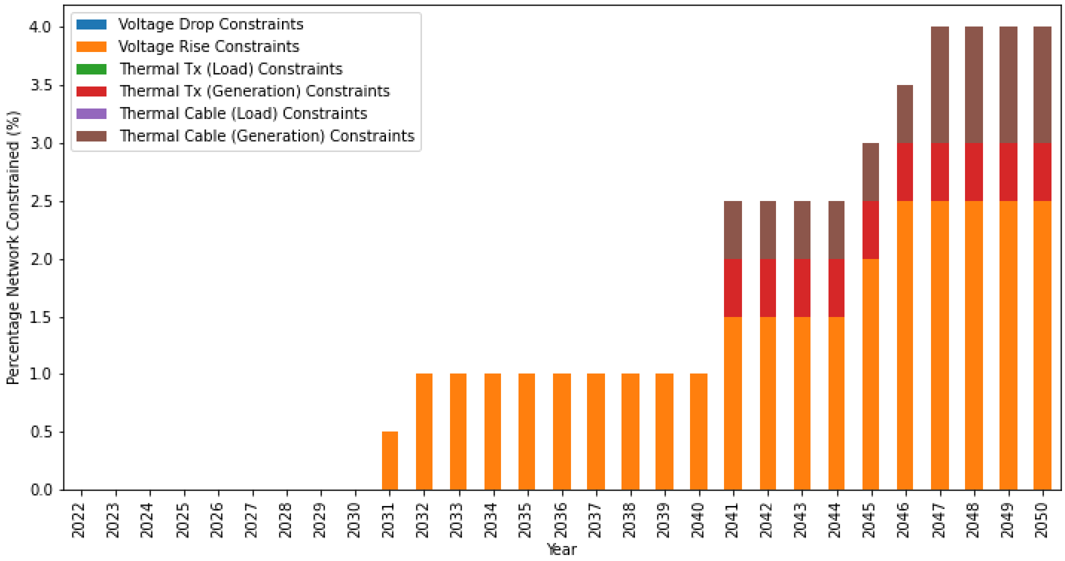


Figure 28: Cumulative Constraints for network archetype LV1 in West Midlands, Best View scenario

LV2 Dense urban (apartments etc)

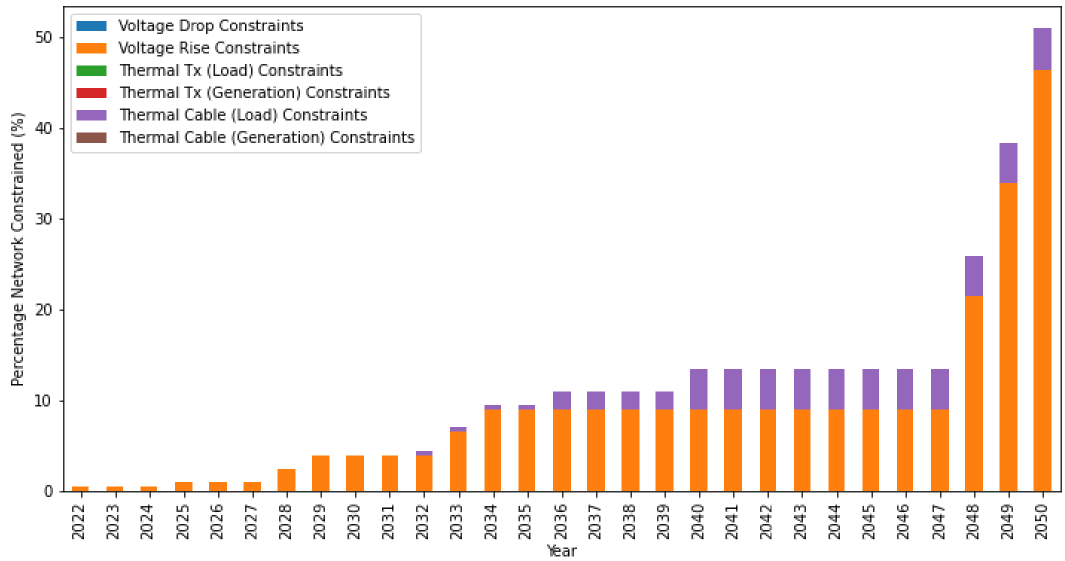


Figure 29: Cumulative Constraints for network archetype LV2 in West Midlands, Best View scenario

LV3 Town Centres

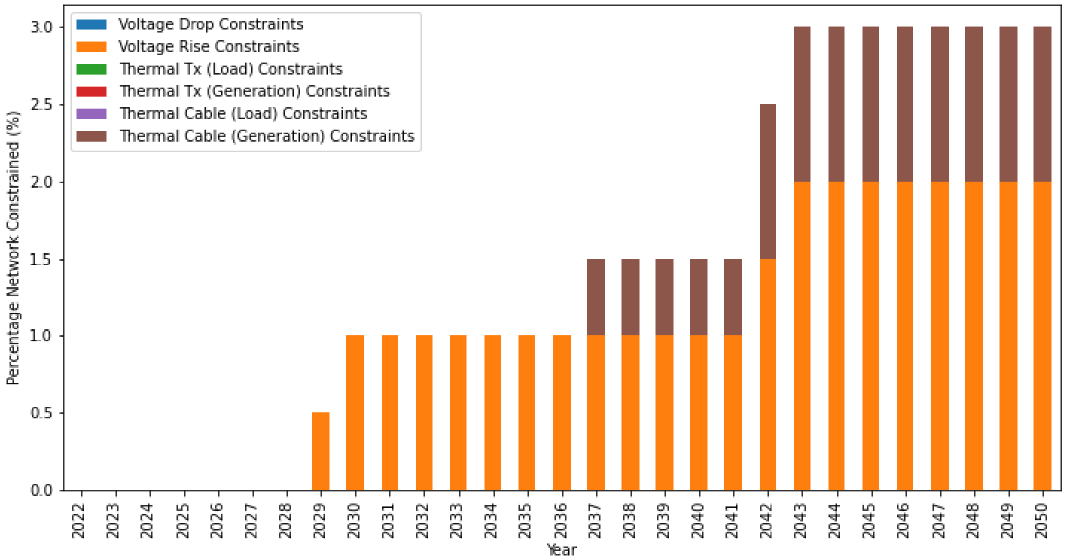


Figure 30: Cumulative Constraints for network archetype LV3 in West Midlands, Best View scenario

LV4 Business Park

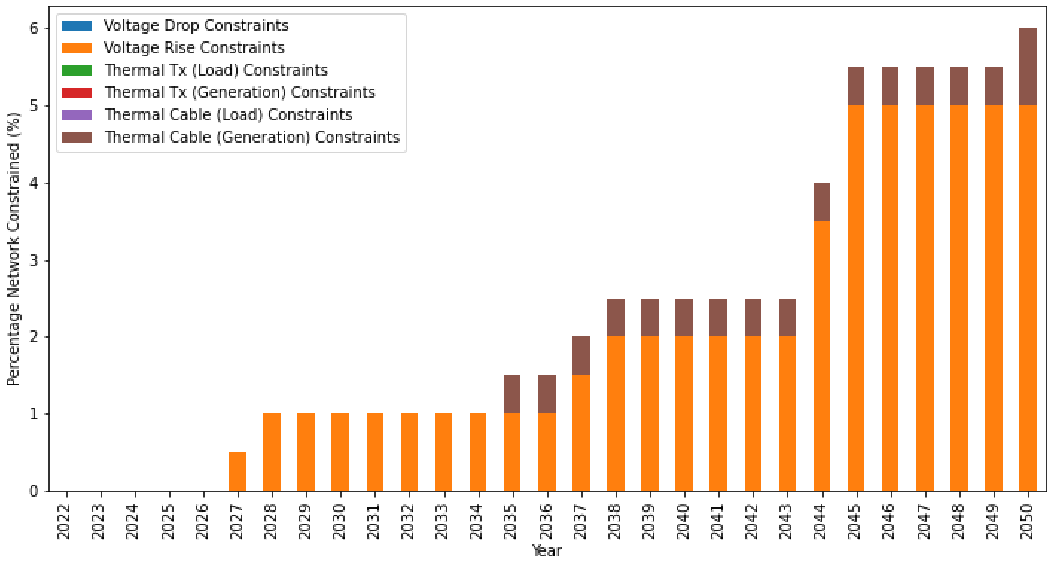


Figure 31: Cumulative Constraints for network archetype LV4 in West Midlands, Best View scenario

LV5 Retail Park

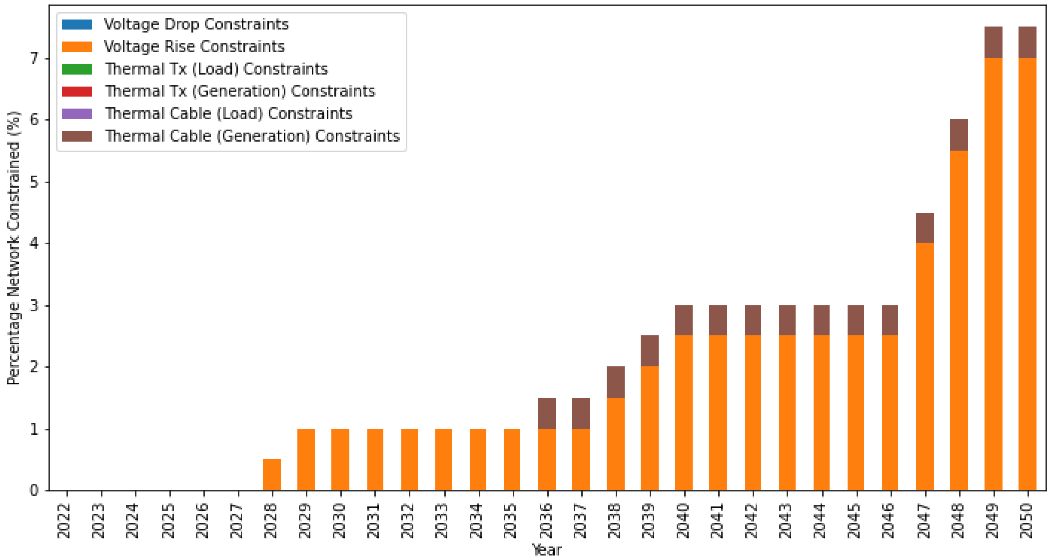


Figure 32: Cumulative Constraints for network archetype LV5 in West Midlands, Best View scenario

LV6 Suburban street (3 4 bed semi detached or detached houses)

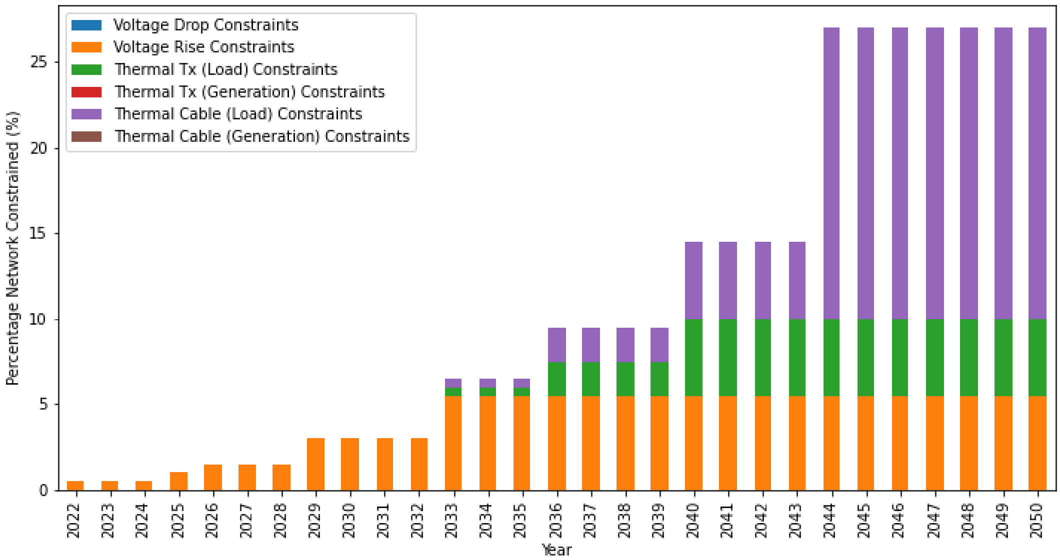


Figure 33: Cumulative Constraints for network archetype LV6 in West Midlands, Best View scenario

LV7 New build housing estate

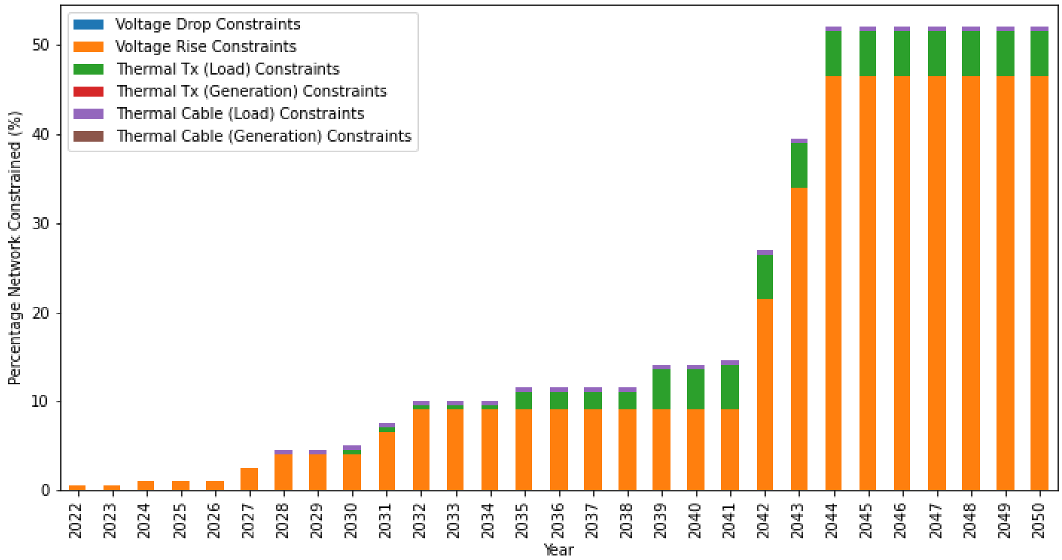


Figure 34: Cumulative Constraints for network archetype LV7 in West Midlands, Best View scenario

LV8 Terraced Street

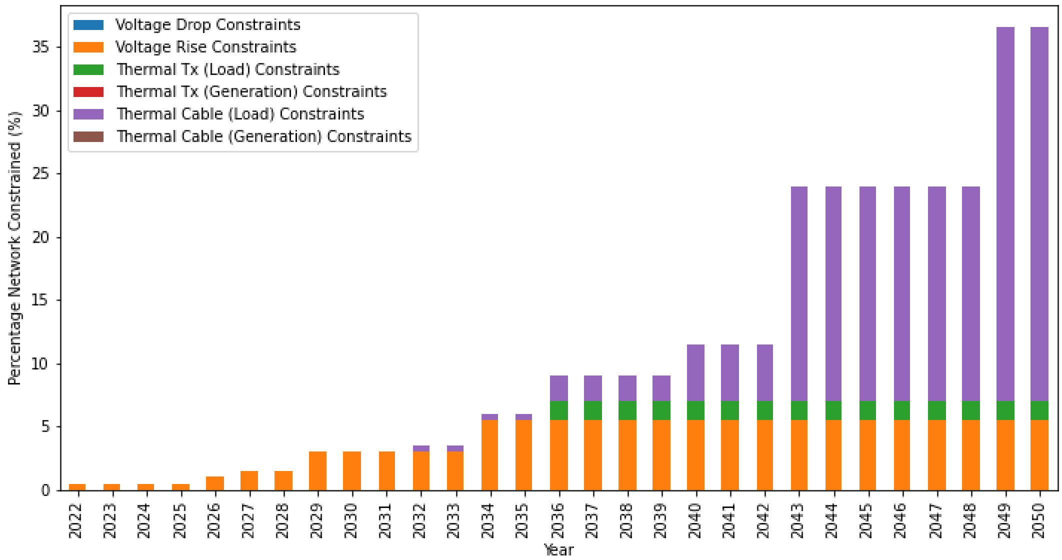


Figure 35: Cumulative Constraints for network archetype LV8 in West Midlands, Best View scenario

LV9 Rural village (overhead construction)

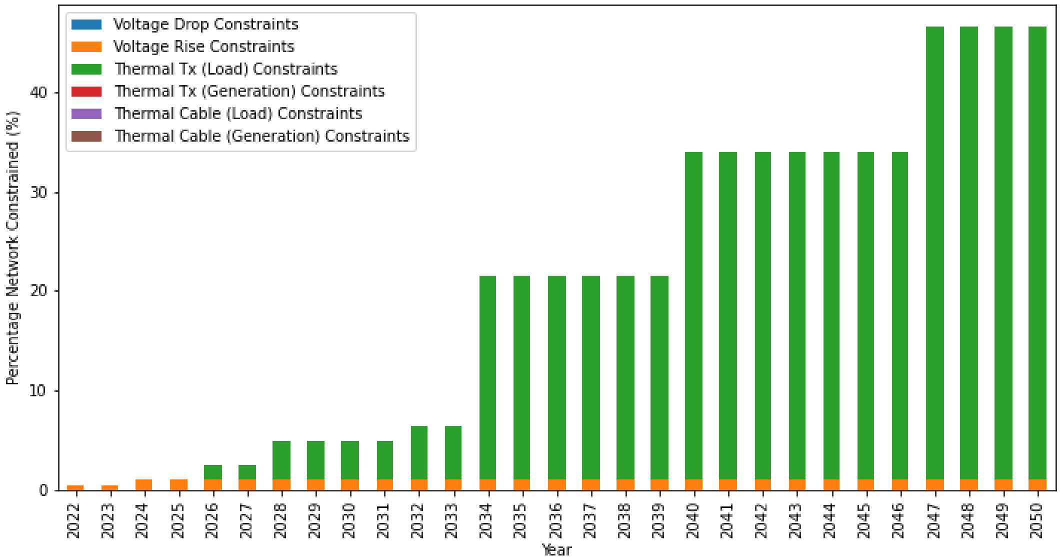


Figure 36: Cumulative Constraints for network archetype LV9 in West Midlands, Best View scenario

LV10 Rural village (underground construction)

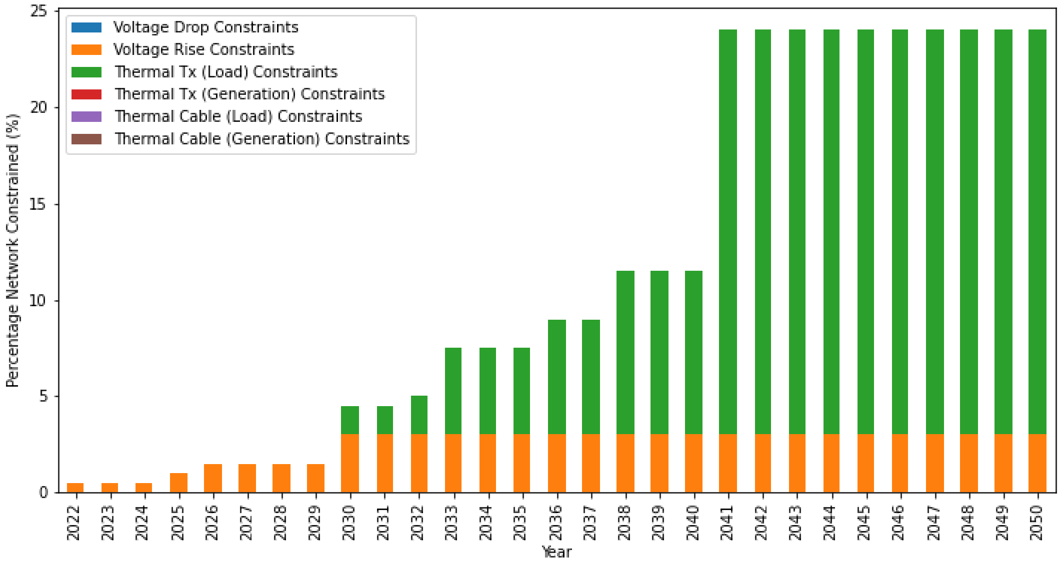


Figure 37: Cumulative Constraints for network archetype LV10 in West Midlands, Best View scenario

LV11 Rural farmsteads small holdings

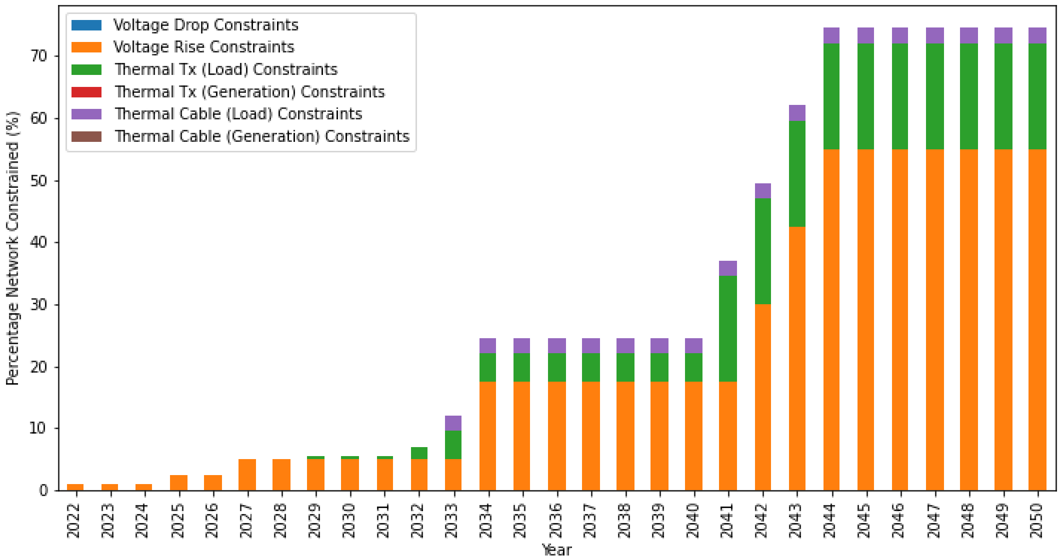


Figure 38: Cumulative Constraints for network archetype LV11 in West Midlands, Best View scenario

4.3.2 Conclusions for Constraint Analysis by Archetype

The following conclusions are drawn from assessing the constraints encountered at a LV network archetype level across licence areas and scenarios.

C7. LV network archetype LV1 (central business districts). LV3 (town centres), LV4 (business parks) and LV5 (retail parks) witness significant voltage rise constraints, typically beginning from the mid-late 2020s. Later thermal cable (generation) constraints begin to be encountered, with occasionally thermal transformer (generation) constraints also being encountered. However, these occur on relatively few networks.

C8. Typically, voltage rise and thermal constraints due to generation on LV1, LV3, LV4 and LV5 occur at relatively low penetration levels even out until 2050.

Conclusion C9must be considered in conjunction with the assumptions used throughout this project. Two assumptions are particularly relevant.

- Firstly, no commercial heat pump profile has been considered throughout this report. The addition of a commercial heat pump profile would increase load on LV1, LV3, LV4 and LV5, all of which are feeder type that serve a significant quantity of commercial customers. This additional load could be sufficient to drive additional network constraints (likely thermal).
- Secondly, the vast majority of the EVCPs included in this study are residential EVCPs, which cannot be installed at commercial properties. Although there are other EVCP types that can connect at commercial properties (e.g. destination), there are relatively few of these EVCPs (see uptake rates in Appendix II) and therefore insufficient to drive network constraints.

Were commercial heat pumps to be considered and non-residential EVCPs to be deployed at higher uptake rates, it is possibly that the type and timing of when network constraints were encountered would be shifted.

C9. LV network archetypes LV2 (dense urban e.g. apartments), LV6 (sub-urban streets), LV7 (new build housing estates), LV8 (terraced streets), LV9 (rural village overhead), LV10 (rural village underground) and LV11 (rural farmsteads) witness voltage rise constraints occur initially, typically at low penetration levels. Later (typically from the mid-late 2030s) thermal constraints become more dominant reaching higher penetration levels.

4.4 GB vs National Grid Analysis

To ensure that conclusions drawn for National Grid's network licence areas is applicable across other regions, this section presents the same constraint analysis carried out across the GB wide model. Uptake scenarios are not available for every region and so the GB model is based off the LCT uptake scenarios associated with the Climate Change Committee Balanced Net Zero Pathway scenario [3]. This is the same scenario that the GB distribution network operators have been asked to consider by Ofgem as part of their RIIO-ED2 submissions and therefore provides a level of consistency across results sets.

Analysis of the Transform outputs to identify the types of network constraint encountered across GB is presented in this section of the report.

4.4.1 Constraints

Figure 39 shows the constraints encountered across the network according to the GB model. As with the analysis carried out for the National Grid licence areas, initially constraints are dominated by voltage rise constraints due to the deployment of PV.

From the late 2020s, thermal constraints requiring upgrades or capacity release for both transformers and cables beginning to dominate across the GB networks.. The number of these thermal constraints continue to grow out to 2050 due to continued deployment of heat pumps and EVCPs across the network.

This follows a similar pattern to that observed across National Grid licence areas. For example, under the Best View scenario, Figure 15 to Figure 18 show the same general pattern of early constraints being dominated by voltage rise constraints at relatively low penetration, before later thermal constraints become increasingly dominant at high penetrations. This supports the hypothesis that the constraints facing National Grid networks are representative of the wider GB network.

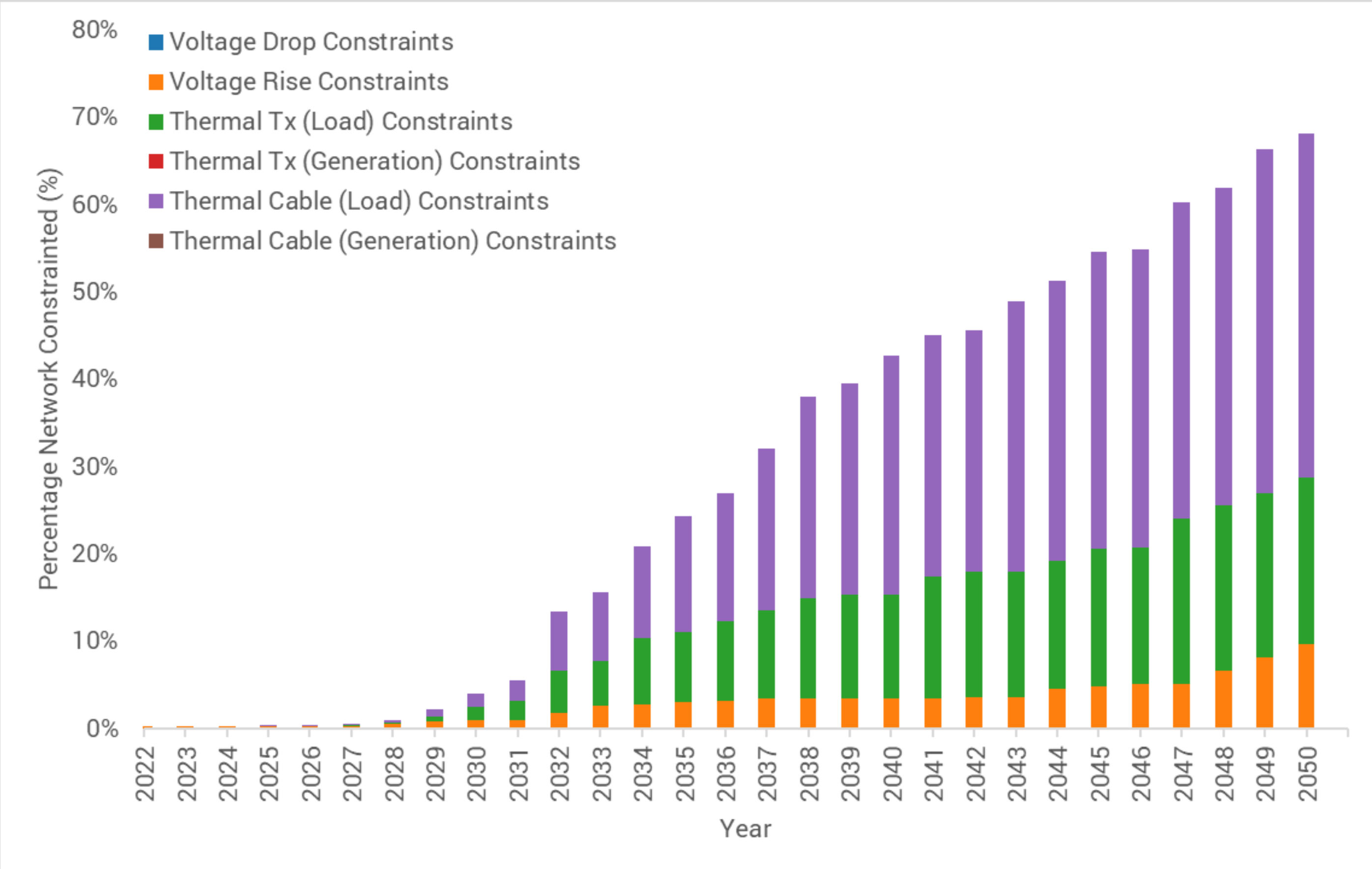


Figure 39: Cumulative constraints in percentage terms across the GB network in GB model

5. Conclusions and Recommendations

Forming a section of the SILVERSMITH project, the purpose of this report is to identify the network constraints that will be encountered across each of National Grid's electricity distribution licence areas as a result of forecast LCT uptake levels. Before conducting analysis to identify the network constraints the Transform models required updates to represent the latest data from the DFES 2021 scenarios both in terms of LCT uptake and LCT profiles. Those inputs and associated assumptions have been detailed in the report and resulted in four updated Transform Models, one model for each of National Grid's distribution licence areas. Each model is based on the latest published assumptions regarding LCT uptake and profiles as outlined in DFES 2021 [1]. A thorough validation process to ensure that the models are representative of each of National Grid's licence areas was carried out and presented in this report.

To understand the challenges facing National Grid in each of its licence area, this report then presents analysis into the types of network constraint encountered across each of National Grid's four licence areas. In addition to identifying network constraint types at a network level, analysis has been conducted to identify the specific network constraints anticipated across each particular LV feeder archetype. This analysis into network constraint types and timing allows identification of the types of solution that will be required to alleviate network constraints and how they could potentially be implemented cost-effectively.

Detailed analysis into the traditional investment options and indicative costs vs the potential savings through novel or emerging solutions will be presented in a subsequent report for Deliverable 2.1 of this project (Functional Requirements). The Functional Requirements will outline the technical requirements from solutions, and also the required price point at which the technology would be deployed in favour of traditional solutions. The Functional Requirement will qualitatively consider wider network impacts of technologies such as flexibility in deployment (can solution be redeployed elsewhere) and the timescales associated with deployment (solution with short timescales to deploy are favourable to those with longer deployment timescales). That analysis will take input from the previous literature review (EA16141-TR2 [4]) and associated RfI process to ensure solutions are represented appropriately to lead into the development of appropriate functional specifications. This will highlight the financial savings (or other consumer benefits) that are available from novel technologies and provide recommendations covering where gaps in technology development exists along with the typical conditions under which they offer the greatest value.

5.1 Conclusions

The following conclusions can be drawn from the detailed analysis carried out in the production of this report and highlighting the learning established so far in this phase of the SILVERSMITH study.

C1. In the near term, the dominant network constraint types will be voltage rise constraints. Voltage rise constraints will arise as solar PV is increasingly deployed across the network. It is witnessed early due to a combination of significant early solar PV uptake deployed in a clustered manner (therefore some network have high levels of PV uptake from the outset in 2022), in addition to a small amount of voltage rise headroom.

C2. Voltage rise issues across many LV network archetypes continue to increase in number out until 2050 due to increasing uptake solar PV. However, for most licence areas and scenarios, the total number of voltage rise constraints increase slowly (or even plateau) after the mid-2030s.

C3. From the mid to late 2020s (as early as 2023 for South Wales and South West in the Best View scenario), the most dominant forms of new network constraint are thermal cable and thermal transformer both under load. These constraints are driven by high uptake rates of both heat pumps and EVCPs.

C4. Voltage drop constraints are not expected to be a significant issue across National Grid's network. This is due to a combination of significant voltage drop headroom and in the case of many solutions, solutions deployed to resolve either voltage rise and thermal (load) constraints releasing additional voltage drop headroom before voltage drop limits are reached. Note not all solutions deployed to resolve voltage rise constraints increase voltage fall headroom; for example adjusting tap positions to increase voltage headroom reduces voltage legroom.

C5. Across National Grid's licence areas, a significant increase in the frequency of (largely thermal) constraints encountered is forecast for the 2034-2040 period. This may warrant investing ahead of need or training of additional staff ahead of this period. Network constraints encountered remains high for the 2041-2050 period.

C6. For each licence area, the types of network constraints encountered in each DFES scenario is similar. The prevalence of network constraints is higher in scenarios with greater levels of LCT uptake (Leading the Way) compared to the scenario with the lowest level of LCT uptake (Steady Progress) and network constraints occur earlier.

C7. LV network archetype LV1 (central business districts). LV3 (town centres), LV4 (business parks) and LV5 (retail parks) witness voltage rise constraints, typically beginning from the mid-late 2020s. Later thermal cable (under generation) constraints begin to be encountered, with occasionally thermal transformer (under generation) constraints also being encountered. However, these occur on relatively few networks.

C8. Typically, voltage rise and thermal constraints due to generation on LV1, LV3, LV4 and LV5 occur at relatively low penetration levels even out until 2050.

C9. LV network archetypes LV2 (dense urban e.g. apartments), LV6 (sub-urban streets), LV7 (new build housing estates), LV8 (terraced streets), LV9 (rural village overhead), LV10 (rural village underground) and LV11 (rural farmsteads) witness voltage rise constraints initially, typically at low penetration levels. Later (typically from the mid-late 2030s) thermal constraints become more dominant reaching higher penetration levels.

5.2 Recommendations

Throughout this study, some assumptions have had to be made and those have led to the following recommendations for National Grid to consider as part of their further analysis in this space.

R1. Develop understanding of commercial heat pump profile(s) such that the effect of commercial heat pumps can be included in future network modelling.

R2. Develop understanding of BESS profile such that it represents realistic use of BESS rather than simply a worst case analysis.

R3. Solutions that cost effectively release voltage headroom capacity will see wide-scale deployment to support the forecast PV uptake, on feeders where many PV installations are clustered together. Due to the high prevalence of this network constraint type, National Grid should continue to closely monitor new technologies that offer potential voltage headroom release as these could provide high value across the electricity distribution network.

R4. Solutions that simultaneously voltage headroom and thermal capacity will also enable the continued support for forecast heat pumps and EVCPs. National Grid should closely monitor new technologies that could offer these as an option to avoid revisiting sites for subsequent capacity release.

6. References

[1] National Grid Electricity Distribution, “Distribution Future Energy Scenarios,” National Grid Electricity Distribution, Nottingham, UK, 2021.

[2] E. Dudek, K. Platt and N. Storer, “Electric Nation Customer Trial Final Report,” 24 10 2019. [Online]. Available: https://electricnation.org.uk/resources/smart-charging-project/. [Accessed 07 11 2022].

[3] Committee on Climate Change, “The Sixth Carbon Budget - The UK's path to Net Zero,” Climate Change Committee, London, UK, 2020.

[4] S. Lindmark and T. Stone, “EA16141-TR1: SILVERSMITH Literature Review,” EA Technology, Chester, UK, 2022.

[5] National Grid, “Distribution Future Energy Scenarios,” 2021. [Online]. Available: https://www.nationalgrid.co.uk/distribution-future-energy-scenarios-application.

[6] EA Technology, “The world's leading techno-economic modelling tool for electricity networks,” EA Technology, Chester, UK, 2022.

Appendix I EV Charge Point Profiles

DFES 2021 [1] contains profiles for a range of EVCP types. In addition to the residential on/off street EVCP profile (Figure 5) (which dominates the total number of EVCPs across all scenarios and licence areas), there are a range of other EVCP profiles included in DFES 2021 whose uptake rates are significantly lower than for the residential EVXPs. The EVCP profiles from DFES modelled in Transform are Workplace, Car Park, Destination, En Route / Local Charging Station and Fleet Depot. These profiles are shown in Figure AI.1 through to Figure AI.5.

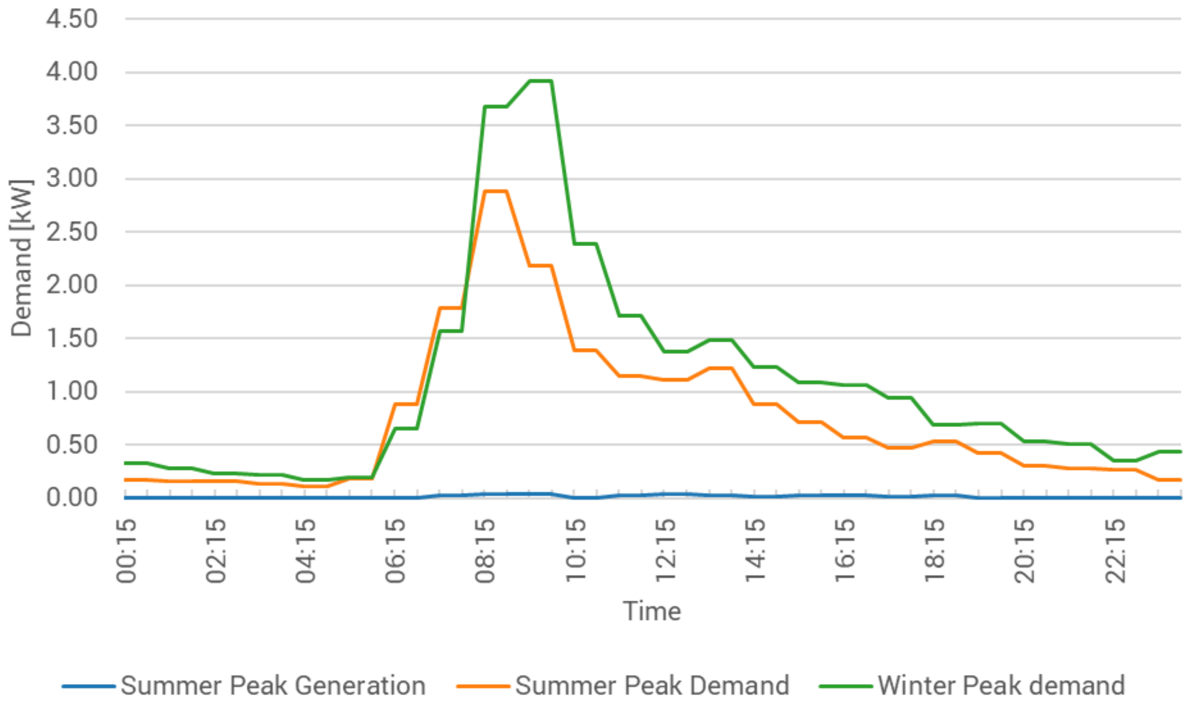


Figure AI.1 Workplace EVCP profile.

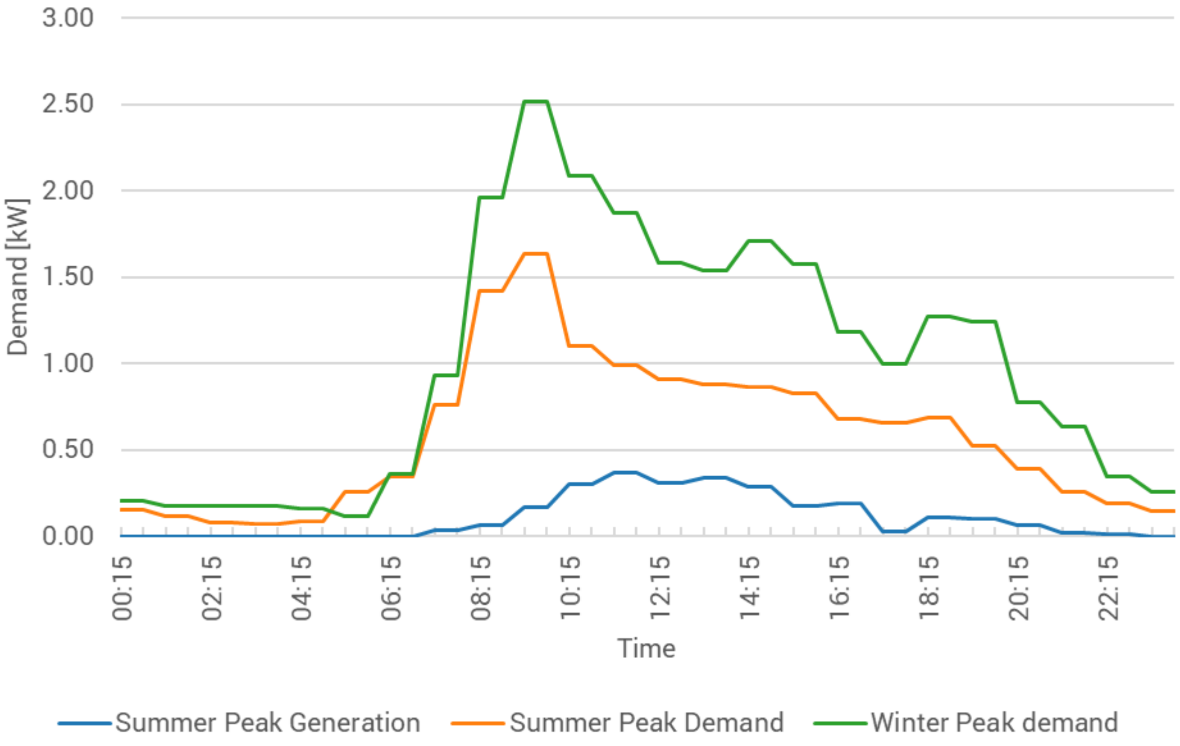


Figure AI.2 Car Park EVCP Profile

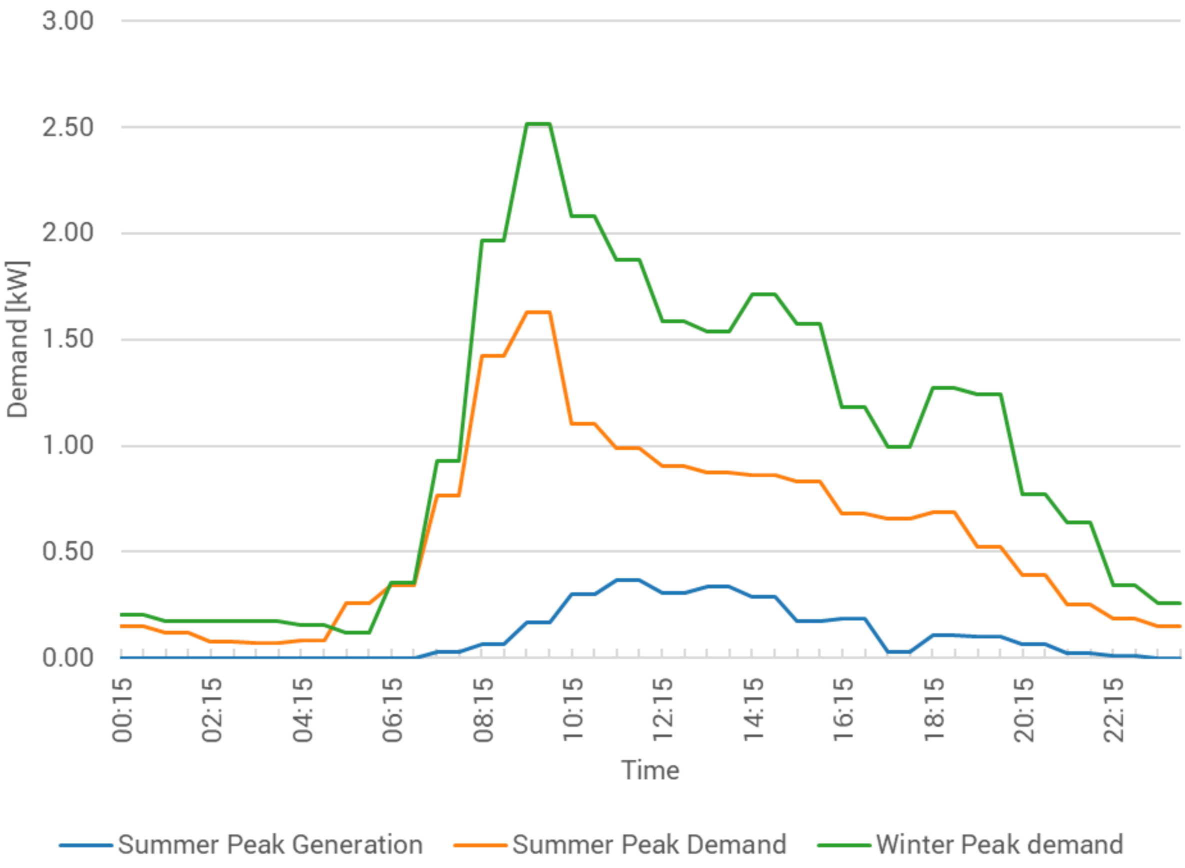


Figure AI.3 Destination EVCP Profile

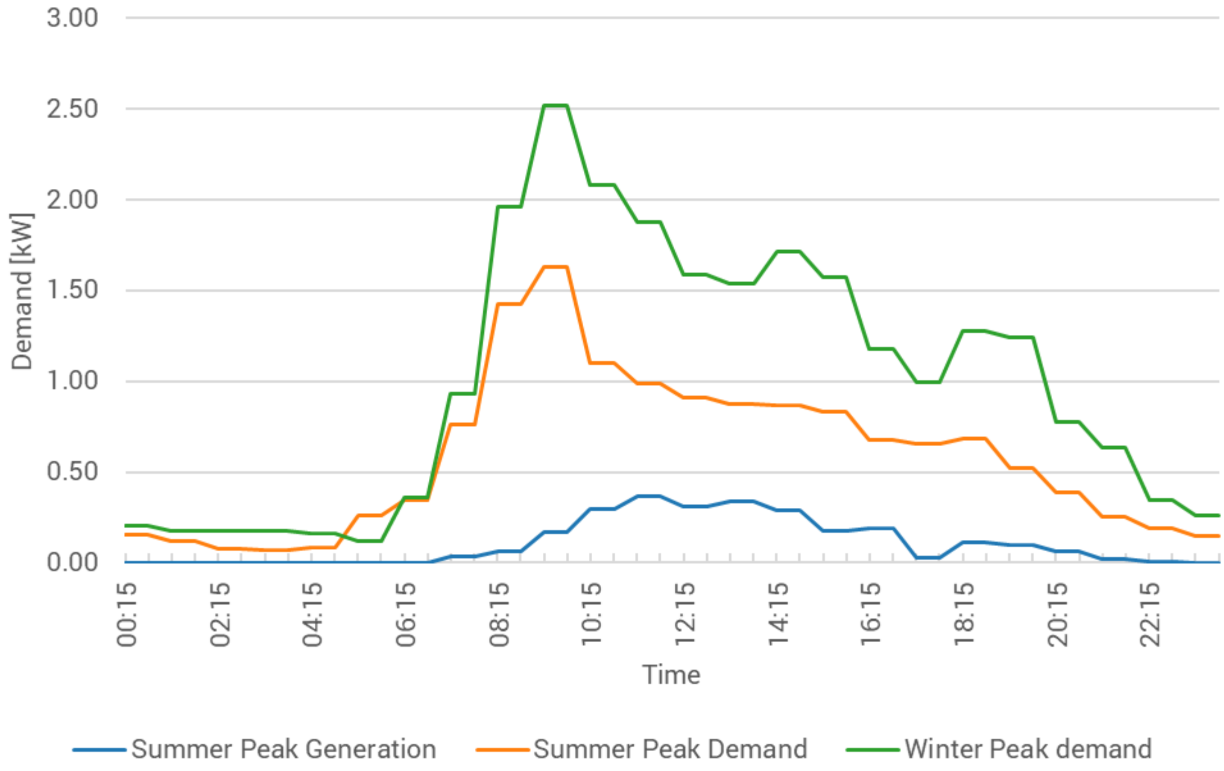


Figure AI.4 En Route / Local Charging Stations EVCP Profile

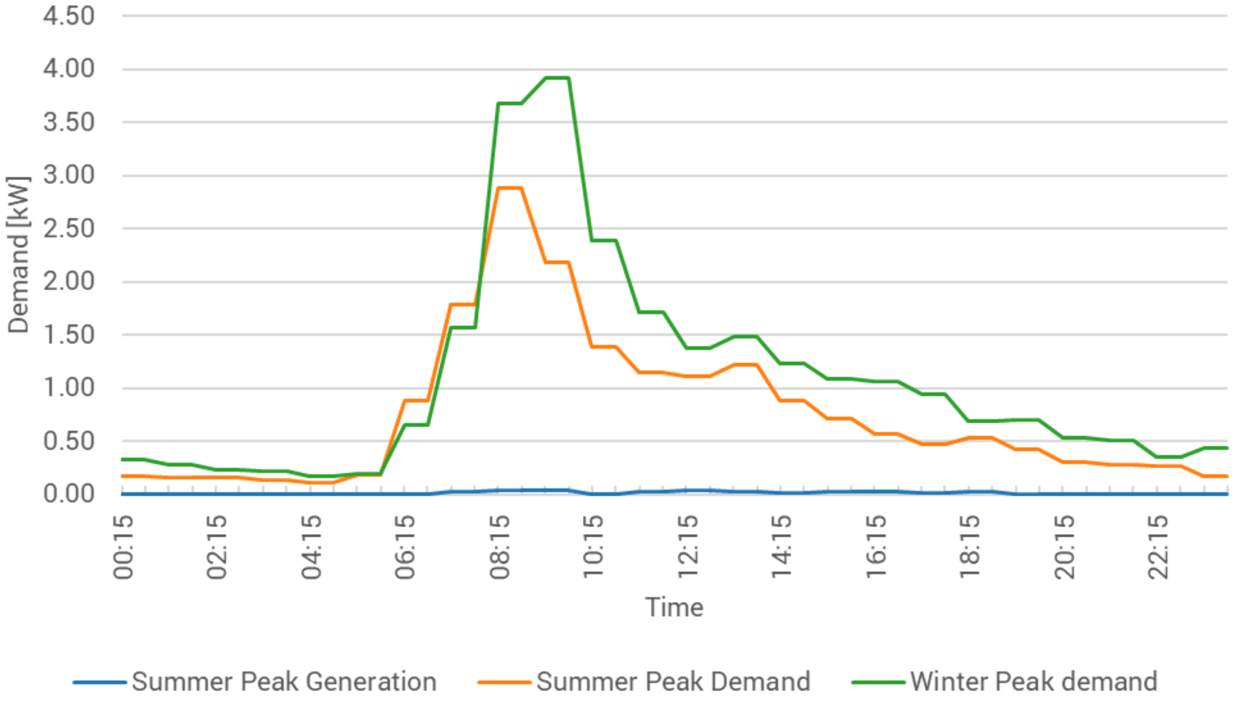
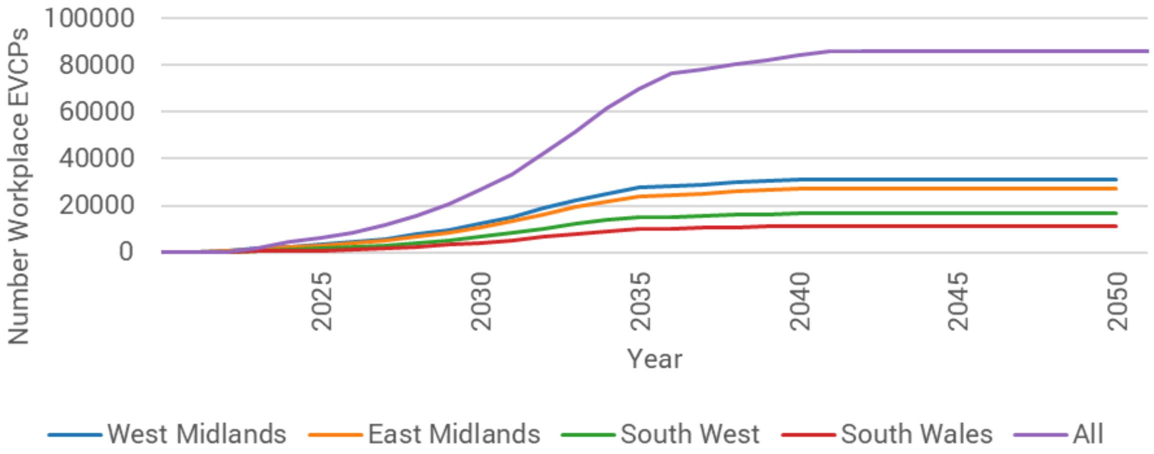


Figure AI.5 Fleet Depot EVCP Profile

Appendix II EV Charge Point Uptake Rates

Residential EVCPs (both on and off street) dominate the total number of EVCPs in the DFES forecast uptake rates in all scenarios. Other types of EVCPs, namely workplace, car park, destination, en route /local charging stations and fleet/depot are also included in DFES and included in the Transform modelling for this project. These EVCPs are able to be deployed on commercial properties, unlike residential EVCPs that can only be deployed on residential properties.



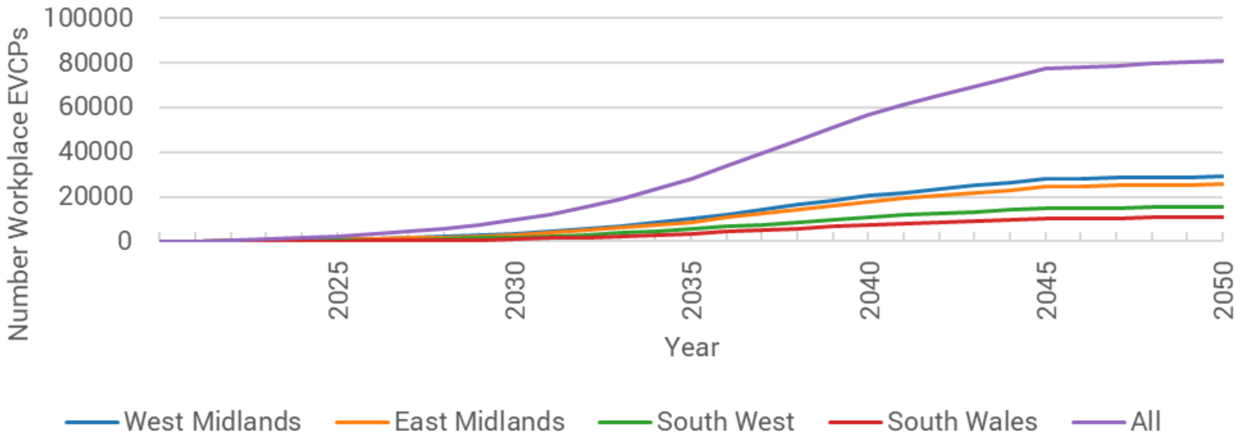


Figure AII.1 : Cumulative workplace EVCPs deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

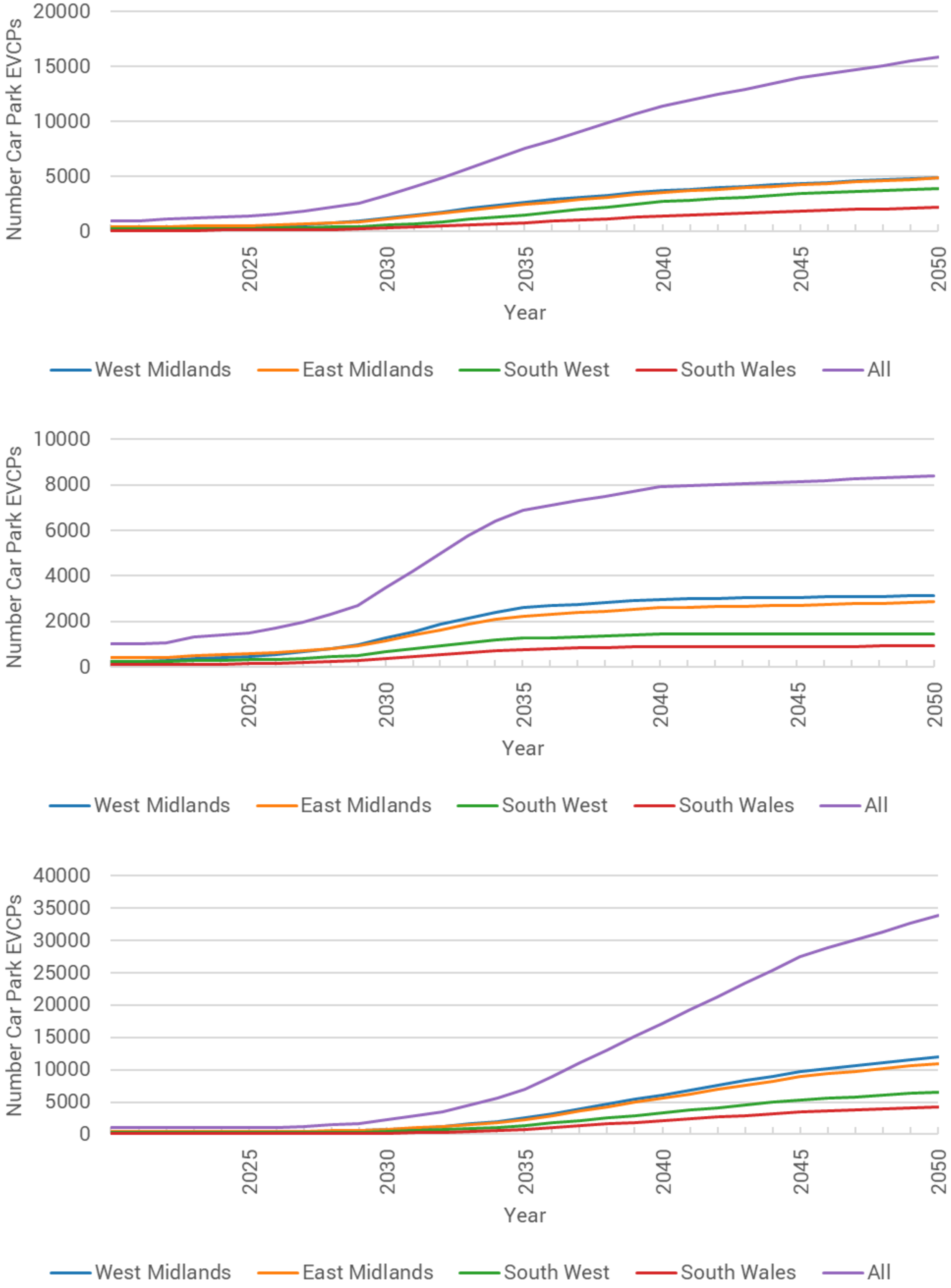
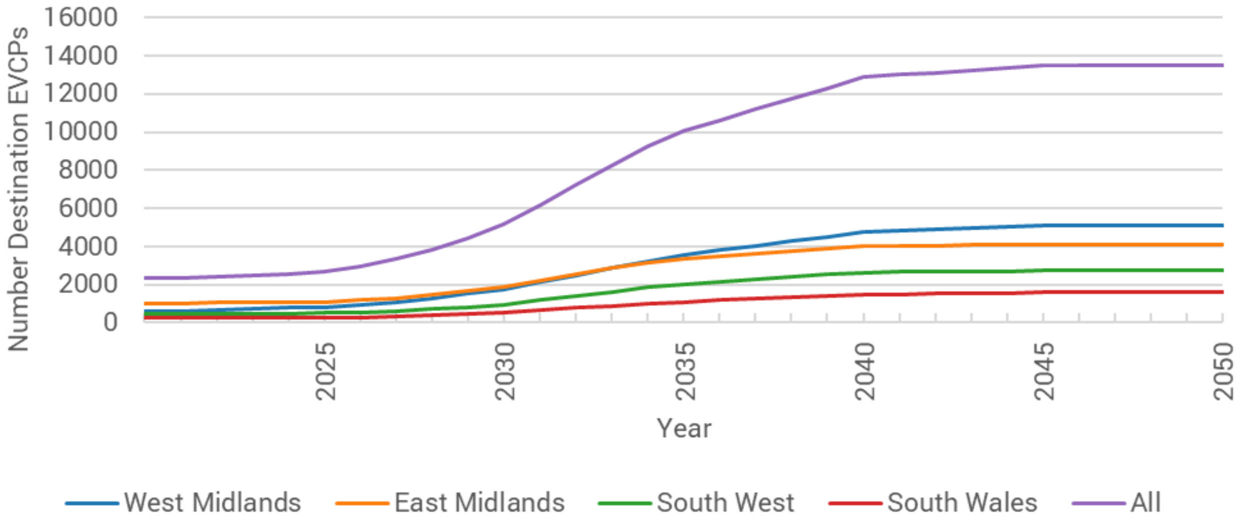
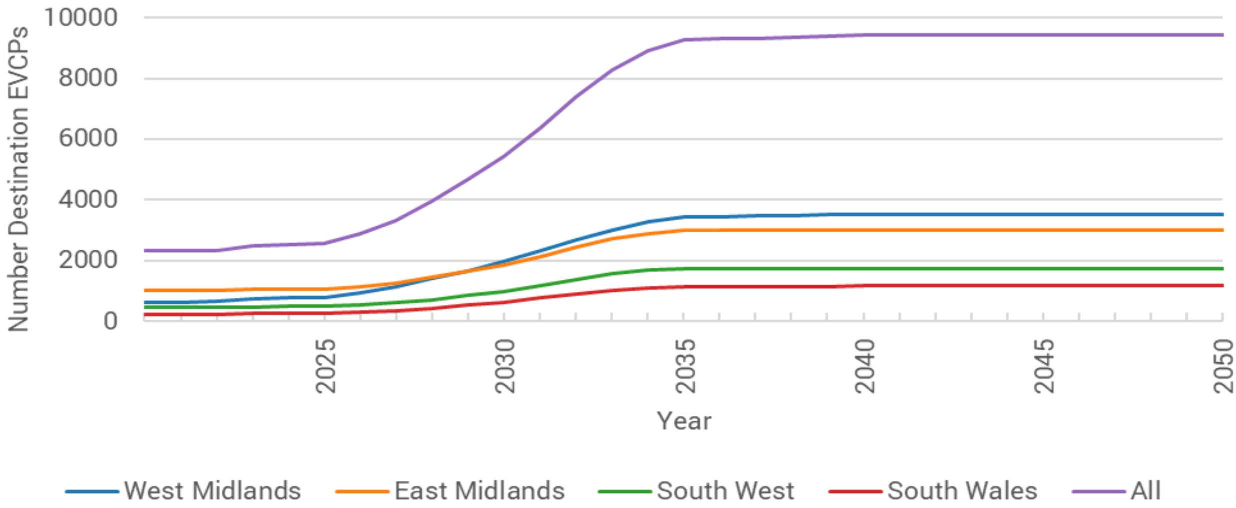


Figure AII.2 : Cumulative car park EVCPs deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.





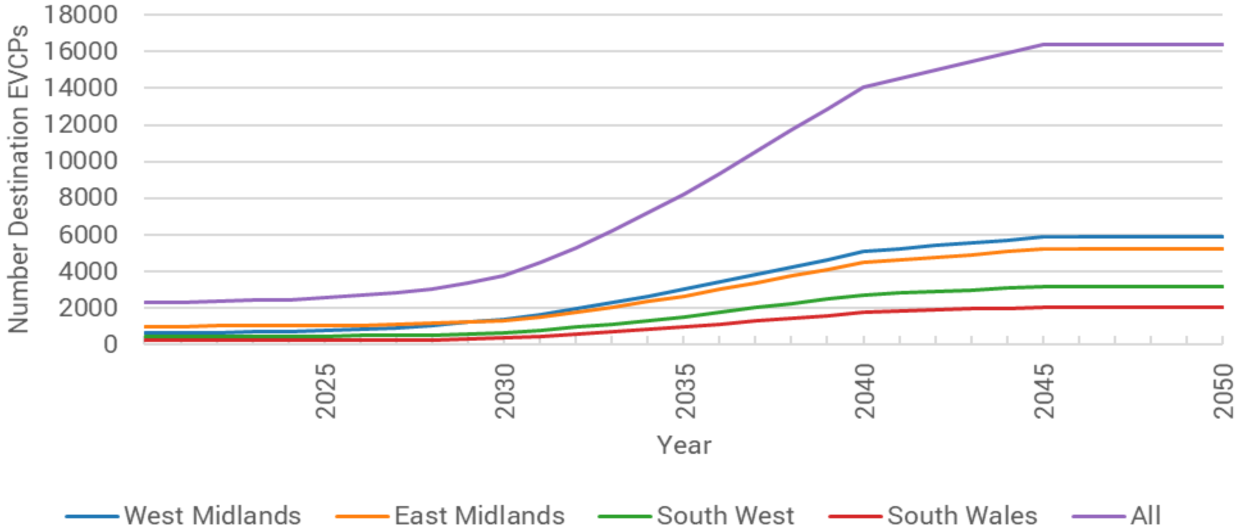


Figure AII.3 : Cumulative destination EVCPs deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

Figure AII.4 : Cumulative en route / local charging stations EVCPs deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

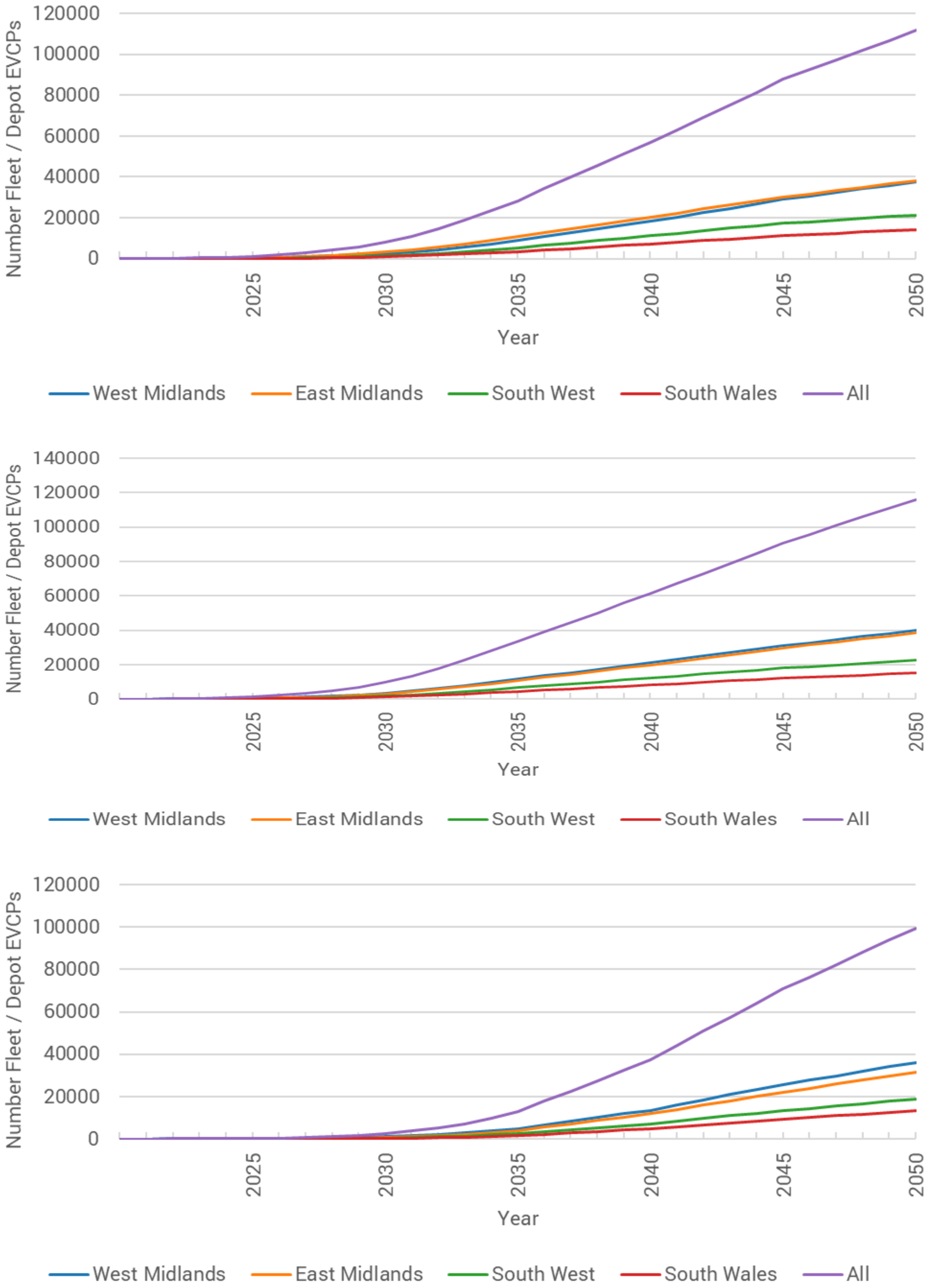


Figure AII.5 : Cumulative fleet /depot EVCPs deployment across National Grid's Licence areas for Best View (top), Leading the Way (central) and Steady Progress (bottom) scenarios.

Appendix III Summary of Transform Models provided to National Grid

EA Technology have provided National Grid with copies of the Transform models used during this study. Table AIII.1 summarises the models used by EA Technology throughout this project for studying each licence area and scenario. These models are provided to National Grid to allow for further analysis of the results or further studies to be carried out subject to suitable Transform licence agreements being in place. The Transform models contain more data than it is possible to provide in the report which is available in each of the models directly.

Table AIII.1 Transform models used during this project by EA Technology, provided to National Grid.

Transform Model Name	Region	Scenario	CSV Results Folder
WPD TRANSFORM MODEL 5.4 - East Mids BestView	East Midlands	WPD Best View	EastMids_BestView
WPD TRANSFORM MODEL 5.4 - East Mids LeadingTheWay	East Midlands	Leading The Way	EastMids_LeadingTheWay
WPD TRANSFORM MODEL 5.4 - East Mids SteadyProgress	East Midlands	Steady Progress	EastMids_SteadyProgress
WPD TRANSFORM MODEL 5.4 - West Mids BestView	West Midlands	WPD Best View	WestMids_BestView
WPD TRANSFORM MODEL 5.4 - West Mids LeadingTheWay	West Midlands	Leading The Way	WestMids_LeadingTheWay
WPD TRANSFORM MODEL 5.4 - West Mids SteadyProgress	West Midlands	Steady Progress	WestMids_SteadyProgress
WPD TRANSFORM MODEL 5.4 - South Wales BestView	South Wales	WPD Best View	SouthWales_BestView
WPD TRANSFORM MODEL 5.4 - South Wales LeadingTheWay	South Wales	Leading The Way	SouthWales_LeadingTheWay
WPD TRANSFORM MODEL 5.4 - South Wales SteadyProgress	South Wales	Steady Progress	SouthWales_SteadyProgress
WPD TRANSFORM MODEL 5.4 - South West BestView	South West	WPD Best View	SouthWest_BestView
WPD TRANSFORM MODEL 5.4 - South West LeadingTheWay	South West	Leading The Way	SouthWest_LeadingTheWay
WPD TRANSFORM MODEL 5.4 - South West SteadyProgress	South West	Steady Progress	SouthWest_SteadyProgress

Appendix IV Network Details

Table AIV.1 Network details used in Transform for the LV network archetypes.

LV Network	Substation Capacity (kW)	Thermal Conductor (kW)	Planning Voltage Upper Headroom Limit (%)	Planning Voltage Lower Limit (%)	kW/%	Number of Networks (East Mids | West Mids | South Wales | South West
LV1 Central Business District	238	231	1%	15%	40	1,275 | 1305 | 484 | 869
LV2 Dense urban (apartments etc)	190	164	1%	15%	40	4,288 | 4389 | 1630 | 2922
LV3 Town centre	190	179	1%	15%	40	2,876 | 3093 | 1124 | 1949
LV4 Business park	238	184	1%	15%	40	4,999 | 5920 | 2235 | 2975
LV5 Retail park	238	184	1%	15%	40	2,517 | 2248 | 1056 | 1369
LV6 Suburban street (3 4 bed semi detached or detached houses)	119	111	1%	15%	40	18,590 | 17547 | 7937 | 9990
LV7 New build housing estate	119	164	1%	15%	40	9,506 | 7060 | 3752 | 4631
LV8 Terraced street	119	111	1%	15%	40	17,033 | 17209 | 6488 | 11227
LV9 Rural village (overhead construction)	48	131	1%	15%	40	12,339 | 16317 |13346 | 16146
LV10 Rural village (underground construction)	100	113	1%	15%	40	6,413 | 7142 | 2773 | 6883

LV Network	Substation Capacity (kW)	Thermal Conductor (kW)	Planning Voltage Upper Headroom Limit (%)	Planning Voltage Lower Limit (%)	kW/%	Number of Networks (East Mids | West Mids | South Wales | South West
LV11 Rural farmsteads small holdings	48	56	1%	15%	40	14,716 | 20860 | 17693 | 21544
LV12 Meshed Central Business District	380	359	1%	15%	40	0 | 0 | 0 | 0
LV13 Meshed Dense urban (apartments etc)	190	328	1%	15%	40	0 | 0 | 0 | 0
LV14 Meshed Town centre	190	359	1%	15%	40	0 | 0 | 0 | 0
LV15 Meshed Business park	190	369	1%	15%	40	0 | 0 | 0 | 0
LV16 Meshed Retail park	190	369	1%	15%	40	0 | 0 | 0 | 0
LV17 Meshed Suburban street (3 4 bed semi detached or detached houses)	190	226	1%	15%	40	0 | 0 | 0 | 0
LV18 Meshed New build housing estate	190	226	1%	15%	40	0 | 0 | 0 | 0
LV19 Meshed Terraced street	190	384	1%	15%	40	0 | 0 | 0 | 0

Appendix V Feeder Loads

Table AV.1, Table AV.2, Table AV.3 and Table AV.4 show the assumed number of different types of residential and commercial property types for each licence area. Transform contains a range of profiles representing the different residential property types.

Table AV.1 East Midlands Feeder Loads

	Very Old Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Commercial
LV1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.05
LV2	0.00	0.00	0.00	0.00	0.00	0.00	3.22	2.00	0.84	14.47	17.23	10.21	0.46
LV3	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.17	0.07	0.70	0.52	0.25	14.49
LV4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.27
LV5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.37
LV6	0.43	6.83	4.54	1.42	16.53	3.42	0.72	3.39	0.60	0.00	0.00	0.00	0.74
LV7	1.48	8.17	5.61	1.57	13.43	3.05	0.15	0.55	0.10	0.19	1.16	0.58	0.00
LV8	0.22	1.26	0.58	1.82	4.15	0.92	9.44	11.58	2.98	2.53	4.89	2.10	0.84
LV9	1.77	4.54	3.08	1.71	4.13	1.41	0.25	0.38	0.09	0.00	0.00	0.00	0.58
LV10	3.50	8.76	6.56	3.23	7.72	2.19	1.33	1.32	0.39	0.35	0.23	0.10	1.34
LV11	2.35	5.75	4.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table AV.2 West Midlands Feeder Loads

	Very Old Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Commercial
LV1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.05
LV2	2.71	1.69	0.70	12.20	14.53	8.61	2.71	1.69	0.70	12.20	14.53	8.61	0.46
LV3	0.23	0.14	0.06	0.59	0.44	0.21	0.23	0.14	0.06	0.59	0.44	0.21	14.49
LV4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.27
LV5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.37
LV6	0.61	2.85	0.50	0.00	0.00	0.00	0.61	2.85	0.50	0.00	0.00	0.00	0.74
LV7	0.13	0.47	0.09	0.16	0.98	0.49	0.13	0.47	0.09	0.16	0.98	0.49	0.00
LV8	7.95	9.76	2.51	2.13	4.13	1.77	7.95	9.76	2.51	2.13	4.13	1.77	0.84
LV9	0.21	0.32	0.08	0.00	0.00	0.00	0.21	0.32	0.08	0.00	0.00	0.00	0.58
LV10	1.12	1.11	0.33	0.30	0.20	0.08	1.12	1.11	0.33	0.30	0.20	0.08	1.34
LV11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table AV.3 South Wales Feeder Loads

	Very Old Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Commercial
LV1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.05
LV2	0.00	0.00	0.00	0.00	0.00	0.00	1.71	2.55	0.68	5.79	16.50	7.07	0.46
LV3	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.38	0.10	0.62	1.07	0.33	14.49
LV4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.27
LV5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.37
LV6	1.17	4.18	2.72	2.55	10.52	3.08	1.37	2.14	0.61	0.00	0.00	0.00	0.74
LV7	4.52	5.26	3.45	2.54	6.17	1.71	0.15	0.23	0.05	0.14	0.40	0.10	0.00
LV8	0.27	2.22	1.84	1.69	8.16	1.52	6.32	8.10	1.59	1.31	2.15	0.67	0.84
LV9	2.80	2.80	1.68	1.82	2.63	0.78	0.17	0.25	0.05	0.00	0.00	0.00	0.58
LV10	5.73	5.21	3.58	3.13	5.05	1.15	0.78	0.95	0.18	0.19	0.21	0.05	1.34
LV11	3.69	3.14	2.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table AV.4 South West Feeder Loads

	Very Old Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Modern Flat	Old Flat	Commercial
LV1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.05
LV2	0.00	0.00	0.00	0.00	0.00	0.00	1.82	1.17	0.70	13.42	10.71	8.23	0.46
LV3	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.14	0.08	0.64	0.45	0.29	14.49
LV4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.27
LV5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.37
LV6	0.49	6.45	3.19	1.14	9.73	2.68	0.41	1.99	0.65	0.00	0.00	0.00	0.74
LV7	1.69	7.36	3.55	1.58	7.18	1.94	0.10	0.34	0.11	0.19	0.78	0.52	0.00
LV8	0.21	0.79	0.23	0.98	2.00	0.46	4.45	7.39	3.48	1.99	4.38	2.77	0.84
LV9	1.46	3.74	1.69	1.44	2.98	0.89	0.16	0.28	0.08	0.00	0.00	0.00	0.58
LV10	2.84	7.46	3.57	2.70	5.41	1.46	0.69	1.06	0.44	0.15	0.23	0.14	1.34
LV11	1.87	5.06	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix VI Constraints Analysis Files

EA Technology have also provided the image files containing the constraints analysis for each scenario. These results files are uploaded to Teams and are available at the following link:

https://eatl.sharepoint.com/:f:/r/sites/SILVERSMITHExternal/Shared%20Documents/General/Updated%20Models/Results/Results%20for%20website/Results%20For%20Upload/Constraints%20images?csf=1&web=1&e=L9eQai

Table AVI.1 : Folders containing resulting image files of constraints analysis for each region and scenario.

Folder	Region	Scenario
EastMids_BestView	East Midlands	WPD Best View
EastMids_LeadingTheWay	East Midlands	Leading The Way
EastMids_SteadyProgress	East Midlands	Steady Progress
GBModel	Great Britain (all licence areas)	Climate Change Committee Balanced Net Zero Pathway
WestMids_BestView	West Midlands	WPD Best View
WestMids_LeadingTheWay	West Midlands	Steady Progress
WestMids_SteadyProgress	West Midlands	Steady Progress
SouthWales_BestView	South Wales	WPD Best View
SouthWales_LeadingTheWay	South Wales	Leading The Way
SouthWales_SteadyProgress	South Wales	Steady Progress
SouthWest_BestView	South West	WPD Best View
SouthWest_LeadingTheWay	South West	Leading The Way
SouthWest_SteadyProgress	South West	Steady Progress

Each folder contains the following images detailed in Table AVI.2.

Table AVI.2 : Image naming convention used in constraints analysis results folders.

Name	Description
Cumulative Constraints.png	Plot showing number of each type of constraint that occurs on the network across all LV network archetypes on a cumulative basis.
Yearly Constraints.png	Plot showing number of each type of constraint that occurs on the network across all LV network archetypes on a year by year basis.
LVX Cumulative Constraints.png	Plot showing number of each type of constraints that occur on LV network X on a cumulative basis.
LVX Yearly Constraints.png	Plot showing number of each type of constraints that occur on LV network X on a year by year basis.

Appendix VII Network Constraints – East Midlands Best View

LV1 Central Business District

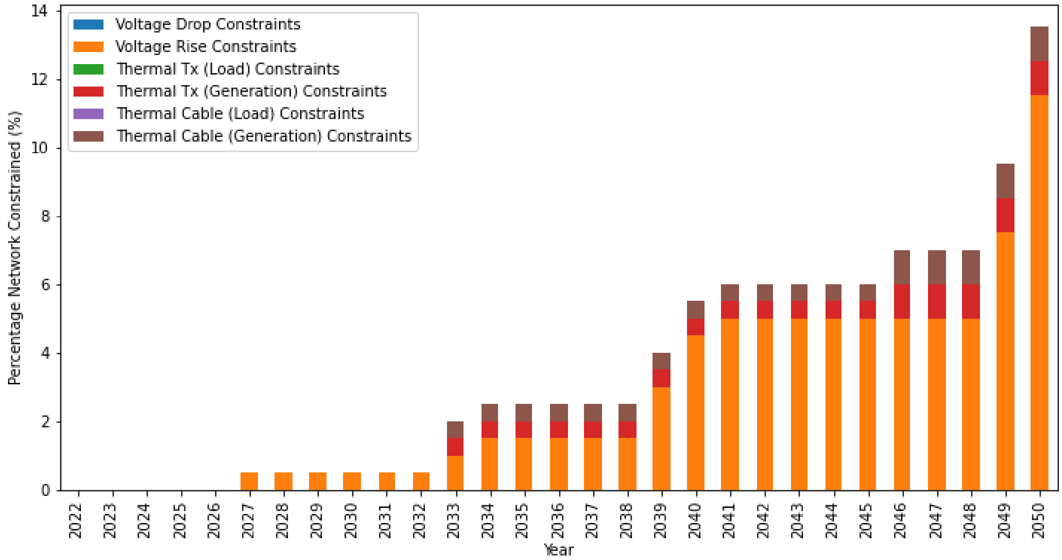


Figure AVII.1 Cumulative Constraints for network archetype LV1 in East Midlands, Best View scenario

LV2 Dense urban (apartments etc)

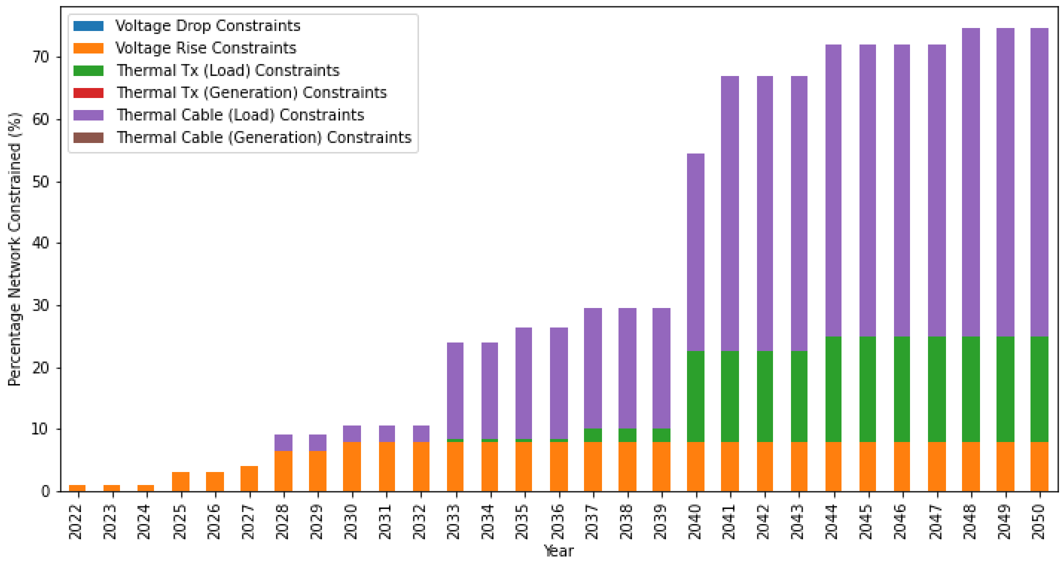


Figure AVII.2 Cumulative Constraints for network archetype LV2 in East Midlands, Best View scenario

LV3 Town Centres

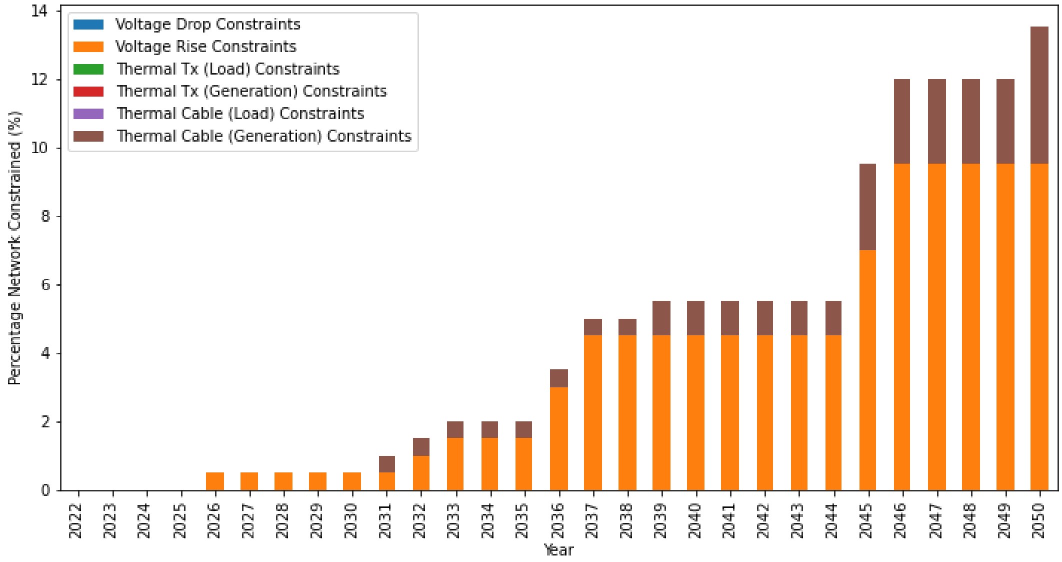


Figure AVII.3 Cumulative Constraints for network archetype LV3 in East Midlands, Best View scenario

LV4 Business Park

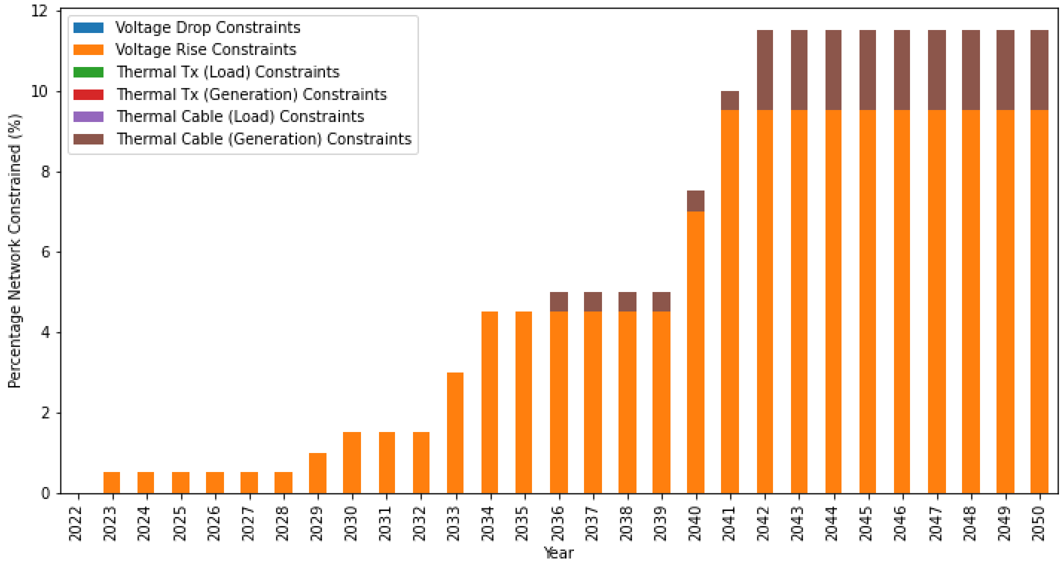


Figure AVII.4 Cumulative Constraints for network archetype LV4 in East Midlands, Best View scenario

LV5 Retail Park

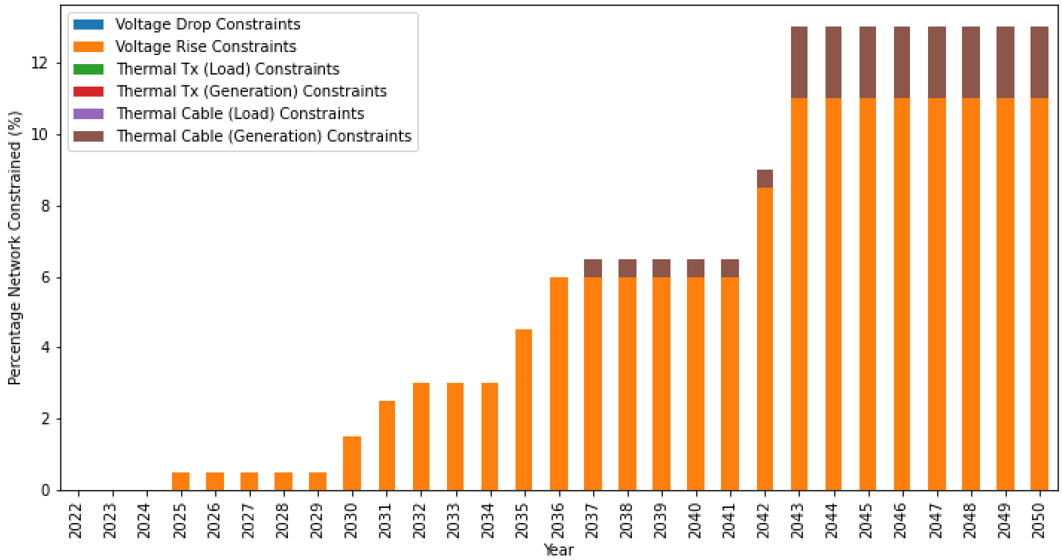


Figure AVII.5 Cumulative Constraints for network archetype LV5 in East Midlands, Best View scenario

LV6 Suburban street (3 4 bed semi detached or detached houses)

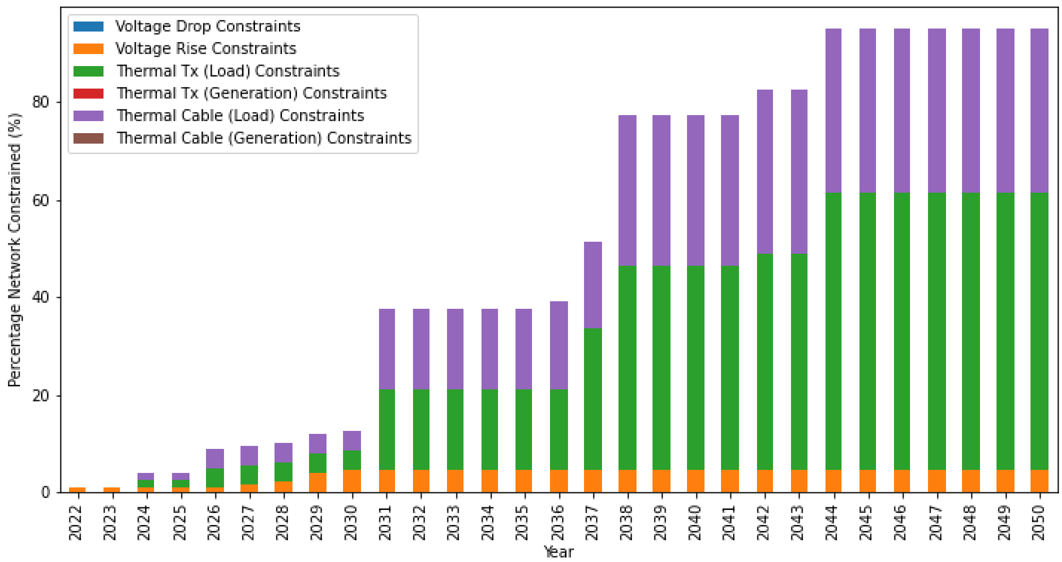


Figure AVII.6 Cumulative Constraints for network archetype LV6 in East Midlands, Best View scenario

LV7 New build housing estate

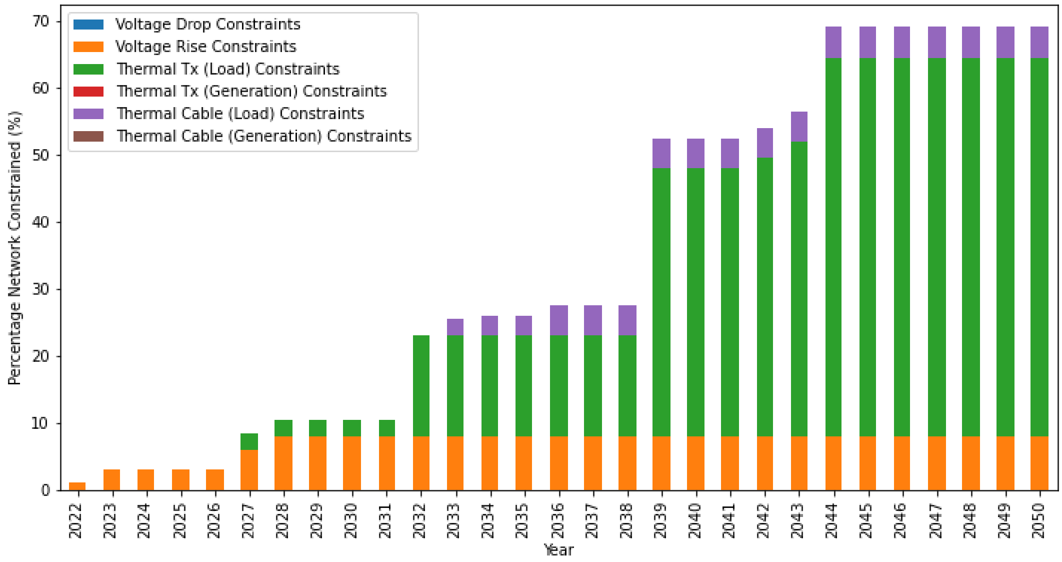


Figure AVII.7 Cumulative Constraints for network archetype LV7 in East Midlands, Best View scenario

LV8 Terraced Street

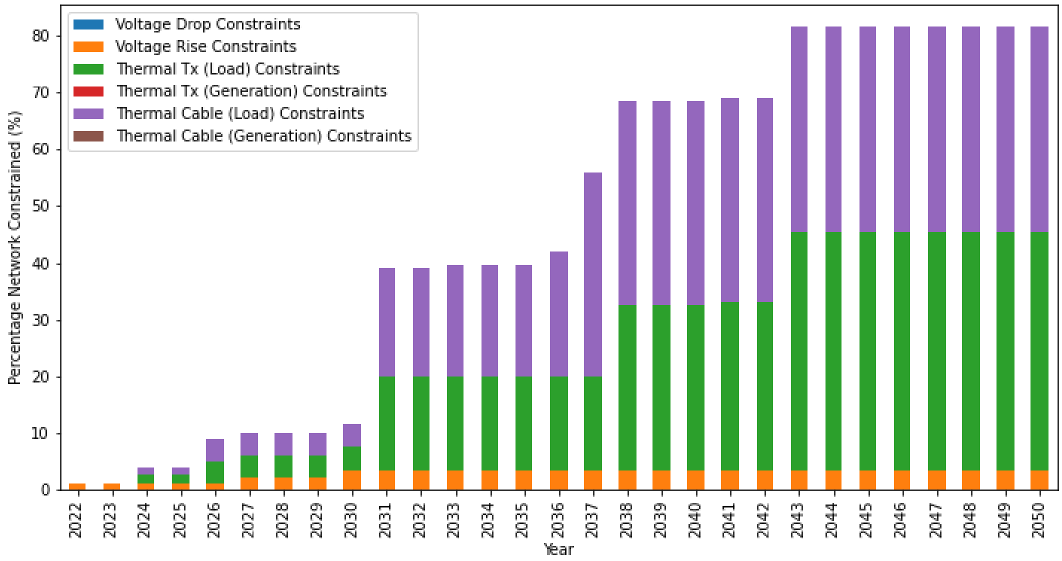


Figure AVII.8 Cumulative Constraints for network archetype LV8 in East Midlands, Best View scenario

LV9 Rural village (overhead construction)

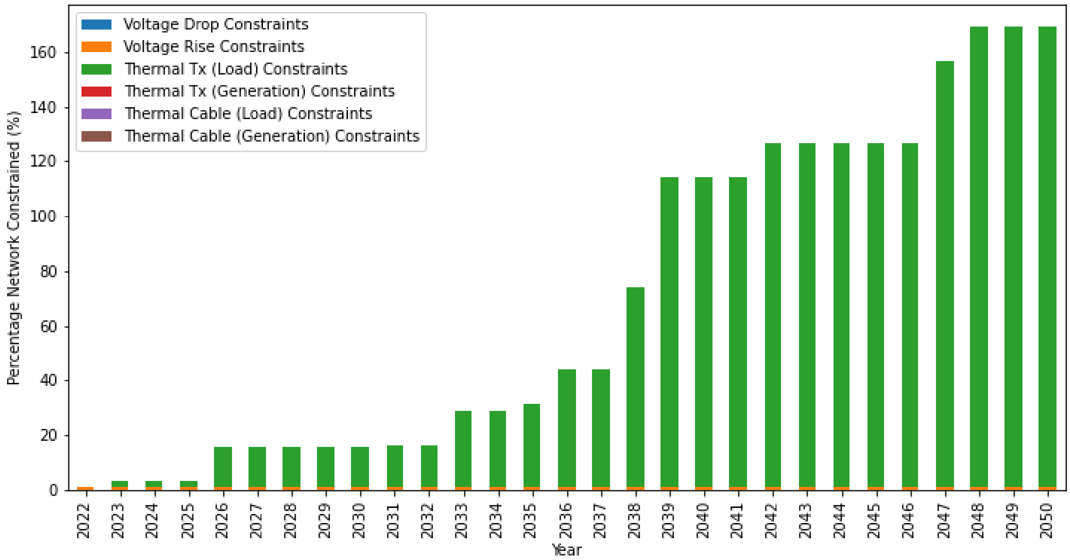


Figure AVII.9 Cumulative Constraints for network archetype LV9 in East Midlands, Best View scenario

LV10 Rural village (underground construction)

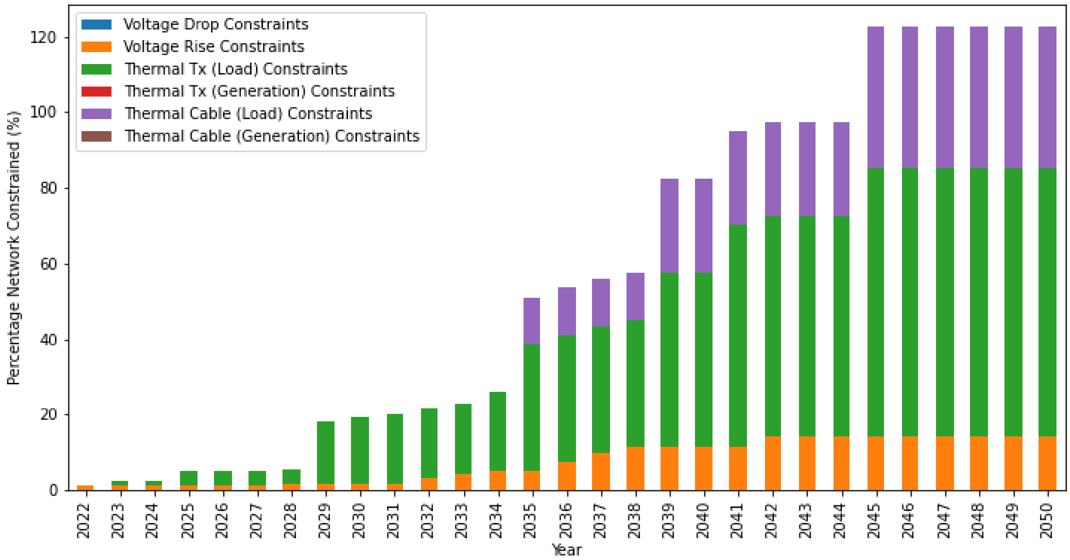


Figure AVII.10 Cumulative Constraints for network archetype LV10 in East Midlands, Best View scenario

LV11 Rural farmsteads small holdings

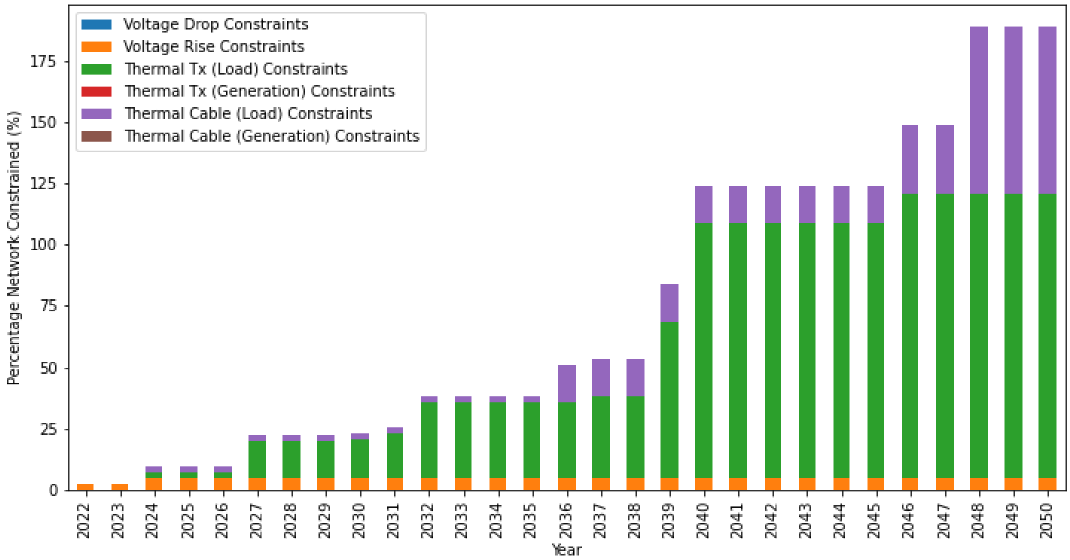


Figure AVII.11 Cumulative Constraints for network archetype LV11 in East Midlands, Best View scenario

Appendix VIII Network Constraints – South Wales Best View

LV1 Central Business District

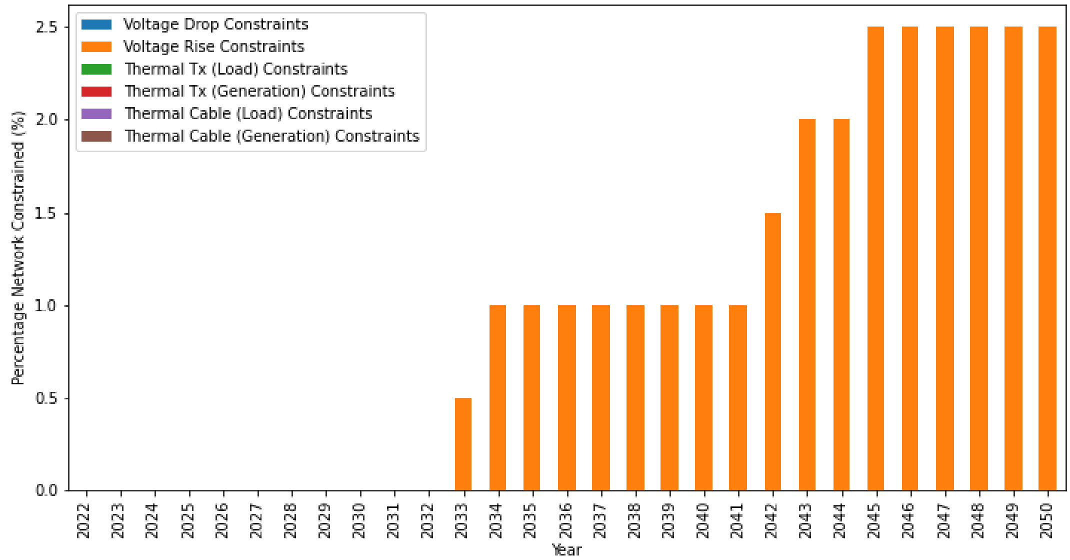


Figure AVIII.1 Cumulative Constraints for network archetype LV1 in South Wales, Best View scenario

LV2 Dense urban (apartments etc)

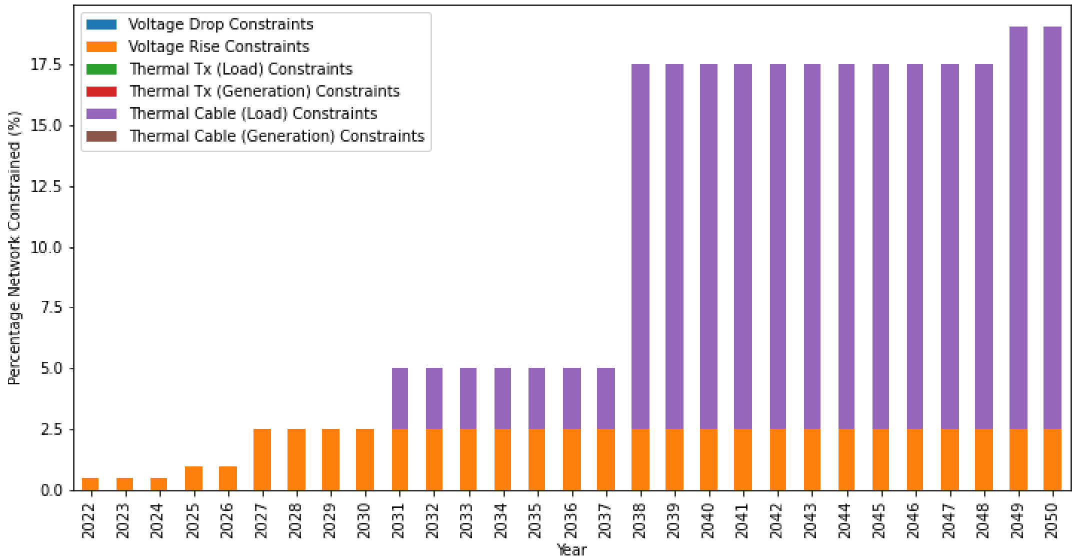


Figure AVIII.2 Cumulative Constraints for network archetype LV2 in South Wales, Best View scenario

LV3 Town Centres

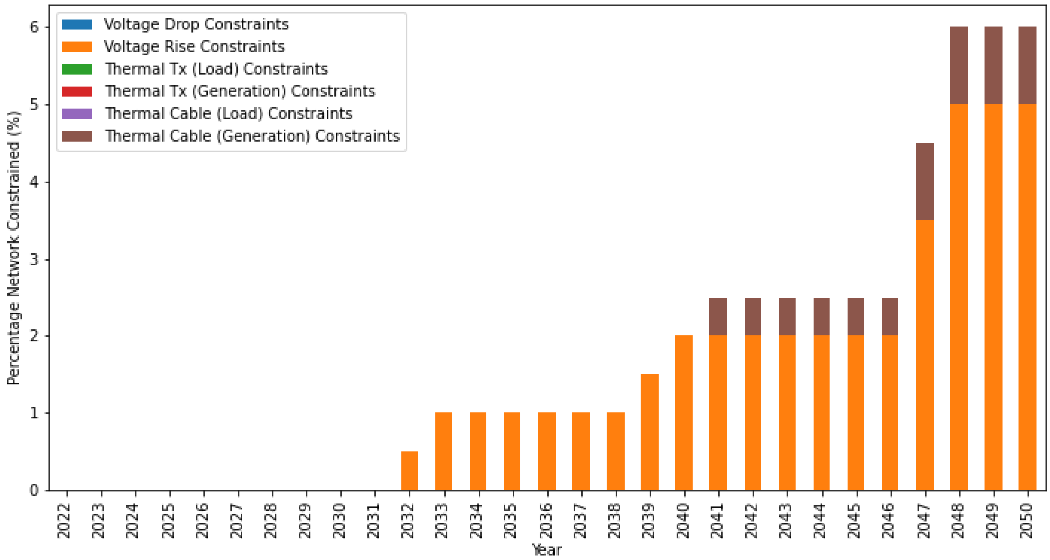


Figure AVIII.3 Cumulative Constraints for network archetype LV3 in South Wales, Best View scenario

LV4 Business Park

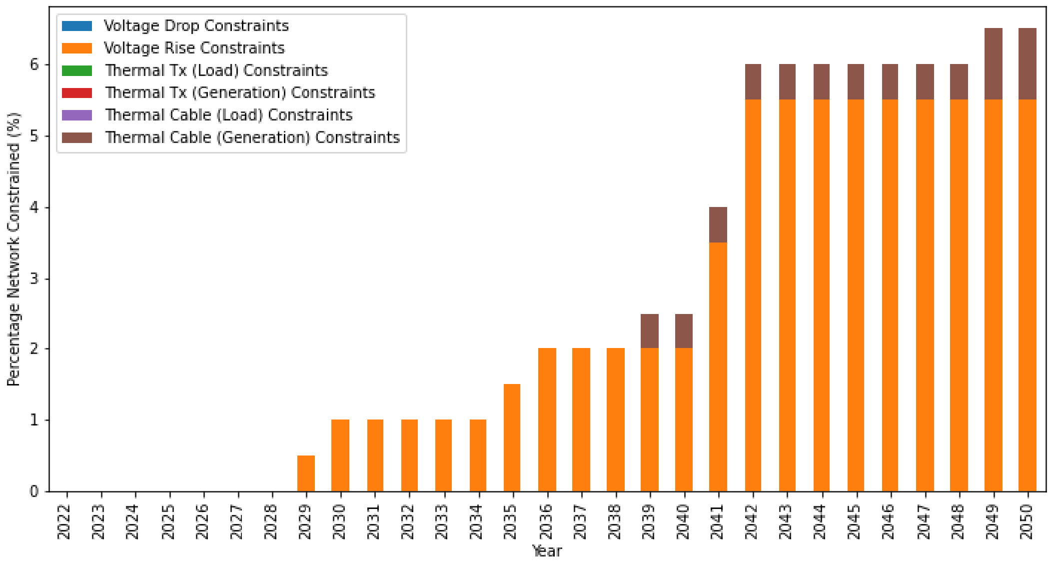


Figure AVIII.4 Cumulative Constraints for network archetype LV4 in South Wales, Best View scenario

LV5 Retail Park

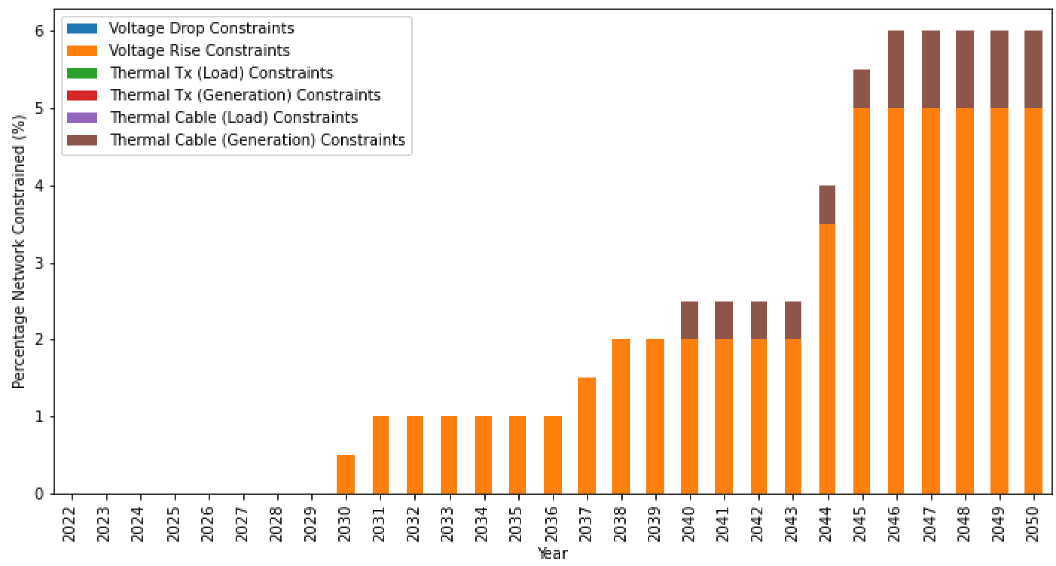


Figure AVIII.5 Cumulative Constraints for network archetype LV5 in South Wales, Best View scenario

LV6 Suburban street (3 4 bed semi detached or detached houses)

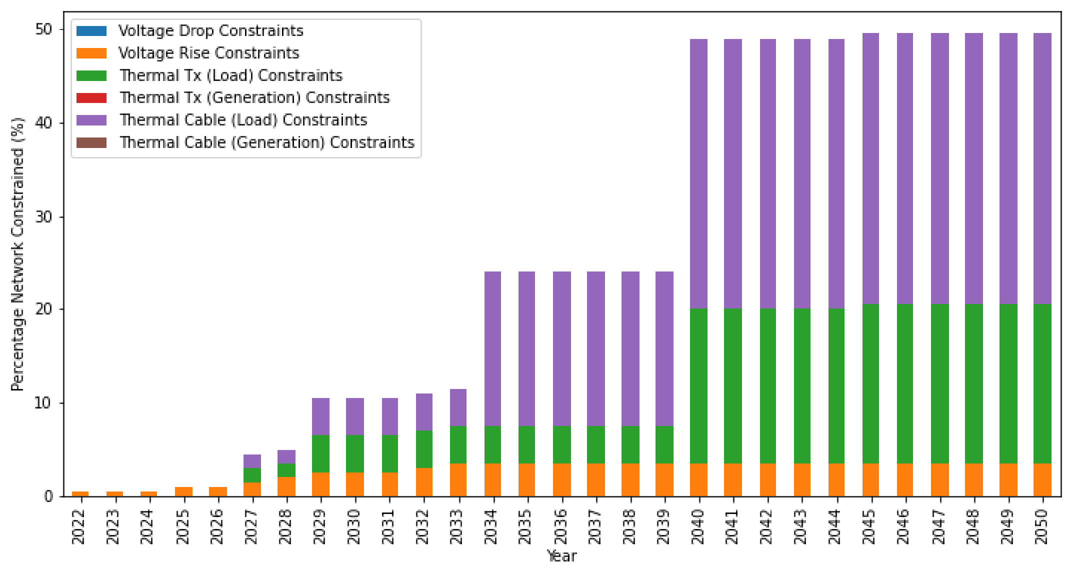


Figure AVIII.6 Cumulative Constraints for network archetype LV6 in South Wales, Best View scenario

LV7 New build housing estate

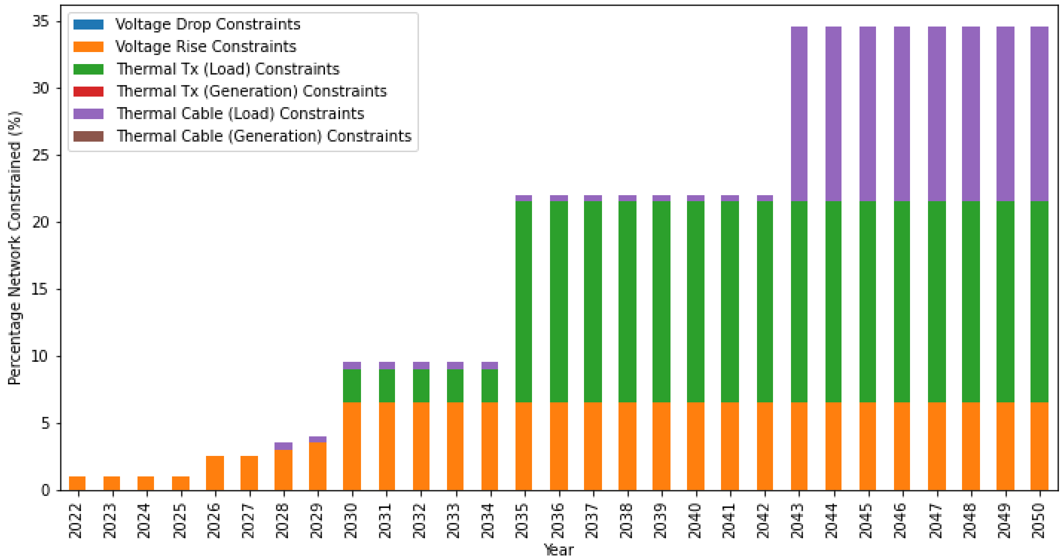


Figure AVIII.7 Cumulative Constraints for network archetype LV7 in South Wales, Best View scenario

LV8 Terraced Street

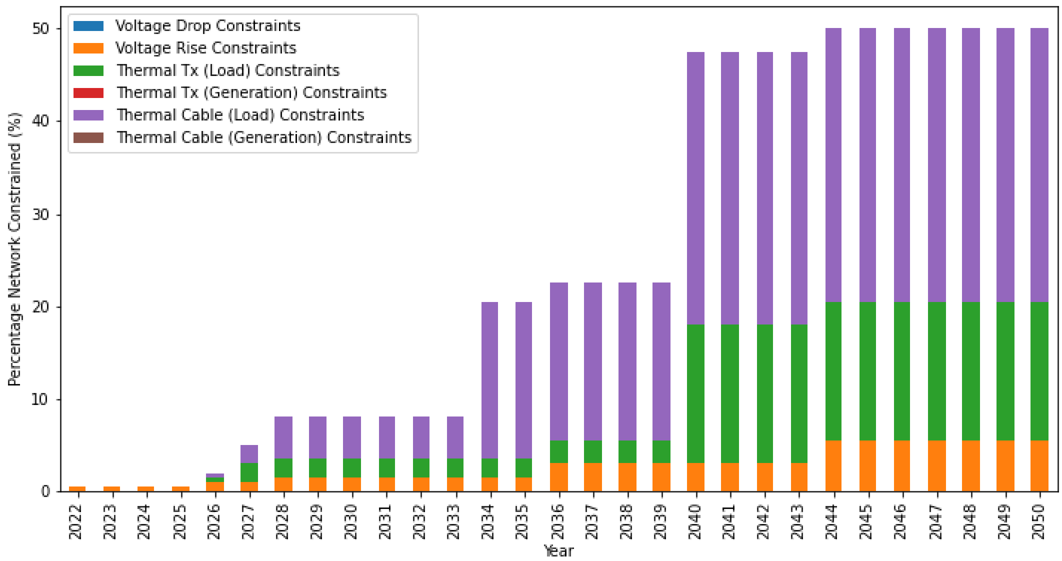


Figure AVIII.8 Cumulative Constraints for network archetype LV8 in South Wales, Best View scenario

LV9 Rural village (overhead construction)

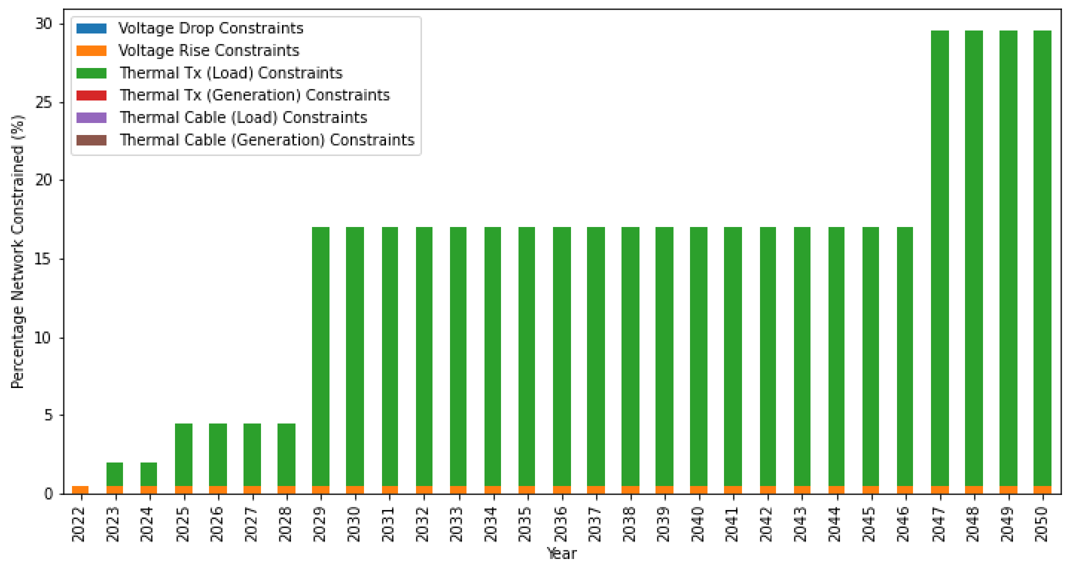


Figure AVIII.9 Cumulative Constraints for network archetype LV9 in South Wales, Best View scenario

LV10 Rural village (underground construction)

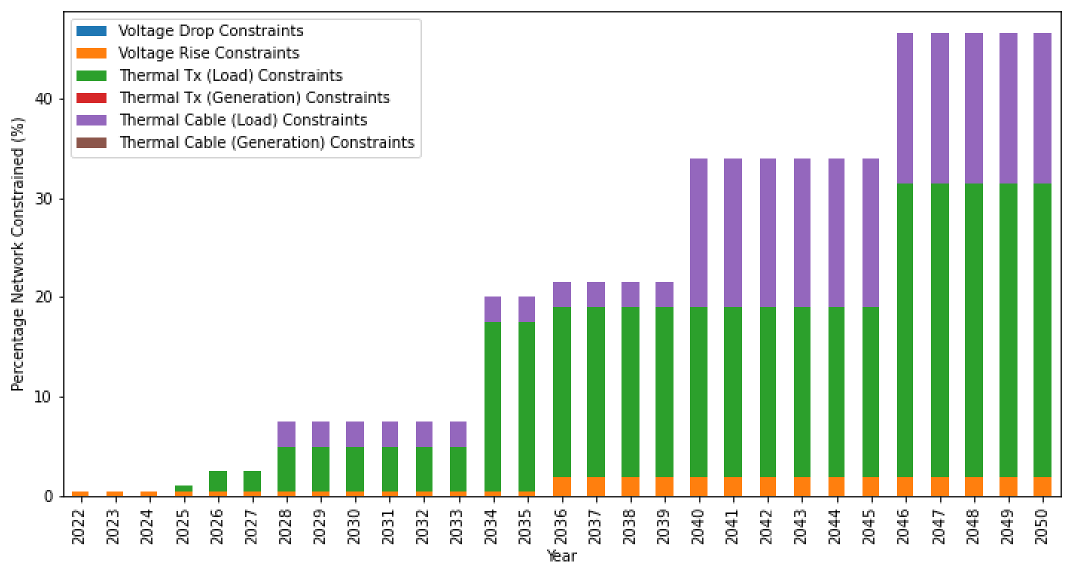


Figure AVIII.10 Cumulative Constraints for network archetype LV10 in South Wales, Best View scenario

LV11 Rural farmsteads small holdings

Figure AVIII.11 Cumulative Constraints for network archetype LV11 in South Wales, Best View scenario

Appendix IX Network Constraints – South West Best View

LV1 Central Business District

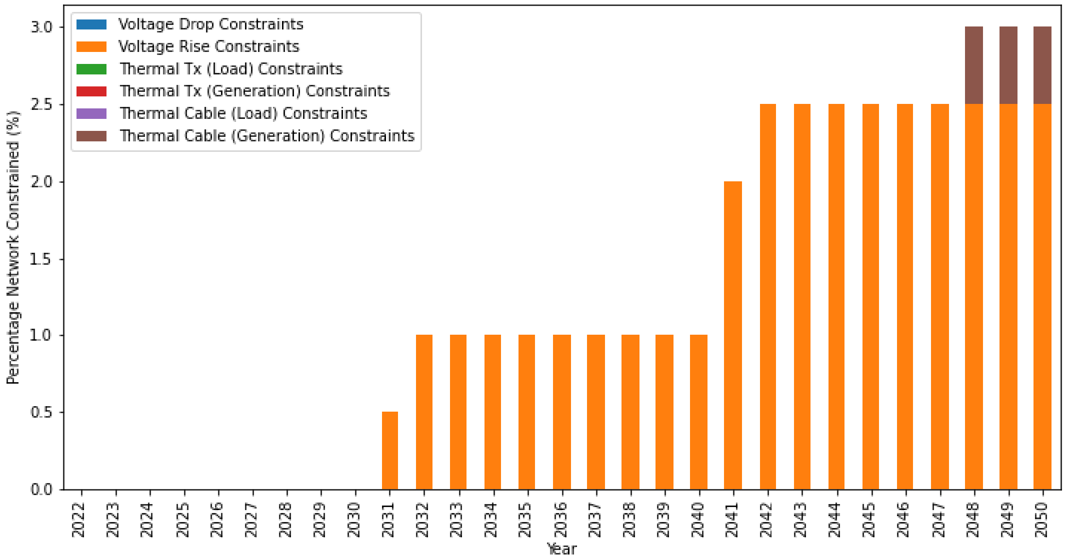


Figure AIX.1 Cumulative Constraints for network archetype LV1 in South West, Best View scenario

LV2 Dense urban (apartments etc)

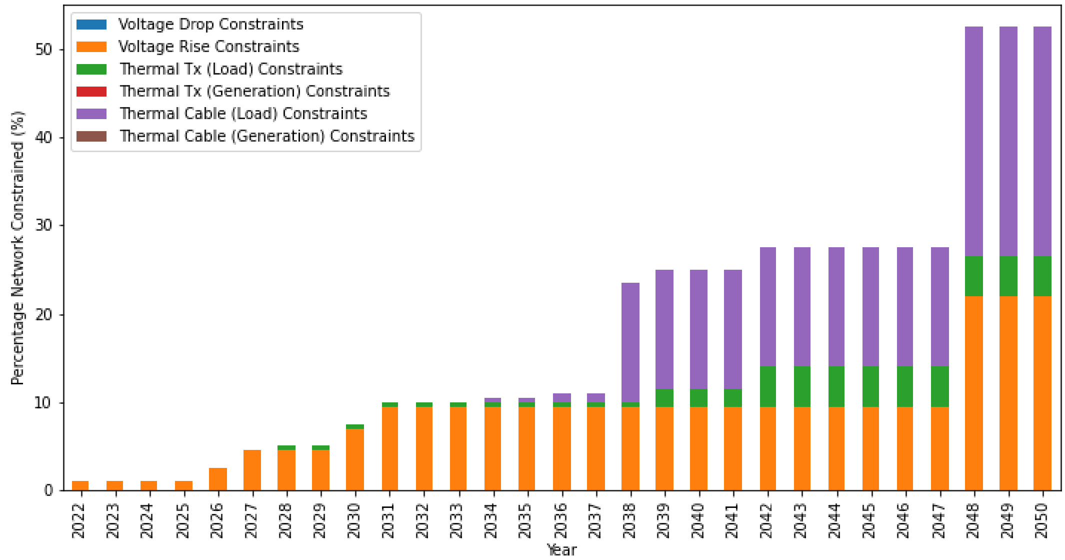


Figure AIX.2 Cumulative Constraints for network archetype LV2 in South West, Best View scenario

LV3 Town Centres

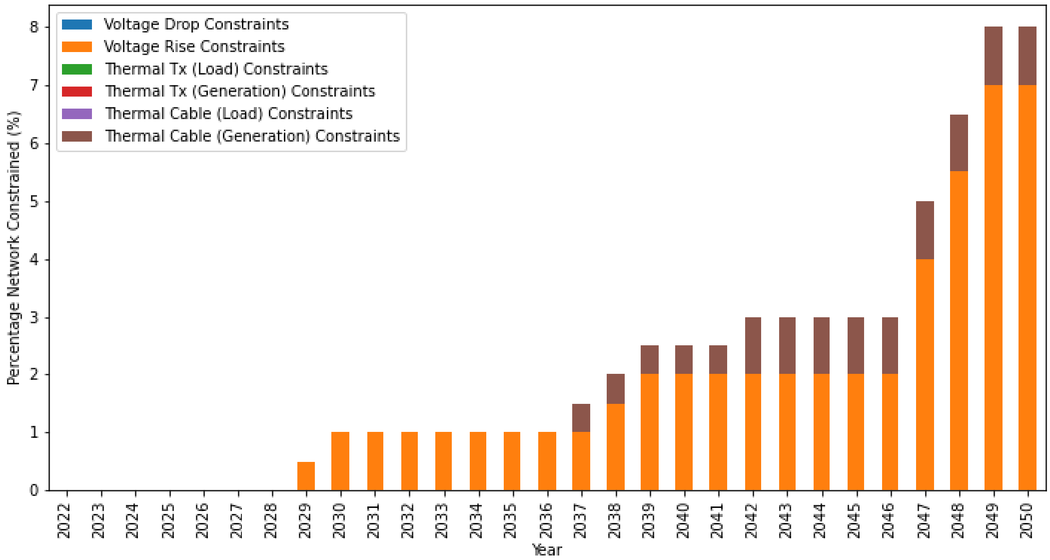


Figure AIX.3 Cumulative Constraints for network archetype LV3 in South West, Best View scenario

LV4 Business Park

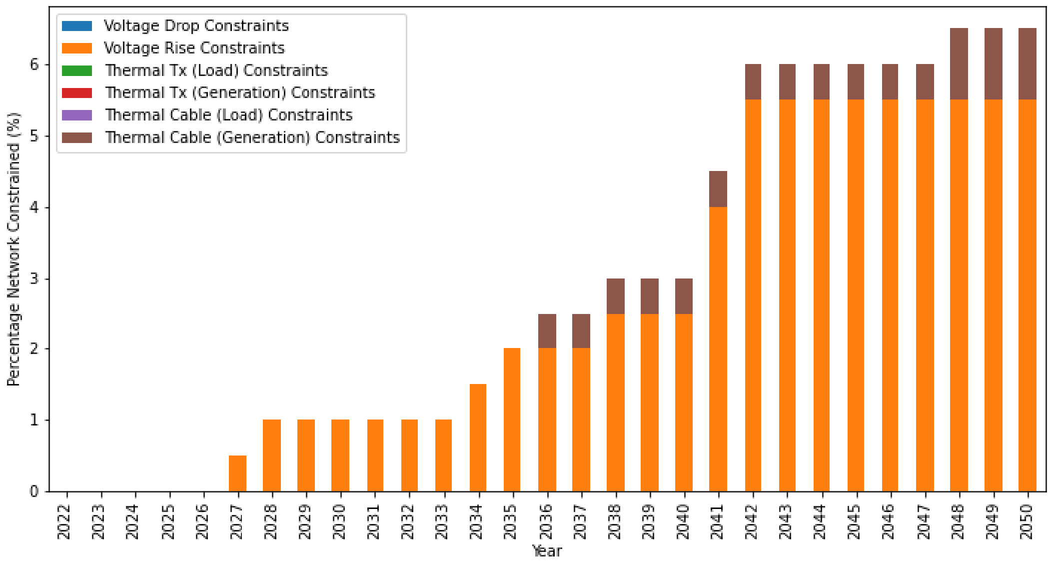


Figure AIX.4 Cumulative Constraints for network archetype LV4 in South West, Best View scenario

LV5 Retail Park

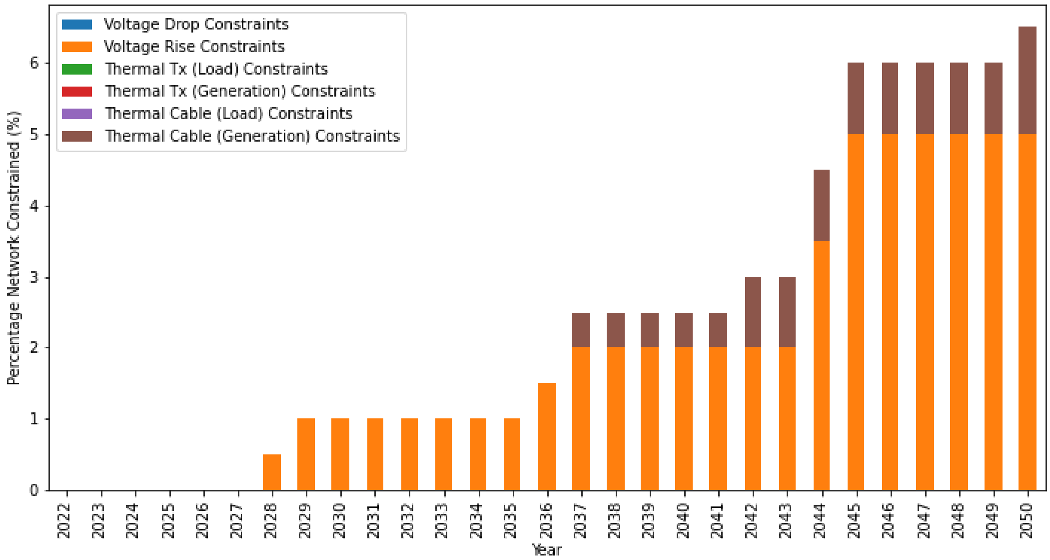


Figure AIX.5 Cumulative Constraints for network archetype LV5 in South West, Best View scenario

LV6 Suburban street (3 4 bed semi detached or detached houses)

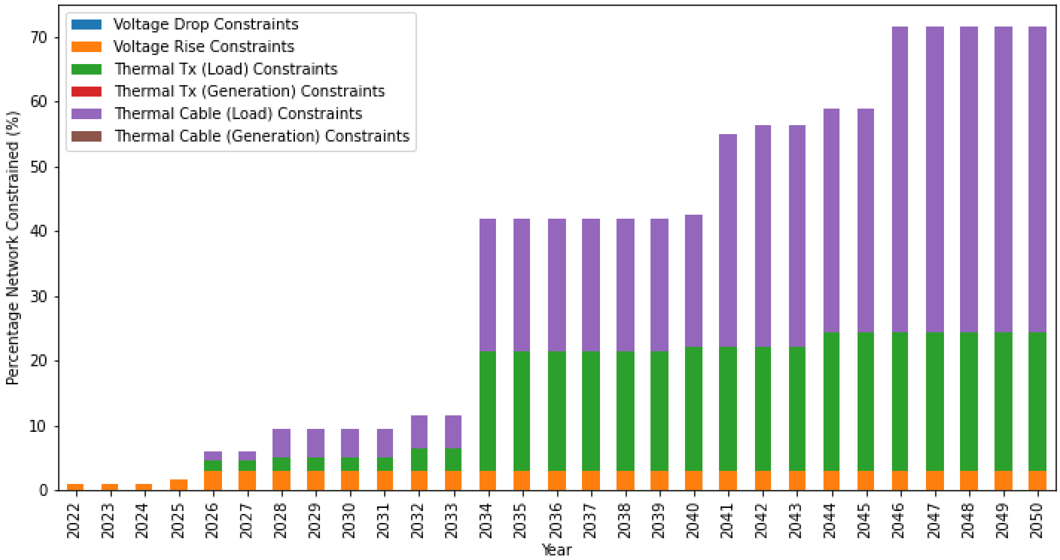


Figure AIX.6 Cumulative Constraints for network archetype LV6 in South West, Best View scenario

LV7 New build housing estate

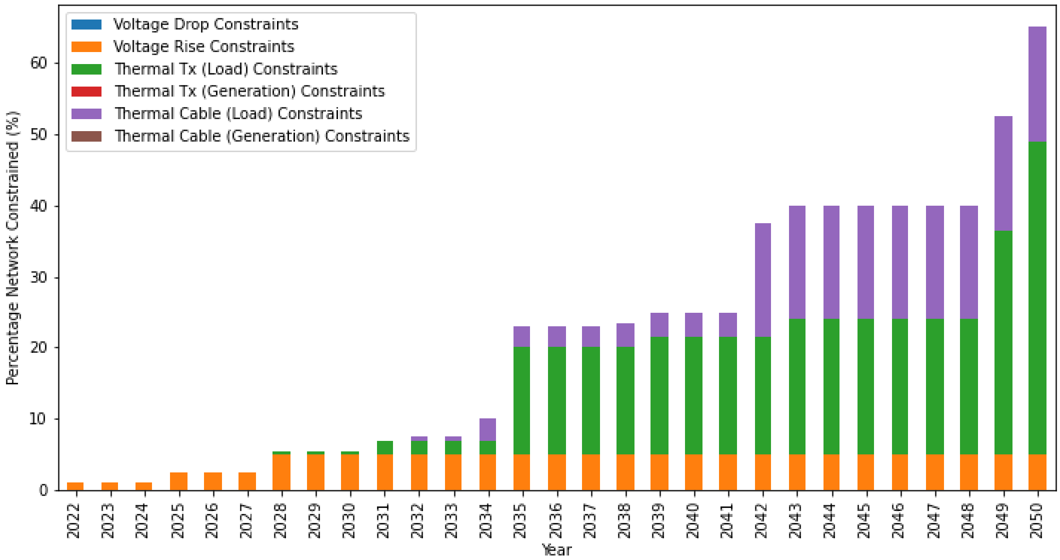


Figure AIX.7 Cumulative Constraints for network archetype LV7 in South West, Best View scenario

LV8 Terraced Street

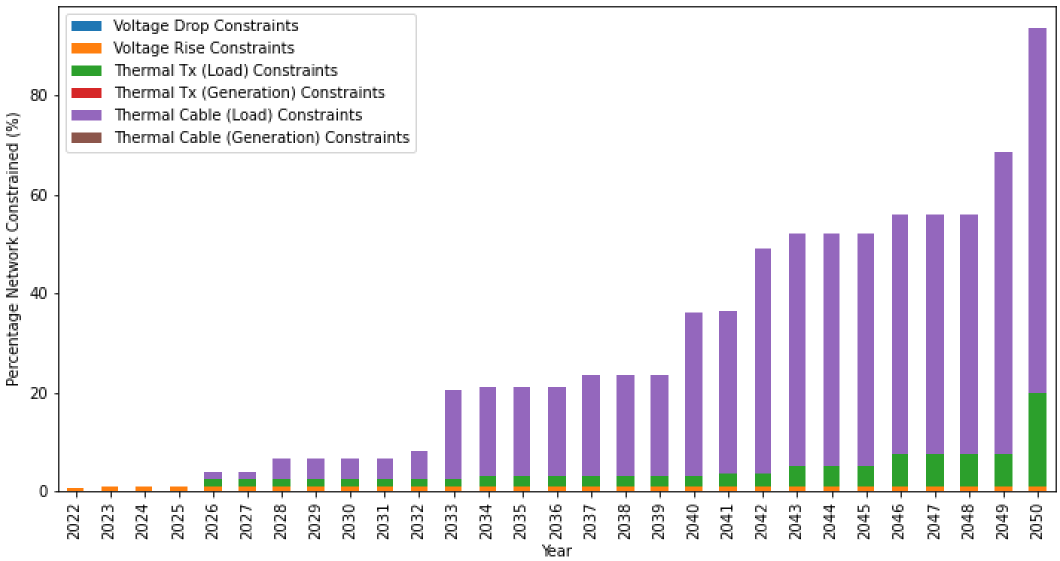


Figure AIX.8 Cumulative Constraints for network archetype LV8 in South West, Best View scenario

LV9 Rural village (overhead construction)

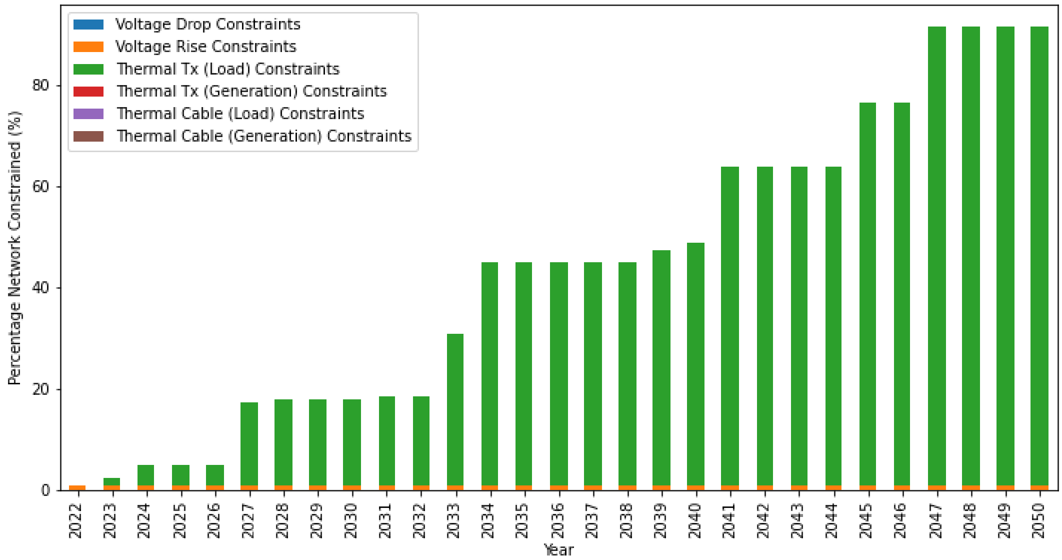


Figure AIX.9 Cumulative Constraints for network archetype LV9 in South West, Best View scenario

LV10 Rural village (underground construction)

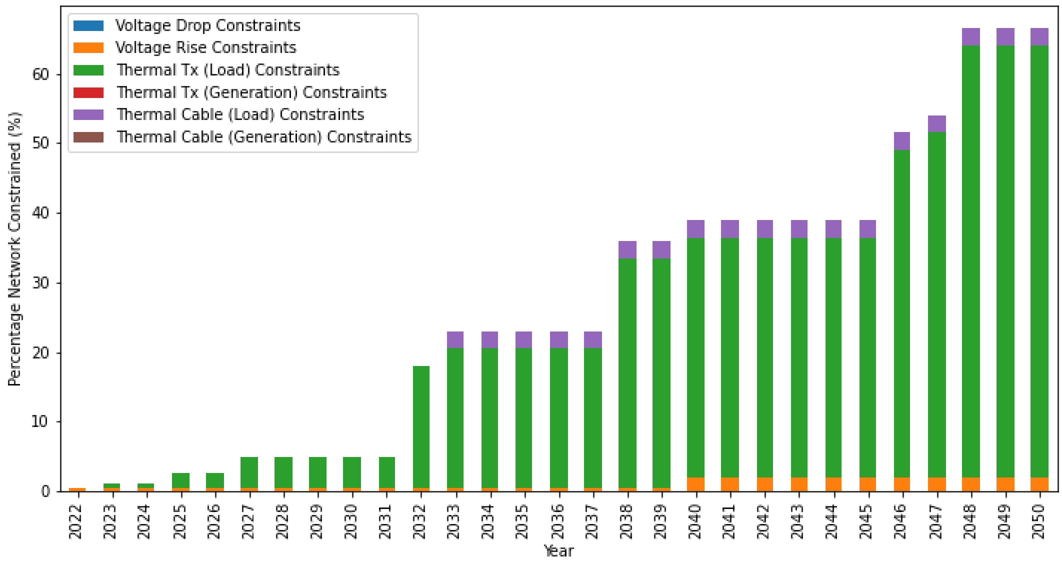


Figure AIX.10 Cumulative Constraints for network archetype LV10 in South West, Best View scenario

LV11 Rural farmsteads small holdings

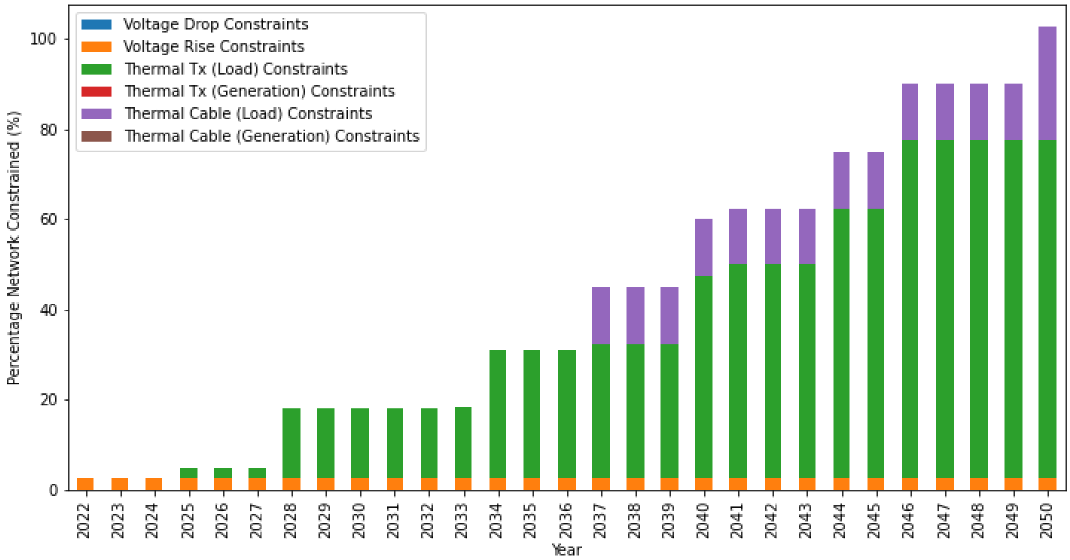


Figure AIX.11 Cumulative Constraints for network archetype LV11 in South West, Best View scenario