2024 Distribution Future Energy Scenarios (DFES)

2024 Outlook for UK Power Networks' licence areas

PREPARED FOR AND WITH

UK Power Networks: Distribution System Operator (UKPN DSO)

DATE
January 2024

REFERENCE
0631965

Document details

The details entered below are automatically shown on the cover and the main page footer. PLEASE NOTE: This table must NOT be removed from this document.	
DOCUMENT TITLE	2024 Distribution Future Energy Scenarios (DFES)
DOCUMENT SUBTITLE	Outlook for UK Power Networks' licence areas
PROJECT NUMBER	0631965
Date	January 2024
Version	02
Author	Sarah Golobish, Alex Speakman, Arna Sigurdardottir
Client name	UK Power Networks: Distribution System Operator (UKPN DSO)

Document history

				ERM APPROVAL TO ISSUE		
VERSION	REVISION	AUTHOR	REVIEWED BY	NAME	DATE	COMMENTS
Version 01	000	Alex Speakman	Arna Sigurdardottir	Ian Walker	08/12/2023	
Version 02	001	Alex Speakman	Arna Sigurdardottir	Ian Walker	08/01/2024	
	002		Minor UKPN edits		17/01/2024	

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acronyms and Abbreviations

Acronyms	Description
AC	Air conditioning
ASHP	Air Source Heat Pump
BCG	Black Cab Green project
BECCS	Bioenergy with carbon capture and storage
BEIS	Department for Business, Energy and Industrial Strategy (now DESNZ)
BEV	Battery electric vehicles
BUS	Boiler Upgrade Scheme
CAES	Compressed Air Energy Storage
CCC	Climate Change Committee
CCGT	Combined cycle gas turbine
CHP	Combined Heat and Power
CT	Consumer Transformation
DESNZ	Department for Energy Security and Net Zero (formerly BEIS)
DFES	Distribution Future Energy Scenarios
DfT	Department for Transport
DGDB	Distributed Generation Database
DH	District Heating
DNO	Distribution Network Operator
DVLA	Driver and Vehicle Licensing Agency
ECCo	Element Energy Car Consumer model
ECR	Embedded Capacity Register
ENA	Energy Networks Association
EPN	Eastern Power Networks

ESO	(National Grid) Electricity System Operator
ERM	Environmental Resources Management Ltd
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
FES	(National Grid ESO's) Future Energy Scenarios
FiT	Feed in Tariff
FS	Falling Short
FSO	Future System Operator
GB	Great Britain
GDP	Gross domestic product
GLA	Greater London Authority
GSHP	Ground source heat pump
GVA	Gross value added
HDV	Heavy-duty vehicle
HEV	Hybrid electric vehicle (non-plug-in)
HGV	Heavy goods vehicle
HP	Heat pump
I&C	Industrial and commercial
ICE	Internal combustion engine (vehicle)
LA	Local Authority
LAES	Liquid Air Energy Storage
LCT	Low carbon technology
LDES	Long Duration Energy Storage
LPN	London Power Networks

LSOA	Lower Layer Super Output Areas
LTDS	Long Term Development Statement
LtW	Leading the Way
MSOA	Middle Layer Super Output Areas
MTS	Mayors Transport Strategy
NDP	Network Development Plan
NGESO	National Grid Electricity System Operator
OCGT	Open Cycle Gas Turbine
OEM	Original Equipment Manufacturer
ONS	Office for National Statistics
PHES	Pumped Hydro Energy Storage
PHEV	Plug-in hybrid electric vehicles
PHV	Private hire vehicle
PV	Photovoltaic
RIIO-ED2	Revenue, Incentives, Innovation, Outputs - Electricity Distribution price control
SFS	Strategic Forecasting System (UK Power Networks system)
SPN	Southeastern Power Networks
ST	System Transformation
TfL	Transport for London
ToUT	Time-of-Use Tariff
UKPN	UK Power Networks
ULEZ	Ultra Low Emissions Zone
V2G	Vehicle to Grid
ZEV	Zero Emission Vehicle

EXECUTIVE SUMMARY

As a result of the drive to Net Zero, the energy system in the UK is undergoing large and rapid changes over the coming years as it becomes increasingly decarbonised, digitised, and decentralised. Such changes are expected across the entire energy landscape and will have a large impact on electricity distribution networks, which will be required to adapt to changes in demand resulting from electrification of heat and transport, uptake of renewable generation, and changes to consumer engagement. These changes have already begun; nearly 400,000 electric vehicles, 43,000 heat pumps and 9.7 GW of distributed generation and storage of various types and scales were using the UK Power Networks distribution network by the end of March 2023.

In addition to these wider developments, electricity distribution networks will also be impacted by near-term changes to energy markets, economic shocks, and government policy. Policy is one of the most powerful tools for shaping the energy system; setting clear long-term targets for the sector is key for building investor confidence and locking-in change in the near term. The COVID-19 pandemic and the invasion of Ukraine have led to considerable energy price volatility in recent years, the effects of which have precipitated a cost-of-living crisis and widespread disruption to the economy. This in turn has impacted the progression of the low carbon transition such as constraining supply chains, reducing technology uptake, and changing consumer behaviour patterns.

UK Power Networks' business plan for the RIIO-ED2 period (April 2023 - March 2028)[1] outlined the expenditure needed to accommodate the demand and generation projected to materialise across the UK Power Networks' licence areas during the RIIO-ED2 period under different possible futures. Those possible futures were underpinned by a previous version of the Distribution Future Energy Scenarios (DFES)[2], and while these scenarios are bespoke to the UK Power Networks' region, they are also consistent with the over-arching narratives of the four scenario worlds developed by National Grid ESO in their Future Energy Scenarios publications. While the DFES is updated annually to reflect new developments, such as updates to the connections baseline, changes in policy and technological advancements, these core scenario worlds remain consistent with the view presented in the RIIO-ED2 business plan.

This update of the DFES continues to reflect those four different scenario worlds, built bottom up by combining bespoke uptake forecasts for individual drivers of demand and generation within UK Power Networks' region. This DFES will be used to build the 2024 planning scenarios for required capacity on the distribution networks in the years ahead.

The scenarios produced in this work will enable UK Power Networks to continue to effectively plan for the future across RIIO-ED2 and beyond, thereby ensuring UK Power Networks delivers a reliable network for customers in the most cost-effective manner, whilst supporting the UK's decarbonisation ambitions.

Updates for DFES 2024

Since the publication of the 2023 DFES, the uptake scenarios for low emission cars and vans have been revised to reflect the latest price changes in battery packs, fuel, and electricity that

[1] UK Power Networks, ED2 Business Plan, December 2022

[2] Element Energy for UK Power Networks, DFES 2021, January 2021.

have changed due to raw material shortages, market shocks resulting from the invasion of Ukraine, and the latent effects of the COVID-19 pandemic. This year also includes the impacts of supply chain constraints, changes to vehicle performance characteristics, and a sensitivity scenario representing the impacts of recent delays to transport-related net-zero targets. As a result of these effects, despite an increase of more than 100,000 EVs or 37.5% on the number of EVs over the last year, the current trajectory for electric cars, vans, and motorcycles is following Falling Short (Figure 1). However, heavy duty vehicles have continued to see high levels of uptake and therefore follow the Leading the Way trajectory (Figure 2).

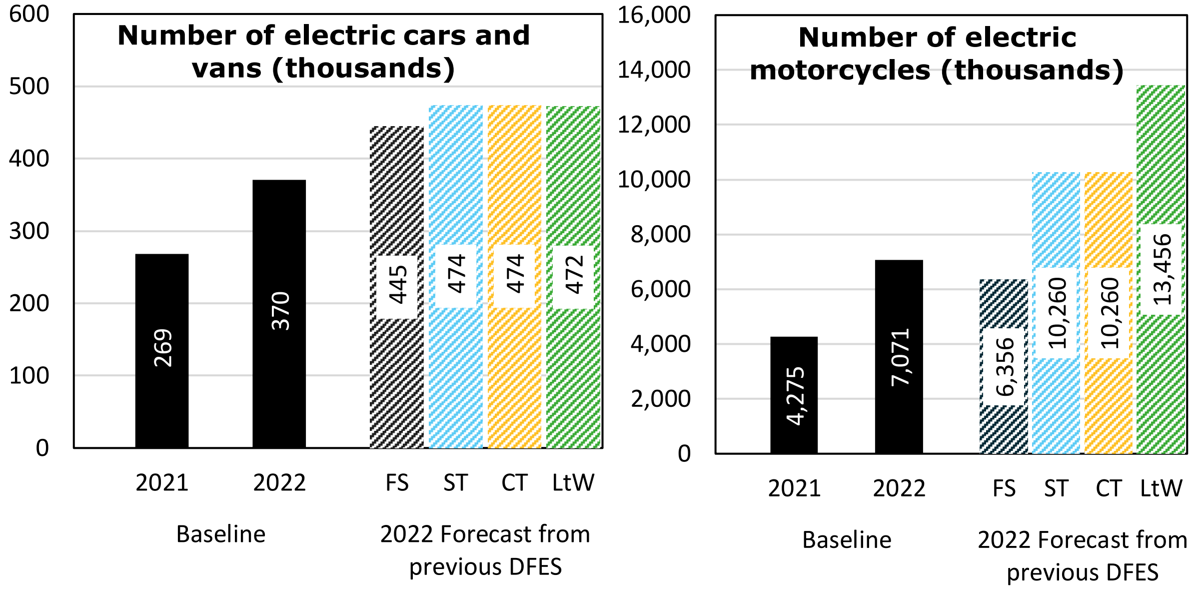


Figure 1: Growth in baseline from last year's DFES (2021 baseline) to this DFES (2022 baseline) for electric cars and vans (left) and electric motorcycles (right) compared to 2022 forecast from last year's DFES

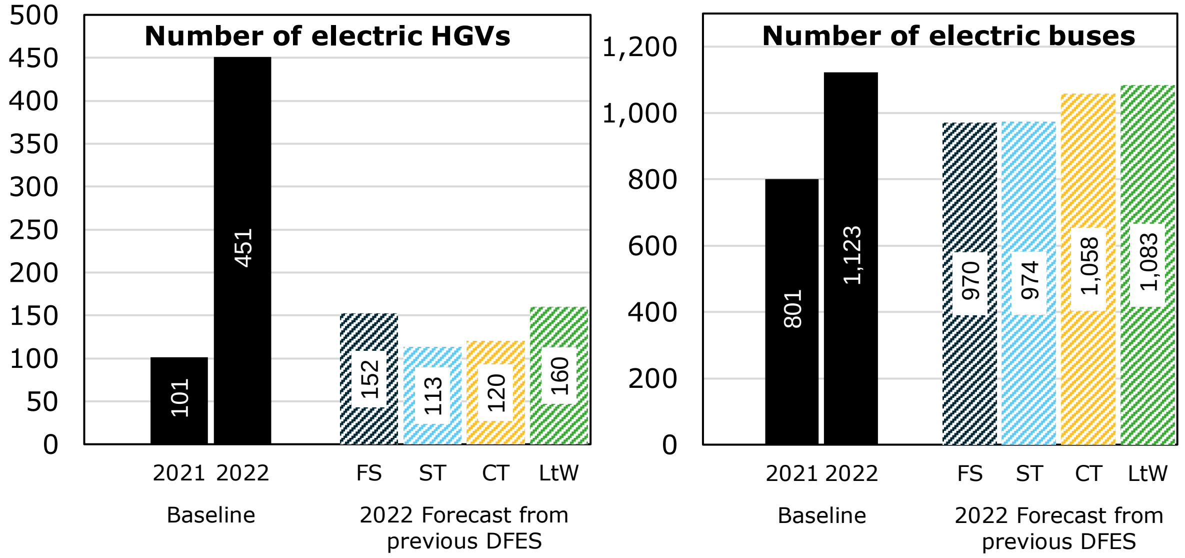


Figure 2: Growth in baseline from last year's DFES (2021 baseline) to this DFES (2022 baseline) for electric HGVs (left) and buses (right) compared to 2022 forecast from last year's DFES

The projections for distributed generation continue to be consistent with stated Government ambition to phase out fossil-fuel generation by 2035. This update includes greater visibility of connected and pipeline generation resulting from a review and extension of the Embedded Capacity Register[3] for all generation types, and the use of the Low Carbon Technology register[4] to establish the baseline uptake of rooftop solar PV. Rooftop PV uptake is currently aligned with the most ambitious Leading the Way and Consumer Transformation trajectories (Figure 3). Large-scale PV is currently aligned with the Falling Short trajectory, with deployment constrained by the limitations of the transmission network; new "technical limits" agreements with National Grid ESO mean more generation and storage projects will be able to proceed to connection in future. Overal this year's forecast is higher than last year's due to a high capacity of accepted connections in the pipeline.

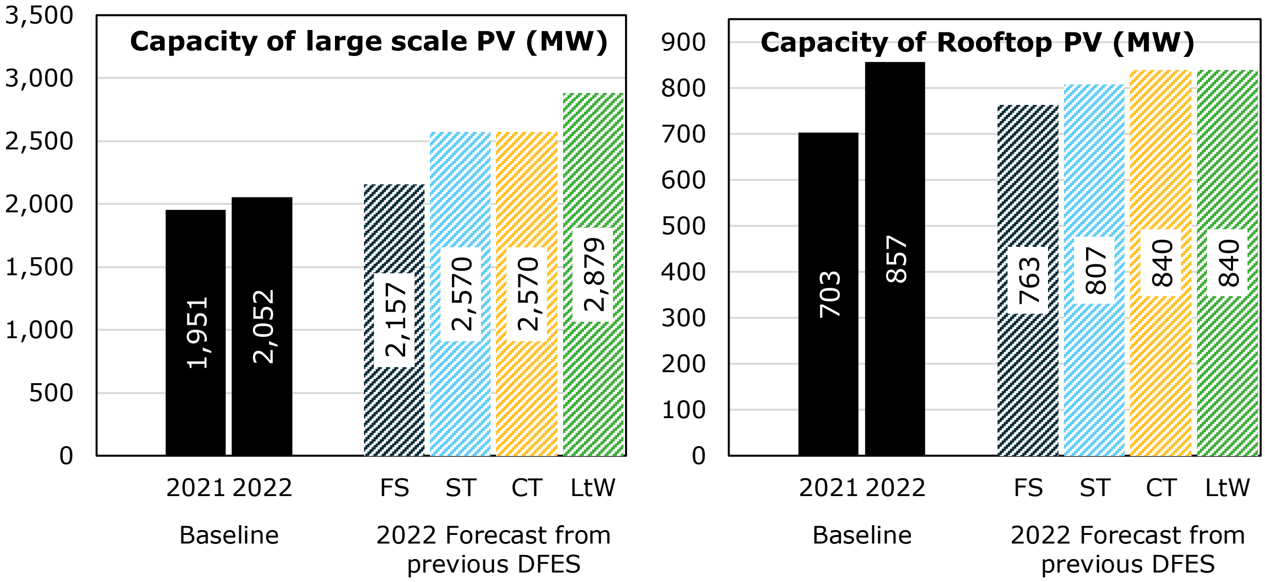


Figure 3: Growth in baseline from last year's DFES (2021 baseline) to this DFES (2022 baseline) for capacity of large (left) and rooftop (right) PV compared to 2022 forecast from last year's DFES

Domestic and I&C storage have been updated with information from the Low Carbon Technology Register, whilst co-located storage and grid-scale storage have benefited from a new pipeline methodology and data, based on an analysis carried out by Regen. Domestic storage has seen a rapid uptake in recent years, whilst I&C storage penetration was found to be considerably lower than previously estimated. With smart meter uptake in line with the Falling Short trajectory (Figure 4), tariff-based flexibility is expected to have slow uptake.

[3] Connected and accepted generation data in the 50kW-1MW and >=1MW categories, with processed internal versions used for this DFES update. Embedded Capacity Register
[4] The Low Carbon Technology Register is a dataset collated by UK Power Networks providing information on the level of uptake of low carbon technologies to a high geospatial resolution. This is available at secondary level from: Low Carbon Technologies (LCT) connected to the UKPN network

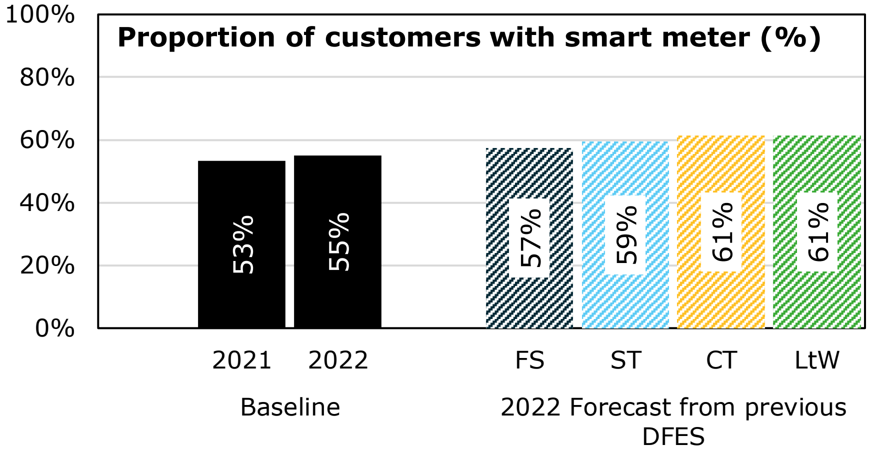


Figure 4: Growth in baseline from last year's DFES (2021 baseline) to this DFES (2022 baseline) for the proportion of customers with a smart meter compared to 2022 forecast from last year's DFES

Regen undertook a high-level assessment of the potential to develop longer-duration storage technologies (four hours or more) in UK Power Networks' distribution network licence areas. Based on FES 2023 models, the GB long-duration energy storage (LDES) capacity is expected to be between c.4 GW and c.16.5 GW, depending on the scenario by 2050. Most of this capacity is proposed to be connected to the transmission system. However, the UK government grant funding via the Longer Duration Energy Storage Demonstration (LODES) competition have encouraged developers to invest in LDES to connect on to the distribution network, though not yet in UK Power Networks licence areas. LDES will kept under review for future DFES.

Furthermore, following recent policy announcements relating to heat decarbonisation, the timeline extension and grant increase of the Boiler Upgrade Scheme are included, as well as updates to represent public awareness of low carbon heating technologies. The current level of heat pump uptake is aligned with the Falling Short trajectory in the domestic sector, and the System Transformation trajectory in the industrial and commercial sector (Figure 5). Similar to the transport sector, a sensitivity analysis examining the impacts of recent policy changes to the phase-out dates of fossil fuel heating systems is included.

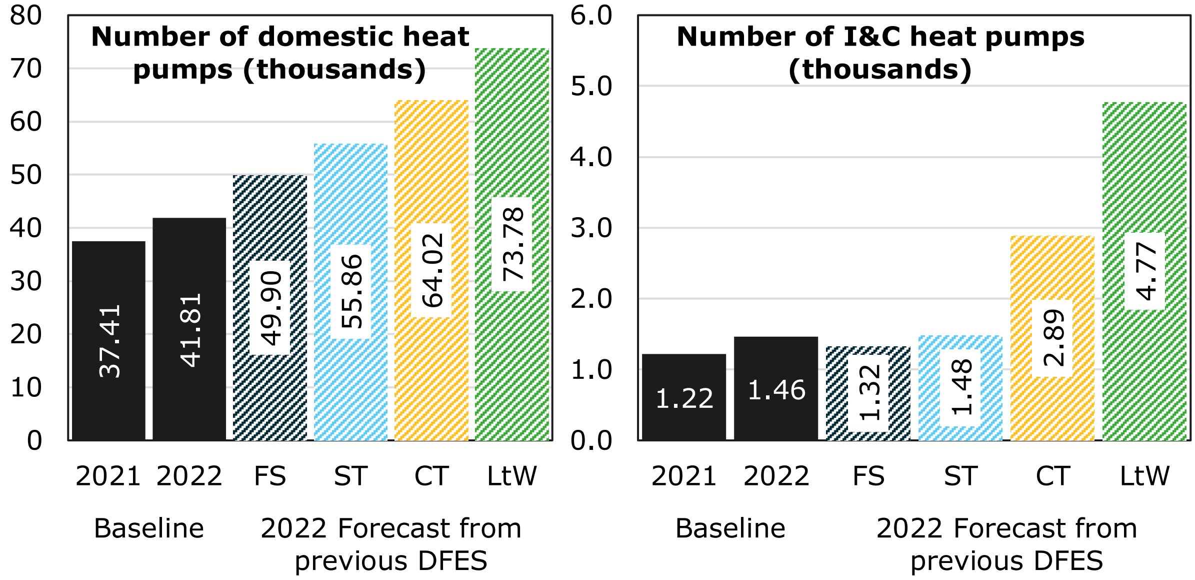


Figure 5: Growth in baseline from last year's DFES (2021 baseline) to this DFES (2022 baseline) for domestic (left) and I&C (right) heat pumps compared to 2022 forecast from last year's DFES

Wider context

UK Power Networks is engaging and collaborating with local authorities to gain a shared understanding of their latest decarbonisation activities. This will enhance future forecasts and ensure UK Power Networks continues to provide a fit for purpose electricity network that facilitates local decarbonisation. UK Power Networks has developed a new energy planning tool that allows users to develop granular data driven Net Zero strategies, compare Net Zero forecasts with the DFES, and gain access to Local Area Energy Planning Open Data. UK Power Networks is exploring new processes designed in partnership with local authorities to make the approach of sharing plans easier and more efficient, so that these can inform plans for the network.

1 INTRODUCTION

1.1 GEOGRAPHIC SCOPE OF THE DFES FOR UK POWER NETWORKS

UK Power Networks serves 8.5 million customers; in doing so they provide the electricity network supplying electricity to the homes and workplaces of 19 million people in the East of England, London, and the Southeast. The UK Power Networks area is broken into three major regions, called licence areas:

- Eastern Power Networks (EPN),
- London Power Networks (LPN), and
- South Eastern Power Networks (SPN).

While these three licence areas are broadly similar in location to the Government Office Regions of East of England, London and the Southeast of England, their boundaries differ considerably from those Government Office Regions. Many of the scenario datasets are published at much higher geospatial resolution to allow stakeholders to consider only those areas of particular interest to them.

To breakdown the scenarios into these smaller geographical regions the following Office for National Statistics (ONS) areas were used:

- Middle Layer Super Output Areas (MSOAs); and
- Lower Layer Super Output Areas (LSOAs).

UK Power Networks' region is made up of about 2,200 MSOAs which in turn are made up of around 11,000 LSOAs. The average dimensions of MSOAs and LSOAs across England are given in Table 1. Outputs at LSOA and MSOA resolution, wherever possible, are being published on UK Power Networks' website alongside this report, both as downloadable datasets and in an interactive map.

Table 1: Average dimensions of MSOA and LSOA across England[5]

Geography	Minimum population	Maximum population	Minimum number of households	Maximum number of households
LSOA	1,000	3,000	400	1,200
MSOA	5,000	15,000	2,000	6,000

This DFES update uses the latest LSOA boundaries as published in the 2021 Census by the office for National Statistics[5]. Where data inputs are still published by 2011 boundaries, this have been mapped to the 2021 boundaries using the connection counts in each LSOA.

The published DFES datasets also show the *indicative* relationship between each LSOA and the larger network substations (Primary substations) which serve that geographic area, based on the Primary substation serving the most customers in that LSOA. UK Power Network's detailed network modelling links connected customers with the appropriate substations, but there is not

[5] Census 2021 geographies - Office for National Statistics (ons.gov.uk)

a direct one-to-one relationship between LSOA and Primary, since different customers within an area may be normally served by different Primary network substations. Grid Supply Points or GSPs then indicate which National Grid ESO interface substation normally serves the area.

1.2 DFES METHODOLOGY

Scenarios for key drivers of demand and generation were developed within UK Power Networks' three licence areas and brought together to create four scenario worlds that represent different views of the evolution of the energy system out to 2050. The scenario worlds closely align with the narrative presented by National Grid ESO[6] but the scenarios were developed with a bottom-up approach to accurately reflect UK Power Networks' region.

The DFES methodology and the modelling approach are aligned with previous DFES, with carefully updated modelling based on the most recent available data, considering technology advancements and new policy frameworks, both of which have been evolving rapidly over the past few years.

A new pipeline methodology for large scale battery storage installations was applied this year, improving the near-term projections for battery storage uptake. Improvements in electricity generation data in the ECR, bringing the categorisation of different generation types closer in line with NGESO FES Building Blocks, also improved the baseline used for the projections of distributed generation.

Other key developments since the publication of the previous DFES that have been captured this year include the addition of supply chain constraints to EV uptake modelling, the timeline extension and increase in grant amounts for the Boiler Upgrade scheme and a sensitivity analysis to examine the potential impacts of recent delays to net zero policy targets. These rapid developments within the sector highlight the value of continuing to develop the DFES in an iterative manner.

The DFES outputs this year have been stated consistent with the updated LSOA definitions in the 2021 census rather than 2011 census, ensuring the presentation and allocation of technologies is up-to-date for any stakeholders using the DFES. Where data inputs are still published by 2011 boundaries, this have been mapped to the 2021 boundaries using the connection counts in each LSOA.

Explanation of baseline year

Where the DFES refers to years, this is always in reference to *regulatory years*, unless otherwise stated. Regulatory years span April to March and are named after the calendar year in which they begin. For example, regulatory year 2015 would encompass the period April 2015 to March 2016. Since all forecasts in this DFES are made ahead of regulatory year 2024 (April 2024 - March 2025) and will be used to produce the network planning scenarios for 2024, this is the 2024 DFES. However, baseline data for all datasets is taken from the end of March 2023, meaning that the base regulatory year used is 2022.

[6] National Grid ESO, *Future Energy Scenarios*, July 2023

1.3 STRUCTURE OF THE REPORT

This report provides an overview of the process of generating UK Power Networks' Distribution Future Energy Scenarios (DFES). First, the report outlines the scenario framework and explain how individual scenarios are brought together to create four different possible future scenario worlds. Next, it details how future scenarios were developed for each of the drivers of demand and generation considered in the DFES, highlighting any key changes and improvements relative to the previous DFES. These drivers include, for example, the number of electric vehicles, uptake of energy efficiency measures and number of solar PV installations. Finally, the report presents the key conclusions drawn from this work. The report is structured as follows:

Section 2 outlines scenario narratives for four different future worlds and details how the different future scenarios for each of the key drivers are combined to produce these "scenario worlds".

Section 3 describes how the different individual uptake scenarios were developed for the key drivers of demand and generation, including the modelling methodology and the geospatial disaggregation across UK Power Networks' region.

Section 4 outlines how UK Power Networks intend to use these scenarios within their business going forward. UKPN's new future DFES approach is explained where DFES 2025 will be evidence-based through proactive engagement with local authorities to understand their net zero plans to inform the DFES. Section 4 also includes the overall conclusions of the 2024 DFES.

This report was written by the ERM's Energy Networks Team on behalf of UK Power Networks' Distribution System Operator, with contributions from Regen, and UK Power Networks' DSO team. Regen carried out the storage pipeline analysis which is new for this year's DFES (see **Sections 3.5.3** and **3.5.4**), while **Sections 1.1**, **2.2**, **4.1**, **4.2**, and **3.1.4** were written by UK Power Networks. The Energy Networks Team was formerly part of Element Energy (see previous DFES reports), which was acquired by ERM in 2021.

2 SCENARIO FRAMEWORK

The detailed modelling work adopted the scenario framework published by National Grid ESO in their latest Future Energy Scenarios[7] as well as that used by the other UK Distribution Network Operators (DNOs) in their DFES. This framework includes four potential energy pathways to 2050, three of which reach Net Zero emissions by 2050 at the latest. These pathways represent different positions on two main axes, speed of decarbonisation and level of societal change (Figure 6). There are minimal updates to this framework since last year and the narratives for each scenario world remain largely unchanged.

Bespoke scenarios were developed for each driver of demand and generation and constructed four overarching scenario worlds that align with the narratives of the pathways from National Grid ESO (see **Section 2.1**). By developing UK Power Networks' own uptake scenarios with local knowledge, the report can more accurately reflect UK Power Networks' region, the customers within this region and the current deployment of low-carbon technologies. The four scenario worlds are structured as follows:

1. **Falling Short:** General progress is made towards decarbonisation; however, this is the only scenario world that does not meet Net Zero by 2050.
2. **System Transformation:** The 2050 Net Zero target is met by relying on hydrogen to decarbonise the more difficult sectors of heat and heavy transport.
3. **Consumer Transformation:** The 2050 Net Zero target is met by a high degree of societal change as well as deep electrification of transport and heat.
4. **Leading the Way:** This is the fastest of the scenario worlds to achieve Net Zero, with the highest level of societal change, utilising both hydrogen and electric low-carbon technologies.

[7] National Grid ESO, *Future Energy Scenarios*, July 2023

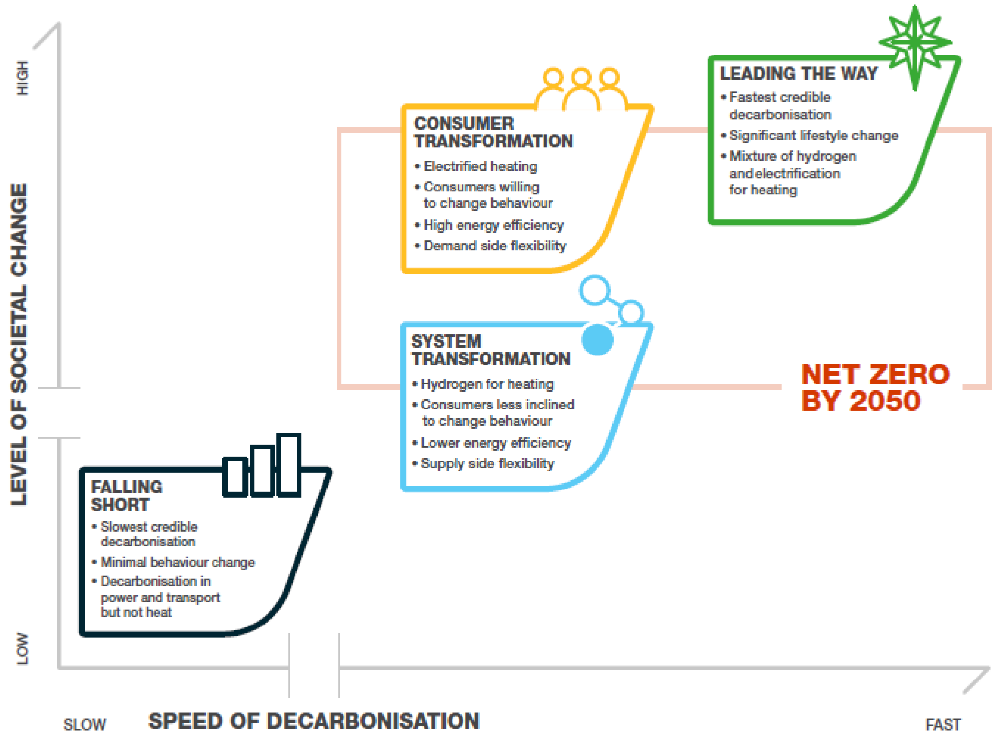


Figure 6: Scenario world framework overview (source: National Grid ESO)

2.1 SCENARIO WORLD OVERVIEW

FS **Falling Short**

The Falling Short world sees the least amount of societal change and has the slowest speed of decarbonisation. Significant progress is made towards Net Zero, but ultimately the target is not reached by 2050.

There is considerable uptake of EVs and by 2050 it is the most popular choice of passenger vehicle; however, a lack of widespread access to public charging infrastructure means that some consumers continue to rely on internal combustion engine (ICE) vehicles instead. A lack of viable options for Heavy Duty Vehicles (HDV) means that decarbonisation of large road vehicles is much slower.

Natural gas continues to be the primary heating fuel and the uptake of heat pumps is limited despite the phase out of oil and other fossil fuel boilers in off-gas properties.

There is a slight increase in the renewable generation capacity of the UK, with increases primarily seen in both small- and large-scale solar photovoltaic installations. There is limited appetite from the public to participate in the energy market via smart mechanisms such as demand side response and time-of-use tariffs. Falling Short sees a lower uptake of small scale distributed storage and consumer flexibility (incl. V2G) and, therefore, this scenario sees the highest uptake of standalone grid storage to balance intermittent renewable generation.

ST

System Transformation

In a System Transformation world, the UK reaches its Net Zero target in 2050 by relying on hydrogen to decarbonise the more difficult sectors of heat and heavy transport.

As battery prices continue to fall, EVs reach price parity with internal combustion engine (ICE) vehicles sooner than previously expected and high demand for EVs is seen from the early 2020s. Global production of hydrogen fuel cells ramps up, which enables large-scale supply of zero emission HDVs, including buses, coaches and heavy goods vehicles, to be available from mid-2030s.

The Government has chosen to decarbonise heat in existing buildings by repurposing the natural gas grid to distribute low-carbon hydrogen and installing electric heat pumps in new builds.

As heat and heavy transport is transitioned to hydrogen, there is less demand on the electricity network from these sources, however this is offset by lower energy efficiency. As a result, the installed capacity of distributed generation, including solar PV and other renewable generation, does not increase to the same extent as in other scenarios. There is also a moderate level of grid flexibility brought by demand side response and electric vehicle smart charging, as well as battery storage installations.

CT Consumer Transformation

The Consumer Transformation world sees the UK reach Net Zero by 2050 thanks to widespread electrification, the decarbonisation of the electricity supply, and consumers willing to modify their behaviour and engage with new, smart technologies. This scenario sees a great deal of societal change, and many of the decarbonisation efforts are aided by increased flexibility in the energy system, such as high uptake of EV smart charging.

This scenario world sees a widespread uptake of EVs, especially cars and vans. The decarbonisation of larger vehicles is slower, but by the mid 2030's there is a wide range of zero emission Heavy Duty Vehicles (HDVs) available, and a nationwide refuelling network completed by 2045. Electrification will be the main decarbonisation option for HDVs, with green hydrogen being deployed for a limited number of use cases.

The Government decides that the electrification of heat is the best way to decarbonise the sector. New build homes cannot install gas boilers from 2025 onwards, and gas boilers are banned outright by 2035. There is a nationwide programme of energy efficiency improvements to all buildings, reducing the amount of electricity needed to heat people's homes. Various subsidies designed to make heat pumps more affordable are put in place and are kept in operation until the late 2020's.

With both heat and transport becoming electrified, there is a requirement for much more electricity in the grid. This increase in demand is met predominantly through solar and wind installations, which become ever more affordable as their industries grow. As the amount of renewable generation grows, so does the amount of both grid scale and domestic battery storage.

Sensitivity Analysis

For Consumer Transformation, an additional sensitivity analysis has been performed to account for recent changes in the policy position around how to achieve national net zero targets. In the transport sector, the ban on ICE vehicle sales has been pushed back by five years to 2035. Additionally, fossil fuel heating systems will now only be banned from 2035 in both new and existing off-gas homes.

LW **Leading the Way**

In Leading the Way, the Net Zero target is reached before 2050 with the highest level of societal change involved. By utilising state-of-the-art low-carbon technologies, both hydrogen and electric options, this is the fastest of the scenario worlds to achieve Net Zero.

A rapid uptake of electric vehicles is seen in this scenario and all ICE and plug-in hybrid electric vehicles (PHEV) sales are banned from 2030 and 2035 respectively. At the same time consumers are more willing to take public transport and opt for active transport such as cycling and walking, resulting in a lower growth of car and van stock relative to other scenarios. For HDVs, both batteries and hydrogen fuel cells are developed at scale, and diesel ICE vehicles are completely phased out by the 2040s.

The decarbonisation of heat is achieved through a hybrid approach, deploying both high numbers of heat pumps as well as a gas grid converted to distributing low-carbon hydrogen. This provides a platform for hybrid heat pumps, combining electric heat pumps with hydrogen boilers.

The electricity generation capacity required to support the many EVs and heat pumps deployed in this scenario is high and will be met with a more centralised approach than in Consumer Transformation. With large solar PV being more popular, there will be a high uptake of co-located battery storage. Consumers are willing to participate in flexibility programmes, with over 80% of those with EV charging at home taking part in some form of smart charging by 2050.

2.2 SCENARIO FRAMEWORK – DIRECTION OF FUTURE TRAVEL

UK Power Networks' DFES 2024 uses the scenario-world framework from National Grid ESO's FES 2023. There will be changes to the next "FES" for 2024, which will influence the next "DFES" in 2025, and these publications may not have the same names in future.

For 2024, the FES is being overhauled with the creation of a new Centralised Strategic Network Plan (CSNP) Stage 1[8] to be delivered by the Future System Operator (FSO), including a move from possible scenarios to more directed "pathways" to net zero. Ofgem has not yet published its decision on this consultation, but National Grid ESO's early thinking on pathways is a variation on the scenario worlds currently used (a combination of technologies/ drivers at different uptake levels).

In addition to the CSNP Stage 1 changes consulted upon so far, the recommendations of the Winser report[9] also indicate the FSO would be responsible for a Strategic Spatial Energy Plan (SSEP). In the medium-term of late 2025/early 2026, introduction of Regional Energy Strategic

[8] Ofgem, Centralised Strategic Network Plan: Consultation on framework for identifying and assessing transmission investment options, July 2023
[9] Electricity Network Commissioner's principle areas of recommendation, June 2023

Planner (RESP) roles to the FSO as indicated by Ofgem's decision on local energy institutions and governance[10] will introduce greater co-ordination across different fuel vectors and geographies.

Thus, it is clear that there will be change for "DFES" in 2025. However, UK Power Networks still needs to develop locally justified planning scenarios to guide their investment in network capacity at the right time, place and cost to support the transition to net zero in our regions. UK Power Networks is working closely with other industry parties including NGESO/FSO to identify how coordinated spatial analysis of customer needs on the journey to net zero will be delivered in 2025 and beyond. The work in DFES 2024 which will feed into UK Power Networks' planning scenarios for 2024 provides an example of the deep analysis and local understanding which should underpin decisions to invest in network capacity to deliver net zero for our communities.

3 SCENARIO DEVELOPMENT

The four scenario worlds described above are constructed by combining uptake forecasts for all the individual drivers of demand and generation. To capture a broad range of different possible futures for demand and generation across UK Power Networks' region, three to four scenarios were produced for each driver and a bottom-up approach taken to modelling that aims to understand the types of customers across the network and thereby reflect the regional differences that may arise as part of the transition to a low-carbon society. The modelled drivers have been categorised to align with the Building Blocks agreed between National Grid ESO, UK Power Networks and the other DNOs to standardise the modelling outputs between National Grid ESO's Future Energy Scenarios (NGESO FES) and the DFES. Table 2lists the main drivers modelled and the uptake scenarios making up each of the four scenario worlds.

The primary focus of the DFES is to provide a credible range of scenarios that describe the long-term view of the energy landscape in UK Power Networks' licence areas. The bottom-up modelling described in this section focuses on the long-term effect of factors such as electricity and fuel prices, consumer attitudes towards new technologies and willingness to invest in such technologies. In order for the forecasts to not be unduly influenced by the current cost-of-living crisis and significant energy price increases, it is assumed these factors revert to historical rates in the short- to medium-term. This mirrors changes to the NGESO FES, in which higher energy prices and slower economic growth impact short-term pathways but do not significantly change the narrative over the long-term[11].

This year's update also includes a sensitivity analysis to examine the impacts of changes announced by the Prime Minister[12] in September 2023 to the UK's new approach to net zero targets. This primarily includes delays to the phase out of ICE cars and vans, and fossil fuel heating systems.

[10] Ofgem, Decision on future of local energy institutions and governance, November 2023
[11] NGESO, Changes from FES 2022 to FES 2023, September 2023
[12] UK Government, PM speech on Net Zero: 20 September 2023, 2023

Table 2: Drivers of demand and generation and the uptake scenarios that make up each of the four scenario worlds

Parameter	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Net Zero by 2050?	No	Yes	Yes	Yes
Core Demand				
Energy efficiency	Low	Medium	High	High
Building stock growth	Medium	Medium	Medium	Medium
Low-Carbon Transport				
Cars and vans: electrification	Limited Uptake	ICE Ban	ICE Ban	Reduced Demand
Heavy duty vehicles: decarbonisation	Baseline	Hydrogen world	High electricity	Fast rollout
Decarbonised Heating				
Heat pumps	Low	Medium	High	High with hybrids
District heat uptake	Low	Medium	High	High
Distributed Generation				
Rooftop solar PV	Low	Medium	High	High
Large-scale solar PV	Low	Medium	Medium	High
Onshore wind	Low	Low	High	Medium
Renewable engines	Low	Medium	High	High
Decentralised biomass	High	Medium	Medium	Low
Non-renewable CHP /Gas engines/ Energy from waste	High	Low	Low	Low
Battery Storage				
Domestic battery storage	Low	Medium	High	High
I&C behind-the-meter battery storage	Low	Medium	High	Medium
Co-located battery storage	Low	Medium	Medium	High
Grid-scale storage	Low	Medium with early phase out	Medium with late phase out	High
Flexibility				
Flexibility	Low	Medium	High	High

3.1 CORE DEMAND

Key Messages

- Core demand is expected to be driven by growth in building stock and energy efficiency changes
- Demand growth varies geo-spatially because of new build developments and differences in expected changes between local authorities.
- Air conditioning may grow considerably as customers respond to hotter summers and extreme weather events.

Most current electricity demand in UK Power Networks' region can be attributed to the demand from either domestic or industrial and commercial (I&C) customers. For the purposes of this report, the 'core demand' from these sectors is defined as the electricity demand related to all existing appliances and cooling. Electric heating, and the demand associated with low-carbon heating technologies such as heat pumps, is excluded from core demand and discussed separately in this report (see **Section 3.3**). Future core demand for these two sectors is primarily controlled by two key variables:

1. The total number of customers connected to the network – assumed to be controlled by the size of the building stock (building and demolition); and
2. The energy intensity of the customers within those properties (energy efficiency).

In this section the report outlines the modelling for each of the aspects of core demand outlined above, how they may change in future and how the scenarios have changed since the publication of the last DFES[13]. Table 3 shows how the uptake scenarios that are generated for the drivers of core demand map to the scenario world framework.

[13] Element Energy for UK Power Networks, DFES 2023, December 2022.

Table 3: Scenario world mapping for main drivers of core electricity demand

Parameter	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Building stock growth (domestic and I&C)	Medium	Medium	Medium	Medium
Electrical energy efficiency	Low	Medium	High	High
Air conditioning	High	Medium	Medium	Low

3.1.1 BUILDING STOCK

Domestic building stock

The same methodology as the previous DFES is followed to model the growth in domestic building stock. Household growth projections are used from the Office for National Statistics (ONS)[14] to define a medium household stock growth scenario for each local authority (LA). The low and high population growth projections from ONS are used to produce scaling factors relative to their central projection to produce low and high stock growth projections. As a result, three projections are obtained for the number of new build dwellings present in each local authority for each future year out to 2050. These local authority specific housing forecasts reflect the fact that certain areas are expected to see much more significant growth in the housing stock. This growth, however, is not expected to be uniformly distributed within those local authorities. A significant fraction of this growth is likely to occur in new housing development growth sites, with the remainder likely to be more evenly distributed. To identify where these concentrated new build developments are expected, UK Power Networks' analysis of local authority growth plans were used, where available (see DFES 2020 for a more detailed methodology)[15].

[14] Office for National Statistics (ONS), *2018-based Household projections for England (principal projection),* June 2020
[15] Element Energy for UK Power Networks, DFES 2020, February 2020

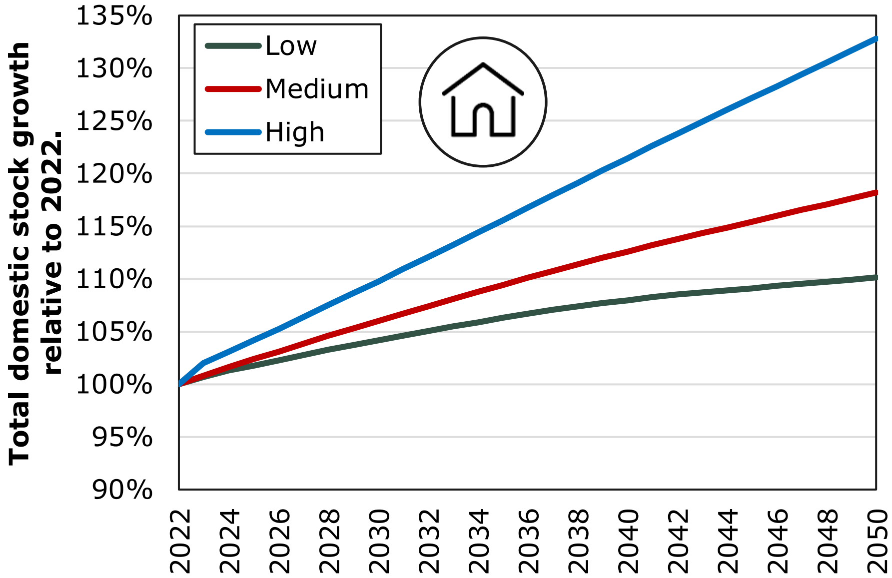


Figure 7: Domestic household growth in UK Power Networks' region out to 2050

Figure 7 shows the resulting projections for the total domestic stock growth in UK Power Networks' region out to 2050. In the scenario framework, the medium growth rate is used as the scenario that best aligns with historic trends, to represent the stock growth in all scenario worlds. While the scenario worlds represent a different view of future deployment of various technologies, in line with their different speed of decarbonisation and level of societal change, they do not vary in assumptions on population and household growth.

Industrial and commercial building stock

For the I&C sector, growth is modelled by considering the growth in floorspace by local authority, as floorspace is a key metric for determining energy consumption. The same methodology is followed as the previous DFES with updated input parameters. The growth in floorspace is modelled by first generating gross value added (GVA) forecasts by local authority, considering historic GVA/head trends along with population projections and national GDP forecasts. The historic relationship between GVA and floorspace is then used to derive future floorspace forecasts. Figure 8 shows the resulting floorspace growth projections. Similar to the domestic sector, a medium growth in I&C floorspace is assumed in all scenario worlds.

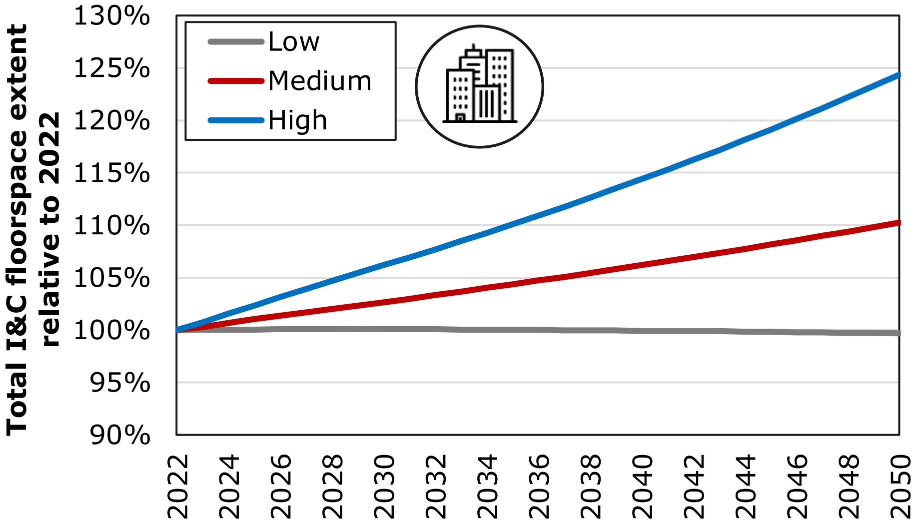


Figure 8: Total industrial and commercial (I&C) floorspace growth in UK Power Networks' region relative to 2022

3.1.2 ELECTRICAL ENERGY EFFICIENCY

Domestic appliances

The scenarios for domestic appliance efficiency continue to use the dataset published as part of UK Power Networks' Low Carbon London project[16], which contains efficiency scenarios for each category of appliance ('wet' appliances, 'cold' appliances, electronics, lighting etc.). It is assumed that in each category, the progress to date has followed the path of the 'current policies' scenario. The scenarios are updated to a 2022 base year and the different load categories are aggregated together according to their relative proportion of current domestic demand. The results, shown in Figure 9, are consistent with the previous DFES.

[16] Low Carbon London, UK Power Networks Innovation project, 2010-2014. Having reviewed the research on domestic appliance efficiency and considering factors such as the past trajectory of improvements and the latest government signals, it was decided that data from the Low Carbon London is still more suitable than other newer sources. This is because no other dataset identified provided the same level of detail and evidence-based analysis. Additionally, the scenarios created from these trends, align well with those from the NG FES, which are based on EU targets for energy efficiency. The scenarios have been rebased to the present day with assumptions that improvements so far had followed the 'current policies' scenario path which appeared generally consistent with recent trends in demand. Research in this area will continue to be monitored in case anything new and more suitable is published ahead of next year's update.

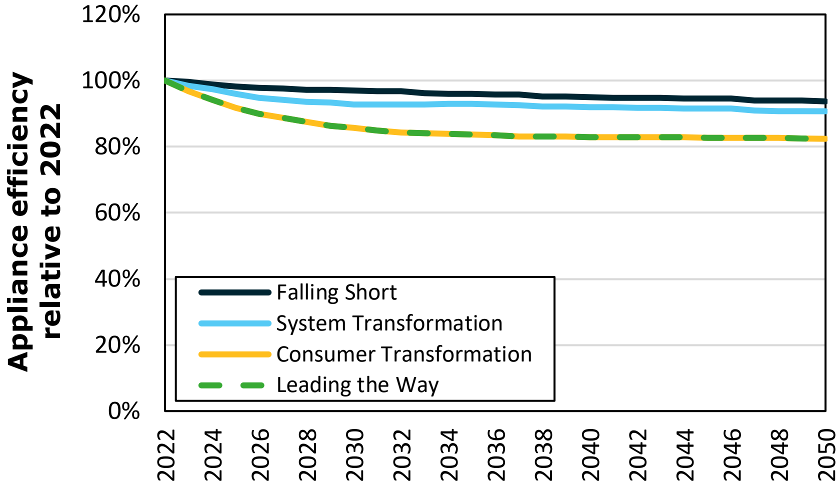


Figure 9: Domestic appliance efficiency, based on forecasts from the Low Carbon London project

I&C baseload

Three scenarios were developed for non-thermal energy efficiency for nine different I&C sectors following the same methodology as the previous DFES. The scenarios are based on cost effectiveness and acceptable payback periods of available energy efficiency measures as well as an estimated technical potential for non-thermal energy efficiency in the I&C sector[17]. Figure 10 shows the resulting energy efficiency projections for each different sector in the System Transformation scenario.

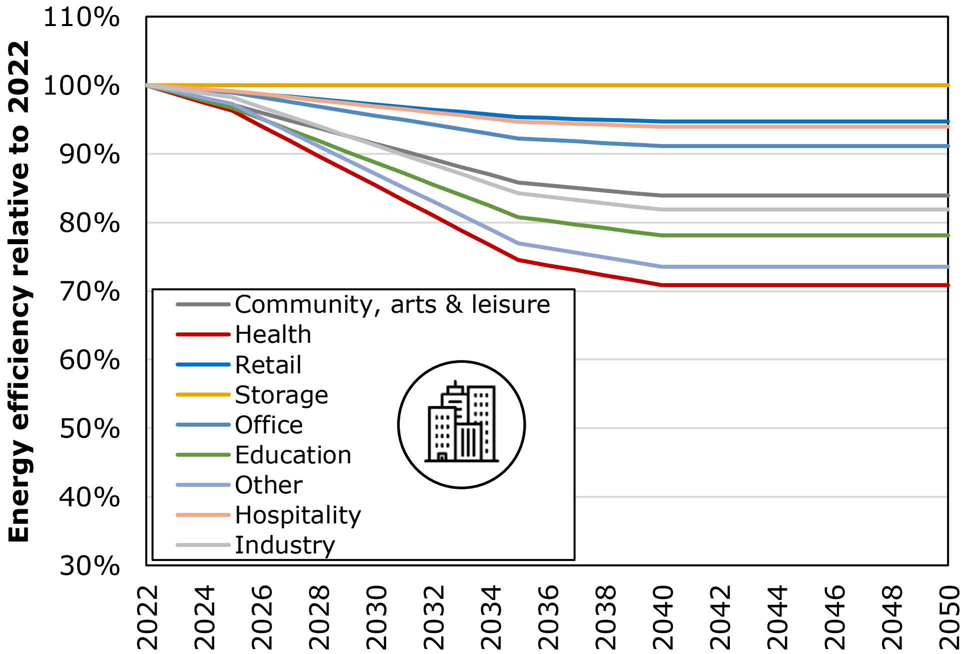


Figure 10: Energy efficiency in different I&C sectors out to 2050, System Transformation

[17] Based on BEIS's Building Energy Efficiency Survey (BEES) that reports on the non-domestic building stock in England and Wales in 2014–15

3.1.3 AIR-CONDITIONING

Due to climate change, hot summers are expected to become more common in the UK[18]. If coupled to increases in economic wealth, there is the potential for these hotter summers to drive the uptake of air conditioning (AC) units in both the domestic and I&C building stock. This year the AC uptake scenarios have been updated to a 2022 baseline, employing the methodology outlined in previous DFES reports[19].

Figure 11 shows the uptake of domestic air conditioning by scenario world out to 2050. The scenario mapping is aligned to the mapping used in National Grid ESO's Future Energy Scenarios[20]. In Leading the Way, it is assumed that the public is very aware of the importance of mitigating climate change and are willing to change their behaviour in order to reach net zero earlier. This includes limiting their energy use and reduced dependence on energy-intensive devices, resulting in a low uptake of AC units. Conversely, in Falling Short, it is assumed that society, not just in the UK but globally, is not as engaged in tackling climate change and instead of changing their behaviour (or buildings design specifications), consumers respond to extreme weather events with the easiest route possible to maintain thermal comfort levels. This behaviour results in increased uptake of AC units.

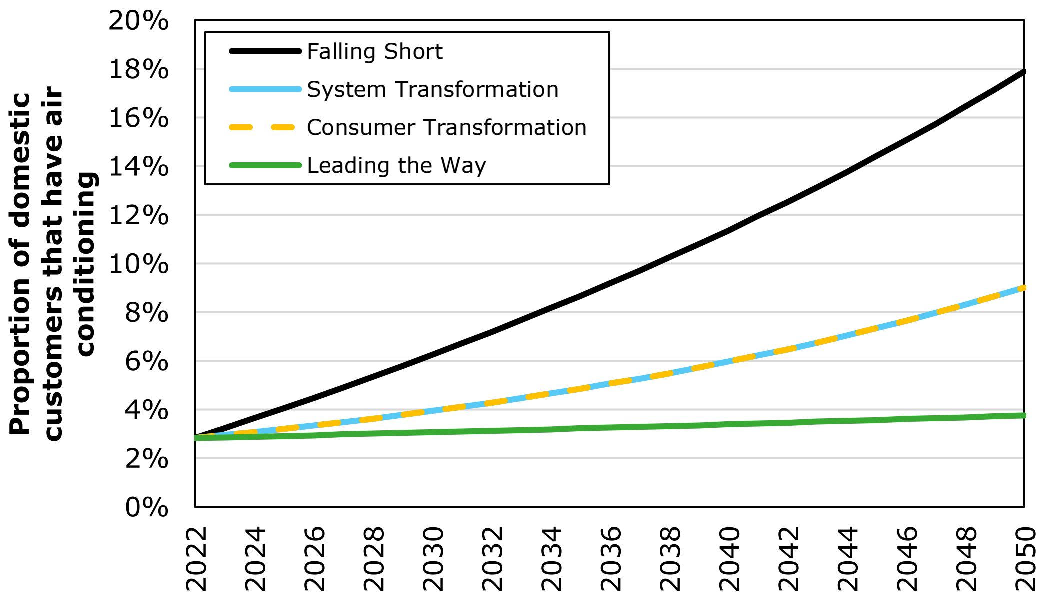


Figure 11: Air conditioning uptake in the domestic building stock within UK Power Networks' licence areas

3.1.4 DATA CENTRES

Demand for data centres and electrolysers is not part of the DFES but added separately based on accepted connections by UK Power Networks when generating demand forecasts at specific

[18] 'UK Climate Projections: Headline Findings', Met Office, 2019
[19] Element Energy for UK Power Networks, DFES 2020, February 2020, Section 3.1.2, and DFES 2021 January 2021, Section 4.1.2
[20] National Grid ESO Future Energy Scenarios, FES 2023 scenario framework and assumptions

substations. Data centres and electrolysers are not linked to housing stock or to general I&C economic activity or floorspace, and therefore need to be captured separately and in addition to those core demand drivers in the DFES.

Data centres are large point loads with a range from 10-600 MW for projects in the UK Power Networks licence areas. The discrete nature of these loads and that their location is driven by commercial reasons (land availability, proximity to network) means that they are best captured directly from connections activity, rather than on a scenario-basis with a geographic distribution across LSOA or MSOA.

UK Power Networks' network demand scenarios for planning purposes (i.e. MW at specific substations) are created in UK Power Networks' Strategic Forecasting System by combining the inputs from the DFES with larger accepted demand connections from UK Power Networks' connections teams and with evidence-based assumptions about load profile and load diversity. Data centres are included as part of these larger demand connections, with each such connection located at the correct substation.

As an indication of scale, in December 2023 UK Power Networks had identified additional data centre load of 260 MW in LPN, 150 MW in SPN, and 1210 MW in EPN assigned to specific substations – these are accepted connection offers. This will be refreshed against latest connections acceptance data in spring 2024 and combined with DFES 2024 to produce UK Power Networks' 2024 demand scenarios for planning purposes.

Information on uptake of data centre load over time for our three licences area is shared with National Grid ESO to inform the national Future Energy Scenarios; only one other DNO licence area proactively provides this data to ESO to inform the national scenarios.

3.2 LOW-CARBON TRANSPORT

Key Messages

- The uptake scenarios for low emission cars and vans have been updated to reflect latest price trends in battery packs, fuel, and electricity and incorporated supply constraints in the modelling.
- Due to a high decarbonisation ambition within London, taxis and PHVs that regularly operate within London are treated separately to others.
- In Leading the Way, a demand reduction in passenger travel is modelled, shifting trips from cars to buses and active mode of travel.

Uptake scenarios were created for low emission vehicles across a range of transport segments: cars, vans, taxis and private hire vehicles (PHVs), heavy goods vehicles (HGV), buses, coaches, and motorcycles. These scenarios were then mapped to the scenario framework outlined in Table 4.

To accurately model the number of electric vehicles in UK Power Networks' region in future, the following was determined:

1. **Baseline:** The total number of vehicles, number of electric vehicles (EVs), and their location.
2. **Uptake modelling:** Scenarios for the rate of uptake of low emission vehicles.
3. **Regional disaggregation**: How the future low emission vehicles are distributed across the region.

A similar process was followed to those outlined in the past DFES for all technologies. The sections that follow highlight key changes and updates to the modelling methods since last year's DFES and present key results.

Table 4: Scenario world mapping for transport modelling

Parameter	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Cars and vans	Limited Uptake	ICE Ban	ICE Ban	Reduced Demand
Taxis and private hire vehicles	Low	Medium	Medium	High
Heavy-duty vehicles (except GLA buses)	Baseline	High Hydrogen	High Electricity	Fast Rollout
GLA Buses	High Electricity	Accelerated High Hydrogen	Accelerated High Electricity	Further accelerated High Electricity
Motorcycles	Low	Medium	Medium	High

3.2.1 LIGHT VEHICLES

Light vehicles include cars, vans, taxis and private hire vehicles (PHVs), and motorcycles.

3.2.1.1 CARS AND VANS

The baseline is established by determining how many cars and vans, as well as how many electric vehicles (EVs), both battery electric vehicles (BEVs) and plug in hybrid electric vehicles (PHEVs), there are in total today and where they are located. This baseline is built using the same methodology as last year's DFES[21] using data from the Driver and Vehicle Licensing Agency (DVLA) and the Department for Transport (DfT).

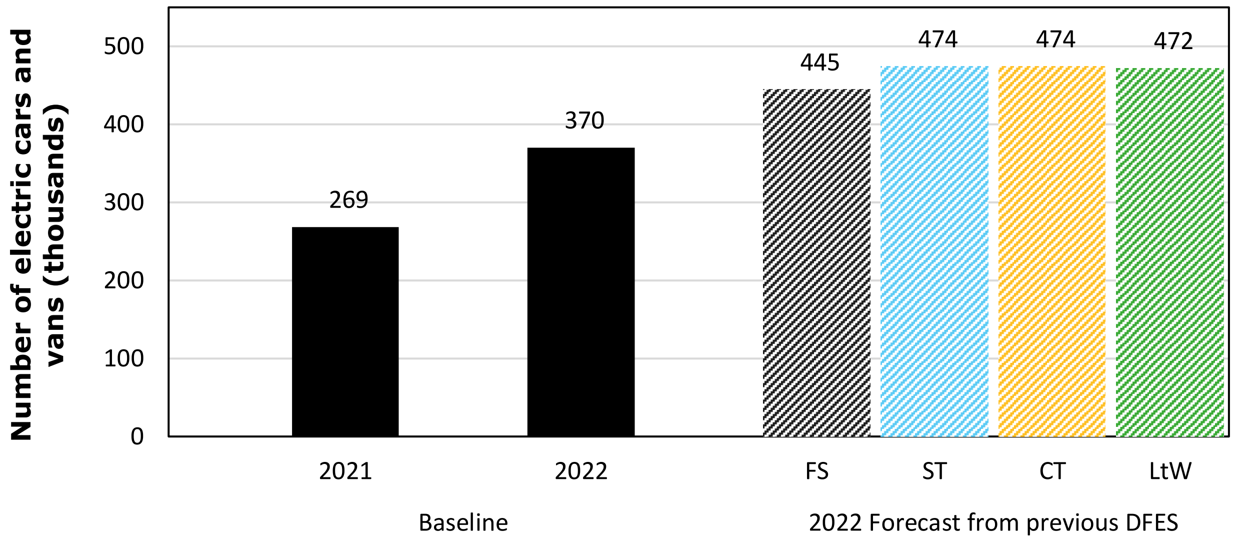


Figure 12: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) count of electric cars and vans compared to 2022 forecast from DFES 2023. 2021 is end March 2022 and 2022 is end March 2023

As of March 2023, there are approximately 370,000 electric cars and vans in the UK Power Networks' region (BEV and PHEV), an increase of 101,000 in one year which is 37.5%. All scenarios from the previous DFES overestimated the level of EV adoption by this time, as shown in Figure 12, which last year estimated 65% growth even in Falling Short. The overestimation of EV uptake in the scenarios from last year's DFES was driven by the high expected growth in demand for new EVs, forecasted by the Element Energy Car Consumer model (ECCo) described below. While demand for new EVs is still expected to be high in the next few years, recent supply chain constraints have resulted in demand outstripping supply and a lower uptake of EVs than expected. Therefore, The ECCo model has been updated to include supply constraints for this year's DFES, as described below. Once the baseline data is established, the Element Energy Car Consumer (ECCo) model is used to model the uptake of BEVs and PHEVs for each future year. The ECCo model takes in scenarios for a full suite of parameters that influence the decisions made by vehicle purchasers such as vehicle costs, fuel costs, government subsidy, model availability and more. It then determines the decisions made by distinct consumer groups when choosing between the different types of vehicles available. Low emission vehicle uptake is calculated at national level, i.e., for Great Britain (GB), as the correlation between consumer segments and geographical characteristics is not strong enough

[21] For more information see Section 3.2.1 of DFES 2023.

to support regional uptake modelling. For this reason, future low emission vehicle uptake scenarios are developed at GB level, and then disaggregated to MSOA and LSOA level.

Ultra Low Emission Zones (ULEZ) were found to have a very limited impact on electric vehicle uptake and therefore, the recent changes to London's ULEZ[22] are not explicitly fed into the modelling. This is because these zones do not require an EV and are free to enter for all new cars; Euro 4 (for petrol cars) and Euro 6 (for diesel cars) standards and above are exempt from charges. Therefore, it is assumed that the expansion of the zone has no impact on new car purchase trends. However, the Congestion Charge[23] within London has stricter rules and as electric vehicles are eligible for a discount on the charge, the impact of this charge on electric vehicle uptake is included in the modelling.

Several updates were made to the ECCo model for this year's analysis, including updating the projections for automotive OEM Li-ion battery prices. These projections are based on Bloomberg New Energy Finance (BNEF) 2022 Battery Price survey[24]. Price increases in 2022 due to raw material shortages were higher than predicted by last year's survey, with the most recent figures predicting a constant battery price between 2022 and 2023 then continuing to decline. The impact of this can be seen by the steeper BEV uptake from 2023 in Figure 13.

Fuel and electricity prices have been updated in accordance with DESNZ's Green Book projections[25] (updated Nov 2022). These updates account for the price shocks observed as a result of the invasion of Ukraine. The ECCo model also captures the wider range of vehicle models available and resulting reductions in EV costs, as well as higher battery capacities for vans.

A further key update to this year's modelling was the introduction of supply chain constraints to the Limited Uptake scenario. This accounts for recent demand outstripping the supply of battery packs as well as computer chip shortages that started during the COVID-19 pandemic. Supply constraints are based on European Automobile Manufacturers' Association projections of European BEV sales[26], scaled for the UK market. Finally, the model has been updated this year to account for slow recovery of total car sales after COVID-19[27], with three scenarios developed that model different recovery rates.

The uptake modelling of low-carbon cars and vans produced three uptake scenarios, with varying levels of decarbonisation ambition. Table 5 gives a high-level overview of the main assumptions for each scenario. **Limited Uptake** represents a low level of ambition, where the proposed ban on internal combustion engine (ICE) vehicles and PHEVs is not enforced and consumer confidence in the public charging network is limited. Overall car sales are slow to recover from the decrease seen during the COVID-19 pandemic, reaching pre-shock levels in 2026. Furthermore, a restriction on the supply of BEVs to the UK market has been applied to the Limited Uptake scenario and provides a ceiling on the number of BEV sales in the given year. In **ICE Ban**, previously announced Government policy (pre-September 2023) is implemented in full, with petrol, diesel, and hybrid cars removed from the market in 2030, and PHEVs in 2035. Total car sales recover at a moderate pace from the decrease seen during COVID-19, reaching pre-shock levels in 2024. No action is taken to reduce private car

---

[22] Mayor of London, The Ultra Low Emission Zone (ULEZ) for London, 2023
[23] Transport for London, Congestion Charge
[24] BloombergNEF, EVO Report 2023, 2022
[25] Department for Energy Security and Net Zero, Green Book supplementary guidance, 2022
[26] European Automotive Manufacturers' Association, Electrification trends worldwide, 2022
[27] Society of Motor Manufacturers and Traders, UK new car registration data, 2023

ownership or use, with minimal effort to incentivise modal shift, demand reduction, and a shift to shared car ownership. Vehicle stock growth in these scenarios follows DfT's Core Scenario projections for total vehicle milage[28], assuming a constant annual mileage per vehicle. In addition to announced policies on banning non-ZEVs, policies to reduce demand for private car mobility to meet near term climate targets are assumed in **Reduced Demand**. Vehicle stock growth in this scenario follows DfT's Mode-Balanced Decarbonisation scenario[28], resulting in a lower vehicle stock by 2050 compared to the other scenarios.

In addition to the three core scenarios produced, a sensitivity analysis was performed on the impact of delaying the ban on new petrol, diesel and hybrid[29] cars from 2030 to 2035, as proposed by the Prime Minister in a recent announcement[30]. This delay in Government ambition, may impact other scenario drivers as well. Therefore, the sensitivity analysis presents a future where, in addition to the delayed ban, public confidence in EVs is reduced, with perceived access to charging increasing at a slower rate, and where reduced confidence from OEMs results in a lower supply of BEVs in the UK up to 2030, as presented in Table 5.

Table 5: Overview of scenario assumptions for electric car and van uptake projections from the ECCo model

Scenario	Perceived access to charging improves	ICE/HEV[29] phase out	PHEV phase out	Post-COVID sales recovery	Demand reduction	Un-constrained supply	Scenario world
Limited Uptake	✗	✗	✗	Slow	✗	✗	FS
ICE Ban	✓ by 2030	✓ 2030	✓ 2035	Moderate	✗	✓	CT / ST
Reduced Demand	✓ by 2030	✓ 2030	✓ 2035	Moderate	✓	✓	LtW
Delayed ICE Ban	✓ by 2035	✓ 2035	✓ 2035	Moderate	✗	✗	Sensitivity

Figure 13 shows the resulting BEV proportion of total car sales for each scenario up to 2050. As noted earlier, actual EV numbers have been tracking the Falling Short scenario, and the net zero scenarios expect an increase in the proportion of BEV sales. The kick-up in 2035 in the Net Zero scenarios is a result of the phase out of PHEV vehicle sales. A very small number of hydrogen fuel cell cars are expected to enter the market and their sale will be permitted post-2035 as they are zero-emission at the tailpipe. As fuel cell prices reduce over time their sales

[28] Department for Transport, National Road Traffic Projections, 2022.
[29] Referring to non-plug-in hybrid electric vehicles (HEV).
[30] UK Government, PM speech on Net Zero: 20 September 2023, 2023

shares increase, however total uptake remains very low, and a wholesale shift from BEVs to hydrogen fuel cell vehicles is not expected.

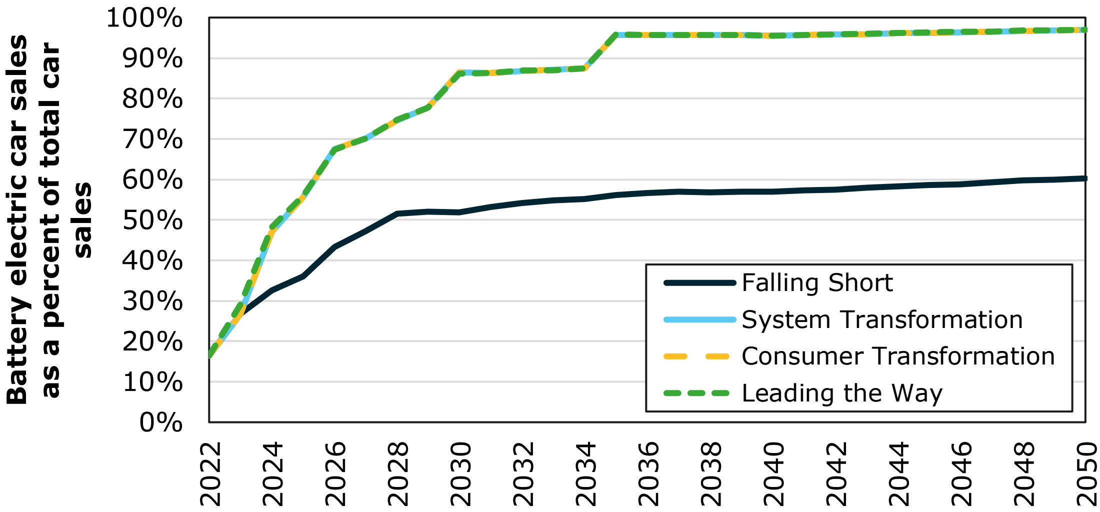


Figure 13: BEV sales as a proportion of total car sales to 2050

Figure 14 shows the resulting breakdown of the car and van stock in UK Power Networks' licence areas. The lowest uptake of BEVs is modelled in Falling Short as limited access to public charging infrastructure can be seen as a barrier to uptake. Additionally, neither ICE vehicles (petrol and diesel fuelled cars and vans) nor PHEVs are fully phased out by 2050 as no policies are put in place to remove them. Uptake of pure BEVs is higher in the Net Zero scenarios where a ban on new sales of ICE and PHEV vehicles is enforced and consumers without access to off-street parking have access to reliable public charging infrastructure. The modelled hydrogen fuel cell electric vehicle (FCEV) uptake in the car and van segment will be predominantly in vehicles that are less suitable for electrification, such as those that frequently travel long distances or carry a heavy load. Based on the different travel patterns between cars and vans, i.e., vans are more likely to carry heavy loads and travel longer distances, a higher uptake of FCEVs in vans than cars is expected.

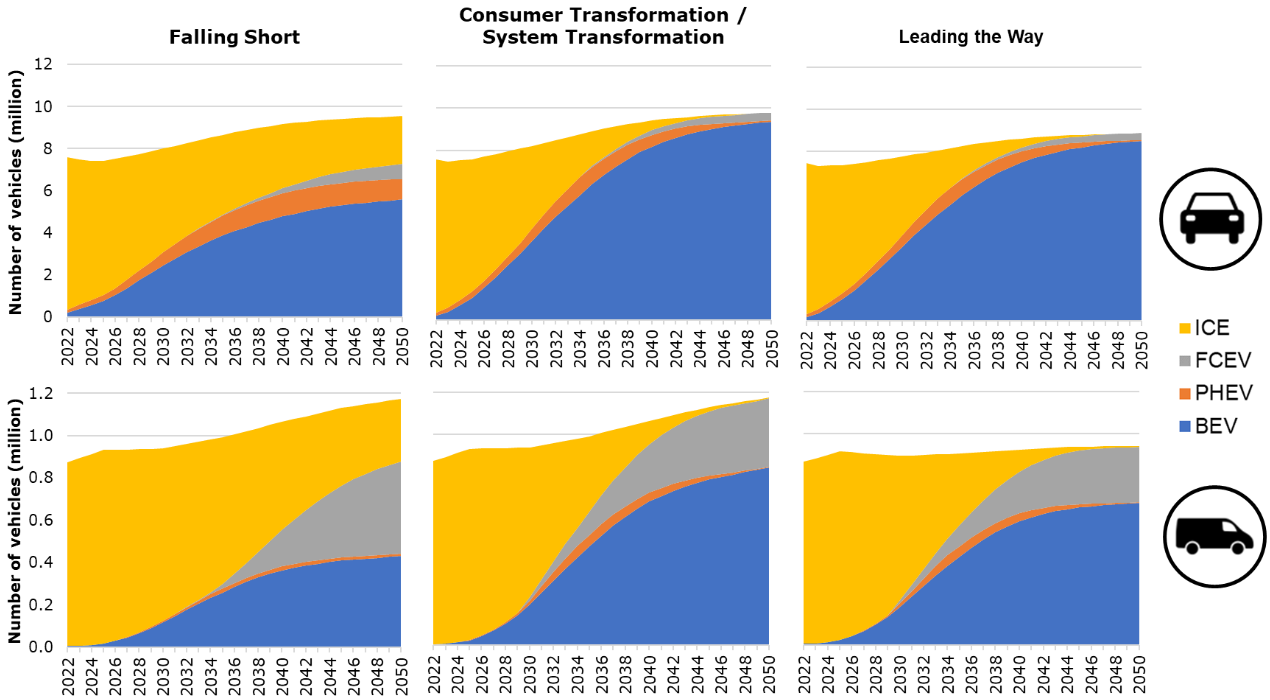


Figure 14: Breakdown of the vehicle stock in UK Power Networks' licence areas 2022-2050, cars (above) and vans (below)

Between 1.8 and 2.4 million electric cars and vans are modelled in UK Power Networks' region by the end of the 2027/28 regulatory year (Referred to in the rest of this document as "2027")[31], with the highest number of EVs in Consumer Transformation and System Transformation (Figure 14). Those figures are somewhat lower than those modelled in last year's DFES (between 2.5 and 3.0 million EVs by 2027) which mainly stems from updates which capture slow vehicle sales recovery after COVID, the inclusion of supply chain constraints, and a lower number of total cars reported by DfT within UK Power Networks' licence areas than last year.

By 2050 there are fewer total cars and vans on the road in Leading the Way compared to the other scenarios, resulting in a lower number of EVs than in Consumer Transformation and System Transformation, despite a very similar proportion of vehicles being electrified in these scenarios.

[31] The years refer to the regulatory year, so "2027" refers to the period from April 2027 - March 2028

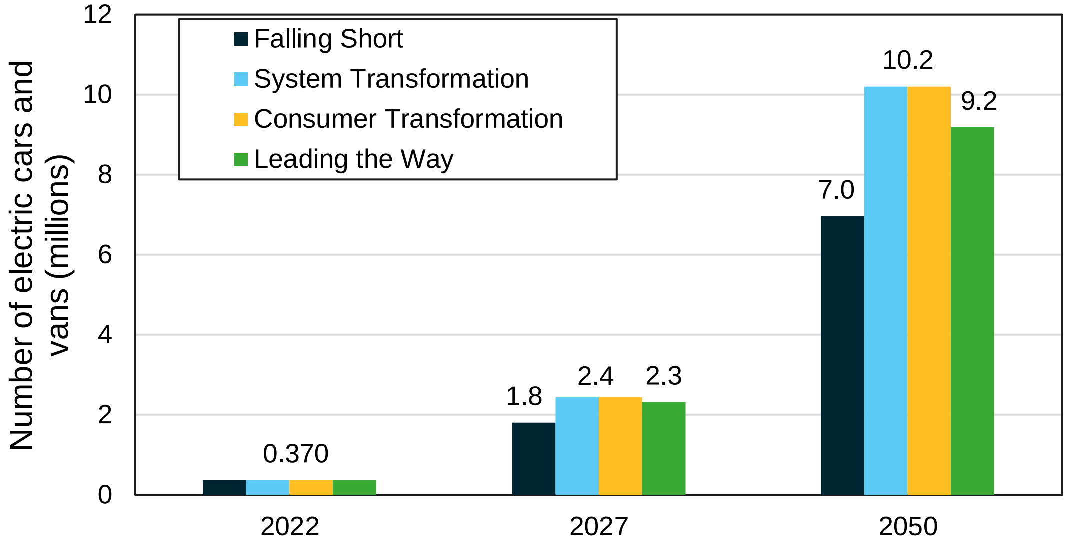


Figure 15: Number of electric cars and vans in UK Power Networks' region in 2022, 2027 and 2050

Sensitivity analysis

For this year's DFES, a sensitivity analysis was undertaken in addition to the four main scenario worlds, in order to capture the impacts of recent changes to net zero policy in the UK, as proposed by the Prime Minister in a recent announcement[32]. For cars and vans, the analysis examines the impact of delaying the phase out of internal combustion engine (ICE) vehicles from 2030 to 2035. The sensitivity scenario also assumes a level of supply constraints, and that the post-Covid sales recovery is moderate (Table 5).

Figure 16 shows the BEV proportion of total car sales between the base year and 2050, for each of the four main scenario worlds and the sensitivity scenario. In the near term, the sensitivity scenario follows a trajectory similar to Falling Short, but continues to steadily increase out to 2035, at which point BEV sales reach near 100%.

[32] UK Government, PM speech on Net Zero: 20 September 2023, 2023

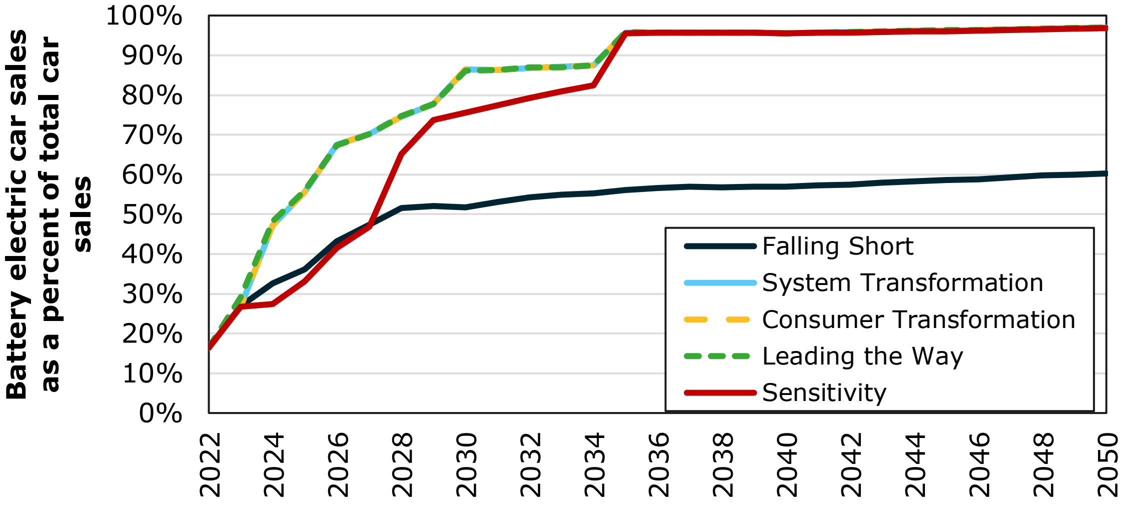


Figure 16: Battery electric car sales as a percent of total car sales for the four main scenario worlds and the sensitivity scenario (national)

The impact of this can be seen in Figure 17, which compares the sensitivity scenario against the four main DFES scenarios in terms of the expected national-level BEV uptake. The sensitivity scenario sees a lower uptake in the near term and reaches a similar level to Falling Short by the end of ED2. However, the number of BEVs by 2050 is the same as the other net zero scenarios at approximately 41 million.

This analysis demonstrates the significant impact that policy can have on consumer purchase decisions, as well as wider development and uptake of low carbon technologies. In particular, changes to phase-out dates can have wide-reaching impacts for the low carbon economy, affecting market uncertainty, investor confidence, and the long-term plans of suppliers.

The sensitivity analysis shows that the impact of the policy change lies within the range of our existing DFES scenarios – moving from Falling Short in the near future to the existing Consumer Transformation/ System Transformation trajectory in the longer term. Due to the uncertainty in whether the September 2023 policy change will be fully implemented, noting potential change in government next year, and that it is unlikely to drive short-term changes because car manufacturers have already been planning based on the 2030 ICE Ban roll out, this analysis supports the approach in this DFES report to defer update of any of the DFES scenarios until the policy revision is confirmed. This will need to be considered as part of the next DFES update.

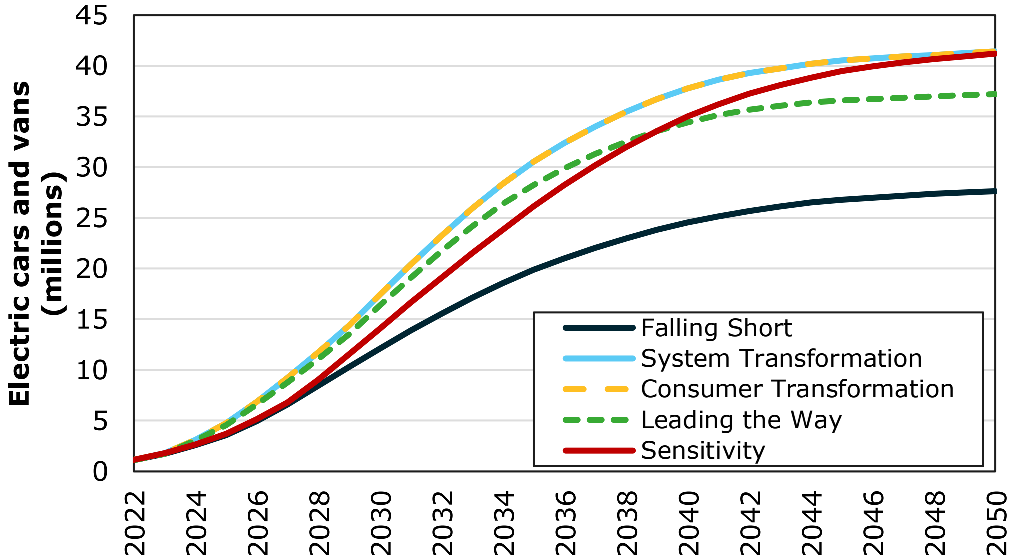


Figure 17: National stock of electric cars and vans for the four scenario worlds and the sensitivity scenario

3.2.1.2 TAXIS AND PRIVATE HIRE VEHICLE

A combination of datasets from TfL[33] and DfT[34] is used to establish the baseline number of taxis and private hire vehicles (PHV) at LSOA resolution, according to the method detailed in previous DFES reports. The number of electric taxis in the baseline (2022) is in line with the uptake forecasted in Leading the Way in the previous DFES, as shown in Figure 18. For electric private hire vehicles, the updated baseline exceeds last year's modelled increase in all scenarios. Based on public data, the total stock of PHVs has increased by 15% between this year and last year, reflecting a much more aggressive stock growth than expected. Consequently, as this stock is gradually electrified, the total number of electric PHVs modelled in this DFES is higher than previously forecast.

[33] To establish the number of taxis and private hire vehicles by partial postcode, the taxi and private hire driver partial postcode data is used. It is assumed that the total number of taxis and vehicles are distributed proportionally to their drivers. Post code district data and electric taxi data was used to estimate the number of electric taxis at end of Q1 2023. TfL licencing information, available from https://tfl.gov.uk/info-for/taxis-and-private-hire/licensing/licensing-information

[34] DfT/DVLA table TAXI0104, available from https://www.gov.uk/government/collections/taxi-statistics

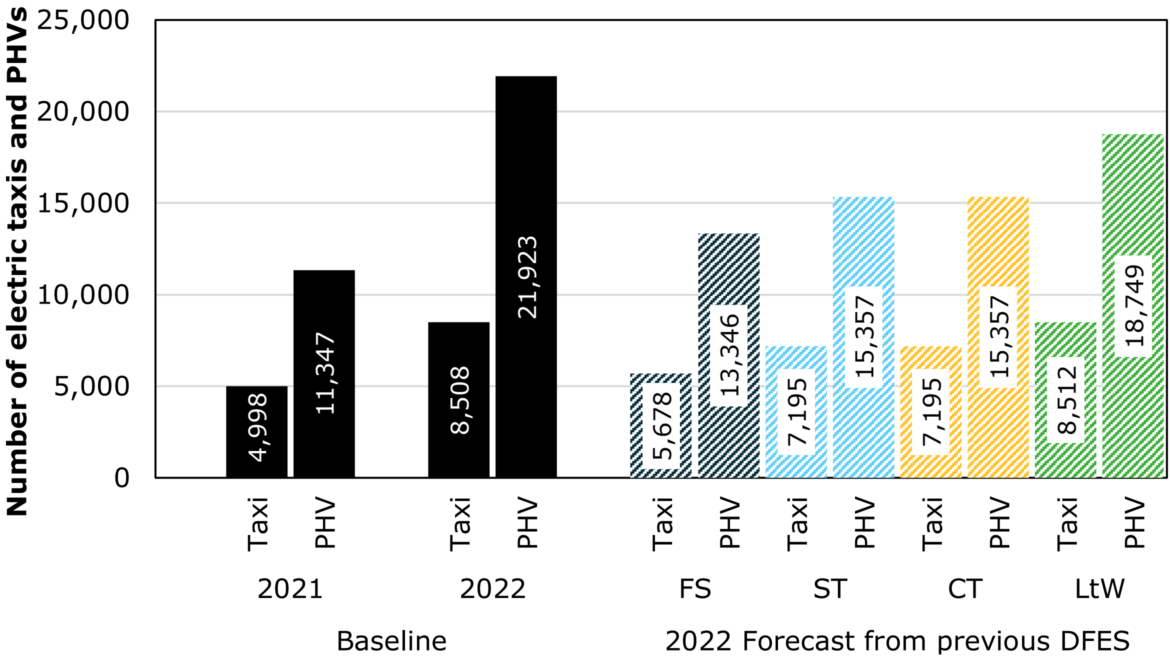


Figure 18: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) count of taxis and PHVs compared to 2022 forecast from DFES 2023

In the modelling, taxis and PHVs that regularly service within London are treated separately to others. This is due to the legislative ability of the GLA to create specific licencing rules for taxis and PHVs, in combination with a high decarbonisation ambition within London. As in the previous DFES, which vehicles are treated separately are established by considering an extension of the Greater London Authority (GLA) boundary by 10 miles in all directions as a barrier. The vehicles located within this boundary (according to the baseline distribution) are on a higher electrification trajectory than those located outside of the boundary.

The methodology used to find which proportion of taxis and PHVs are electric is consistent with the in-house modelling that has been detailed in previous DFES reports[35]. As in previous updates, three scenarios are defined for taxis and PHVs, each of which contains different assumptions for vehicles within and outside of the extended GLA boundary. These assumptions and the resulting dates of full electrification are summarised in Table 6 and Table 7.

[35] Element Energy for UK Power Networks, DFES 2023, December 2022, Section 3.2.1.

Table 6: Taxi Key assumptions

Scenario name	Scenario world	Region	Full electrification	Stock growth	Targets and assumptions
Low	Falling Short	GLA	2032	Constant	Based on scenario developed in BCG project[36], in line with targets from MTS[37]
		Non-GLA	2037	Constant	Five-year delay to BCG
Medium	Consumer Transformation, System Transformation	GLA	2028	Constant	Accelerated electrification
		Non-GLA	2032	Constant	Based on BCG
High	Leading the Way	GLA	2026	Constant	Follows current uptake trends
		Non-GLA	2028	Constant	Acceleration of BCG

Table 7: PHV Key assumptions

Scenario name	Scenario world	Region	Full electrification	Stock growth	Targets and assumptions
Low	Falling Short	GLA	2036	Constant	Low sensitivity based on medium trajectory
		Non-GLA	2037	Constant	Five-year delay of the BCG scenario
Medium	Consumer Transformation, System Transformation	GLA	2033	0.5% year-on-year increase	Reflects current TfL licensing rules and stated ambitions from private hire vehicle operators[38]
		Non-GLA	2037	0.5% year-on-year increase	Four-year delay on the Medium GLA scenario
High	Leading the Way	GLA	2031	1% year-on-year increase	High sensitivity based on medium trajectory
		Non-GLA	2032	1% year-on-year increase	Based on High sensitivity for GLA

Figure 19 shows the uptake trajectory for the total stock of electric taxis and PHVs within UKPN's licence area. The result of this modelling suggests that by 2027 (end of March 2028), there could be up to 110,000 electric taxis and private hire vehicles in UK Power Networks' region (Figure 19). In Leading the Way, the entire taxi fleet is electrified by 2028, with Consumer Transformation and System Transformation following shortly after in 2032. Leading the Way sees the highest growth of PHVs as consumers shift their travel behaviour, relying less on private passenger cars and more on shared methods of travel, such as PHVs. All PHVs are

[36] UK Power Networks, 2018, Black Cab Green project, info and reports available from: http://www.smarternetworks.org/project/nia_ukpn_0026
[37] Greater London Authority, Mayor's Transport Strategy, 2018
[38] Several London private hire vehicle operators have stated an ambition to go electric, including Uber, Kapten, and Addison Lee.

fully electrified in all scenarios by 2037 and any increase in the number of electric vehicles after that date is due to stock growth. By 2050, between 122,000-152,000 electric taxis and PHVs are forecasted.

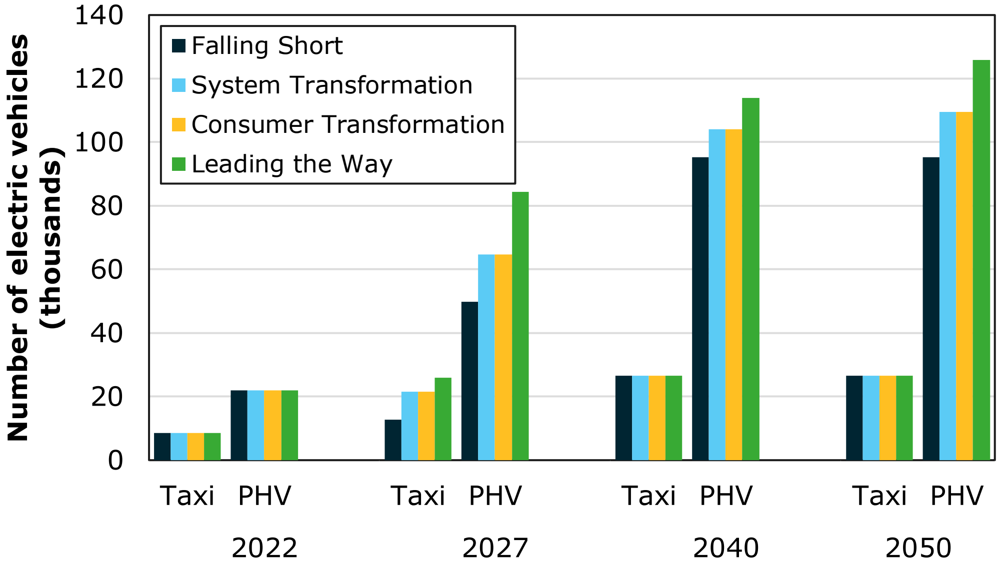


Figure 19: Number of electric taxis and private hire vehicles in UK Power Networks' licence areas at present (2022), in 2027, 2040, and 2050

3.2.1.3 MOTORCYCLES

The number of motorcycles and proportion that are electric in UK Power Networks' region is established from the DfT vehicle licence statistics, which report vehicle licences at LSOA level[39], and number of electric motorcycles at local authority level[40]. These statistics log a total baseline for 2022 of 7,071 electric motorcycles registered in UK Power Networks' licence areas. This baseline is slightly above the Falling Short forecast (11.2%) from last year's DFES but lower than the uptake projected in other scenario worlds.

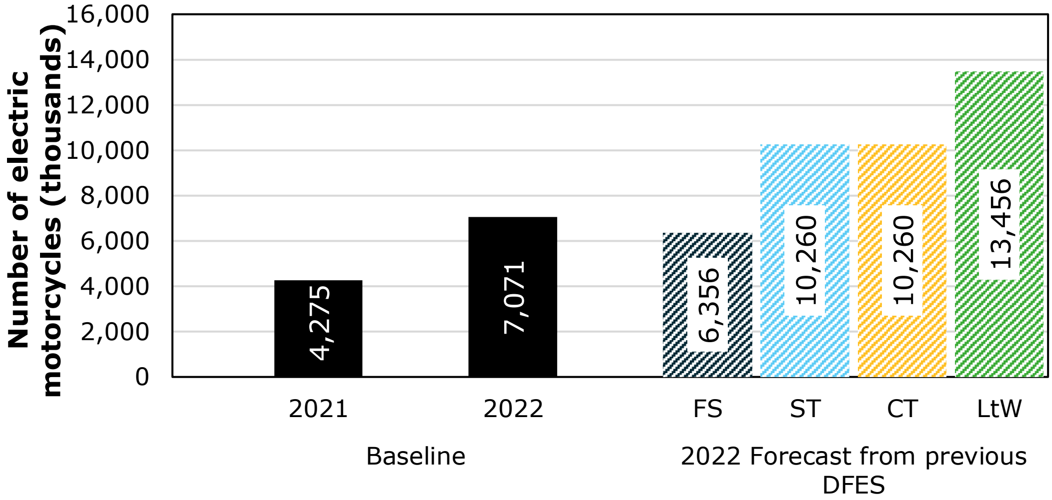


Figure 20: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) count of electric motorcycles compared to 2022 forecast from DFES 2023

The uptake modelling is based upon the electrification scenarios for motorcycles developed by TfL, as reported in the London Climate Action Plan[41]. The Mayor's Transport Strategy (MTS) Near Zero scenario was used to define the uptake in Consumer Transformation and System Transformation. This scenario represents a complete electrification of the motorcycle stock by 2050, consistent with the narrative in Consumer Transformation and System Transformation across all three UK Power Networks' licence areas. Additionally, two uptake pathways were added, one that does not fully decarbonise the motorcycle stock by 2050, representing the lower ambition in Falling Short, and another that is based on the uptake of electric cars in Leading the Way, representing a higher level of ambition present in that scenario (Figure 21).

[39] Motorcycle data is extracted from the DfT/DVLA table VEH0125, available from https://www.gov.uk/government/collections/vehicles-statistics.

[40] Baseline electrification proportion of motorcycles in the UK Power Network's region is assumed to be uniform across the UKPN LSOAs. The number of electric motorcycles used to calculate this proportion is extracted from DfT/DVLA table VEH0142 at a local authority level, available from https://www.gov.uk/government/collections/vehicles-statistics. The estimated fraction of each local authority that is served by UK Power Networks is considered to derive number of motorcycles.

[41] The London's Climate Action Plan Work Package 3: Zero Carbon Energy Systems, for Greater London Authority / C40 Cities, January 2019.

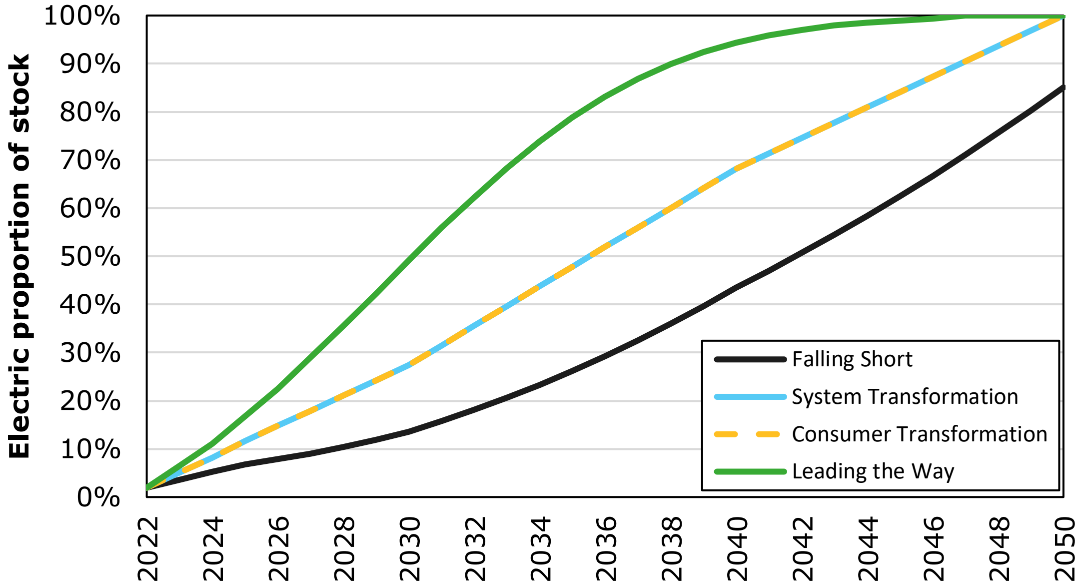


Figure 21: Uptake of electric motorcycles in UK Power Networks' region in 2022-2050

3.2.2 HEAVY DUTY VEHICLES

Heavy duty vehicles include heavy goods vehicles (HGV), minibuses, buses and coaches.

The Element Energy Fleet Finder tool was used to establish the baseline number of heavy-duty vehicles (and their depot locations). Publicly accessible registration data (collected in June 2020), was analysed, cleaned, and used to identify the location and size of depots for both HGVs and buses. The number of electric buses and coaches was extracted from DfT[42] data at local authority level. The baseline for the year 2022 for electric HGVs is a significant jump from the 2021 baseline and forecasts from last year's DFES. This shift is due to significant growth in the EPN region (and Cambridgeshire in particular) recorded in the DfT dataset used to create the baseline. The number of electric buses used as a baseline for this year is also an increase on the forecasted values in last year's DFES for all scenario worlds, but this difference is less pronounced than in HGVs.

[42] Extracted from DfT/DVLA data table VEH0142 from Q1 2022, available from https://www.gov.uk/government/collections/vehicles-statistics. The estimated fraction of each local authority that is served by UK Power Networks is considered to derive number of buses.

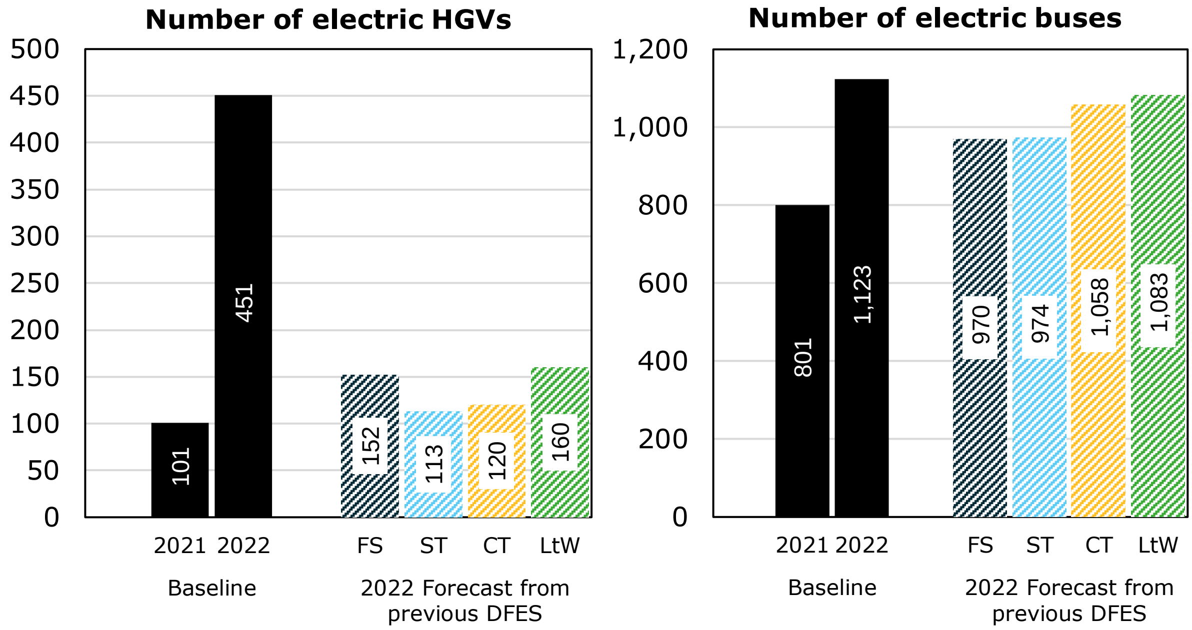


Figure 22: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) count of electric HGVs (Left) and buses (Right) compared to 2022 forecast from DFES 2023

The scenarios for the uptake of low emission heavy duty vehicles are consistent with previous DFES[43] reports. One set of scenarios describes the uptake of low emission buses, another low emission coaches and the third, low emission heavy goods vehicles. These scenarios are consistent with the FES scenario worlds, and the baseline has been realigned in each of these scenarios to match the latest available data. Based on the 2021 announcements from the Mayor of London[44], committing to deliver a 100% zero-emission bus fleet in London by 2034, with further interest in reaching that target by 2030, an accelerated rate of decarbonisation is still used in the bus scenarios that apply to London. These accelerated scenarios, shown in Figure 23, are created to match stated ambitions and do not necessarily represent typical vehicle turnover rates. In both Consumer Transformation and System Transformation, the complete bus stock is decarbonised by 2034, with approximately 36% of the stock using hydrogen fuel in the latter scenario. It is assumed that the more ambitious target of 2030 is reached in Leading the Way.

[43] Element Energy for UK Power Networks, DFES 2021, January 2021, Section 4.2.2, DFES 2022, February 2022, Section 3.2.2, and DFES 2023, January 2023, Section 3.2.2.
[44] https://www.london.gov.uk/press-releases/mayoral/mayor-host-zero-emission-bus-summit-at-city-hall

Table 8: Scenario assumptions for HDVs

Parameter	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Bus scenario: GLA	High electricity	High Hydrogen 2034 phase out	High electricity 2034 phase-out	High electricity 2030 phase out
Coach / minibus scenario: GLA	Baseline	High Hydrogen	High electricity	Fast rollout
Bus/coach/minibus scenario: Non-GLA	Baseline	High Hydrogen	High electricity	Fast rollout
HGVs	Baseline	High Hydrogen	High electricity	Fast rollout

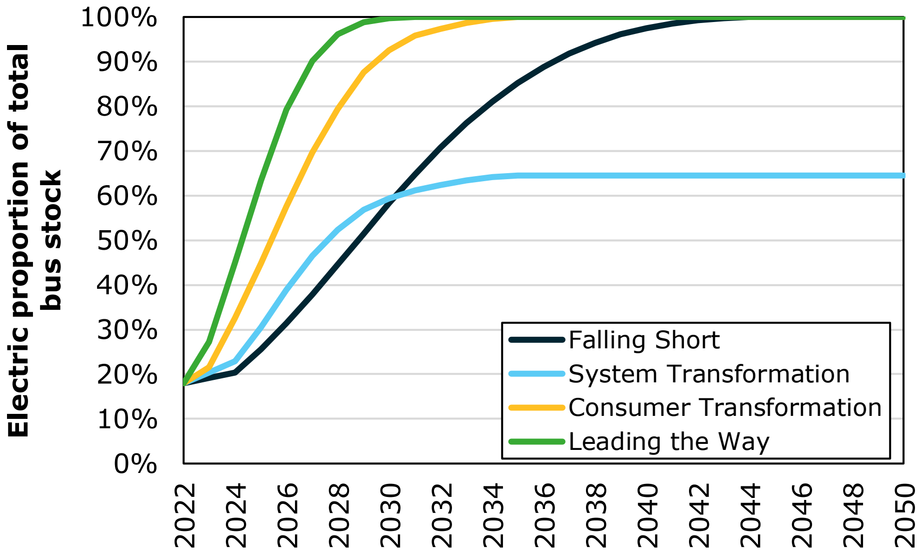


Figure 23: Electric bus uptake rates for the bus stock within the GLA

In line with the change in travel behaviour in Leading the Way, it is assumed a higher stock growth of buses in Leading the Way than the other scenarios, using the methodology detailed in previous DFES reports. The resulting stock growth is a 5% (outside the GLA) and 10% (within the GLA) increase in total bus stock by 2050, compared to a 2022 baseline.

Figure 24 illustrates that there could be between 55,000 – 132,000 electric heavy-duty vehicles in UK Power Networks' region by 2050, the highest deployment being in Consumer Transformation, where nearly all the heavy-duty vehicle stock is electrified. A rollout of hydrogen refuelling infrastructure in Leading the Way results in a higher number of hydrogen fuel cell vehicles, mainly heavy HGVs and coaches that travel long distances. Even higher numbers of hydrogen vehicles are assumed in System Transformation and no electric coaches and minibuses are modelled in this scenario.

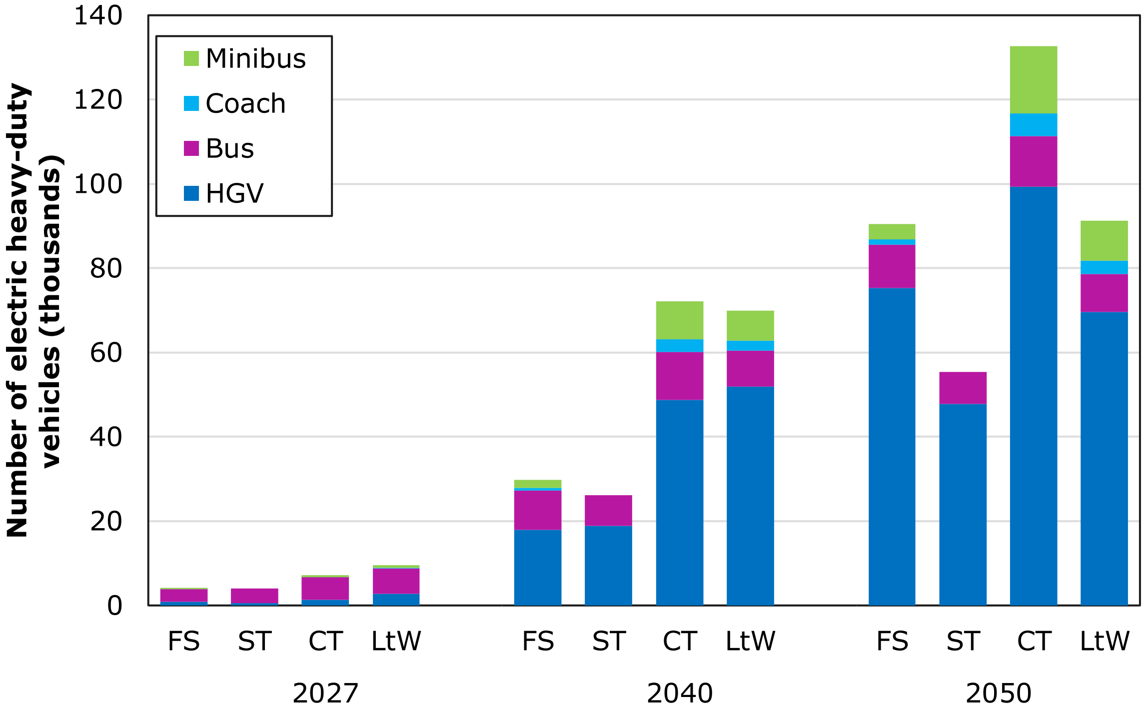


Figure 24: Number of electric heavy-duty vehicles in UK Power Networks' licence areas in 2027, 2040 and 2050

3.3 DECARBONISED HEATING

Key Messages

- In Leading the Way and Consumer Transformation, heat pumps are the dominant heating technology in 2050
- All Net Zero scenarios phase out natural gas boilers by 2050 with System Transformation converting to hydrogen boilers through a phased transition.
- Extensions to financial support for low carbon heating systems are reflected in all scenario worlds, while delays to the phase out of fuel heating systems are captured in the sensitivity analysis.

There are two main pathways under consideration for the decarbonisation of heat. One that relies on the electrification of heat and potentially decommissioning of the gas grid, and the other that continues to rely on gas boilers but requires conversion of the gas grid to supply a decarbonised gas, most likely dominated by hydrogen. These two alternative outcomes are represented by Consumer Transformation (the electrification pathway) and System Transformation (the hydrogen pathway) as outlined in Table 9. The pathway for heat decarbonisation in the UK could equally be a mix of those components and Leading the Way represents a scenario world where high uptake of heat pumps is combined with a decarbonised gas grid, which sustains a market for hybrid heat pumps. Falling Short represents a scenario world where the heating sector is not decarbonised by 2050, which might reflect a world with a lack of sufficiently strong government policy, for example.

Furthermore, improving the thermal efficiency of the building stock and deploying district heating can play an important role in the decarbonisation of the heating sector. The following sections outline the modelling methodology for developing scenarios for the heating sector and present the results for the uptake of low carbon heating technologies, thermal efficiency, and district heating.

Table 9: Scenario world mapping for decarbonised heating

Parameter	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Heat pump deployment	Low	Medium	High	High with hybrids
District heat uptake	Low	Medium	High	High
District heat supply	Baseline	Decarbonised gas	High electrification	Decentralised[45]

[45] Decentralised in this context refers to a scenario where the heat supply is sourced from multiple small sites instead of large, centralised sources and is a mixture of heat pumps and waste heat. There is no decarbonised gas in this scenario.

3.3.1 MODELLING METHOD

The modelling approach taken for this year is consistent with the previous DFES[46]. This is based on the work Element Energy did with UK Power Networks on decarbonised heating, Heat Street[47], with an additional bespoke consumer choice module to obtain temporally resolved uptake scenarios (Figure 25).

The Heat Street model considers over 2,000 different building archetypes, present in UK Power Networks' region, and assesses the best option for a package of energy efficiency measures and a low-carbon heating solution, based on cost-effectiveness and the policy environment in each scenario. The consumer choice module builds on the Heat Street results and produces the uptake rates for the heating technology and energy efficiency packages for each individual archetype. The consumer choice module cycles through each year and compares the business case for the optimum thermal energy efficiency and heating technology package against the counterfactual technology for each archetype and assesses the number of homes switching their heating system in each year out to 2050.

The results of this modelling were then combined with the district heating uptake described in **Section 3.3.5** to obtain LSOA-level outputs for heat pumps. A more detailed description of the methodology and modelling components can be found in the DFES 2022 report.

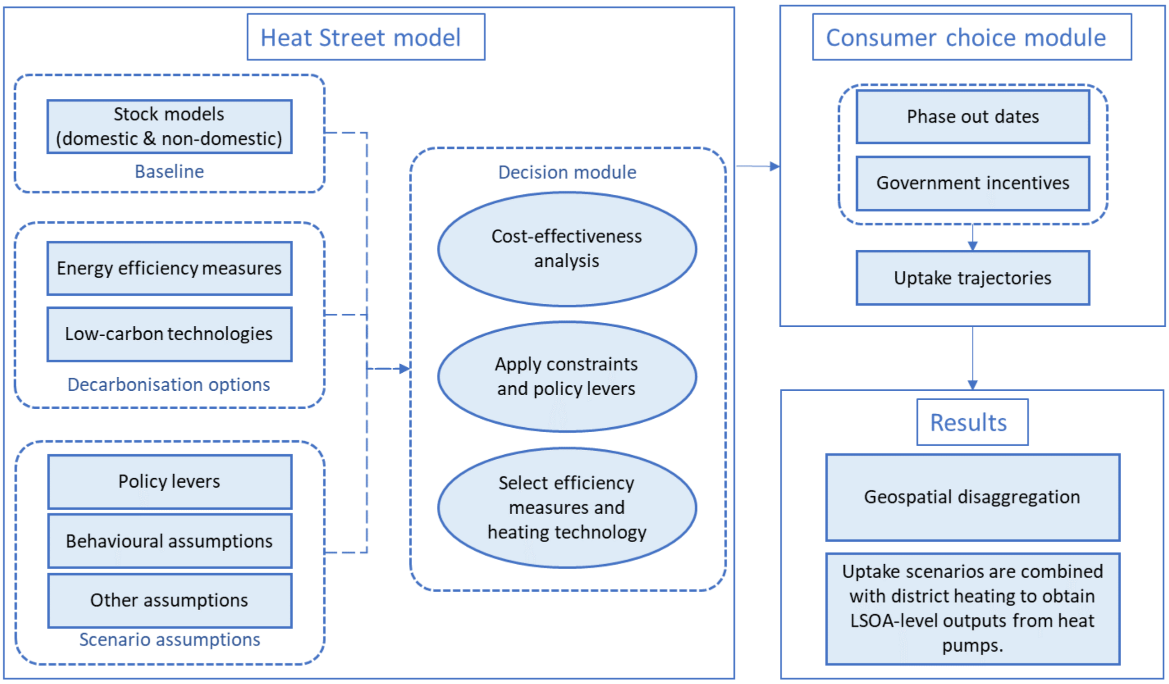


Figure 25: Schematic of the modelling approach for the uptake of low carbon heating

To establish the baseline stock of heat pumps, the baseline established in previous years is found, which was based on a scaling of reported uptake of heat pumps through the Renewable Heat Incentive (RHI)[48] within UKPN's licence areas. The number of additional heat pumps installed during regulatory year 2022 was then identified for each of UK Power Networks'

[46] Element Energy for UK Power Networks, DFES 2022, February 2022, p26
[47] UK Power Networks Innovation, Heat Street: local system planning, 2021
[48] DESNZ and BEIS, Renewable Heat Incentive statistics, 2022. The RHI expired in 2022 and the has been replaced by the Boiler Upgrade Scheme (BUS).

licence areas using the E7[49] data, which is part of the 2022/23 regulatory reporting submission.

To establish how the additional heat pumps are split between domestic and non-domestic properties, and to find the split between Air Source Heat Pumps (ASHPs) and Ground Source Heat Pumps (GSHPs), data from the Boiler Upgrade Scheme (BUS) was used. The results of this baselining approach found there to be a total of 43,270 heat pumps deployed in UKPN, 98% of which are domestic, and 89% of which are ASHP. 71.3% of total heat pumps are in EPN, 25.3% in SPN, and 3.4% in LPN. In Figure 26, this final baseline value is compared with the 2022 projected uptake from last year's DFES, as well as showing the increase from the 2021 baseline value.

In the domestic case, the DFES 2024 values (2022 baseline) lag behind the projected values from last year's DFES (2021 baseline). For non-domestic heat pumps, the 2022 baseline is approximately aligned with the Falling Short and System Transformation projections. Since the current level of uptake is lower than expected, the modelling approach for this year introduces an 'awareness factor' to represent the proportion of customers that have some knowledge of low carbon heating systems. This data was drawn from the DESNZ Public Attitudes Tracker[50] and assumes that by 2035, when most scenarios assume fossil fuel heating systems are phased out, awareness reaches 100%.

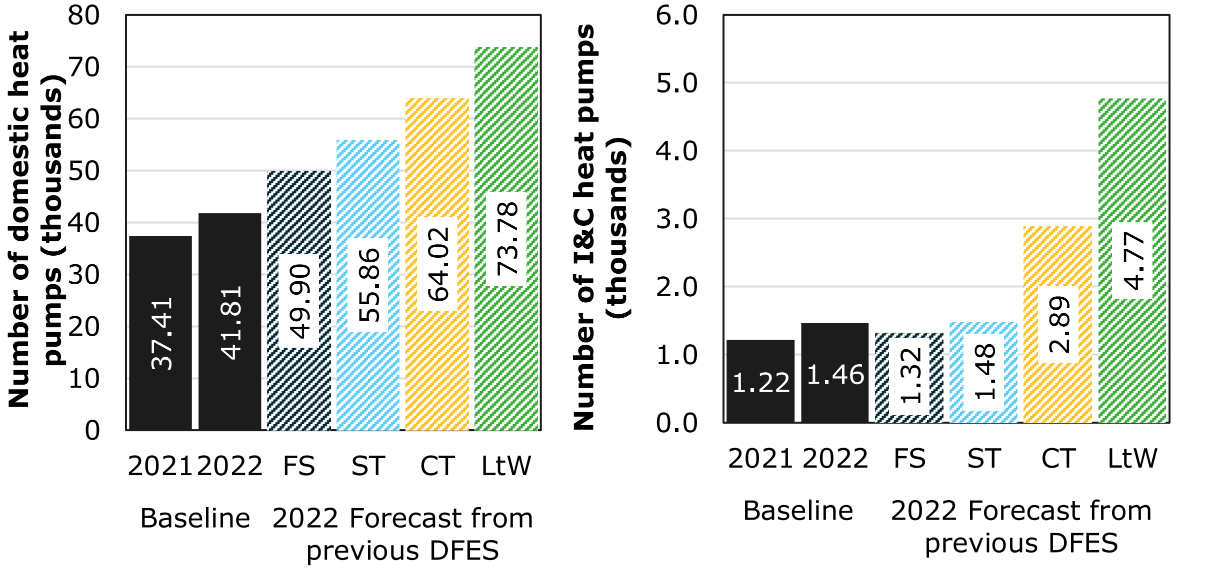


Figure 26: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) count of domestic (left) and I&C (right) heat pumps compared to 2022 forecast from DFES 2023

Key inputs to the consumer choice module, which determines the rate of uptake of low carbon heating technologies, are phase-out dates for high carbon fuels and up-front grants that support consumer in replacing the systems that use these fuels. It was found that Government policy is the factor that has the largest effect on the rate of uptake. Based upon the recommendation made by the Climate Change Committee (CCC) to ban gas boilers in new

[49] Produced by UKPN for Ofgem as part of Annex J – Environment and Innovation regulatory requirement. Data sources include the Micro Generation Certification scheme installation database (MID), UK Power Networks' LCT register, and the Domestic and Non-Domestic Renewable Heat Incentive databases.
[50] DESNZ, Public Attitudes Tracker: Heat and Energy in the Home, Summer 2023

homes[51], as well as feedback gained from consultation with UK Power Networks' stakeholders, the building stock was split into three key sectors: new builds, off-gas existing buildings, and gas-heated existing buildings. The different policy assumptions for the phase-out of fossil fuels were modelled in each of these sectors, as detailed in the following section.

In the domestic segment of our consumer choice module, four different occupant types for each building archetype were considered as in previous years – owner occupied, private rented, social housing, and occupants that are identified as fuel poor[52]. Different up-front grants are available from the Government for each of these occupant types. The Boiler Upgrade Scheme that is available to domestic and non-domestic property owners, the Social Housing Decarbonisation Fund (Wave 1 and 2 funding cycles) that is available for social housing, and the Sustainable Warmth Competition[53] for fuel poor consumers were included.

Additionally, the impacts of recent policy changes[54] are captured through a sensitivity scenario, which examines the impact of delays to the phase-out of fossil fuel heating systems; this analysis is presented in the following section.

3.3.2 LOW CARBON HEATING UPTAKE SCENARIO ASSUMPTIONS

The detailed scenario narratives and policy assumptions for the uptake of decarbonised heating in each scenario world are outlined in the boxes below.

Falling Short

- Low electrification.
- Off-gas policy intervention only.
- Up-front grants as announced.

In Falling Short, the only policy intervention assumed is a ban on fossil fuel heating in the off-gas sector from 2035, with no new builds on oil or LPG boilers from 2025 (Table 10). Additionally, it is assumed that the Boiler Upgrade Scheme will run for the announced duration, including the recent extension to 2028, and that the grant value per installation is consistent with recent announcements (£7,500 for Air/Ground-Source Heat Pumps and £5,000 for Biomass Boilers). It is also assumed that the Social Housing Decarbonisation Fund and Sustainable Warmth Competition will be available for social housing and fuel poor customers during the announced timeframes proposed by each scheme.

[51] Committee on Climate Change, UK housing: Fit for the future, 2019

[52] Based on Sub-regional fuel poverty data (2018 data) (2020) BEIS – this follows the *Low Income High Costs (LIHC) indicator*. A household is Fuel Poor if:

1. they have required fuel costs that are above average (the national median level); And
2. were they to spend that amount, they would be left with a residual income below the poverty line.

Note that the fuel poor category includes all buildings occupied by fuel poor customers, whether they are owner occupied, private rented or social housing.

[53] This competition has now closed as of 31st March 2023, which is reflected in the Falling Short Scenario. However, it is assumed in the net-zero scenarios that this funding is replaced by an equivalent scheme targeted towards the same consumer group. The grant amount per household is gradually reduced to zero by 2025 for System Transformation, and 2029 for Consumer transformation and System Transformation.

[54] Prime Minister's Office, PM speech on Net Zero, 2023

System Transformation

- Gas grid repurposed for low-carbon hydrogen instead of natural gas by 2050.
- Off-gas and new build fossil fuel bans enforced. On-gas required to be hydrogen ready.
- Up-front grants extended for some consumer groups.

In System Transformation a ban on fossil fuel heating in new builds is assumed from 2025, in line with the proposed Future Homes and Buildings Standard, as well as a ban on fossil fuel heating in the off-gas sector from 2030. It is assumed that the Boiler Upgrade Scheme will run for the announced duration and amount of grant given per installation. However, the Social Housing Decarbonisation Fund and Sustainable Warmth Competition will also be extended further than their proposed end dates.

Consumer Transformation

- High electrification.
- Off-gas, new build, and on-gas fossil fuel bans enforced.
- Up-front grants extended for some consumer groups.

Consumer Transformation is a scenario that relies on the electrification of the heating sector and this scenario sees the highest number of pure electric heat pumps deployed. A ban on fossil fuel heating in new builds is assumed from 2025 and existing off-gas properties can no longer choose a high carbon fuel from 2027, in line with the recommendations from BEIS to phase out the installation of high carbon forms of fossil fuel heating in properties off the gas grid during the 2020s[55]. In 2035, a ban on gas boilers is enforced for existing buildings (Table 11). It is assumed that the Boiler Upgrade Scheme will run for the announced duration and amount of grant given per installation, while the Social Housing Decarbonisation Fund and Sustainable Warmth competition have extended funding beyond what is used for System Transformation.

Leading the Way

- High electrification and gas grid repurposed to distribute hydrogen.
- Off-gas, new build, and on-gas fossil fuel bans enforced, with exemptions for hybrid heat pumps and H_2 boilers.
- Up-front grants extended for some consumer groups.
- Environmental taxes shifted from electricity to natural gas.

In addition to the Government action assumed in Consumer Transformation, it is assumed that in Leading the Way, environmental taxes will be removed from the cost of electricity and shifted onto natural gas prices in a phased transition from 2025-2028. Another key difference between Leading the Way and Consumer Transformation is that the 2035 ban on gas boilers does not include hybrid heat pumps in Leading the Way.

[55] BEIS, *Clean Growth Strategy*, 2017.

Sensitivity Analysis

- Based on Consumer Transformation.
- Includes recent delays to fossil fuel phase-out dates.

The sensitivity analysis is based on the Consumer Transformation scenario but includes the recent announcements regarding delays to the phase out of fossil fuel heating systems. Fossil fuel heating systems will only be banned from 2035 in existing off-gas homes.

The assumptions for the timescales and ambition of different policies in each scenario are summarised in Table 10 and Table 11 below.

Table 10: Date at which new builds can no longer choose heating fuel

Existing heating technology	Falling Short	System Transformation	Consumer Transformation	Leading the Way	Sensitivity
Gas boilers	No restrictions	2025	2025	2025	2025
Oil & LPG boilers	2025	2025	2025	2025	2025

Table 11: Date at which existing buildings can no longer choose existing heating fuel

Existing heating technology	Falling Short	System Transformation	Consumer Transformation	Leading the Way	Sensitivity
Gas boilers	No restrictions	All switch to H_2 by 2050	2035	2035	2035
Oil & LPG boilers	2035	2030	2027	2025	2035

3.3.3 UPTAKE OF LOW CARBON HEATING TECHNOLOGIES

Figure 27 shows the heating technology breakdown for domestic buildings in each scenario out to 2050. These figures describe the housing stock and provide an overview of the dominant technologies in each scenario world. The technology breakdown for the I&C sector can be found in Appendix A.

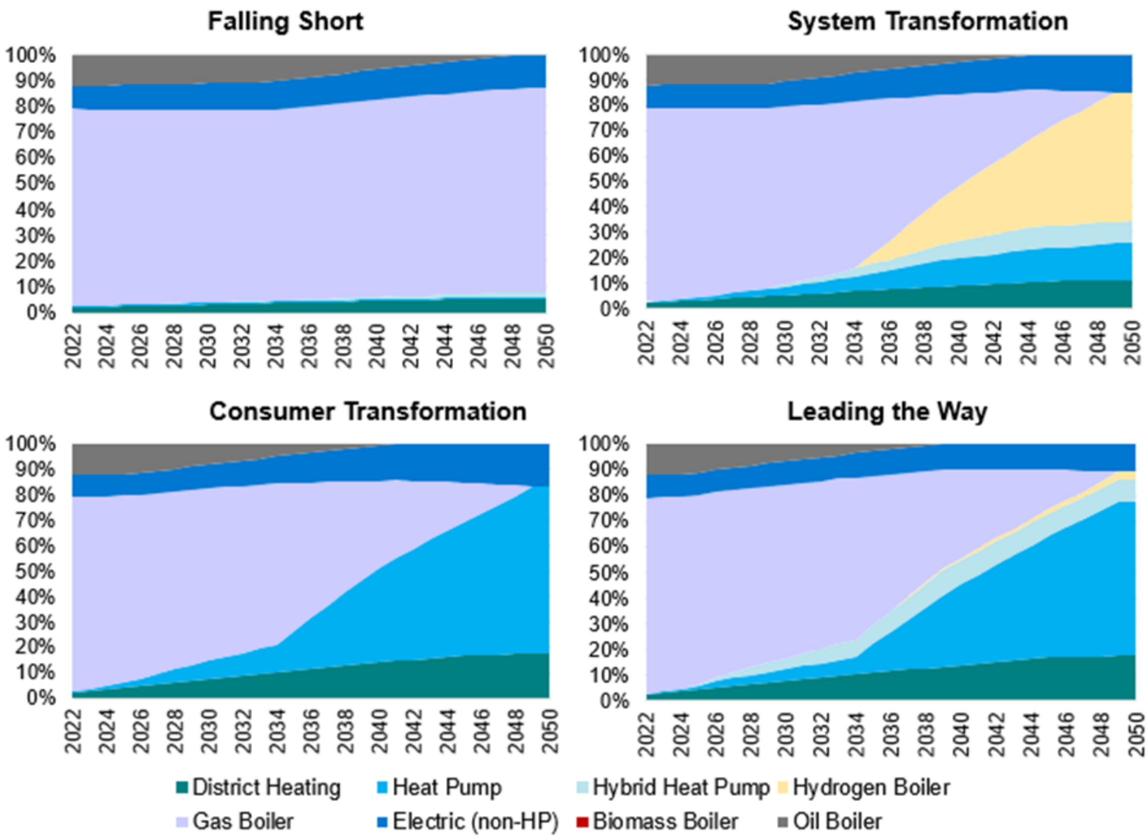


Figure 27: Heating technology breakdown for domestic buildings in UK Power Networks' licence areas

Falling Short fails to fully decarbonise the heating sector, as it still relies heavily on natural gas in 2050. The heat pumps that come into operation are predominantly in the off-gas grid sector. This scenario suggests that without Government intervention, the business case for gas boilers will remain strong, resulting in low uptake of low-carbon heating technologies. In contrast, System Transformation relies on the decarbonisation of the gas grid, with the gas grid assumed to be repurposed to distribute hydrogen by 2050, through a gradual roll-out across the licence area. In both Consumer Transformation and Leading the Way, the 2035 ban on natural gas boilers in existing homes (Table 10) coupled with the assumption of a 15-year lifetime of heating technologies, ensures a near-complete phase-out of gas boilers by 2050. The key difference between Leading the Way and Consumer Transformation is that Leading the Way retains a gas grid distributing low-carbon hydrogen, allowing for the uptake of hybrid heating systems.

Figure 28 shows the resulting number of total domestic heat pumps in each scenario. This figure indicates that by 2027 (March 2028), there could be between 67,000 and 434,000 heat pumps operating in UK Power Networks' licence areas, with a range of about 5,000 and 110,000 heat pumps being installed each year between the lowest and the highest scenario.

The Government has announced ambitions for the 2028 annual heat pump installation rate to reach a target of 600,000, which translates to around 120,000 installations within UK Power Networks' licence areas. The results of this modelling indicate that further Government intervention may be required to reach these ambitious targets. By 2050, the modelled total number of domestic heat pumps in UK Power Networks' licence areas is between 241,000 to 6.1 million, spanning a broader range than reported in last year's DFES (631,000 to 6.60 million by 2050). Most of the domestic building stock is on heat pumps by 2050 in both Leading the Way and Consumer Transformation, the difference between these scenarios being an earlier adoption of heat pumps as well as hybrid heat pumps in Leading the Way, with Consumer Transformation having a higher number of homes on alternative electric heating (e.g., electric storage heaters).

The final 2050 uptake for Falling Short is considerably lower than projected in previous years primarily as a result of the awareness factor introduced to this year's modelling. Since Falling Short assumes no policy bans in later years, uptake is driven only by the business case for low carbon heating systems. Consequently, the awareness factor that moderates uptake in the early years has a more significant effect on the final stock in 2050, since there is no mandatory phase-out of fossil fuel heating systems to drive uptake in later years.

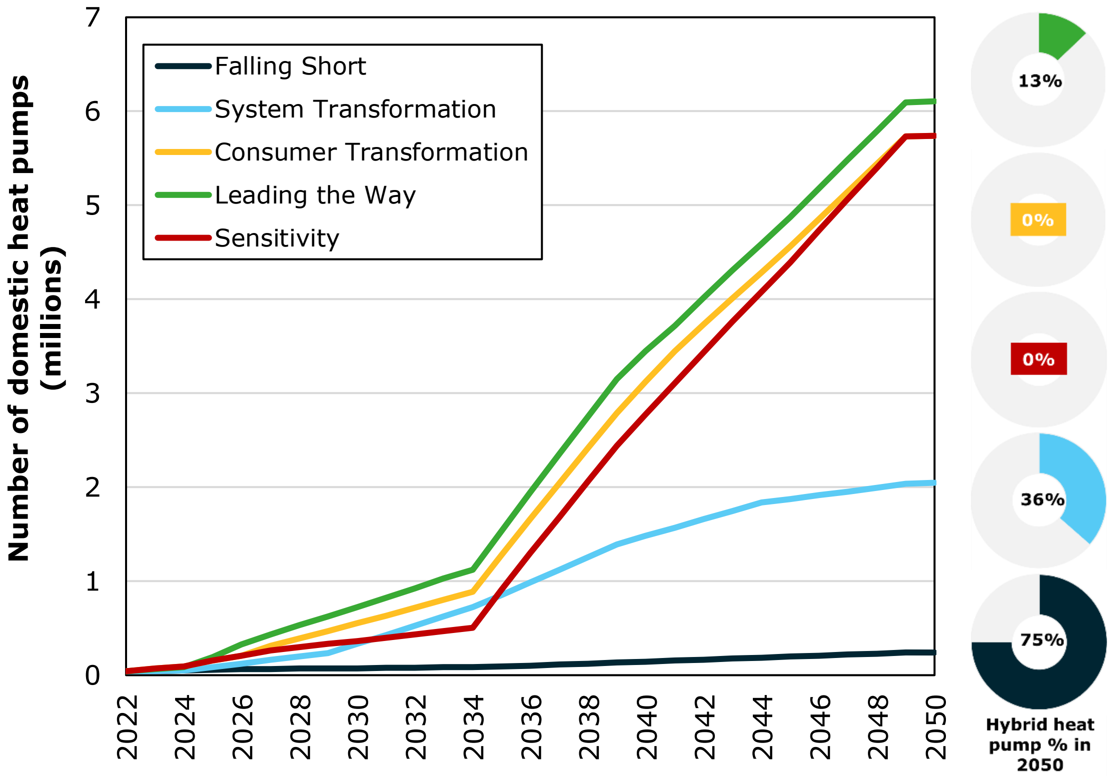


Figure 28: Total number of domestic heat pumps installed in UK Power Networks' licence areas and the proportion of heat pumps that are hybrids in 2050

Similar trends are observed in the I&C sector and Figure 29 indicates that by 2027, there could be between 2,000 and 86,000 I&C heat pumps operating in UK Power Networks' licence areas, rising to between 5,000 and 473,000 by 2050, comparable to the range reported in last year's DFES (4,240 to 385,000 by 2050). In Consumer Transformation and Leading the Way, a high uptake of heat pumps is modelled in the near term, in line with ambitious targets from the Government. Falling Short represents a world where gas boilers still dominate the heating sector by 2050 and uptake of heat pumps in the I&C sector is particularly low.

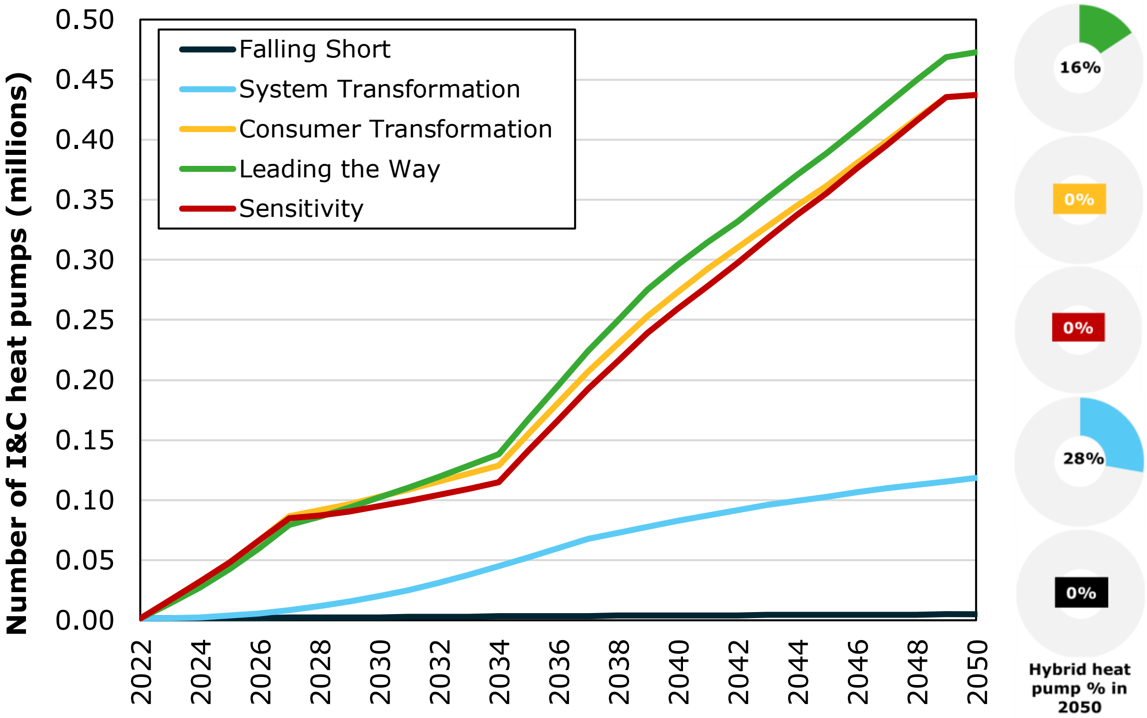


Figure 29: Total number of I&C heat pumps operating in UK Power Networks' licence areas and the proportion of heat pumps that are hybrid in 2050

Sensitivity analysis

For this year's DFES, a sensitivity analysis was undertaken in addition to the four main scenario worlds, in order to capture the impacts of recent changes to net zero policy in the UK. The key policy change for decarbonised heating is the delay of fossil-fuel phase-out dates, as proposed by the Prime Minister in a recent announcement[56]. There have been no changes to phase-out dates in new builds or homes on the gas grid, however, in existing buildings consumers can now continue to purchase oil and LPG-based heating systems until 2035 (Table 11), where previously these were proposed to be banned from 2026[57]. Other input parameters are consistent with Consumer Transformation.

Figure 28 and Figure 29 show the near-term impacts of this change on both domestic and non-domestic heat pumps. After 2027, the sensitivity scenario shows a notably lower uptake of heat pumps, particularly for the domestic sector. The effect is less pronounced for the I&C sector since a significant share of off-gas properties are assumed to adopt biomass boilers rather than heat pumps, particularly in the near term. This highlights the extent to which policy can influence consumers purchase decisions of low carbon technologies, particularly phase-outs and bans.

[56] UK Government, PM speech on Net Zero: 20 September 2023, 2023
[57] UK Government, Consultation: Phasing out the installation of fossil fuel heating in homes off the gas grid, October 2021

In the sensitivity scenario, all fossil fuel heating systems are banned by 2035, and since a 15-year lifetime is assumed for all heating systems, this scenario still reached net zero by 2050. However, while the target is still met, a delayed pathway will lead to total higher emissions due to fossil-fuel heating systems operating for a longer period before decommissioning.

3.3.4 THERMAL EFFICIENCY

During the Heat Street work, a detailed analysis of the domestic and I&C building stock was performed to identify which energy efficiency measures were available for each building archetype and how much they would cost. The building stock in UK Power Networks' region was segmented into over 2,000 different building archetypes, and a thermal energy demand determined for each one, representing the energy required to heat each building (kWh/year). The decarbonised heating technology model, developed in the Heat Street project, was used to identify an optimal thermal energy efficiency and low-carbon technology package for each building archetype.

A thermal energy efficiency package can include multiple improvements, such as window glazing, wall cavity filling and roof insulation, each providing a saving in energy use based on building characteristics. It is assumed that energy efficiency measures are applied at the same time as a new heating technology is fitted and the rate of uptake is determined by the consumer choice module that has been added to the Heat Street work, described previously. The total thermal energy demand for each year was then found by summing up the thermal energy demand for all domestic/I&C buildings in UK Power Networks' licence areas, taking into account the thermal energy efficiency improvements modelled in each scenario. Figure 30 shows the resulting energy efficiency scenarios, relative to a 2022 baseline, for the domestic building stock within UK Power Networks' licence areas.

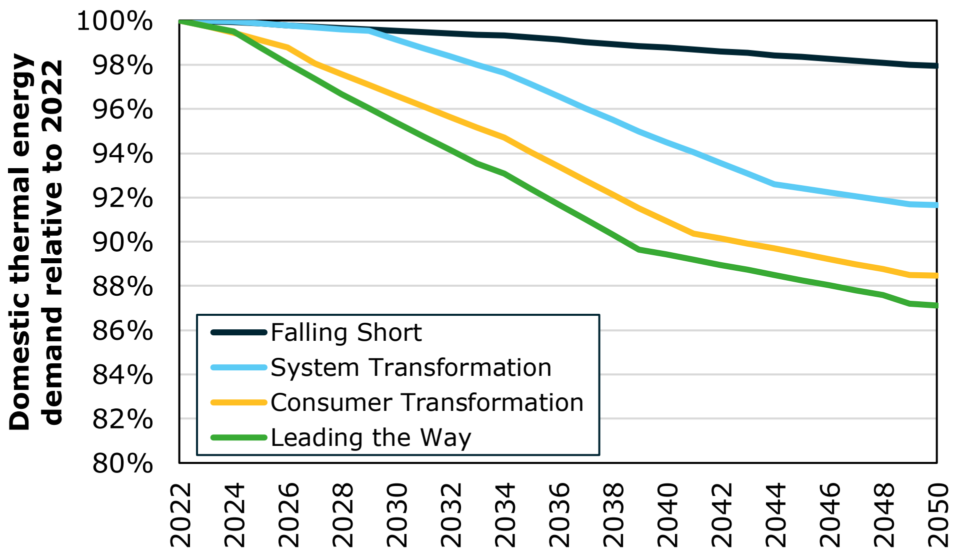


Figure 30: Thermal energy demand in the domestic building stock compared to a 2022 baseline

In the case of I&C building stock, System Transformation has the lowest improvements in thermal energy efficiency compared to all other scenarios, as shown in Figure 31 below. There are several explanations for this, the main one being that energy efficiency measures improve the cost-effectiveness for electric heating technologies, hence scenarios relying on these technologies see higher energy measure uptake. In the case of System Transformation, which is dominated by non-electric, hydrogen-ready boilers, very limited uptake in energy efficiency measures is forecast. This is elaborated on further in the Heat Street Work[58].

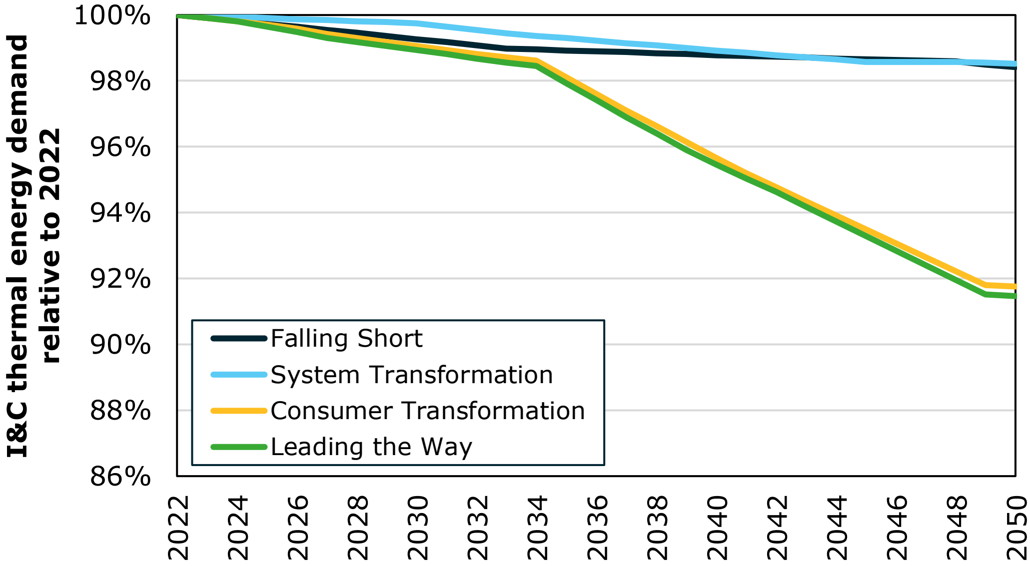


Figure 31: Thermal energy demand in the I&C building stock compared to a 2022 baseline

3.3.5 DISTRICT HEATING

The uptake scenarios for district heating (DH) networks are based on LSOA-level heat density analysis. Areas with higher density heating demand are assumed to be more suitable for district heating. The process used to generate forecasts for district heating is the same as in the previous DFES[59] and is based upon Element Energy work for the Greater London Authority (GLA) and C40 Cities[60].

Figure 32 presents the resulting number of homes on district heating out to 2050. Between 214,000 and 438,000 homes on district heating are modelled by 2027, rising to between 491,000 and 1.55 million by 2050.

[58] UK Power Networks Innovation, Heat Street, 2021.

[59] Element Energy for UK Power Networks, DFES 2023, December 2022, Section 3.3.4 and DFES 2021, January 2021, Section 4.3.3.

[60] Element Energy for the Greater London Authority, London's Climate Action Plan: WP3 Zero Carbon Energy Systems (September 2018)

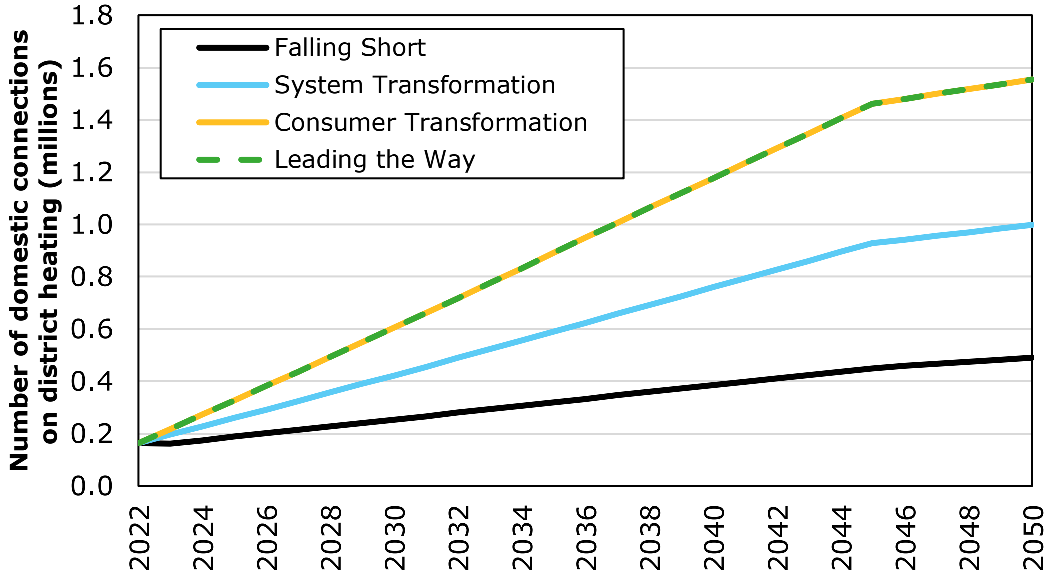


Figure 32: Number of homes within UK Power Networks licence areas using district heating

Figure 33 presents the resulting number of I&C connections on district heating out to 2050. Between 22,000 and 39,000 I&C connections on district heating are modelled by 2027, rising to between 47,000 and 118,000 by 2050.

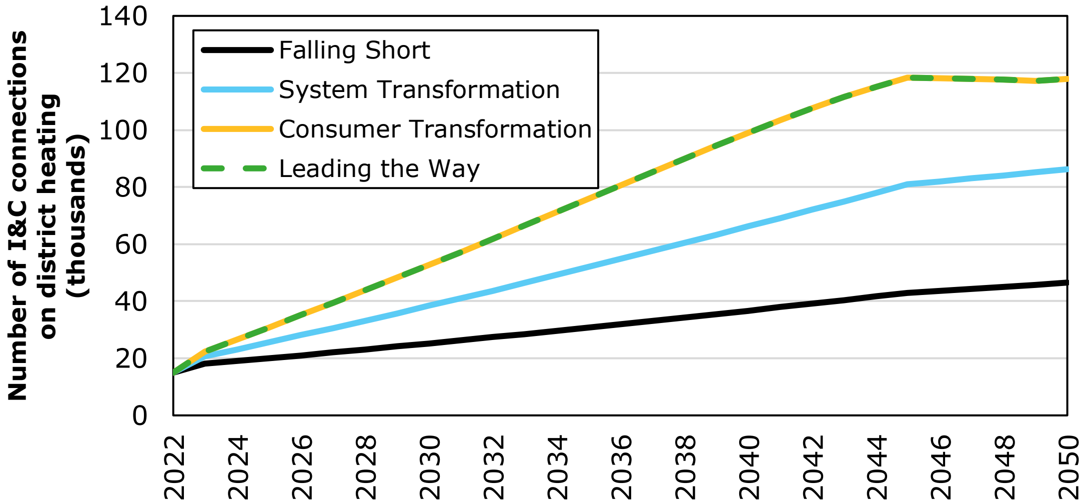


Figure 33: Number of I&C connections within UK Power Networks licence areas using district heating

In addition to the uptake of district heating in the domestic and I&C building stock, four different scenarios are modelled for the heat supply technologies deployed in these heat networks. These scenarios are based on the work Element Energy did for the GLA[60] and the CCC[61] and involve varying degrees of dependence on electrified heating and decarbonised gas, as shown in Figure 34.

[61] Element Energy in partnership with Frontier Economics and Imperial College London, commissioned by the CCC, Research on district heating and local approaches to heat decarbonisation (2015)

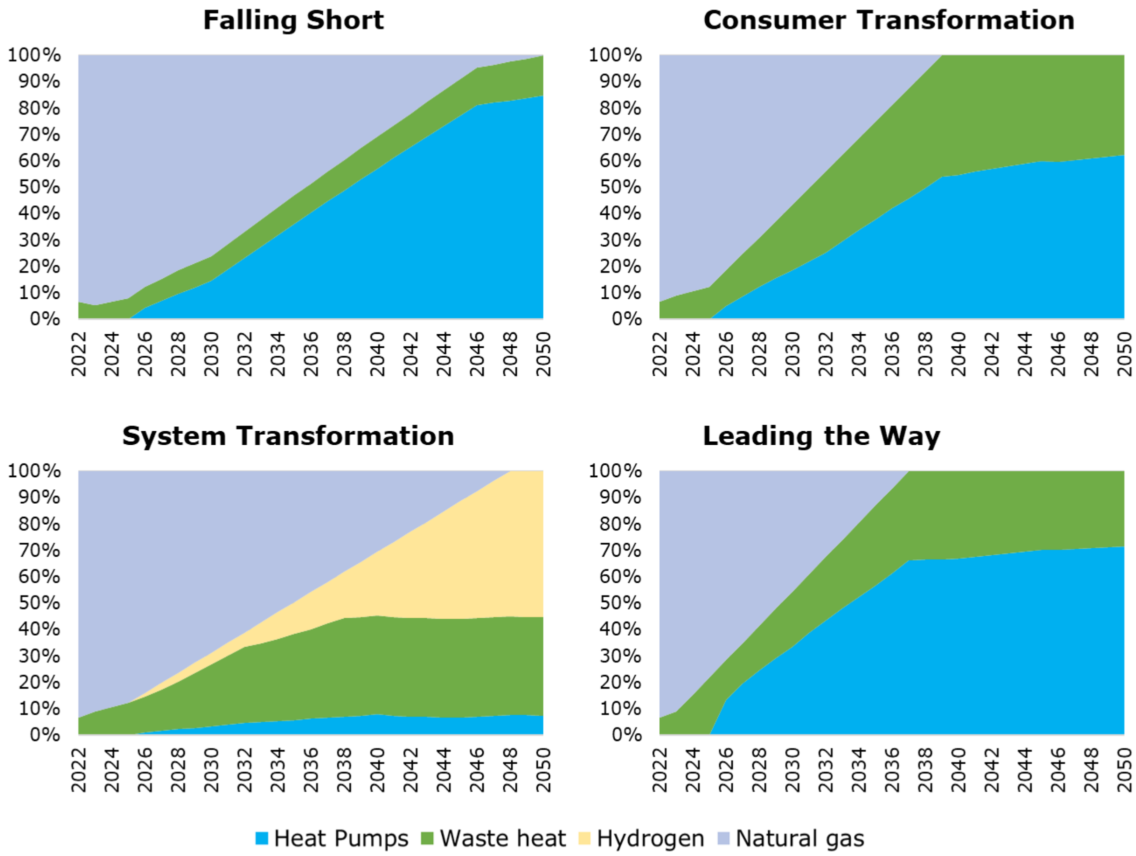


Figure 34: Breakdown of the supply for district heat networks in 2022-2050

3.4 DISTRIBUTED GENERATION

Key Messages

- Scenarios for large-scale solar photovoltaic (PV) capacity are higher than previously due to high capacity of accepted large scale solar generation in the pipeline.
- The forecasted future uptake of decentralised hydrogen generation is significantly higher than in last year's DFES, in line with trends from National Grid FES.
- Gas generation is phased out faster, in line with the CCC's recommendation and the Government's stated ambition.

A broad range of generation technologies that would connect to the distribution network are considered. The different types of distributed generation are categorised to align with the Building Blocks agreed between National Grid ESO and the DNOs through the Energy Networks Association joint working group. For each technology, three future uptake scenarios (low, medium, and high) have been developed and assigned to the four scenario worlds according to how they align with the scenario world narratives (Table 12).

Table 12: Distributed generation uptake scenarios modelled in this work and their mapping to the scenario world framework

Parameter	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Rooftop solar PV*	Low	Medium	High	High
Large-scale solar PV*	Low	Medium	Medium	High
Onshore wind	Low	Low	High	Medium
Renewable engines (landfill-, sewage- and biogas)	Low	Medium	High	High
Waste incineration (including CHP)	High	Medium	Medium	Low
Biomass and energy crops (including	High	Medium	Medium	Low
Hydrogen generation	Low	High	Medium	Medium
Non-renewable CHP	High	Low	Low	Low
Non-renewable engines (non-CHP)	High	Low	Low	Low
OCGTs and CCGTs	High	Low	Low	Low

* Rooftop solar PV is defined as installations of capacity less than or equal to 150 kW and large-scale solar PV refers to installations larger than 150 kW.

3.4.1 MODELLING METHOD

The approach used for modelling the uptake of distributed generation consists of three steps, as outlined in Figure 35.

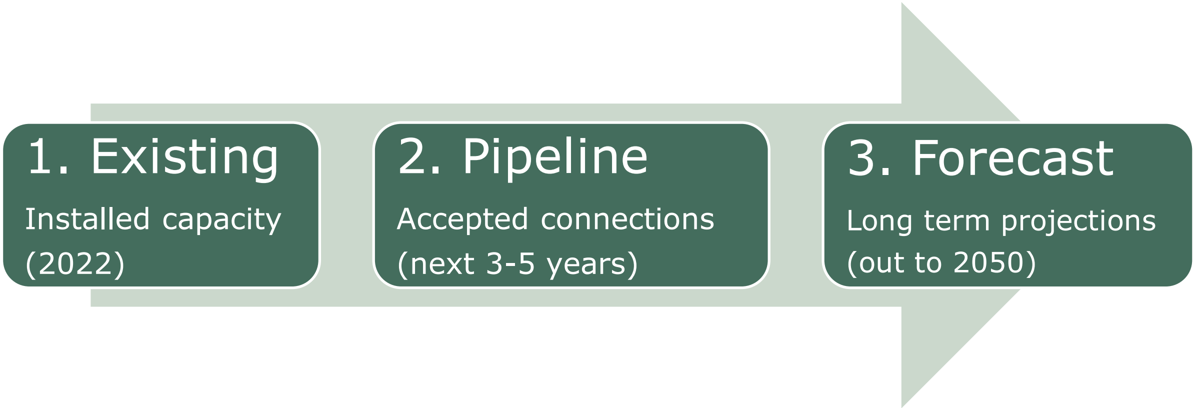


Figure 35: Pathway for modelling distributed generation

A variety of data sources were used to determine the baseline of existing generation capacity in the UK Power Networks region. Three capacity bands were defined for installation size and information gathered on connections for each band from a suitable data source (Table 13). Combined, these sources provided a detailed baseline for installed capacity, generation site locations and installation dates.

Table 13: Existing generation capacity bands and data sources

Capacity band	Data source
Less than or equal to 50 kW	Feed-in Tariff (FiT) data (installations prior to April 2019) LCT Register (rooftop PV installations after April 2019)
Between 50 kW and 1 MW	Embedded Capacity Register (ECR) and Low Carbon Technology (LCT) Register (rooftop PV installations after April 2019)
Larger than or equal to 1 MW	Embedded Capacity Register (ECR)

The ECR is updated monthly and since the last DFES, the ECR has been extended down to 50 kW[62], replacing the Distributed Generation Database (DGDB) and R180 as the source for installations between 50 kW and 1 MW. Additionally, there have been further improvements to the categorisation of different generation types in the ECR, bringing it closer in line with NGESO FES Building Blocks agreed via the Energy Networks Association's Open Networks project. An example of the improved categorisation is further detail on generation sites using biomass and biogas, allowing for a clearer allocation of these sites to the Building Blocks "Biomass" and "Renewable Engines (Landfill gas, Sewage gas, Biogas". The key changes observed in the ECR since last year's DFES are confirming 99MW of OCGT sites in LPN are no longer connected/exporting and a re-categorisation of non-renewable engines to non-renewable CHP, and of waste incineration to biomass and renewable engines. This led to

[62] The ECR previously covered only installations larger than or equal to 1 MW.

improved accuracy of the established generation baselines and as a result, the existing capacity reported may differ from the baseline in last year's DFES (2023).

This update is the first to use the LCT register[63] to establish the baseline for rooftop solar PV, which provides much more detailed information than the data that was previously used. Where previous datasets only gave the total installed capacity for each quarter, the LCT register provides the capacity of each installation, similar to the FiT dataset. This is of particular use for establishing the baseline of the different sizes of solar PV, since modelling of this technology considers uptake within several discrete capacity bands (**Section: 3.4.2.1**).

As shown in Figure 36, the baseline capacity of rooftop PV in 2022 used this year grew from the 2021 baseline and is in-line with the forecasted capacity in Leading the Way and Consumer Transformation scenarios from the last DFES.

For large-scale PV, the growth in the baseline installed capacity was smaller and had not matched the growth projected in the last DFES forecasts. As discussed in the previous DFES report, the capacity of accepted large-scale solar PV connections grew significantly between 2021 and 2022, resulting in a high near-term (pipeline) forecast of large-scale solar PV (see pipeline methodology below). While the DFES presents an 'unconstrained' view of the future, some of the generators in that pipeline may experience delays in installation timescales due to transmission network constraints, which will have been a factor in a lower capacity being realised over the past year than modelled in the last DFES, but which may be less material in future with the introduction in 2023 of reforms[64] to how transmission constraints affect connections to the distribution network.

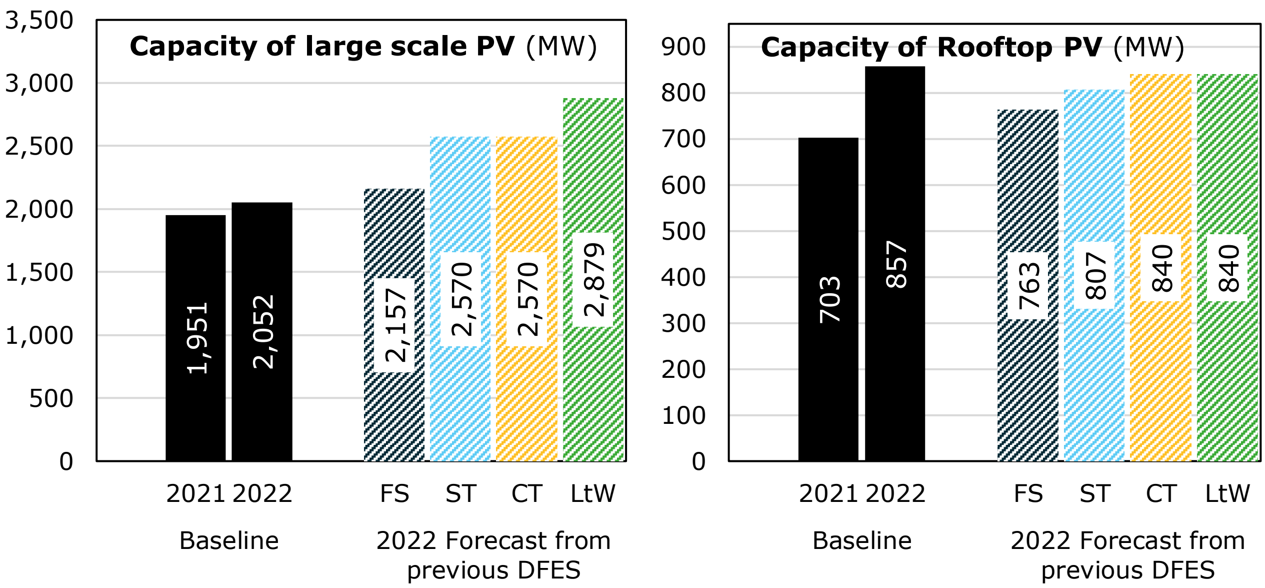


Figure 36: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) capacity of large (left) and rooftop (right) PV compared to 2022 forecast from DFES 2023

Table 14 shows the 2021 and 2022 baselines for all distributed generation technologies (excluding storage) compared to the forecast from last year's DFES. In most cases the 2022

[63] UK Power Networks, Low Carbon Technology Register, 2023
[64] Energy Networks Association (ENA), How we're improving grid connections, 2023

baseline is broadly aligned with the forecast with some changes in baseline values due to updates to the ECR, particularly for non-renewable CHP and renewable engines.

Table 14: DFES 2024 (2021 baseline) and DFES 2024 (2022 baseline) installed capacity of all distributed generation (excluding storage) compared to 2022 forecast from DFES 2023

	Baseline (MW)		2022 forecast from previous DFES (MW)			
	2021	**2022**	**FS**	**ST**	**CT**	**LtW**
OCGTs and CCGTs	2600	2359	2678	2618	2618	2618
Non-renewable engines	769	882	815	774	774	774
Non-renewable CHP	46	205	52	47	47	47
Hydrogen	0	0	0	0	0	0
Renewable engines	272	348	276	284	290	290
Biomass	362	386	380	374	374	366
Waste incineration	438	366	459	452	452	442
Offshore wind	961	961	961	961	961	961
Onshore wind	643	657	643	643	646	645
Large scale solar	1951	2052	2157	2570	2570	2879
Rooftop solar (small)	478	553	503	528	550	550
Rooftop solar (large)	225	304	260	279	290	290
Other Generation[65]	56	111	56	56	56	56
Total	**8800**	**9182**	**9240**	**9586**	**9628**	**9918**

For all technologies, the near-term uptake was modelled based on the UK Power Networks' database of accepted connection offers for generators, or "pipeline" data. Based on stakeholder consultation, a typical acceptance-to-connection conversion rate was modelled and assumed an average period between acceptance and installations. These conversion rates and installations timescales were varied between technologies; with the help of external stakeholders, in previous DFES work [66], technology-specific scenarios were developed for the connection rates and timescales (Table 15).

A range of sources was analysed to develop the long-term generation forecasts. ERM consumer choice and investor decision modelling was used for solar PV, which is most suited to this type of uptake modelling. The modelling method for solar PV is described in detail in past DFES[67] reports. Another source of information used is the NGESO FES Building Block data, which is published by National Grid ESO with the generation capacity forecasts available to GSP level. Using this Building Block data, the NGESO view is readily established at a UK Power Networks licence area level. Past assessment (from the previous three DFES) of suitability of different generation technologies to UK Power Networks' region are then used to sense check the National Grid ESO long-term allocation of these technologies to UK Power Networks' licence

[65] No forecast is provided for this generation category, linked to generation <1MW recorded without a fuel type; capacity in future years is assumed equal to the base year.

[66] Element Energy for UK Power Networks, DFES 2020, February 2020, Section 4.4

[67] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, DFES 2020, February 2020, Section 3.4.1 and DFES 2021, January 2021, Section 4.4.1.

areas. These sources are used to generate scenarios of distributed generation specific to UK Power Networks' region.

Table 15: Modelling method for distributed generation technologies

Technology	Renewable	Pipeline connection rate in scenario (low / medium / high)	Pipeline length	Long-term forecast
Solar PV	✓	20% / 60% / 90%	5 years	ERM in-house modelling
Offshore wind	✓	No accepted connections	-	Expected to connect at transmission level in future
Onshore wind	✓	20% / 60% / 90%	5 years	Regional disaggregation of NGESO's FES
Renewable engines (landfill-, sewage- and biogas)	✓	20% / 60% / 90%	3 years	Regional disaggregation of NGESO's FES
Waste incineration (including CHP)	*	20% / 60% / 90%	5 years	Regional disaggregation of NGESO's FES
Biomass and energy crops (including CHP)	✓	20% / 60% / 90%	5 years	Regional disaggregation of NGESO's FES
Hydrogen generation	**	No accepted connections	-	Regional disaggregation of NGESO's FES
Non-renewable CHP	✗	20% / 60% / 90%	3 years	Regional disaggregation of NGESO's FES
Non-renewable engines (non-CHP)	✗	10% / 40% / 90%	3 years	Regional disaggregation of NGESO's FES
OCGTs and CCGTs	✗	20% / 60% / 90%	3 years	Regional disaggregation of NGESO's FES

* Energy from waste is only partially renewable due to the presence of fossil-based carbon in the waste.

** Electricity produced from hydrogen will only be renewable if the hydrogen is renewable, i.e., produced via electrolysis using renewable electricity.

Figure 37 shows the total distributed generation forecast in the UK Power Networks' region for all four scenario worlds in 2027 and 2050. This figure demonstrates that, based upon the modelling, solar PV is likely to be the dominant distributed generation technology in UK Power Networks' region in a decarbonised future. The three Net Zero compliant scenario worlds phase out non-renewable generation technologies and rely strongly on solar and onshore wind, whereas Falling Short continues to rely on electricity from gas out to 2050. Due to the high uptake of rooftop solar PV and large-scale solar PV in Leading the Way, the highest total installed capacity is seen in 2027 and 2050 for this scenario world. In the following sections, these results are discussed in more detail and together with a detailed outlook for solar PV, the largest single contributing factor to the generation mix in 2050 for all four scenario worlds.

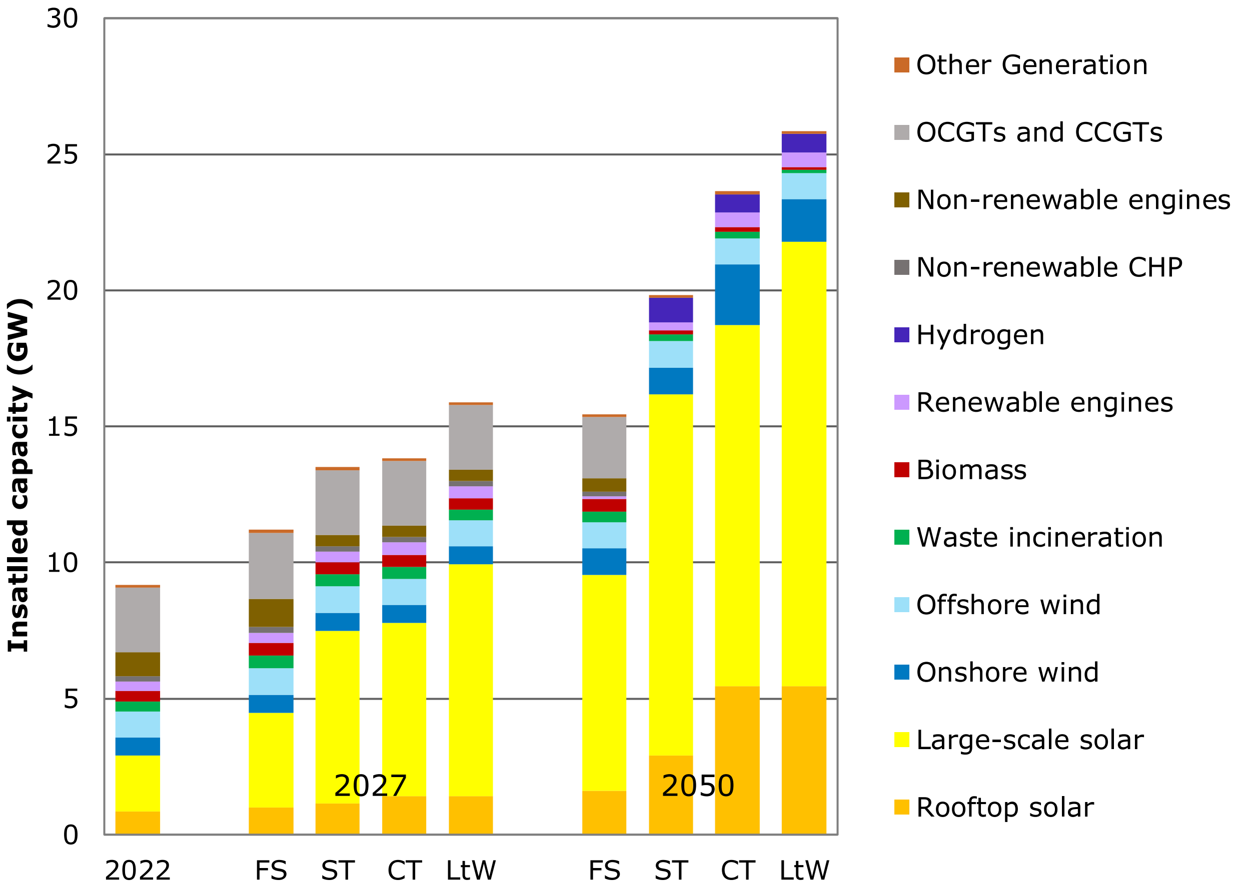


Figure 37: Capacity of distributed generation installed in UK Power Networks' licence areas in the base year of the scenarios (2022), in 2027 and 2050

3.4.2 RENEWABLE GENERATION

A range of renewable generation technologies is modelled as listed in Table 15. In the following section the modelling of these technologies is outlined, with an emphasis on solar generation as it is expected to be the dominant distributed technology in UK Power Networks' region going forward.

3.4.2.1 SOLAR PV

Solar PV uptake scenarios are derived using the consumer choice model and investor decision model for rooftop (≤150 kW) and large-scale (>150 kW) generation uptake, respectively. The modelling approach remains consistent with the previous DFES.

The uptake models account for variation in solar PV installation properties and economics by modelling different size bands. The size bands have been associated with typical installation types[68], as summarised in Table 16 below, and different installation costs applied to each band.

Table 16: Solar PV sizing brackets and respective classifications

Solar PV Size Bracket (kW)	Classification
≤ 4	Small rooftop (domestic)
4 – 150	Large rooftop (industrial and commercial)
> 150	Large-scale (typically ground-mounted)

Rooftop solar PV (≤150kW)

Rooftop solar PV is defined as being those installations that occur on rooftops of domestic and I&C buildings (Table 16). Figure 38 illustrates that in 2050, between 0.794 and 3.39 GW of small rooftop PV capacity is expected to be installed in UK Power Networks' licence areas, corresponding to between 0.3 and 1.1 million homes having rooftop solar PV (assuming an average installation of 3 kW per household), consistent with the results from the previous DFES. In the I&C sector, between 0.818 and 2.06 GW of large rooftop solar PV capacity is modelled by 2050, broadly consistent with the previous DFES. The lowest uptake is modelled in Falling Short as the energy system in that scenario will continue to rely on gas-fired generation in 2050 and less emphasis will be placed on incentives for the uptake of renewable generation. A drop-off in cumulative installations can be seen in 2040 in Falling Short, when early installations reach the end of their life, assuming a 20–30-year lifetime of rooftop solar PV.

[68] Based upon data from the LCT register, 91% of domestic connections are ≤4kW, and 20% of I&C connections are also ≤4kW. Noting that the ≤4kW category is predominantly but not entirely domestic (99.4%), we have updated the name of this category for DFES 2024. However, the modelling approach remains the same since the volume of domestic connections is much higher than I&C connections, so it is possible to make the generalisation that everything ≤4kW is domestic for simplicity.

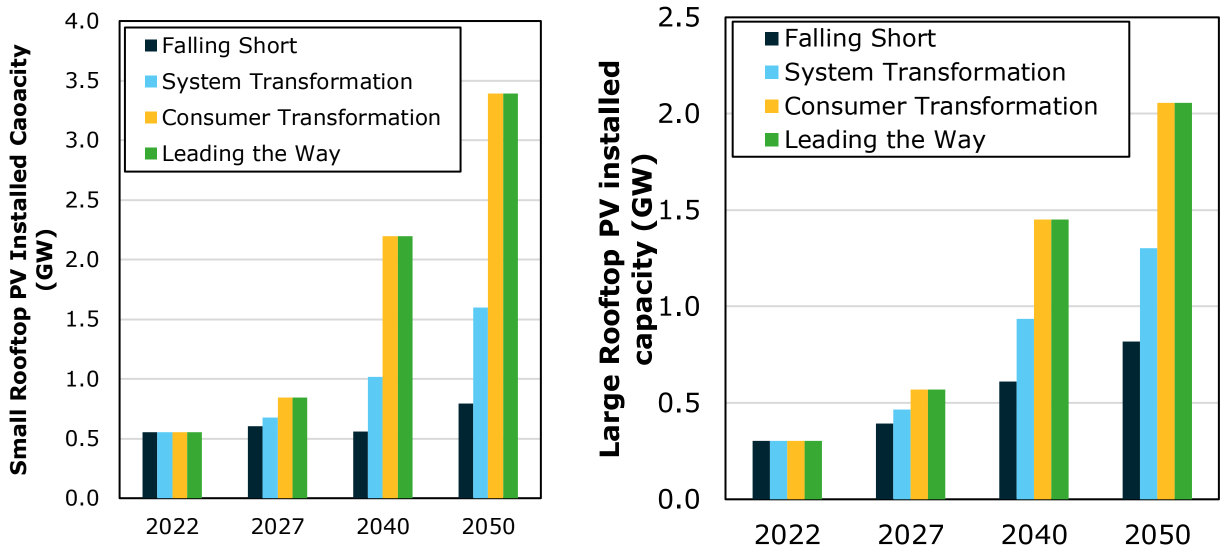


Figure 38: Installed capacity of small (left) and large (right) rooftop solar PV

Large-scale solar PV (>150kW)

A significant capacity increase is expected in large-scale ground mounted solar arrays. This growth is expected to be centred in areas which are particularly suitable for solar, such as the East of England where land availability and good solar resources will continue to drive high uptake (Figure 39). Between 7.9 and 16.3 GW of installed capacity of large-scale solar PV are modelled in UK Power Networks' licence areas by 2050, somewhat higher than in previous DFES (between 7.4 and 14.6 GW by 2050). This difference stems from the significant increase in capacity of accepted connections for large-scale solar PV generators in SPN, resulting in a steeper uptake over the pipeline years. As presented in Table 15, the pipeline duration for large-scale solar PV is 5 years and the connection ratios are 20%, 60%, and 90% in the low, medium and high scenarios, respectively. This translates to 90% of all accepted connections being connected in the next 5 years in Leading the Way (high scenario).

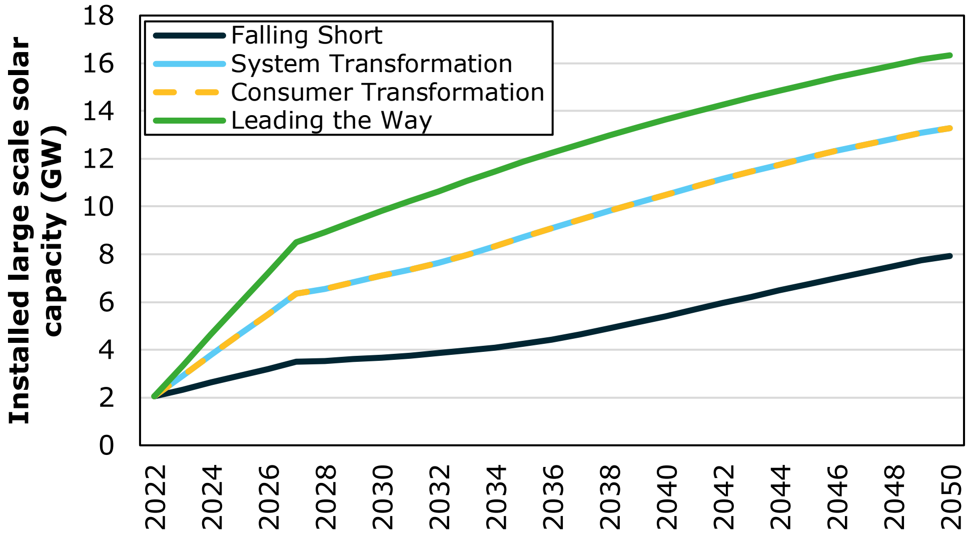


Figure 39: Installed capacity of large-scale solar PV in UK Power Networks' licence areas out to 2050

3.4.2.2 OTHER RENEWABLE GENERATION

Table 17 summarises the uptake of the renewable generation technologies across the four scenarios. In the National Grid Future Energy scenarios, bioenergy is still relied on to deliver net-zero power sector emissions through BECCS. However, this technology is not expected to be deployed at scale before 2030, since it still requires emissions accounting standards, investor confidence, and further technology demonstration. In the UKPN region, the biomass electricity installations are all below 50 MW, making them unlikely to be suitable for BECCS. The distribution connected biomass generation (Figure 40) baseline has been slightly increased in this year's DFES (7%). It can be seen however that there is a precipitous decrease in biomass capacity in the Net Zero scenarios towards 2050, reflecting the shift to transmission-connected biomass generation.

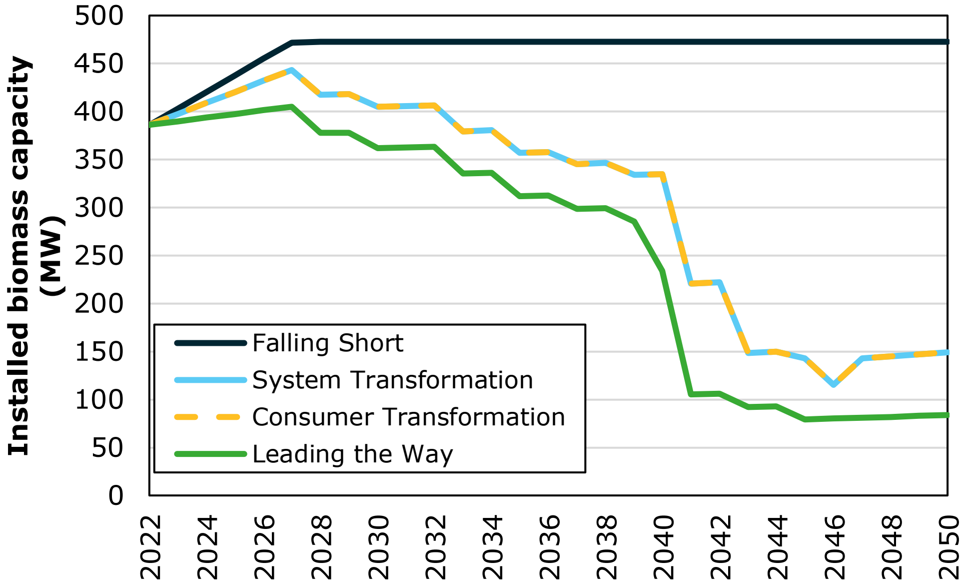


Figure 40: Biomass and energy crops (including CHP) distribution network connected generation capacity for the UKPN region

3.4.2.3 ONSHORE WIND

The onshore wind uptake reflects the narrative of the scenario worlds from the National Grid Future Energy Scenarios[69]. The Consumer Transformation scenario sees the highest uptake as the future in which electrification is the highest and more decentralised technologies, including onshore wind, are used to achieve decarbonisation. The most ambitious scenarios assume that planning law reform enables a higher uptake, however growth in the near term for other scenarios is still relatively limited due to uncertainty surrounding the exact nature of such changes and when they may occur. Furthermore, short-term growth is assumed to be suppressed by other barriers such as overcoming network connections and increased material costs due to recent price inflation. Less ambitious scenarios also assume lower levels of societal change, where there is a greater preference for offshore wind due to land use and visibility concerns.

[69] National Grid ESO, Future Energy Scenarios, 2023

Table 17: Modelled outputs of renewable generation in 2050 by scenario world

Technology	2050 Installed Capacity (MW)			
	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Onshore wind	982	982	2220	1572
Renewable engines (landfill-, sewage- and biogas)	98	285	554	554
Waste incineration (including CHP)	380	253	253	126
Biomass and energy crops (including CHP)	473	149	149	84
Hydrogen fuelled generation	0	909	669	669

3.4.2.4 WASTE INCINERATION

The baseline for waste incineration has decreased by 17% for this update, as a result of updates to the ECR dataset. All Net Zero scenarios reflect the view that waste as a feedstock should only be a transitional fuel and should not be viewed as a sustainable energy source (Figure 41). This is reflected by a 2030 peak followed by reducing uptake out to 2050. The rate of capacity reduction in the net-zero scenarios is greater than in previous years.

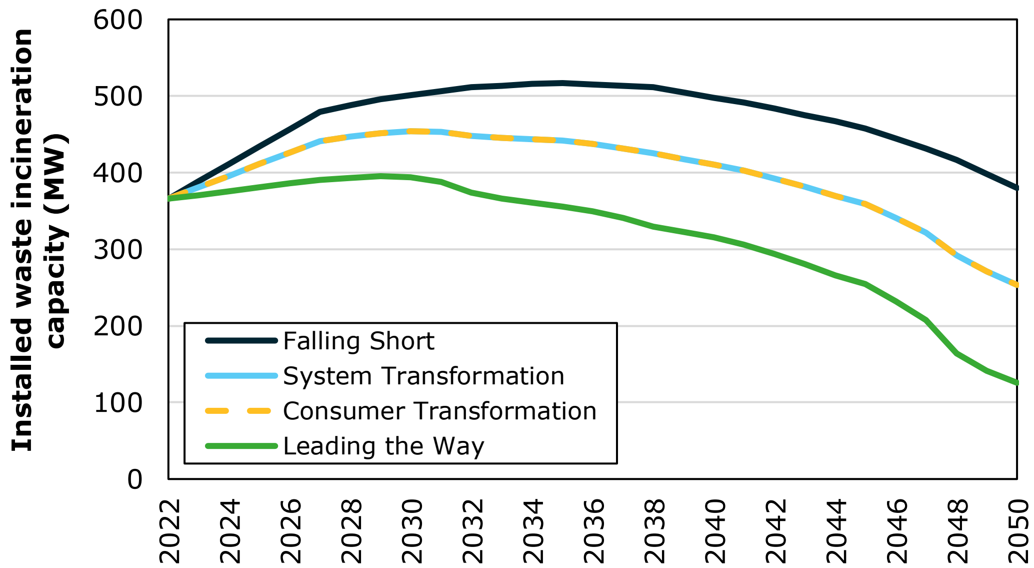


Figure 41: Waste incineration generation capacity for the UKPN region

3.4.3 NON-RENEWABLE GENERATION

A range of distributed non-renewable generation technologies are modelled. In the Net Zero scenarios, generation from non-renewable sources is phased out by 2035 (Table 18), consistent with the "low" uptake scenarios (Table 12). This aligns with the scenarios of the Climate Change Committee in its 6th Carbon budget and the ambition of the UK Government to decarbonise electricity generation by 2035 expressed in the Net-Zero strategy[70]. National Grid ESO's FES phases out unabated gas generation capacity by 2035 in the Leading the Way scenario, 2043 in System Transformation, and after 2046 in Consumer Transformation. Despite this, National Grid ESO expects the future grid CO_2 intensity to fall below zero before 2035 for all Net Zero scenarios due to increased role of BECCS and other negative emission technologies.

Table 18: Non-renewable electricity generation capacity in the UKPN region

Installed generation capacity (MW)	Falling Short			Net Zero scenarios (ST, CT, LtW)		
	2022	2035	2050	2022	2035	2050
Non-renewable CHP	205	208	181	205	0	0
CCGTs and OCGTs	2,359	2,257	2,237	2,359	0	0
Non-renewable engines	882	683	488	882	0	0

The updated baseline and pipeline generation capacities have shifted relative to last year's DFES due to additional detail available in UK Power Networks' generation databases and the extension of the ECR down to 50 kW. This data allowed for more accurate classification of the installed fossil gas capacity, in particular as either large gas turbines, non-renewable CHP or non-renewable engines. As shown in Table 14, there is a considerable difference in the baseline capacity of Non-renewable CHP from last year's DFES (an increase from 46 MW to 205 MW), as well as a 9% decrease in baseline capacity of CCGTs and OCGTs and a 15% increase in capacity of Non-renewable engines.

[70] HM Government, *Net Zero Strategy: Build Back Greener*, October 2021

3.5 ENERGY STORAGE

Key Messages

- The number of domestic batteries in UKPN has increased very rapidly over the past 2-3 years, a trend which appears set to continue.
- The high uptake of co-located storage as well as V2G services diminish the need for standalone grid storage in Leading the Way.
- A new pipeline methodology has been applied that more accurately captures the near-term uptake of large-scale battery storage.

The uptake of four different battery storage use cases was modelled. For each use case, three to four future uptake scenarios were developed which were then assigned to the four scenario worlds as outlined in Table 19.

Table 19: Battery storage types modelled and their mapping to scenario worlds

Scenario World	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Domestic battery storage	Low	Medium	High	High
I&C behind-the-meter battery storage	Low	Medium	High	Medium
Co-located battery storage	Low	Medium	Medium	High
Standalone grid-connected battery storage[71]	High	Medium with early phase out	Medium with late phase out	Low

3.5.1 MODELLING METHOD

The uptake of battery storage for each use case is modelled based on a specific set of assumptions around the associated business case for those particular battery storage installations. Table 20 shows the different use cases, the relevant business case considered, and the modelling method used.

[71] Refer to Section 3 for additional detail on how standalone grid-connected battery storage capacity is determined. The capacity required for this segment depends on the total system storage requirement and the deployment across the other storage segments.

Table 20: Modelled battery storage use cases and the corresponding business cases and modelling methods

Technology use case	Modelled business case	Modelling method	Pipeline methodology
Domestic battery storage	**Coupled to solar PV** Maximise own use	Consumer choice modelling coupled with small rooftop solar PV uptake modelling	Near term uptake based upon consumer choice modelling
I&C battery storage	**Arbitrage and system balancing** Electricity price arbitrage, avoidance of network charges and provision of services to National Grid	Consumer choice modelling	Near term uptake based upon consumer choice modelling
Co-located battery storage	**Coupled to solar PV** Electricity price arbitrage, capacity market	Investor decision modelling coupled with large-scale solar PV uptake modelling	Based upon site-by-site analysis
Standalone grid-connected battery storage	**System balancing and arbitrage** Provision of services to National Grid, wholesale market price arbitrage	Based on modelling of total storage requirements	Based upon site-by-site analysis

The baseline of installed capacity of domestic and I&C storage is based on figures from the LCT register[72]. The LCT register provided an improvement of baseline estimates from previous DFES publications, which were not based on actual data of installed capacity of storage connections[73], but rather modelled with the consumer choice models used for the uptake modelling for each technology. Figure 42 shows that last year's DFES baseline figures likely underestimated the capacity of domestic storage connected to UK Power Networks' network but overestimated the capacity of I&C behind-the-meter storage connected to the network.

[72] UK Power Networks, Low Carbon Technology Register, 2023
[73] This data has only recently become available.

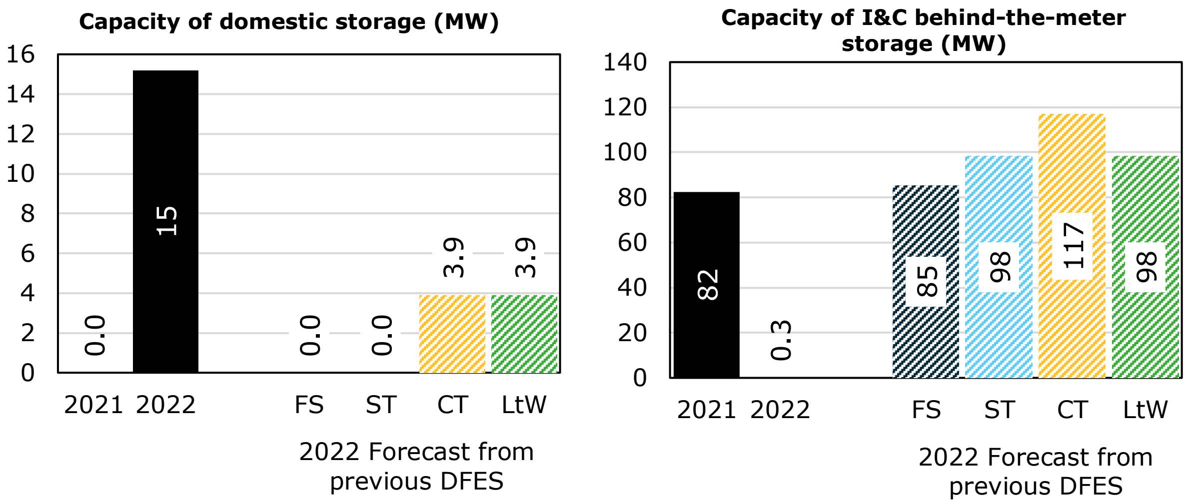


Figure 42: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) capacity of domestic (Left) and I&C (Right) battery storage compared to 2022 forecast from DFES 2023

Figure 43 shows how the capacity of domestic storage in particular has increased rapidly over the course of two years, according to data from the LCT register.

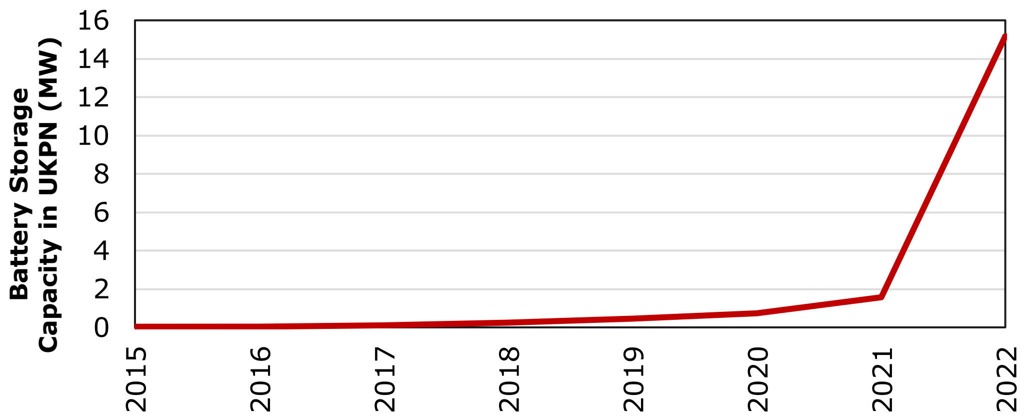


Figure 43: Cumulative capacity of domestic battery storage since 2015

The baseline for large scale battery storage, both batteries co-located with generation and standalone grid connected batteries, is from the ECR and is supported by an analysis by Regen, described below, to determine which sites belong to each category. The increase in co-located battery storage capacity between DFES 2023 and DFES 2024 is slightly higher than the forecasted increase in System Transformation and Consumer Transformation. In the previous DFES, these scenarios assumed that 60% of the capacity of accepted connections from the ECR would materialise in the first 5 modelled years (with the increase in each of the 5 years representing one-fifth of the 60% of the total accepted capacity). The baseline of standalone grid scale battery storage capacity decreased between DFES 2023 and DFES 2024 due to an updated approach of assigning large scale battery storage sites to each of these categories. The baseline is defined as capacity installed as of end March 2023, and it should be noted that between April and September 2023, 298 MW of additional standalone battery storage capacity was installed to UK Power Networks' network.

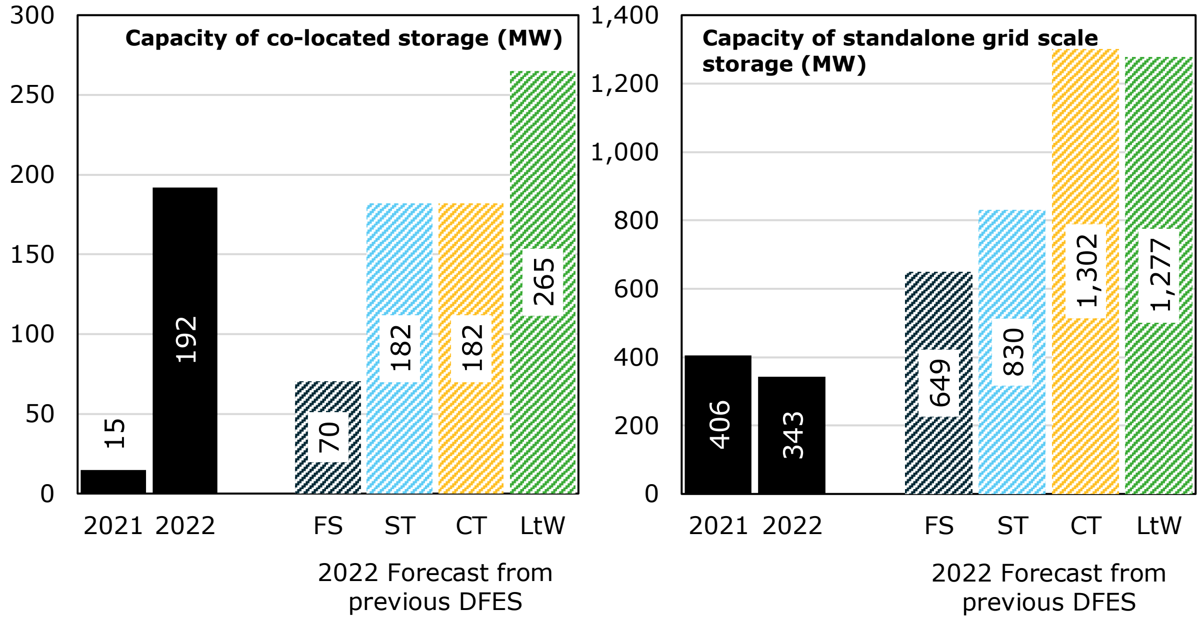


Figure 44: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) capacity of co-located (left) and standalone grid scale (right) battery storage compared to 2022 forecast from DFES 2023

Figure 45 shows the total battery storage capacity forecast in the UK Power Networks' region for all four scenario worlds in 2027 and 2050. Significant growth in battery capacity out to 2050 is expected in all scenarios. Consumer Transformation is a scenario world in which distributed technologies dominate the approach to reaching Net Zero emissions. As a result, it sees the highest uptake of behind-the-meter storage, including both domestic batteries and I&C batteries. Leading the Way has the highest uptake of large-scale solar generation, resulting in the highest deployment of batteries co-located with large-scale solar PV. In Leading the Way, the need for grid-connected standalone batteries is diminished by 2050 as system balancing is performed by distributed sources such as behind-the-meter batteries, batteries co-located with generation, and vehicle-to-grid services from the EV stock (see **Section 3.6.3**). In Falling Short, lower levels of both behind-the-meter storage and co-located storage are deployed, and there is no uptake of vehicle-to-grid services from electric vehicles. This results in a greater requirement for large scale standalone batteries in the long term. In System Transformation, a mixture of technologies is deployed. In the following sections, the modelling approaches and assumptions are outlined, and the results are discussed in more detail.

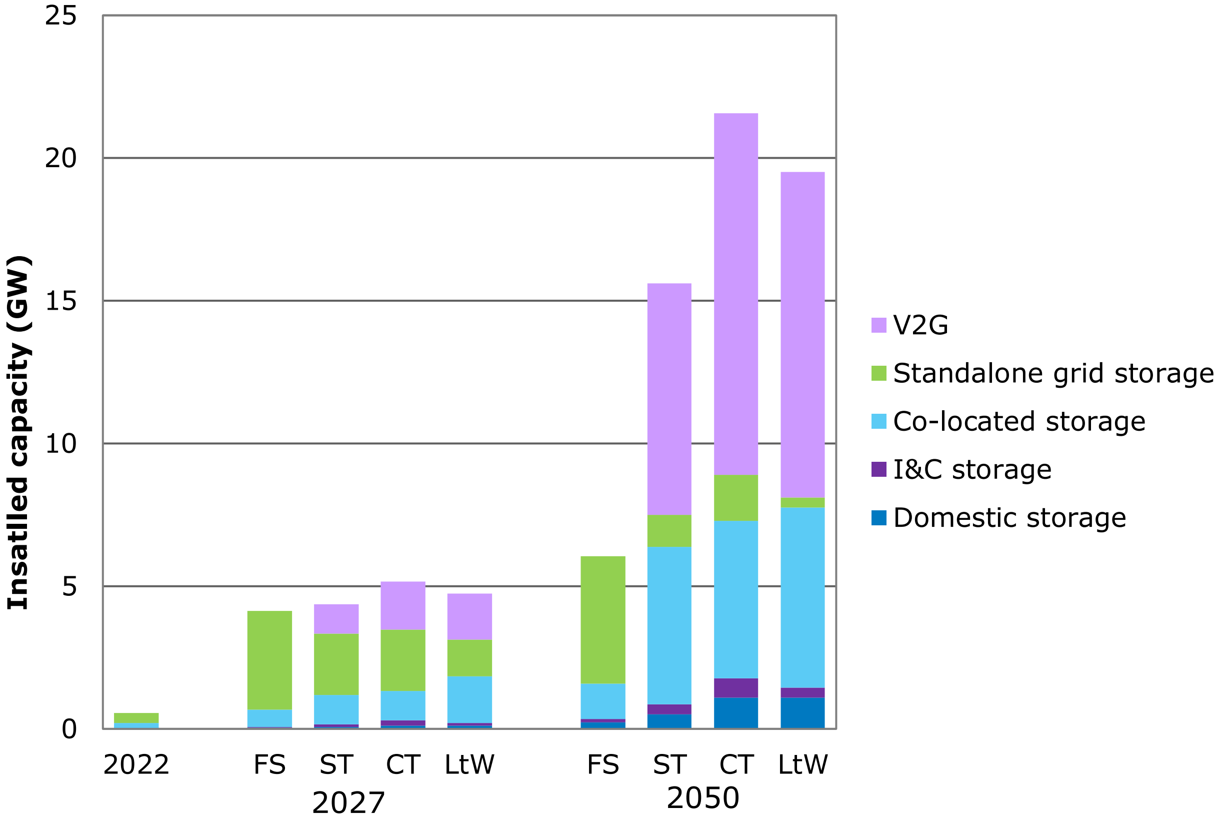


Figure 45: Distributed battery storage in UK Power Networks' region at baseline (2022), in 2027 and 2050

3.5.2 BEHIND-THE-METER BATTERY STORAGE

The modelling approach determines uptake of two distinct cases of behind-the-meter battery storage: domestic batteries, and industrial and commercial batteries.

Domestic battery storage

The business case for domestic storage is coupled to the uptake of small rooftop solar PV (capacity ≤ 4 kW). Uptake scenarios for domestic storage were derived using ERM's consumer choice model described in the previous DFES[74]. Purchase decisions are considered only for the following cases: a solar PV system; a solar PV system with a battery; retrofitting a battery to an existing solar PV installation; or neither solar PV nor battery. An average battery power of 2 kW with a two-hour storage capacity is assumed, and variances in battery pack costs, installation costs, and product availability are accounted for across the three scenarios. If the battery option is chosen, the owner is assumed to use it primarily to maximise their own consumption of their solar PV generated electricity.

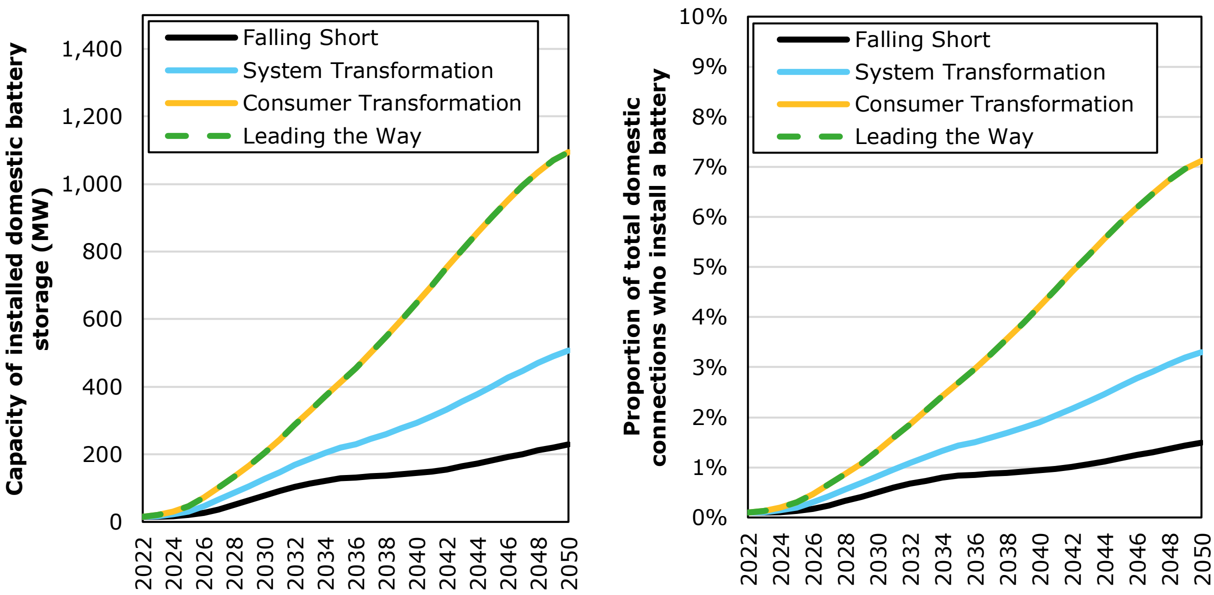


Figure 46: Capacity of domestic battery storage (left) and proportion of all domestic customers who install a battery (right) in UK Power Networks' region

The results from the modelling (Figure 46) indicate that between 1.5% and 7.1% of all domestic customers (or between 44% and 49% of small rooftop solar PV owners across the three solar PV uptake scenarios) in UK Power Networks' licence areas may install a battery by 2050. The highest uptake is seen in Consumer Transformation and Leading the Way, in line with the higher consumer engagement in these scenarios, with installed capacity of 1.1 GW in 2050, corresponding to around 550,000 homes installing a battery. System Transformation follows, with installed capacity of 510 MW by 2050, followed by Falling Short with 230 MW, corresponding to 250,000 and 110,000 homes, respectively[75].

[74] Element Energy for UK Power Networks, DFES 2020, February 2020, Section 3.5.1 and DFES 2021, January 2021, Section 4.5.1.
[75] The modelling methodology applied here has some commonalities with that applied in NG ESO's FES, however, results differ due to consideration of factors specific to the UKPN region and calibration to historic uptake.

I&C storage

Uptake scenarios for I&C behind-the-meter storage were derived using ERM's consumer choice model, where I&C customers are divided into archetypes, based on different business types, and uptake is based on the payback period for investing in a battery and the willingness to pay of I&C organisations. The modelling approach is consistent with the previous DFES, however the revenues available are continuously updated and reviewed, as this is a rapidly changing space due to charging reforms[76] and new markets becoming accessible to smaller battery installations.

The model evaluates the revenue stack, used to determine the payback period, on the highest value streams available for each scenario: distribution and transmission network charge avoidance, wholesale electricity pricing, and grid services, such as the Balancing Mechanism. Additionally, the modelling approach accounts for possible changes in the wholesale electricity price fluctuations due to higher share of renewable generation in the long term. As the UK relies more on intermittent renewables in the future, wholesale electricity price fluctuations may be expected to become more dominated by the level of renewable generation, rather than dominated by the level of demand.

Due to the uncertainty around future wholesale electricity prices, and consequently the uncertainty in potential revenues available from electricity price arbitrage and provision of services to National Grid, it is assumed that different revenues from these streams are available in each scenario. The assumptions made are consistent with those in the previous DFES, resulting in similar outcomes, with high uptake in Consumer Transformation, medium in Leading the Way and System Transformation and low in Falling Short (Figure 47). Due to the decrease in baseline capacity of I&C storage from last year's DFES (moving from modelled to actual figures), the forecasted capacity in all scenarios is slightly lower than forecasted in last year's DFES.

[76] Ofgem, *Access and Forward-Looking Charges Significant Code Review*

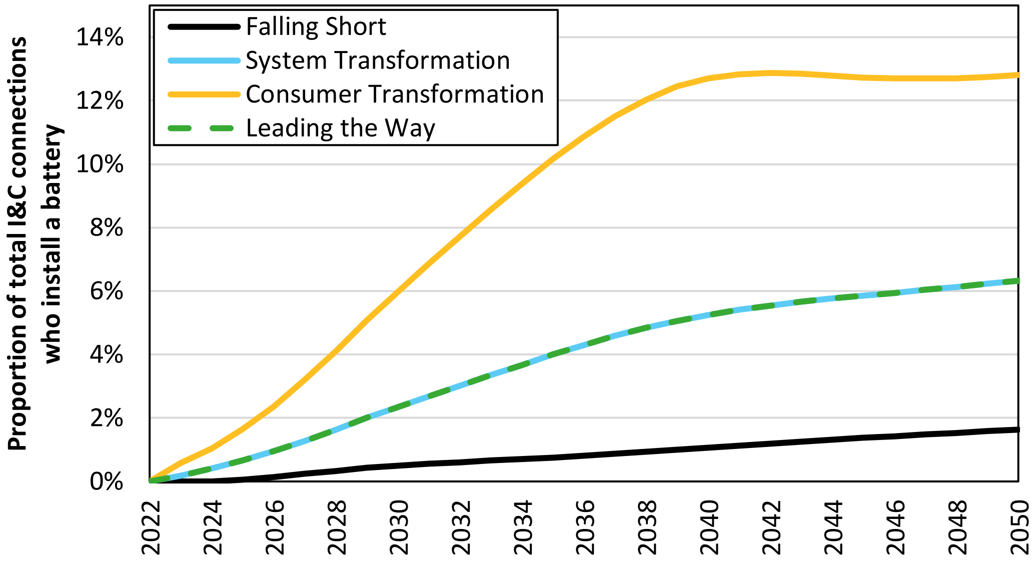


Figure 47: Proportion of all I&C customers who install a battery in UK Power Networks' licence areas

3.5.3 LARGE-SCALE BATTERY STORAGE

The uptake of two cases of large-scale battery storage is modelled; batteries co-located with solar generation, and standalone grid-connected batteries.

3.5.3.1 PIPELINE

The pipeline of large-scale storage connections is modelled based on work Regen carried out for UK Power Networks in 2023. This involved a detailed analysis of battery storage projects that have a connections agreement with UK Power Networks. The output of this analysis was a list of sites along with the evidence gathered for each one and an estimation of the 'earliest' and 'latest' year that these sites might connect to the network.

Battery storage capacity projections

Regen undertook a detailed analysis of the pipeline of prospective battery projects at various stages of network connection progress with UKPN. This analysis included determining:

- The planning status (approved, submitted, rejected) for each site, by reviewing both the Renewable Energy Planning Database (REPD) and individual local authority planning portals.
- Any activity in EMR Delivery Body Capacity Market T-4 and T-1 auctions for future delivery years, determining sites with pre-qualifications and sites with Capacity Agreements awarded.
- Specific intention to build and anticipated energisation timelines by directly contacting a number of the organisations that hold accepted connection offers with UKPN.

For sites where evidence of progression was found, the 'earliest' and 'latest' year that each of these sites might connect to the network was identified, according to the following methodology:

- Sites confirmed to be currently under construction were assumed to be built within 2023 or 2024, depending on the size of the project.
- For sites where the developer indicated specific plans to commence construction, this was used as the delivery year. This evidence was drawn from direct engagement with developers and the notes associated with the connection in UKPN's connection database.
- For sites that had a Capacity Market Agreement for a specific year, this was applied as the delivery year.
- For sites that had submitted a planning application or had planning permission approved, the time taken between planning and build-out was analysed using operational battery site milestone dates in the REPD.
  - This analysis determined a range of build-out timeframes based on planning status, project capacity and business model (standalone or co-location). This range informed the 'earliest' and 'latest' delivery years.

Sites where no evidence of progression was found were not modelled to connect at all.

Source: Regen**,** 31st October 2023

Based upon the outcomes of this work, the pipeline is determined through the following four key parameters:

- **Likelihood:** the likelihood of an installation materialising, defined as a label of "Excluded", "Not likely", "Likely", or "Very Likely" appended to each installation. A label of "Connected" is applied to sites that are already operational.
- **Energisation year:** the year when each installation will come online. An earliest and latest energisation year is determined for each installation, and which one is used varies by scenario.

- **Execution ratio:** the proportion of accepted capacity assumed to be built, defined as a percentage for each likelihood category and varies by scenario.
- **Execution timeline:** the number of years that it takes for an installation to reach full anticipated capacity from the energisation year and does not vary by site or scenario.

A likelihood is assigned to each installation based on the evidence gathered by Regen, following a set of rules that are determined by the following general principles:

1. Already operational sites are assigned connected status and treated as part of the baseline and not the pipeline.
2. Sites that are not modelled by previous analysis, rejected, have expired planning or are too small for planning are excluded from the pipeline.
3. Sites that are already under construction are considered Very Likely.
4. Having both secured planning and being active in the capacity market indicates higher likelihood whereas no information indicates lower likelihood.
5. The further an installation is in the planning process, the likelier it is considered to materialise.

Figure 48 presents the outcome of this analysis. A total of 5.8 GW of battery storage capacity was excluded from the analysis as no evidence for progression was found for these sites. Not counting the capacity of storage that is already connected to the network, that leaves close to 8 GW of battery storage in the pipeline, out of which 1.2 GW were considered Very likely to connect. While 641 MW of standalone storage are connected to UK Power Networks' network as of September 2023, only 343 MW were connected at the time the baseline capacity is defined (end of March 2023).

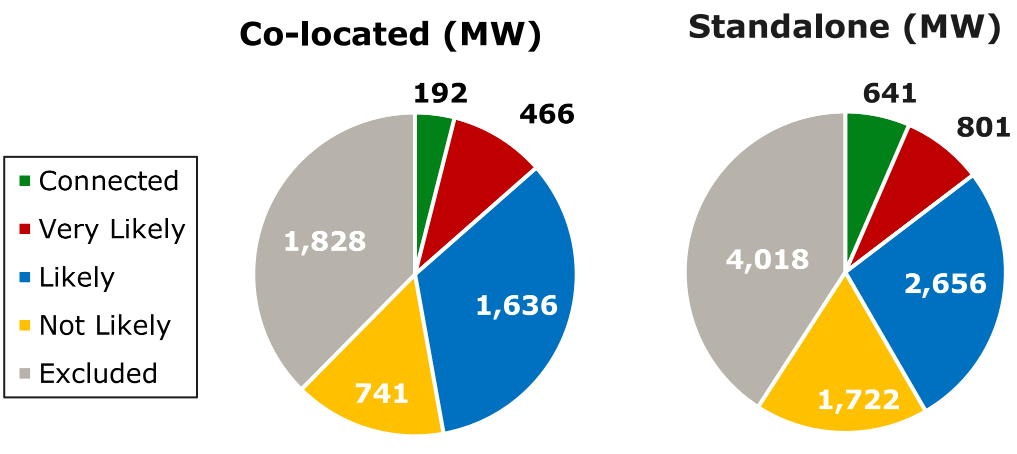


Figure 48:Total capacity by likelihood of co-located (left) and standalone (right) large-scale battery storage sites

Three pipeline scenarios for near-term uptake of large-scale battery storage were developed from this analysis. The scenario assumptions are presented in Table 21. The resulting pipeline for co-located storage spans the years 2023-2032 and for standalone storage, the pipeline period is 2023-2031.

Table 21: Large-scale storage pipeline scenario assumptions

Scenario	Execution ratio				Energisation year	Execution timeline
	Very Likely	Likely	Not Likely	Excluded		
Low	100%	0%	0%	0%	Latest	1 year
Medium	100%	50%	0%	0%	Earliest	1 year
High	100%	100%	50%	0%	Earliest	1 year

3.5.3.2 CO-LOCATED BATTERY STORAGE

Uptake scenarios for co-located storage were derived using ERM's investor decision model, as used for the large-scale solar PV uptake scenarios described in previous DFES reports[77]. Decision makers have the choice to install a large-scale solar PV system alone, a large-scale solar PV system with co-located battery storage, or nothing. A battery would be chosen to optimise revenues from electricity price arbitrage, reduce curtailment, and participate in the capacity market. The model considers a battery with a power output equal to the installed PV capacity and with an energy storage capacity of two hours. It also accounts for variances in battery pack costs and the availability of curtailable generation connections in the future.

Figure 49 shows the range of possible uptake of co-located battery storage across UK Power Networks' region. The changes in the pipeline methodology result in a different near-term uptake than what was modelled in the previous DFES, with the scenarios spanning a narrower range throughout the pipeline period (2023-2032) as well as out to 2050. Due to the high forecasted large scale solar capacity, relatively lower forecasted battery prices compared to historic prices, and a large pipeline of accepted connections, a high uptake of large-scale batteries co-located with solar PV is seen. Leading the Way has the highest deployment of large-scale solar PV and thus the highest capacity of co-located storage installed. In Falling Short, the business case for co-located storage remains unfavourable and uptake remains low.

[77] Element Energy for UK Power Networks, DFES 2020, February 2020, Section 3.5.3 and DFES 2021, January 2021, Section 4.5.2.

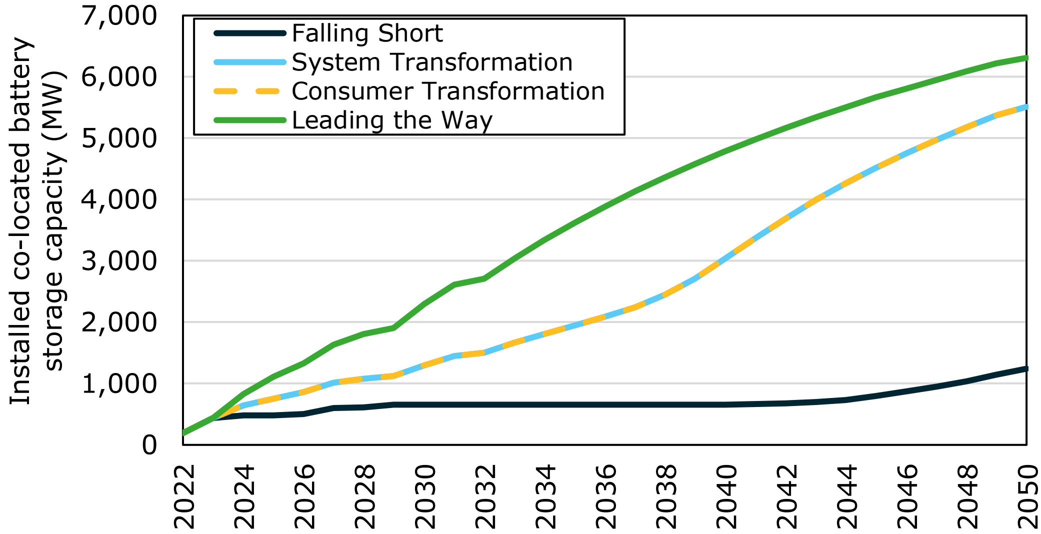


Figure 49: Capacity of battery storage co-located with solar generation in UK Power Networks' licence areas

3.5.3.3 STANDALONE GRID-CONNECTED BATTERIES

The total storage capacity needed in UK Power Networks' licence areas is modelled by considering a relationship between required storage power capacity and increased share of variable generation[78]. National Grid's national level uptake forecast of wind and solar along with their predicted peak demand through to 2050 is used to quantify the future share of intermittent renewables in the system. Scenarios are subsequently calculated for the total storage capacity required at national level and then disaggregated to create scenarios specific to UK Power Networks' region.

It is assumed that the resulting total storage requirement can be met by I&C behind-the-meter batteries, vehicle-to-grid services, batteries co-located with renewable generation or grid-connected standalone batteries. Therefore, to obtain the capacity required for grid-connected standalone batteries, the capacity of I&C batteries, co-located batteries, and capacity obtained from vehicle-to-grid services (see **Section 3.6.3**) is subtracted from the total storage capacity requirements. It is assumed that Consumer Transformation and Leading the Way require high total battery capacity, System Transformation medium and Falling Short low.

Once the total storage requirement for each scenario world was calculated, the near-term pipeline was applied to each scenario. In order to determine which pipeline (i.e., low/medium/high) to apply to each scenario world, the near-term storage requirements were compared with the pipeline trajectories. This comparison showed that Falling Short aligned with the high pipeline since it had a high requirement for grid-scale storage, resulting from low uptake of other storage types. The medium pipeline was used for Consumer Transformation and System Transformation, while the high pipeline was used for Leading the Way.

Figure 50 shows the resulting uptake of standalone grid-connected batteries in UK Power Networks' region. In the near term, the grid-scale storage forecast is determined by the pipeline while the long-term forecast is determined by the total storage requirement according to the methodology described above. As the uptake of I&C batteries, co-located batteries, and

[78] Drax, *Electric Insights – Quarterly*, 2019

vehicle-to-grid increases, the requirement for grid-scale storage decreases. However, it is assumed that grid-scale storage sites have a maximum lifetime of 15 years, thereby limiting the rate at which sites are decommissioned, and reducing the rate at which grid-scale storage falls in the long-term.

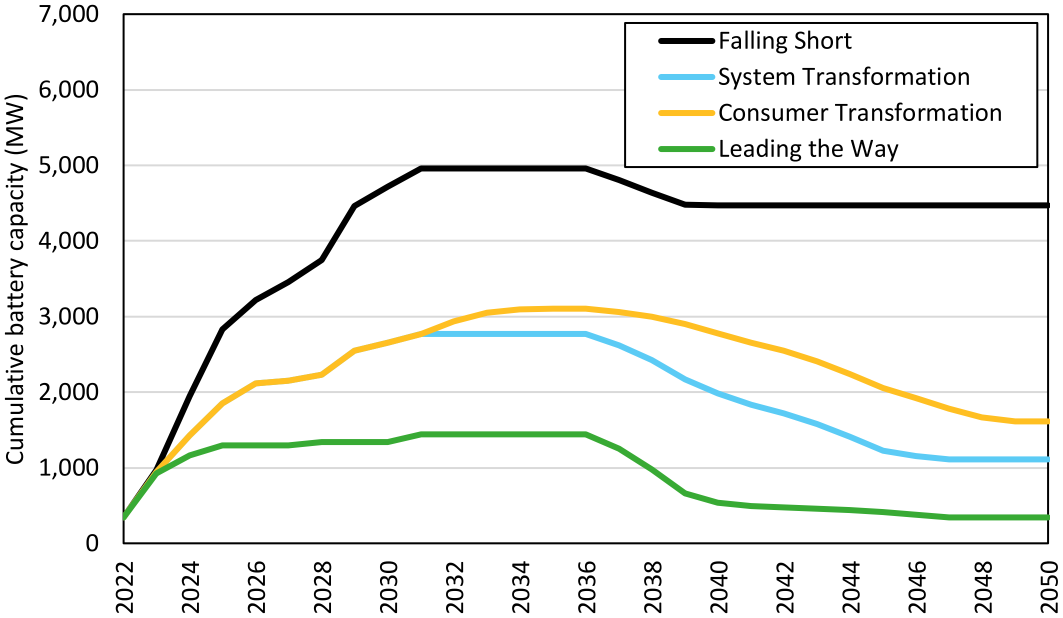


Figure 50: Capacity of grid-connected standalone batteries in UK Power Networks' region

3.5.4 LONG DURATION ENERGY STORAGE

This section, the detail and figures 58-66 in Appendix B were provided by Regen

UK Power Networks (UKPN) is currently experiencing significant growth in the development of grid-scale electricity storage projects seeking to connect to its network.

The current requirements of the electricity system for flexibility, and the markets that the ESO runs to value this flexibility, are heavily tailored to short duration batteries providing frequency response, balancing actions and short duration price arbitrage.

However, longer duration energy storage (LDES) will be required to enable a highly electrified, high renewable net zero electricity system[79].

To enable UKPN to plan for the development of LDES, Regen has carried out a review of the potential development of these technologies in UKPN's licence areas. The review is based on current development evidence and direct engagement with companies developing the technology.

The UK government has made a number of announcements and commitments to support the development of LDES and a range of trial, pre-commercial and commercial LDES technologies are now in development. Government support measures include:

- A call for evidence around facilitating the development of LDES[80] and follow-up response
- Commitment to publishing a further government consultation around the next policy intervention to enable LDES, towards the end of 2023/into 2024[81].
- Two phases of grant funding competition for LDES technologies covering power-to-x, electricity storage and thermal storage[82]
- Commitment to an equity fund for LDES projects through the UK Infrastructure Bank[83]

As this is a rapidly developing area, it will be important for UKPN to keep this technology area under regular review, as the market design and policy support becomes clearer.

Regen's high-level assessment indicates that the Eastern (EPN), South Eastern (SPN) and London (LPN) networks are not currently high priority areas for the development of distribution network connected LDES project. Geographical resources, land classifications and scale of energy system constraints are leading LDES developers to look at other parts of the UK.

This assessment is based on:

- The current policy position for LDES technologies in the UK
- Projections for LDES across the UK in the FES 2023 data workbook
- Winners of the LODES funding competition in 2021 and 2022

---

[79] See National Grid ESO Future Energy Scenarios 2023, July 2023: https://www.nationalgrideso.com/future-energy/future-energy-scenarios

[80] Facilitating the deployment of large-scale and long-duration electricity storage: call for evidence, July 2021: https://www.gov.uk/government/calls-for-evidence/facilitating-the-deployment-of-large-scale-and-long-duration-electricity-storage-call-for-evidence and https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1096002/large-scale-long-duration-electricity-storage-govt-response.pdf

[81] Comments from Andrew Bowie, MP for DESNZ at the Electricity Storage Network 2023 conference: https://www.regen.co.uk/event/electricity-storage-network-winter-conference-2023/

[82] Longer Duration Energy Storage Demonstration (LODES) competition, 2021-2022: https://www.gov.uk/government/collections/longer-duration-energy-storage-demonstration-lodes-competition

[83] Powering Up Britain: Energy Security Plan, April 2023: https://www.gov.uk/government/publications/powering-up-britain/powering-up-britain-energy-security-plan

- Spatial factors in the deployment of LDES and the geography of UKPN's network
- Development appetite in UKPN's network from key LDES technology companies

However, with the potential for further government policy announcements and support in the coming months, ongoing grid connection reform and grant funding available through the UK Infrastructure Bank, the LDES development sector could evolve rapidly.

Regen's recommendations are:

1) To continue to prioritise the modelling of shorter duration battery capacity development in the UK Power Networks' licence areas. These could begin to increase their durations from 0.5-1 hours up to 2-4 hours, based on feedback from operators and project developers.
2) To continue to engage with LDES developers about their future plans and development appetite in UK Power Networks' region, including with Cheesecake Energy about their CAES demonstrator if they apply for a network connection in Colchester.

3.6 FLEXIBILITY

Key Messages

- Uptake of smart meters over the past year was lower than expected in last year's DFES.
- The rollout of smart charging is in line with the recent Government mandate requiring all public charge points to be smart charging capable.

Different sources of flexibility are considered that could be available to be accessed or controlled by a DNO. Each use case is based on a specific set of assumptions around a business case.

Table 22: Flexibility measures modelled and their mapping to scenario worlds

Scenario World	Falling Short	System Transformation	Consumer Transformation	Leading the Way
Time-of-Use Tariff uptake	Low	Medium	High	High
Battery based flexibility	Low	Medium	High	High
EV smart charging	Low	Medium	High	High

3.6.1 TARIFF-BASED FLEXIBILITY

Time-of-use tariff uptake

In many cases, the uptake of time-of-use (ToU) tariffs will enable increased flexibility. However, one limiting factor in the uptake of ToU tariffs is the deployment of smart meters. Three scenarios are modelled for smart meter deployment rate with the high scenario aligned with the BEIS smart meter policy framework[84]. The approach for forecasting the low and medium scenarios is kept the same as in DFES 2023, and uses DESNZ smart meter roll-out values from March 2023[85].

DESNZ indicates that 55% of consumers have a smart meter. Figure 51 shows that the uptake of smart meters between March 2022 and March 2023 was lower than modelled in all DFES scenarios from last year. Furthermore, UK Power Networks data from November 2023 showed that smart meter uptake is now at 58% (with EPN/SPN ~62% and LPN ~48%), indicating that this technology is tracking closest to the Falling Short pathway.

[84] BEIS, *Smart meter policy framework post 2020,* 2021
[85] DESNZ, *Smart meters in Great Britain, quarterly update March 2023,* March 2023

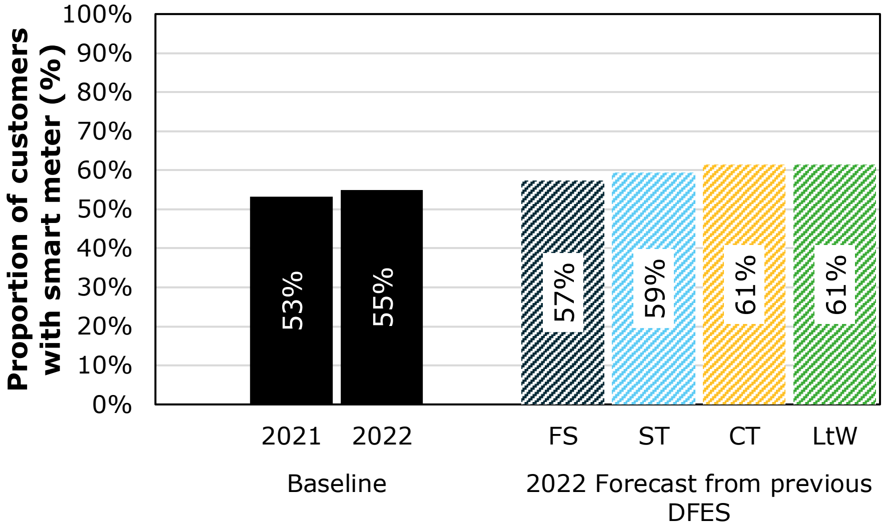


Figure 51: DFES 2023 (2021 baseline) and DFES 2024 (2022 baseline) proportion of customers with a smart meter compared to 2022 forecast from DFES 2023

Based on the scenarios for the smart meter rollout, and expected ToU tariff availability, ToU uptake curves were developed for domestic customers and small/medium I&C customers (Figure 52) following the same methodology as the past DFES. For domestic customers, it is assumed that there is a five-year delay between ToU and smart meter uptake. These uptake figures exclude domestic customers on Economy 7 tariffs and large I&C customers, as they are assumed to be already on a ToU tariff.

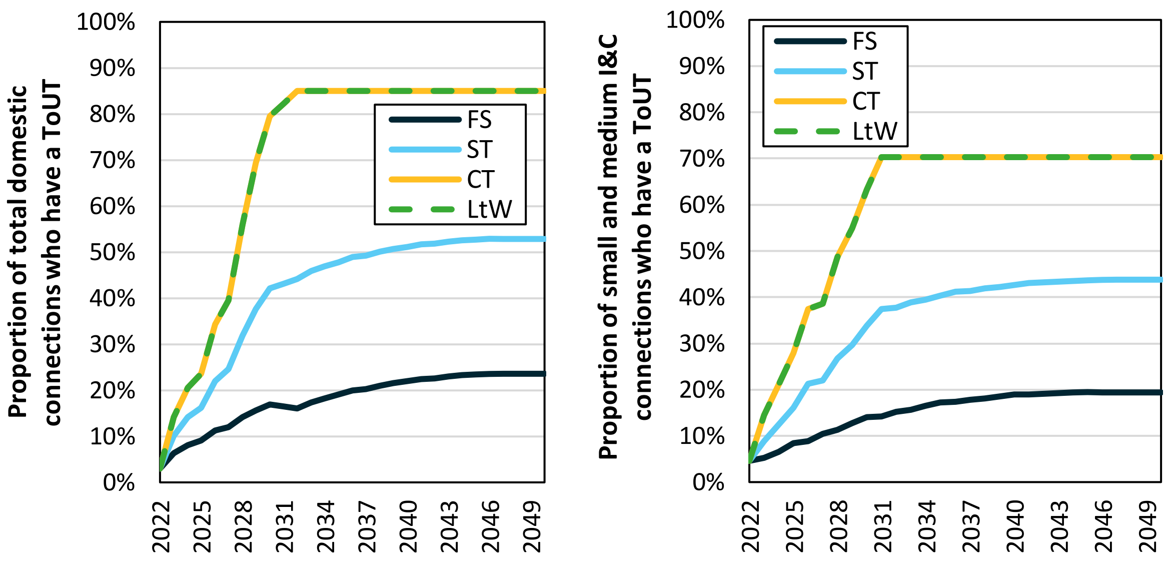


Figure 52: Uptake of Time-of-use tariffs (ToUT) in the domestic sector (left) and in small and medium I&C customers (right)

3.6.2 DEMAND SIDE RESPONSE

Two models were developed to create scenarios of demand reduction potential of domestic and I&C customers. While the domestic demand side response (DSR) potential is based on smart appliances, the I&C potential is based on shiftable demand. The modelling methodology and results for smart appliances and shiftable demand are both consistent with those published in the previous DFES[86], and are not repeated here.

As an example, UK Power Networks actively procures DSR or flexibility services for its own network, targeted to specific locations with a need for additional capacity and where flexibility services are shown to be cost-effective. UK Power Networks' Autumn 2023 tender[87] is for 850MW of flexibility across 452 zones.

3.6.3 BATTERY-BASED FLEXIBILITY

3.6.3.1 DOMESTIC BATTERY-BASED FLEXIBILITY

In order to lower their bills, it is assumed that domestic battery owners will use the electricity stored in their batteries during peak demand. However, this will not necessarily use the full capacity; therefore, it is assumed that the remaining discharge capacity will be available to provide flexibility to third parties such as the distribution system operator (DSO), directly or via an aggregator/ supplier. The battery-based flexibility accessible to a DSO is modelled by considering the uptake of domestic batteries, discussed in **Section 3.5.2**, and assumes that the proportion of battery owners that participate in flexibility follows the uptake of time-of-use tariffs, outlined above. The resulting capacity available for flexibility is in line with previous year's modelling[88], however the near-term uptake is lower due to a slower uptake of EVs during this period which results in less capacity available for smart charging and V2G.

3.6.3.2 EV SMART CHARGING

EV charging was divided into three categories: non-managed charging (NMC); user-managed charging (UMC); and externally managed charging (EMC). Externally managed charging is further subdivided into "standard" externally managed charging and Vehicle-to-grid (V2G). The latter allows for the possibility for the third party controlling the EV charger to discharge the vehicle battery and export electricity to the grid.

The modelling approach continues to follow the proposed faster rollout of smart charging uptake proposed in Government legislation[89], mandating all new non-public charge points to be smart charging capable, with smart charging being the default option. It is assumed that all new domestic chargers are smart from 2022 in Consumer Transformation and Leading the Way, in line with the aforementioned legislation, and from 2024 in System Transformation, assuming a 2-year lag between the smart functionality being in place and them being used as such. By 2027, this results in 50% uptake of smart charging technology in System Transformation and 71% uptake in Consumer Transformation and Leading the Way. Prior to 2027, a slower uptake of smart charging is forecasted in Consumer Transformation and Leading the Way compared to last year's DFES due to a low deployment of smart charging to date.

[86] Element Energy for UK Power Networks, DFES 2020, February 2020, Section 3.6.2.
[87] Flexibility - UKPN DSO (ukpowernetworks.co.uk)
[88] Element Energy for UK Power Networks, DFES 2021, January 2021, Section 4.6.2.
[89] Department for Transport (DfT), *Electric vehicle smart charging consultation; summary of responses,* updated 2021.

The scenarios still see some level of non-managed charging as consumers will be able to override the default smart settings, to operate the charge points in a 'non-smart' way. In System Transformation, Consumer Transformation and Leading the Way the proportion of sessions overridden by consumers is based upon on the results from Shift[90], a UK Power Networks innovation project. System Transformation uses the initial Shift results from a small set of users, which had a higher degree of override. Consumer Transformation and Leading the Way use the results from the full Shift trial which saw a slightly higher level of consumer engagement, lowering the proportion of session overrides. Although the Government has now mandated the rollout of smart charging capable charge points, in Falling Short it is assumed that most charging sessions will be overridden, and that the majority of charging sessions remain non-managed out to 2050 (Figure 53).

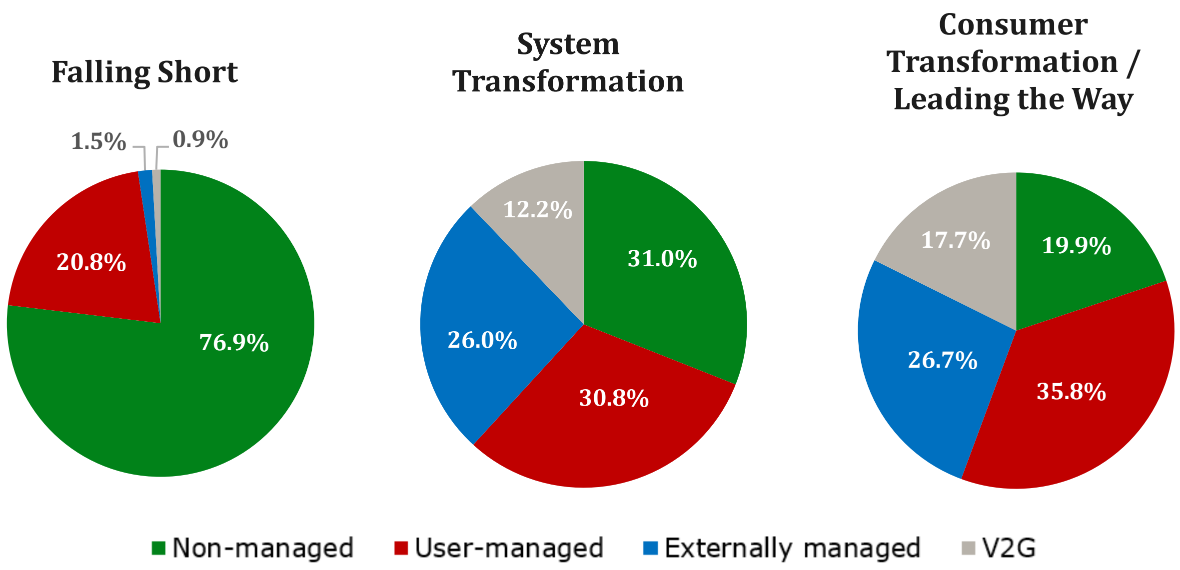


Figure 53: EV residential charging distribution in 2050

To calculate the export capacity available from vehicle-to-grid at system peak, the same methodology is followed as in the previous DFES[91]. The available battery capacity assumed in System Transformation and Consumer Transformation is assumed to be 20% of the total battery capacity of the vehicles participating in V2G and in Leading the Way, the available capacity is equivalent to 36% of the total. No growth in V2G participation is assumed in Falling Short.

[90] UK Power Networks Innovation, *Shift*, 2021

[91] Element Energy for UK Power Networks, DFES 2021, January 2021, Section 4.6.2.

4 DFES APPLICATION AND FUTURE WORK

4.1 APPLICATION OF THE DFES

DFES 2024 will feed into UK Power Networks' Strategic Forecasting System (SFS), an integrated set of software tools that enables forecasting of load growth on the networks under different scenarios. Using the DFES, the SFS shows the implications of the scenarios for network operation and investment, over RIIO-ED2 and beyond. Outputs from the SFS are used to inform network planning (both traditional reinforcement and flexibility services procurement) and a range of publications / regulatory submissions.

Using the DFES to create forecasts for demand and generation per network asset

Each year UK Power Networks take the regional assumptions set out in the DFES scenarios (as set out in this document, assumptions both at the network level of the licence area and sub-regionally at LSOA/MSOA) and combine them with baseline data on the actual demand and generation on the network. This translates DFES to projections at network assets, such as substations.

In 2024, the 2024 DFES scenario assumptions will be combined with substation demand profiles for the year April 2023 – March 2024 to produce UK Power Networks DFES scenarios at network asset level. This assessment of network loading is used as the updated baseline for the 2024 **demand** MW forecast cycle from summer 2024 onwards. In 2024, UK Power Networks will also use the generation baseline in the 2024 DFES (from end March 2023) to produce the scenarios of **generation** MW installed per network asset.

The outputs of the DFES are used by UK Power Networks for network planning and to inform UK Power Networks' stakeholders, Ofgem and National Grid ESO, and therefore have a clear utility and purpose.

Choice of Best View scenario

For planning purposes UK Power Networks uses the Consumer Transformation scenario as its "Best View" scenario. This is aligned with feedback from stakeholders who stated that their priorities were to achieve Net Zero whilst keeping bills as low as possible. In the assessment ahead of UK Power Networks' business plan submission, Consumer Transformation came out as the lowest cost Net Zero compliant scenario over the ED2 period. The choice of Best View scenario is based on justification criteria related to:

- alignment with existing/announced policies,
- alignment with stakeholder engagement inputs, and
- alignment with regional and local characteristic inputs.

In 2023 using DFES 2023, UK Power Networks' Best View is based on Consumer Transformation. In 2024, UK Power Networks will review and confirm the choice of Best View scenario for 2024, taking account of local engagement as described in **section 4.2**.

Use of the Best View and other DFES scenarios by UK Power Networks

The Best View scenario is shown in the Long-Term Development Statement (LTDS)[92] for five years ahead e.g., Table 3 in the LTDS shows Grid and Primary substation peak demand forecasts. LTDS for all licence areas are published on UK Power Networks' Open Data Portal.

The DFES also informs UK Power Networks' Network Development Plan (NDP) for ten years ahead. The NDP was a new biannual regulatory requirement from 1st May 2022 and the next full publication will be on 1st May 2024 based on DFES 2023 demand (last report) and DFES 2024 generation (this report).

The NDP covers all the substations in LTDS i.e. primary and Grid substations. Each year includes a Network Scenario Headroom Report (NSHR), using LTDS as its baseline, and presenting unused substation capacity to 2050 for demand and generation in all four DFES and a Best View if different.

The NDP also contains development plans for the next ten years, informed by DFES. The Best View scenario will be the primary input to the development plans for the next ten years. However, in preparing the development plans for the NDP, the impact of the other DFES scenarios will be considered to ensure that no pathways are closed off and to reflect the greater level of uncertainty that exists towards the end of the ten-year period. At primary substation level and above, UK Power Networks' framework within the Distribution System Operator for decisions on providing capacity (either from flexibility services or from traditional reinforcement) is now set out in UK Power Networks' Distribution Network Options Assessment (DNOA). The DFES is one of the primary inputs to the scenarios at substation level which feed into the DNOA.

4.2 LINKING BETWEEN DFES, LAEP AND LOCAL AUTHORITY ENGAGEMENT

Local authorities have a key role to play in delivering Net Zero, influencing over 80% of the UK's carbon emissions according to the Climate Change Committee[93]. The majority of the decarbonising actions depend on the take up of Low Carbon Technology (LCT) solutions.

Significant number of local authorities across UK Power Networks' regions have set ambitious targets to decarbonise their local areas and are now creating plans to meet those targets. Of the 133 local authorities UK Power Networks serves, 80% have declared a climate emergency and 87% have ambitions to be Net Zero or carbon neutral before the national Net Zero 2050 target. This is key, as UK Power Networks' central planning forecast - Consumer Transformation - is anchored on the national Net Zero 2050 target.

This DFES report is informed by a variety of datasets at local authority and LSOA/MSOA level. These inputs are sourced in the same way across UK Power Networks' licence areas, such as using Office for National Statistics data as modelling inputs.

However, UK Power Networks decided to move further by proactively engaging and collaborating with local authorities to gain a shared understanding of their latest

[92] The most recent LTDS tables from November 2023 are based on DFES 2023 (published January 2023), with the LTDS November 2024 to be based on this assumptions in this DFES document, DFES 2024.
[93] UK Net Zero Strategy - Net Zero Strategy: Build Back Greener - GOV.UK (www.gov.uk)

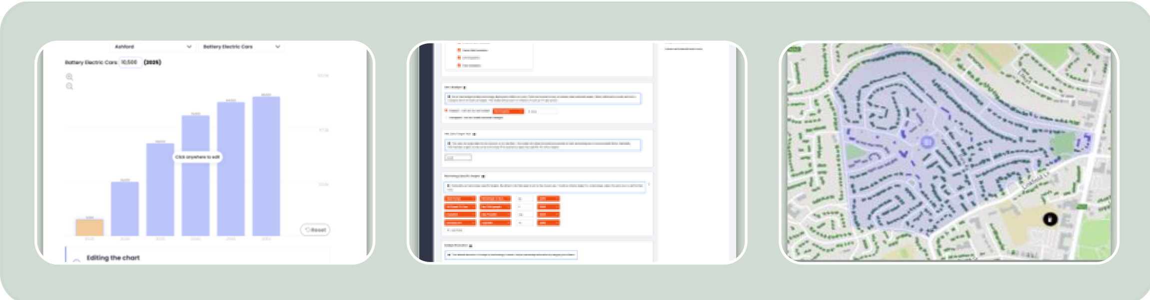
decarbonisation activities to enhance forecasts and ensure UK Power Networks continues to provide a fit for purpose electricity network that facilitates local decarbonisation.

133 Local authorities in our licence area	Network investment plan benchmarked against a scenario that achieves Net Zero by 2050	Many local authorities targetting Net Zero ahead of 2050

Figure 54: Reasons for pursuing locally-informed decarbonisation forecasts

To support local authorities with their Net Zero plans, UK Power Networks has established the Local Net Zero team, responsible for engaging with local authorities on their regional or local climate change action plans. Through this collaboration, local authorities share their planned decarbonisation activities (such as deployment of electric vehicles).

UK Power Networks is creating new tools and exploring new processes designed in partnership with local authorities to make the approach of sharing plans easier and more efficient.



DFES Widget: Share long term high level forecasts of low carbon technologies	Scenarios: Share granular long term forecasts of low carbon technologies	Projects: Share plans for specific projects expected to connect in the short term

Figure 55: Ways in which local authorities can share their plans with UK Power Networks

Making use of the Local Area Energy Planning (LAEP) framework ensures that UK Power Networks can be confident that a consistent level is met before any local climate change action plans are used to adjust the annually updated Distribution Future Energy Scenarios (DFES), and to facilitate local Net Zero plans whilst investing with confidence.

All the support offered by the Local Net Zero team is brought together in Your Local Net Zero Hub. Here you can:

- Read case studies and understand best practice from completed Local Area Energy Plans
- Book a 30-minute meeting with a member of the Local Net Zero team to discuss your ambitions for decarbonising the local area

- Access the new energy planning tool, which allows users to develop granular, data driven Net Zero strategies and collaborate in individual decarbonisation projects
- Submit details of your Net Zero forecasts and compare them to the DFES
- Access UK Power Networks Local Area Energy Planning Open Data Page – containing over 150 datasets deemed useful for Net Zero planning

The insight gained from UK Power Network's Local Net Zero team's engagement with local authorities will be combined with one of the core DFES scenarios described in this report to produce a '**Locally Enhanced'** best-view planning scenario to drive UK Power Networks investment plans.

UK Power Networks' early thinking is that for 2024, the Best View will be based on Consumer Transformation supplemented by inputs from local authority engagement via the Local Net Zero team as described in this section. This Locally Enhanced scenario would be a 5th scenario in addition to the four core DFES scenarios as described in this report. All the four DFES scenarios in this report benefit from a variety of LA, LSOA and MSOA-level data sets. However, the Locally Enhanced scenario would be an adjusted DFES scenario using additional inputs from those local authorities who have provided well evidenced, data driven decarbonisation plans.

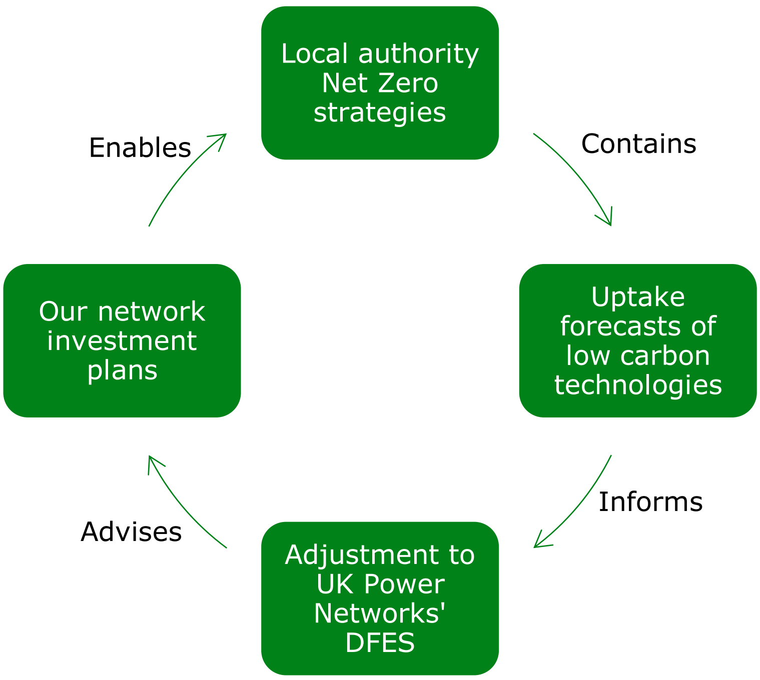


Figure 56: How local decarbonisation plans inform network investment

If you are a local authority who wishes to share your plans for local decarbonisation, please contact the Local Net Zero team at LAEP@ukpowernetworks.co.uk, or by visiting Your Local Net Zero Hub.

4.3 CONCLUSIONS FROM THE 2024 DFES

This report notes methodology changes in **Section 2.1** for DFES 2024 which have improved the quality of the DFES outputs (particularly in relation to generation categorisation/ inputs, storage pipeline and update to the 2021 census LSOA boundaries).

In terms of outputs, baseline figures have been updated with the necessary spatial resolution for this to be valuable for UK Power Networks' planning, but significant changes in the scale of the forecasts for low-carbon technology uptake have not been identified as part of DFES 2024.

- Forecasted PV uptake in DFES 2024 is slightly stronger than forecasted last year due to a supportive policy and price environment.
- While EV uptake has increased, it has been lower than forecasted due to slow recovery of car sales after COVID-19 and raw material shortages impacting battery supply, factors which have been added to the modelling in DFES 2024 resulting in slightly lower uptake being forecasted in the near term than in DFES 2023.
- Heat pump uptake lags policy expectation and the introduction of awareness factors in the modelling in DFES 2024, to better reflect consumer behaviour, led to a significant drop in heat pump uptake in the Falling Short scenario.
- Linking ERM's DFES work to UK Power Network's work with Regen on storage resulted in capturing an expanded storage pipeline of 15GW approaching UK Power Networks' connection teams. This total has been scaled back to realistic scenarios in the DFES based on developer evidence. Also, it was confirmed that long-duration energy storage is not currently expected to have an impact in UK Power Networks' region.

Overall, it is understandable that this DFES 2024 does not introduce major changes relative to DFES 2023, noting that the aspects relating to electricity distribution customers in National Grid ESO's FES 2023 were not a material change from FES 2022[94].

As described in **Section 2.2**, more significant changes to both the FES 2024 framework and thus to DFES 2025 are expected, and this may be the last time that FES and DFES are published with these names and structure. However, UK Power Networks still needs to develop locally justified planning scenarios to guide the investment in network capacity at the right time, place and cost to support the transition to net zero in our regions. UK Power Networks is working closely with other industry parties including NGESO/FSO to identify how coordinated spatial analysis of customer needs on the journey to net zero will be delivered in 2025 and beyond. The work in this report, DFES 2024, which will feed into UK Power Networks' planning scenarios for 2024, provides an example of the deep analysis and local understanding which should underpin decisions to invest in network capacity to deliver net zero for our communities.

[94] NGESO, Changes from FES 2022 to FES 2023, September 2023

APPENDIX

A - HEATING TECHNOLOGY BREAKDOWN IN THE I&C SECTOR

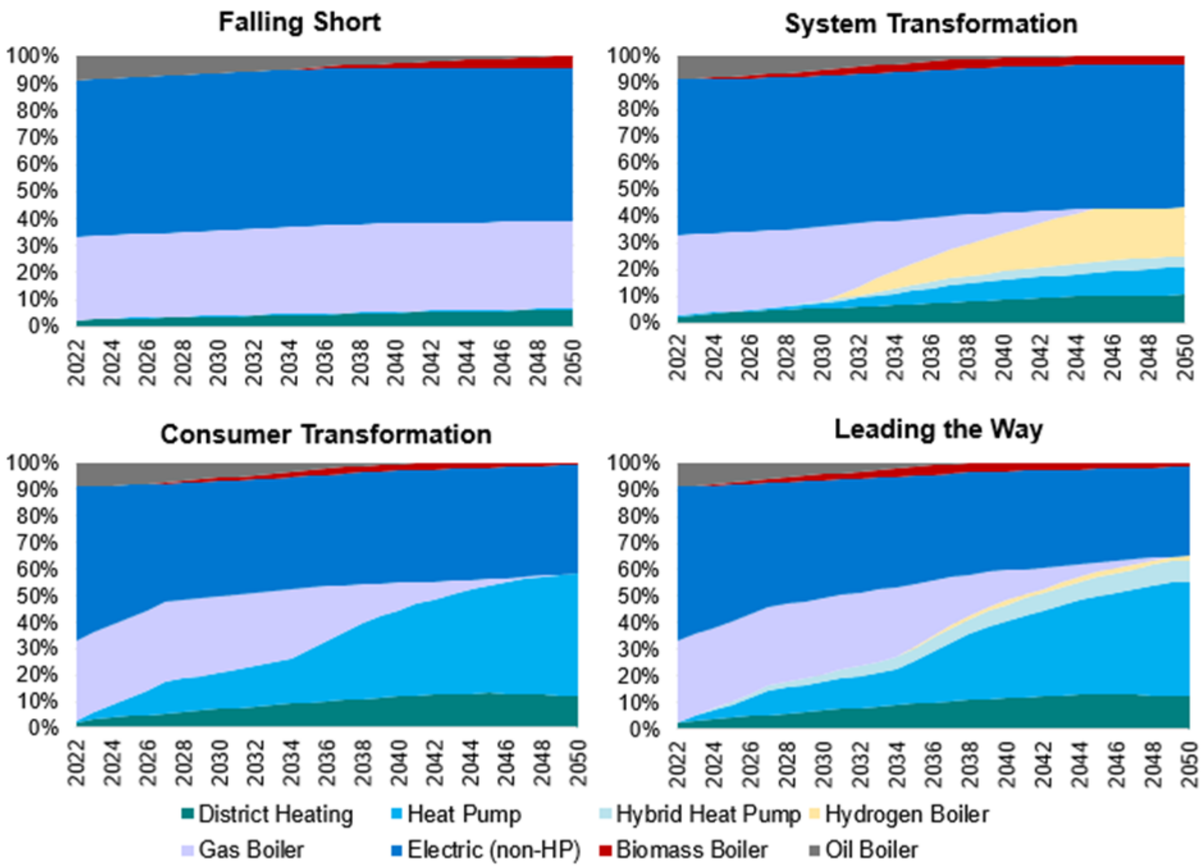


Figure 57: Heating technology breakdown for I&C properties in UK Power Networks' licence areas

B - LONG DURATION ENERGY STORAGE

Long duration energy storage development viability assessment – high level methodology

Regen undertook a high-level assessment of the potential to develop longer-duration storage technologies in UKPN's distribution network licence areas. This assessment comprised four stages:

1) An analysis of the Future Energy Scenarios 2023 GSP-level projections for pumped hydro and liquid air energy storage in UKPN's licence areas. The FES 2023 GSP data showed zero capacity connecting to the distribution network in UKPN's licence areas by 2050 for either technology.
2) An analysis of the winners of the UK Government Long Duration Energy Storage funding competition programme. This showed only one project in UKPN's licence area, a 2.2 MW / 11 MWh Compressed Air Energy Storage asset being developed by Cheesecake Energy.
3) A high-level assessment of the presence of key spatial factors in UKPN's regions that could correlate with the deployment of LDES technologies. These factors include topography for pumped hydro (including high-density pumped hydro), disused mineshafts for gravitational storage, industrial land and other technology-specific factors that may be relevant.
4) This was augmented by direct engagement with some leading UK LDES developers, such as RheEnergise (high-density pumped hydro), Highview Power (liquid air energy storage), Gravitiricity (gravitational energy storage) and Cheesecake Energy (developer of compressed air energy storage project in Colchester).

Long duration energy storage in the ESO Future Energy Scenarios (FES) 2023

As part of the scenario data for electricity storage within the FES 2023 framework, electricity storage capacity projections are broken down into short, medium and long duration categories. The FES considers LDES to be centred around three key technologies with the potential for 4 hours or more storage duration: compressed air energy storage (CAES), liquid air energy storage (LAES) and pumped hydro energy storage (PHES). Overall FES 2023 models between c.4 GW and c.16.5 GW, depending on the scenario, of LDES capacity across GB by 2050, see Figure 58

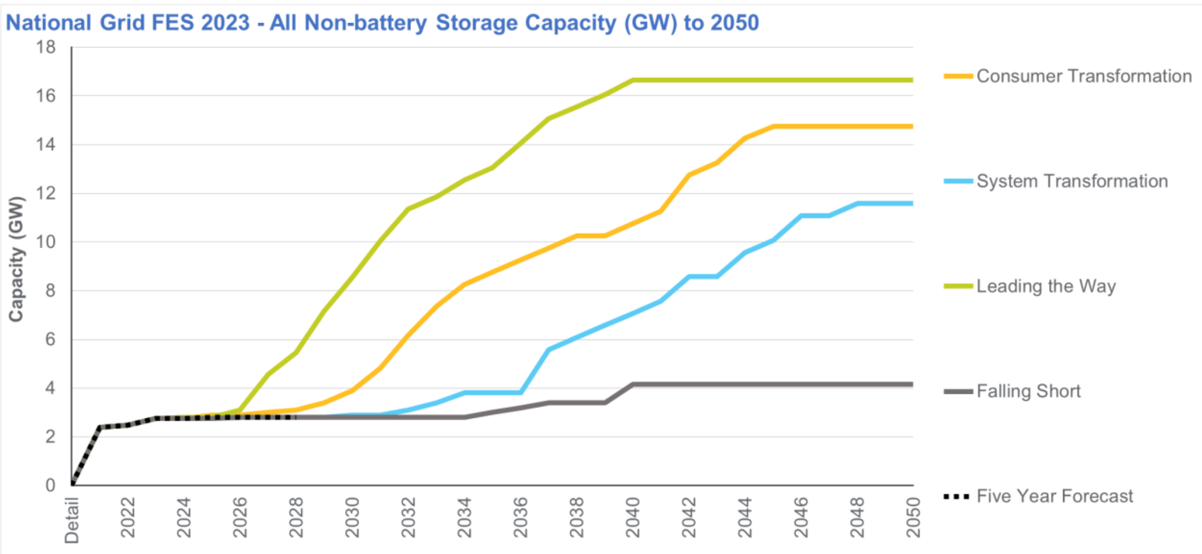


Figure 58: National Grid ESO FES 2023 - Long duration energy storage capacity projection to 2050, by scenario

Of this total LDES GB capacity by 2050, the vast majority (c.15.5 GW) is proposed to connect to the transmission system, with only 708 MW proposed to connect to the distribution network. Of this distributed LDES capacity, the majority (605 MW) is modelled to be LAES capacity, with the rest being PHES (100 MW) and a very small amount of CAES (3 MW), see Figure 59and Figure 60.

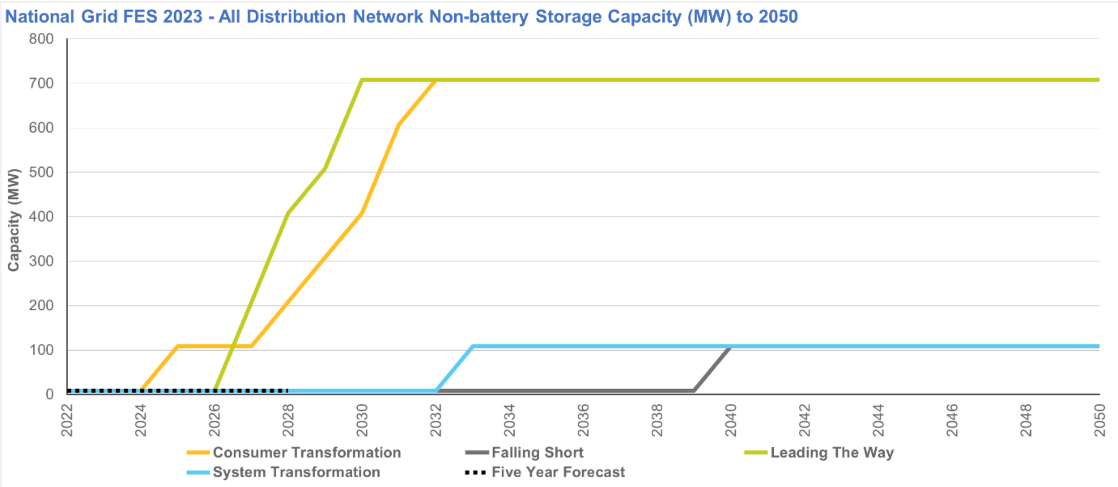


Figure 59: National Grid ESO FES 2023 - Long duration energy storage capacity on the distribution network, by scenario

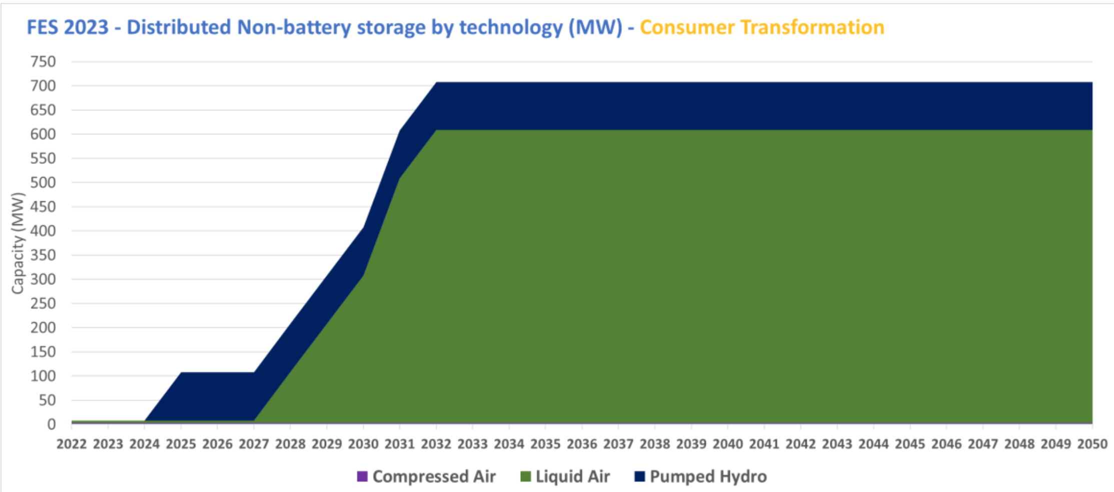


Figure 60: National Grid ESO FES 2023 - Long duration energy storage capacity on the distribution network under Consumer Transformation, by technology

None of this relatively small amount of distributed LDES capacity is modelled to connect within UKPN's licence areas. All of the proposed LDES sites are modelled to connect in either the Electricity Northwest (ENWL) North West licence area, the Northern Powergrid North East licence area or SP Energy Networks North Wales (SP MANWEB) licence area, see Figure 61.

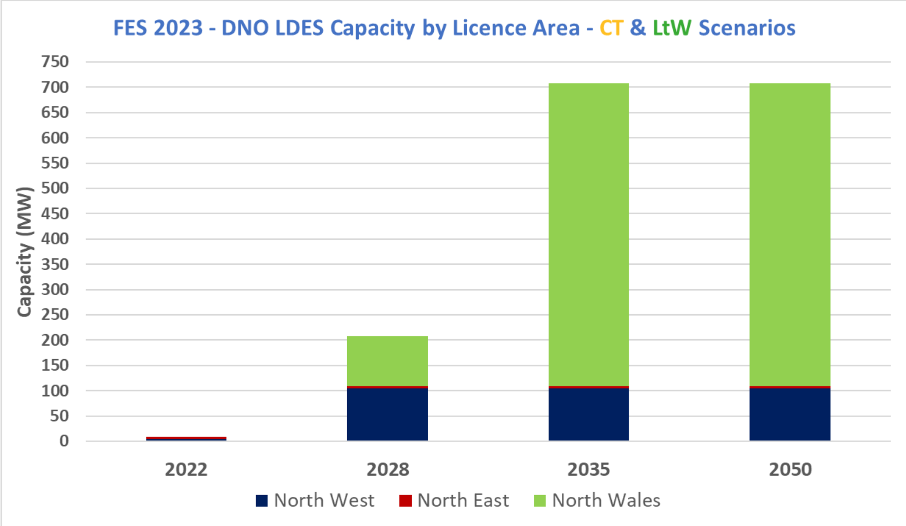


Figure 61: National Grid ESO FES 2023 - long duration energy storage capacity out to 2050, by DNO licence area

This analysis highlights that, under the FES 2023 framework, no LDES capacity has been modelled to connect to the distribution network in UKPN's licence areas out to 2050, under any scenario.

Government grant funding – Long Duration Storage Competition Fund

Across 2021 and 2022, the (then) Department for Business, Energy and Industrial Strategy (BEIS) launched an innovation competition aimed to "accelerate the commercialisation of innovative longer duration energy storage projects." This Long Duration Energy Storage Demonstration (LODES) competition fund was split into three technology categories:

- Power-to-X
- Thermal energy storage
- Electrical storage

The funding competition was then operated under two streams, with two phases per stream:

- Stream 1: Actual demonstrator
    - Phase 1: Feasibility
    - Phase 2: Build and commission
- Stream 2: Prototype demonstrator
    - Phase 1: Mobilisation
    - Phase 2: Build and commission

Over these categories, phases and streams, £69.4million of funding was awarded to 32 projects, representing 24 LDES technology developers, see Table 23.

Table 23: Summary of LODES funding competition winners, by LDES category

LDES category	Successful projects	Funding awarded
Power-to-X	6	£9.3m
Thermal energy storage	7	£12.6m
Electrical energy storage	19	£47.6m

Total LDES funding	32	£69.4m

Of the 32 successful projects, only 1 project was found to be potentially located in UKPN's licence areas, a 2.25MW / 11 MWh compressed air and thermal energy storage prototype demonstrator called 'FlexiTanker', targeted to be located in Colchester, developed by **Cheesecake Energy**[95].

Cheesecake's eTanker technology uses low carbon electricity to charge the storage system through an electrically powered air compressor. The high temperature heat is captured in a thermal store made from packed gravel beds, and the compressed air is captured in an air tank, using compressed air cylinders. The air is compressed using electric motor driven ex-truck engine pistons, resulting in no fuel combustion related emissions.

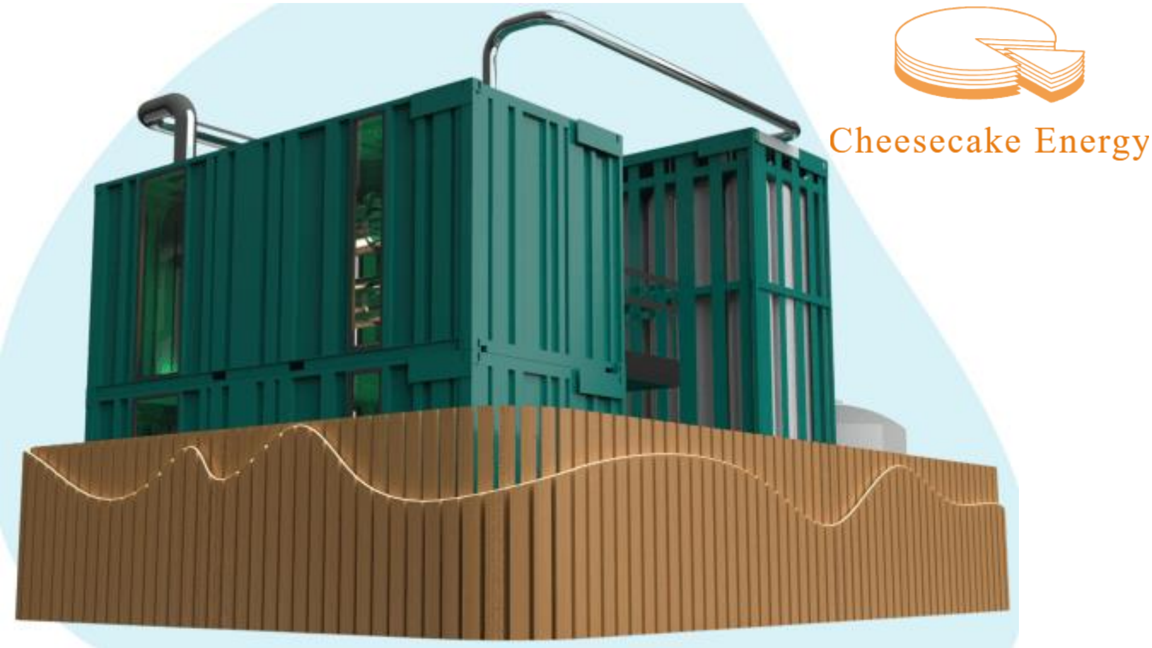


Figure 62: eTanker concept image, credit and source: Cheesecake Energy, 2023 https://i0.wp.com/cheesecakeenergy.com/wp-content/uploads/2021/10/Untitled-design-16.png?w=640&ssl=1

Due to the locational information about some of the LODES competition funding winners being very high level, there is the potential that other successful LDES demonstrator projects could be located in UKPN's licence area. However, the majority of sites were located in Scotland or other areas of the UK, such as Portsmouth, Nottingham, Chester, Sheffield and Plymouth.

The full list of competition winners is shown in Table 24.

[95] See Cheesecake Energy news article, April 2023: https://cheesecakeenergy.com/2023/04/12/cheesecake-energy-awarded-9-4m-to-install-energy-storage-systems/

Table 24: List of DESNZ longer duration energy storage competition funding winners 2021, 2022
Source data and information: DESNZ, Analysis: Regen

Project	Technology description	Developer	Capacity	Location	LDES Category	Stream	Phase	Funding Received
Ballylumford	Membrane-free H2 electrolysis	B9 Energy Storage	20 MW	Ballylumford, Northern Irelar	Power-to-X	1 - Actual demo	1 - Mobilisation	£986,082
GraviSTORE	Gravitational weight storage	Gravitricity	TBC	Northern England	Electrical energy storage	1 - Actual demo	1 - Mobilisation	£912,410
Long Duration Offshore Bundle	Hydro-pneumatic storage (compressed air + pressurised seawater)	FLASC B.V.	1 MWh	Aberdeen, Scotland	Electrical energy storage	1 - Actual demo	1 - Mobilisation	£471,760
Vanadium Flow Battery Demonstrator	Vanadium flow battery + solar hybrid system	Invinity Energy Systems	40 MWh	Bathgate, Scotland	Electrical energy storage	1 - Actual demo	1 - Mobilisation	£708,371
Cheshire Energy Storage Centre	Advanced compressed air storage and mothballed EDF gas cavities	IO Consulting	TBC	Cheshire, England	Electrical energy storage	1 - Actual demo	1 - Mobilisation	£1,000,000
Vanadium Flow Battery Demonstrator	Vanadium flow battery at key NGET node	Invinity Energy Systems	7 MW / 30 MWh	West Lothian, Scotland	Electrical energy storage	1 - Actual demo	2 - Build & commission	£11,000,000
EXTEND	Heat battery pairing with domestic energy management systems	Sunamp Ltd	Domestic	East Lothian, Scotland	Thermal energy storage	2 - Prototype demo	1 - Feasibility study	£149,893
Exergy3	Ultra-high temperature energy storage system	Edinburgh University	36 MWh	Edinburgh, Scotland	Thermal energy storage	2 - Prototype demo	1 - Feasibility study	£149,779
ADSorB	Long duration thermal storage of heat within homes	Active Building Centre	Domestic	Swansea, Wales	Thermal energy storage	2 - Prototype demo	1 - Feasibility study	£143,440
Utilising Composite Phase Change Materials	Composite phase change materials for thermal storage	Vital Energi	Domestic	Blackburn, England	Thermal energy storage	2 - Prototype demo	1 - Feasibility study	£131,214
INHERENT	Q-zeta domestic thermal storage	Energy Systems Catapult	TBC	Birmingham, England	Thermal energy storage	2 - Prototype demo	1 - Feasibility study	£149,831
HyDUS	Metal hydride storage conversion for use in storing Hydrogen (protium	EDF R&D UK	TBC	Oxfordshire, England	Power-to-X	2 - Prototype demo	1 - Feasibility study	£149,602
HEOS	Hydrogen and metal hydride P2X demonstrator	Haskins & Davey Ltd	TBC	Chester, England	Power-to-X	2 - Prototype demo	1 - Feasibility study	£141,000
RIPCURL	Reducing PGM in electrolyser plants	ITM Power	TBC	Sheffield, England	Power-to-X	2 - Prototype demo	1 - Feasibility study	£149,388
Hydrilite Refueller Prototype	Carbon280 Hyrdilye hydrogen storage	Corre Energy Ltd	TBC	Anglesey, Wales	Power-to-X	2 - Prototype demo	1 - Feasibility study	£149,922
FlexiTanker	Thermal and compressed air energy storage	Cheesecake Energy	TBC	Nottingham, England	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£139,411
Sustainable Single Liquid Flow Battery	Lithium-Sulphur flow battery	StorTera	MW scale	Edinburgh, Scotland	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£148,940
High Density Pumped Hydro	High Density Pumped Hydro tech	RheEnergise	TBC	Plymouth, England	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£149,537
e-Zinc Energy Storage	Zinc based battery storage tech	e-Zinc	TBC	UK	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£144,990
BlueStor	Organic flow battery	MSE International	TBC	Portsmouth, England	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£149,779
Marine Pumped Hydro	Marine pumped hydro using 3D concrete printing	RCAM Technologies	TBC	Edinburgh, Scotland	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£150,000
Compressed Air Storage in Offshore UK Continental Shel	Offshore compressed air storage	Crondall Energy	TBC	UK	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£149,086
Co-location of Flow Battery with Solar PV	Flow battery storage and solar PV co-location	Locogen	TBC	Edinburgh, Scotland	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£121,400
Renewable Copper	Copper-Zinc battery storage - 4 to 12 hour operation	Cumulus Energy Storage	1-100MWh range	Kilgallioch, Scotland	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£149,954
PTES Demonstrator	Grid scale pumped thermal energy storage	SynchroStor	1 MW / 10 MWh	Edinburgh, Scotland	Electrical energy storage	2 - Prototype demo	1 - Feasibility study	£79,560
EXTEND	Thermal batteries and smart heating controllers	Sunamp Ltd	100 homes	--	Thermal energy storage	2 - Prototype demo	2 - Build & commission	£9,245,261
ADSorB	Long duration thermal storage and intelligent control of heat within ho	Sheffield University	TBC	Nottingham, England	Thermal energy storage	2 - Prototype demo	2 - Build & commission	£2,595,571
HyDUS	Hydrogen Depleted Uranium Storage	EDF R&D UK	TBC	--	Power-to-X	2 - Prototype demo	2 - Build & commission	£7,733,821
Sustainable Single Liquid Flow Battery	Sulphur based single liquid flow battery (SLIQ) technology	StorTera	8 x 200kW/1.6MWh	Edinburgh, Scotland	Electrical energy storage	2 - Prototype demo	2 - Build & commission	£5,019,402
High Density Pumped Hydro	High Density Pumped Hydro tech	RheEnergise	250kW/1 MWh	Plymouth, England	Electrical energy storage	2 - Prototype demo	2 - Build & commission	£8,242,965
PTES Demonstrator	Pumped thermal energy storage.	SynchroStor	1 MW / 10 MWh	--	Electrical energy storage	2 - Prototype demo	2 - Build & commission	£9,439,302
FlexiTanker	Thermal and compressed air energy storage	Cheesecake Energy	2.25 MW /11 MWh	Colchester, England	Electrical energy storage	2 - Prototype demo	2 - Build & commission	£9,447,225

Spatial factors and engagement with LDES technology sectors

Regen assessed UKPN's licence areas, at a high level, for the presence of spatial or resource factors that could correlate with the potential development of certain LDES technologies.

This analysis was augmented by direct engagement with a cross-section of LDES developers.

Table 25 provides a high-level summary of the viability rating of the technologies, based on desktop analysis of the spatial factors linked to each technology, augmented by direct engagement (where possible) with LDES technology developers.

Table 25: Summary of likelihood of near-term LDES technology development in UKPN's licence areas

LDES Technology	Viability Rating	Comments
Liquid air energy storage (LAES)	**Low**	Linked to industrial land and potential for co-location with solar farms and data centres. Developer feedback states UKPN areas are not a priority currently.
High Density Pumped Hydro (HD-PHES)	**Low**	Geographical resource requirements, GIS assessment shows UKPN licence areas to be low priority for new sites compared to other areas of UK.
Gravitational storage	**Unknown**	There are existing disused mineshafts present in UKPN Eastern licence area, but viability for LDES technology is unknown. Awaiting further developer feedback.
Compressed Air Energy Storage (CAES)	**Medium**	Live CAES demonstrator project located in Colchester. Broader viability for CAES is largely linked to industrial land and access to grid capacity. Awaiting further developer feedback.

Liquid air energy storage

Description: Liquid Air Energy Storage (LAES) systems cool and compress air or nitrogen to the point of liquification when electricity is available. Liquid air is stored in insulated tanks, then heated and expanded across a generator turbine when electricity is needed.

The technology is well suited to applications which involve daily cycling, such as balancing daily generation or demand fluctuations. Over longer periods of storage, efficiency decreases as a result of thermal losses; for this reason, it is less well suited to storage for longer durations.

The duration of discharge and capacity is determined by the size of storage tanks and turbine generator. This scalability means the technology could be deployed with a range of capacity and duration parameters, to meet particular energy needs.

Active organisations: Highview Power are a global leader in the development of LAES projects. They operate a grid-scale demonstrator LAES project in Manchester, which has demonstrated balancing services capabilities, including participation in Short Term Operating Reserve (STOR)[96].

Viridor, a waste management and recycling company, are partnered with Highview in this project, providing waste heat from their Manchester landfill gas site. When used during the re-liquification phase, this waste heat can improve the overall efficiency of a LAES system.

Relevant spatial factors and presence in UKPN's licence areas: Given the potential of LAES to smooth generation variation, locating with renewables or renewable energy dense areas of the UK could be advantageous. Within FES 2023, the Eastern licence area has amongst the highest projected solar PV capacity by 2050 of any DNO licence area, as shown in Figure 63. The DFES projections for large scale solar show an area of abundant renewable energy generation in the north of the Eastern licence area that could be attractive for LAES development.

Similarly, to provide DSO grid services in the future, locating in constrained areas of the network could be a suitable use case for LAES technology. Procurement of DSO flexibility could be one indicator for the location of the development of LAES and other LDES technologies.

Further engagement with developers to indicate the likely scale of future LAES projects would help identify if this will be a technology suited to connection to the transmission or distribution network.

[96] https://highviewpower.com/projects/#uk-projects-mob

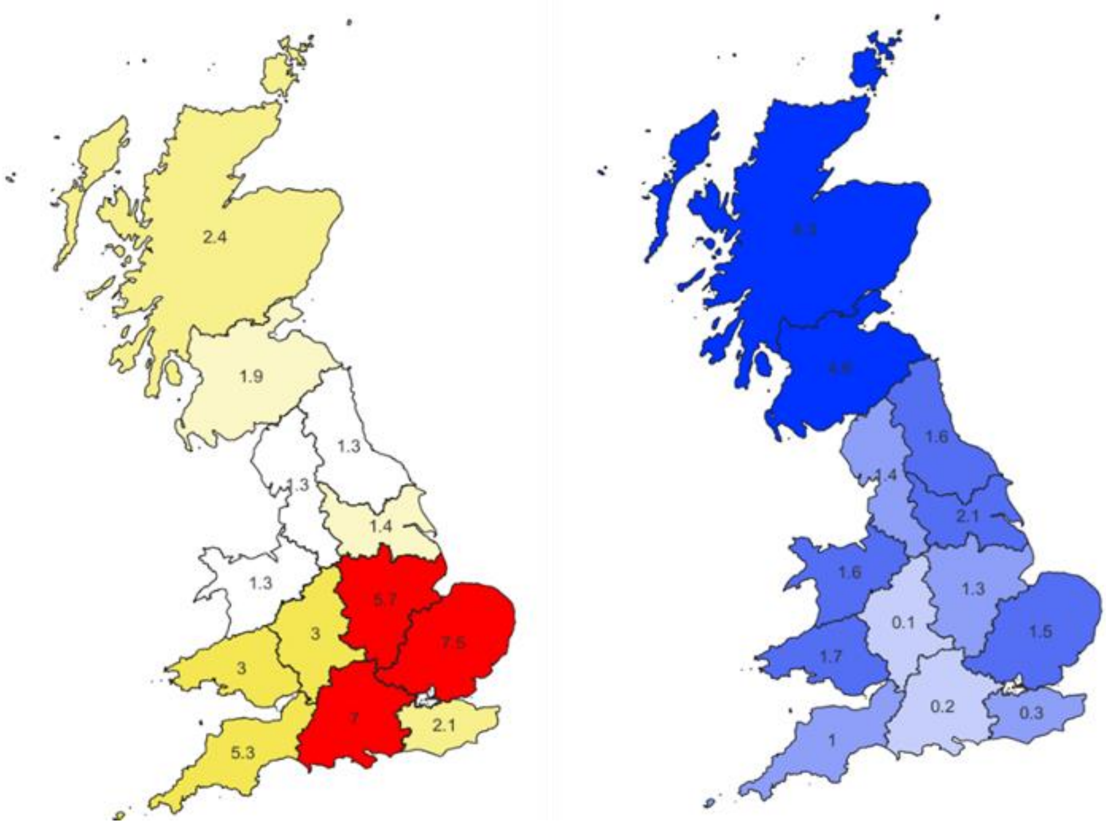


Figure 63: FES 2023 projections for large scale solar (G99) (left) and onshore wind (>=1MW) (right) deployed capacity in 2050 under the Leading the Way scenario (GW)

Suitability for daily balancing also gives LAES the potential to locate in urban and industrial locations to help manage peak demand. Waste heat from industrial processes could be exploited to improve system efficiency in these cases. For UK Power Networks, this could manifest at other waste management sites, as has already been piloted between Highview Power and Viridor Waste.

Data centres are a significant source of future electricity demand. They require cooling and produce waste heat. The nature of the LAES as a technology could potentially provide onsite energy management support to data centre sites. With London being at the centre of the UK's internet infrastructure[97], and 19 data centres currently deployed on UK Power Networks' network (see Figure 64 and Table 26), this could be a potential co-location opportunity for future LAES sites e.g. in London.

Figure 64: Data Centres within UK Power Networks' licence areas (left) and London licence area (right), with strategic industrial land shaded in grey.

The location of data centres will be impacted by the current trend towards larger sites, requiring more land and higher capacity connections. Data centres require large volumes of import capacity, which has recently impacted West London[98] at the LPN/SSEN boundary. These factors suggests that data centres may begin to locate in areas with more network headroom and land availability, which may result in potential co-location opportunities for LAES in the South Eastern and Eastern Licence areas, rather than just in London. Sites that do seek a London location are more likely to locate on land allocated for industrial development, shown in Figure 64, alongside existing data centre sites.

[97] https://www.datacentermap.com/united-kingdom/

[98] West London Electricity Capacity Constraints, Mayor of London, 2022: https://www.london.gov.uk/media/98682/download

Table 26: Data centres connected/accepted to connect.

Licence Area	No. data centres	Total capacity	Capacity range	Connection Voltage
Eastern	7	1,318 MW	38 – 600 MW	Primarily 132kV
London	11	420 MW	2 – 200 MW	132kV and 11kV
Southern	1	90 MW	90 MW	132kV

Sources: UKPN connections data & UK Gov 'London Datastore', November 2023.
Note: Excludes three sites with no location information.

Developer engagement: Highview Power has advised that they are not currently developing any LAES projects in UKPN's licence areas. They are focusing on regions with higher expected levels of renewable curtailment. Their website[99] also states that their next two projects will be located in Scotland and the north east of England. However, they advised they are not ruling out LAES projects in UKPN's licence areas in the medium/longer term. The development of renewables and grid infrastructure in the Eastern licence area is seen as a key determining factor.

In relation to grid infrastructure, this relates to wider developer views around connection capacity headroom and availability of securing a grid connection (affected by both transmission and distribution capacity). Choice of site for LAES will favour areas with good import ane expot capacity primary factor, alongside any locational services they are targeting such as ESO pathfinder for voltage or inertia. LAES may actively seek areas with active generation constraints to mitigate through their technology, so perhaps import demand capacity availability is more prevalent. However, in order to secure a connection agreement, they are likely pursuing areas with capacity headroom availability in general.

High-density pumped hydro energy storage (HD-PHES)

Description: High-density pumped hydro (HD-PHES) is a development of traditional pumped hydro storage. It makes use of advanced materials, turbine and pump technologies to deliver increased energy density over a traditional system. This widens the envelope of potential sites which could support a project. Where previously UK pumped hydro projects have only been developed in Scotland and North Wales, HD-PHES projects could operate beneath small hills across wider areas of UK. The potential use of underground reservoirs would also reduce land use requirements and environmental impacts, further removing barriers to development.

As with LAES, HD-PHES would be able to offer balancing of generation and demand over daily cycles. However, it is also able to store energy with minimal losses over longer periods, making weekly and even seasonal energy storage potential applications.

Active organisations: RheEnergise are a UK based company developing an HD-PHES solution which makes use of their proprietary high density fluid, R-19. This fluid has a density 2.5x that of water, potentially allowing 2.5x the energy to be stored for a project of a given size[100].

[99] https://highviewpower.com/projects/#uk-projects-mob
[100] https://www.rheenergise.com/how-it-works

The company has conducted demonstration tests in Canada, but does not currently have any active UK projects. In August 2023, RheEnergise entered into an agreement with Mercia Power Response to explore deploying 100 MW of HD-PHES into commercial operation by 2030. These projects would utilise Mercia's existing grid connection agreements.[101] An analysis of where Mercia holds connection agreements would provide some indication of where a future HD-PHES site could locate.

Relevant spatial factors and presence in UKPN: While significantly less geographically constrained than traditional pumped hydro, HD-PHES still requires a location providing adequate elevation between reservoirs and slope gradient. Road access and grid connection proximity are also considerations within RheEnergise's own *Pre-Feasibility* analysis, seen in Figure 65. When viewed relative to the wider UK, UKPN is an area of 'low potential' according to GIS surveys, see Figure 66.

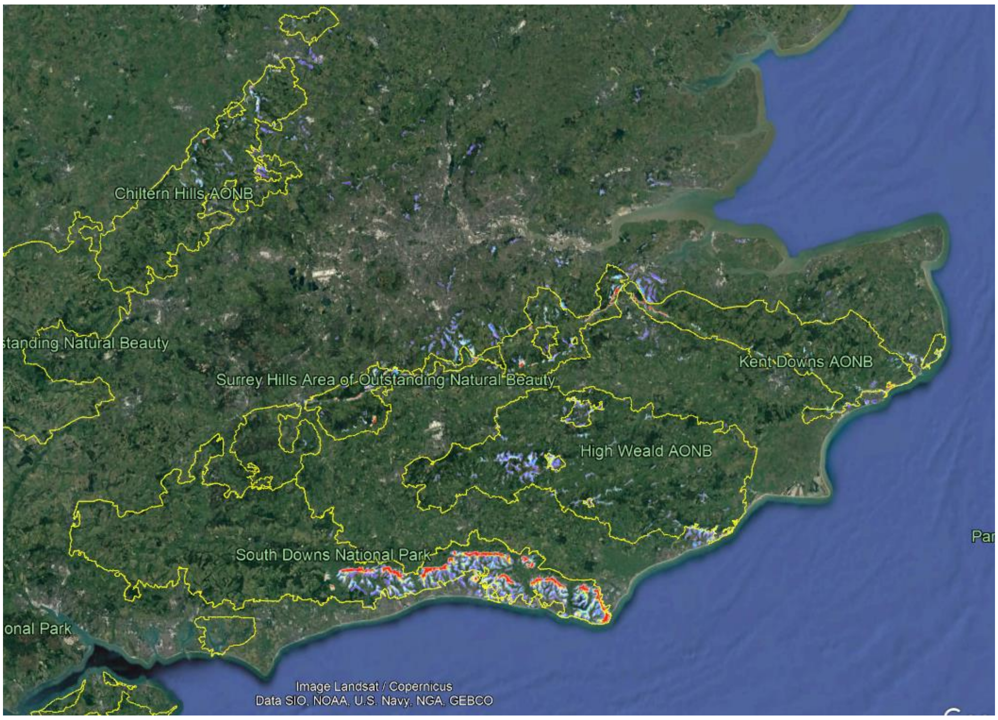


Figure 65: RheEnergise GIS survey for HD-PHES pre-feasibility survey and AONB/national park areas in South East England

[101] https://www.rheenergise.com/press-release---mercia-rheenergise-mou

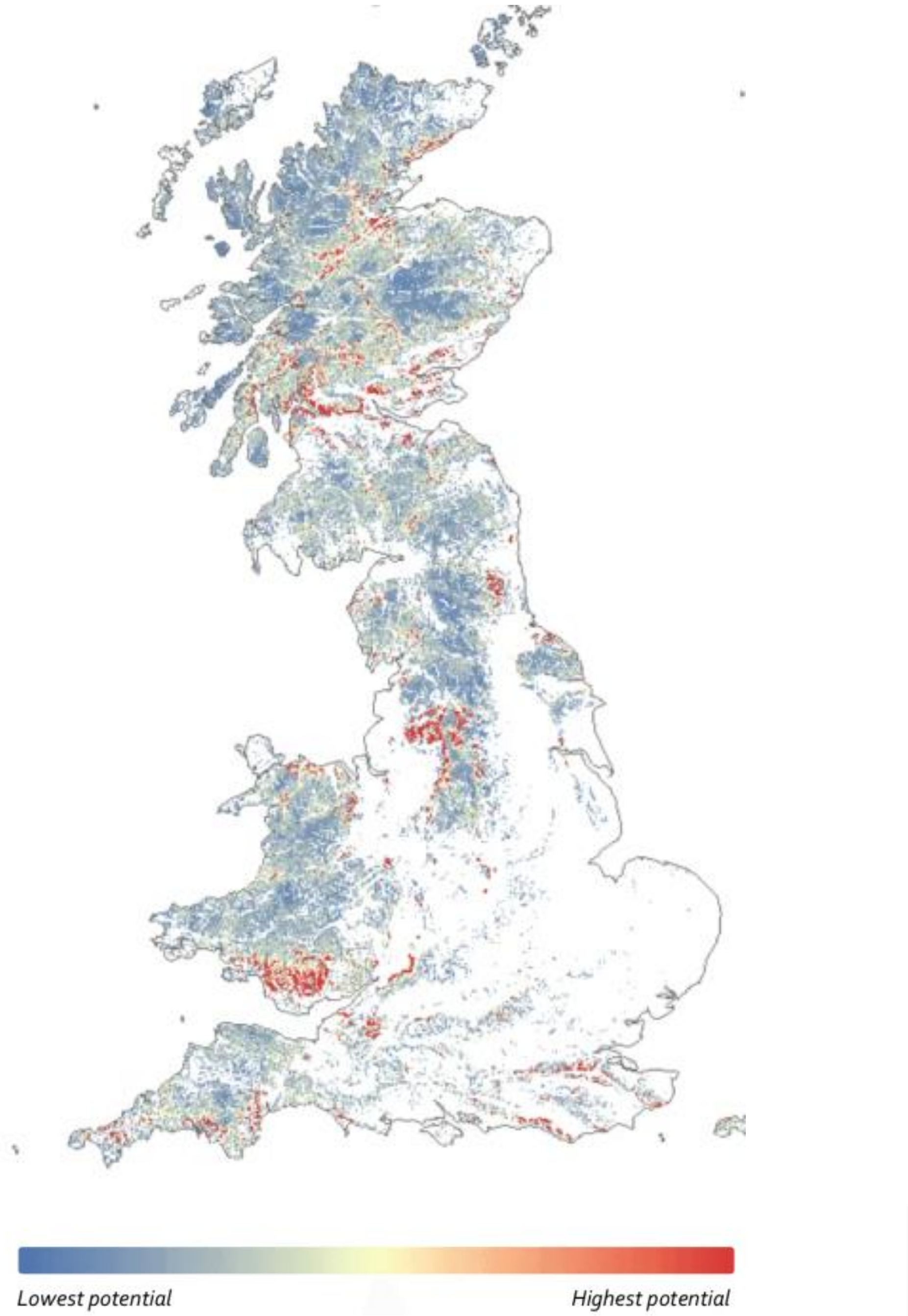


Figure 66: RheEnergise GIS survey of the UK assessing potential for HD-PHES projects, considering elevation, slope, road access and grid connection proximity[102]

the majority of geographically and infrastructurally feasible sites for HD-PHES sites in UKPN's licence areas fall within the South Downs National Park, or the High Weald, Kent Downs or Surry Hills AONBs. This would make their development more unlikely. Based on this, it is reasonable to assume that HD-PHES will not be locating within UKPN's licence areas in the near term and deployment in the longer term is also unlikely.

Developer engagement: RheEnergise were contacted and have contributed by supplying the view of their pre-feasibility survey, used and summarised above.

[102] https://www.rheenergise.com/opportunities

Gravitational energy storage

Description: Gravitational energy storage functions by elevating mass when electricity is available to 'charge'. This energy is stored as gravitational potential energy until discharge, when the mass is allowed to descend and directly drive a generator. The key requirements for this system are a large singular mass or system of mass, an elevation range to raise and lower the mass, and an electro-mechanical or hydraulic system which can do so efficiently. The technology is scalable, and different approaches are being tested which deliver a range of operational capabilities, ranging from short term frequency response, to long term energy storage.

Active organisations: Gravitricity, based in Edinburgh, is developing a system which makes use of abandoned mineshafts through which mass is raised and lowered mechanically. They have secured funding through a number of government support programmes:

- £650k though the Innovate UK 'Infrastructure Systems Innovation' competition in 2018.
- £300k under the Innovate UK 'Energy Catalyst' programme in 2020.[103]
- £912k through the BEIS LODES competition in 2022.

Gravitricity has developed a 250 kW demonstrator in Edinburgh, is conducting feasibility studies in the Czech Republic, Finland, India and South Africa, and entering into partnerships to investigate sites in the United States[104]. In addition, a Swiss company, Energy Vault, is developing a system using an above ground crane which raises and lowers a system of weights. Gravity Power, a US company, is developing a hydraulic system using high pressure pumps to lift a large mass, which then forces water though a turbine on discharge.

Relevant spatial factors and presence in UKPN: While Gravitricity claims that purpose-built shafts could be feasible in the future[105], at present, the solutions being developed by Gravitricity make use of abandoned mineshafts. Regen has investigated acquiring data on abandoned mineshafts from the UK government coal authority[106], but this would need to be complemented with additional filtering based on project requirements. Without further information at this time, this filtering could include factors such as minimum depths and bore, the angle of the mineshaft, degree of flood risk, ground stability and accessibility. Through further engagement with Graviticity, a more detailed assessment of potentially viable sites within UKPN could be developed.

As with LAES, colocation with renewables, or in constrained areas with high renewables penetration, could be a potential use case for gravity-based energy storage projects. This would again link to the potential future concentration of solar projects in the north of the Eastern licence area, as demonstrated inFigure 66. Availability of land and grid capacity will also be a consideration.

Developer engagement: Regen is engaging Gravitricity around their site assessment methodology and potential to develop projects in UKPN's licence area.

[103] https://www.nsenergybusiness.com/projects/gravitricity-gravity-based-energy-storage-demonstrator/#:~:text=Gravitricity%20fundraise%20and%20grants&text=Gravitricity%20was%20also%20earlier%20awarded,grant%20of%20approximately%20%C2%A3175%2C000.
[104] https://renewablesnow.com/news/gravitricity-to-target-us-funds-for-clean-energy-projects-at-mines-820911/
[105] https://gravitricity.com/technology/#:~:text=Purpose%2Dbuilt%20shafts%20can%20be,to%20the%20point%20of%20demand.
[106] https://www.gov.uk/government/organisations/the-coal-authority

ERM has over 160 offices across the following countries and territories worldwide

Argentina
Australia
Belgium
Brazil
Canada
China
Colombia
France
Germany
Ghana
Guyana
Hong Kong
India
Indonesia
Ireland
Italy
Japan
Kazakhstan
Kenya
Malaysia
Mexico
Mozambique
The Netherlands
New Zealand
Peru
Poland
Portugal
Puerto Rico
Romania
Senegal
Singapore
South Africa
South Korea
Spain
Switzerland
Taiwan
Tanzania
Thailand
UAE
UK
US
Vietnam

ERM's London Office
2nd Floor Exchequer Court
33 St Mary Axe
London
EC3A 8AA
T +44 20 3206 5200

www.erm.com