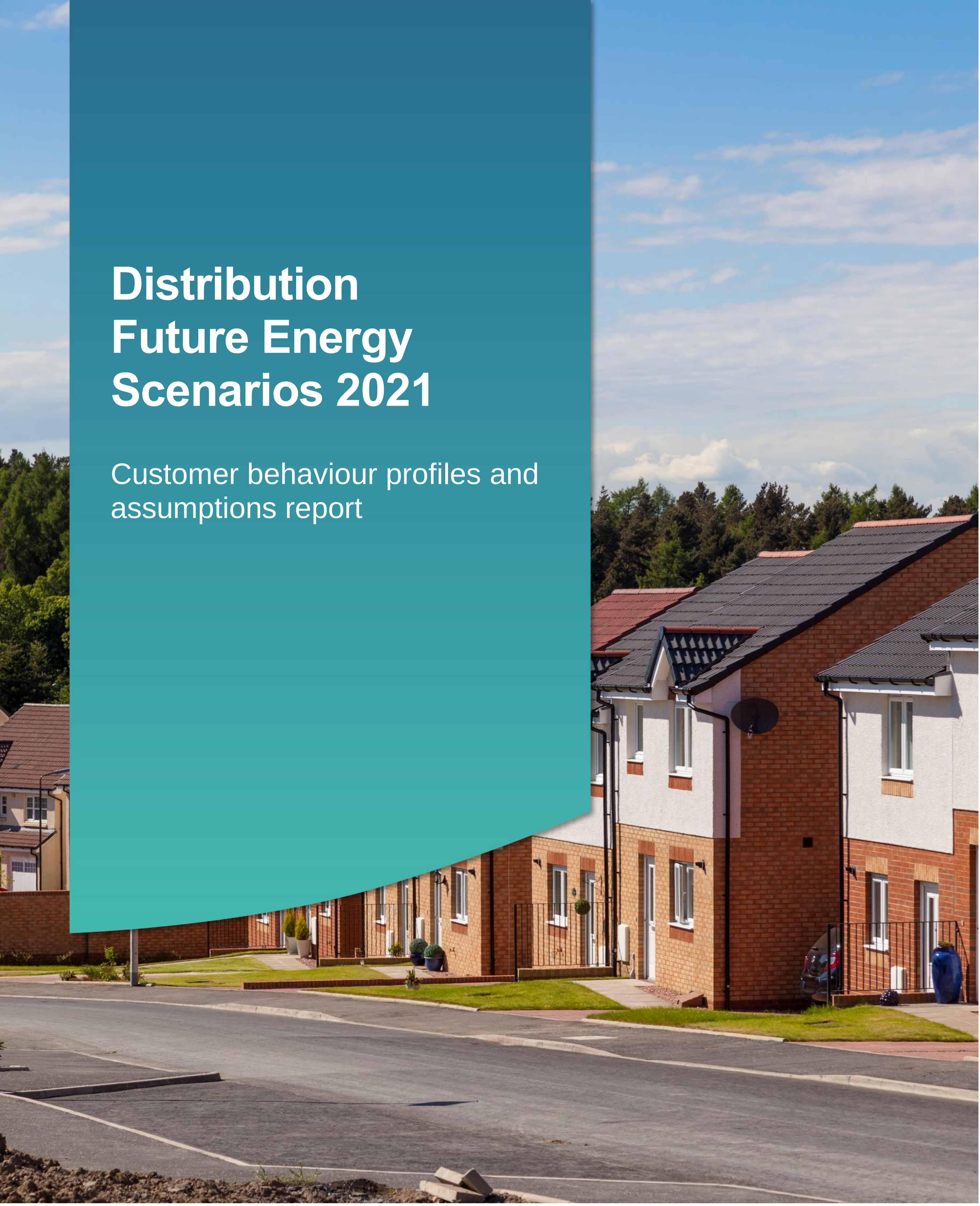

Distribution Future Energy Scenarios 2021

Customer behaviour profiles and assumptions report

Produced: February 2022

Version: 1

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales
a nationalgrid company

Table of Contents

Foreword

This document outlines the assumptions that Western Power Distribution (WPD) use for customer behaviour as part of the strategic network analysis activities. These assumptions are to be used in conjunction with the Distribution Future Energy Scenarios (DFES) studies which are run on an annual basis. The DFES studies and subsequent analysis aim to understand how customer requirements for energy will change the development and operation of the distribution network as the UK transitions to a Net Zero future.

This document sits within a suite of current and planned documents that WPD aim to publish on a regular basis as part of the investment planning process.

When the customer behaviour assumption in this document are applied to the DFES projections a load set of MW/MVAr values can be generated. This load set is a key input to the network analysis processes, whereby the DFES projections are assessed to identify any network constraints. The output of the network analysis is used to determine where WPD-led flexibility services could be used to help the operation of the distribution network, or where conventional reinforcement may be required. The output from the network analysis will be used to publish a Network Development Plan (NDP) in 2022.

For DFES 2021 we have changed the reporting period for forecast years to run by financial year as opposed to calendar year. This better aligns with our reporting periods and outage seasons and will provide clearer data for use both in the business and by stakeholders. As a result, the baseline year is now 2021 which covers FY 2020/21, whereas using the old methodology the baseline for DFES 2021 would have been the calendar year 2020.

It is worth noting that any customer behaviour assumptions must be made with reference to the purpose and level of network analysis that is being undertaken. The profiles that are presented in this document have been created with the purpose of assessing the network's capability and compliance of the WPD 33 kV networks. These can also be applied to relevant studies on the 66 kV and 132 kV networks if appropriate levels of diversity are applied to the projected volumes.

This document utilises a variety of data sources, including metering data from connected customers as well as outputs from innovation projects across the industry. The profiles presented in this document cover some emerging low carbon technologies. The impact of how large scale electrification of heat and transport will affect the operation of distribution networks is not fully understood, these profiles will be reviewed regularly and improved where new data sources are available.

Introduction

Western Power Distribution (WPD) deliver the Distribution Future Energy Scenarios (DFES) project on an annual basis for all four licence areas covered by the WPD network. This provides granular scenario projections for the growth (or reduction) of generation, demand and storage technologies which are expected to connect to the GB electricity distribution network. WPD use a scenario framework that is consistent with National Grid ESO (NGESO), along with all other Distribution Network Operators (DNOs) in Great Britain.

The DFES process can be split into three parts, each of which is summarised below.

Part 1: Volumes

The first part of the DFES process aims to provide granular scenario projections for the number of demand customers and MW of installed generation that are expected to connect to the GB electricity distribution network. The projections are informed by stakeholder engagement to understand the specific needs and plans of local stakeholders in each licence area. WPD undertake this process in conjunction with Regen. The DFES volumes are provided at an Electricity Supply Area (ESA) level, which represents the geographic area supplied by a Primary substation (which contains WPD-owned distribution substations) providing supplies at a voltage below 33 kV, or a customer directly supplied at 132, 66 or 33 kV or by a dedicated Primary substation'. This allows the volumes for each technology to be spatially allocated to where it would be most likely to connect to the distribution network.

The output of this process is a large dataset of granular projections for different technologies, years, scenarios and areas of the WPD network, along with a suite of reports. The data is available on the interactive DFES map on the WPD website. It provides a key data resource and evidence base to enable WPD to appraise different investment options and develop the business case necessary to support future investment, including regulated business plans.

In addition, an extra scenario is developed as a hybrid of the four DFES scenarios. This is called the WPD Best View, and covers the most likely growth pathway that WPD expect to materialise in the next 10 years. This view is curated through extensive stakeholder engagement, to allocate one of the four DFES scenarios that is most applicable to the medium term ambition and delivery for different local stakeholders.

Part 2: Customer Behaviour

For the DFES volume projections to be used by WPD in strategic network analysis, customer behaviour assumptions are allocated to the projected volumes. This accounts for the expected demand and generation profiles of new and existing customers connected to the distribution network. The output of this process is a dataset of load profiles suitable for strategic analysis of the distribution network.

Part 3: MW growth data and application of growth rates

Once the expected customer behaviour assumptions are applied to the DFES volume projections, a demand set of the expected loads on the WPD network can be generated. This data is then mapped to a network model in power system analysis software to undertake detailed network analysis. This data will be published on the DFES map to allow the customer to investigate future network loadings.

The MW growth dataset for the WPD Best View scenario is used to generate percentage growth rates, which WPD use in a range of regulatory submissions, such as the Long Term Development Statement (LTDS), Regulatory Reporting Packs and annual data exchange with National Grid.

Customer Behaviour Modelling

Context

The primary purpose of the DFES projects for WPD is to inform strategic network analysis to understand how the projected change in customer numbers will affect the operation of the distribution network as the UK transitions to a Net Zero future. Table 1 shows a matrix which describes the different components required in order to undertake detailed electrical analysis of any electricity distribution network.

Table 1: Summary table of the aspects required for detailed electrical analysis of the distribution network

	Network	Customers
Assets	Network topology and connectivity information, including impedance and 'nuts and bolts' data about the assets connected to the WPD network. Normally this is captured in a network model in power system analysis software.	Customers connected to the distribution network, including the type of demand or generation connected. This also includes information on the machines or assets that customers have connected to the network (such as Electric Vehicles or Heat Pumps).
Behaviour	Actions taken by the DNO to actively manage the network. This can be in the form of updated running arrangements once an arranged outage is taken, or load management schemes in place to manage network flows. This information is vital if contingency analysis is required.	Expected behaviour of customers connected to the distribution network, with reference to the focus and purpose of the network analysis to be undertaken.

The DFES volumes project provides projections for the number of customer assets that are expected to connect to the WPD network in the next 30 years. It is important to note that the units used in the DFES volumes project are all quantifiable (i.e. they can be counted).

This document outlines the customer behaviour assumptions that WPD use for the purpose of strategic network analysis. These customer behaviour assumptions must be relevant to the purpose of the network analysis that is undertaken. Different factors that may impact the customer behaviour assumptions that are required could include:

- **The voltage level used as the focus of the study** – different customer behaviour assumptions are used depending on the voltage level that is the focus of the network analysis.
- **The aim of the analysis** – different customer behaviour assumptions are applicable depending on what the study aims to deliver. For example, network capability and compliance edge case assessments will require a different set of customer behaviour assumptions to a study which aims to calculate average asset utilisation over a year.
- **The level of risk** – this theme is discussed throughout the document, as there are external factors to the customer behaviour assumptions not directly in the control of a DNO. The balance between studying credible edge-case network conditions to achieve network compliance and designing a network that is operated efficiently will be different for each network company.

Intended use of profile assumptions

The profiles that are presented in this document have been created with the purpose of assessing the network's capability and compliance of the WPD 33 kV networks. These can also be applied to relevant studies on the 66 kV and 132 kV networks if appropriate levels of diversity are applied to the projected volumes.

Case study 1: Impact of diversity on Customer Behaviour

Background

When assessing the network impact, careful consideration needs to be given to ensure the level of diversity applied to customer behaviour is appropriate for the study being undertaken. In the context of customer behaviour profiling, diversity is the assessment of the coincident behaviour of a group of customers or technology types. Not accounting for diversity would result in overly onerous expected loading in network analysis. This could lead to constraints triggered by network analysis that are not observed in network operation, and unnecessary reinforcement schemes started as a result. Conversely, applying too much diversity could lead to credible network constraints being missed.

There are two methods of assessing demand diversity on the Extra High Voltage (EHV) distribution network:

1. **Aggregated demand as substation level –** A load survey is undertaken to determine the substation demand at the cardinal network edge-cases. This is with all generation unmasked to give the true underlying demand.
2. **Profiling technologies –** Each technology category that is connected, or projected to connect is assigned an explicit profile that is appropriate for the study being undertaken.

An aggregated Primary substation demand profile has traditionally been used for EHV network design, due to the challenge of building up a representative Primary level profile from the constituent volumes and other factors that can influence network loading. This inherently captures the level of diversity of all demand connected downstream and is suitable for assessing existing network demand and for short-term network assessments. The aggregated approach does not provide any information on what customers are contributing to the edge-case peaks. This makes modelling changing demand behaviour challenging.

Diversified Profiles

The ACE49 methodology[1] used for LV design is an example of how the average demand assumed per customer reduces as the size of the group increases. Figure 1 shows how the kW per customer of domestic unrestricted profile class 1 reduces as the group size increases. This tends towards a constant value as the number of customers increases; this is sometimes referred to as a fully diversified profile.

[1] ACE Report no.49, *Report on Statistical Method for Calculating Demands and Voltage Regulations on LV Radial Distribution Systems*, Energy Networks Association, 1981;

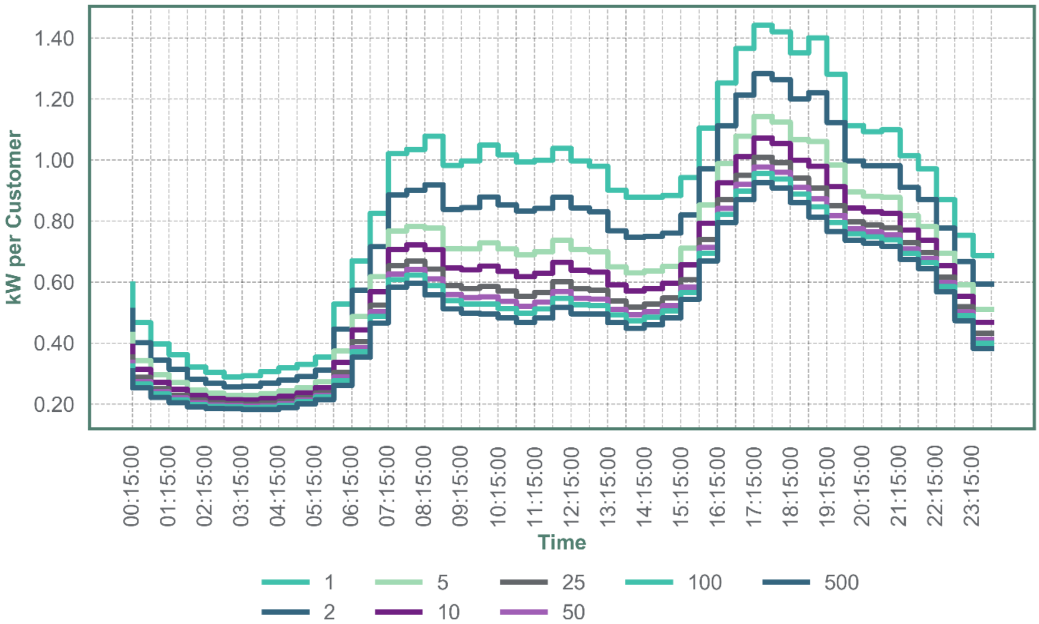

Figure 1: Impact of diversity on typical domestic demand (based on Elexon 1 profile class - domestic unrestricted) for different number of customers

When profiling specific technologies at EHV, consideration of an appropriate level of diversity is important. At EHV, the group size of a given technology (e.g. heat pumps) may be sufficiently large that the profile can be considered full diversified. It is worth noting that the ACE49 methodology aims to provide a suitable level of risk such that LV networks are designed adequately, but not over-generously for the demands on each part of the network. The profiles used in this document for application to the WPD EHV networks do also account for a level of risk; however this risk is not quantified in this document.

Coincident Peaks of different technologies

The diversity of a single technology is only one part of determining the worst credible network conditions. All demand needs to be considered when analysing network edge-cases, as not all demand is coincident.

Figure 2 shows a few of the DFES technologies winter peak profiles described in this report with different profile shapes. It highlights that technologies can have notably different profile shapes and peaks. Taking the peak of each of these profiles without accounting for the non-coincident nature would not accurately represent the demand on the network. To account for this, the DFES profiles are full half-hourly profiles for all representative days.

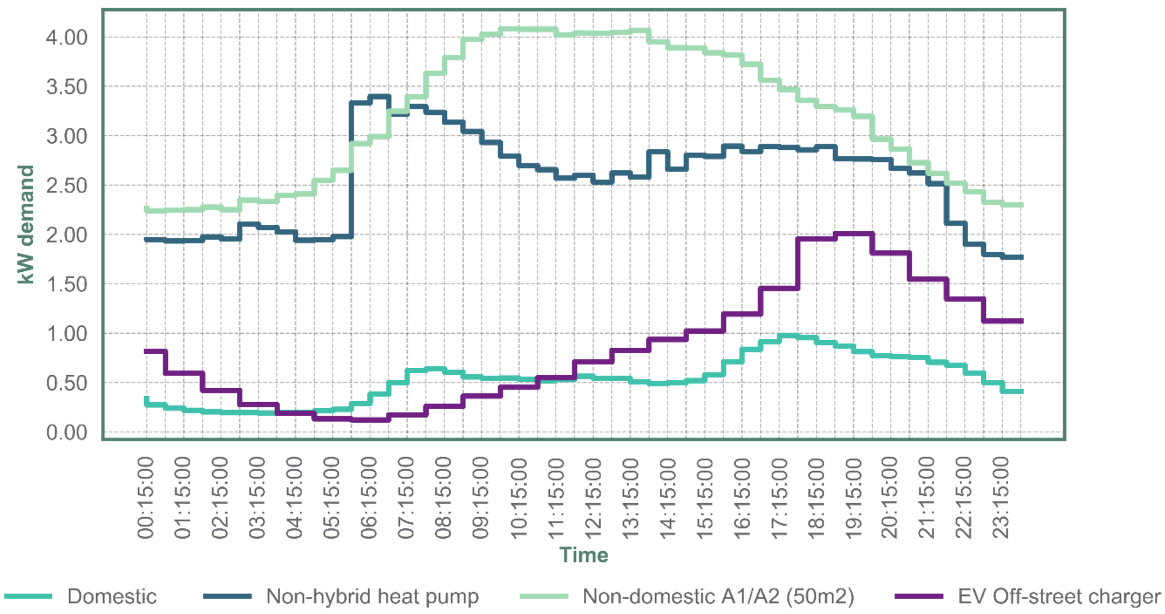

Figure 2: Example of DFES technology winter peak profiles differences

The magnitude and time of peak of a substation will depend on the constituent parts that make up the overall aggregated substation demand. The aggregated peak may change over time as the volumes and individual technology profile changes.

Diversified Primary Demand

This example highlights the impact of Primary level diversity using real-world network loadings from Portishead Bulk Supply Point (BSP) in South West WPD licence area. This aggregated substation demand inherently captures the diversity observed between everything connected downstream of the Primary substation, but does not capture the diversity between Primaries.

Substations dominated by unrestricted domestic customers will typically peak in winter around 18:00; substations dominated by non-domestic customers often peak in the middle of the day. Not all substations peak in winter, an example of this is a substation that feeds demand in a holiday destination, where the peak is typically over the holiday periods.

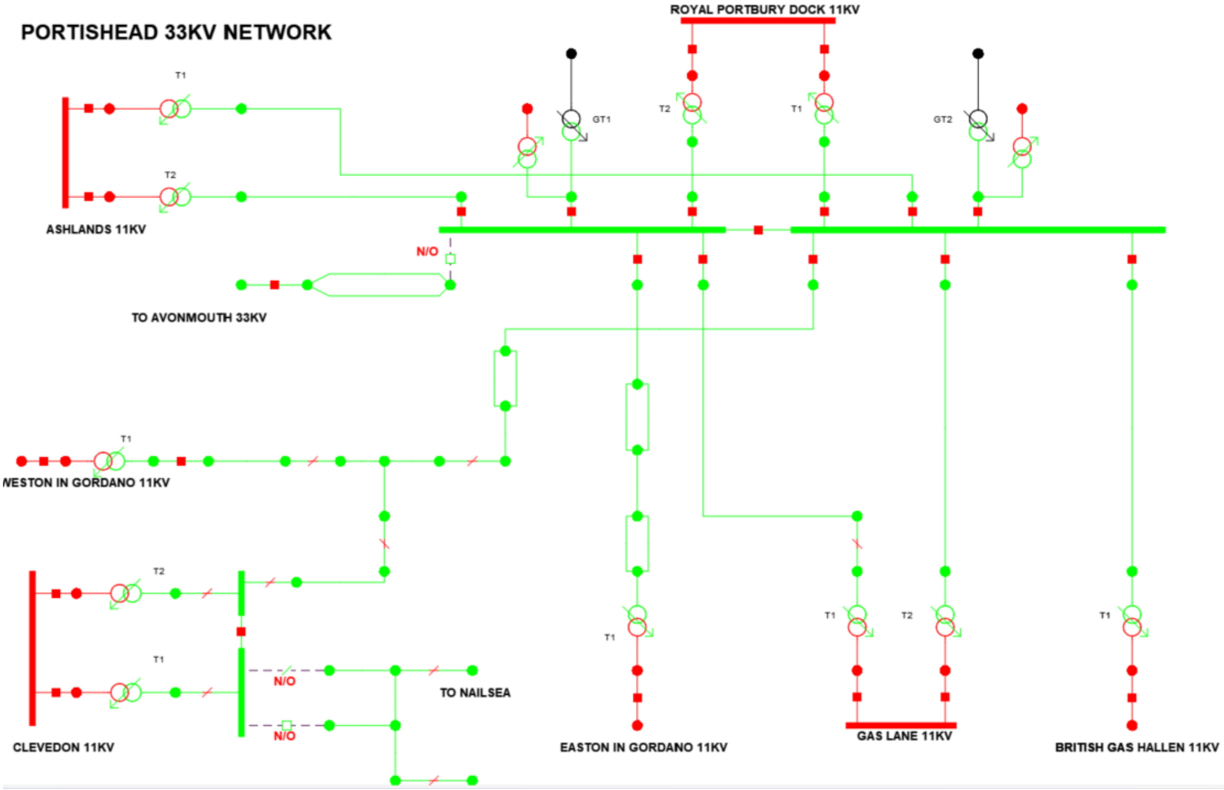

Figure 3: Portishead 33 kV Network

Table 2 summarises the Primary peak and Primary at BSP peak demand for all substations connected downstream of Portishead BSP. The time of the Primary peak varies notably between 09:00 and 19:30, with the majority peaking between 17:30 and 19:00. All Primaries except British Gas Hallen 11 kV peak in the winter season, noting that all have a different date of peak. The sum of the Primary Peaks is 51.43 MVA.

Table 2 gives a breakdown of the Primary demand at the time of BSP peak; the total is 45.12 MVA. This is 12.3% lower than the sum of the Primary peaks. At the time of the upstream Seabank Grid Supply Point (GSP) peak, Portishead BSP total demand is 42.64 MVA, which is 17.1% lower than the sum of Primary peaks.

Table 2: Portishead substation peaks vs BSP peak

Substation	Primary Peak (MVA)	Time of Peak	Date of Peak	Primary @ BSP Peak (MVA) *
Portishead Ashlands 11kV	6.17	19:30:00	09/01/2020	5.92
British Gas Hallen 11kV	0.71	15:00:00	07/08/2019	0.37
Clevedon 11kV	15.39	18:30:00	29/01/2020	12.74
Easton In Gordano 11kV	3.82	17:30:00	05/01/2020	3.47
Gas Lane 11kV	9.63	18:30:00	17/12/2019	9.22
Royal Portbury Dock 11kV	11.16	09:00:00	31/01/2020	8.40
Weston in Gordano 11kV	4.55	18:00:00	12/01/2020	5.01
Total	**51.43**			**45.12**

*BSP peak was at 19:00 on the 09/01/2020

This highlights the importance of using the appropriate diversified Primary demand set when analysing the EHV network. Using a Primary peak demand set to assess GSP loadings would give loadings that are 10-20% higher than are actually observed by network monitoring. Conversely, using a Primary at GSP peak demand set to assess 33 kV constraints means genuine network issues could be missed.

Representative Days

Traditionally, distribution networks are assessed using edge-case modelling, where only a snapshot of the network condition that is deemed most onerous is analysed. As the installed capacity and behaviour of demand, generation and storage is rapidly changing, it has become difficult to predict what network condition will be most onerous.

To cover a range of likely onerous cases, WPD consider a range of different potential representative days, which are used to assess network capability for the analysis purpose identified in the aforementioned *Intended use of profile assumptions* section:

- **Winter Peak Demand**, with minimum coincident generation – an assessment of the network's capability to meet peak demand conditions and determine group demand as per Engineering Recommendation P2/7[2];
- **Summer, Intermediate Warm Intermediate Cool Peak Demand**, with minimum coincident generation – an assessment of the network's capability to meet access window demand conditions;
- **Summer Peak Generation**, with minimum coincident demand – an assessment of the network's capability to handle generation output.

The definition of seasons is taken from Engineering Recommendation P27/2 (Current rating guide for high voltage overhead lines operating in the GB distribution system)3:

- **Winter:** January, February and December
- **Intermediate Cool:** March, April and November
- **Intermediate Warm:** May, September and October
- **Summer:** June, July and August

The DFES 2021 study projects high customer uptake of low carbon technologies, such as Electric Vehicles (EVs) and Heat Pumps (HPs). Low carbon technologies are expected to allow customers to manage their demand at an individual level, such as shifting energy usage away from traditional times of peak network loading. As a result, the five representative days studied include a half-hourly power profile. This aims to help us to understand how the shape of the demand profile will change over time, which could inadvertently introduce local network peaks at times which are away from the existing time of network peak.

---

[2] Engineering Recommendation P2 Issue 7, *Security of Supply*, Energy Networks Association, 2019;

[3] Engineering Recommendation P27 Issue 2, *Current rating guide for high voltage overhead lines operating in the UK distribution system*, Energy Networks Association, 2020;

Case Study 2: Importance of studying multiple seasons

This case study highlights the potential impact of only considering a representative day for one season only, traditionally being the Winter Peak Demand, when assessing networks. Winter Peak Demand can often represent the maximum demand but it is not always the most onerous network condition. The demand profile for many areas of the network show that although the peak demand may appear in the cooler months, the reduction of the network's asset ratings in the subsequent warmer seasons can be greater than the corresponding reduction in demand. This can shift the network's most onerous condition away from the traditional winter Peak and onto intermediate cool, intermediate warm, or summer seasons.

Consider the demand profile below which has been observed on Halesfield 33/11 kV Primary substation in Telford in Figure 4.

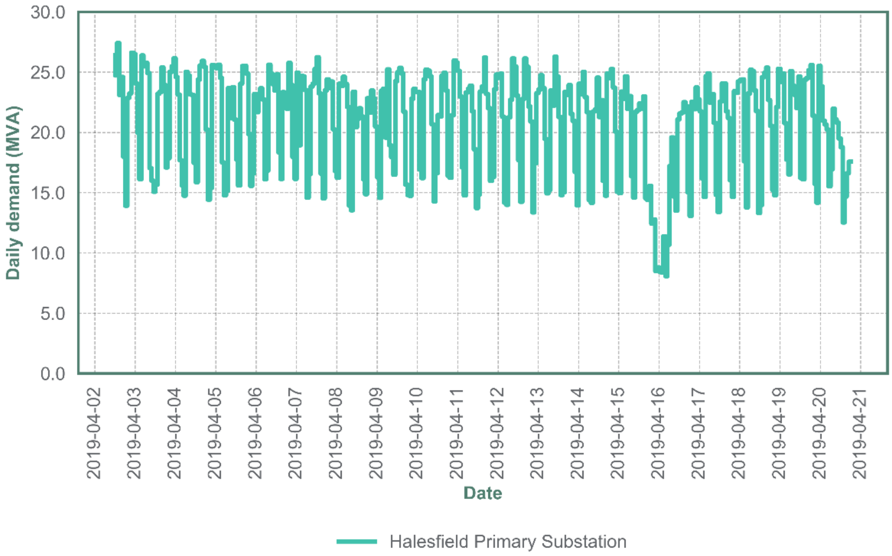

Figure 4: Output graph to show total 'underlying' demand over a yearly period at a Primary substation

Prior to reinforcement, the site was fed via two 33 kV circuits each rated 31 MVA, 29 MVA, 29 MVA, and 25 MVA for winter, intermediate cool, intermediate warm, and summer respectively. The substation's maximum demand across all four seasons was 27.4 MVA, falling within the intermediate cool season in April. This makes the site Class C under Engineering Recommendation P2/7[4], requiring Group Demand to be restored within 3 hours following a First Circuit Outage (FCO). Under a fault condition on one of the incoming circuits, the following demand would be observed on the second remaining circuit:

[4] Energy Networks Association, *Engineering Recommendation P2 Issue 7*, p9

Table 3: Substation seasonal peak demand and rating comparison

Demand Edge-case	Month	Demand (MVA)	Asset Rating (MVA)	Utilisation
Winter Peak	February	25.4	31	81.9%
Intermediate Cool Peak	April	27.4	29	94.5%
Intermediate Warm Peak	October	26.2	29	90.3%
Summer Peak	July	26.3	25	105.2%

Table 3 highlights that although the site's maximum demand appeared in the intermediate cool season (outside of the traditionally assessed winter season), the most onerous representative day was in fact the Summer Peak Demand when taking into account the circuit's seasonal ratings.

These scenarios, typically seen in industrial and commercially dominated areas, are becoming more common as customers move towards increasingly efficient and smarter technologies, and to utilise more economic variable tariffs.

The case study shows a need to study networks across multiple seasons to identify the most onerous conditions. It further underlines the requirement to carry out these studies periodically as it can be seen from the case above that the asset utilisation per season can be relatively close to each other so the most onerous season can vary from one year to another.

Changing Nature of Demand

On 31st December 2020, changes to the Electricity Distribution Licence were introduced as part of the EU Electricity Directive 2019/944, part of the Clean Energy of all Europeans Package[5]. As part of these Licence Condition changes, DNOs are required to develop a Network Development Plan (NDP) to outline the expected development of the distribution system over a 5 to 10 year period. As part of this requirement, DNOs are required to justify any assumptions on the expected uptake of demand-side response (DSR) and energy efficiency, as a means to alter existing demand observed on the network.

In order to understand the changing nature of demand, these assumptions can be split into two separate categories of flexibility and energy efficiency services:

- **Passive/Customer led:** these are actions that customers actively take to manage their electricity demand. This can be in response to behind the meter assets installed, or as part of measures to increase energy efficiency. It is important to note that the DNO has no active part in this process and currently would have no mechanism to determine if an individual customer has changed their consumption behaviour.
- **Active/Network led:** this accounts for flexibility services that are procured and dispatched by a network operator to alleviate a particular network constraint or to defer network reinforcement. These are currently delivered by WPD through the Flexible Power brand.

[5] Ofgem, *Open letter on changes to licence conditions as a result of the transposition of the Clean Energy Package,* 8th December 2020; https://www.ofgem.gov.uk/system/files/docs/2020/12/electricity_directive_open_letter_0.pdf

The DFES 2021 customer behaviour assumptions aim to use credible, evidence based assumptions for how passive/customer led flexibility and energy efficiency services can alter the existing levels of demand observed on the network. The network led flexibility services should be employed following detailed analysis to identify areas where flexibility services are required on the network. WPD published an article as part of the Distribution System Operability Framework (DSOF) in 2018 which investigated how changing load profiles could impact network design[6].

Whilst DNOs must account for the credible expected use of customer led energy efficiency and flexibility measures, these must also be balanced with the ongoing requirement to operate and maintain an economic, efficient and coordinated network. The risk associated with assumptions on the expected level of customer led energy efficiency and flexibility measures are that if the assumptions do not materialise DNOs could be investing in a network that is inoperable at times of peak network loading.

Consider the condition where the peak demand observed on a local network is not coincident with the time and date of the GB electricity system peak. For this condition, the expected availability of customer led flexibility services at GB electricity system peak demand (which if not directly contracting with a DNO are largely driven by the electricity wholesale price signals) may not be available for the local network peak. As a result, it is prudent for DNOs to use more conservative assumptions on the expected use of customer led flexibility services, if the local network constraint is not coincident with periods of high network loading on the GB electricity system.

Application of customer behaviour profiles

To capture the complex nature of the customer behaviour modelling in the DFES studies, two different types of profiles are used:

- **Unabated profiles:** all technologies use an 'unabated' profile, which captures that credible edge-case demand profile for each of the representative days considered.
- **Flexed profiles:** Some technologies may also utilise a 'flexed' profile, which is one where a customer would respond to an external driver to flex their demand, not as part of a DNO contracted and procured service.

A flexed profile in itself is not necessarily representative of the expected behaviour of a group of customers. Instead, a split of the proportion of customers expected to be consuming energy using an unabated and flexed profile is applied. The combination of the unabated and flexed profiles together represent the average expected impact per customer on the distribution network. This profile split factor is year and scenario dependent, to account for the differing levels of consumer engagement in the DFES scenario framework.

In addition to the option of altering expected customer behaviour to account for customer led flexibility services, a profile scaling factor is also applied to the profiles. This scaling factor accounts for any expected energy efficiency increases made by customers connected to the WPD network. The yearly scaling factor is used to linearly scale each demand profile from the baseline year. It is year and scenario dependent, to account for different expected energy efficiency measures in the DFES scenario framework.

To calculate the expected aggregate customer behaviour profile, the profile components are combined with the profile scaling and expected split between unabated usage and flexed usage.

---

[6] Distribution System Operability Framework, *Changing Load Profiles*, Western Power Distribution, 2018. https://www.westernpower.co.uk/downloads/18622

Worked Example

A visual representation of how the customer behaviour profiles are assigned to the DFES volumes projections is included in Figure 5 for the following criteria.

- **Technology:** Domestic
- **Units:** Number of new domestic dwellings
- **Licence area:** East Midlands
- **Scenario:** Consumer Transformation
- **Year:** 2050

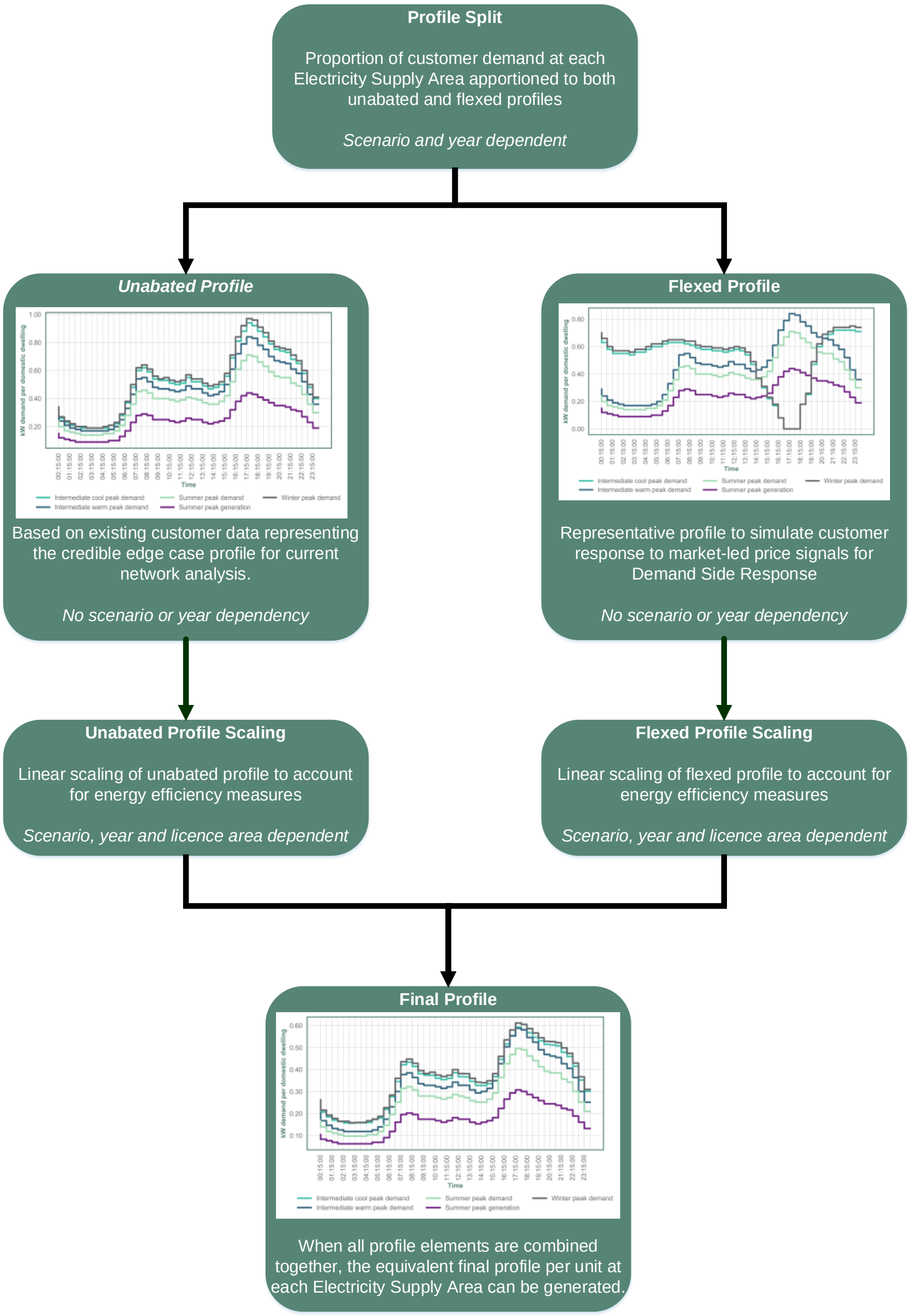

Figure 5: Representation of how customer behavioural changes are applied to the profiles for DFES analysis

Structure of profile sections

In the following sections of this report, each of the technology types studied as part of the DFES 2021 study is analysed with the customer behaviour profiles used by WPD. Each technology type section follows the structure outlined below:

- **Methodology** – a detailed description of the methodology used to obtain representative profiles with any data sources used.
- **Representative Day Profiles** – a graphical representation of the profiles used.
- **How these profiles will change over time** – how WPD expect these profiles will change over time, due to customer-led actions that the DNO is not able to influence directly.
- **Energy modelling** – outline of the assumption WPD use to benchmark the expected energy consumption of demand technologies across the WPD network against other scenario based forecasting, such as those used in the Committee for Climate Change 6th Carbon Budget[7].
- **Known limitations** – a description of the areas where the profiles used could be improved to better align with expected customer behaviour
- **Future developments** – how WPD plan to improve the profiles to address some of the known limitations.

[7] Committee for Climate Change, *The Sixth Carbon Budget: The UK's path to Net Zero,* 2020; https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

Customer Behaviour assumptions

Generation and storage technologies

Solar Generation

Table 4: Table of solar generation technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Solar Generation	Commercial rooftop (10kW - 1MW)	MW of installed capacity
	Domestic rooftop (<10kW)	
	Ground mounted (>1MW)	

Methodology

Each solar generation customer is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. Solar generation volumes are provided as the installed capacity (MW) of generation connected.

Real power output data from all solar generation sites across the WPD licence areas was collected and aggregated by each half hour in the calendar year of 2021. Only sites with an installed capacity greater than or equal to 100 kW were considered. Table 5 shows the solar generation data sample:

Table 5: Sample size of solar generation site used to create profiles

Licence Area	Number of sites in sample	Total installed capacity of sites in sample
East Midlands	412	1096 MVA
South Wales	156	513 MVA
South West	454	1049MVA
West Midlands	353	445 MVA

Half hourly generation profiles were created for each of the five representative days used for network analysis. This was achieved by considering the maximum and minimum generation output observed during each half hour across the whole of each season in the aggregated generation data and normalising this by installed capacity of the sample to give a per unit value.

To account for varying levels of diversity of solar generation output across the network, the analysis was completed with different subcategory groups of licence area totals, 132 kV connected, 33 kV connected and Primary substation connected sites. The licence area aggregated profiles represent the expected per unit output of solar generation when viewed as part of the total generation installed across a licence area. At lower levels of diversity the profiles represent the worst case observed profile of all sites considered in the sample group.

The grouped profiles represent the maximum output of each group combined, so lead to a more pessimistic profile showing greater generation output due to local diversity being less than that of the whole licence area. Given the purpose of the analysis for the studies was focussed on the EHV networks, a worst case Primary substation diversified profile was chosen for this analysis. A comparison of the South West licence area profile to a grouped profile is shown in Figure 6 to demonstrate the difference in diversity and the motivation for this approach.

Example of solar generation diversity

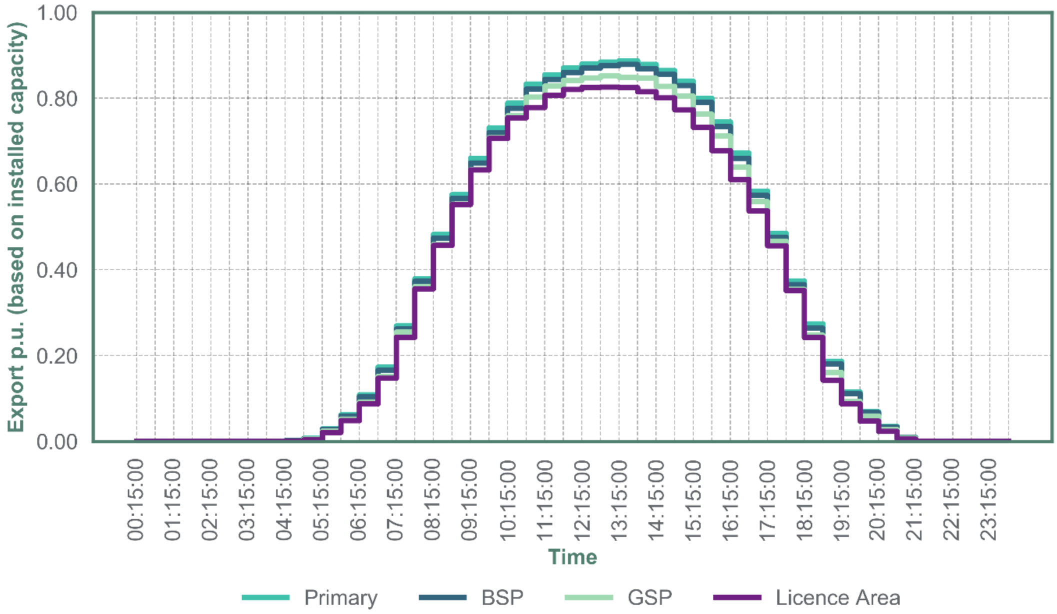

Figure 6: Representative worst case solar generation profiles at different diversity levels observed in the South West licence area

As each licence area was analysed separately, there are four sets of solar generation profiles used for network analysis.

Representative Day Profiles

South West

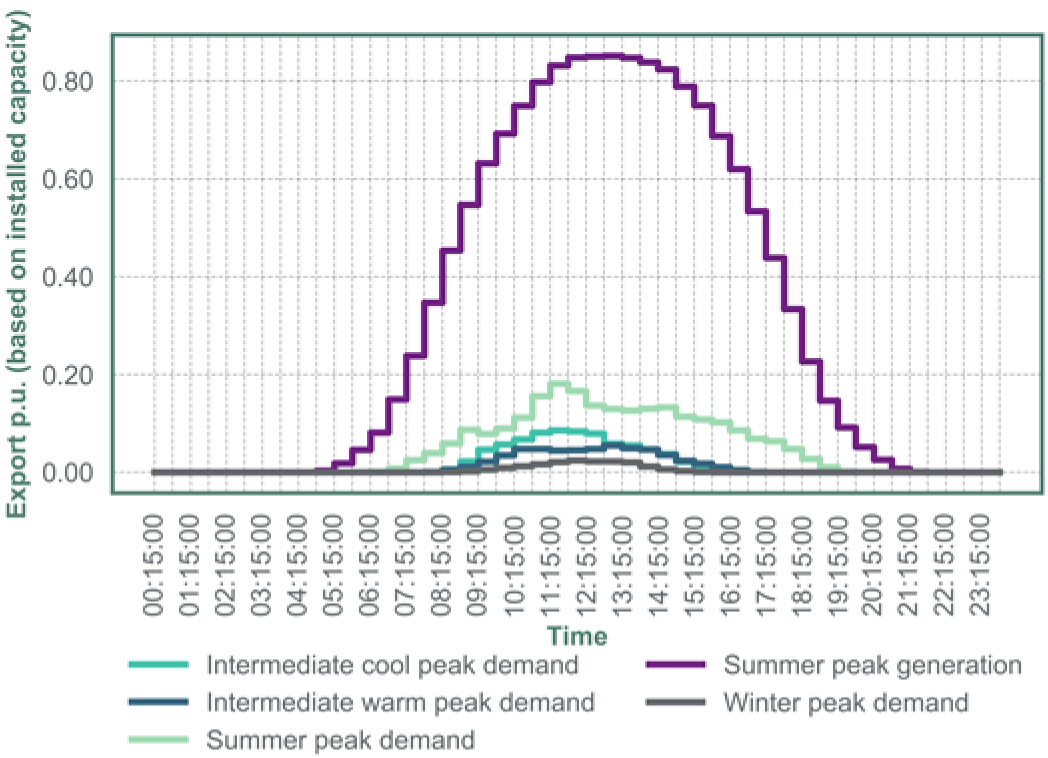

Figure 7: Representative solar generation profiles for customers in the South West licence area

South Wales

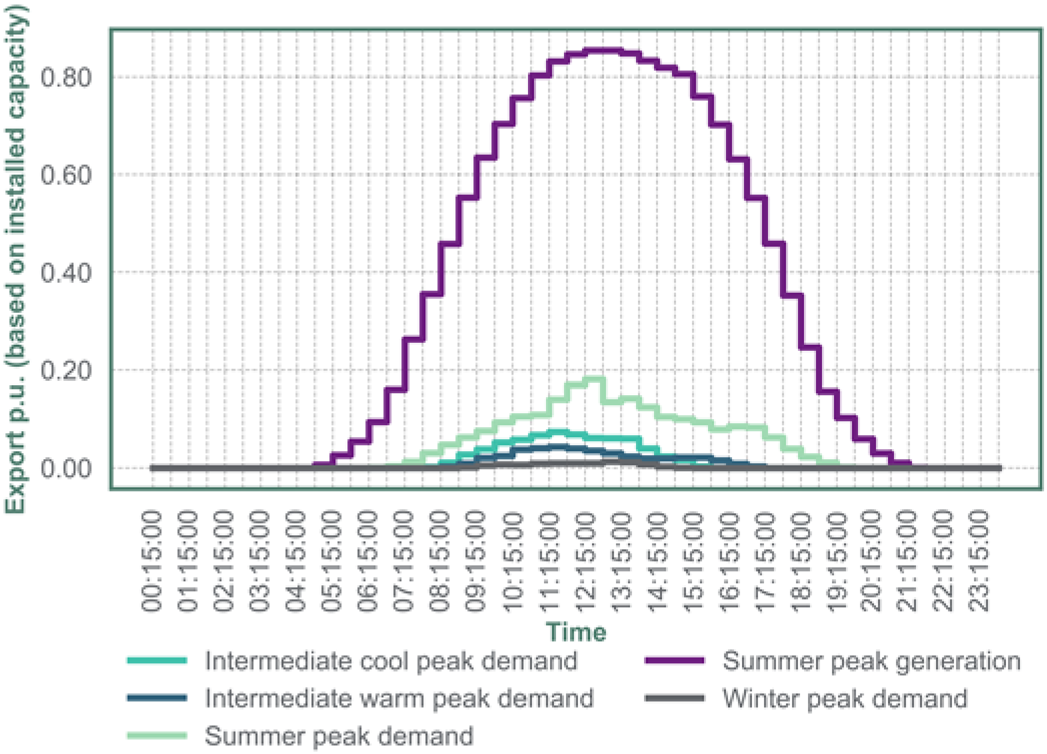

Figure 8: Representative solar generation profiles for customers in the South Wales licence area

East Midlands

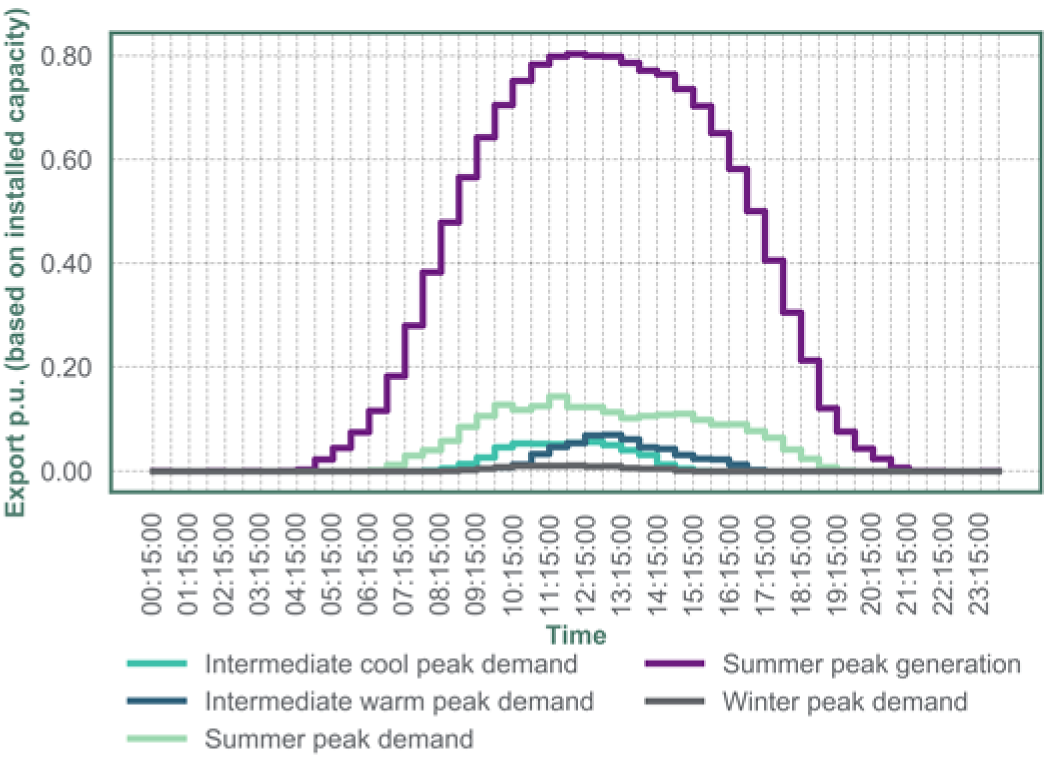

Figure 9: Representative solar generation profiles for customers in the East Midlands licence area

West Midlands

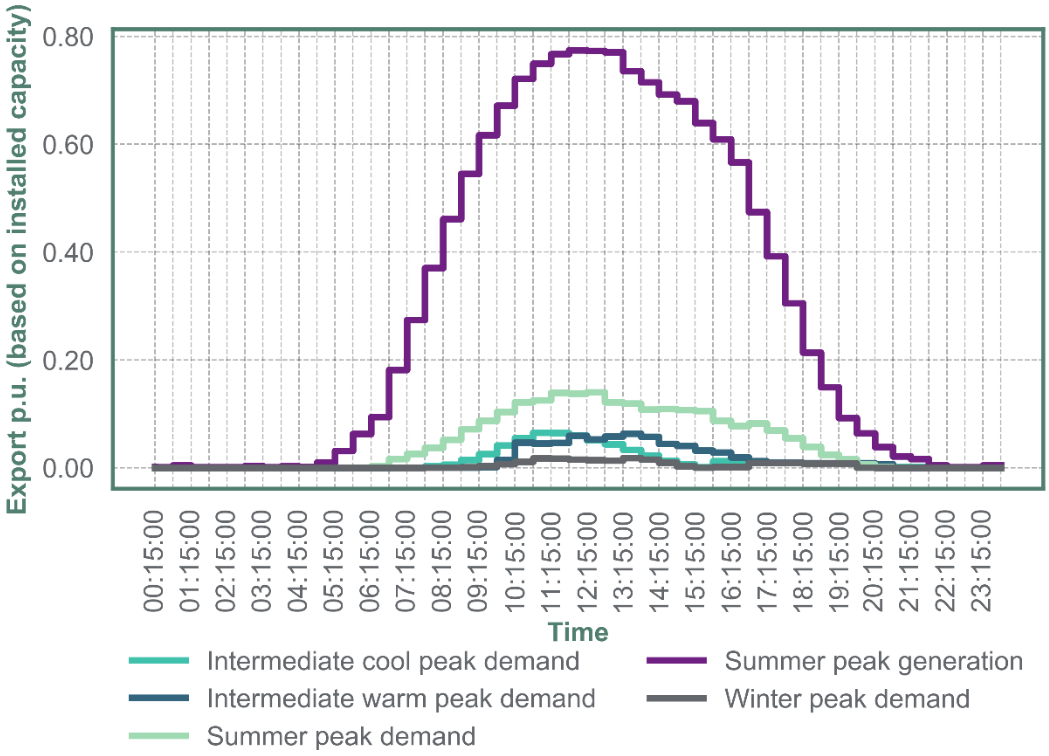

Figure 10: Representative solar generation profiles for customers in the West Midlands licence area

How will these profiles change over time

It is assumed that the load profiles for solar generation sites will not change in the future.

These profiles are normalised around the installed capacity, rather than the contracted export capacity. For instances where a customer installs much more generating plant than the contracted capacity, an export limitation scheme is implemented in the network analysis stage to limit the export of any over-installed generation. This is also the case for any generation sites with an installed Active Network Management (ANM) scheme, where the logic for the load management scheme is incorporated into the network analysis.

Known Limitations

The solar generation profile is assigned to all generation customers across a licence area, regardless of the size and type of solar generation. Due to different efficiencies of small scale rooftop solar compared to a large scale ground mounted installation, explicit profiles may be required for the subtechnologies in Table 4.

As some of the solar generation sites across the WPD network are due to reach the end of the operational life in the next 30 years, there may be opportunities for customers to replant with more efficient equipment, as well as utilising behind the meter storage and customer led load management schemes. These potential changes have not been accounted for in this analysis.

Future Developments

Further analysis will be undertaken to develop more granular profiles related to specific sizes of solar generation customers and to account for regional variations in solar generation output within a licence area.

Onshore Wind Generation

Table 6: Table of onshore wind generation technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Wind	Onshore Wind <1MW	MW of installed capacity
	Onshore Wind >=1MW	

Methodology

Each onshore wind generation customer is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. Onshore wind generation volumes are provided as the installed capacity (MW) of generation connected.

Real power output data from all onshore wind generation sites across the WPD licence areas was collected and aggregated by each half hour for the calendar year of 2021. Only onshore wind sites with an installed capacity greater than or equal to 100 kW were considered. Table 7 shows the onshore wind generator data sample:

Table 7: Sample size of onshore wind generation site used to create profiles

Licence Area	Number of sites in sample	Total installed capacity of sites in sample
East Midlands	109	398 MVA
South Wales	104	525 MVA
South West	123	303 MVA
West Midlands	22	46 MVA

Half hourly generation profiles were created for each of the five representative days used for network analysis. This was achieved by considering the maximum and minimum generation output observed during each half hour across the whole of each season in the aggregated generation data and normalising this by installed capacity of the sample to give a per unit value.

To account for varying levels of diversity of onshore wind generation output across the network, the analysis was completed with different subcategory groups of licence area totals, 132 kV connected, 33 kV connected and Primary substation connected sites. The licence area aggregated profiles represent the expected per unit output of onshore wind generation when viewed as part of the total generation installed across a licence area. At lower levels of diversity the profiles represent the worst case observed profile of all sites considered in the sample group.

The grouped profiles represent the maximum output of each group combined, so lead to a more pessimistic profile showing greater generation output due to local diversity being less than that of the whole licence area. Given the purpose of the analysis for the studies was focussed on the EHV networks, a worst case Primary substation diversified profile was chosen for this analysis. A comparison of the South West licence area profile to a grouped profile is shown in Figure 11 to demonstrate the difference in diversity and the motivation for this approach.

Example of onshore wind generation diversity

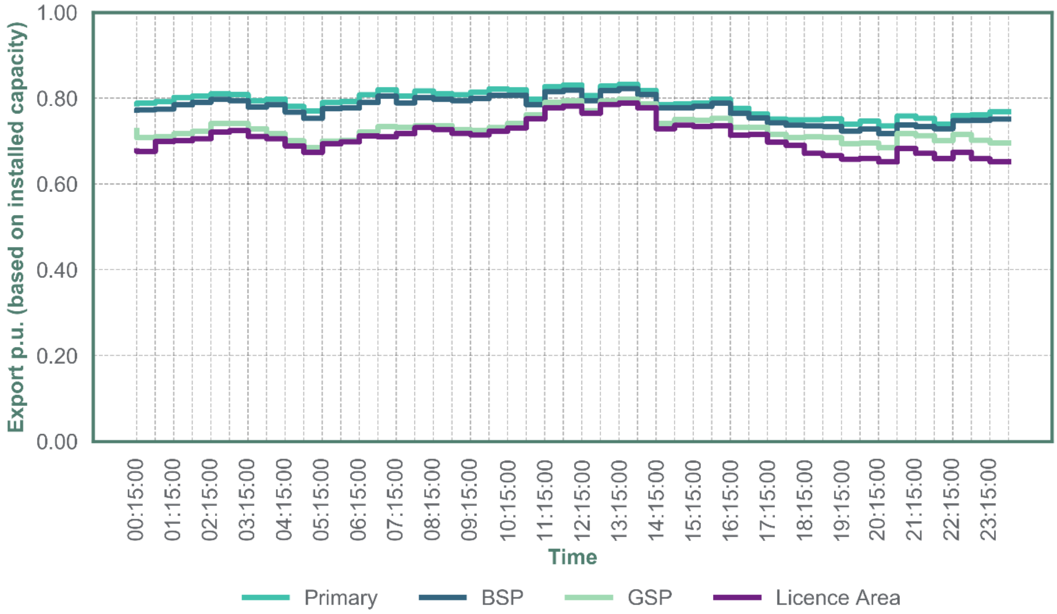

Figure 11: Representative worst case onshore wind generation profiles at different diversity levels observed in the South West licence area

As each licence area was analysed separately, there are four sets of onshore wind generation profiles used for network analysis.

Representative Day Profiles

South West

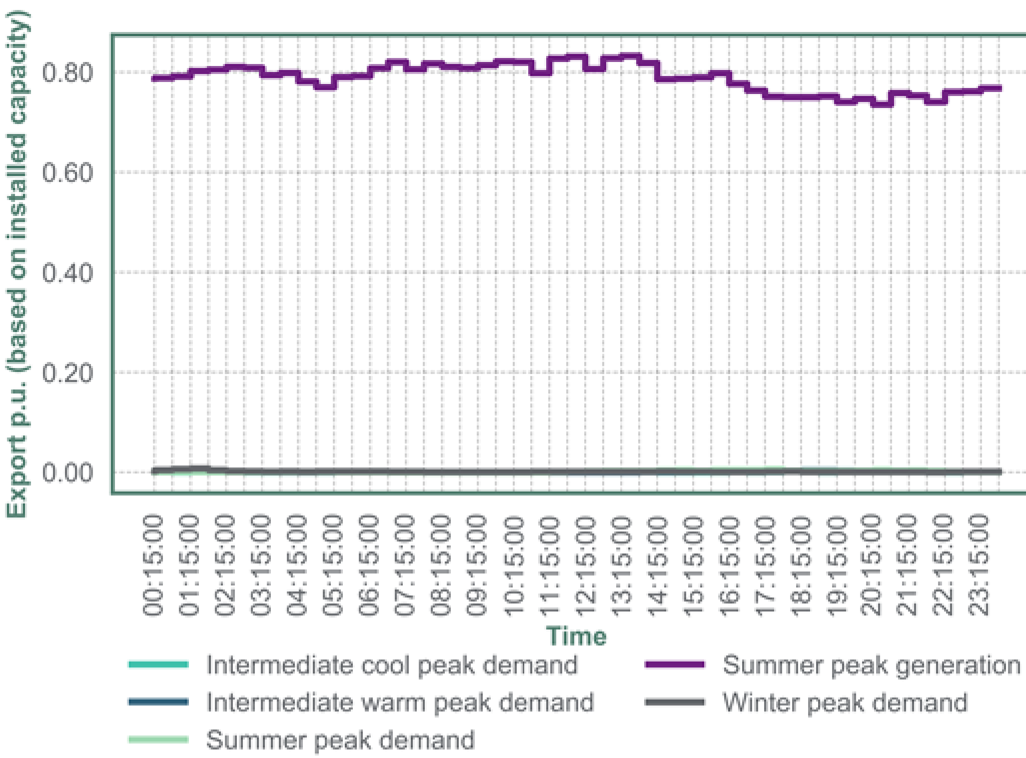

Figure 12: Representative onshore wind profiles for customers in the South West licence area

South Wales

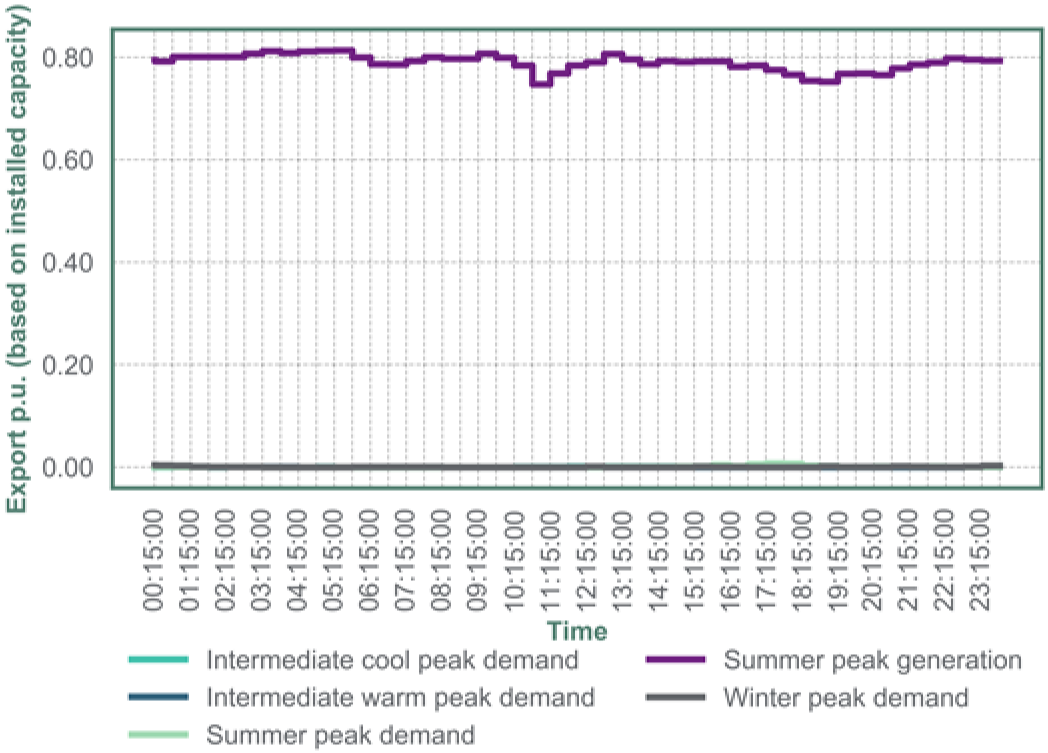

Figure 13: Representative onshore wind profiles for customers in the South Wales licence area

East Midlands

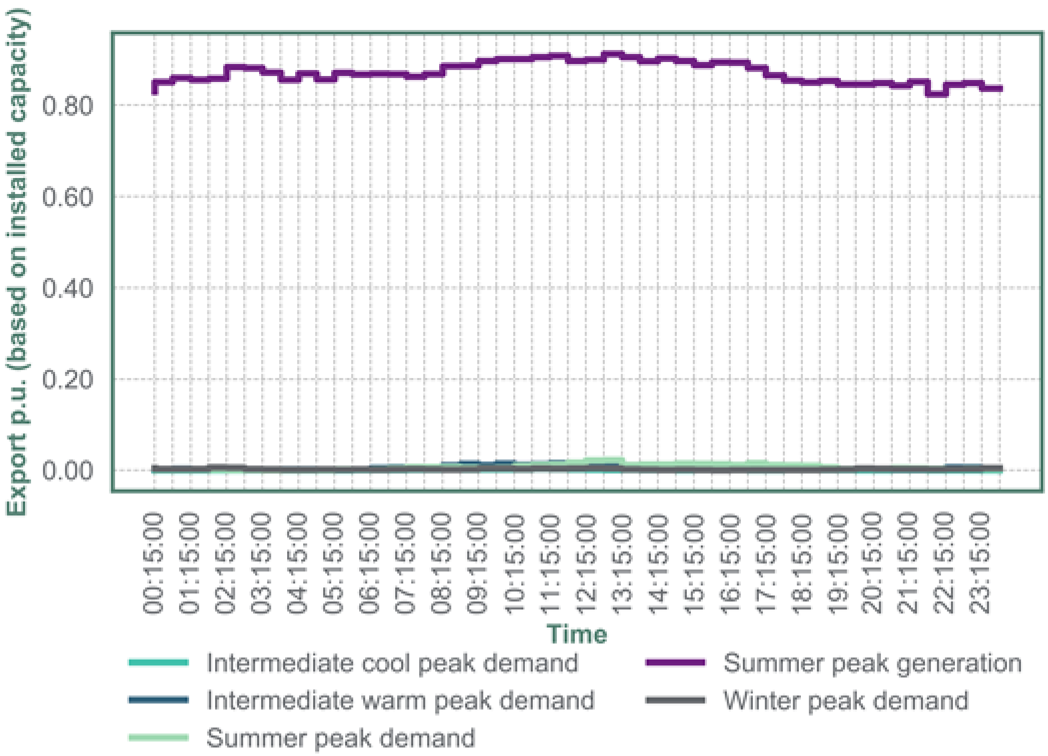

Figure 14: Representative onshore wind profiles for customers in the East Midlands licence area

West Midlands

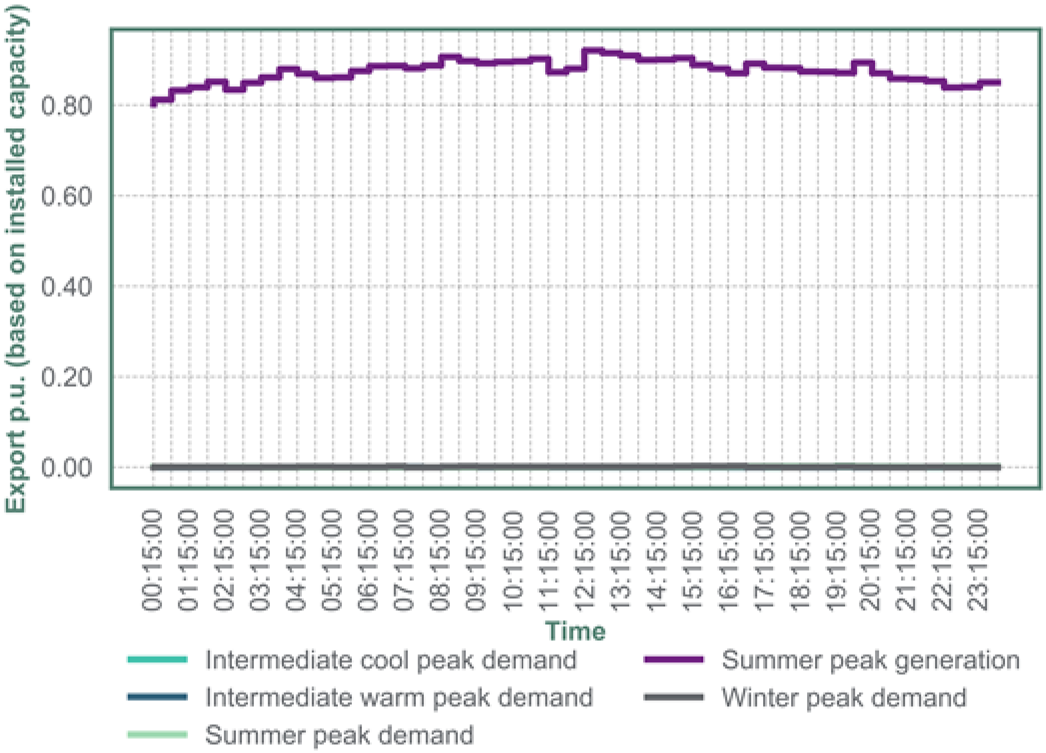

Figure 15: Representative onshore wind profiles for customers in the West Midlands licence area

How will these profiles change over time

It is assumed that the load profiles for onshore wind generation sites will not change in the future.

These profiles are normalised around the installed capacity, rather than the contracted export capacity. For instances where a customer installs much more generating plant than the contracted capacity, an export limitation scheme is implemented in the network analysis stage to limit the export of any over-installed generation. This is also the case for any generation sites with an installed Active Network Management scheme, where the logic for the load management scheme is implemented in the network analysis.

Known Limitations

The DFES volume projections assume that existing onshore wind sites will replant with a larger installed capacity when these sites reach the end of their design life. In addition, there may be future opportunities for onshore wind sites to co-locate with demand sources, such as hydrogen electrolysis or energy storage. Any potential changes in onshore wind turbine efficiency and change of import requirements have not been accounted for in these profiles.

Future Developments

Further analysis will be undertaken to develop more granular profiles related to specific sizes of onshore wind generation customers and to account for regional variations in onshore wind generation output within a licence area.

Offshore wind Generation

Table 8: Table of offshore wind generation technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Wind	Offshore Wind	MW of installed capacity

Methodology

Each offshore wind generation customer is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. Offshore wind generation volumes are provided as the installed capacity (MW) of generation connected.

Real power output data from all offshore wind generation sites across the WPD licence areas was collected and aggregated by each half hour for the calendar year of 2021. Only two offshore wind generation customers are connected to the WPD network, both situated off the coast of the East Midlands licence area.

Half hourly generation profiles were created for each of the five representative days used for network analysis. This was achieved by considering the maximum and minimum generation output observed during each half hour across the whole of each season in the aggregated generation data and normalising this by installed capacity of the sample to give a per unit value.

Both offshore wind sites currently connected to the WPD network are connected at 132 kV, so no study of different diversity levels is applicable. However, as any future offshore wind sites connected to the distribution network would be most likely to connect at the 132 kV voltage level, the generated profiles are deemed at a suitable level to be used for network analysis. This profile is applied to all WPD licence areas where offshore wind is projected to connect.

Representative Day Profiles

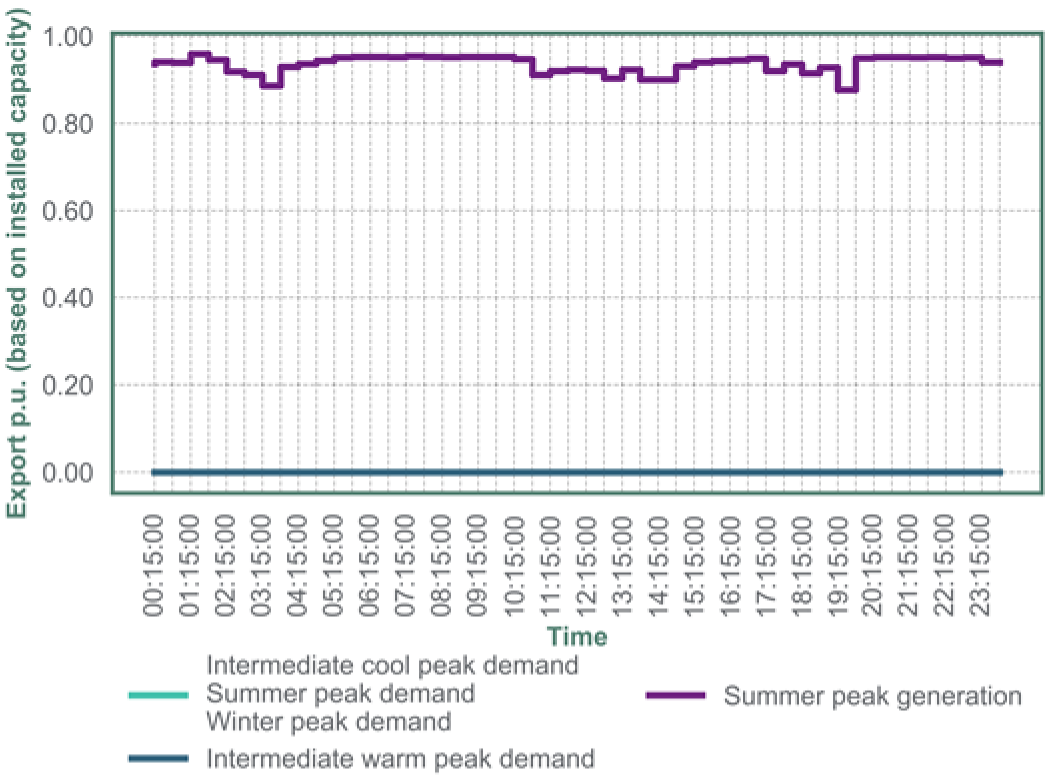

Figure 16: Representative offshore wind profiles

How will these profiles change over time

It is assumed that the load profiles for offshore wind generation sites will not change in the future.

These profiles are normalised around the installed capacity, rather than the contracted export capacity. For instances where a customer installs much more generating plant than the contracted capacity, an export limitation scheme is implemented in the network analysis stage to limit the export of any over-installed generation. This is also the case for any generation sites with an installed Active Network Management scheme, where the logic for the load management scheme is implemented in the network analysis.

Known Limitations

The sample size used to generate offshore wind profiles is very small and may not be representative of the behaviour of a larger number of customers connected across the WPD network.

Future Developments

Given the small sample size of existing customers and the relatively low projections of future offshore wind connections, no future developments have been identified for offshore wind customers.

Non-weather Dependent Generation

Table 9: Table of non-weather dependent generation technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Biomass & Energy Crops (including CHP)	-	MW of installed capacity
CCGTs (non CHP)	-	
Geothermal	-	
Hydro	-	
Hydrogen-fuelled generation	-	
Marine	Tidal stream	
	Wave energy	
Micro CHP	Domestic (G98/G83)	
Non-renewable CHP	<1MW	
	>=1MW	
Non-renewable Engines (non CHP)	Diesel	
	Gas	
OCGTs (non CHP)	-	
Other generation	-	
Renewable Engines (Landfill Gas, Sewage Gas, Biogas)	-	
Waste Incineration (including CHP)	-	
Retained Connection	-	

Methodology

All non-weather dependent generation customers are geographically allocated to an Electricity Supply Area where they would be most likely to connect to the distribution network. Generation volumes are provided as the installed capacity (MW) of generation connected.

In the case of infrequently despatched, non-intermittent generation, measured flows may not reflect the potential network impact. Instead, a flat (continuous output) profile was assumed for each representative day, representing the realistic behaviour that would have the worst impact upon the network. These were assumed as follows:

- **Summer Peak Generation day**: continuous export at agreed supply capacity; and
- **Peak Demand days** (all seasons): zero export.

Generation output may in reality be limited by load management schemes, such as Export Limited connections or Active Network Management schemes. In addition to this, some generation customers may hold flexibility contracts with WPD that mandate a certain profile at certain times of day or year. The behaviour of these customers is included, as part of the network analysis, but the output of non-weather dependent generation must be assumed full before network management systems can take effect in order to accurately assess network capability.

In DFES 2021, an additional category of generation has been added to represent retained connection. Across the four DFES scenarios, some technologies will see a level of decommissioning between the baseline year and 2050. This largely consists of technologies that are incompatible with net zero carbon emissions, such as unabated fossil fuel power generation.

Upon ceasing of conventional operation, the connection agreement held by the operator and the associated contracted export capacity secured with WPD is not automatically relinquished and some sites will likely retain this connection capacity. The motivation behind retaining this capacity will be to connect an alternative generation or storage technology that is more compatible with net zero emission targets.

Representative Day Profiles

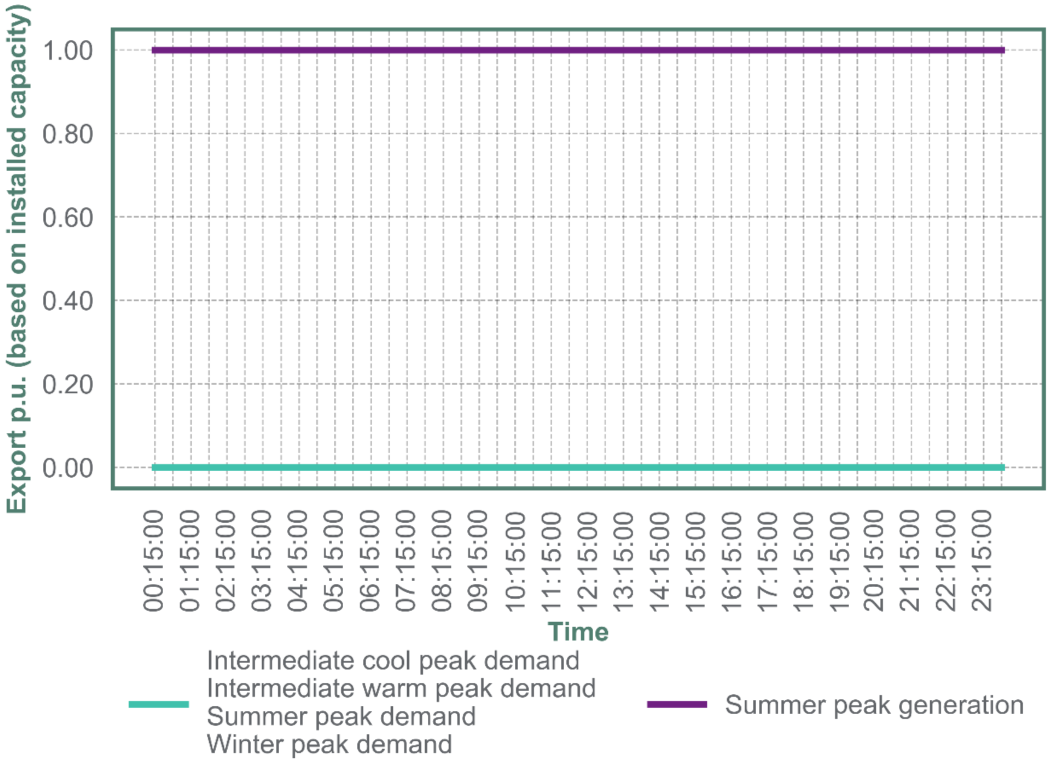

Figure 17: Non-weather dependent generation representative day profiles

How will these profiles change over time

It is assumed that the load profiles for non-weather dependent generation sites will not change in the future.

These profiles are normalised around the installed capacity, rather than the contracted export capacity. For instances where a customer installs much more generating plant than the contracted capacity, an export limitation scheme is implemented in the network analysis stage to limit the export of any over-installed generation. This is also the case for any generation sites with an installed Active Network Management scheme, where the logic for the load management scheme is implemented in the network analysis.

Known Limitations

These profiles are considered to be pessimistic as rarely all generation installed across an area of the network is exporting at the full installed capacity at any single time. When assessing each connected customer in isolation this approach is justifiable, but when assessing a group of generators connected at a Primary substation the coincident behaviour of all generators need to be used to assess a credible edge-case profile.

Future Developments

WPD is continuing to develop the tools to assess the coincident behaviour of generators connected at a Primary substation level to determine a suitable profile per generator that balances the safe design and operation of the distribution network and the design of an economic and efficient network.

Battery storage

Table 10: Table of battery storage technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Storage	Co-location	MW of installed capacity
	Domestic Batteries (G98)	
	Grid services	
	High Energy User	
	Other	

Methodology

All battery storage customers are geographically allocated to an Electricity Supply Area where they would be most likely to connect to the distribution network. Battery storage volumes are provided as the installed capacity (MW) of storage connected.

WPD previously worked with Regen to develop an approach to model the growth and operation of storage. As part of this modelling work, a consultation paper was developed and issued, aiming to validate some of the key assumptions used to model energy storage. The results from the consultation paper are published on the WPD website.

The consultation paper proposed different energy storage business models and asked for feedback on the behaviour of energy storage in each of these business models. One noteworthy response to the consultation was that customers expressed a desire to be able to 'stack' different business models and revenue streams. Respondents also identified a preference not to commit to a specific operating mode, as the evolving nature of procurement of balancing services by the Great Britain System Operator (GBSO) in the future may change some of the proposed operating modes.

The consultation responses demonstrated that energy storage customers prefer flexibility to operate energy storage without a specific operating profile. As a result, the profile assumptions used in this study are:

- **Summer Peak Generation day**: continuous export at agreed supply capacity; and
- **Peak Demand days** (all seasons): continuous demand at agreed import capacity; and zero export.

This unconstrained mode of operation is onerous for networks. In some cases, it may trigger major reinforcements that would prove unnecessary with relatively minor changes in the behaviour of energy storage connections. Where battery storage customers hold flexibility contracts with WPD that mandate a certain profile at certain times of day or year, the behaviour of these customers is included, as part of the network analysis. However; in the absence of load management schemes to limit battery storage usage, the output of battery storage must be assumed to be worst-case in order to assess network capability.

Representative Day Profiles

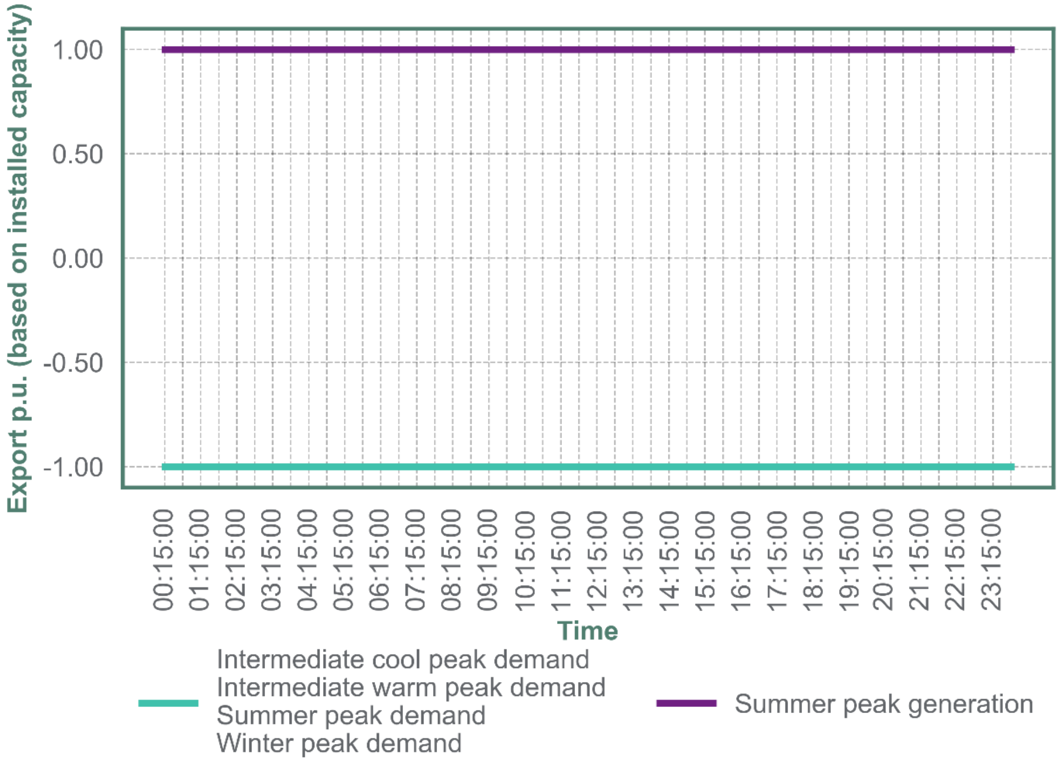

Figure 18: Battery storage representative day profiles

How will these profiles change over time

It is assumed that the load profiles for battery storage sites will not change in the future. These profiles are normalised around the installed capacity, rather than the contracted export capacity.

Known limitations

The projections and profiles only consider the impacts of battery storage. It is noted that there are other forms of energy storage, which may connect to the distribution network in the next 30 years. This feedback was given as part of the DFES 2021 stakeholder engagement exercise and will be incorporated into future DFES studies.

These profiles are considered to be pessimistic as rarely all storage capacity installed across an area of the network will be operating in a way to increase network loadings for each of the representative days studied. When assessing each connected customer in isolation this approach is suitable, but when assessing a group of generators connected at a Primary substation the behaviour of storage coincident to local network loadings need to be used to assess a credible edge-case profile.

Future Developments

The energy storage profiles will be reviewed in future studies, with the expansion of the suite of representative days to assess the energy curtailment impact of measures such as ANM and DSR. WPD and National Grid have collaborated on the Regional Development Plan 4 (RDP)[8] to investigate how energy storage or other customers can provide flexibility to the system. This RDP looks to extend the flexibility arrangements given to generation so that they apply to storage demand. This will allow storage projects to become part of the solution to network capacity issues, rather than capacity planning standards being a potential barrier to them.

[8] Regional Development Programmes, *West Midlands RDP,* Western Power Distribution, 2020; https://www.westernpower.co.uk/downloads-view/106888

Customer Behaviour assumptions

Demand technologies

Underlying Demand

For the purposes of this document, underlying demand refers to the aggregate behaviour to the existing WPD customer base currently connected to the distribution network, and how electricity demands from existing customers will change over time.

Methodology

The underlying demand profiles are not included as part of the DFES Part 1: Volumes project, as this is data that WPD has access to as part of internal network design processes. As the purpose of the analysis is to study the network impact of the DFES projections on the 33 kV, 66 kV and 132 kV networks, the demand at each Primary substation needed to be modelled individually.

WPD undertake an engineering load survey on an annual cycle to update the Primary demand sets for network design purposes. This focuses on an annual peak demand figure and accounts for abnormal network running arrangements and the export of any downstream connected generation customers. However to be used in the half-hourly analysis, further analysis was required to determine representative half hourly profiles for different Primary substations.

Due to the absence of directional MW/MVAr monitoring at all Primary substations, it was not possible to use data directly for each Primary across the WPD network. Instead, a sample of 200 Primary substations with directional MW/MVAr monitoring was used to determine a set of representative profiles that could be retrospectively applied to other Primary substations with similar metrics.

The Primary underlying demand profiles are created as a profile normalised around the peak demand observed as part of the engineering load survey. For each half hour and representative day, the peak demand multiplied by the profile value gives an expected MW demand at each Primary substation.

Clustering Methodology

A bespoke machine learning Python-based program was written to cluster the Primary substations in the sample into groups with similar profile characteristics for the representative days used for analysis. This used metering data for a yearly period for all sample sites. More information about the cluster methodology is contained in *Appendix B: Primary substation clustering* of this report.

The output of the clustering was a list of Primary substations with 'similar' behaviour (in terms of the time of peak and the profile shape) for all five representative days.

Grouping Methodology

The most important part for categorising primaries is using its time of peak. As part of the engineering load survey two distinct groups of Primary substations were found, one with a morning peak and another with an evening peak. The Primary substations with a morning/midday peak were identified and these substations grouped to create a representative morning/midday peaking profile. The clustering methodology outlined above was used for the evening peaking Primaries in the sample to identify two different demand profiles for evening peaking Primary substations.

After profiles were clustered there was a need to find available data that could correlate with each group to define the profile. This involved collating a list of publicly available data for the geographic areas supplied by Primary substations, including the customer density and average energy consumption for domestic and non-domestic customers.

Creating the profiles

Combining both grouping methods Primary substations are grouped into three demand types:

- **Morning** peaking (usually industrial type profiles), with a period of sustained high levels of demand throughout a daily period for each representative day,
- Evening peaking with a relatively high output in early morning and more notable higher peak in the intermediate warm and summer seasons. This sample of sites correlated with an expected **rural** demand type, which was supported by an average domestic customer density of fewer than 150 domestic customers per km².
- Evening peaking with no noticeable drop in demand between the hours of 09:00 and 17:00, with a lower peak in the intermediate warm and summer seasons. This sample of sites correlated with an expected **urban** demand type, which was supported by an average domestic customer density of greater than 150 domestic customers per km².

Using the methodologies described in Figure 19 the sample of 200 Primary substations was grouped into the three demand types, with profiles being generated for each representative day. For the peak demand representative days, the average profile of all sites within the group was taken for each season, this was renormalized to ensure there was a 1 per unit peak to assign each Primary substation to its peak annual demand. For the peak generation representative day the mean of the minimum profile for the sample was used.

Application methodology

After profiles were created for the sample of 200 Primary substations, the remaining Primary substations needed to be categorised into one of the three demand types. Figure 19 shows how the two methods were applied to categorise the remaining Primary substations across the WPD network not originally identified in the sample for clustering.

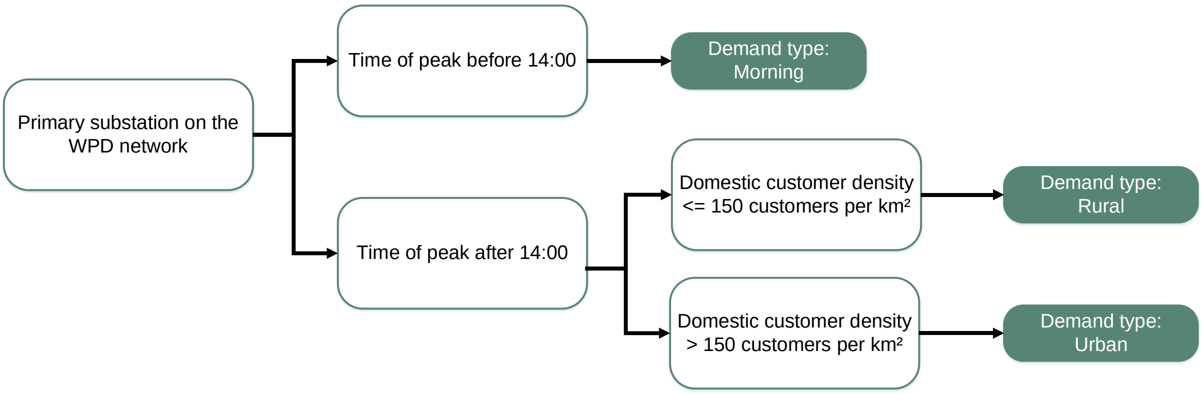

Figure 19 - Primary substation category by underlying demand

The map in Figure 20 demonstrates a geographic view of how the Primary substations were categorised into the three demand types.

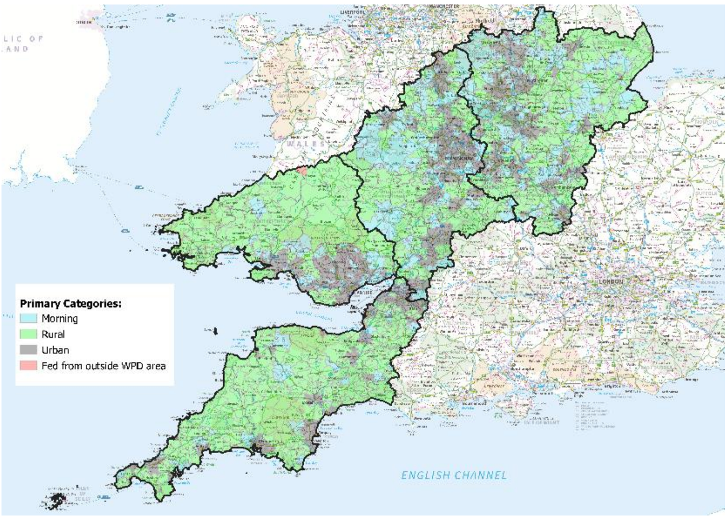

Figure 20 – Primary Categorisation Map

Single customers

There are a number of customers connected to the WPD network with connections at 132 kV, 66 kV, and 33 kV or by a dedicated Primary transformer at a Primary substation. Such customers do not have a regular daily or seasonal demand profile. As a result, the assumed profile for these customers is:

- **Peak Demand days**: continuous demand at peak annual demand observed in the engineering load survey; and
- **Summer Peak Generation day**: zero demand.

Representative Day Profiles

Profiles for both active power and reactive power were generated from this analysis. For detailed network design, a power factor per site may be used instead of the reactive profiles generated using this process where detailed network monitoring can be used.

Morning

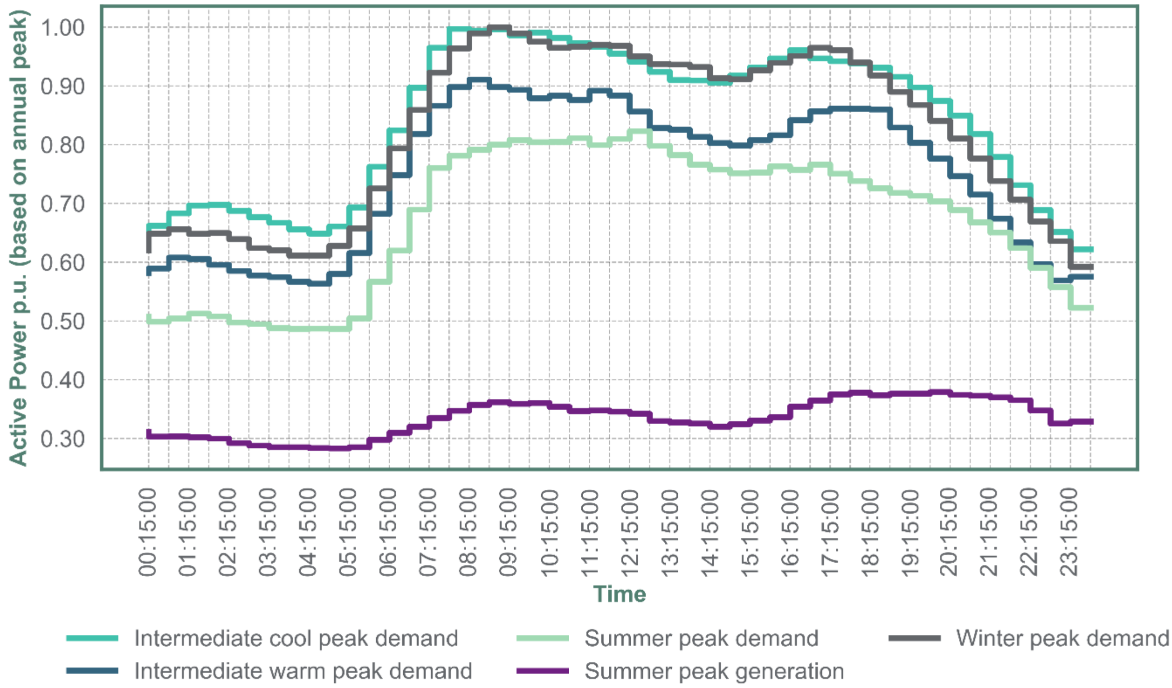

Figure 21: Representative morning peaking underlying demand active power profiles

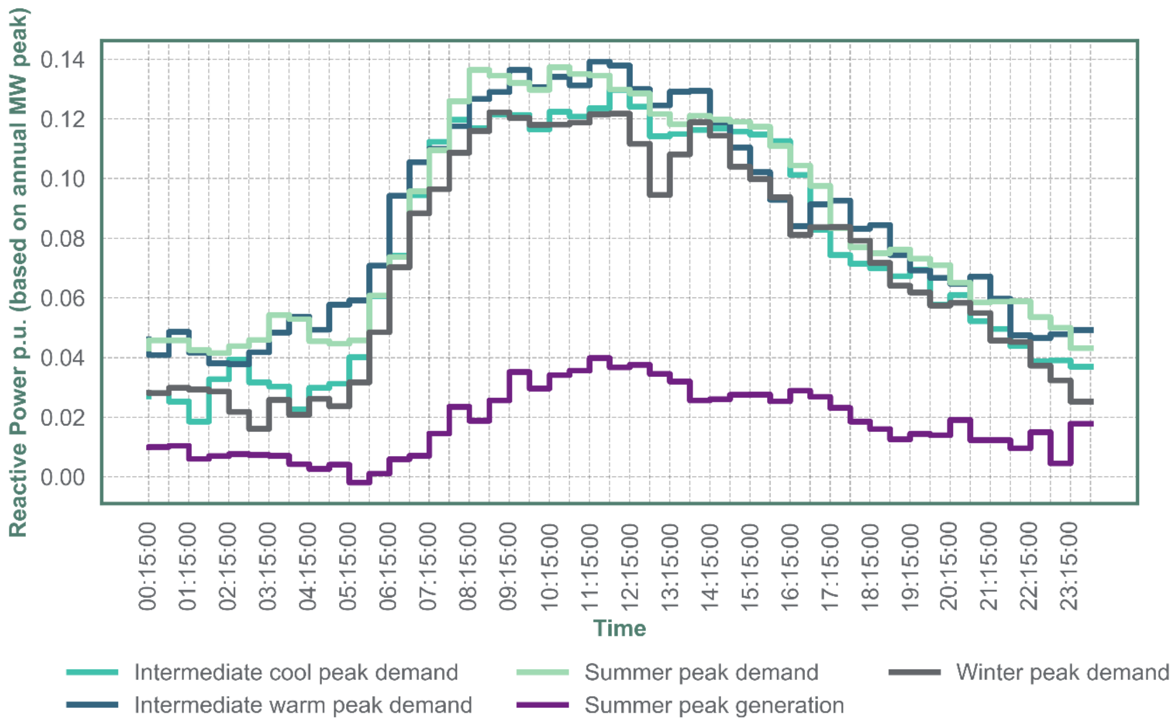

Figure 22: Representative morning peaking underlying demand reactive power profiles

Rural

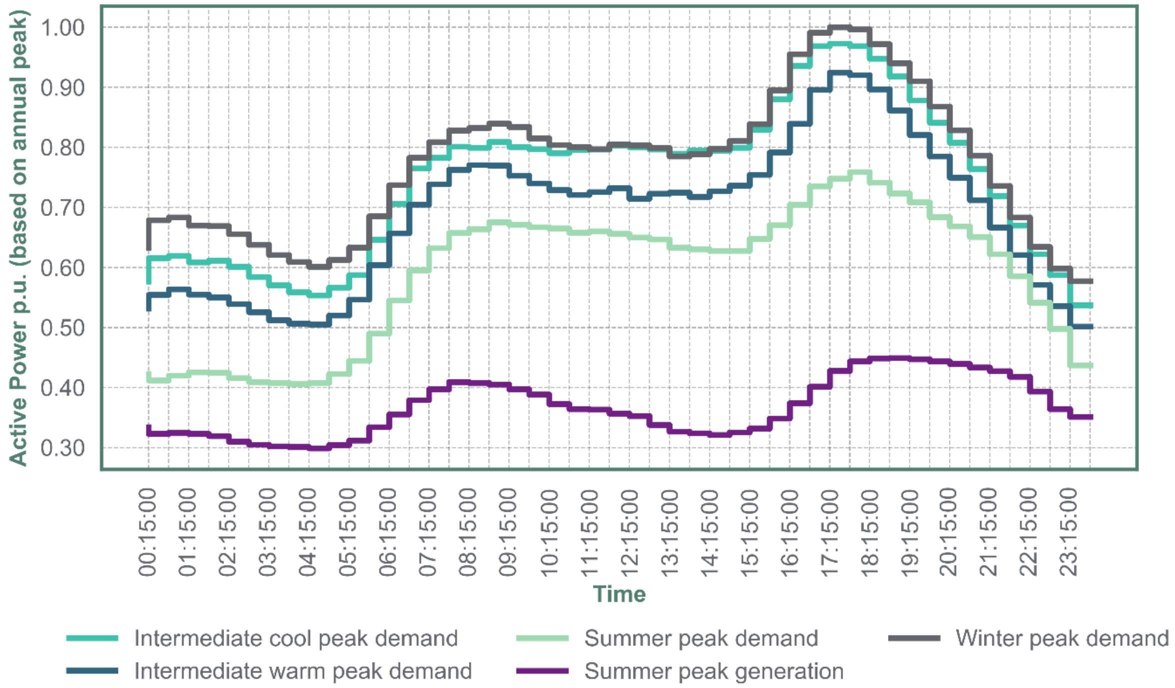

Figure 23: Representative rural underlying demand active power profiles

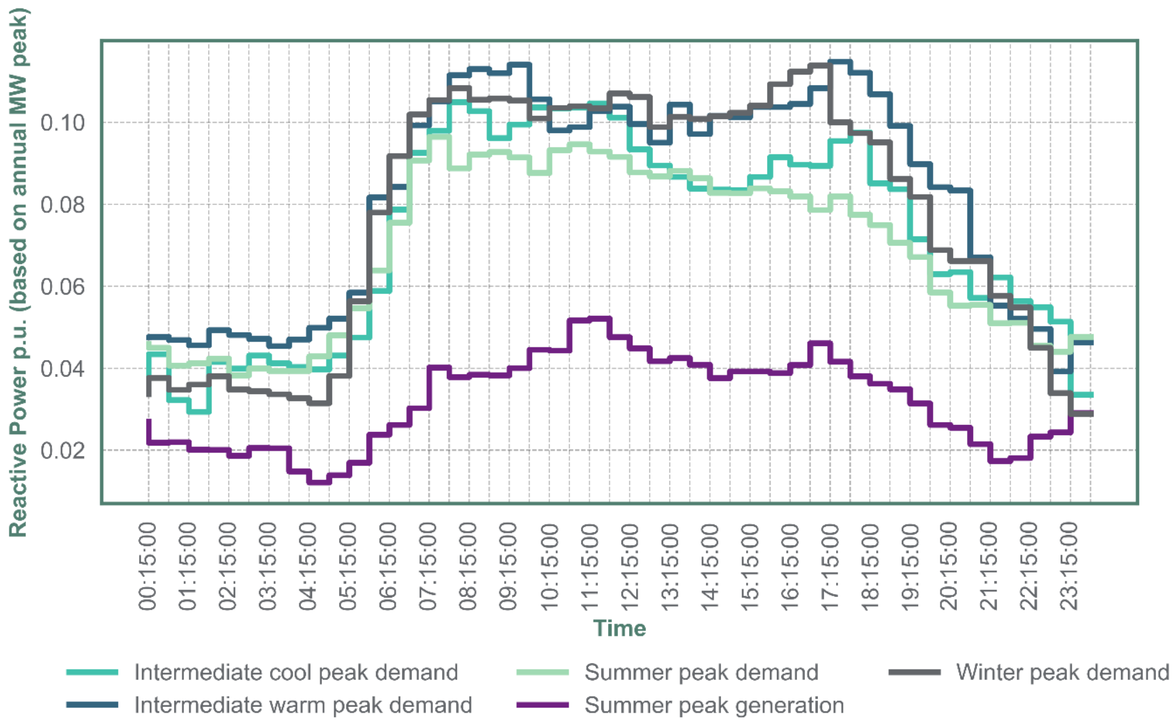

Figure 24: Representative rural underlying demand reactive power profiles

Urban

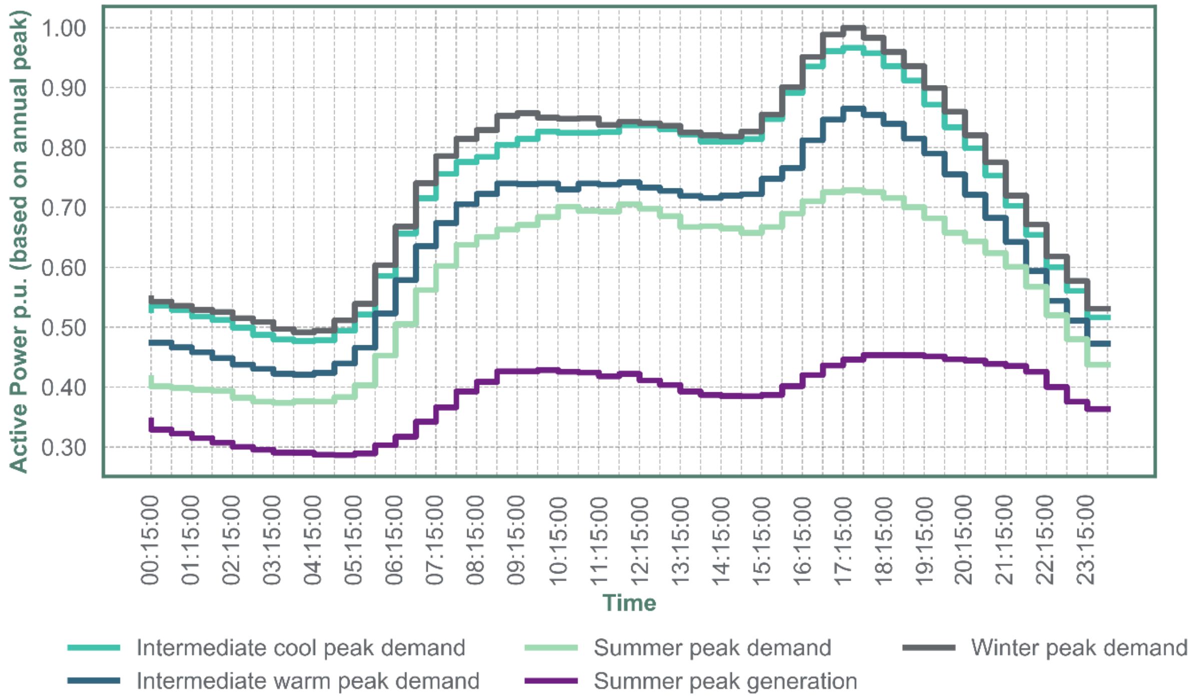

Figure 25: Representative urban underlying demand active power profiles

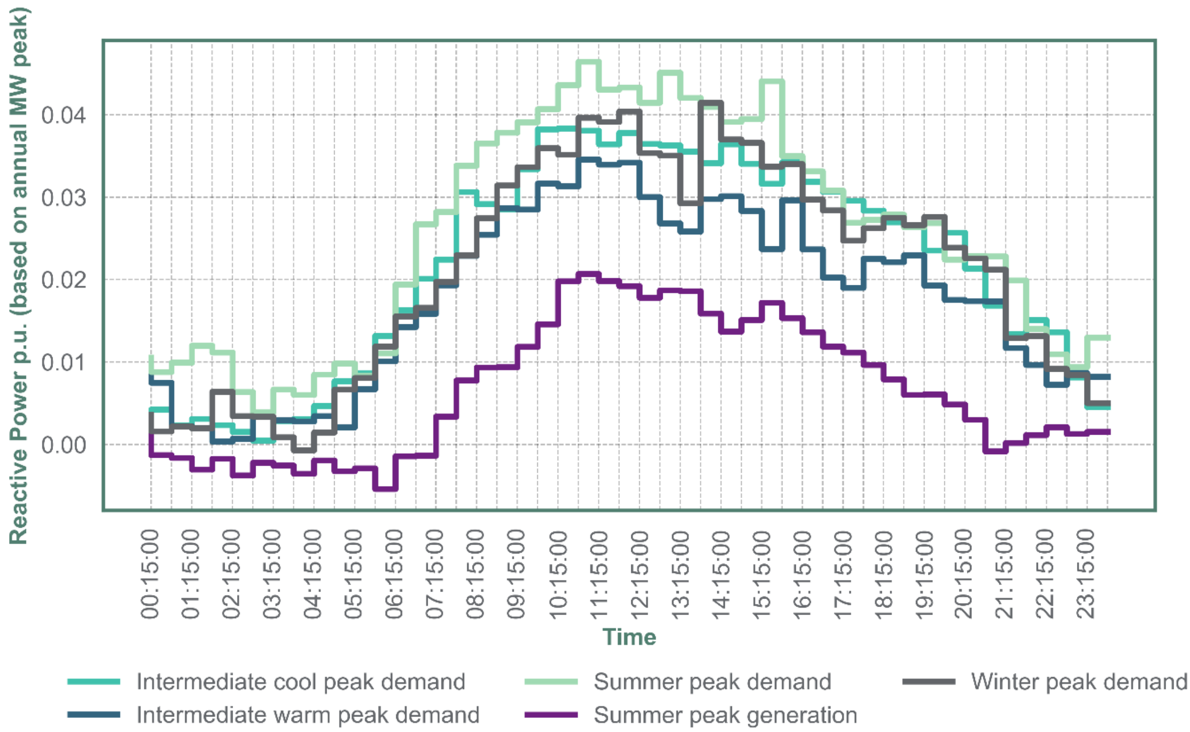

Figure 26; Representative urban underlying demand reactive power profiles

Single Customer

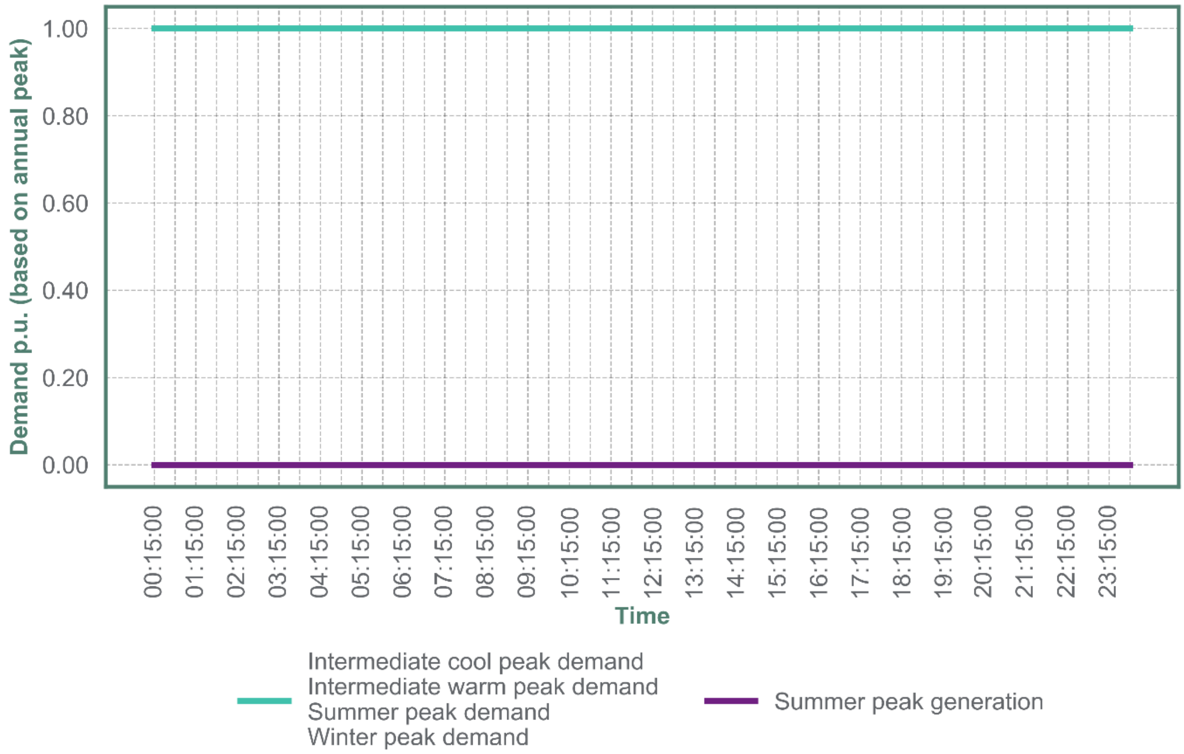

Figure 27: Representative single customer underlying demand profiles

How will these profiles change over time

Investigations of the following three variables as published in the RIIO-ED1 Network Performance Summary reports[9] demonstrate that aggregate customer demand usage has changed over the previous 10 years. Figure 28 plots the total customers connected to the WPD network over a ten-year period, alongside the total WPD electrical energy consumption and sum of licence area peak demand.

[9] Ofgem, *RIIO-ED1 Electricity Distribution Network Performance Summary 2019-20* [Data set] https://www.ofgem.gov.uk/system/files/docs/2021/03/riio-ed1_annual_report_2019-20_supplementary_data_file_0.xlsm

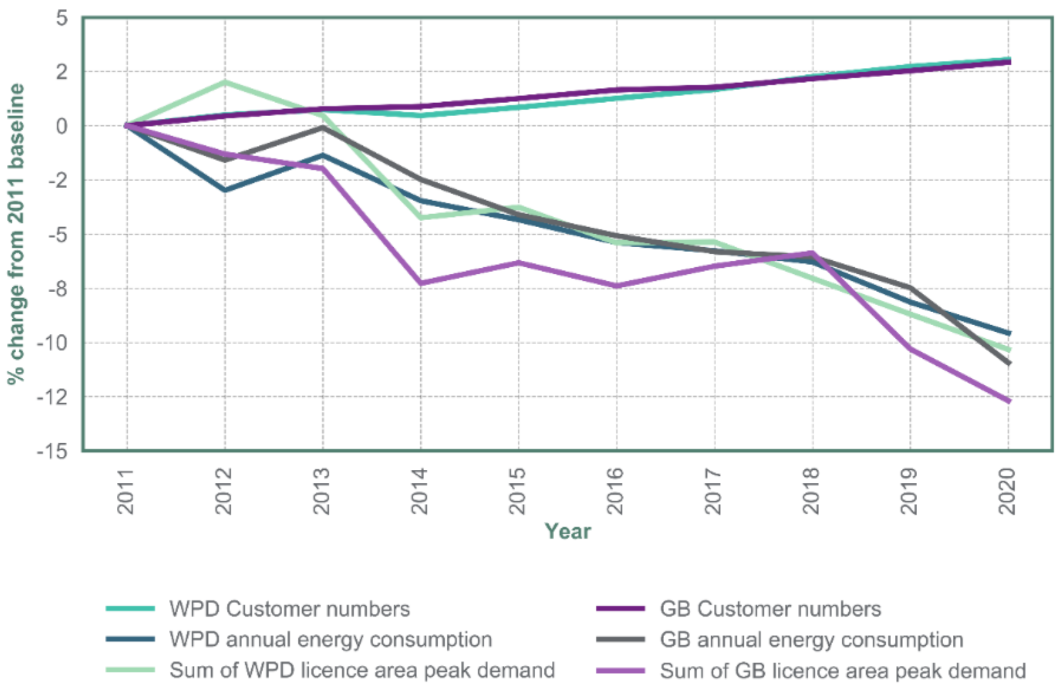

Figure 28: Total change from 2011 baseline of customer numbers, annual energy consumption and peak demand for WPD licence areas and Great Britain

These figures demonstrate that although greater numbers of customers have connected to the distribution network, the total observed peak demand per licence area and the total energy consumption has reduced over the same period. This aligns with increasing customer uptake of more energy efficient devices and a more energy conscious consumer.

However, extrapolating from these datasets to inform future peak power demand reduction due to energy efficiency does not provide a complete picture. Further analysis to estimate the additional demand contribution from newly connected customers over a three year period was used to determine a more accurate underlying demand reduction without accounting for any new connections. These assumptions have been used to infer a licence area specific peak demand reduction for each year and scenario using measureable data observed from historic WPD licence area peak demand figures.

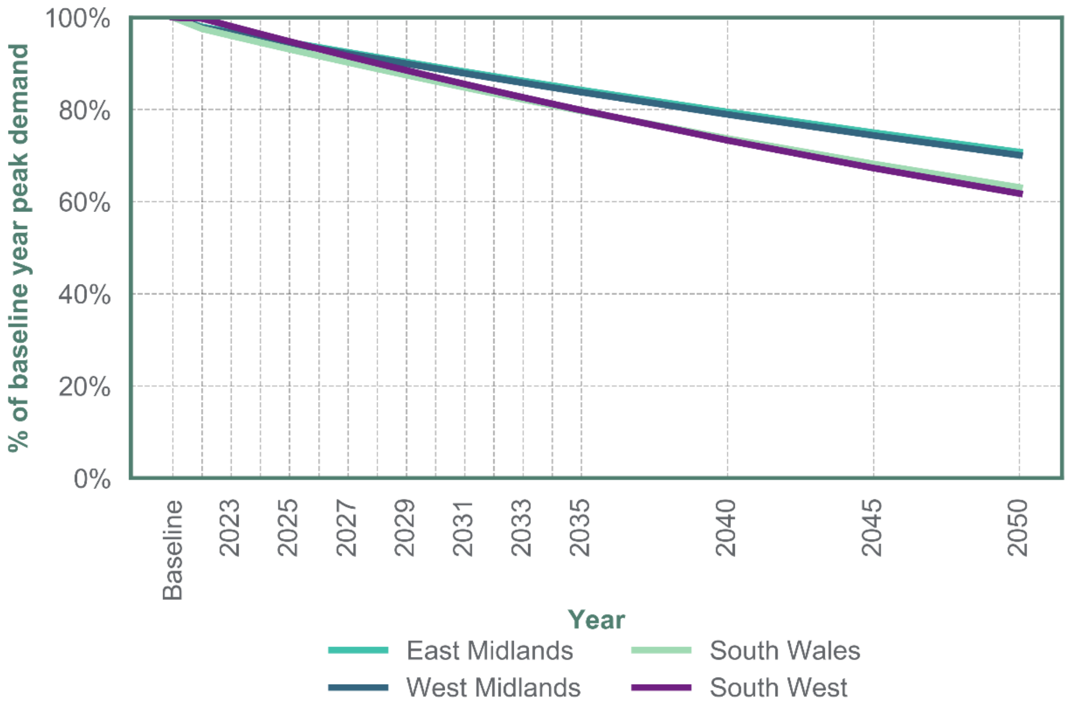

Figure 29: Expected underlying demand change for each licence area as a result of energy efficiency assumptions.

Energy Assumptions

The energy consumption figures reported on for DFES 2021 focus on the licence area total energy consumption, and are not provided at a more granular level. As demonstrated in Figure 28, the energy consumption across WPD has decreased in the previous ten years. A similar process to the underlying demand decreases was undertaken to extrapolate these trends into the future, also accounting for the fact that new connections made in the previous 10 years. These assumptions have been used to infer a licence area specific energy reduction for each year and scenario using measureable data observed from historic WPD specific energy consumption figures. The 2020 data was excluded from this analysis as the long-lasting impact of covid-19 on customer behaviour is not yet known therefore 2020 energy consumption data was treated as anomalous. We will be further reviewing this in DFES 2022 once there is more data available.

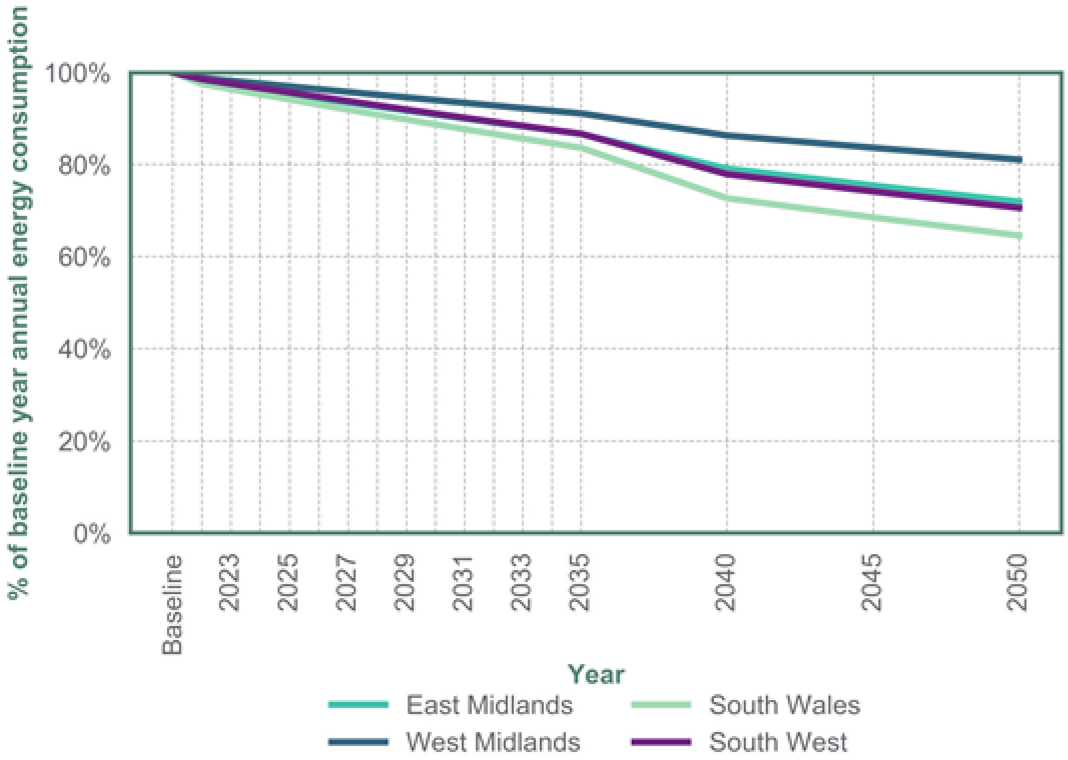

Figure 30: Expected annual energy consumption change for each licence area as a result of energy efficiency assumptions.

Known Limitations

The underlying demand profiles currently all assume a profile peak which occurs in the winter season. Analysis from the engineering load survey demonstrates that not all Primary substations across WPD peak in the winter season.

The expected underlying demand reduction due to energy efficiency analysis was completed at a licence area level, and may not account for the more granular changing demand trends on a per Primary substation basis.

Future Developments

WPD has committed to improving the network monitoring installed across Primary substations during ED2[10]. Once the data for these substations is available, this can be used directly in the analysis to provide more accurate data without the need for assigning a representative profile.

Where Primary substation monitoring is not suitable to use the data directly in network analysis, the above process has demonstrated to provide useful clusters of sites with similar behaviour based on observed data. This can further be improved by subcategorising the sample by the season that the peak demand occurred, also further subcategorising the time of peak to capture early morning and midday peaking substations as different categories.

[10] Western Power Distribution, *RIIO-ED2 Business Plan 2023-2028,* 2021; https://yourpowerfuture.westernpower.co.uk/downloads/40290

Domestic

Table 11: Table of domestic technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Domestic	-	Number of new dwellings

Methodology

The DFES volumes project includes an analysis of all local authority development plans to identify new domestic developments. Each development is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. This only accounts for the electrical household demand due to lighting, cooking and entertainment. Any additional domestic demand due to the installation of Heat Pumps, Direct Electric Heating, Air Conditioning or Electric Vehicle chargers are covered in other sections of this report.

Domestic developments are provided with units of the number of domestic dwellings. Each new domestic customer is assigned an electrical demand profile for each of the five representative days considered in the analysis.

The customer behaviour assumptions are based on the Elexon Profile Class 1 profiles[11] used in the electricity settlement purposes, and are consistent with the WPD Policy Document ST:SD5A (Design of Low Voltage Domestic Connections)[12]. This process is developed for the purposes of Low Voltage network design, and uses a statistical methodology consistent with that published in the ACE49 methodology[13]. For the application of these domestic profiles for use in strategic analysis of the EHV networks, a diversity level of 57 customers was chosen. This represents the profile to be a credible usage profile for a single domestic customer, aggregated as part of a wider group of 57 domestic customers. The diversity level was chosen as the average number of additional domestic dwellings per Primary substation per year considered in the DFES volumes projections.

A limitation of the ACE49 methodology is it does not produce a half-hourly profile for all representative days assessed. To create a profile for all demand representative days, the ratio of the urban underlying demand profile referenced to winter peak was used as an approximation for seasonal scaling.

In addition to the increased level of diversity to make the profiles suitable for network analysis, an Estimated Annual Consumption (EAC) was used that is consistent with the Total Domestic Consumption Values (TDCVs) recommended by Ofgem in January 2020[14]. This was deemed a suitable figure for new-build domestic properties. The application of revised TDCV values into existing WPD system design policy is under review.

---

[11] Elexon, *Load Profiles and their use in Electricity Settlement,* 2018; https://www.elexon.co.uk/documents/training-guidance/bsc-guidance-notes/load-profiles/

[12] Western Power Distribution, *Standard Technique: SD5A/5, Design of Low Voltage Domestic Connections,* 2020;

[13] Energy Networks Association, *ACE Report no.49*, p5

[14] Ofgem, *Open letter: Decision on revised Typical Domestic Consumption Values for gas and electricity and Economy 7 consumption split,* 2020; https://www.ofgem.gov.uk/system/files/docs/2020/01/tdcvs_2020_decision_letter_0.pdf

To account for customers who alter their electricity demand in response to flexibility services, a flexed profile is also used. This assumes a domestic demand of zero for the time of day where a GB electricity system peak is assumed to occur in the winter and intermediate cool seasons. The total energy consumption of the flexed profile is the same as used in the unabated profile, however it allows a total domestic energy reduction at time of system peak to be consistent with the residential white good DSR at peak figures published in the Future Energy Scenarios (FES) data workbook[15].

Representative Day Profiles

Domestic (unabated)

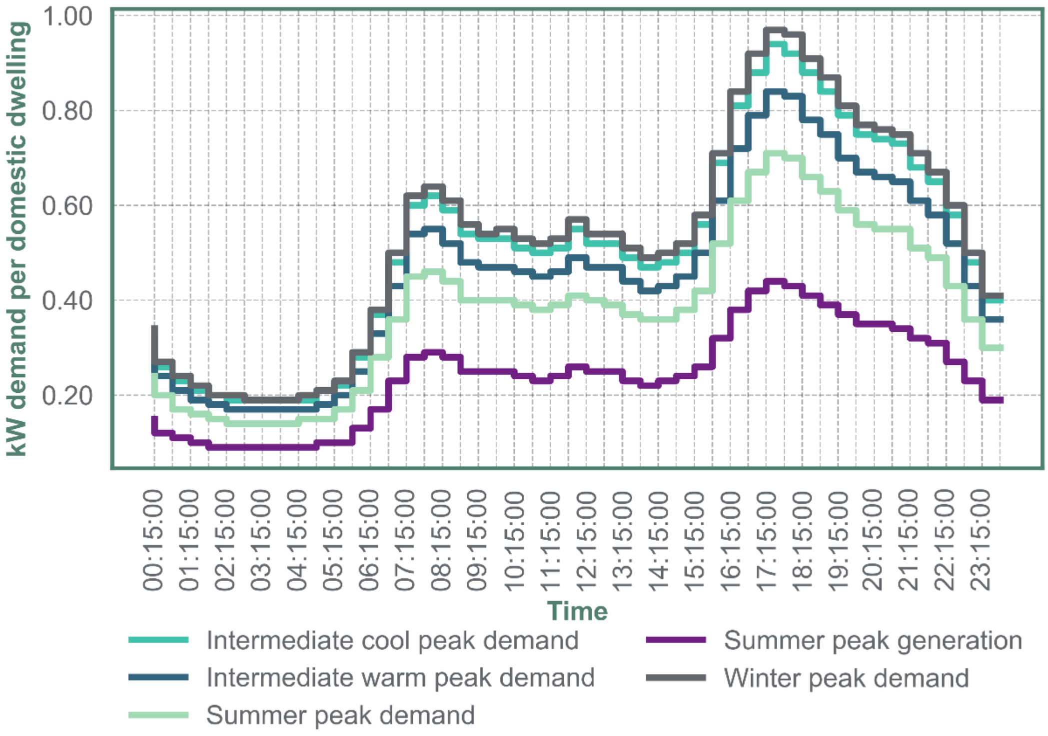

Figure 31: Representative unabated domestic profiles

[15] National Grid ESO, *Future Energy Scenarios 2020 Data Workbook v1.4* [Data set] https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents (Accessed 01/10/2020)

Domestic (flexed)

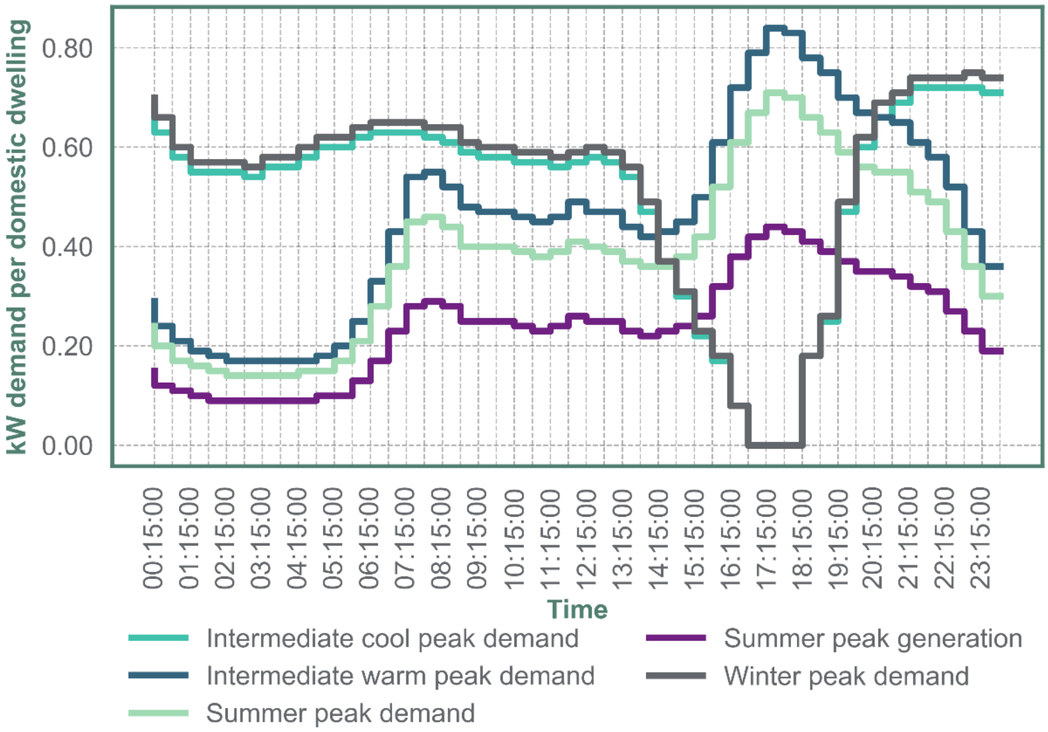

Figure 32: Representative flexed domestic profiles

How will these profiles change over time

As noted above, the flexed domestic profile is used to account for customers engaged to flex their domestic demand at times of system peak. For the demand reduction due to energy efficiency measures, the same profile scaling figures as applied to the underlying demand shown in Figure 29 are used for new domestic customers. This assumption is made on the basis that a large proportion of the customers across WPD are domestic and energy efficiency measures (such as replacing appliances) will also apply for new customers. The lower value of Total Domestic Consumption Values applied also accounts for a more energy efficient home as is currently being connected to the WPD network.

Energy Assumptions

The energy assumptions for new domestic customers projected to connect to the distribution network are consistent with the Total Domestic Consumption Values recommended values of 2900 kWh per year, scaled to the new baseline of 2021. This is projected to decrease further, in line with the expected annual energy consumption reduction assumptions used in **Figure 30**.

Known Limitations

The domestic profile used for Profile Class 1 does not fully reflect the varying energy requirements of new domestic customers. Further subcategorising the domestic customer type by the size of house and number of electrical appliances could improve the granularity and accuracy of domestic customer behaviour.

The assumptions for the demand contribution and energy consumption reductions for domestic customers align with the licence area observed demand and energy reductions. Further subcategorisation by customer type of the existing underlying demand could improve the assumptions for expected customer behaviour change for domestic customers.

Future Developments

With an increased amount of domestic customers switching to smart meters and half-hourly metering, this data could be used to infer how customer behaviour changes with reference to price signals which a DNO does not directly impact. WPD plan to investigate the suitability of aggregated smart meter data to inform assumptions on the behaviour of existing and future domestic customers.

Non Domestic

Table 12: Table of distinct non-domestic technology types used in the DFES 2021 analysis, with description of the planning use class definition for each category

Technology	Subtechnology	Description of customer types	Units used in DFES volume projections
Non domestic	A1/A2	Shops, financial and professional services	Floorspace (metres squared) of new I&C developments
	A3/A4/A5	Restaurants, cafes, drinking establishments and hot food takeaways.	
	B1	Business (including offices)	
	B2	General industrial processes	
	B8	Storage and distribution	
	C1	Hotels	
	C2	Residential institutions (including secure residential institutions)	
	D1	Non-residential institutions	
	D2	Assembly and leisure	
	Sui Generis	Other customer types not covered by the categories above	

N.B. category C3/C4 (Dwelling and houses of multiple occupation) not included as the projections as covered by domestic projections.

Methodology

The DFES volumes project includes an analysis of all local authority development plans to identify new industrial and commercial developments. Each development is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network.

Non-domestic developments are provided with units as m² of floor space in the development. There are ten difference categories used in the DFES volume analysis, which encompass different industrial and commercial customer types. These are consistent with the planning use classes, before they were updated in September 2020[16]. The units and categories of industrial and commercial customer were chosen as they are the most consistently used in local authority development plans and the Energy Performance Certificate (EPC) database.

For large non-domestic customers with an accepted connection offer to the WPD 33 kV, 66 kV or 132 kV networks, these customers are modelled as a distinct category and profiled based on the requested import capacity as per the connection offer.

Creating a sample of connected customers

To create representative profiles for each non-domestic customer type suitable for strategic network analysis, a demand profile per m² of development floorspace is required. This requires two datasets with the necessary information to be joined together as shown in Table 13.

[16] Planning Portal, *Change of Use – Use Classes,* 2020; https://www.planningportal.co.uk/info/200130/common_projects/9/change_of_use

Table 13: Summary of input data required for non-domestic customer behaviour analysis

Data source	Information required
WPD asset management systems	• Meter Point Administration Number (MPAN) • Address
Energy Performance Certificate database[17]	• Address • Property use class (matching the list in Table 12) • EPC rating • Floor space (m²)

As the address is the only common field to join the two datasets, a bespoke Python string-matching program was developed match the different address fields for each customer. This uses an adaption of an algorithm published by Ratcliff and Obershelp (commonly known as the Getsalt Pattern Matching algorithm)[18]. This process generates a large sample of half-hourly metered customers with the required fields as in Table 13.

For the purposes of DFES 2021 analysis, it is assumed that new industrial and commercial customers connected to the network will have an EPC rating of C and above. This assumption is intended to remove the impacts of customers with low EPC ratings influencing the representative profiles for future non-domestic connections, and broadly aligns with proposals made in the Future Building Standard consultation[19].

Creating Representative Demand Profiles

For each customer in the sample above, half-hourly metering data is collected for the calendar year of 2019. Analysis of Valuation Office Agency (VOA) data on the number of non-domestic properties in each Local Authority was cross-referenced against the WPD geographic polygon datasets for Primary substations. This process creates a representative sample size of the number of customers of each non-domestic customer type connected to each Primary substation. The table below shows the total sample size available of customers used to generate non-domestic profiles, alongside the representative sample size for the average number of customers per non-domestic customer type connected to a Primary substation.

---

[17] Ministry of Housing, Communities and Local Government, *Energy Performance of Buildings Data* [Data set], https://epc.opendatacommunities.org/ (Accessed 13th September 2019)

[18] Python Software Foundation, *difflib – Helpers for computing deltas,* 2020; https://docs.python.org/2/library/difflib.html (Accessed 19th August 2020)

[19] Ministry of Housing, Communities and Local Government, *Future Buildings Standard: Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for non-domestic buildings and dwellings; and overheating in new residential buildings, 2021;* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/956037/Future_Buildings_Standard_consultation_document.pdf

Table 14: Total sample size and representative sample size per Primary substation of customers used to derive non-domestic profiles

Property Use Class	Number of customers in sample	Representative sample size used
A1/A2	276	150
A3/A4/A5	68	65
B1	129	100
B2	64	60
B8	79	75
C1	60	30
C2	60	25
D1	69	35
D2	38	20
Sui Generis	9	5

For each customer type, the representative sample size was randomly selected from the input dataset. The total demand for all half-hourly periods across a year was extracted from metering data and normalised over the total floor space of the sample. For each of the seasons identified in the

Representative Days section of this report, a daily demand profile was generated for each representative day using the following logic:

- **Peak demand representative day**: for each season studied, the maximum normalised value for the sample was extracted for each half hour; and
- **Peak generation representative day**: for each season studied, the minimum normalised value for the sample was extracted for each half hour; and

To ensure the worst-case network conditions were captured, the above process was repeated 1,000 times with different randomly selected input data for each customer type. The maxima and minima of all repeated samples taken was used to derive the demand profiles.

Profile Benchmarking

The representative profiles were benchmarked against a range of data sources to validate their suitability for use in network analysis, including similar data shared by other DNOs.

- **Non-domestic profiles used by WPD in previous strategic studies:** WPD has used non-domestic normalised around the industrial and commercial floorspace in previous strategic studies[20]. The profiles generated using the above process are similar when compared for network impact totals for the same input volume data. A key improvement is the ability to split the ‘Factory and warehouse’ customer type into distinct ‘General Industrial/B2’ and ‘Storage and Distribution/B8’ categories, as it is observed they follow different electrical profiles.
- **BSRIA Rules of Thumb[21]:** This document is for building services engineers to specify the electrical requirements for non-domestic buildings. The ‘rules of thumb’ for the after diversity maximum demand figures (of kW/m²) compared favourably to the newly generated profiles. Any differences can be explained by the aggregate behaviour of a group of customers connected at a Primary substation level, rather than the individual customer demand.

Representative Day Profiles

A1/A2 (shops and retail)

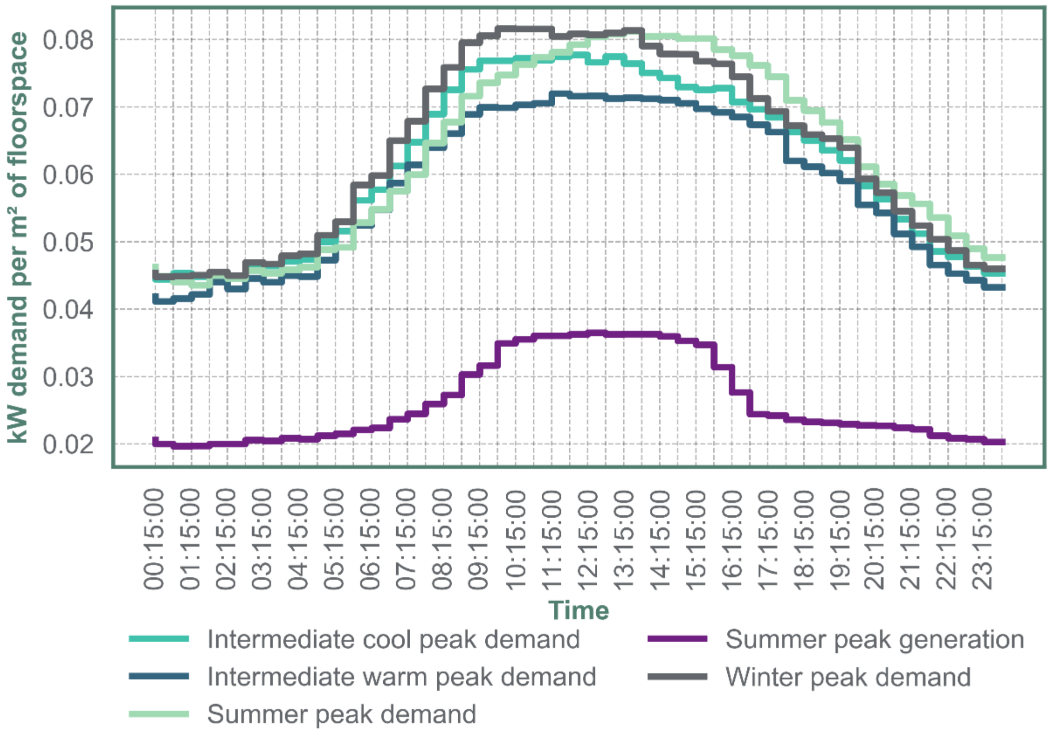

Figure 33: Representative A1/A2 non-domestic profiles

A3/A4/A5 (eating and drinking establishments)

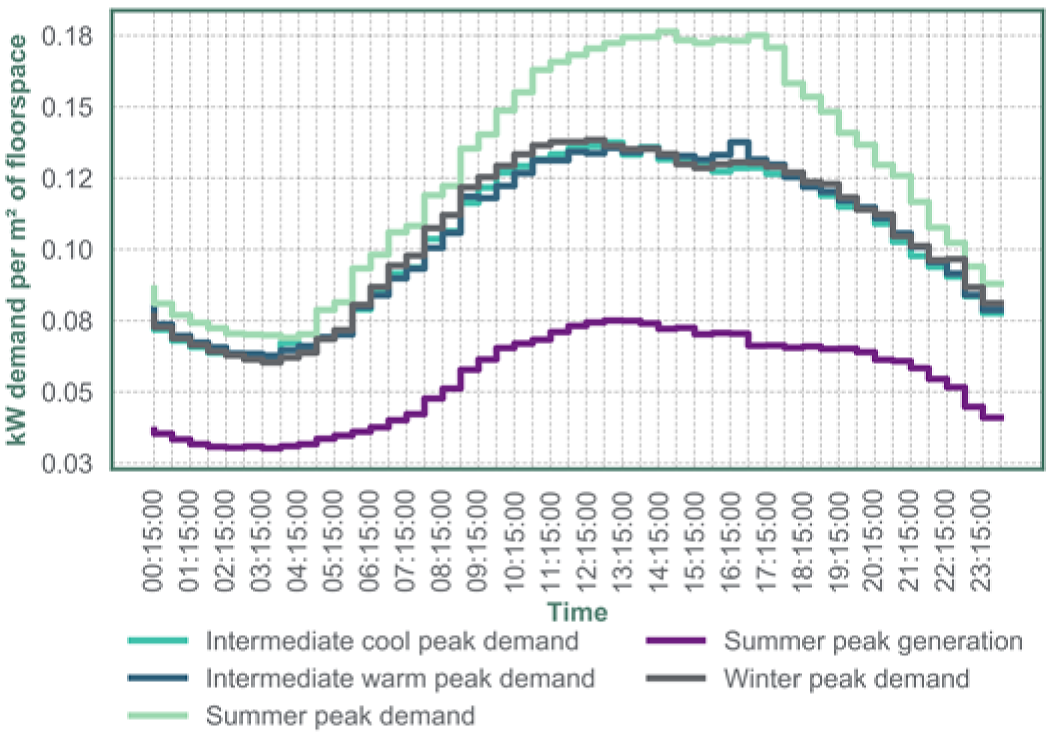

Figure 34: Representative A3/A4/A5 non-domestic profiles

B1 (office)

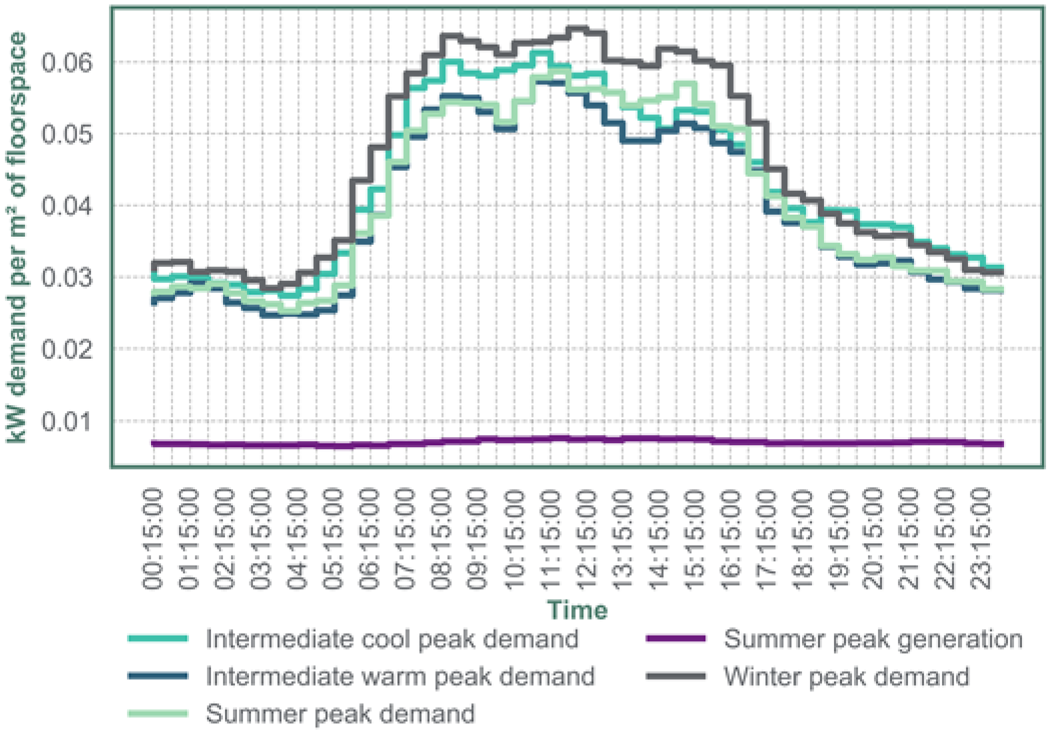

Figure 35: Representative B1 non-domestic profiles

B2 (general industrial)

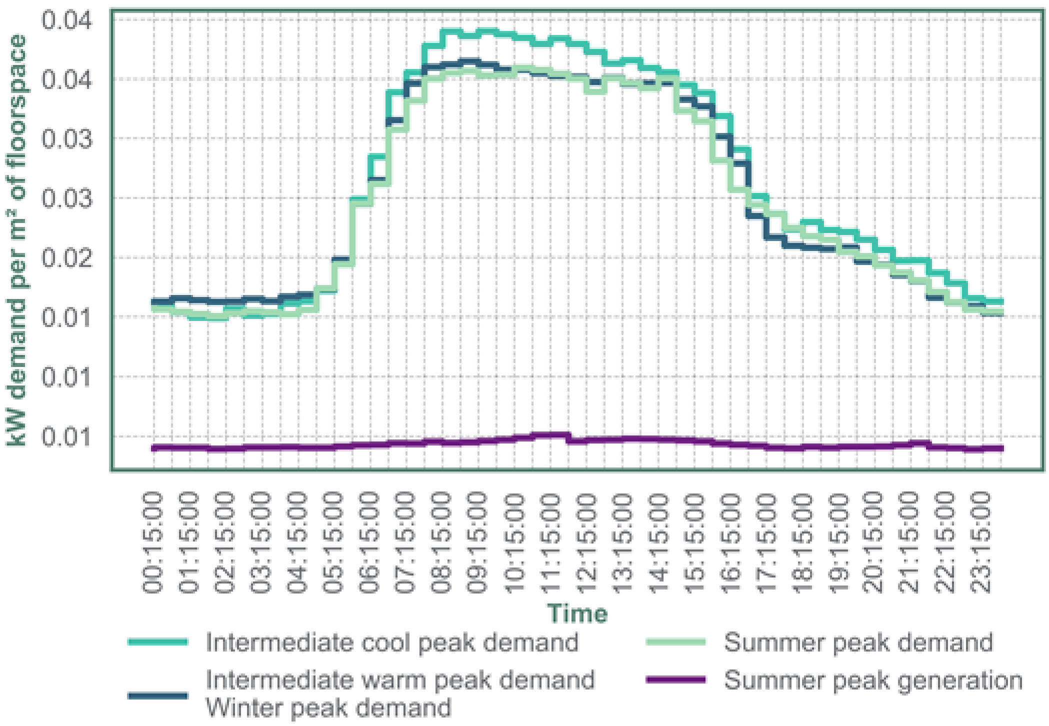

Figure 36: Representative B2 non-domestic profiles

B8 (storage and distribution)

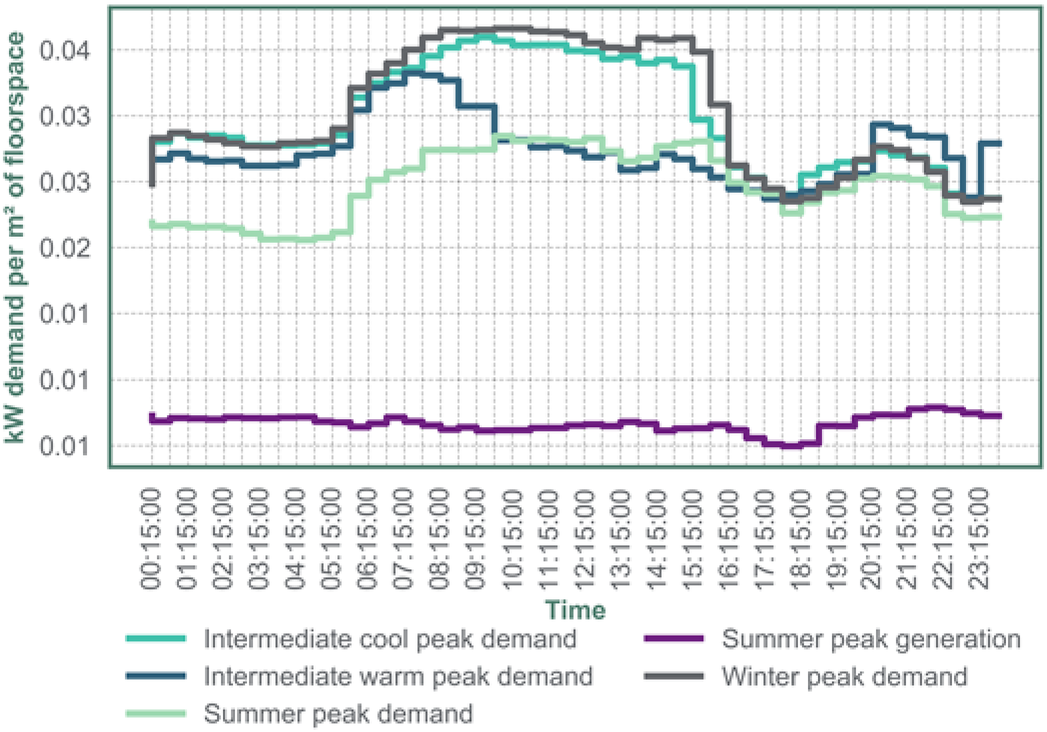

Figure 37: Representative B8 non-domestic profiles

C1 (hotel)

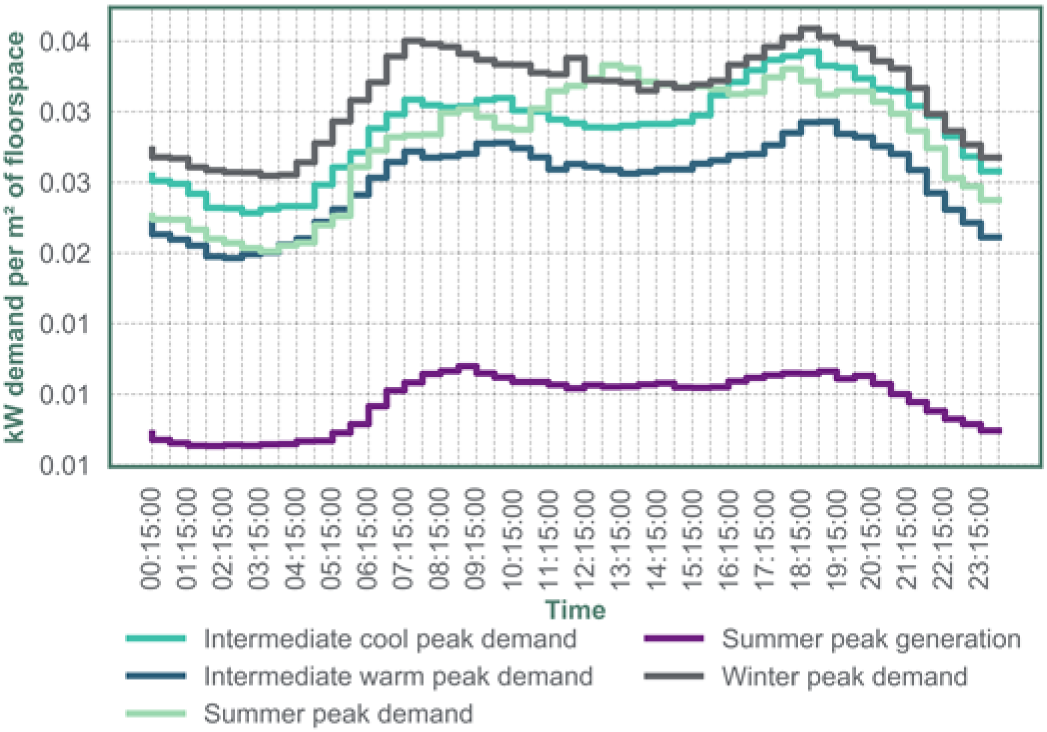

Figure 38: Representative C1 non-domestic profiles

C2 (residential institutions)

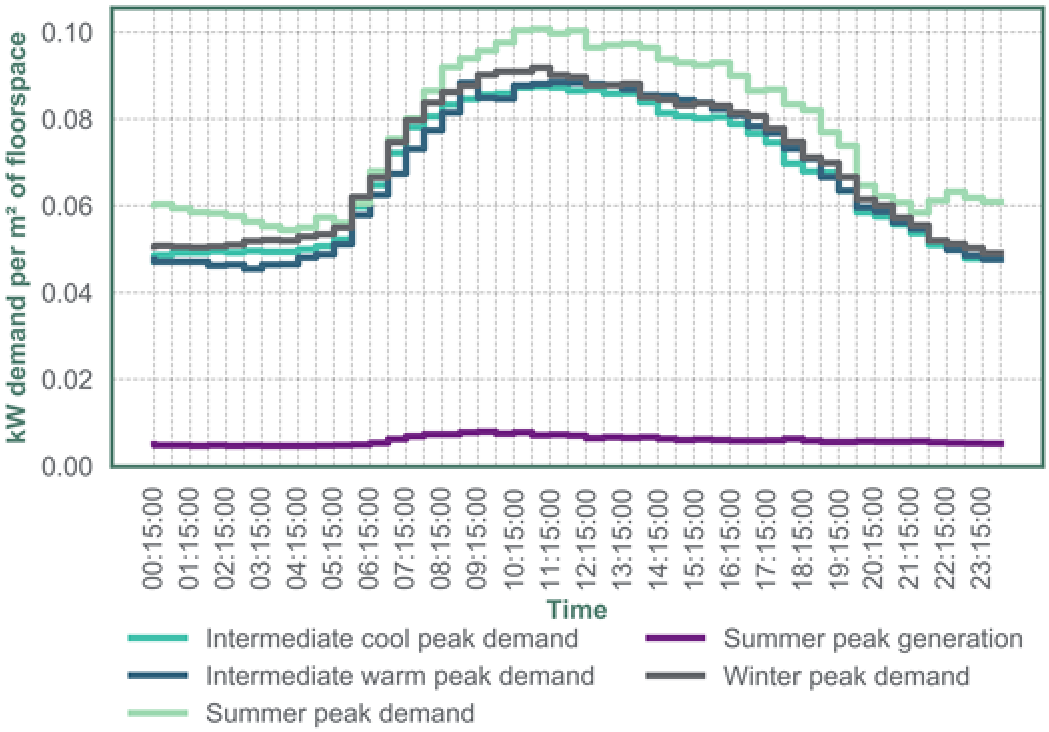

Figure 39: Representative C2 non-domestic profiles

D1 (non-residential institutions)

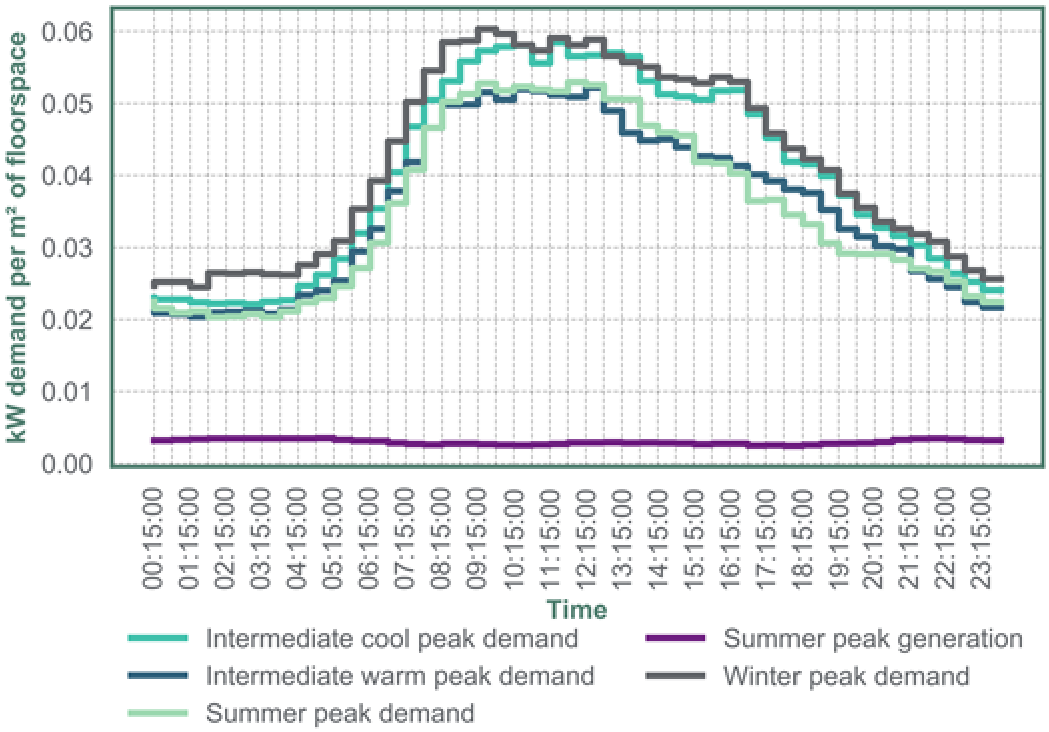

Figure 40: Representative D1 non-domestic profiles

D2 (assembly and leisure)

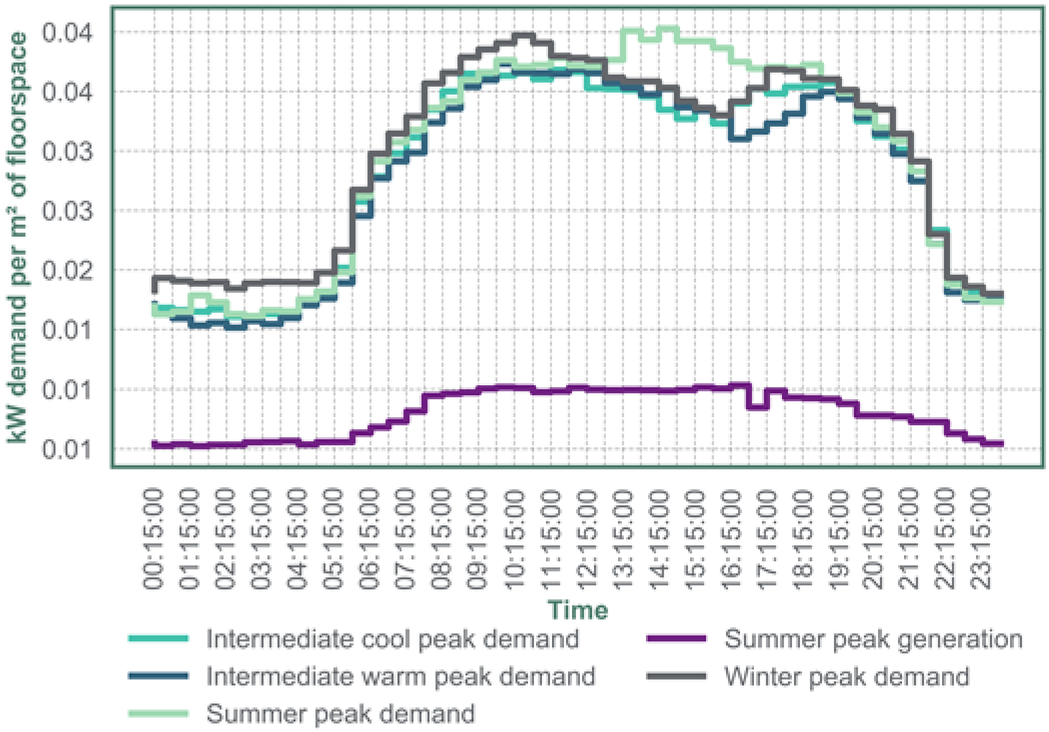

Figure 41: Representative D2 non-domestic profiles

Sui Generis

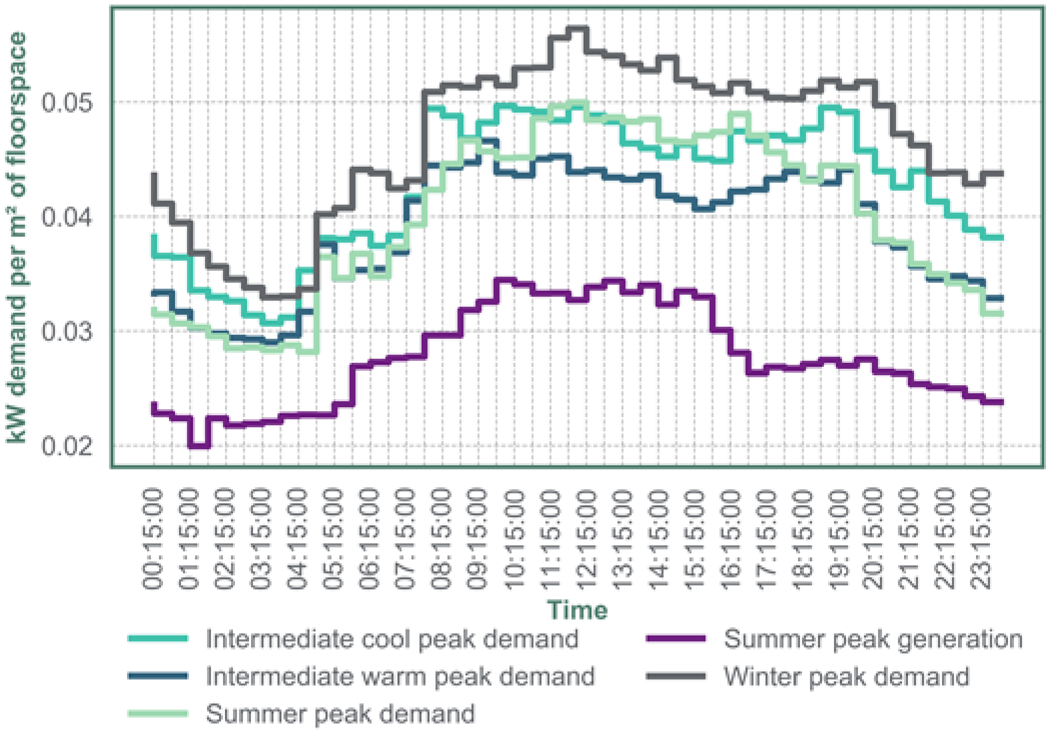

Figure 42: Representative Sui Generis non-domestic profiles

How will these profiles change over time

No flexed profile for non-domestic customers is used as part of the customer behaviour analysis. Whilst the market for industrial and commercial DSR is still relatively immature, suitable data to inform expected uptakes of load management for the purposes of 33 kV, 66 kV and 132 kV network analysis is not currently available for the representative days studied.

For the demand reduction due to energy efficiency measures, the same profile scaling figures as applied to the underlying demand shown in Figure 29 are used for new non-domestic customers. This assumption is made on the basis that a large proportion of the energy consumption across WPD is non-domestic and energy efficiency measures are expected to continue.

Energy Assumptions

As part of the non-domestic profiling exercise, the years' worth of metering was collated for the sample and normalised over the total floorspace. An annual scaling factor for the floorspace to annual energy consumption in kWh was generated. To obtain total estimated annual energy consumption from new non-domestic customers, the values in Table 15 can be used. The energy consumption for new non-domestic customers is expected to decrease further in line with the expected annual energy consumption reduction assumptions used in Table 15: Average scaling factor from floorspace (m^2) to total annual energy consumption (kWh) for each non-domestic customer type

Property Use Class	Scaling factor from development floorspace to total annual energy consumption (m^2 to kWh/year)
A1/A2	360.6
A3/A4/A5	742.2
B1	186.9
B2	132.6
B8	166.8
C1	147.8
C2	211.1
D1	117.2
D2	144.3
Sui Generis	312.7

Known Limitations

The non-domestic profiling exercise is reliant on the accuracy of the EPC database of non-domestic properties. There are some instances whereby the floorspace did not correlate to the floorspace of a customer connected to the WPD network.

The electrification of industrial processes for existing customers is not captured as part of this analysis. As the profiles are based on existing customer metering data, this covers the existing penetration of electric heating and cooling for non-domestic customers.

Future Developments

As a large proportion of existing non-domestic customers switch to half-hourly settlement[22], half hourly data could be used to infer how customer behaviour changes with reference to price signals which a DNO does not directly impact. WPD plan to investigate the suitability of aggregated smart meter data to inform assumptions on the behaviour of existing and future non-domestic customers.

Electric Vehicles

Table 16: Electric vehicle and charger types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Electric vehicles	Hybrid bus and coach	Number of electric vehicles
	Hybrid car (autonomous)	
	Hybrid car (non autonomous)	
	Hybrid HGV	
	Hybrid LGV	
	Hybrid motorcycle	
	Pure electric bus and coach	
	Pure electric car (autonomous)	
	Pure electric car (non autonomous)	
	Pure electric HGV	
	Pure electric LGV	
	Pure electric motorcycle	
EV Charge Point	Car parks	Number of EV charge points
	Destination	
	Domestic off-street	
	Domestic on-street	
	En-route / local charging stations	
	En-route national network	
	Fleet/Depot	
	Workplace	

Methodology

The DFES 2021 has been developed to include vehicle and charger projections for all WPD licence areas. There are 12 vehicle and 8 charger types projected for all years and scenarios. Each vehicle and charger is geographically allocated to an Electricity Supply Area where it would be most likely to be registered or connect to the distribution network; noting that EVs will charge at multiple locations. All vehicle and charger types projected are given in Table 16. Out of the 12 vehicle types assessed, hybrid bus and coach, hybrid HGV, hybrid motorcycle and hybrid car (non-autonomous) were identified as not being credible vehicle types and the volumes for all years and scenarios remain at zero. They are included in the DFES projections volumes for completeness. All charger types are considered viable and the volumes connected increase under all scenarios.

The distribution of EVs in the near term is based on affluence, rurality, existing vehicle baselines and the distribution of on and off street parking. However, in the late 2020s under all Net Zero scenarios uptake is assumed ubiquitous. This means that almost all consumers are assumed to have the same likelihood of adopting an EV.

Early EV forecasting typically sub-categorised vehicle types into Battery Electric Vehicles (BEV) and Plug-in Hybrids (PHEV). The majority of BEV and PHEV early adopters had access to off-street charging; meaning the majority of early charging data available was from residential off-street chargers. EV adoption has increased significantly in recent years and the type of vehicles and chargers available are more diverse. By including eight viable vehicle types in the projections, differences in annual mileage and energy are used to build a more representative energy model. The Department for Transport (DfT) and FES datasets were used to determine average mileage and energy figures for each vehicle subtechnology. More information on the energy assumptions for each vehicle type can be found in the *Energy Assumptions* section.

To assess the impact EVs will have on the WPD network, profiles for all five representative days are required. These need to capture EV demand at existing peak demand periods and possible new peaks caused by the largescale adoption of EVs. There are two methods for profiling the impact of EVs:

1. **EV Profile –** Assign a profile to each EV; or
2. **Charger Profile –** Assign a profile to each charger

There are a number of limitations of directly profiling vehicles:

- **EV charging location –** EVs will use multiple charger types and locations to fulfil their energy requirement. Profiling an EV based on its registered location does not account for this. EVs registered at addresses without access to off-street charging will use a combination of work, slow/fast and rapid chargers to fulfil their energy requirements. These charger types may be located in a separate ESA and will have a notably different charging profile and utilisation.
- **Vehicle stock –** The total vehicle stock needs to be accurately represented when profiling EVs. This is more important as the volumes of electric LGVs and HGVs increase, as they will have a significantly different charging behaviour and energy requirement.
- **Multiple EVs to a charger** - Modelling 1 EV to a charger, does not assess the utilisation and diversity impact of multiple EVs on a house; particularly at peak demand periods.
- **Charger uptake –** The volumes and proportion of charger types available are projected to change under each scenario. Different charger categories have notably different charging behaviours, which is particularly important when profiling for network edge-cases.
- **EV to charger ratio –**By profiling each EV on a static profile it assumes the EV to charger ratio remains constant.

For the reasons described above, only assessing vehicles or chargers independently does not give sufficient information to determine the network impact of the EV transition. The DFES 2021 projections of vehicles and chargers allows the creation of a more representative EV model that accounts for scenario and year dependent energy requirement and the chargers that are available to deliver this energy.

This methodology has a number of benefits over directly profiling EVs:

- It accounts for the total vehicle stock yearly energy requirement
- It is profiling the chargers that are actually connected to the distribution network, based on location and type
- Factors in the vehicle to charger ratio and the utilisation of chargers

A number of projects, datasets and reports were assessed to determine the most appropriate profiles. The main projects used to derive and validate these profiles are:

- **Element Energy's EV Charging Behaviour Study (29th March 2019)** [23]– This project developed a set of annual charging demand profiles, covering all 8,760 hours within a year, based upon a dataset of over 8 million real-world charging events collected from major charge point operators.
- **Electric Nation** [24]– When launched, Electric Nation was the world's largest home smart charging trial with nearly 700 Electric Vehicle (EV) owners taking part in the project. The large-scale smart charging trial provided invaluable data on how EV owners charge their vehicle at home and included a trial looking at managed charging.

Charger Categorisation

The Element Energy model is one of the most comprehensive assessment of charging behaviour (~8 million transactions) within the UK. The charging behaviour demand profiles produced as part of this project were used as a starting point to produce charger specific profiles for the DFES EV Charge Point subtechnologies. The Element Energy work grouped all chargers into one of four categories:

- **Residential** - Charge points located at or near EV drivers' homes
- **Work** - Charge points installed in workplaces, for use by employees who commute to work using an EV
- **Slow/Fast Public** - Publicly accessible charge points, excluding those classified as Work or Residential.
- **Rapid Public** - Publicly accessible charge points with a charging capacity ≥43 kW

The mapping from the WPD charger subtechnologies to the Element Energy charger types are given in Table 17.

Table 17: Mapping of WPD EV Charge Point subtechnologies to corresponding Element Energy categorisations

Charger Grouping	WPD Charger Subtechnology
Residential	Domestic off-street
	Domestic on-street
Work	Fleet/Depot
	Workplace
Slow/Fast Public	En-route / local charging stations
	Car parks
	Destination
Rapid Public*	En-route national network

*"The rapid public charger data was not made publically available, as the relatively low sample size could be traced back to individual customers. As stated in the Element Energy report "this charger type classification provides an effective trade-off between distinctions in usage while ensuring each type has a large enough data volume".

[23] Element Energy, *Electric Vehicle Charging Behaviour Study, Final Report for National Grid ESO,* 2019; https://www.smarternetworks.org/project/nia_ngso0021/documents

[24] Western Power Distribution, *Electric Nation,* 2019; https://www.westernpower.co.uk/projects/electric-nation

The WPD DFES charger types are forecast at a more granular level to help inform interested stakeholders and aid in the future development of EV customer behaviour modelling. The profiles described below were created for the four overarching charging groups, and then applied to the more granular WPD charger types.

Normalised Profile Creation

The Element Energy dataset provides a whole yearly hourly profile for residential, work and slow/fast for each WPD licence area. These profiles underwent detailed validation, including removal of erroneous charging events, correcting for increasing EV and charger stock and ensuring anomalously high and low demand were reflected in the final profiles. The final profiles used in this analysis are normalised hourly profiles that give a kW per yearly kWh.

The process below was used to create the representative day profiles per charger category:

1. Group the yearly profiles from each WPD licence area into the corresponding charger category.
2. Discount any licence area profiles that did not meet the Element Energy diversified threshold check. This is to exclude profiles that have an insufficient sample size to be statistically significant.
3. Assign the relevant season from the
4. Representative Days to each day and hour within the year.
5. For each hour within a day, find the maximum across all licence areas within each season for all 3 available charger categories. This give a credible worst-case peak demand profile for each season.
6. For each half hour within a day, find the minimum across all licence areas for the summer season for all 3 available charger categories. This give a credible worst-case summer minimum demand profile.

The output of this process gave a profile for each representative day for the residential, work and slow/fast charger categories. These profiles are kW per yearly kWh. This approach enables the energy from a changing vehicle stock to be distributed across a year; accounting for increased utilisation and numbers. These profiles are shown in Figure 43, Figure 45 and Figure 46.

The maximum for each licence area was taken and applied to all licence areas, rather than attempting to apply licence area specific diversity. This is because the South Wales profiles did not meet the diversified threshold for Work and Slow/Fast chargers. There is also a risk that any differences are due to uptake rate and sample size limitations, rather than actual licence area specific variances. Note there is not a significant difference between the fully diversified profiles.

Due to the lack of available data on rapid charger utilisation and the low number of EVs that are capable of fully utilising the rapid charge, the profile for rapid chargers is modelled at a constant 350 kW for all demand representative days. This does not represent how rapid chargers are likely to operate, but is a worst-ca Managed Charging Residential Profile

To account for residential smart charging, the Electric Nation managed charging trial data was analysed. The amount of energy time-shifted due to managed charging was calculated and this assumption was applied to the residential charger category to create a residential flexed profile. This final flexed profile is shown in Figure 44. It is important to note that the profile assumes no charging between 5-6pm, to enable the FES assumption of energy time-shifted at peak to be applied.

Apportioning Energy

To determine the energy requirement for each representative day, the total vehicle stock energy is apportioned to each charger type. The proportion of energy delivered via each charger type is taken from the Element Energy model.

Table 18: Share of charging demand across charger categories

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

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

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

This final output is a year and scenario dependent profile that accounts EV energy requirements and how this will be apportioned across the available chargers. These profiles are then applied to the WPD EV Charge Point subtechnologies using the mapping given in Table 17.

Representative Day Profiles

Residential EV Charge Point (unabated)

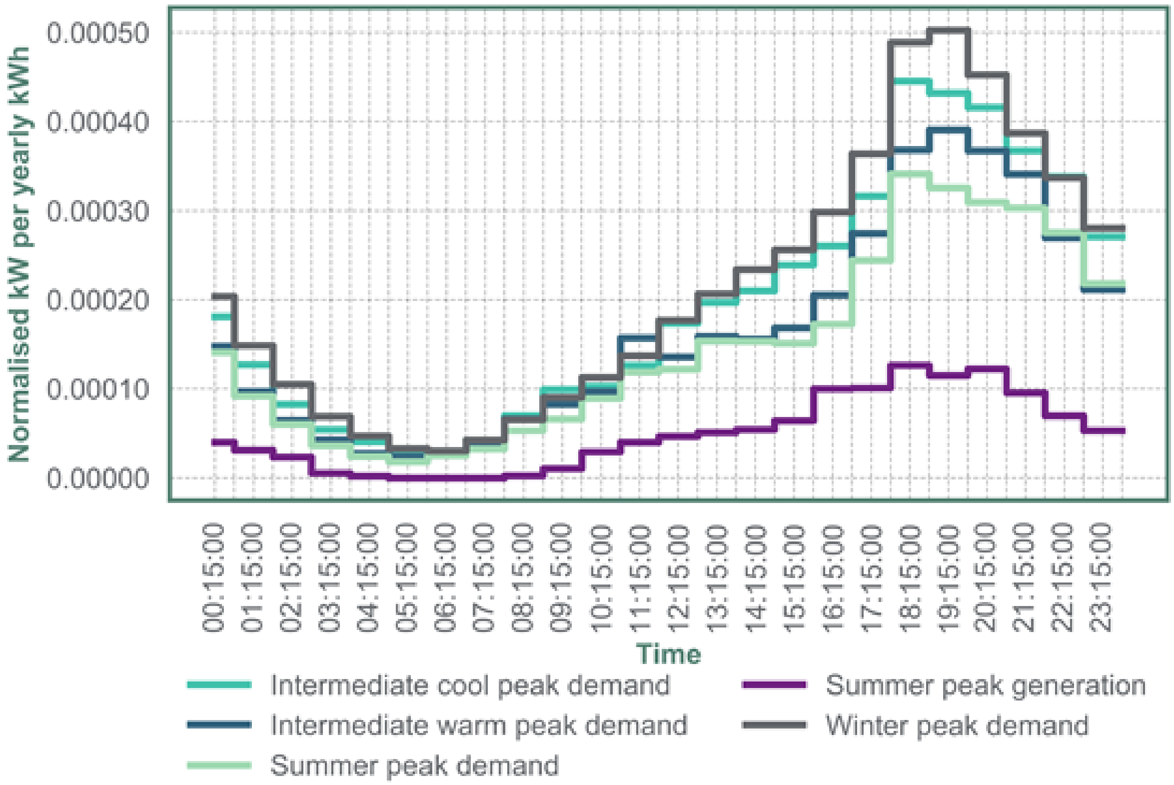

Figure 43: Residential unabated kW/yearly kWh representative day charging profile

Residential EV Charge Point (flexed)

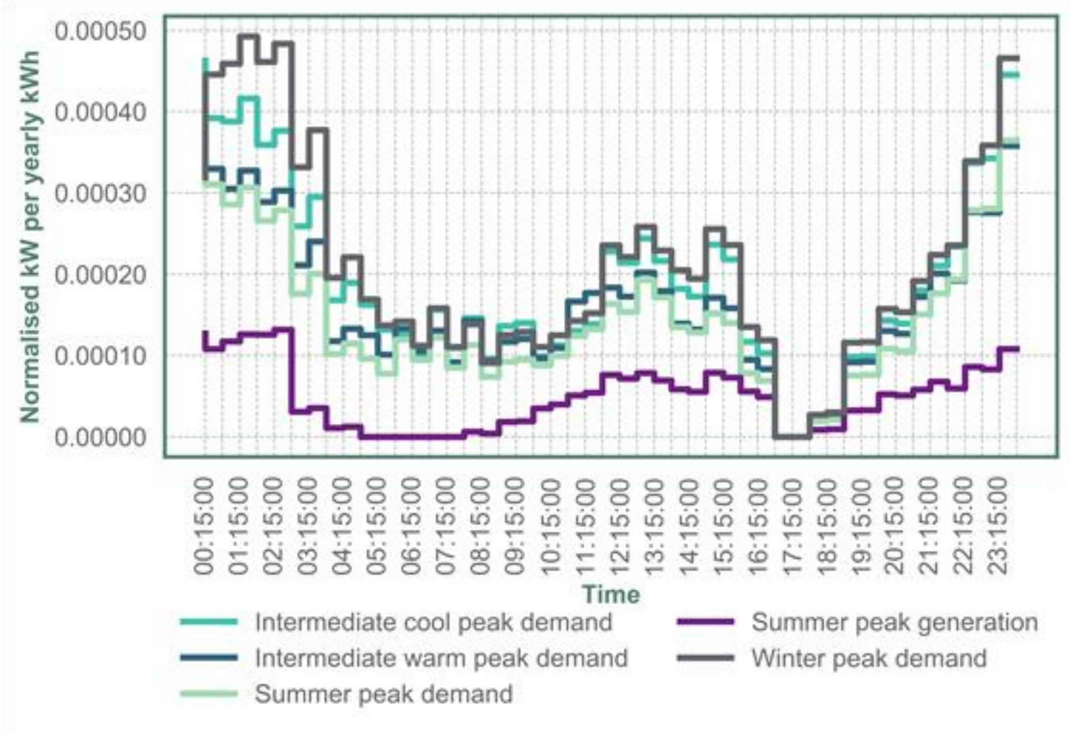

Figure 44: Residential managed charging (flexed) kW/yearly kWh representative day charging profile

Work EV Charge Point (unabated)

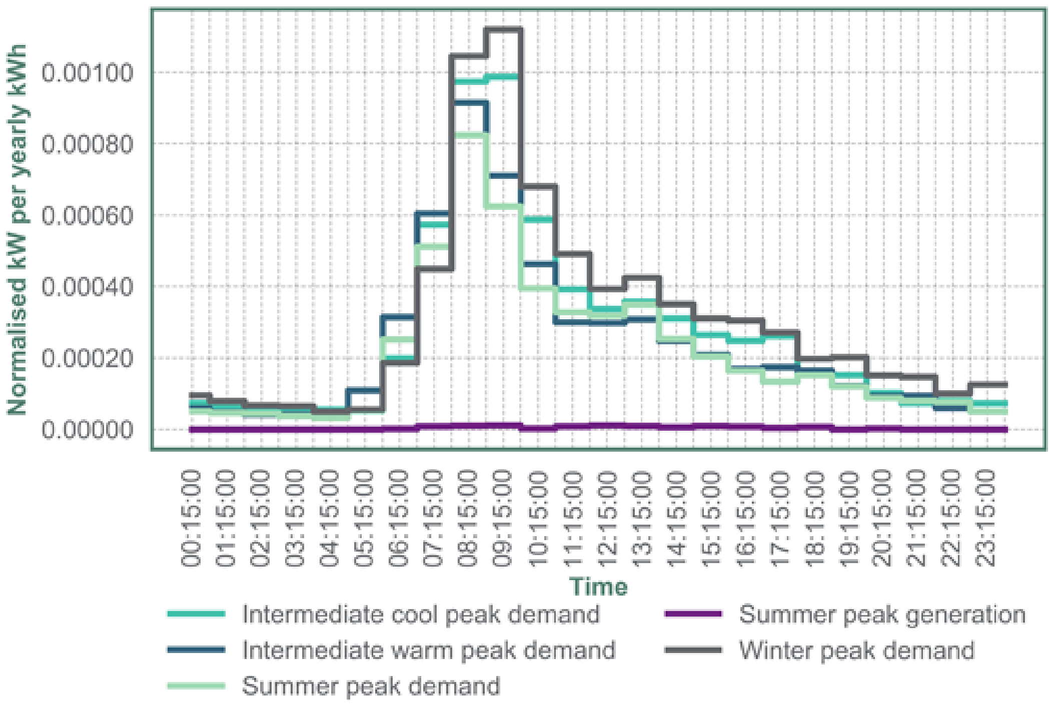

Figure 45: Work unabated kW/yearly kWh representative day charging profiles

Slow/fast EV Charge Point (unabated)

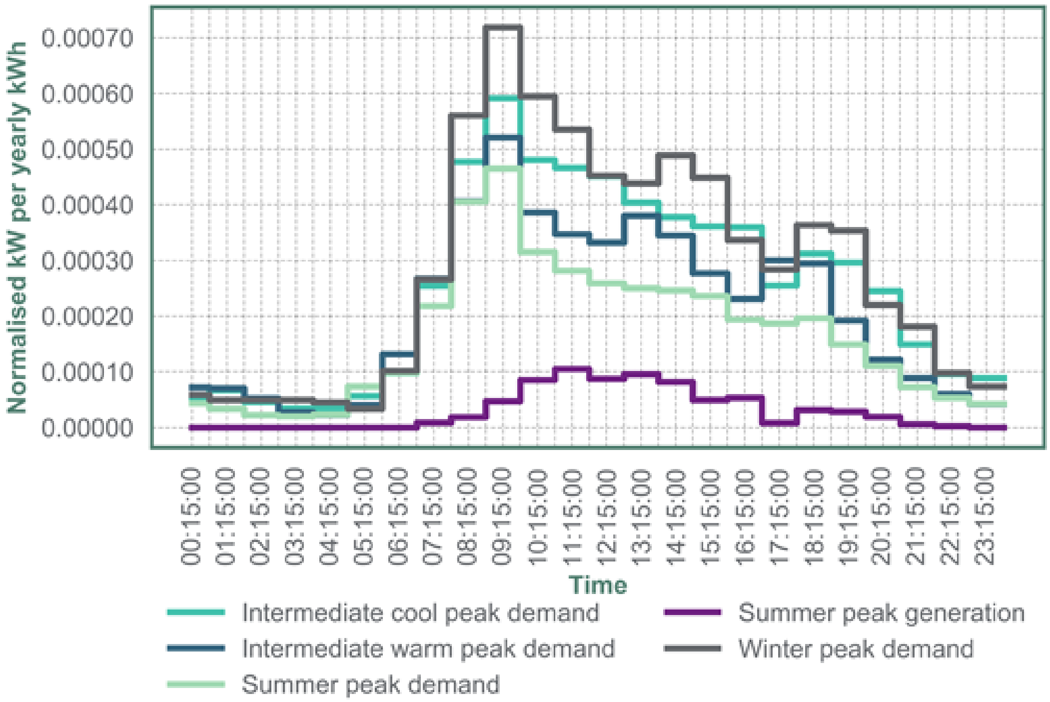

Figure 46: Slow/Fast unabated kW/yearly kWh representative day charging profile

How will these profiles change over time

As described in detail in the Methodology section, the EV charger profiles will change over time due to:

- Total EV energy based on vehicle stock
- EV to charger ratio
- Increase in managed residential charging

In addition to the above, the improvement in car (including autonomous), motorbike and LGV energy efficiency (kWh/mile) is modelled. These figures are taken from the DfT Transport Analysis Guidance[25] model and are applied to all scenarios equally. The energy efficiency improvements are shown in Figure 47. The DfT Transport Analysis Guidance model does not currently provide energy and efficiency figures for HGV or bus and coaches. Due to this and the relative uncertainty surrounding the immature HGV and the bus and coach category, no energy efficiency figures were applied; this assumption will be periodically reviewed as more data becomes available.

[25] Department for Transport, *Transport Analysis Guidance Data Workbook v1.13.1* [Data set] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/898797/tag-data-book.xlsm (Accessed 9th February 2021)

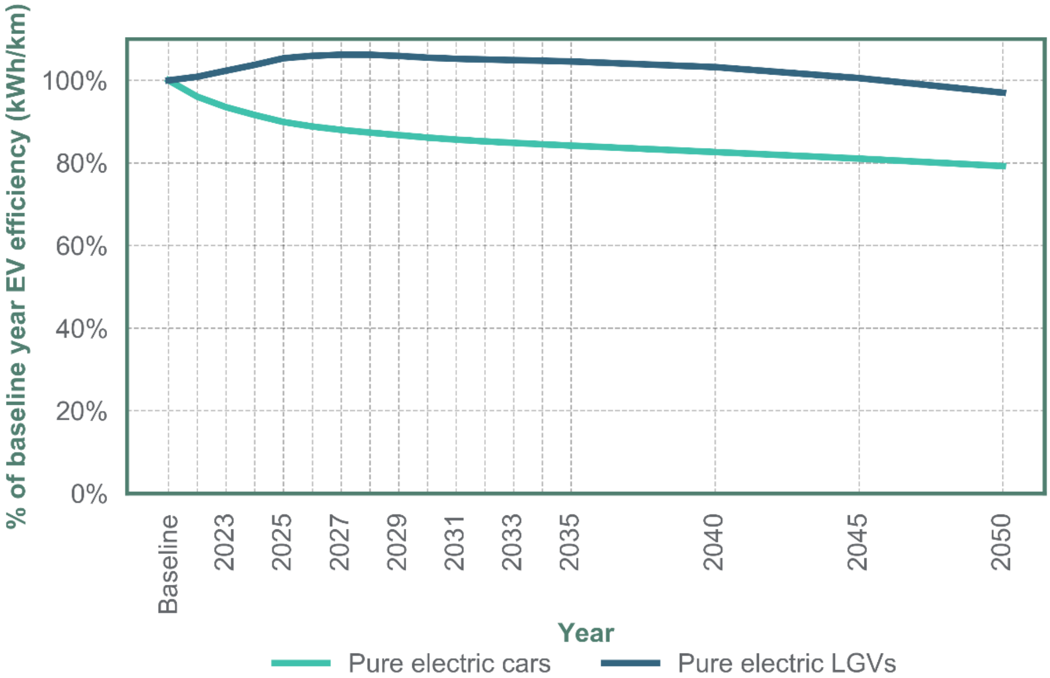

Figure 47: Car and LGV efficiency improvement assumptions taken from DfT TAG model

Energy Assumptions

The baseline energy assumptions per vehicle category are given in Table 19.

Table 19: Electric vehicle average annual mileage, kWh/mile and yearly energy requirement in Baseline year

Subtechnology	Average Mileage	kWh/mile (Baseline)	kWh per Year (Baseline)
Hybrid car (non autonomous)	4799*	0.3059	1,468
Hybrid LGV	7410*	0.3724	2759
Pure electric bus and coach	15943	1.6030	25557
Pure electric car (autonomous)	8726	0.3059	2669
Pure electric car (non autonomous)	8726	0.3059	2669
Pure electric HGV	34693	1.33925	46462
Pure electric LGV	13472	0.3724	5017
Pure electric motorcycle	2386	0.29058	693

*Mileage when running on electric only

The efficiency improvements described in the above section are also applied for years after baseline. Table 19 and the DFES volumes data are used to determine the yearly energy requirement. This can be calculated at an ESA level or aggregated to a licence area or WPD view.

Known Limitations

Rapid chargers are currently not profiled due to the limited number of providers of rapid public charger. Where rapid charger data is available, it includes charging of vehicles like the Nissan leaf that can only charge at < 50kW. The risk of using existing rapid charger data to determine future utilisation is that it does not represent new vehicles with larger batteries that are able to charge at a higher rate.

No modelling of Vehicle to Grid (V2G) has been assumed due to the uncertainty around behaviour at a granular substation level, in particular if V2G will resolve network constraints that do not align with system peak demand.

Customers charging directly from a 13A plug are not explicitly captured as a charger type. This is largely mitigated, as the total energy requirement of all EVs is captured and apportioned across the available chargers.

The proportion of energy apportioned to each charger category is modelled as constant, based on existing vehicle stock. The total energy required for the vehicle stock is still delivered, but it does not fully capture an increased proportion of total energy being supplied via a growing charger type segment.

This is the first year where autonomous vehicles have been included in the DFES volumes. The operation of autonomous vehicles is still uncertain and potential annual mileage and charging behaviours are not well understood. Autonomous vehicles were assigned the same annual mileage as their non-autonomous counterparts. The growth of autonomous vehicles only significantly increases in the late 2030s.

Profiles derived from the Element Energy model are only hourly, rather than half-hourly. Distribution networks are traditionally designed at a half-hour granularity. Benchmarking the residential off-street profiles against the Electric Nation profile shows that the hourly profile is largely representative of a full-diversified profile.

Future Developments

As more data becomes available, improve the modelling assumptions on autonomous vehicles. This includes understanding credible autonomous market models, including annual mileage and charging behaviour.

Planned reviews of Electric Nation Powered Up[26] and other V2G trials that are focussing on the impact of V2G at a distribution level. This will help inform the benefit that V2G can provide to the distribution network for different market models.

Improve the constant EV energy apportionment assumption to charger category based on number of available chargers and the chargers each vehicle type will utilise.

Evaluate ways to better capture EV customers who are charging via 13A plugs, who do not have a dedicated EV charger.

Assess the outputs of the ongoing SP Energy Networks CHARGE[27] innovation project, which is combining transport and electricity network data to highlight the best location for public EV charge points at the lowest cost. It will also trial deployment of smart management of public chargers. The output of this project should help inform public charger profiles and quantify the potential reduction due to smart public charging.

---

[26] Western Power Distribution, *Electric Nation – Powered Up,* 2020; https://www.westernpower.co.uk/projects/electric-nation-powered-up
[27] SP Energy Networks, *CHARGE,* 2020; https://www.spenergynetworks.co.uk/pages/charge.aspx

Planned review of UK Power Networks OPTIMISE PRIME[28] innovation project that is the world's biggest trial of commercial EVs. It is looking at how to minimise the impact the electrification of commercial vehicles will have on the distribution network. The results of this project will help inform our commercial EV charging behaviour.

As more charging data becomes available, producing EV charging profiles at a higher granularity (half-hourly or better) will help identify any short duration peaks that will not be fully captured with a hourly profile. Additional charging data will also enable explicit profiling of all WPD EV Charge Point subtechnologies, rather than grouping into high-level categories.

[28] UK Power Networks, *Optimise Prime Project Overview,* 2020; https://www.optimise-prime.com/project-overview

Resistive Electric Heating

Table 20: Resistive electric heating technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Resistive electric heating	Direct electric heating	Number of customers with resistive electric heating
	Night storage heating	

Methodology

Resistive electric heating is a system using electricity to provide primary space heat and hot water to domestic buildings that is not driven by a heat pump. Typically, this is night storage heating or direct electric heating. This does not include heat networks.

The baseline number of resistive electric heating units is based on analysis of domestic heating technology types from EPC data, census data and WPD connected customers. The installation rate of direct electric heating in new builds is also based on local EPC data. The most recent national data shows that c.11% of new builds are heated by resistive electric heating, a proportion which has been relatively stable over recent years. The WPD DFES 2021 analysis of new build domestic properties is used to project increases in the number of resistive electric heating installations. Resistive electric heating has a higher running cost than a heat pump, they are assumed not to be the target of national policy to decarbonise domestic heating.

The customer behaviour assumptions for resistive electric heating and night storage are based on the Elexon profile classes[29]. They are consistent with the WPD Policy Document ST:SD5A (Design of Low Voltage Domestic Connections)[30]. This process is developed for the purposes of Low Voltage network design, and uses a statistical methodology consistent with that published in the ACE49 methodology[31]. For the application of these resistive heating profiles for use in strategic analysis of the EHV networks, a diversity level of 50 customers was chosen. This represents a credible usage profile for a single resistive electric heating installation, aggregated as part of a wider group of 50 domestic customers with night storage.

A limitation of the ACE49 methodology is it does not produce a half-hourly profile for all representative days assessed. To create a profile for all demand representative days, the ratio of HP energy requirement referenced to winter peak was used as an approximation for seasonal scaling.

The way that resistive electric heating is modelled has changed in DFES 2021 from DFES 2020. The limitations from DFES 2020 have been addressed in this analysis, as the night storage and direct electric heating have the same projected energy requirement per installation but a notably different MW profile. By splitting them out, any uncertainties in profile split are avoided.

Night storage

The Elexon profile class 2 represents domestic economy 7 customers. This is the profile class normally allocated to domestic customers with night storage. Profile class 2 includes the energy requirement for domestic demand, not just the night storage heating. To derive a night storage only profile, the delta between Elexon profile class 1 and profile class 2 was calculated. The profiles for night storage in the baseline year is shown in Figure 48.

---

[29] Elexon, *Load Profiles and their use in Electricity Settlement,* p41

[30] Western Power Distribution, *Standard Technique: SD5A/5, Design of Low Voltage Domestic Connections, p41*

[31] Energy Networks Association, *ACE Report no.49*, p5

Direct Electric Heating

The direct electric heating profile was created using a similar methodology to the night storage profile. The delta between profile class 1 and the unrestricted profile with electric heating was taken to create a direct heating only profile. The energy per installation for each year and scenario is detailed in the Energy Assumptions section.

Representative Day Profiles

Night storage profile

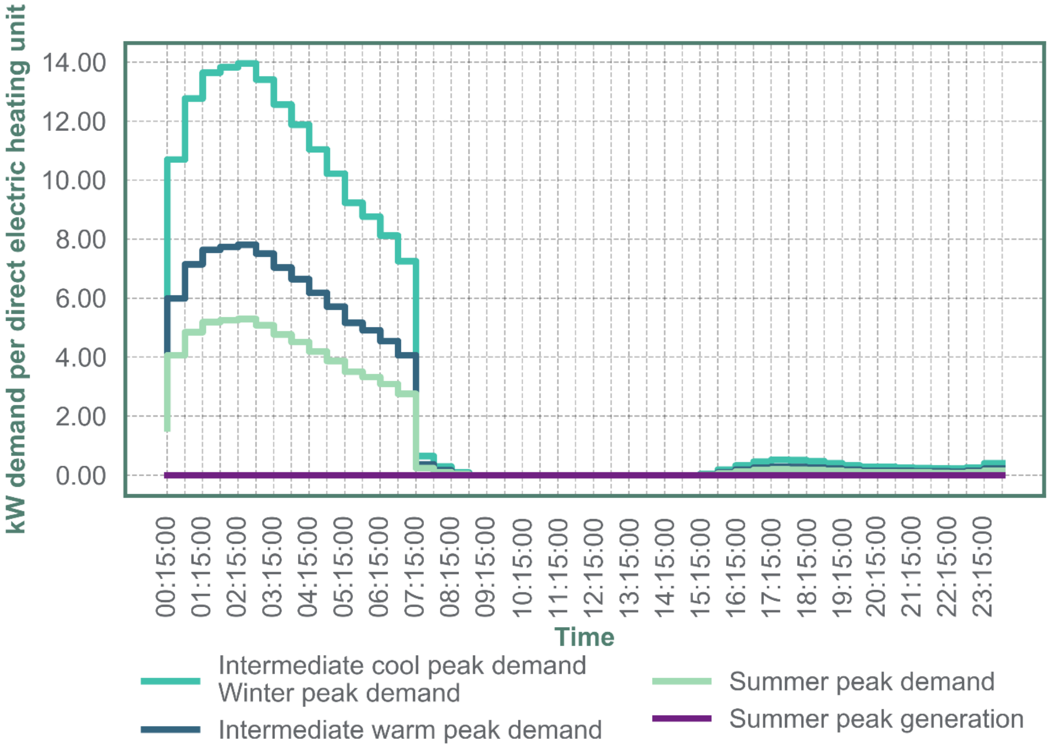

Figure 48: Night storage profile per installation in baseline year

Direct electric heating profile

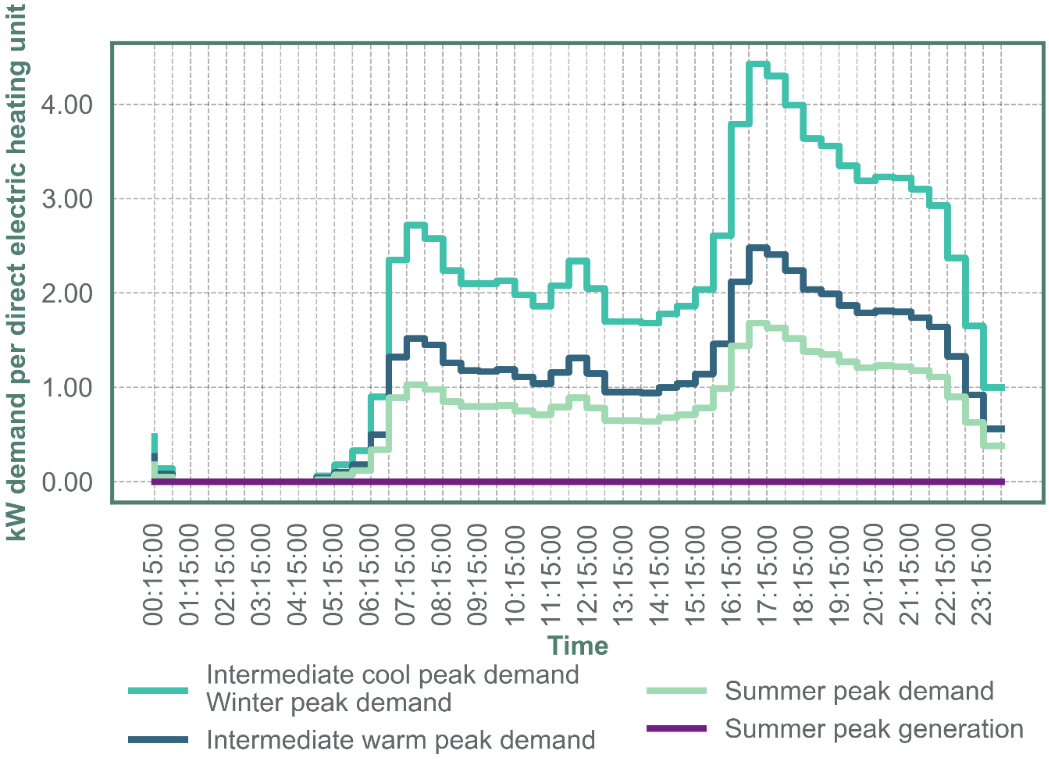

Figure 49: Direct Electric heating profile per installation in baseline year

How will these profiles change over time

The yearly energy requirement per installation is projected to reduce under all scenarios; more information can be found in the Energy Assumptions section. The ACE49 methodology used to derive both profiles are scaled around the yearly energy requirement per resistive electric heating customer. To account for how the reducing energy per installation will affect the MW profiles, a scaling factor based on the data in Figure 50 and Figure 51 is applied. The scaling factor is normalised around the baseline for each year and scenario and can be linearly applied to the profiles in Figure 48 and Figure 49.

Energy Assumptions

The yearly energy for direct electric heating and night storage broken down by year and scenario are taken from the FES data workbook[32]. The yearly energy is assumed to remain the same for direct electric heating and night storage. The yearly energy requirement is projected to reduce under all scenarios, due to improvements in existing and new housing stock thermal efficiency. The projected efficiency improvements in heating are shown in Figure 50.

---

[32] Ibid

Annual energy consumption percentage change from baseline per direct electric heating customer

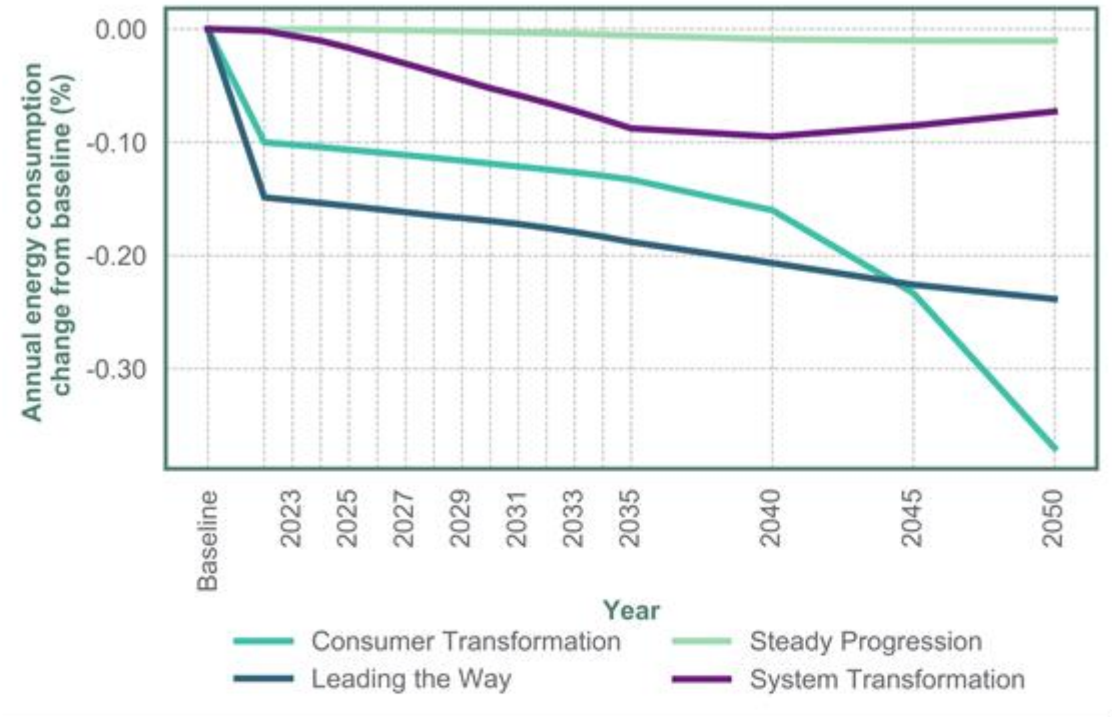

Figure 50: Direct electric heating energy percentage change from baseline by scenario

Annual energy consumption percentage change from baseline per night storage heating customer

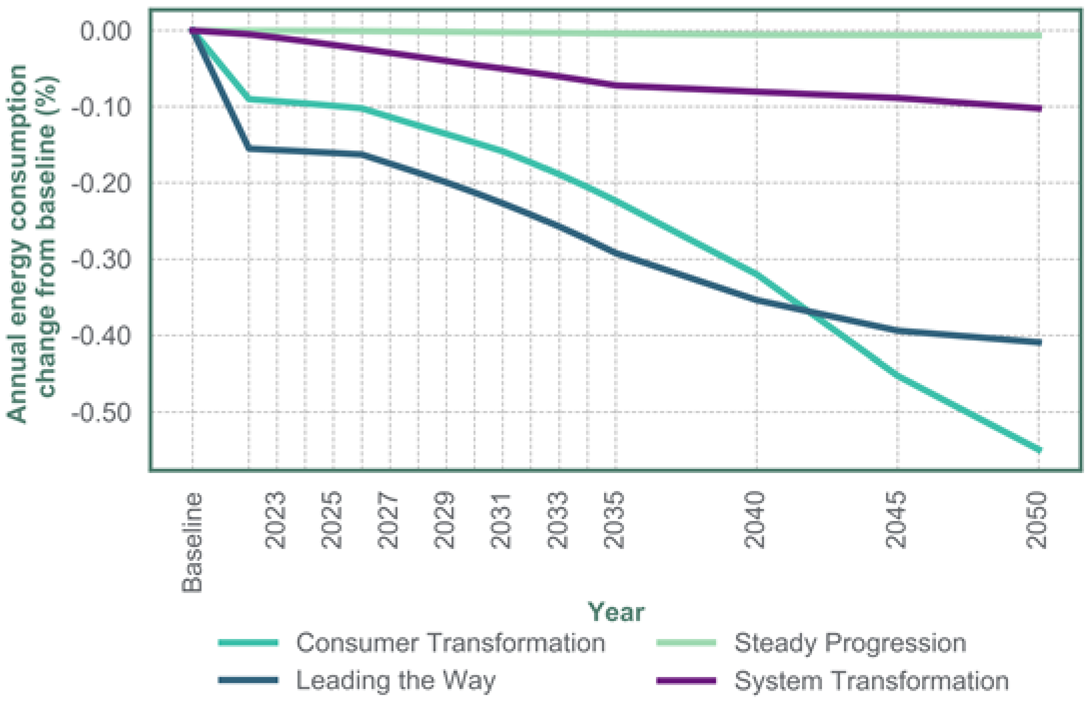

Figure 51: Night storage heating energy percentage change from baseline by scenario

Known Limitations

The known limitations from DFES 2020 have been addressed through the separation of direct electric heating and night storage profiles.

Future Developments

In future there is scope to integrate these heating profiles into a heat model that also includes both heat pumps and district heating, along with further categorisation into building types.

Heat Pumps

Table 21: Heat pump technology types used in the DFES 2021 analysis

Technology	Subtechnology	Units used in DFES volume projections
Heat pumps	Domestic - Hybrid	Number of heat pumps
	Domestic - Hybrid + thermal storage	
	Domestic - Non-hybrid ASHP	
	Domestic - Non-hybrid ASHP + thermal storage	
	Domestic - Non-hybrid GSHP	
	Domestic - Non-hybrid GSHP + thermal storage	

Methodology

Each heat pump connection is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. Heat pump volumes are provided in number of heat pumps. As described in the Domestic section, heat pumps are forecast independently to new domestic properties. This allows the retrofitting of heat pumps in the existing housing stock to be more accurately captured.

Ground Source Heat Pumps (GSHP) and Air Source Heat Pumps (ASHP) have been forecast separately, an addition compared to last year's analysis; however, it is expected that GSHPs will be less prevalent due to GSHPs space requirements for the ground source loop and cost of installation. It is worth noting that GSHPs do have a higher coefficient of performance, particularly at times of low ambient temperatures.

Recent developments in hybrid heat pumps, which work with a backup technology (primarily gas), have started to reduce some of the barriers and raise potential for much higher growth in the sector. As well as starting to make it a cost-effective option for an on-gas grid customer, a hybrid system also requires less disruptive change. The higher temperature heat can use existing radiators and the heat pump operates at times when it is most efficient (e.g. low electricity prices or moderate heat requirements), with back up sources taking over when it is not.

The majority of substations see a yearly peak demand during the winter or intermediate cool seasons, at times of cold ambient temperatures. The majority of heat pump energy demand is also within the winter and intermediate cool seasons, with a peak demand that is shown to correlate very closely with existing peak demand.

With non-hybrid heat pumps, all energy is provided via the electricity network, compared with hybrid systems that can switch between electricity and gas. At times of high network demand and low ambient temperatures, non-hybrid systems coefficient of performance can drop significantly. An additional electrical backup source is used where the non-hybrid heat pump is unable to maintain the required temperature. A hybrid system is able to switch over to its alternate fuel source at times of high electricity demand.

When determining the heat pump profiles, it was important to consider the coincident nature of existing peak demand and heat pump peak demand. The use of average or typical profiles does not capture the onerous network loading that will be seen for a 1-in-20 winter.

Non-hybrid Profiles

A review of available heat pump data was undertaken to determine the best source to derive edge-case heat pump profiles. The projects, data sources and reports evaluated include:

- Electricity North West Limited Network Innovation Allowance (NIA) funded study: Managing the Impact of Electrification of Heat.[33]
- Customer-Led Network Revolution Insight Report[34]: Domestic Heat Pumps, dated January 2015. This included the associated TC3 datasets [35]with heat pump mean and standard deviation for a 48 half hourly period for all months.
- Energy Policy report on "Decarbonising domestic heating: What is the peak GB demand?"[36]
- Applied Energy "The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial" [37](Applied Energy 204 (2017) 332–342)
- National Grid FES 2021 Report and Data workbook [38]

The non-hybrid heat pump profiles needed to capture the maximum electrical demand for all representative days. This includes demand from any electrical backup that may operate at times of extreme cold.

The Customer-Led Network Revolution TC3 dataset provide an average and standard deviation for a full 48 half hour period for each month in the year. This data enabled production of a half-hourly profile for each network capability season. It was determined that 3 standard deviations from the average was a credible peak, representing a cold period, where a large portion of electric backup heating is required. The unabated non-hybrid profiles are given in Figure 53.

A development in DFES 2021 is splitting the profiles of hybrid and non-hybrid heat pumps that are co-located with thermal storage. Thermal storage is the capturing of energy at times of low network demand, when electricity prices are lower. The thermal storage subtechnology profiles use the same underlying profiles as the profiles without thermal storage, but with no electrical demand during the morning or evening period. The non-hybrid thermal storage co-location profile is shown in Figure 54.

---

[33] Electricity North West Lid, *NIA ENWL001 – Demand Scenarios with Electric Heat and Commercial Capacity Options,* (2017) https://www.enwl.co.uk/globalassets/innovation/enwl001-demand-scenarios--atlas/enwl001-closedown-report/nia-enwl001-closedown-report-final.pdf

[34] Northern Powergrid, *Customer Led Network Revolution Insight Report: Domestic Heat Pumps,* 2015; http://www.networkrevolution.co.uk/wp-content/uploads/2015/01/CLNR-L091-Insight-Report-Domestic-Heat-Pumps.pdf

[35] Northern Powergrid, *Customer Led Network Revolution TC3 Dataset,* [Data set] (2014) http://www.networkrevolution.co.uk/wp-content/uploads/2015/01/TC3-Dataset_December-2014.xlsx (Accessed July 2019)

[36] Watson, S.D. et al, (2019), *Decarbonising Domestic Heating: What is the peak GB demand?* Energy Policy 126, p533-544

[37] Love, J et al, (2017), *The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial,* Applied Energy 204, p332-342

[38] National Grid ESO, *FES Data Workbook v07*, pED1

The residential thermal storage adoption rate (%) and the residential demand shaved at peak (%) are taken from the FES data workbook[39]. These figures are given for each year and scenario. The multiplication of both of these values gives the total percentage of non-hybrid heat pump demand shaved at peak. Figure 52 shows how this changes over time for each scenario.

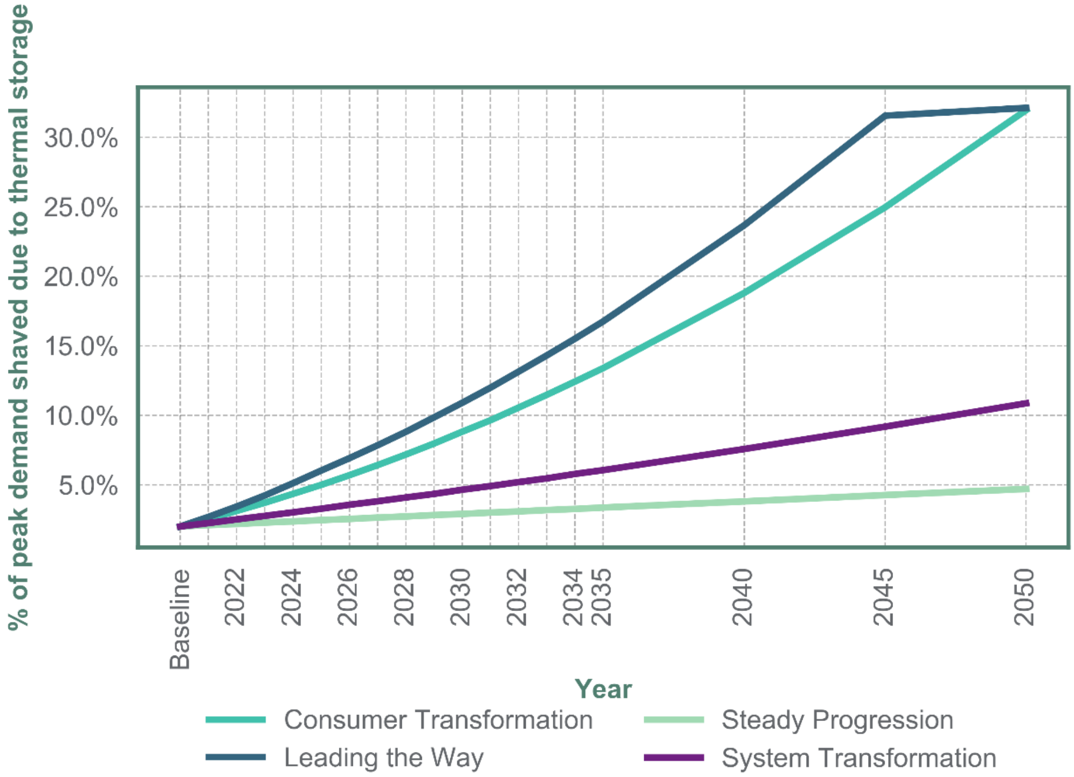

Figure 52: Peak shaved due to thermal storage at time of system peak demand

Assigning the year- and scenario-dependent percentage given in Figure 52 to the thermal storage profile and the remaining the profile without thermal storage gives a total peak shaved that aligns with the FES figures.

Hybrid Profiles

Hybrid heat pumps are an emerging technology and there is still a level of uncertainty as to how they will operate. A hybrid system manages heat delivery from both a gas boiler, meaning the level of energy delivered from electricity can vary significantly dependent on mode of operation and price signals.

A key source of information on hybrid heat pump operation is the Freedom Project[40], which was a joint innovation project between Western Power Distribution, Wales & West Utilities and Passive Systems. It used air source heat pump and high-efficiency gas boiler hybrid system in 75 residential properties, the project has demonstrated the significant benefits that an integrated whole energy systems approach to deploying smart dual-fuel technologies can deliver.

The systems were operated in a range of different fuel price scenarios, including different ranges of gas pricing and with both fixed and variable rate electricity tariffs. When optimising

[39] National Grid ESO, *FES Data Workbook v07*, pED1

[40] Western Power Distribution, *FREEDOM: Flexible Residential Energy Efficiency Demand Optimisation and Management,* 2019; https://www.westernpower.co.uk/projects/freedom

for consumer cost with today's energy prices, the systems strongly favour gas boiler usage due to the very low cost of gas compared with electricity.

The FREEDOM Final Report states:

> *"The field trial demonstrated that hybrids can provide fully flexible loads with the ability to: constrain peak whole-home demand below the existing Elexon Profile Class 1 peak whilst still delivering 50% of the heat demand through the heat pump; enforce a capacity cap across a population, including a cap of zero ASHP demand; increase ASHP demand at times of plentiful low-cost renewable electricity; for the first time ever live carbon forecasts were used so that the ASHP could track grid carbon intensity and avoid times of high carbon peaking plant generation".*

Based on the FREEDOM project findings, hybrid heat pumps are modelled as running on gas for the Winter and Intermediate Cool Peak Demand representative days. Both of these representative are focussed on extreme cold ambient temperatures, where the ASHP coefficient of performance will be greatly reduced and it is presumed that the heat pump control system and price signals will incentive gas sufficiently during these representative days.

Summer and intermediate warm representative days are profiled at 80% of the non-hybrid profile, accounting for hybrid systems that are still operating on gas even during less onerous periods. The profiles used for hybrid heat pumps can be found in Figure 56.

Representative Day Profiles

Non-hybrid heat pump profile

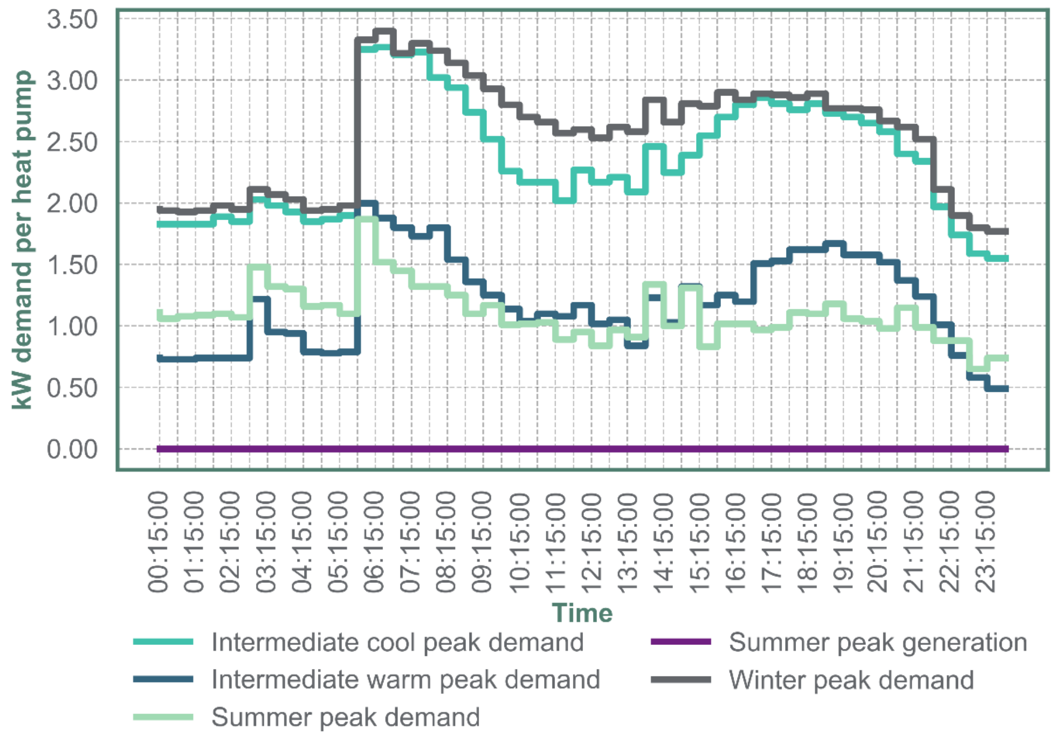

Figure 53: Non-hybrid heat pump profiles in baseline year

Non-hybrid heat pump profile with thermal storage

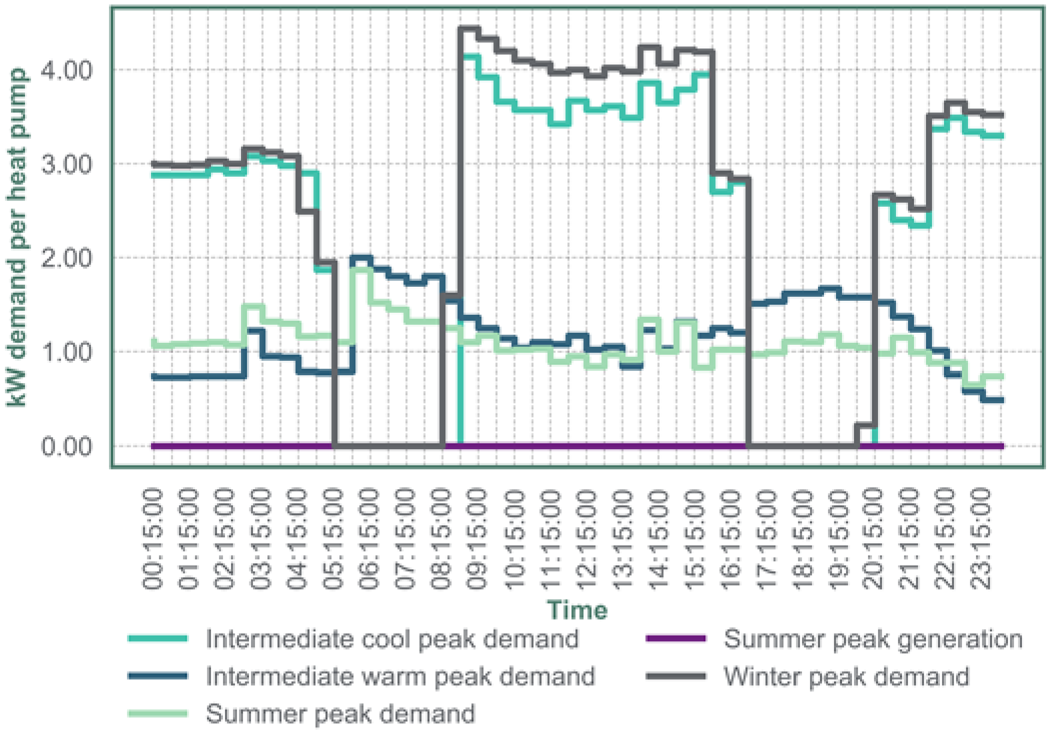

Figure 54: Non-hybrid heat pump with thermal storage profiles in baseline year

Hybrid heat pump profile

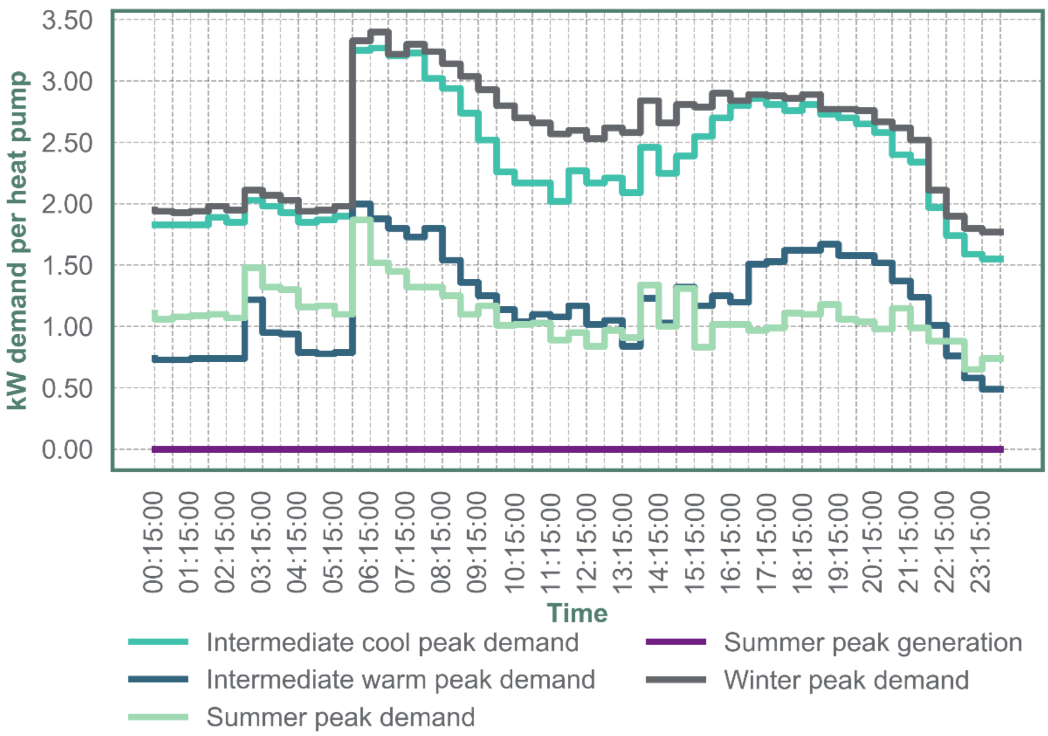

Figure 55: Hybrid heat pump in baseline year

Hybrid heat pump profile with thermal storage

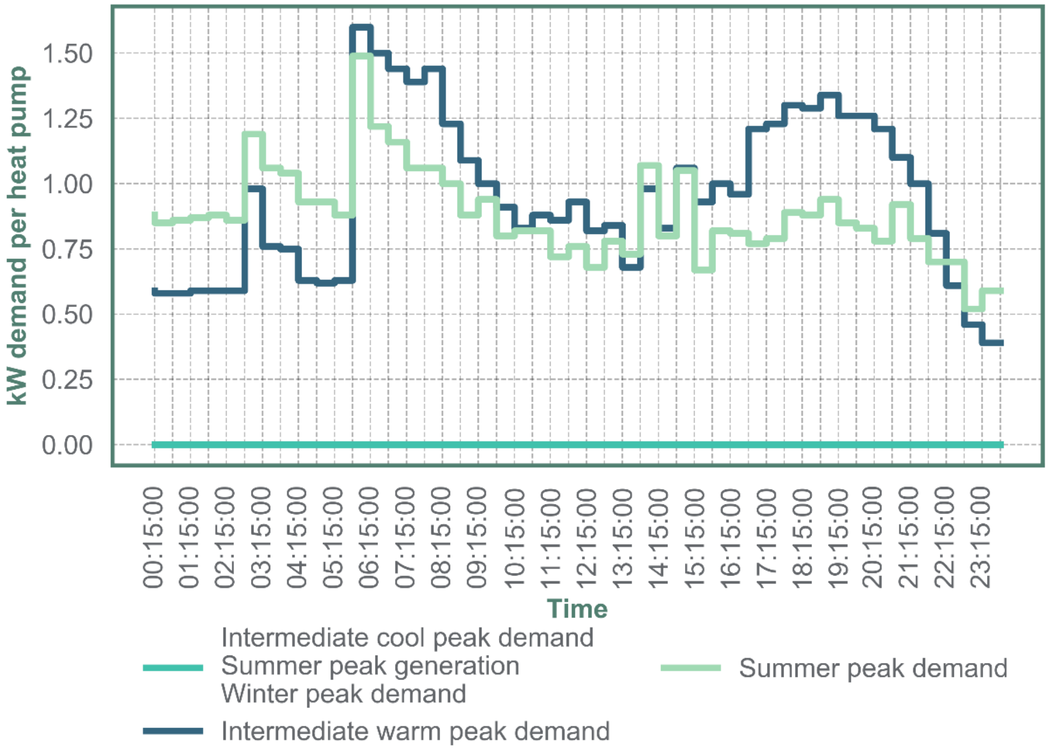

Figure 56: Hybrid heat pump with thermal storage profiles in baseline year

How will these profiles change over time

The uptake of non-hybrid and hybrid systems vary significantly with each scenario. This has a notable impact when assessing the MW growth on the network, particularly for the Winter and Intermediate Cool Peak Demand representative days. Hybrid systems are able to switch to an alternate fuel source at times of high electricity demand; scenarios where a higher proportion of hybrid systems are forecast will have a reduced MW growth at times of high demand due to heat pumps.

The energy requirement of non-hybrid systems is forecast to reduce as the thermal efficiency of housing is improved and the coefficient of performance of heat pumps increases. The profiles are scaled linearly with the overall energy requirements for each year and scenario, as described in the Energy Assumptions section below.

A new development in this year's DFES is splitting out of heat pump systems co-located with thermal storage. The operating behaviour of these are represented by the profiles shown in Figure 54. The profile creation is described in more detail in the Methodology section. The residential thermal storage adoption rate (%) and the residential demand shaved at peak (%) are taken from the FES workbook.

Energy Assumptions

The energy requirements of non-hybrid (ASHP and GSHP) and hybrid heat pumps for each year and scenario were derived from the FES workbook.

As described in the above section, these energy improvement figures were applied to the non-hybrid profiles to represent the reduction in peak MW requirement as housing stock thermal efficiency improves and coefficient of performance of heat pumps increases. This does not apply to the winter and intermediate cool hybrid profiles, where they are already assumed to be operating on an alternate fuel source.

Non-hybrid Air Source Heat Pump (and Non-hybrid Air Source Heat Pump co-located with thermal storage) annual energy consumption

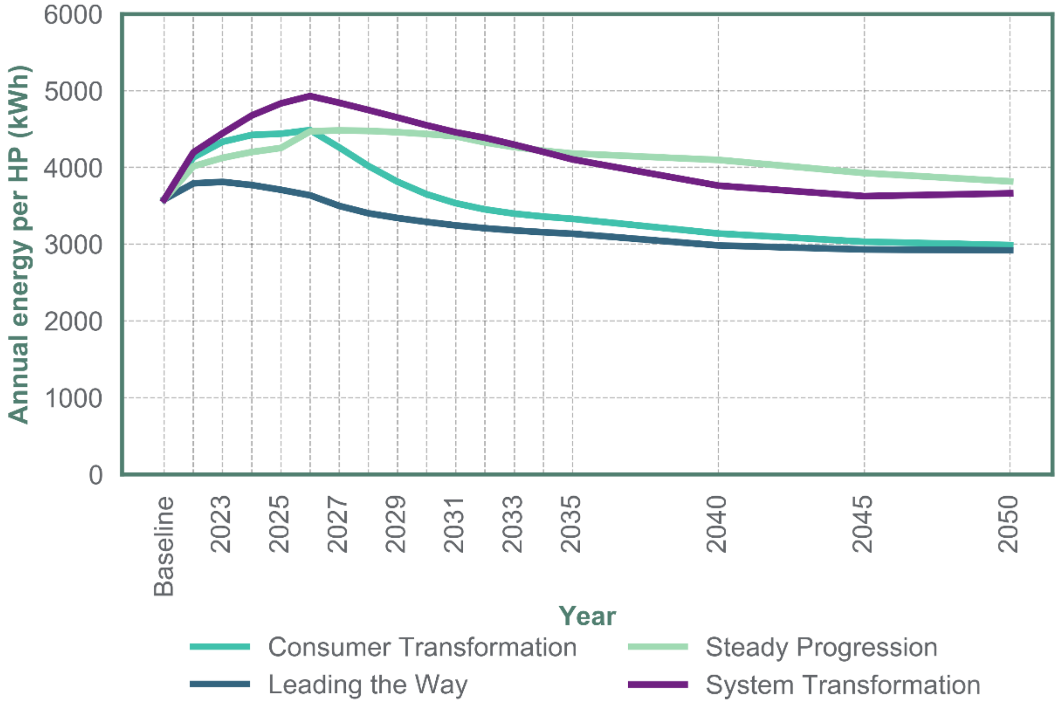

Figure 57: Yearly energy requirement per non-hybrid air source heat pump

Non-hybrid Ground Source Heat Pump (and Non-hybrid Ground Source Heat Pump co-located with thermal storage) annual energy consumption

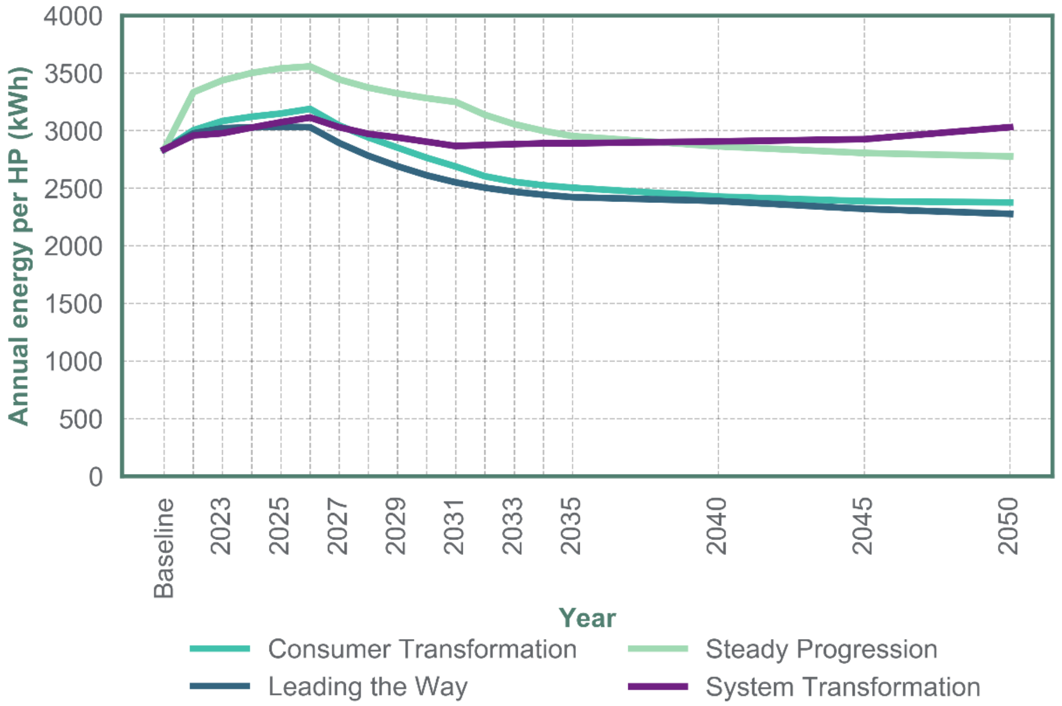

Figure 58: Yearly energy requirement per non-hybrid ground source heat pump

Due to the current FES output not modelling hybrid heat pumps for the baseline, there are no energy requirement values per heat pump for this technology type in the baseline. Figure **59** shows the forecast energy consumption of this technology type.

Hybrid Heat Pump (and hybrid Heat Pump co-located with thermal storage) annual energy consumption

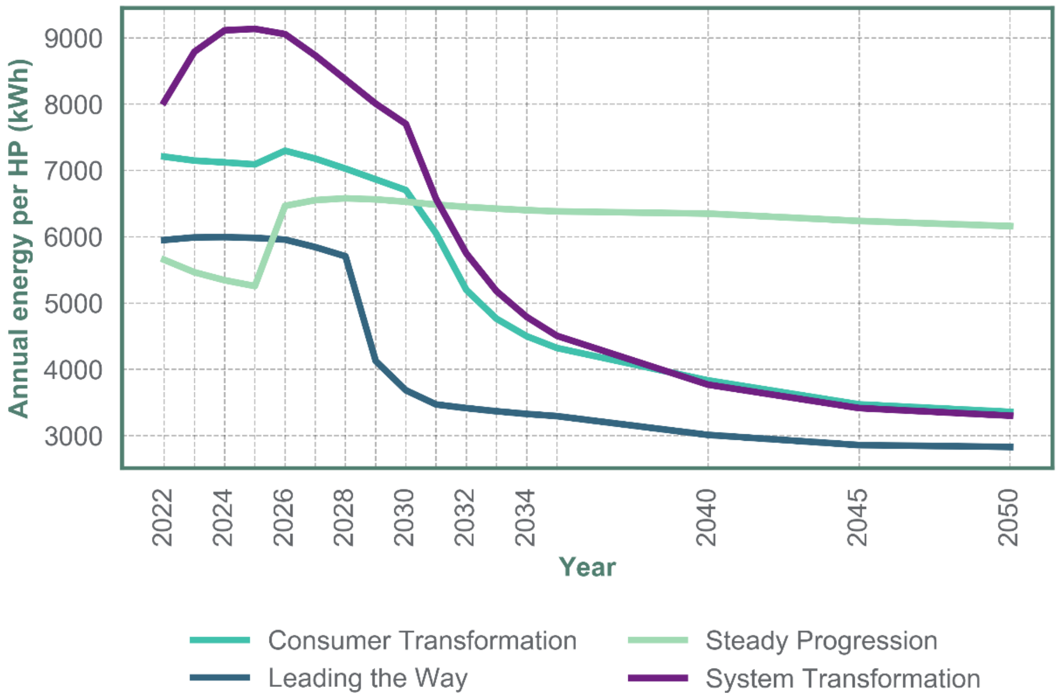

Figure 59: Yearly energy requirement per hybrid heat pump

Known Limitations

Currently only domestic heat pumps are forecast as part of the DFES volumes process. The inclusion of non-domestic heat pump volumes would enable a more representative profile to be applied to the entire building stock across the WPD network.

Future Developments

Forecasting of GSHPs as a separate subtechnology would enable the creation and application of a more representative profile. This could capture the improved coefficient of performance of a GSHP, particularly at times of cold ambient temperature, where ASHP coefficient of performance can drop significantly.

WPD will continue to monitor the progress of existing projects, trials and business as usual processes for assigning customer behaviour for Heat Pumps suitable for network analysis of the EHV networks and update the assumptions as necessary.

Air Conditioning

Methodology

Each air-conditioning unit is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. Air-conditioning volumes are provided in number of air-conditioners.

The daily profile for all of the demand representative days was assumed to be zero. The reasoning for this was that the peak demand representative days in winter, intermediate warm and summer all coincide with a cold day where domestic air conditioning was assumed not to be in use.

The profile for the Summer Peak Generation representative day was also modelled as zero for network assessments. This does not necessarily coincide with high ambient temperatures, particularly on networks with high wind penetration. There is a risk that modelling air-conditioning demand for the summer peak generation day will mask the worst-case condition.

Representative Day Profiles

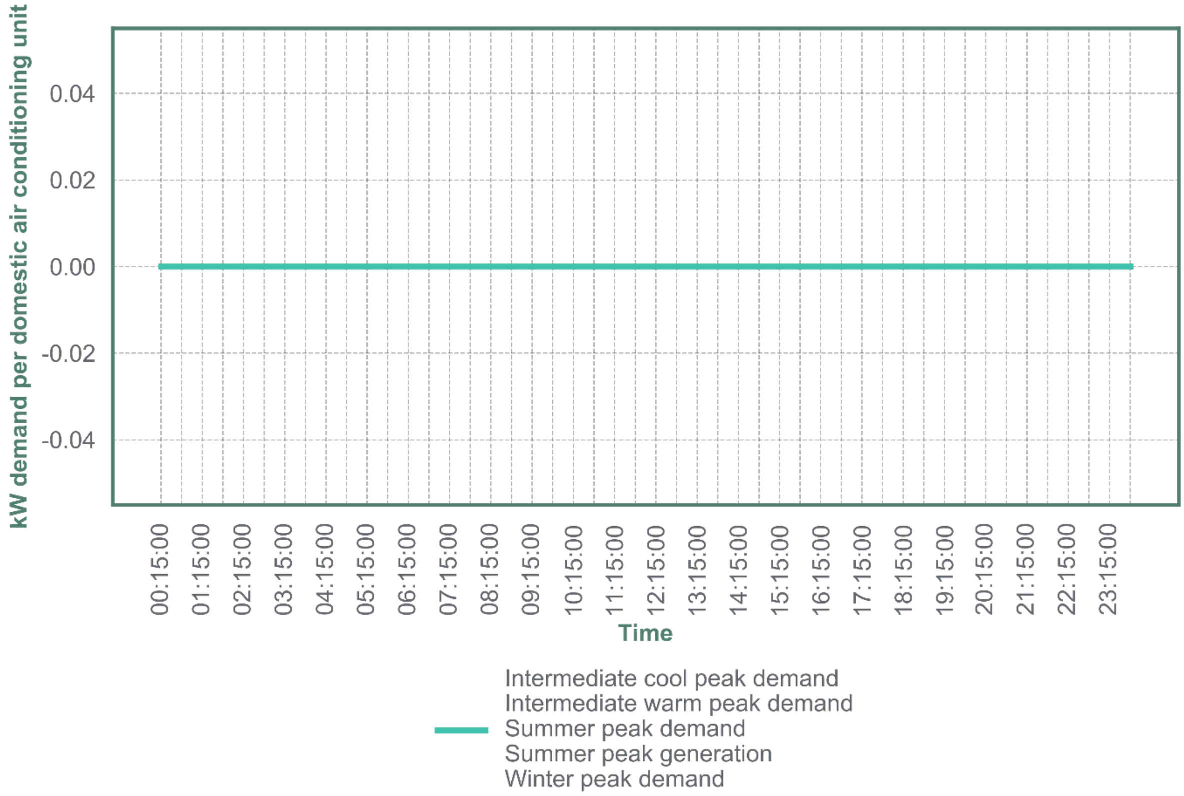

Figure 60: Representative air-conditioning profiles

How will these profiles change over time

These profiles do not change for any year and scenario.

Energy Assumptions

As described in the Methodology section, the air-conditioning demand is assumed as zero for all existing representative days. However, the overall energy is modelled as 500 kWh/year for each installation. This figure is taken from the FES workbook and is assumed to not change by year and scenario.

Known Limitations

The current representative profiles do not capture the minimum coincident air-conditioning demand at time of peak generation.

This air-conditioning technology currently only captures domestic installations. Non-domestic units are more prevalent and the impact is largely captured in the existing demand behaviour described in the non-domestic section.

As more domestic air-conditioning units connect, demand at times of high ambient temperature could cause a new network edge-case. Similar to hot countries with high levels of air-conditioning, the peak demand can actually occur at high ambient temperatures. All four demand representative days are currently focussed on peaks due to cold ambient temperatures.

Future Developments

WPD plan to undertake analysis on domestic and non-domestic air-conditioning operating behaviour. Focussing on existing behaviour at time of network peak and potential for new edge-cases to occur as uptake increases. Consideration of increased energy requirement as average temperature increases could also be reviewed.

Hydrogen Electrolysis

Methodology

Each hydrogen electrolysis plant is geographically allocated to an Electricity Supply Area where it would be most likely to connect to the distribution network. Hydrogen electrolysis volumes are provided in installed capacity (MW).

The daily profile for all of the demand representative days was assumed to be one. The reasoning for this was that the production of hydrogen from hydrogen electrolysis, although likely to be coincident with peaking renewable generation, is not limited to times of high renewable generation. As our modelling only took into account those hydrogen electrolysers that are directly connected to our network, not located behind the meter at weather dependent generation sites, there is increased likelihood of the demand not aligning with renewable generation peaks.

The profile for the Summer Peak Generation representative day was modelled as zero for network assessments. This is to remove the risk of worst-case conditions for the summer peak generation days being masked when hydrogen electrolysis is not guaranteed to be operating at times of high generation.

Representative Day Profiles

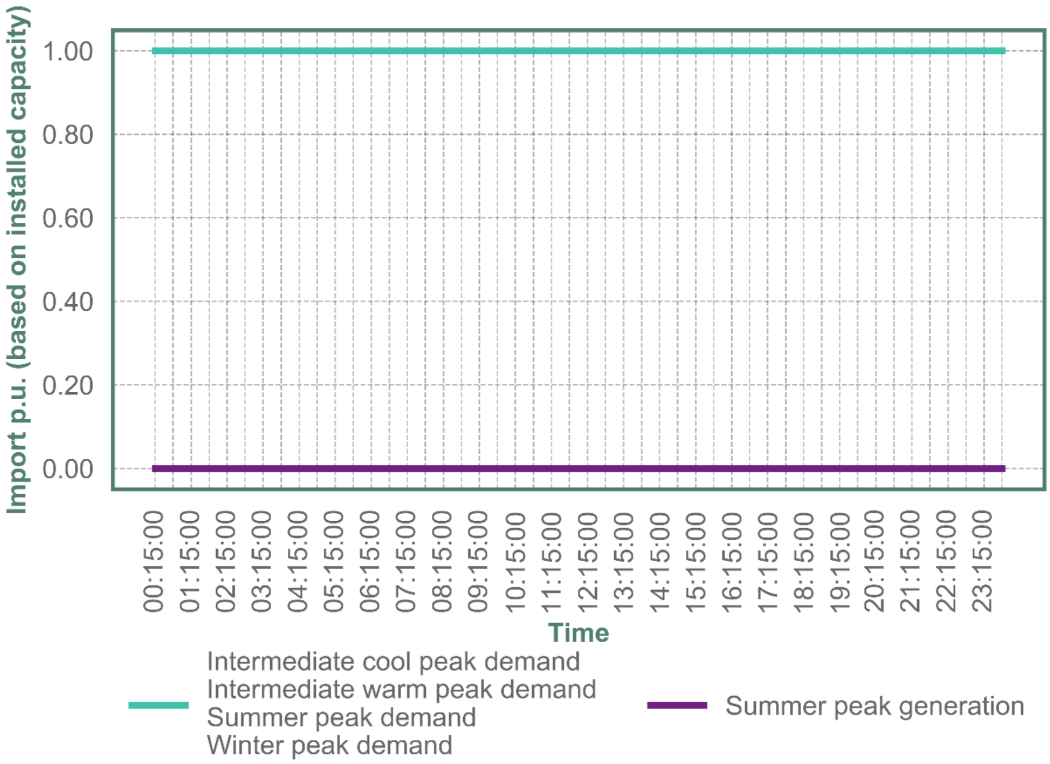

Figure 61: Representative hydrogen electrolysis profiles

How will these profiles change over time

These profiles do not change for any year and scenario.

Energy Assumptions

As described in the Methodology section, the hydrogen electrolysis demand is assumed as one for all existing representative days. However, the overall energy is modelled as increasing from 51% in 2025 to 63% in 2050 as the load factor; in line with the BEIS figures and represents the efficiency in generation and electrolysis processes increasing[41]. The load factor has the potential to vary from 25% up to 95% depending upon the running style of the electrolysers[41]. The selected load factor is constant across the scenarios.

Known Limitations

There is currently limited knowledge about the running of hydrogen electrolysers as they are in the early stages of development. As more hydrogen electrolysers are rolled out we will be able to apply real-world use cases and data to our forecasting.

Future Developments

WPD plan to undertake agile analysis on the operating behaviour of hydrogen electrolysers and continue to develop the forecasts as the industry gains further insight into the operational workings of this new technology. Focussing on existing behaviour at time of network peak and potential for new edge-cases to occur as uptake increases.

[41] BEIS, *Hydrogen Production Costs 2021*, (2021)

Summary of future developments

WPD welcome any feedback on the profiles presented in this document. Any improvements in the analysis used to create these profiles will be incorporated into future editions of the DFES process and strategic investment planning activities within WPD, with an annual review of each technology type planned. Publication of customer behaviour assumptions allows for transparency in the strategic investment planning activities, also to drive further discussion and data sharing between stakeholders to improve the assumptions used. Regional variations in profiles across the UK are expected and any differences in profile behaviour should be justified by the DNO. The list below covers some of the areas of focus for improvements to the DFES customer behaviour analysis in 2021:

- Incorporation of projections for the connection of different types of energy storage, including analysis on the expected usage profiles.
- Consideration of co-location of generation customers with behind the meter sources of demand (such as Hydrogen electrolysers). These will be explored as a potential new source of demand in the DFES 2021 analysis and geospatially allocated to the areas of the network most suited to new connections of this type.
- Further update and application of new national level policies into the customer behaviour assumptions of new domestic and non-domestic connections.
- Developing a greater understanding of the coincidence between demand behaviour of different technologies.
- Investigation into using more granular profiles and energy efficiency assumptions based on existing customer breakdown within a smaller geographic area. This area of focus will utilise smart meter data to inform better assumptions on how customers react to price signals and how coincident price signals are to existing times of increased network loading.
- Creation of a suite of profiles accounting for differing levels of diversity across the network to suit all of the required analysis for strategic investment planning purposes.

Appendix A: Technology comparison to Open Networks building blocks

As part of the Open Networks projects led by the Energy Networks Association, distribution network operators proactively work with National Grid ESO (NGESO) to drive further standardisation between Future Energy Scenarios and Distribution Future Energy Scenarios processes. As part of the work delivered in 2020, common 'building blocks' were agreed between member companies. This allows for easy comparison between NGESO and DNOs of the forecast volumes. A list of the technology types considered in the WPD DFES analysis is included below, with the relevant building block number to which it refers.

Table 22: DFES technology to building block lookup

DFES technology	DFES sub-technology	Equivalent Building block ID number
Air conditioning	-	-
Battery storage	Domestic batteries (G98)	Srg_BB002
Battery storage	Grid services	Srg_BB001
Battery storage	Co-location	Srg_BB001
Battery storage	High energy user	Srg_BB001
Biomass & Energy Crops (including CHP)	-	Gen_BB010
CCGTS (non CHP)	-	Gen_BB009
Electric vehicles	Pure electric motorcycle	Lct_BB001
Electric vehicles	Pure electric car (non autonomous)	Lct_BB001
Electric vehicles	Hybrid car (non autonomous)	Lct_BB002
Electric vehicles	Hybrid motorcycle	Lct_BB002
Electric vehicles	Pure electric bus and coach	Lct_BB003
Electric vehicles	Pure electric LGV	Lct_BB003
Electric vehicles	Pure electric HGV	Lct_BB003
Electric vehicles	Hybrid LGV	Lct_BB004
Electric vehicles	Hybrid bus and coach	Lct_BB004
Electric vehicles	Hybrid HGV	Lct_BB004
Electric vehicles	Pure electric car (autonomous)	-
Electric vehicles	Hybrid car (autonomous)	-
EV charge point	Domestic	-
EV charge point	Workplace	-
EV charge point	En route	-
EV charge point	Destination	-
Floating wind	-	Gen_BB014
Geothermal	-	Gen_BB019
Heat pumps	Electric back-up	Lct_BB005
Heat pumps	Gas back-up	Lct_BB006
Hydrogen electrolysis	-	Dem_BB009

Hydrogen-fuelled generation	-	Gen_BB023
Hydropower	-	Gen_BB018
Marine	Tidal stream	Gen_BB017
Marine	Wave energy	Gen_BB017
Non renewable engines (CHP)	> 1 MW	Gen_BB001
Non renewable engines (CHP)	< 1 MW	Gen_BB002
Non renewable engines (CHP)	(G98/G83)	Gen_BB003
Non-renewable Engines (non CHP)	Diesel	Gen_BB005
Non-renewable Engines (non CHP)	Gas	Gen_BB006
OCGTS (non CHP)	-	Gen_BB008
Offshore wind	-	Gen_BB014
Onshore wind	Large scale (>1MW)	Gen_BB015
Onshore wind	Small scale (<1MW)	Gen_BB016
Other generation	-	-
Renewable engines (landfill gas, Sewage Gas, Biogas)	-	Gen_BB004
Retained connection	-	-
Solar PV	Ground mounted (>1MW)	Gen_BB012
Solar PV	Commercial rooftop (10kw - 1MW)	Gen_BB013
Solar PV	Domestic rooftop (<10kw)	Gen_BB013
Waste Incineration (including CHP)	-	Gen_BB011

Appendix B: Primary substation clustering

Methodology

In order for a computer to imitate the behaviour of a human manually grouping profiles, Machine learning (ML) techniques were used. ML can be defined as a field of study which allows computers to learn without being clearly programmed to do so

Specifically, *unsupervised* ML techniques can be used to produce profile groups for further human analysis. The term “unsupervised” refers to the ML algorithm working with unlabelled data. In this context of this project, a “label” would be a descriptor for a group of profiles with similar behaviours.

This section aims to give a high-level overview of the ML techniques used to produce the profile clusters; the reader should consult other reference material for an in-depth explanation of how the ML techniques work.

The starting point for devising the ML clustering methodology was to consider how a human would group similar demand profiles. An intuitive way of doing this would be to plot the demand profiles, and match those with similar profile shapes. For example, one group may consist of profiles with morning and evening peaks, and another group may consist of profiles with a midday peak. When creating these groups, a human would also consider the “context” of a profile peak. Peaks do not occur at the same time, but fall within a range. For example, the evening peak could fall between 5 pm to 7 pm.

The ML clustering is divided in to two stages:

1. Calculating a metric to determine the similarity between profiles
2. Using the profile similarity metrics to divide the profiles in to clusters

For determining the similarity of profile shapes, dynamic time warping (DTW) was used. Given a temporal sequence, DTW calculates an optimum matching between the two sequences. Figure 62 provides an example of where DTW has mapped the minimum and maximum points of two sinusoidal signals.

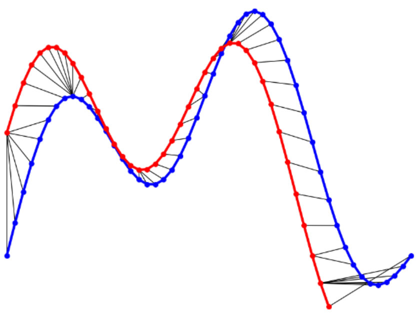

Figure 62: Dynamic time warping for two signals

This is analogous to a human matching up profiles by examining the similarity of their shapes. To prevent DTW from excessively warping the profiles in attempt to match the profile shapes (e.g. attempting to match evening peaks with midday peaks), a constraint was set so that the algorithm could only match points within a 90-minute range.

The DTW algorithm was applied to all pairs of profiles. In turn, this produced a matrix containing a measure of similarity between the profiles. This matrix was used as the input for second stage of ML clustering. To partition the profiles in to groups using the similarity matrix, the k-means algorithm was used. This algorithm produces *k* clusters by minimising the *within-*

cluster-sum-of-squares criterion. In other words, the algorithm aims to produce *k* clusters where the variance between samples inside each cluster is minimised.

The optimum value of *k* was chosen by sweeping across a range of *k* for each season used in the representative days and recording the sum of squared distance of samples to the closest cluster centre. Figure 63 is an example of a plot produced after sweeping through a range of *k*. The optimum value of *k* is selected by picking the "elbow" of the plot (i.e. the point at which the curve bends from a high slope to a low slope). In the case of Figure 63, the elbow value would be identified at $k = 5$.

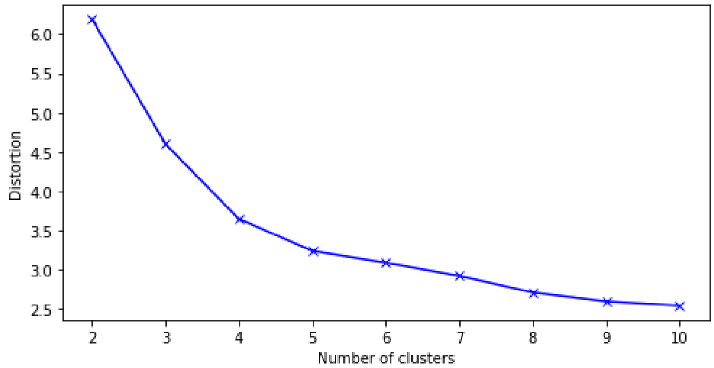

Figure 63: Elbow method

Table 23: Example of substation cluster similarities

Substation Name	Cluster Assignment			
	Winter	Intermediate Cool	Summer	Intermediate Warm
A	1	4	0	1
B	2	3	0	2
C	1	4	0	1
D	0	3	1	2

Table 23 provides an example of this analysis. As substations "A" and "C" have identical cluster assignments, they have the same profile behaviour over the course of the year. This can be used as an input for mapping behaviour to categorisation metrics (e.g. housing density, proportion of domestic/commercial customers etc.). The k-means algorithm was repeated for each seasonal rating, using the optimum value of *k* identified. This clustering provides a starting point for further analysis. Given that each substation has been assigned a cluster for each seasonal rating, substations with identical cluster assignments can be viewed as having similar behaviour. Figure 64 is an example of the clusters that are produced using ML clustering.

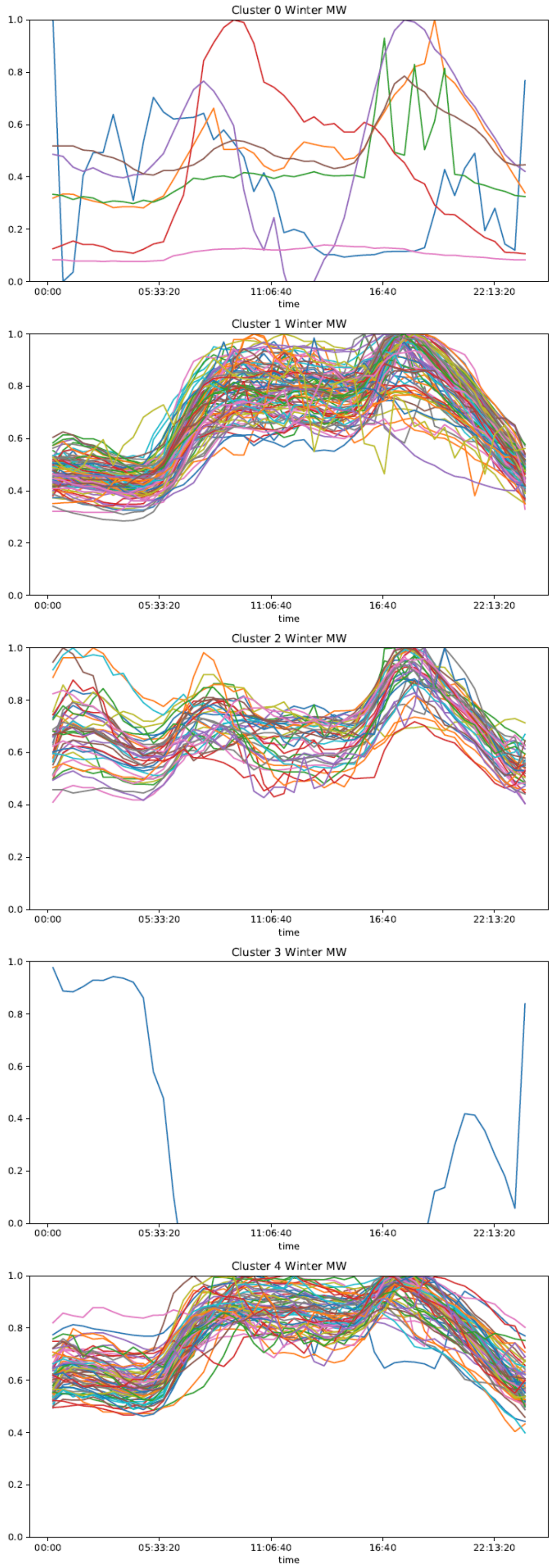

Figure 64: Example of ML clustering output

Glossary

Acronym	Term	Definition
–	Access Window	The period of spring, summer and autumn in which arranged outages are normally taken.
ANM	Active Network Management	The ENA Active Network Management Good Practice Guide summarises ANM as: *Using flexible network customers autonomously and in real-time to increase the utilisation of network assets without breaching operational limits, thereby reducing the need for reinforcement, speeding up connections and reducing costs.*
ASHP	Air Source Heat Pump	Type of Heat Pump that absorbs heat from outside air for the purposes of space heating and hot water.
BEV	Battery Electric Vehicle	Electric vehicle with a battery as the only means of propulsion
BSP	Bulk Supply Point	A substation comprising one or more Grid Transformers and associated switchgear
–	Demand	The consumption of electrical energy.
DSR	Demand Side Response	Ofgem led tariffs and schemes which incentivise customers to change their electricity usage habits
DfT	Department for Transport	The governmental department responsible for the transport network in England and part of Scotland, Wales and Northern Ireland which are not devolved.
DFES	Distribution Future Energy Scenarios	An annual process undertaken by Distribution Network Operations to forecast future growth on the distribution network
DG	Distributed Generation	Generation connected to a distribution network. Sometimes known as Embedded Generation.
DNO	Distribution Network Operator	A company licenced by Ofgem to distribute electricity in the United Kingdom who has a defined Distribution Services Area.
DSOF	Distribution System Operability Framework	A document published by Western Power Distribution that assesses the technical issues facing Distribution Network Operators as they transition to Distribution System Operator (DSO).
DTW	Dynamic Time Warping	An algorithm to measure similarity between two time series
EV	Electric Vehicle	General term for a vehicle which uses electric motors as its method of propulsion.
ESA	Electricity Supply Area	Each ESA represents a block of demand and generation as visible from the distribution network. For the 2020 DFES studies, each ESA represents the geographic area supplied by a Primary Substation (which contains WPD-owned distribution substations) providing supplies at a voltage below 33 kV, or a customer directly supplied at 132, 66 or 33 kV or by a dedicated Primary Substation.
ENA	Energy Networks Association	The Energy Networks Association is an industry association funded by gas or distribution or transmission licence holders.
EPC	Energy Performance Certificate	Rating scheme to summarise the energy efficiency of buildings.
ER	Engineering Recommendation	A document published by the Energy Networks Association.
EAC	Estimated Annual Consumption	An estimated rate of consumption, nominally expressed in kWh/year that is used in electricity settlement.

FCO	First Circuit Outage	P2/7 defines a First Circuit Outage as: *…a fault or an arranged Circuit outage…* Also referred to as N-1 in some contexts.
FES	Future Energy Scenarios	A set of scenarios developed by Nation Grid to represent credible future paths for the energy development of the United Kingdom.
GB	Great Britain	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
GBSO	Great Britain System Operator	National Grid is the system operator for the National Electricity Transmission System (NETS) in Great Britain. Responsible for coordinating power station output, system security and managing system frequency.
GSP	Grid Supply Point	A substation comprising one or more Super Grid Transformers and associated switchgear
GSHP	Ground Source Heat Pump	Type of Heat Pump that absorbs heat from the ground for the purposes of space heating and hot water.
HP	Heat Pump	General term for a heating system that extracts heat from surroundings which can then be used to produce hot water or space heating.
HGV	Heavy Goods Vehicle	A large goods vehicle with a gross mass greater than 3500 kg
LGV	Light Goods Vehicle	Commercial vehicle with a gross mass of less than or equal to 3500 kg
LTDS	Long Term Development Statement	A document published by all DNO's to assist current and future users of the distribution network to identify and assess opportunities available to them for making new or addition use of the network.
ML	Machine Learning	A field of study which allows computers to learn without being clearly programmed to do so
MPAN	Meter Point Administration Number	Unique reference number used in Great Britain to identify electricity supply points, such as individual domestic residences
NGESO	National Grid Electricity System Operator	National Grid Electricity System Operator is the electricity system operator for Great Britain.
NDP	Network Development Plan	Requirement as part of Electricity Distribution Licence Condition 25B for Distribution Network Operators to cover the investments planned for the next 5 to 10 year period in relation to the 11 kV network and above.
NIA	Network Innovation Allowance	Funding scheme for innovation projects introduced as part of RIIO-ED1. For the RIIO-ED1 period, WPD requested the minimum 0.5% of total regulated income.
Ofgem	Office for Gas and Electricity Markets	Ofgem is responsible for regulating the gas and electricity markets in the United Kingdom to ensure customers' needs are protected and promotes market competition.
–	Open Networks	The Open Networks Project is a major energy industry initiative that will transform the way our energy networks work, underpinning the delivery of the smart grid. This project brings together 9 of UK and Ireland's electricity grid operators, respected academics, NGOs, Government departments and the energy regulator Ofgem. Note: Open Networks was previously known as the ENA TSO-DSO Project.
PV	Photovoltaic	Type of distributed generation which uses solar irradiance to generate electricity.
PHEV	Plug-in Hybrid Electric Vehicle	Electric vehicle with a battery and a supplementary engine, which is able to run on both modes of propulsion.

–	Primary Distribution	The sections of an electrical distribution network which provide the interface between transmission and Primary or Secondary Distribution. In WPD's network the 33kV circuits and Primary Substations are considered to be Primary Distribution.
–	Primary Substation	A substation comprising one or more Primary transformers and associated switchgear
–	Primary Transformer	A transformer that steps voltage down from 66 or 33kV to 11kV or 6.6kV
RDP	Regional Development Plan	A study which looks at the complex interaction between the distribution and transmission network, also between different distribution networks.
TDCV	Total Domestic Consumption Values	Industry standard values for the annual gas and electricity usage of a typical domestic customer
V2G	Vehicle to Grid	Where a plug-in EV can export to the power grid.
VOA	Valuation Office Agency	UK government body responsible for the valuation of properties for the purpose of council tax and for non-domestic rates in England and Wales
WPD	Western Power Distribution	A Distribution Network Operator (DNO) company that is licenced by Ofgem to distributed electricity in the East Midlands, West Midlands, South West, and South Wales regions of United Kingdom.

Table of Units

Term	Definition
kV	Kilovolt, a unit of Voltage (x103)
LV	This refers to voltages up to, but not including, 1kV
HV	Voltages over 1kV up to, but not including, 22kV
EHV	Voltages over 20kV up to, but not including, 132kV
kW	Kilowatt, a unit of Power (x103)
MW	Megawatt, a unit of Active Power (x106)
MVA	Mega volt-ampere, a unit of Apparent Power (x106)
MVAr	Mega volt-ampere (reactive), a unit of Reactive Power (x106)
kWh	Kilowatt hour, a unit of energy (x103). Equivalent to a constant 1kW of Active Power delivered for an hour

Disclaimer

Neither WPD, nor any person acting on its behalf, makes any warranty, express or implied, with respect to the use of any information, method or process disclosed in this document or that such use may not infringe the rights of any third party or assumes any liabilities with respect to the use of, or for damage resulting in any way from the use of, any information, apparatus, method or process disclosed in the document.

Western Power Distribution (East Midlands) plc, No2366923
Western Power Distribution (West Midlands) plc, No3600574
Western Power Distribution (South West) plc, No2366894

Western Power Distribution (South Wales) plc, No2366985

Registered in England and Wales
Registered Office: Avonbank, Feeder Road, Bristol BS2 0TB

wpdnetworkstrategy@westernpower.co.uk

www.westernpower.co.uk **@wpduk**