# 2023 Distribution Future Energy Scenarios

## Regional Outlook: UK Power Networks' projections
## December 2022

UK Power Networks

element energy
an ERM Group company

# Executive Summary

The volatility of the global energy markets due to recent geo-political instability has accelerated the post-COVID-19 surge in energy prices and has caused countries across Europe, including the United Kingdom to reprioritise their climate action strategies to focus on long-term energy security. However, the United Kingdom remains legally committed to the ambitious target of reaching Net Zero emissions by 2050, as well as the interim goal set by the Climate Change Committee's 6th carbon budget recommendation of a 78% reduction relative to 1990 levels by 2035.

In April 2022, as a response to this 'call to action', the Government published the British Energy Security Strategy[1] which in addition to the Ten Point Plan[2] and Net Zero Strategy[3] is anticipated to drive up to £100 billion of private sector investment by 2030 and accelerate the progress towards Net Zero. In this strategy, the Government identified several priorities to address the issues caused by the energy crisis, the most immediate being providing financial assistance to households and businesses struggling to pay higher energy prices. The strategy also highlights the importance of energy demand reduction through efficiency improvements as a first step in reducing energy bills. Furthermore, the report stresses the need to reduce British dependence on the foreign fossil fuel markets by accelerating the rollout of new renewable energy projects, "investing massively in nuclear power"[4] and sourcing domestic fossil fuel reserves from the North Sea. Lastly, the strategy aims to prioritise cost-effective planning to build ahead of need as well as promoting "hyper-flexibility in matching supply and demand so that minimal energy is wasted".

UK Power Networks' business plan for the RIIO-ED2 period (April 2023 - March 2028)[5] outlines 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)[6], and while bespoke to the UK Power Networks' region are consistent with the over-arching scenario narratives of the four scenario worlds developed by National Grid in their Future Energy Scenarios publications. While the DFES are updated annually to reflect new developments, such as changes in policy and technological advancements, these core scenario worlds remain consistent with the view presented in the RIIO-ED2 business plan.

In this update of the DFES, we continue to update 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. Since the publication of the previous DFES, we have updated our uptake scenarios for low emission cars and vans to reflect the latest Li-ion battery price projections that have changed due to COVID-19 related material price increases and supply chain issues. We continue to make our projections for distributed generation consistent with stated Government ambition to phase out fossil-fuel generation by 2035. Furthermore, we include the new Boiler Upgrade Scheme and second wave of the Social Housing Decarbonisation Fund in the policy support for decarbonised heating.

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 they deliver a reliable network for their customers in the most cost-effective manner, whilst supporting the UK's decarbonisation ambitions.

1 British Energy Security Strategy, HM Government, 2022
2 The Ten Point Plan for a Green Industrial Revolution, HM Government, 2020
3 Net Zero Strategy, BEIS, 2021
4 British Energy Security Strategy, HM Government, 2022
5 UK Power Networks, ED2 Business Plan, December 2021
6 Element Energy for UK Power Networks, Distribution Future Energy Scenarios January 2021.

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## Disclaimer

# Acronyms

| | |
|---|---|
| AC | Air conditioning |
| BEV | Battery electric vehicles |
| CCC | Climate Change Committee |
| CT | Consumer Transformation |
| DFES | Distribution Future Energy Scenarios |
| DfT | Department for Transport |
| DNO | Distribution Network Operator |
| ECCo | Element Energy Car Consumer model |
| ECR | Embedded Capacity Register |
| EPN | Eastern Power Networks |
| EV | Electric vehicle |
| FCEV | Fuel cell electric vehicle |
| FES | (National Grid) Future Energy Scenarios |
| FS | Falling Short |
| GB | Great Britain |
| GDP | Gross domestic product |
| GLA | Greater London Authority |
| HDV | Heavy-duty vehicle |
| HGV | Heavy goods vehicle |
| HP | Heat pump |
| I&C | Industrial and commercial |
| ICE | Internal combustion engine (vehicle) |
| LA | Local Authority |
| LPN | London Power Networks |
| LSOA | Lower Layer Super Output Areas |
| LW | Leading the Way |
| MSOA | Middle Layer Super Output Areas |
| NG | National Grid |
| PHEV | Plug-in hybrid electric vehicles |
| PHV | Private hire vehicle |
| PV | Photovoltaic |
| SPN | South Eastern Power Networks |
| ST | System Transformation |
| TfL | Transport for London |
| ToUT | Time-of-Use Tariff |

# 1 Introduction

## 1.1 UK Power Networks

UK Power Networks serves 8.4 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. We publish many of the scenario datasets 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 we used Office for National Statistics (ONS) areas called:

- 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 resolution, wherever possible, will published on UK Power Networks' Open Data portal alongside this report.

**Table 1: Average dimensions of MSOA and LSOA across England[7].**

| 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 |

[7] https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography

## 1.2 Structure of the report

This report provides an overview of the process of generating UK Power Networks' Distribution Future Energy Scenarios (DFES). First, we outline the scenario framework and explain how individual scenarios are brought together to create four different possible future scenario worlds. Next, we detail 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, we present 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** presents the conclusions drawn from this work and outlines how UK Power Networks intends to use these scenarios within their business going forward.

## 2 Scenario framework

In this work, we adopted the scenario framework published by National Grid in their latest Future Energy Scenarios[8] 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. These pathways represent different positions on two main axes, speed of decarbonisation and level of societal change (Figure 1). A notable update from the latest Future Energy Scenarios is the renaming of the least ambitious scenario, formerly Steady Progression, to Falling Short reemphasising how the scenario does not reach the UK target for Net Zero by 2050. The general scenario narrative for Falling Short has remained unchanged. We developed bespoke scenarios for each driver of demand and generation and constructed four overarching scenario worlds that align with the narratives of the pathways from National Grid (see **Section 2.2**). By developing our own uptake scenarios with local knowledge, we are able to 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.

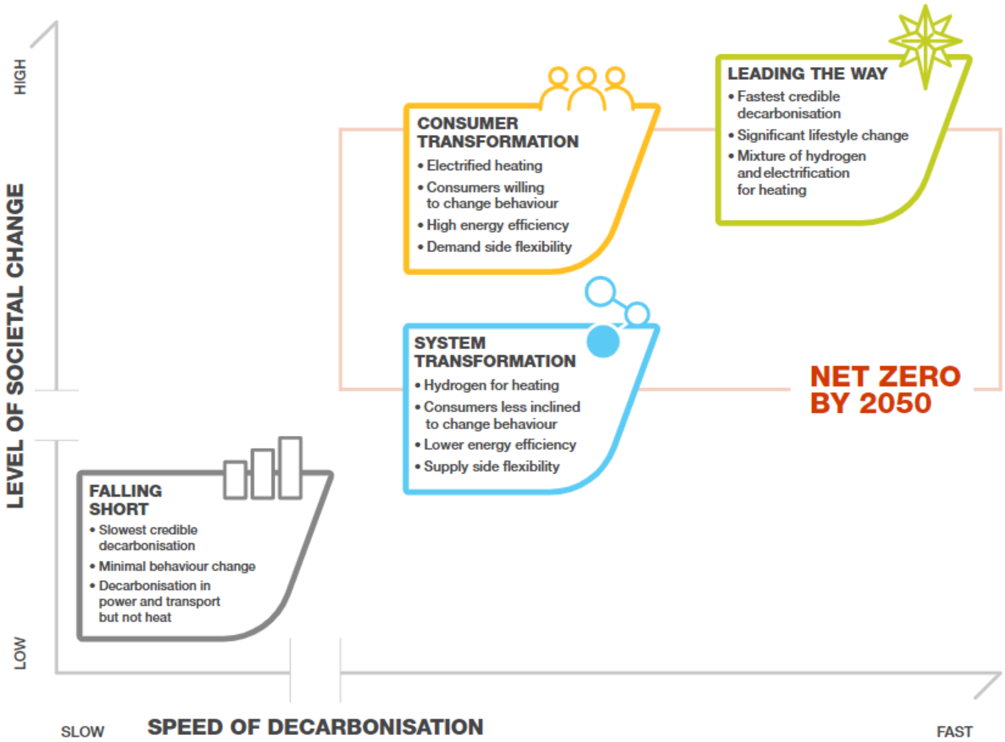


**Figure 1: Scenario world framework overview (source: National Grid).**

[8] National Grid ESO, *Future Energy Scenarios,* July 2022

## 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.

**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.

### 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 Building blocks and application of the DFES

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, we produced three to four scenarios for each driver and took a bottom-up approach 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's Future Energy Scenarios (NG FES) and the DFES. Table 2 lists the main drivers modelled and the uptake scenarios making up each of the four scenario worlds.

### 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 our 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 our network. This translates DFES to network assets such as substations.

In 2023, the 2023 DFES scenario assumptions will be combined with substation demand profiles for the year April 2022 – March 2023 to produce our DFES scenarios at network asset level e.g. per substation. We use that assessment of network loading as the updated baseline for our 2023 demand forecast cycle from summer 2023 onwards. In 2023, we will also use the generation baseline in the 2023 DFES (from end March 2022) to produce our DFES scenarios of generation per network asset e.g. per substation.

These outputs are used by UK Power Networks for network planning – this is DFES with a purpose – and to inform our stakeholders, Ofgem and National Grid ESO.

### Use of the best view scenario and other DFES scenarios

For planning purposes UK Power Networks uses the Consumer Transformation scenario as its "Best View" scenario. This is aligned with feedback from our stakeholders who told us their priorities were to achieve Net Zero whilst keeping bills as low as possible. In our assessment ahead of our business plan submission, Consumer Transformation came out as the lowest cost Net Zero compliant scenario. 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.

The "Best View" scenario is shown in the Long-Term Development Statement (LTDS)[9] for five years ahead e.g. Table 3 in the LTDS shows Grid and Primary substation peak demand forecasts. The "Best View" scenario is also the key input to the network developments plans shown in the LTDS for five years ahead. LTDS for all licence areas are published on our Open Data Portal.

In the Network Headroom Report (NHR) tables in our Network Development Plan (NDP), the "Best View" is shown alongside other DFES demand and generation scenarios to 2050 at substation level, for all substations in the LTDS. The NHR must indicate unused substation capacity for demand and generation, based on the licensee's latest LTDS and the latest application of the DFES forecasts for demand and generation at the substation. Publication of the NDPs was a new regulatory requirement in May 2022. Like the LTDS, the NDP is also published on our Open Data Portal. The May 2022 NDP reflected the LTDS from November 2021 and DFES 2021.

[9] The most recent LTDS November 2022 tables are based on DFES 2022 (published February 2022), with the LTDS November 2023 to be based on this assumptions in this DFES document, DFES 2023.

The 2022 NDP also contained development plans for the next ten years, informed by DFES. The "Best View" scenario is the primary input to the development plans for both infrastructure and flexibility services. However, in preparing the development plans for the NDP, the impact of the other DFES scenarios is 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.

The NDP is fully updated every two years, with an annual update of the NHR tables but not of the development plans. The May 2023 NDP will reflect the 2022 demand and generation assessment based with a baseline of the end of March 2022 – this means demand will be based on the DFES 2022 (prior to the summer 2023 demand update to reflect DFES 2023 and a new baseline year of 2022/23), while generation will be based on DFES 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 |
| Gas grid availability | Remains at current availability | Remains at current availability | Decommissioned by 2050 | Reduced utilisation |
| Gas grid composition | Mainly natural gas, with some biogas | After 2040: $H_2$ and other low-carbon gases | Mainly natural gas, with some biogas until 2050 | Possibly a mixture of low-carbon gases |
| District heat uptake | Low | Medium | High | High |
| **Distributed Generation** | | | | |
| Small-scale 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 |
| Standalone grid-connected battery | Progressive High | Medium | Sustained Early High | Early High |
| **Flexibility** | | | | |
| Flexibility | Low | Medium | High | High |

# 3 Scenario development

In developing the scenarios used to model the uptake of different drivers of demand and generation, we ensure that the assumptions used in our analysis are aligned with firm policy positions made by the UK Government. In this year's update we align our analysis with the UK Government's recently published British Energy Security Strategy (BESS)[10] as well as statements or policy made by other regulatory bodies such as Ofgem.

The main priority of the BESS is ensuring energy security and less volatile energy prices for the UK. Related to the drivers considered in this DFES analysis, the BESS outlines ambition to:

1. **Demand:** "Accelerate energy efficiency deployment and phase out fossil fuel use".
2. **Solar:** "Ramp up deployment, on both roofs and ground".
3. **Wind:** "[Ensure] cheaper power for local areas by cutting planning and delivering better connections".
4. **Hydrogen ($H_2$):** "Boost out commitment to green $H_2$, accelerating our $H_2$ economy.

The ambitions outlined above have translated into slightly increased uptake of solar PV generation as well as increased policy support for low carbon heating and energy efficiency upgrades through the Boiler Upgrade Scheme and the continuation of the Social Housing Decarbonisation Fund.

It must be noted that 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 our forecasts to not be unduly influenced by the current cost-of-living crisis and significant energy price increases, we assume these factors revert to historical rates in the short to medium term. This aligns with feedback from our stakeholder engagement sessions.

## 3.1 Core demand

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, we define the 'core demand' from these sectors as the electricity demand related to all existing appliances and cooling. Electric heating, including 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 we outline the modelling for each of the aspects of core demand outlined above, how they may change in future and how our scenarios have changed since the publication of the latest DFES[11]. Table 3 shows how the uptake scenarios that we have generated for the drivers of core demand maps to the scenario world framework.

[10] HM Government, British Energy Security Strategy, April 2022
[11] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 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

We follow the same methodology as the previous DFES to model the growth in domestic building stock. We used household growth projections for each local authority (LA) from the Office for National Statistics (ONS)[12] to define a medium household stock growth scenario for each local authority and used the low and high population growth projections from ONS to produce scaling factors relative to their central projection to produce low and high stock growth projections. As a result, we now obtain three projections 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, we used UK Power Networks' analysis of local authority growth plans where available (see past DFES for more detailed methodology).

[12] Office for National Statistics (ONS), *2018-based Household projections for England (principal projection),* June 2020

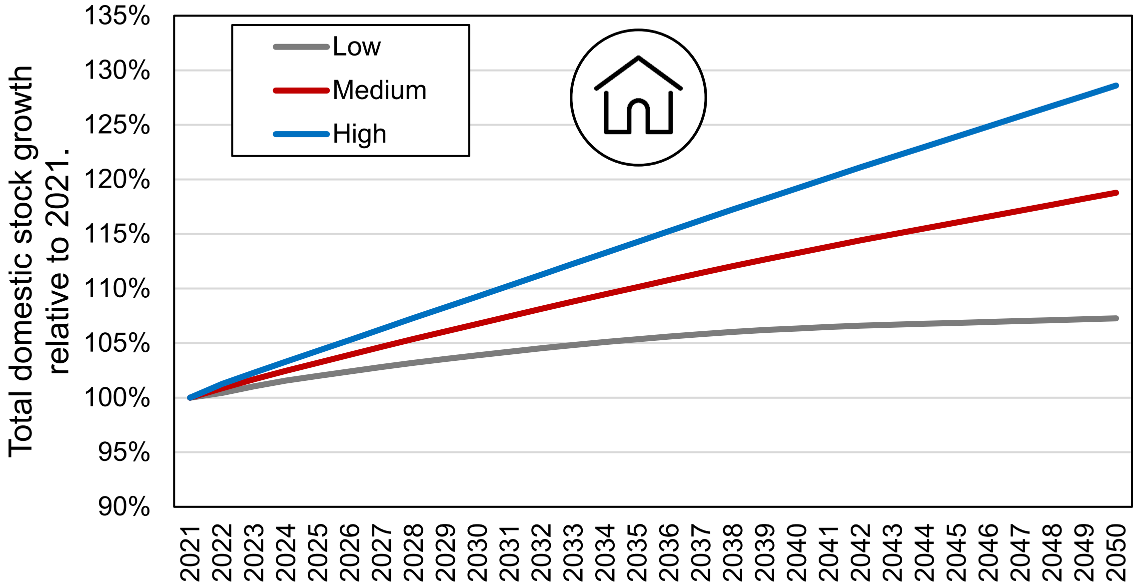


**Figure 2: Domestic household growth in UK Power Networks' region out to 2050.**

Figure 2 shows the resulting projections for the total domestic stock growth in UK Power Networks' region out to 2050. In our scenario framework, we choose the medium growth rate, 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, we model growth by considering the growth in floorspace by local authority, as floorspace is a key metric for determining energy consumption. We follow the same methodology as the previous DFES with updated input parameters. Among these inputs are projections for GDP growth, which were significantly impacted by the lockdown in response to the COVID-19 pandemic. We use economic growth as an indication for growth in the I&C sector. Since the % GDP change in 2020 was negative, and the growth in 2021-2022 was not high enough to exceed 2019 values, we assume no growth in GDP in both these years. We then modify the GDP projections from the Office for Budgetary Responsibility (OBR)[13] and set the GDP growth in 2022 to the projected net increase from pre-COVID-19 levels to avoid unrealistic fluctuations in I&C floorspace over the next year. Figure 3 shows the resulting floorspace growth projections. Similar to the domestic sector, we assume a medium growth in I&C floorspace in all scenario worlds.

[13] Office for Budgetary Responsibility (OBR), Economic and fiscal outlook – March 2022, available from: [Economic and fiscal outlook - March 2022 (obr.uk)]

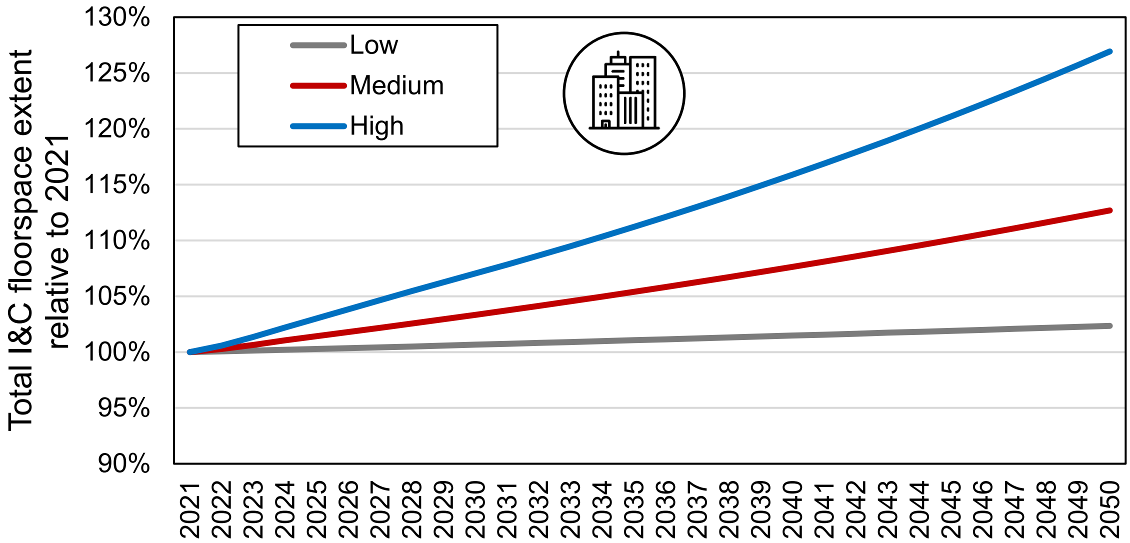


**Figure 3: Total industrial and commercial (I&C) floorspace growth in UK Power Networks' region relative to 2021.**

### 3.1.2 Electrical energy efficiency

#### Domestic appliances

We continue to use the dataset published as part of UK Power Networks' Low Carbon London project[14], which contains efficiency scenarios for each category of appliance ('wet' appliances, 'cold' appliances, electronics, lighting etc.). We have assumed that in each category, the progress to date has followed the path of the 'current policies' scenario. We are then able to update the scenarios to a 2021 base year and aggregate the different load categories together according to their relative proportion of current domestic demand. The results, shown in Figure 4, are consistent with the previous DFES.

[14] Low Carbon London, UK Power Networks Innovation project, 2010-2014. We have reviewed the research on domestic appliance efficiency. Considering factors including the past trajectory of improvements and the latest government signals, we have decided that data from the Low Carbon London is still more suitable than other newer sources. We have rebased the scenarios 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. We will continue to monitor research in this area in case anything new and more suitable is published ahead of next year's update.

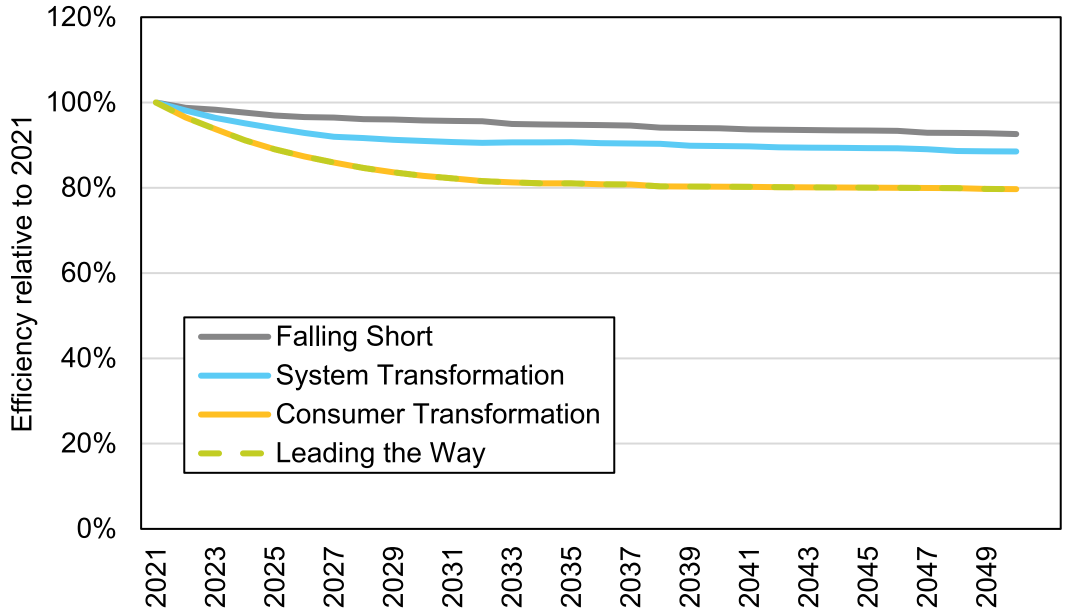


**Figure 4: Domestic appliance efficiency, based on predictions from the Low Carbon London project**

## I&C baseload

We developed three scenarios for non-thermal energy efficiency for 9 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[15]. Figure 5 shows the resulting energy efficiency projections for each different sector in the System Transformation scenario.

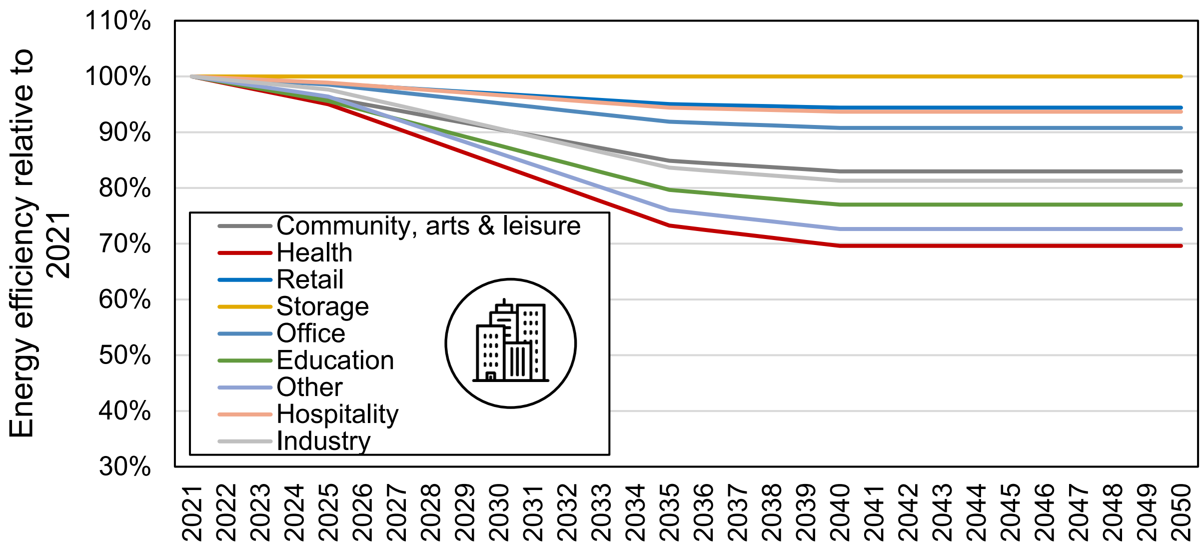


**Figure 5: Energy efficiency in different I&C sectors out to 2050, System Transformation.**

[15] 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[16]. 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 we have updated the AC uptake scenarios to a 2021 baseline, employing the methodology outlined in the previous DFES[17].

Figure 6 shows the uptake of domestic air conditioning by scenario world out to 2050. Our scenario mapping is aligned to the mapping used in National grid's Future Energy Scenarios[18]. 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, we assume 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.

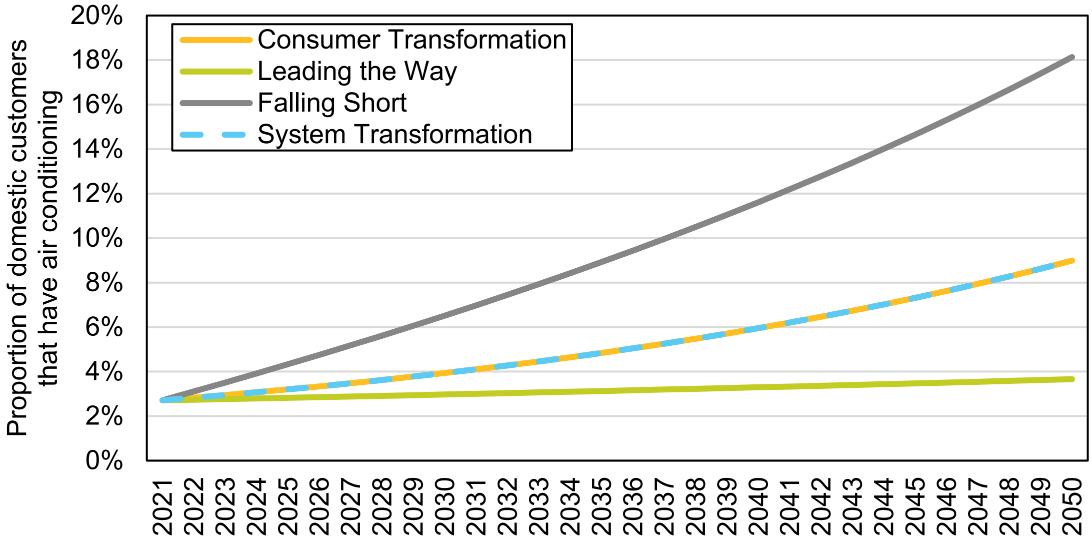


**Figure 6: Air conditioning uptake in the domestic building stock within UK Power Networks' licence areas**

[16] 'UK Climate Projections: Headline Findings', Met Office, 2019
[17] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.
[18] National Grid Future Energy Scenarios, FES 2022 Scenario assumptions, 2022

## 3.2 Low-carbon transport

**Key Messages**

- We updated our approach to establish the baseline values for electric cars and vans, resulting in higher EV numbers reported in the near term than in the previous DFES.
- Due to a high decarbonisation ambition within London, we treat taxis and PHVs that regularly service within London separately to others.
- In Leading the Way, we model a demand reduction in passenger travel, shifting trips from cars to buses and active mode of travel.

We created uptake scenarios 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 are 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, we determined the following:

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.

We have followed a similar process to those outlined in the past DFES for all technologies. In the sections that follow, we highlight key changes and updates to the modelling methods since the previous 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 System Transformation | 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.

#### Cars and vans

For our baseline, we need to start by establishing 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. To do this, we use a processing of several data tables published by the Driver and Vehicle Licensing Agency (DVLA) and the Department for Transport (DfT), including VEH0135, which provides the number of BEV and PHEV vehicles at LSOA resolution, and VEH0125, which gives the number of total cars, motorcycles, and other body types by LSOA. The baseline year is the regulatory year 2021, or the period from April 2021 – March 2022, and therefore we use data from end of Q1 2022. As the former dataset does not resolve the electric vehicle counts by body type (cars, vans, buses, etc.) and the latter does not contain the number of vans by LSOA, further processing of this data is required, using as inputs various other DVLA and DfT datasets that are available at lower geographic resolution (usually by local authority).

Additionally, we perform a company car redistribution, adjusting for the low proportion of company cars registered within UK Power Network's licence areas, and perform subsequent data cleaning steps to remove hotspots of high EV registrations, usually associated with leasing companies. The DVLA/DfT definition of cars includes private hire vehicles; as we model these separately, the final step to obtain the baseline for cars only is to subtract our baseline of private hire vehicles, detailed in the next section, from the baseline for cars. Due to the updated methodology for establishing the baseline this year, particularly around the redistribution of company cars (including electric cars), the resulting baseline number of electric cars and vans is considerably higher than what was reported last year, with 269,000 EVs estimated within UK Power Networks' licence areas in March 2022 compared to 106,000 estimated for March 2021 in the previous DFES.

Once we have our baseline data, to commence uptake modelling we use the Element Energy Car Consumer (ECCo) model[19] to model the number 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 bespoke 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 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.

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 access to public charging is limited. In **ICE Ban,** announced Government policy is implemented in full, with petrol, diesel, and hybrid cars removed from the market in 2030, and PHEVs in 2035. No action is taken to reduce private car 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 projections for total vehicle milage[20]. 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**

[19] The Element Energy Car Consumer model was originally commissioned by the Energy Technologies Institute (ETI) in 2010 and has been updated regularly since for the Department for Transport, with the latest update delivered 2022 Q1. The latest update includes the reviews of the Plug-in Car Grant and Plug-in Van Grant. For more information, refer to http://www.element-energy.co.uk/sectors/low-carbon-transport/project-case-studies/#project_1

[20] Department for Transport, Road Traffic Forecasts, 2018.

**Demand.** Annual mileage per vehicle remains constant in this scenario and growth in total car stock follows population growth projections, resulting in a lower vehicle stock by 2050 compared to the other scenarios.

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

| Scenario name | Euro 7 regulations introduced | Perceived access to charging improves | ICE phase out | Demand reduction | Scenario world |
|---|---|---|---|---|---|
| **Limited Uptake** | ✓ | ✗ | ✗ | ✗ | **Falling Short** |
| **ICE Ban** | ✓ | ✓ | ✓ | ✗ | **Consumer Transformation, System Transformation** |
| **Reduced Demand** | ✓ | ✓ | ✓ | ✓ | **Leading the Way** |

Several updates were made to the ECCo model for this year's analysis, including updating our projections for automotive OEM Li-ion battery prices. These projections are based on BNEF's 2021 Battery Price survey[21]. Battery prices increased from 2021-2022 due to COVID-19 related material price increases and supply chain issues. These cost increases are expected to continue into 2022, before falling from 2023.The impact of this can be seen by the steeper BEV uptake from 2023 in Figure 7.

Figure 7 shows the resulting BEV proportion of total car sales for each scenario up to 2040. 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 shares increase, however total uptake remains very low and we do not expect a wholesale shift from BEVs to hydrogen fuel cell vehicles.

[21] BloombergNEF, BNEF 2021 Battery Price Survey, 2021

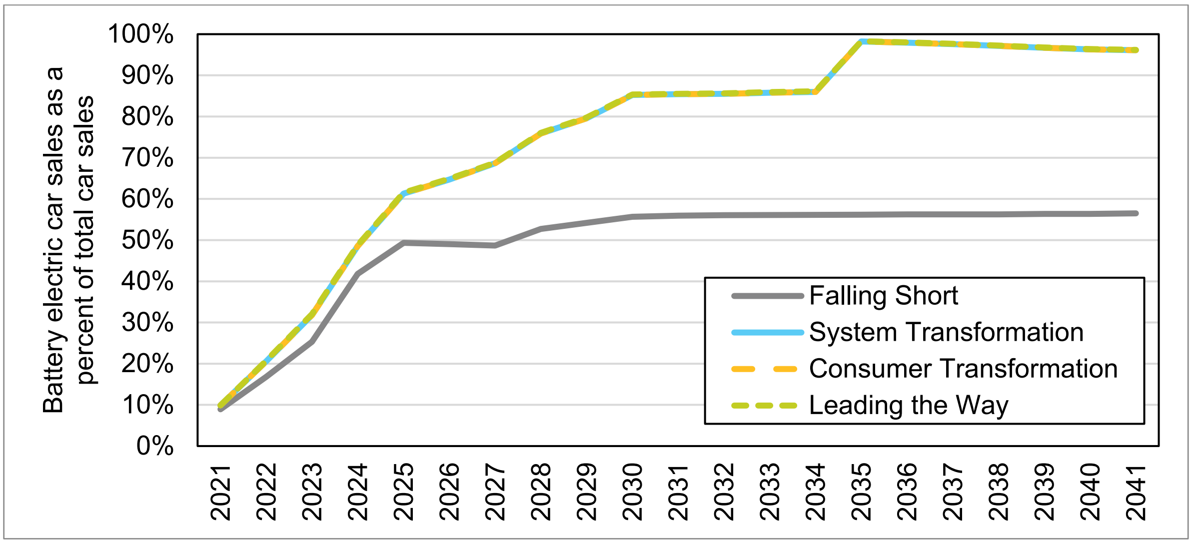


**Figure 7: BEV sales as a proportion of total car sales to 2040.**

Figure 8 shows the resulting breakdown of the car and van stock in UK Power Networks' licence areas. We model the lowest uptake of BEVs 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 hydrogen fuel cell vehicle uptake that we see 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, we see a higher uptake of $H_2$ Fuel Cell EVs (FCEVs) in vans than cars.

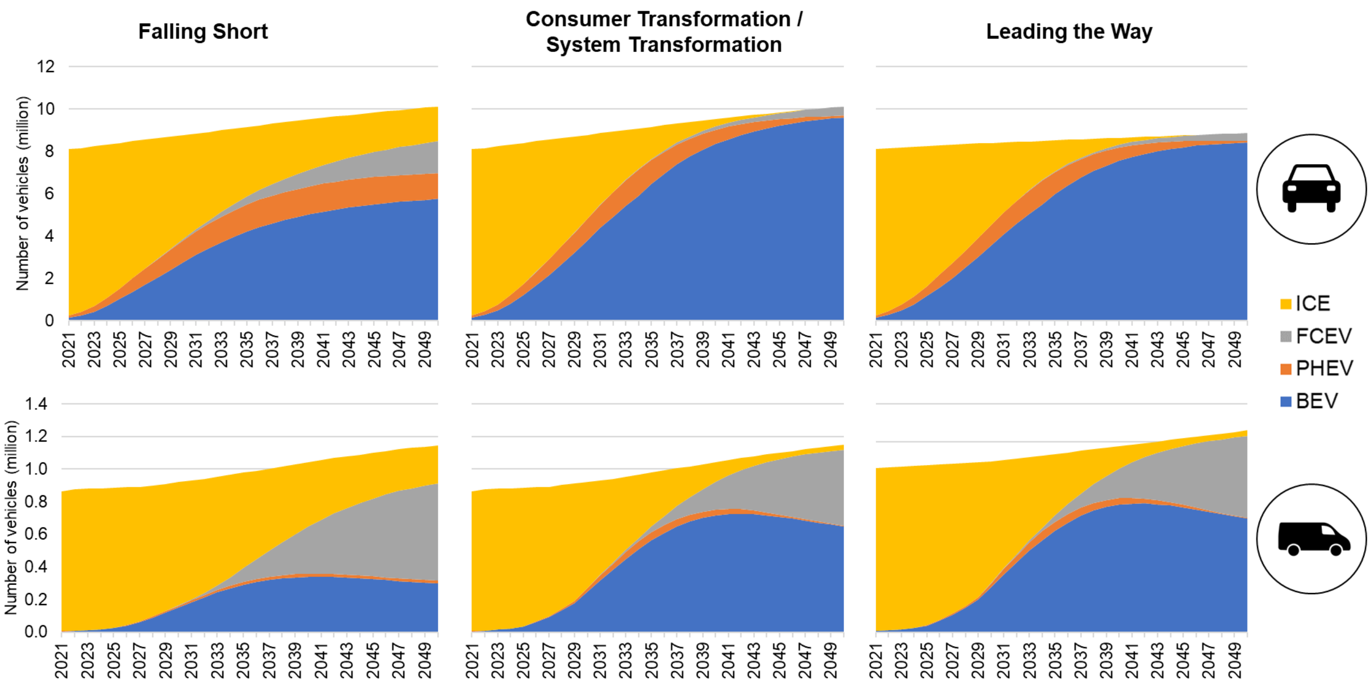


**Figure 8: Breakdown of the vehicle stock in UK Power Networks' licence areas 2020-2050, cars (above) and vans (below).**

We model between 2.5 and 3.0 million electric cars and vans in UK Power Networks' region by the end of the 2027/28 regulatory year (Referred to in the rest of this document as "2027")[22], with the highest number of EVs in Consumer Transformation and System Transformation (Figure 9). Those figures are somewhat higher than those modelled in the previous DFES (between 1.7 and 2.4 million EVs by 2027) which mainly stems from an update in our company car redistribution methodology and the higher baseline EV numbers calculated this year. These changes impact the near-term forecast as the national EV uptake scenarios from our ECCo model are disaggregated to MSOAs within UK Power Networks' licence areas based on the share of national cars and vans present in each MSOA.

Each year, we distribute the new EV sales in GB to MSOAs and add them to the number of EVs already present in each MSOA. In the near term, new EVs in GB are distributed to MSOAs according to the current EV distribution, reflecting the concentration of EVs within regions of early adopters. In the long term, new EVs are distributed according to the total car/van distribution.[23] Therefore, with a higher proportion of the national EV stock now being allocated to MSOAs within UK Power Networks' licence areas in the base year, we expect that trend to continue and allocate a higher share of national EVs to the region in the near-term compared to last year's numbers. By 2050 there are fewer total cars and vans on the road in Leading the Way compared

[22] The years refer to the regulatory year, so "2027" refers to the period from April 2027 - March 2028
[23] For further information on the methodology, refer to: Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021

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.

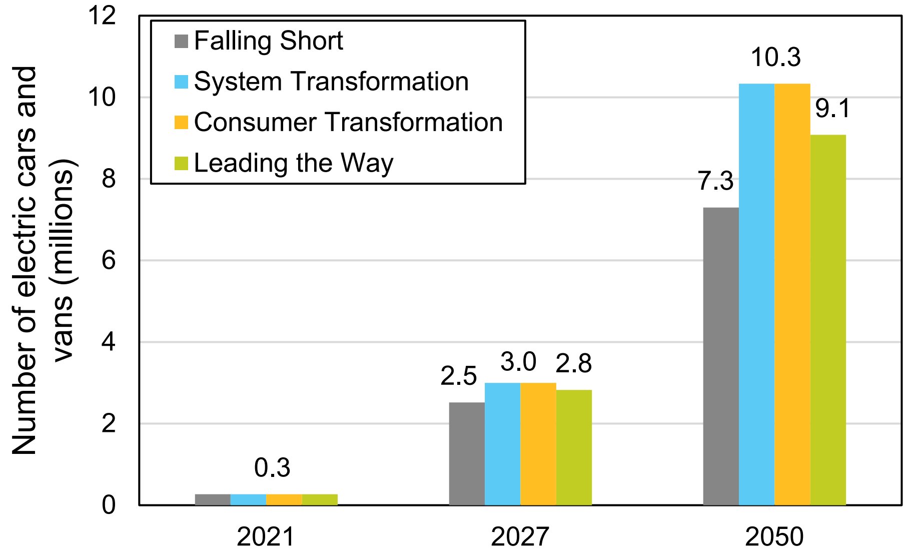


**Figure 9: Number of electric cars and vans in UK Power Networks' region in 2021, 2027 and 2050.**

## Taxis and private hire vehicles

We use a combination of two datasets to establish the baseline number of taxis and private hire vehicles (PHV) at LSOA resolution. Firstly, the number of taxis and PHVs registered by Transport for London (TfL)[24], available at partial postcode resolution, and secondly the number of taxis and PHVs by local authority from the Department for Transport (DfT)[25]. The former is mapped to MSOA resolution by considering proportional land area overlaps between postcode districts and MSOAs and the latter is distributed to MSOAs based on the car distribution from the previous section. We then allocated vehicle numbers to LSOAs by considering UK Power Networks' customer counts.

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

Finally, to establish the proportion of taxis within the extended GLA boundary that are electric, we use the number of electric taxis in London, published by TfL[24], and we use findings from an internal Element Energy study for the baseline electric proportion of PHVs within the boundary. For taxis and private hire vehicles outside the boundary, we assume the same electric proportion as the baseline electric proportion for cars, detailed in the previous section (**Cars and vans**).

In the last DFES, we developed new, accelerated uptake scenarios for electric taxis within the extended GLA boundary[26] that we continue to use in this update, with slight modifications to account for latest historic uptake (Figure 10). In Consumer Transformation and System Transformation, 100% electrification is reached in 2028, in line with ambition for decarbonising taxis expressed by some of the regional stakeholders consulted with

[24] To establish the number of taxis and private hire vehicles by partial postcode, we used the taxi and private hire driver partial postcode data and assume that the total number of taxis and vehicles are distributed proportionally to their drivers. Post code district data dated June 2022, electric taxi data from September 2021 and August 2022 was used to estimate the number of electric taxis at end of Q1 2022. TfL licencing information, available from https://tfl.gov.uk/info-for/taxis-and-private-hire/licensing/licensing-information
[25] DfT/DVLA table TAXI0104, available from https://www.gov.uk/government/collections/taxi-statistics
[26] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2022.

during previous DFES work. In Leading the Way, uptake is assumed to follow current electric taxi uptake trends in London, reaching 100% electrification in 2026. Outside the extended GLA boundary, we continue to use modifications of the uptake scenario developed in the Black Cab Green (BCG) project[27]. A five-year delay of the BCG scenario is assumed in Falling Short and an acceleration to reach 100% electrification in 2028 is applied in Leading the Way (see Appendix A). We model a constant stock of taxis out to 2050.

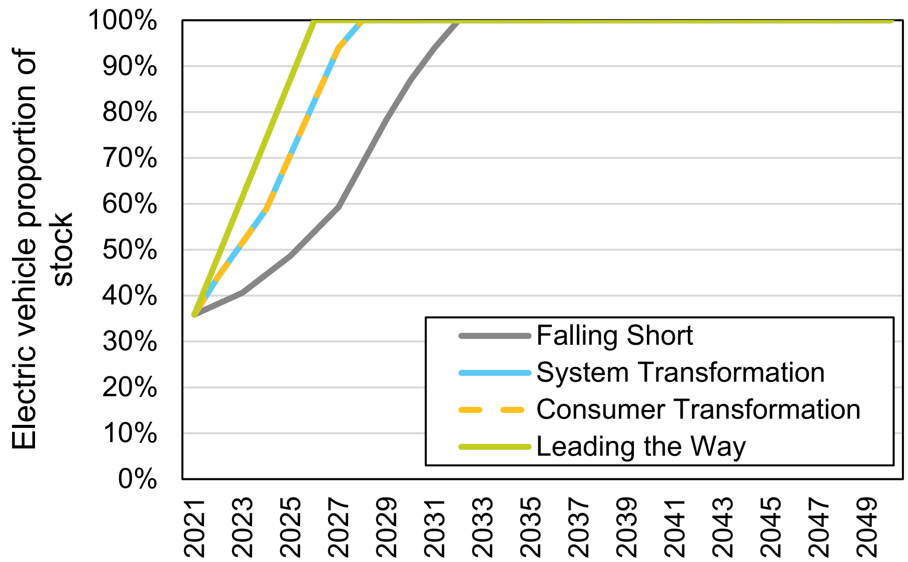


**Figure 10: Uptake of electric taxis within the extended GLA boundary.**

For PHVs within the extended GLA boundary, we continue to use electrification trajectories created using Element Energy's in-house modelling, consistent with the last DFES. The base scenario reflects the current TfL licensing rules and stated ambitions from private hire vehicle operators[28], and a low and high sensitivity. The medium and high scenarios for PHVs outside the boundary are based on the low and high sensitivities respectively, and the low scenario is the five-year delay of the BCG scenario (see Appendix A). We model a constant stock of PHVs in Falling Short, consistent with a 'business as usual' scenario, a moderate growth of 0.5% year on year increase in stock in Consumer Transformation and System Transformation, and a 1% year on year stock growth in Leading the Way. 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.

The result of this modelling suggests that by 2023 (end of March 2024), there could be up to 37,000 electric taxis and private hire vehicles in UK Power Networks' region, rising to up to 96,000 by 2027 (Figure 11). In Leading the Way, the entire taxi fleet is electrified by 2030, with Consumer Transformation and System Transformation following shortly after in 2032. All PHVs are 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, we model between 105,000-130,000 electric taxis and PHVs.

[27] UK Power Networks, 2018, Black Cab Green project, info and reports available from: http://www.smarternetworks.org/project/nia_ukpn_0026
[28] Several London private hire vehicle operators have stated an ambition to go electric, including Uber, Kapten, and Addison Lee.

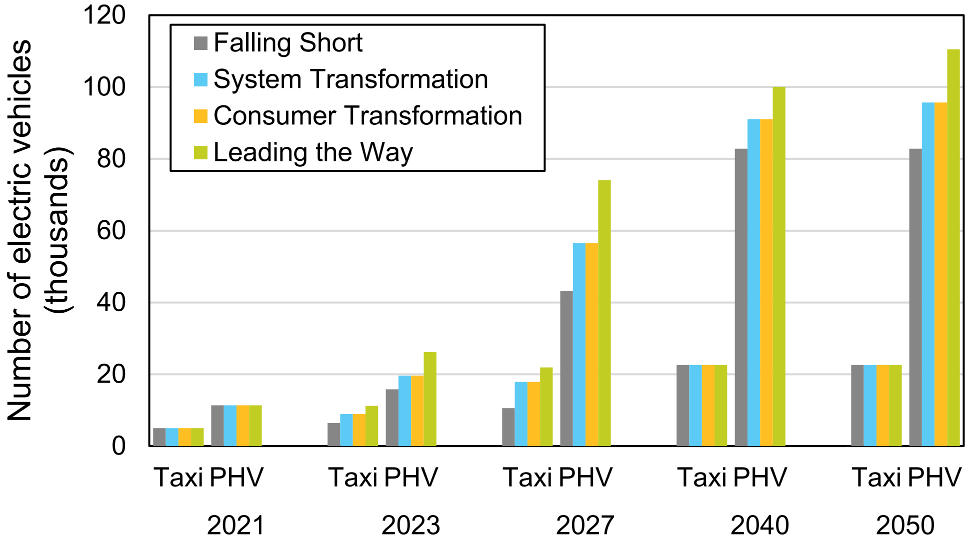


**Figure 11: Number of electric taxis and private hire vehicles in UK Power Networks' licence areas at present (2021), in 2023, 2027, 2040, and 2050.**

### Motorcycles

The number of, and baseline electric proportion of motorcycles in the UK Power Networks' region is established from the DfT vehicle licence statistics, which report vehicle licences at LSOA level[29], and number of electric motorcycles at local authority level[30].

To produce our uptake modelling we use the electrification scenarios for motorcycles developed by TfL, as reported in the London Climate Action Plan[31]. We made use of the Mayor's Transport Strategy (MTS) Near Zero scenario 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, we added two uptake pathways, 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 12).

[29] Motorcycle data is extracted from the DfT/DVLA table VEH0125, available from https://www.gov.uk/government/collections/vehicles-statistics.
[30] 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. We consider the estimated fraction of each local authority that is served by UK Power Networks to derive number of motorcycles.
[31] The London's Climate Action Plan Work Package 3: Zero Carbon Energy Systems, for Greater London Authority / C40 Cities, January 2019.

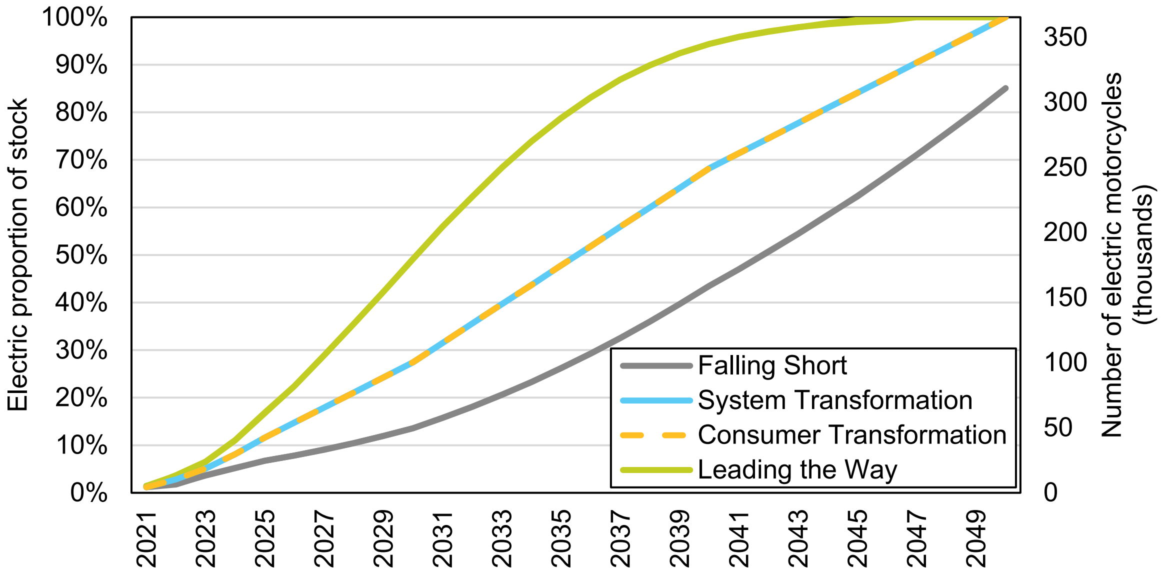


**Figure 12: Uptake of electric motorcycles in UK Power Networks' region in 2021-2050.**

### 3.2.2 Heavy duty vehicles

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

In order to establish the baseline number of heavy-duty vehicles (and their depot locations), we used the Element Energy Fleet Finder tool and analysed publicly accessible registration data (collected in June 2020), applied in-house data cleaning, and then used the data to identify the location and size of depots for both HGVs and buses. We extract the number of electric buses and coaches from DfT[32] data at local authority level.

Our scenarios for the uptake of low emission heavy duty vehicles are consistent with previous DFES[33] 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 we have realigned the baseline in each of these scenarios to match the latest available data. Based on the 2021 announcements from the Mayor of London[34], committing to deliver a 100% zero-emission bus fleet in London by 2034, with further interest in reaching that target by 2030, thus, we continue to use an accelerated rate of decarbonisation in the bus scenarios that apply to London. These accelerated scenarios, shown in Figure 13, 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. We assume that the more ambitious target of 2030 is reached in Leading the Way.

[32] Extracted from DfT/DVLA data table VEH0142 from Q1 2022, available from https://www.gov.uk/government/collections/vehicles-statistics. We consider the estimated fraction of each local authority that is served by UK Power Networks to derive number of buses.
[33] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021 and February 22.
[34] https://www.london.gov.uk/press-releases/mayoral/mayor-host-zero-emission-bus-summit-at-city-hall

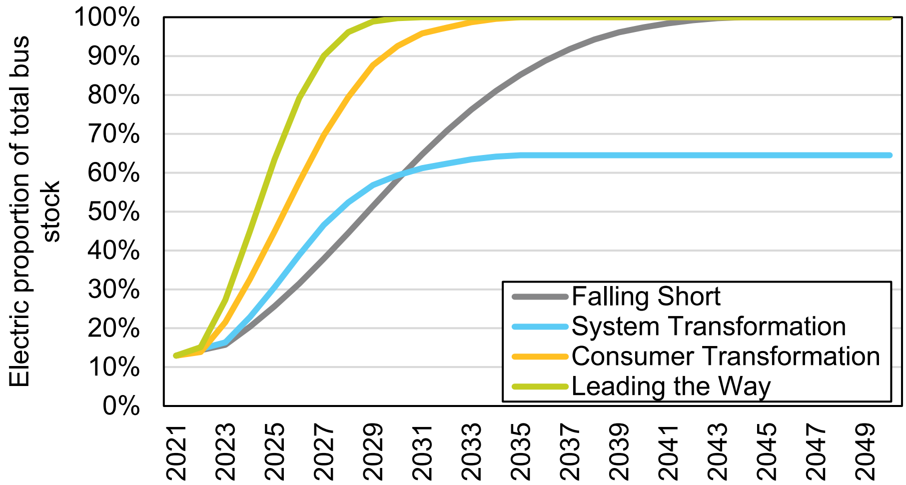


**Figure 13: Electric bus uptake rates for the bus stock within the GLA.**

In line with the change in travel behaviour in Leading the Way, we assume a higher stock growth of buses in Leading the Way than the other scenarios. We use the difference between the ICE Ban and the Reduced Demand car scenario to find the average number of journeys that are not being taken by car in the Reduced Demand scenario. These journeys will either be skipped or shifted onto walking, cycling and public transport. We then use trip statistics (both national[35] and GLA-specific[36]) to estimate how many journeys will be shifted onto buses and finally calculate the bus stock growth rate required to meet that additional demand. The resulting stock growth is a 9% (outside the GLA) and 18% (within the GLA) increase in total bus stock by 2050, compared to a 2020 baseline.

Figure 14 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.

[35] Department for Transport, *National Travel Survey: England 2021,* August 2022. Available from: 2021 National Travel Survey Factsheet (publishing.service.gov.uk), *Statistical data set: Mode of travel*, August 2022.
[36] Transport for London, *Travel in London, report 14,* 2021. Available from: travel-in-london-report-14.pdf (tfl.gov.uk) and Transport for London, *Roads task Force. Thematic Analysis – Technical Note 14,* 2012

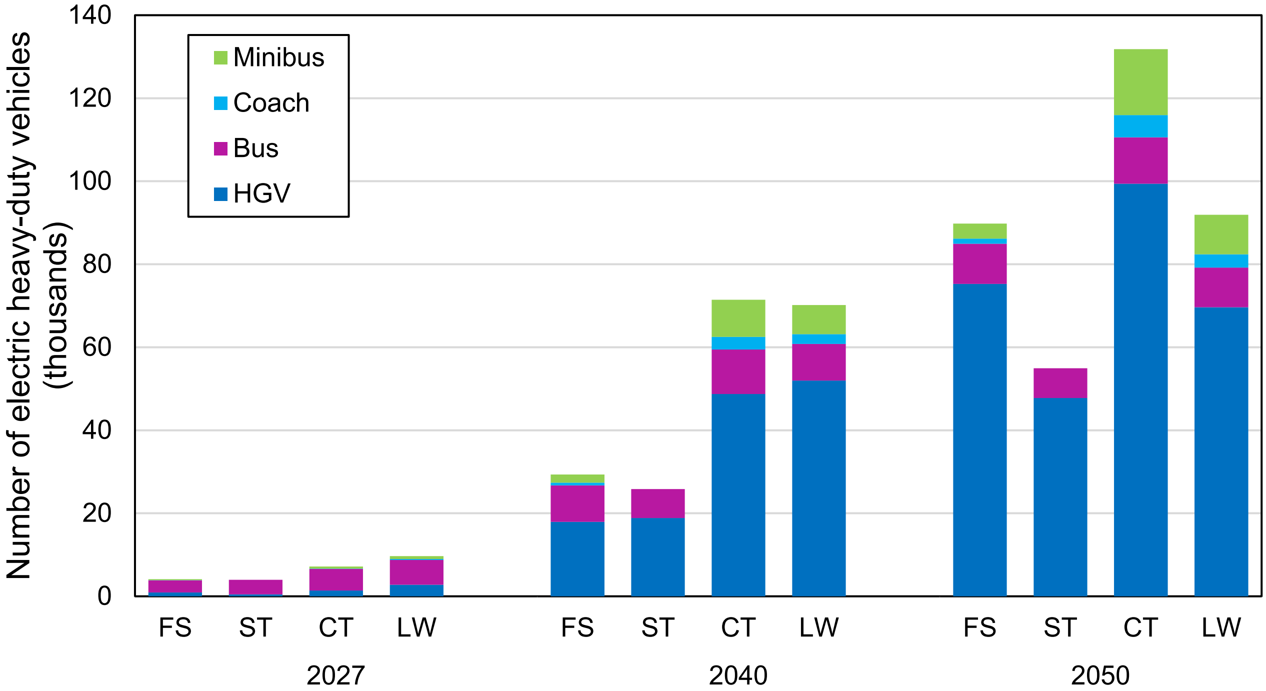


**Figure 14: Number of electric heavy duty vehicles in UK Power Networks' licence areas in 2027, 2040 and 2050.**

## 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.
- To reach the ambitious annual heat pump installation targets set by the Government, more policy support for decarbonised heating will be required.

There are two main pathways under consideration for the decarbonisation of heat. One that relies on the electrification of heat and potentially decomissioning 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 outcomesare represented by Consumer Transformation (the electricification pathway) and System Transformation (the hydrogen pathway) as outlined in Table 6. 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 sustsains 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. In the following sections we outline our 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 6: 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 |
| Gas grid availability in 2050 | Remains at current availability | Remains at current availability | Decommissioned by 2050 | Reduced utilisation |
| Gas grid composition | Mainly natural gas, with some biogas | After 2040: $H_2$ and other low-carbon gases | Mainly natural gas, with some biogas until 2050 | Possibly a mixture of low-carbon gases |
| District heat uptake | Low | Medium | High | High |
| District heat supply | Baseline | Decarbonised gas | High electrification | Decentralised[37] |

[37] 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 approach

The modelling approach taken for this year is consistent with the previous DFES[38], where we supplemented the work we did with UK Power Networks on decarbonised heating, Heat Street[39], with our bespoke consumer choice module to obtain geospatially disaggregated outputs and uptake scenarios. These were then combined with district heating to obtain LSOA-level outputs from heat pumps. A more detailed description of the methodology and modelling components can be found in last year's DFES report.

In the domestic segment of our consumer choice module, we consider the same four different occupant types for each building archetype as last year – owner occupied, private rented, social housing, and occupants that are identified as fuel poor. Note that the fuel poor category includes all buildings occupied by fuel poor customers, whether they are owner occupied, private rented or social housing. Different up-front grants are available from the Government for each of these occupant types. This year we include the newly announced Boiler Upgrade Scheme that is available to domestic and non-domestic property owners, the Social Housing Decarbonisation Fund (Wave 1 and 2 funding cycles), available for social housing, and the Sustainable Warmth Competition for fuel poor consumers.

We have found that Government policy is the factor that has the largest effect on the rate of uptake. Extensive heat decarbonisation – whether via gas grid decarbonisation, electrification or a mix of both – will rely on top-down Government intervention. Based upon the recommendation made by the Climate Change Committee (CCC) to ban gas boilers in new homes[40], as well as feedback gained from consultation with UK Power Networks' stakeholders, we modelled future policy interventions to encourage decarbonised heating, including the phase out of heating technologies that depend on high carbon fuels such as gas, oil and LPG boilers. In our scenarios we split the building stock into three key sectors: new builds, off-gas existing buildings, and gas-heated existing buildings and model different policy assumptions for the phase-out of fossil fuels in each of these sectors, outlined in Table 7 and Table 8 below.

**Table 7: Date at which new builds can no longer choose heating fuel**

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

**Table 8: Date at which existing buildings can no longer choose existing heating fuel**

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

[38] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 22
[39] UK Power Networks Innovation, Heat Street: local system planning, 2021
[40] Committee on Climate Change, UK housing: Fit for the future, 2019

### 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 grant amount from schemes.
- Low electrification.

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 7). Additionally, we assume that the Boiler Upgrade Scheme will run for the announced duration (from 2022 until 2025) and amount of grant given per installation (£5,000 for Air/Ground-Source Heat Pumps and £6,000 for Biomass Boilers). We also assume 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

**System Transformation**

- Medium grant amount from schemes.
- Gas grid repurposed to distribute low-carbon hydrogen instead of natural gas by 2050.

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. We assume 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 grant amount from schemes.
- High electrification.

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[41]. In 2035, a ban on gas boilers is enforced for existing buildings (Table 8). We assume 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.

[41] BEIS, *Clean Growth Strategy,* 2017. Available from: https://www.gov.uk/government/publications/clean-growth-strategy

**Leading the Way**

- High grant amount from schemes.
- High electrification and gas grid repurposed to distribute hydrogen.

In addition to the Government action assumed in Consumer Transformation, we assume 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.

The consumer choice model calculates the number of buildings selecting to switch to the optimal technology and efficiency package in each year by comparing the business case of switching to that of the counterfactual heating technology. Each grant considered in the model is applied to the building archetypes that match the required counterfactual heating system type and/or tenure type and is accounted for when considering the business case. As an output, the model returns the cumulative grant value used to obtain the final state of technology and efficiency package uptake by 2050, assuming all consumers will make use of the most profitable grant available to them over the valid duration of the grants (2022 – 2028). Table 9 compares these values to the total grant announced, available within UK Power Networks' licence areas[42]. 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). Therefore, it can be seen from this table that significantly more funding may be needed to realise this target.

The cumulative grant values calculated in Table 9 include the aforementioned grants, applied for the duration specified in the above information boxes. Hence, the calculated grant values give a short term (2022 – 2028) view on the amount of each grant that could be spent to fund the annual conversions until the last date of available funding. The Social Housing Decarbonisation Fund (SHDF) and Sustainable Warmth competition (SWC) are primarily targeted at energy efficiency improvements for the applicable housing archetypes. As mentioned earlier, the Heat Street model finds the optimal combination of low carbon heating system and energy efficiency package for each archetype. Thus, the assumption is that when a housing archetype converts to the optimal low carbon heating technology, they will also adopt the optimal appropriate energy efficiency measures. Therefore, the cumulative grant values for the SHDF and SWC follow the same trends as the BUS between scenario worlds.

Table 9 shows that System Transformation requires a lower cumulative grant allocated compared to Falling Short despite having higher Net Zero ambition and thus higher uptake of low carbon heating measures. The reason for this is that most heat pump installations in the short term in System Transformation are hybrid heat pumps which are not covered by the Boiler upgrade scheme. When the gas grid conversion to $H_2$ starts (around 2035), the housing stock that do not convert to $H_2$ boilers in System Transformation will be required to switch to alternative low carbon heating technologies, such as air/ground-source-heat-pumps for which there will be no available grant at that time. Similarly, although Leading the Way has higher uptake in total heat-pumps than Consumer Transformation, in the short-term, there is a significantly higher proportion of hybrid heat pumps than Consumer Transformation. Hence, the cumulative grant value for the BUS in Leading the Way is lower than Consumer Transformation.

[42] For the Boiler Upgrade Scheme, this disaggregation was based on the proportion of UK building stock in the UK Power Networks' licence areas, ca. 28%. The Social Housing Decarbonisation Fund and the Sustainable Warmth competition grant totals were calculated based on the funding announced for each Local Authority or council that won funding.

**Table 9: Announced and calculated cumulative grant amount for low carbon heating in UKPN.**

| Scheme | Boiler Upgrade Scheme | Social Housing Decarbonisation Fund | Sustainable Warmth Competition |
|---|---|---|---|
| **Available Funding** | £ 130 million | £ 55 million (Wave 1)<br>£ 220 million (Wave 2) | £ 260 million |
| **Falling Short** | Domestic: £ 200 million<br>Non-domestic: £ 1.4 million | £ 470 million | £ 73 million |
| **System Transformation** | Domestic: £ 46 million<br>Non-domestic: £ 3.1 million | £ 100 million | £ 45 million |
| **Consumer Transformation** | Domestic: £ 550 million<br>Non-domestic: £ 190 million | £ 1.4 billion | £ 770 million |
| **Leading the Way** | Domestic: £ 330 million<br>Non-domestic: £ 140 million | £ 2.2 billion | £ 470 million |

Figure 15 shows the heating technology breakdown for domestic buildings in each scenario out to 2050. These figures describe the housing stock that is not on district heating 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 B.

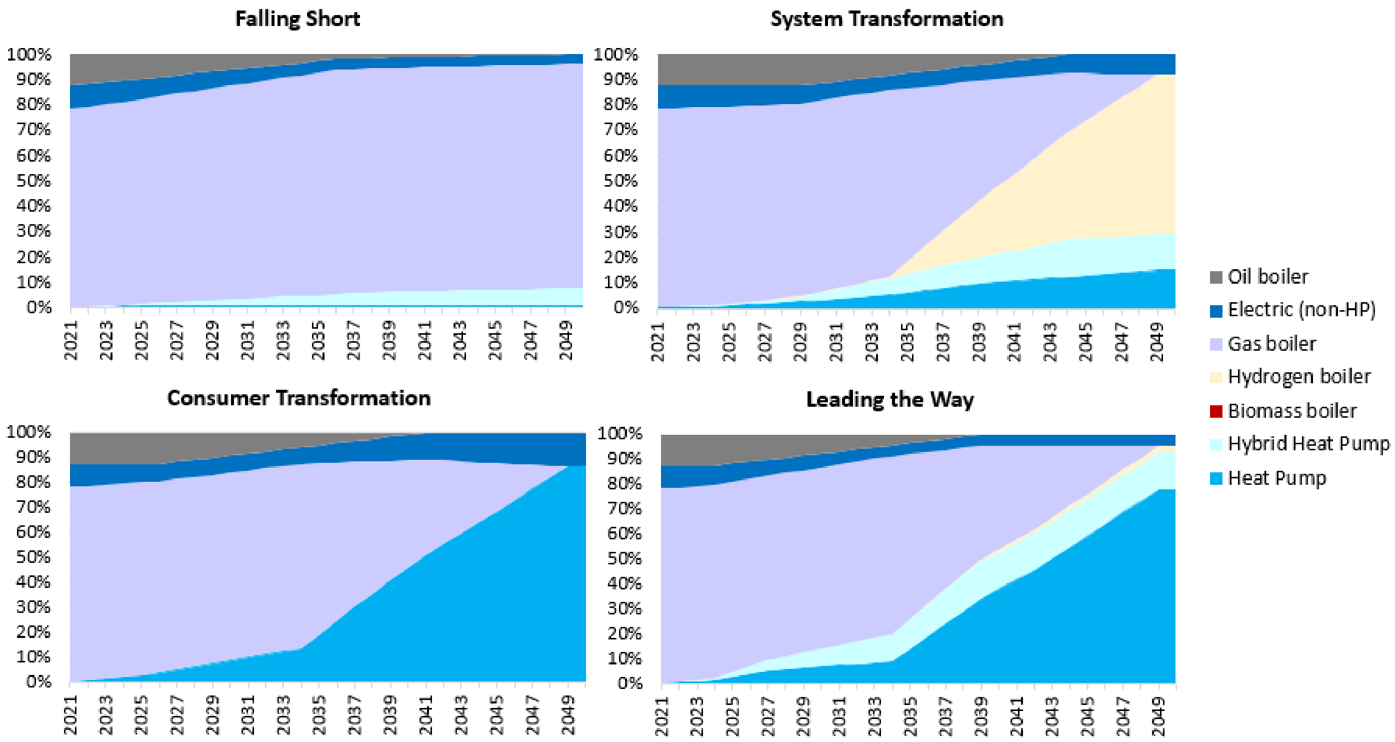


**Figure 15: Heating technology breakdown for domestic buildings not on district heating in UK Power Networks' licence areas.**

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 8) coupled with our 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 16 shows the resulting number of total domestic heat pumps in each scenario. This figure indicates that by 2027, there could be between 181,000 and 717,000 heat pumps operating in UK Power Networks' licence areas, rising to between 631,000 to 6.6 million by 2050, comparable to the ranged reported in last year's DFES (640,000 to 6.7 million by 2050). The majority 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).

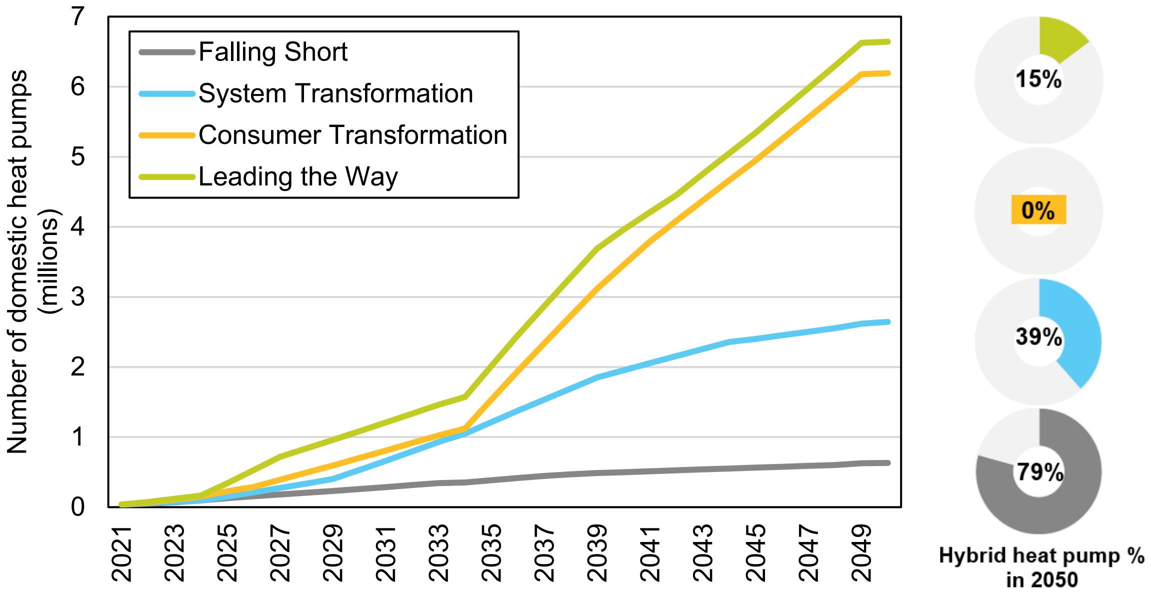


**Figure 16: Total number of domestic heat pumps installed in UK Power Networks' licence areas and the proportion of heat pumps that are hybrids in 2050.**

Similar trends are observed in the I&C sector and Figure 17 indicates that by 2027, there could be between 1,900 and 49,200 I&C heat pumps operating in UK Power Networks' licence areas, rising to between 4,240 and 385,000 by 2050, comparable to the range reported in last year's DFES (4,400 to 407,000 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.

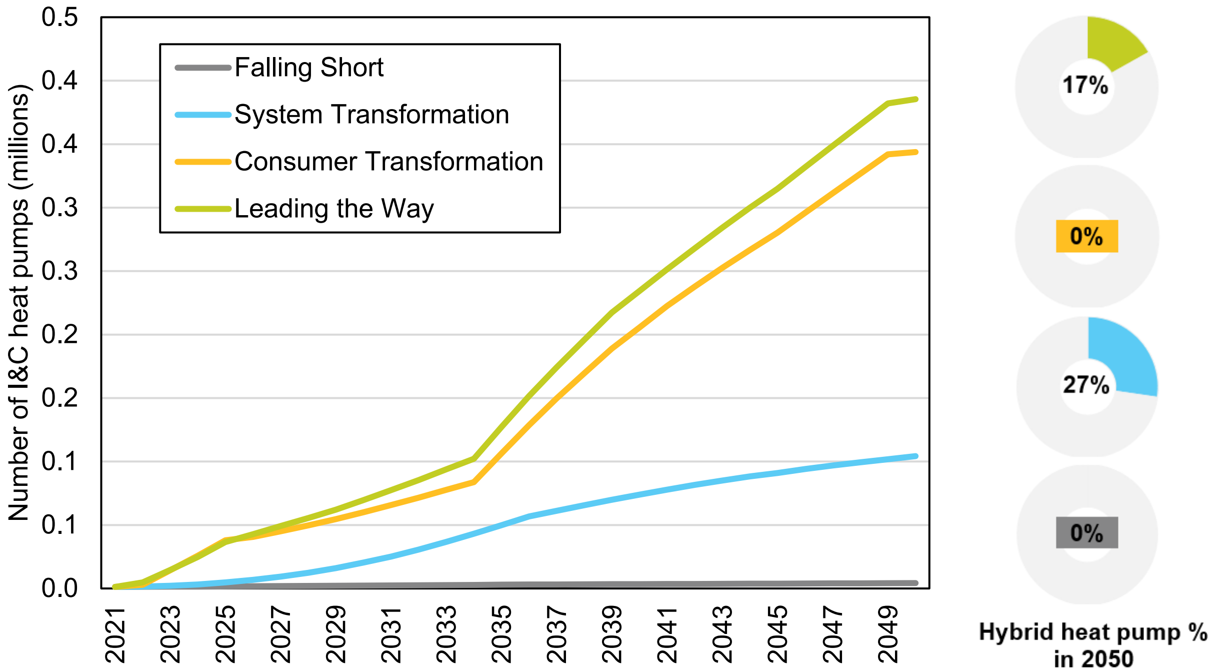


**Figure 17: Total number of I&C heat pumps operating in UK Power Networks' licence areas and the proportion of heat pumps that are hybrid in 2050.**

**Customers facing fuel poverty**

As discussed above, we account for Government grants that support the purchase of heat pumps specifically for fuel poor customers and those in social housing. These grants support the uptake of heat pumps and result in a more rapid uptake rate of heat pumps in those properties, compared to other domestic properties (Figure 18).

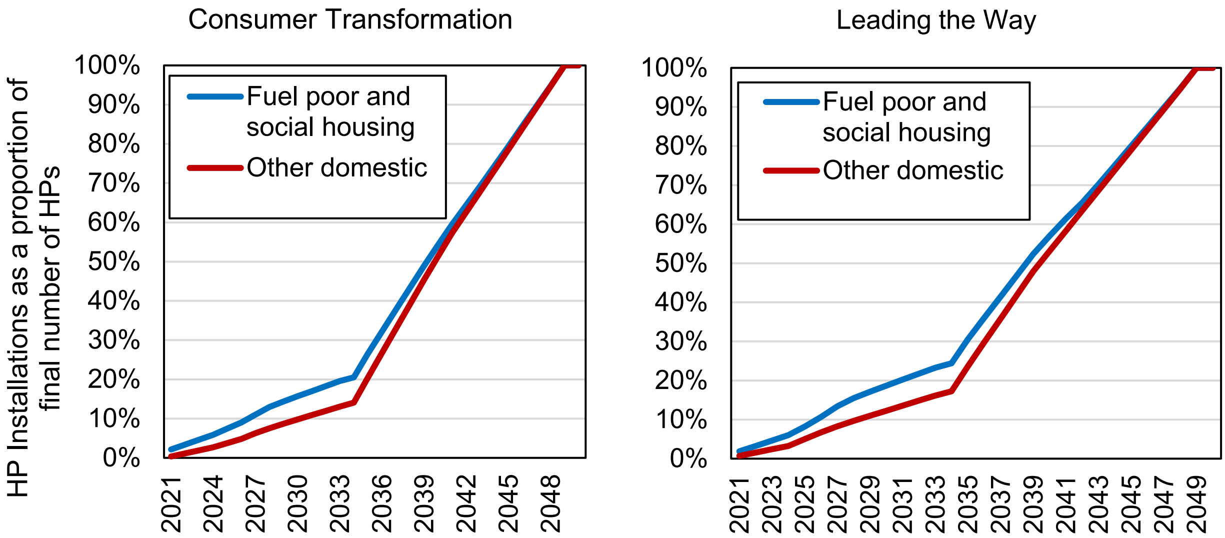


**Figure 18: Heat pump rate of uptake for fuel poor and social housing compared to other domestic properties.**

### 3.3.3 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. As described above, we used the decarbonised heating technology model, developed in the Heat Street project, 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. We assume 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. Figure 19 shows the resulting energy efficiency scenarios for the domestic building stock within UK Power Networks' licence areas. In Appendix B, the equivalent figure is shown for the I&C building stock.

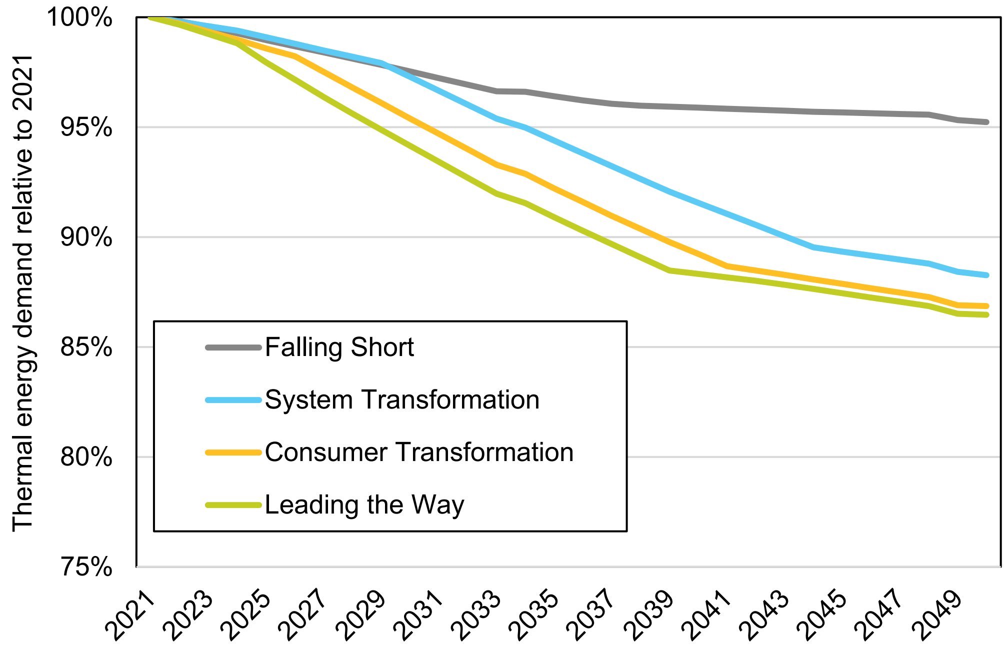


**Figure 19: Thermal energy demand in the domestic building stock compared to a 2021 baseline.**

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 20 below. There are several explanations for this, the main 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[43].

[43] UK Power Networks Innovation, Heat Street, 2021, available from https://innovation.ukpowernetworks.co.uk/projects/heat-street-local-system-planning/

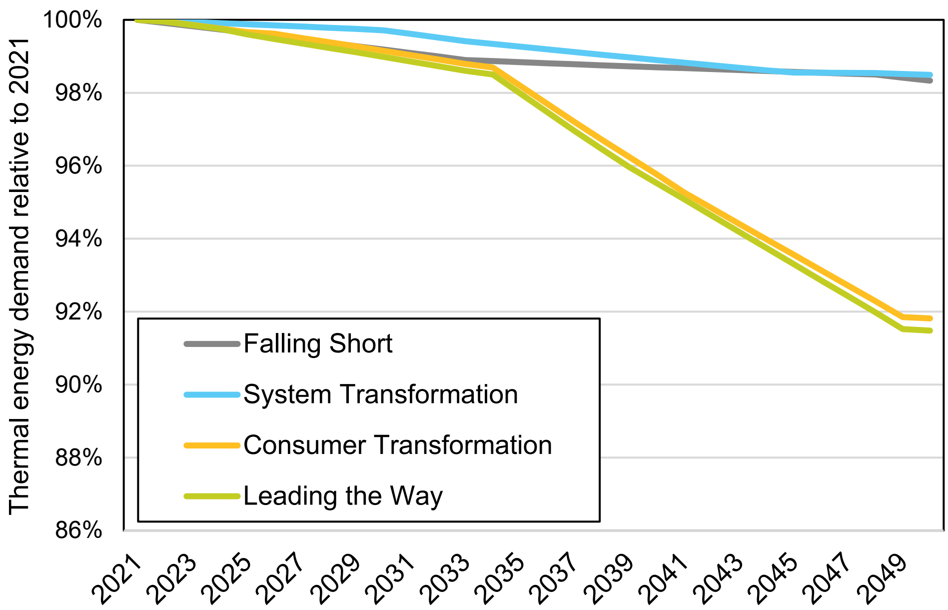


**Figure 20: Thermal energy demand in the I&C building stock compared to a 2021 baseline.**

### 3.3.4 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[44] and is based upon our work for the Greater London Authority (GLA) and C40 Cities[45].

- The heat demand density of each LSOA is estimated using gas demand density as a proxy,
- Gas demand density thresholds are applied to determine areas suitable for heat networks,
- For areas of sufficient heat demand density, a fraction of customers is assumed to connect to heat networks over time.
- Information on clustered new build developments is also used to determine areas suitable for heat networks.
- For new build regions, a fraction of the clustered new build developments is assumed to connect to heat networks at the time of construction.

We assume that once a heat network is established, it continues to grow as surrounding customers connect over time. Figure 21 presents the resulting number of homes on district heating out to 2050. We model between 198,000 and 450,000 homes on district heating by 2027, rising to between 475,000 and 1.57 million by 2050.

[44] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021.
[45] Element Energy for the Greater London Authority, London's Climate Action Plan: WP3 Zero Carbon Energy Systems (September 2018)

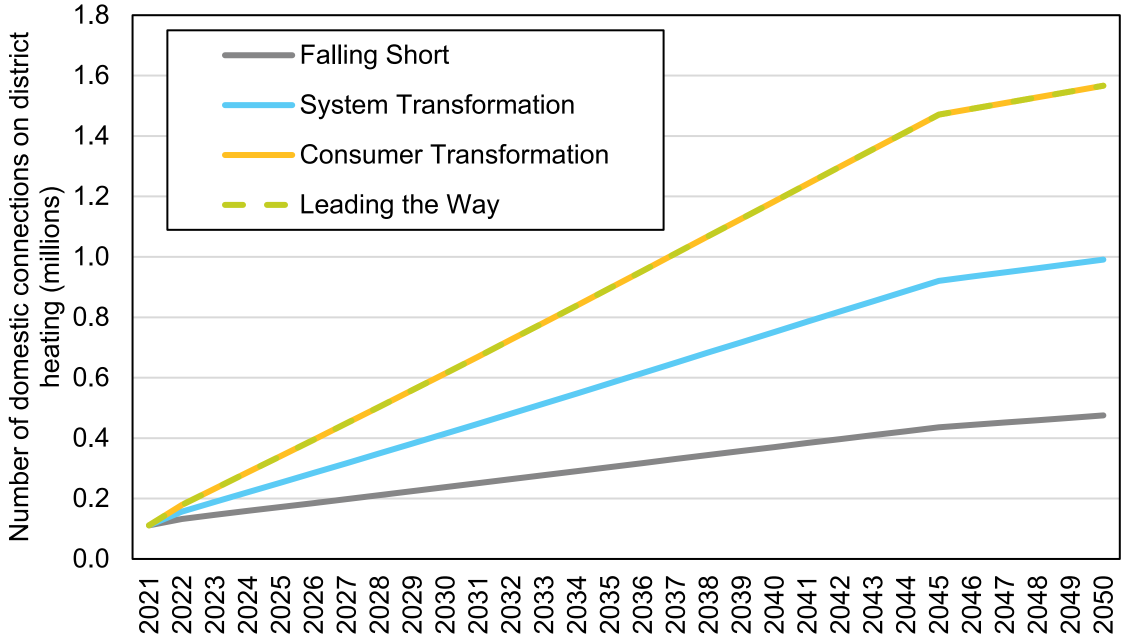


**Figure 21: Number of homes within UK Power Networks licence areas using district heating.**

In addition to the uptake of district heating in the domestic and I&C building stock, we model four different scenarios for the heat supply technologies deployed in these heat networks. These scenarios are based on our work for the GLA[45] and the CCC[46] and involve varying degrees of dependence on electrified heating and decarbonised gas, as shown in Figure 22.

[46] 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)

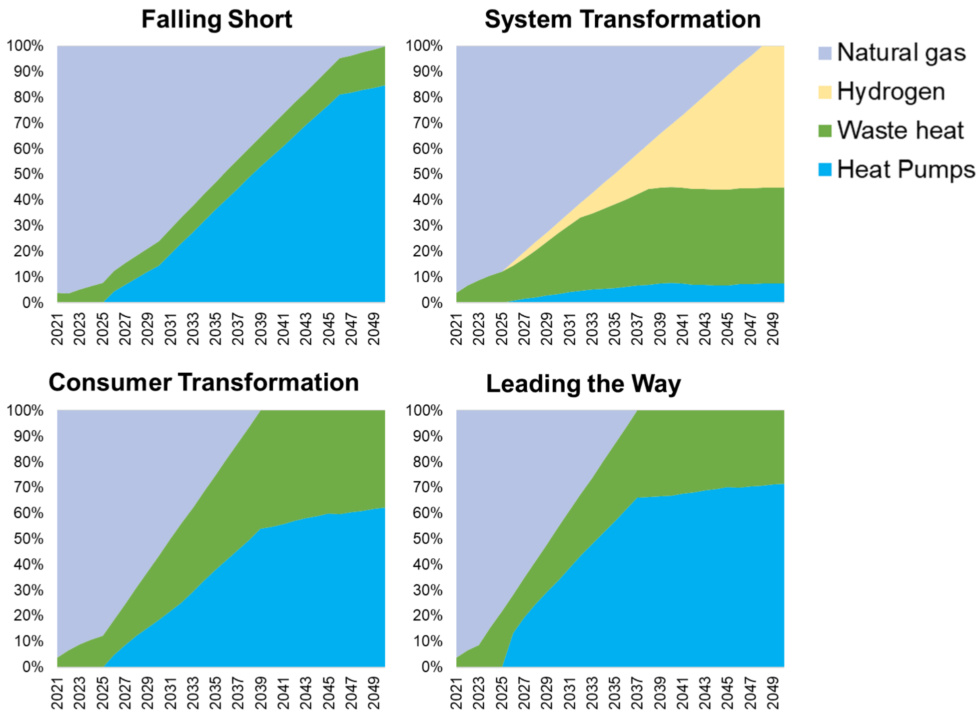


**Figure 22: Breakdown of the supply for district heat networks in 2021-2050.**

## 3.4 Distributed generation

**Key Messages**

- Scenarios for large-scale solar PV capacity are higher than previously due to high capacity of accepted large scale solar generation in the pipeline.
- Uptake of decentralised hydrogen generation is significantly lower than in previous 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.

We consider a broad range of generation technologies that would connect to the distribution network. We have categorised the different types of distributed generation 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, we developed three future uptake scenarios (low, medium, and high) and assigned them to the four scenario worlds according to how they align with the scenario world narratives (Table 10).

**Table 10: 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 |
|---|---|---|---|---|
| Small-scale 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 CHP) | 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 |

* Small-scale 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.

**Modelling method**

The approach that we used for modelling the uptake of distributed generation consists of three steps, as outlined in Figure 23.

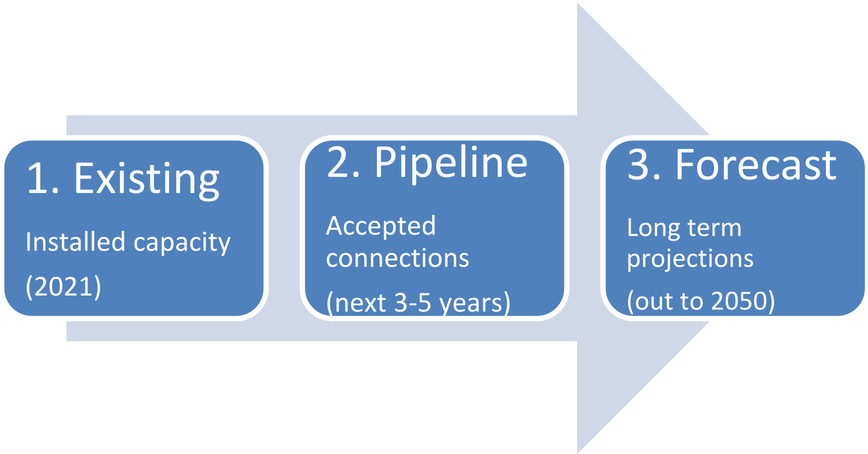


**Figure 23: Pathway for modelling distributed generation.**

A variety of data sources were used to determine the baseline of existing generation capacity in the UKPN region. We defined three capacity bands for installation size and gathered information on connections for each band from a suitable data source (Table 11). Combined, these sources provide us with a detailed baseline for installed capacity, generation site locations and installation dates.

**Table 11: Existing generation capacity bands and data sources.**

| Capacity band | Data source |
|---|---|
| **Less than or equal to 50 kW** | Feed-in Tariff data (installations prior to April 2019)<br>G98 and G83 data (installations after April 2019) |
| **Between 50 kW and 1 MW** | Distributed Generation Database (DGDB) and R180 |
| **Larger than 1 MW** | Embedded Capacity Register (ECR) |

The ECR is updated regularly and since the last DFES, the categorisation of different generation types has been re-evaluated, bringing it closer in line with ENA Building Blocks. This led to improved accuracy of the established generation baselines and as a result, the existing capacity reported may differ from our baseline in the last DFES.

For all technologies, we modelled the near-term uptake based on the UK Power Networks' database of accepted connection offers for generators, or "pipeline" data. Based on stakeholder consultation, we modelled a typical acceptance-to-connection conversion rate 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, we developed technology-specific scenarios for the connection rates and timescales (Table 12).

Since the last DFES, the capacity of accepted connections has increased significantly, particularly for large scale solar PV generators in EPN. While in reality, some of these generators may experience delays in installation timescales due to transmission network constraints, we do not model these constraints explicitly in the DFES and as such we assume that the connection rates and timescales from Table 12 hold.

We analyse a range of sources to develop the long-term generation forecasts. Element Energy consumer choice and investor decision modelling is used for solar PV, which is most suited to this type of uptake modelling. We describe the modelling method for solar PV in detail in past DFES[47] reports. Another source of information used is the NG FES Building Block data, which is published by National Grid with the generation capacity forecasts available to GSP level. Using this Building Block data, we can readily establish the NG view at a UK Power Networks licence area level. We then use our past assessment (from the previous three DFES) of suitability of different generation technologies to UK Power Networks' region to sense check the National Grid long term allocation of these technologies to UK Power Networks' licence areas. We used these sources to generate scenarios of distributed generation specific to UK Power Networks' region.

[47] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.

**Table 12: 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 | Element Energy 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 NG's FES |
| ***Renewable engines (landfill-, sewage- and biogas)*** | ✓ | 20% / 60% / 90% | 3 years | Regional disaggregation of NG's FES |
| ***Waste incineration (including CHP)*** | * | 20% / 60% / 90% | 5 years | Regional disaggregation of NG's FES |
| ***Biomass and energy crops (including CHP)*** | ✓ | 20% / 60% / 90% | 5 years | Regional disaggregation of NG's FES |
| ***Hydrogen generation*** | ** | No accepted connections | - | Regional disaggregation of NG's FES |
| ***Non-renewable CHP*** | ✗ | 20% / 60% / 90% | 3 years | Regional disaggregation of NG's FES |
| ***Non-renewable engines (non-CHP)*** | ✗ | 10% / 40% / 90% | 3 years | Regional disaggregation of NG's FES |
| ***OCGTs and CCGTs*** | ✗ | 20% / 60% / 90% | 3 years | Regional disaggregation of NG'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 renewable, i.e. produced via electrolysis using renewable electricity.

Figure 24 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 our 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 small- and large-scale solar PV in Leading the Way, we see the highest total installed capacity in 2027 and 2050 for this scenario world. In the following sections, we discuss these results in more detail and take a detailed outlook for solar PV, the largest single contributing factor to the generation mix in 2050 for all four scenario worlds.

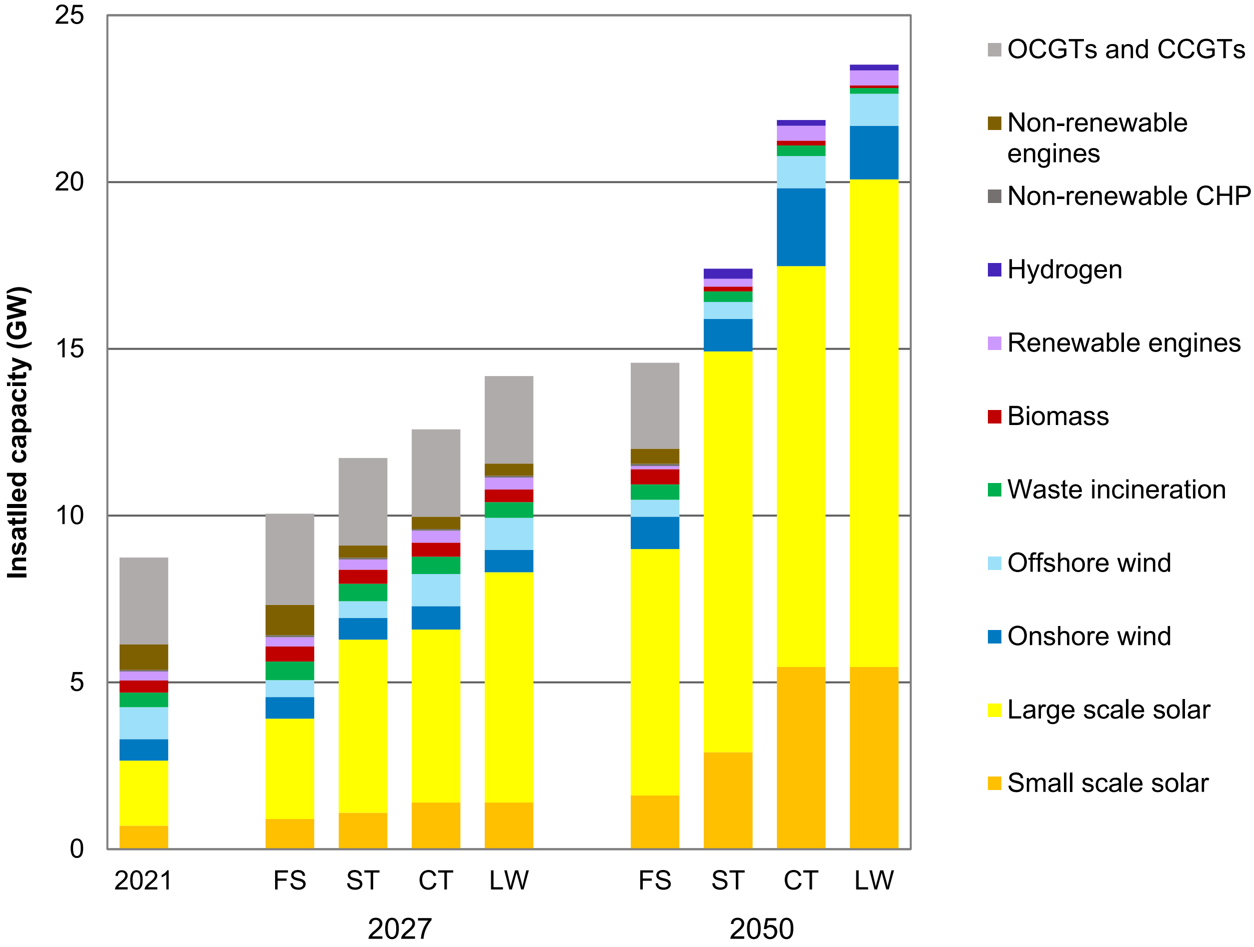


**Figure 24: Capacity of distributed generation installed in UK Power Networks' licence areas in the base year of the scenarios (2021), in 2027 and 2050.**

### 3.4.1 Renewable generation

We model a range of renewable generation technologies as listed in Table 12. In the following section, we outline the modelling of these technologies, with an emphasis on solar generation as we expect that to be the dominant distributed technology in UK Power Networks' region going forward.

#### Solar PV

We derived solar PV uptake scenarios using our consumer choice model and investor decision model for small-scale (<=150 kW) and large-scale (>150 kW) generation uptake, respectively. The modelling approach remains consistent with the previous DFES but with updated input parameters, such as electricity price forecasts and the assumed technical potential.

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, as summarised in Table 13 below, and different installation costs applied to each band.

**Table 13: Solar PV sizing brackets and respective classifications.**

| Solar PV Size Bracket (kW) | Classification |
|---|---|
| **<= 4** | Small-scale domestic (rooftop) |
| **4 – 150** | Small-scale industrial & commercial (rooftop) |
| **> 150** | Large-scale (ground-mounted) |

**Small-scale solar PV (<=150kW)**

We define small-scale solar PV as being those installations that occur on rooftops of domestic and I&C buildings (Table 13). Figure 25 illustrates that in 2050, between 0.5 and 1.1 million homes in UK Power Networks' licence areas are forecast to have a rooftop solar PV installation in the Net Zero scenarios, consistent with the results from the previous DFES. In the I&C sector, we model between 0.8 and 2.1 GW of rooftop solar PV capacity by 2050, broadly consistent with the previous DFES. We model the lowest uptake 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 small-scale solar PV.

One of the key inputs in the solar PV model is the cost of electricity to consumers. Higher electricity prices could result in higher uptake as by installing a solar PV, consumers both avoid paying these high prices for their electricity, and they also could get higher revenues from selling their generation back to the grid. With the current spike in electricity prices, we therefore may expect to see a large increase in uptake of rooftop solar PV panels. However, the general higher cost of living that the UK is currently experiencing may impact consumers willingness and ability to invest in technologies, and this could balance out the impact of higher electricity prices and reduce installations again. As the primary focus of the DFES is to produce projections for a long term view that's in line with a Net Zero transition, detailed analysis of the current market landscape is not included here and we assume that the current spike in electricity prices has a limited effect on the uptake of rooftop solar PV.

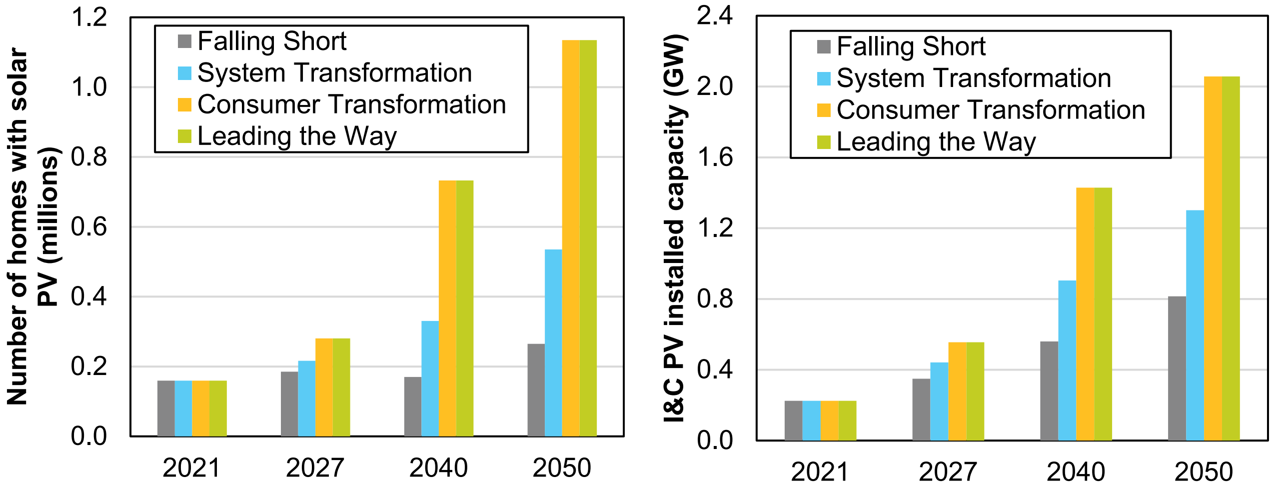


**Figure 25: Small scale solar uptake. Number of domestic installations (left) and installed capacity of I&C solar PV (right).**

**Large-scale solar PV (>150kW)**

We expect significant capacity increases in large-scale ground mounted solar arrays. We expect this growth 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 26). We model between 7.4 and 14.6 GW of large-scale solar PV capacity installed in UK Power Networks' licence areas by 2050, somewhat higher than in previous DFES (between 3.7 and 12 GW by 2050). This difference stems from the significant increase in capacity of accepted connections for large scale solar PV generators in EPN, resulting in a steeper uptake over the pipeline years.

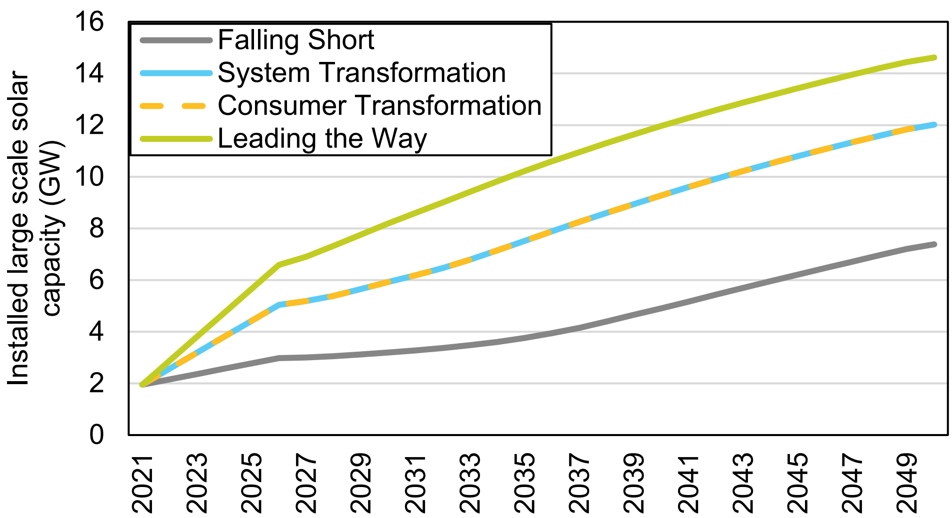


**Figure 26: Installed capacity of large-scale solar PV in UK Power Networks' licence areas out to 2050.**

## Other renewable generation

Table 14 summarises the uptake of the renewable generation technologies across the four scenarios. In the National Grid Future Energy Scenarios, compared to last year, there is an increase in the amount of bioenergy allocated to power generation in all scenarios besides Leading the Way which reflects the expected focus on using biomass as bioenergy with carbon capture and storage (BECCS), which is most economically viable for large transmission-connected power stations. Leading the Way still relies on BECCS for negative emissions but there are more negative emissions coming from Land Use, Land Use-Change and Forestry (LULUCF). The distribution connected biomass generation (Figure 27) baseline has been slightly increased in this year's DFES. 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.

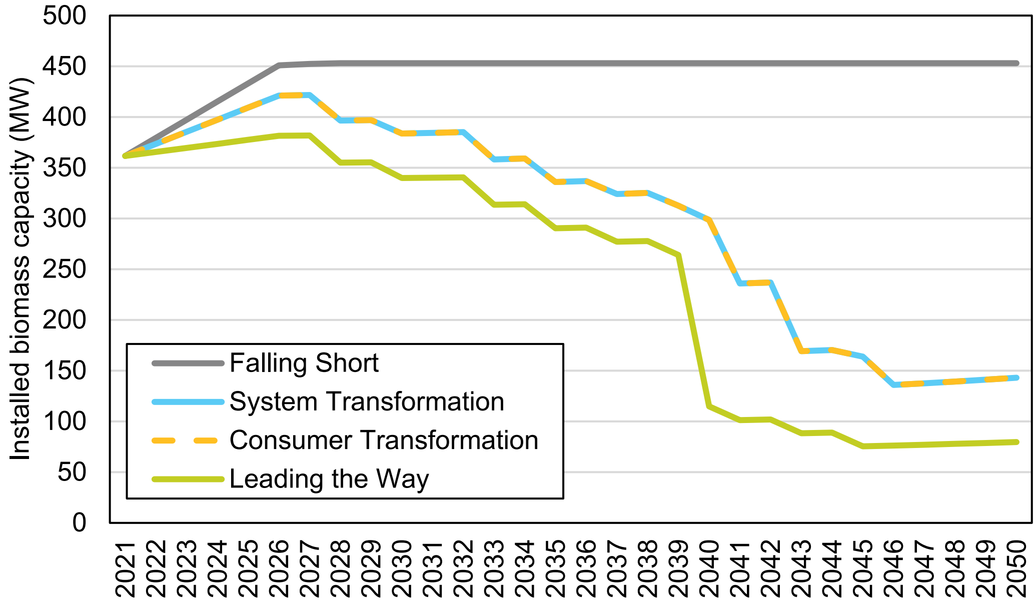


**Figure 27: Biomass and energy crops (including CHP) distribution network connected generation capacity for the UKPN region**

## Onshore wind

The onshore wind uptake reflects the narrative of the scenario worlds. 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 System Transformation and Falling Short scenarios assume that the installation of distribution-connected onshore wind is slower due to lower societal acceptance. System Transformation, however, is assumed to have a large amount of transmission-connected offshore wind generation for green hydrogen production. Finally, in the Leading the Way scenario, both distribution-connected onshore wind and transmission-connected offshore wind are moderately high.

**Table 14: 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** | 973 | 973 | 2,338 | 1,607 |
| **Renewable engines (landfill-, sewage- and biogas)** | 96 | 237 | 448 | 448 |
| **Waste incineration (including CHP)** | 463 | 318 | 318 | 171 |
| **Biomass and energy crops (including CHP)** | 453 | 143 | 143 | 80 |
| **Hydrogen fuelled generation** | 0 | 301 | 172 | 172 |

## Waste incineration

Our forecast for distribution connected generation from waste incineration (Figure 28) decreased slightly for all Net-Zero scenarios, mainly due to significant decreases in the SPN projections. This year, all Net Zero scenarios reflect view that waste as a feedstock should only be a transitional fuel and should not be viewed as a sustainable energy source. This is reflected by a 2030 peak followed by reducing uptake out to 2050.

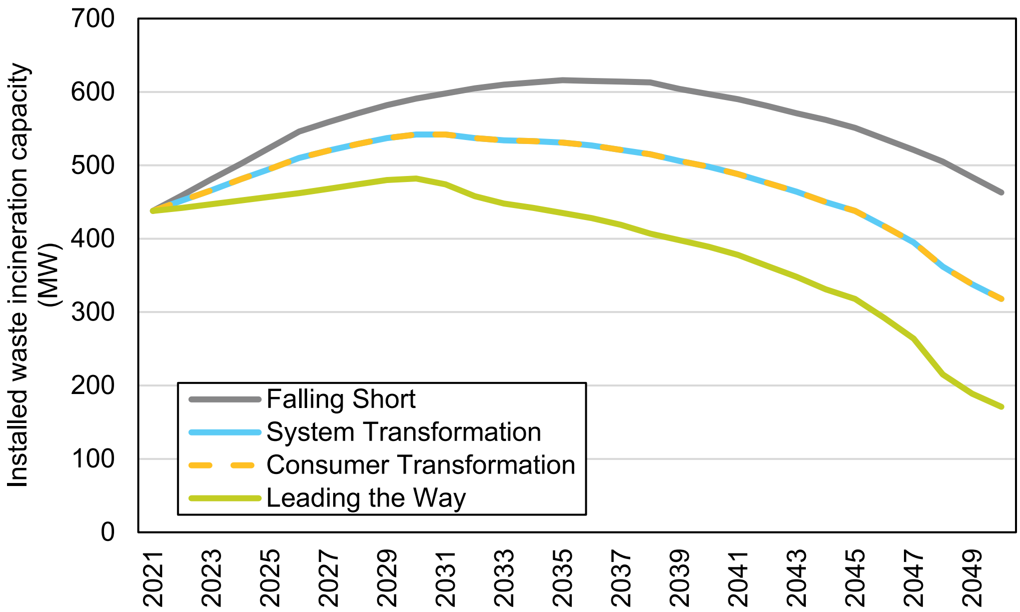


**Figure 28: Waste incineration generation capacity for the UKPN region**

### 3.4.2 Non-renewable generation

We model a range of distributed non-renewable generation technologies. In the Net Zero scenarios, generation from non-renewable sources is phased out by 2035 (Table 15), consistent with the "low" uptake scenarios (Table 10). 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[48]. National Grid's FES phases out unabated gas generation capacity by 2036 in the Leading the Way scenario and after 2044 in the other Net Zero scenarios. Despite this, National Grid 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 15: Non-renewable electricity generation capacity in the UKPN region**

| Installed generation capacity (MW) | Falling Short | | | Net Zero scenarios (ST, CT, LtW) | | |
|---|---|---|---|---|---|---|
| | **2021** | **2035** | **2050** | **2021** | **2035** | **2050** |
| **Non-renewable CHP** | 46 | 65 | 68 | 46 | 0 | 0 |
| **CCGTs and OCGTs** | 2,600 | 2615 | 2575 | 2,600 | 0 | 0 |
| **Non-renewable engines** | 769 | 562 | 451 | 769 | 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. These 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.

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

## 3.5 Battery storage

**Key Messages**

- We model a higher uptake of batteries co-located with solar PV than in previous DFES due to higher uptake of large scale solar.
- The high uptake of co-located storage as well as V2G services diminish the need for standalone grid storage in Leading the Way.

We modelled the uptake of four different battery storage use cases. For each use case, we developed three to four future uptake scenarios and assigned them to the four scenario worlds as outlined in Table 16.

**Table 16: 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[49] | Progressive High | Medium | Sustained Early High | Early High |

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 17 shows the different use cases, the relevant business case considered, and the modelling method used.

**Table 17: Modelled battery storage use cases and the corresponding business cases and modelling methods.**

| Technology use case | Modelled business case | Modelling method |
|---|---|---|
| ***Domestic battery storage*** | **Coupled to solar PV**<br>Maximise own use | Consumer choice modelling coupled with domestic solar PV uptake modelling |
| ***I&C battery storage*** | **Arbitrage and system balancing**<br>Electricity price arbitrage, avoidance of network charges and provision of services to National Grid | Consumer choice modelling |

[49] Refer to Section 3.5.2 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.

| | | |
|---|---|---|
| ***Co-located battery storage*** | **Coupled to solar PV**<br>Electricity price arbitrage, capacity market | Investor decision modelling coupled with large scale solar PV uptake modelling |
| ***Standalone grid-connected battery storage*** | **System balancing and arbitrage**<br>Provision of services to National Grid, wholesale market price arbitrage | Based on modelling of total storage requirements |

The baseline and pipeline data for large-scale battery storage, both co-located and standalone grid-connected battery storage, is from the ECR. The pipeline length and connection rates for co-located battery storage are the same as for large-scale solar PV generation (5 years and 20%/60%/90%) whereas for standalone batteries we assume a 3-year pipeline with connection rates of 10%/40%/90%.

Figure 29 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 3.6.2**). 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, we outline the modelling approaches and assumptions and discuss the results in more detail.

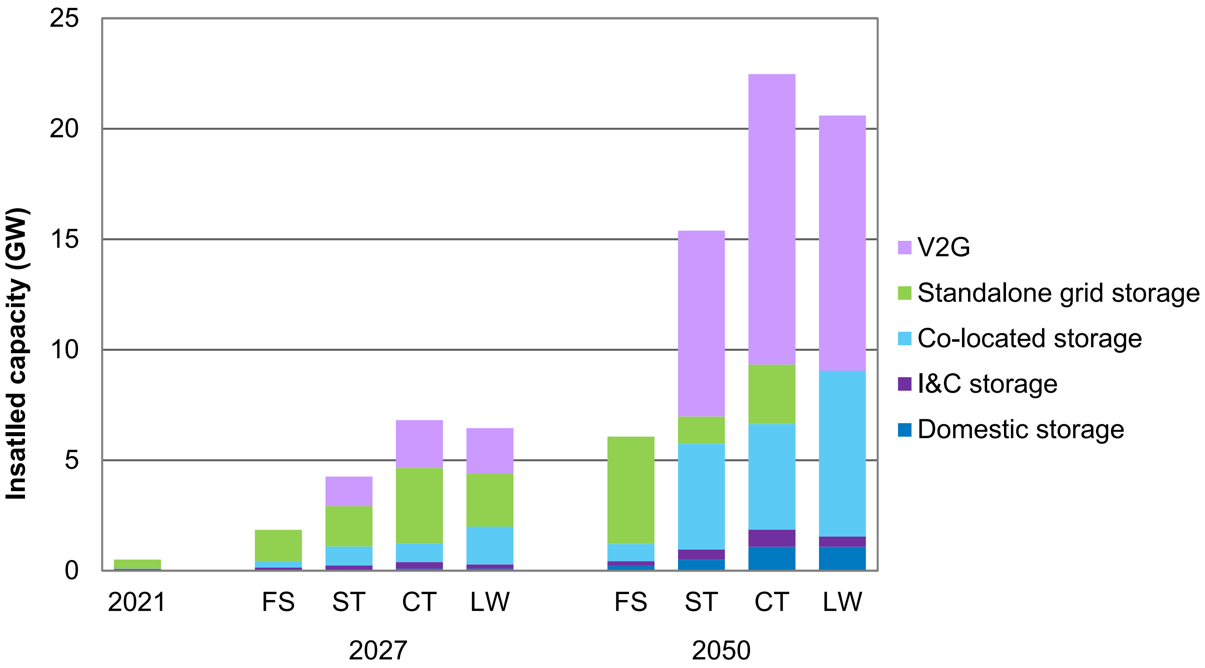


**Figure 29: Distributed battery storage in UK Power Networks' region at baseline (2021), in 2027 and 2050.**

### 3.5.1 Behind-the-meter battery storage

We model the 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 our uptake of domestic solar PV (capacity <= 4 kW). We derived uptake scenarios for domestic storage using our consumer choice model described in the previous DFES[50]. We consider the purchase decision for a solar PV system only, a solar PV system with a battery, retrofitting a battery to an existing solar PV installation, or neither solar PV nor battery. We consider an average battery power of 2 kW with a two-hour storage capacity, and account for variances in battery pack costs, installation costs, and product availability 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.

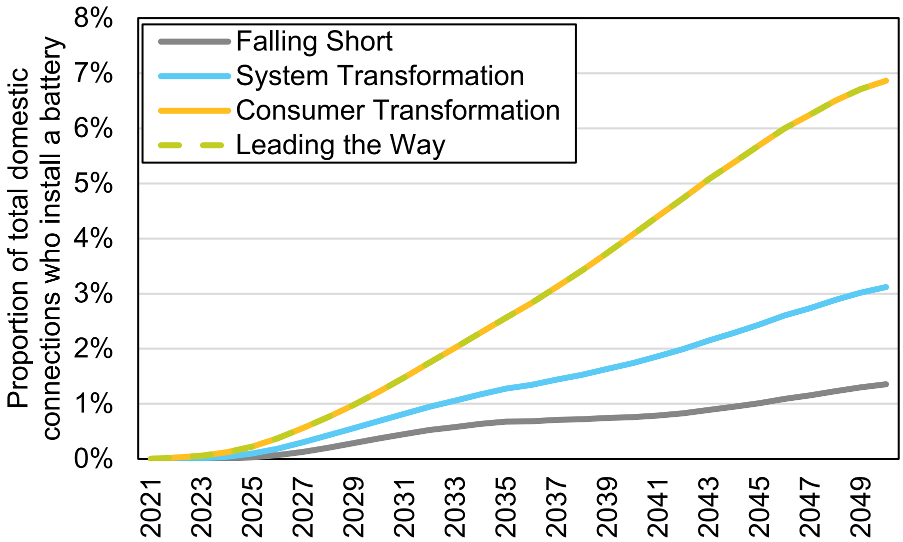


**Figure 30: Proportion of all domestic customers who install a battery in UK Power Networks' region.**

The results from our modelling (Figure 30) indicate that between 1% and 7% of all domestic customers (or between 40% and 48% of domestic 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 540,000 homes installing a battery. System Transformation follows, with installed capacity of 500 MW by 2050, followed by Falling Short with 220 MW, corresponding to 250,000 and 110,000 homes, respectively.

#### I&C storage

Uptake scenarios for I&C behind-the-meter storage were derived using Element Energy'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 willingness to pay of I&C organisations. The modelling approach is consistent with the previous DFES and we continue to review and update what revenues are available, as this is a rapidly changing space due to Ofgem's charging reforms[51] and new markets becoming accessible to smaller battery installations.

[50] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.
[51] Ofgem, *Electricity Network Access and Forward-Looking Charging Review: Open Letter on our shortlisted policy options,* March 2020.

We modelled 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, we account 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, we assume that different revenues from these streams are available in each scenario. In Consumer Transformation, we assume that the current spike in electricity prices will continue to impact future wholesale electricity prices, allowing I&C customers to continue to access high revenues from grid services such as the Balancing Mechanism. This results in a high uptake of batteries from the 2020s (Figure 31). In Falling Short, we assume that these revenues quickly drop after the electricity price spike in 2021-22, and in Leading the Way and System Transformation, we assume that accessible revenues slowly return to values seen before the price spike, resulting in a medium uptake of I&C batteries.

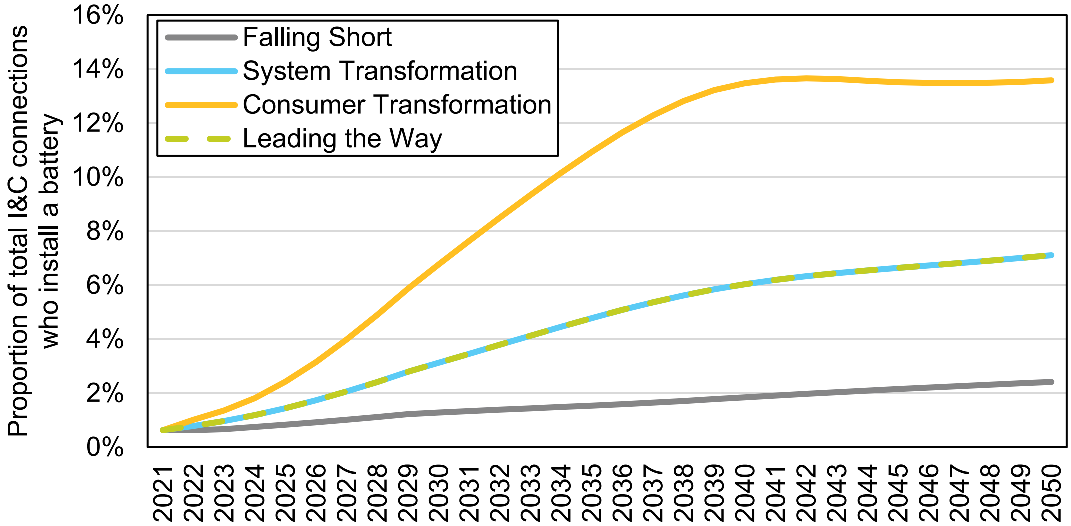


**Figure 31: Proportion of all I&C customers who install a battery in UK Power Networks' licence areas.**

### 3.5.2 Large-scale battery storage

We model the uptake of two cases of large-scale battery storage, batteries co-located with solar generation, and standalone grid-connected batteries.

#### Co-located battery storage

Uptake scenarios for co-located storage were derived using our investor decision model, as used for the large-scale solar PV uptake scenarios described in previous DFES reports[52]. 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 flexible generation connections in the future.

Figure 32 shows the range of possible uptake of co-located battery storage across UK Power Networks' region. Due to the high forecasted large scale solar capacity, relatively lower forecasted battery prices compared to historic prices, and a higher pipeline of accepted connections, we see a high uptake of large-scale batteries co-located with solar PV. 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.

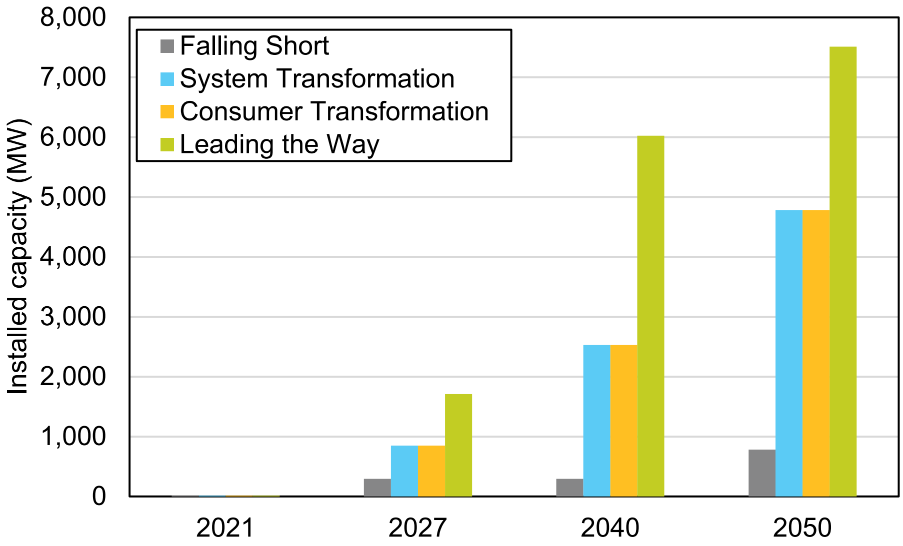


**Figure 32: Capacity of battery storage co-located with solar generation in UK Power Networks' licence areas.**

#### Standalone grid-connected batteries

We model the total storage capacity needed in UK Power Networks' licence areas by considering a relationship between required storage power capacity and increased share of variable generation[53]. We make use of National Grid's national level uptake forecast of wind and solar along with their predicted peak demand through to 2050 to quantify the future share of intermittent renewables in the system. We then calculate scenarios for the total storage capacity required at national level and then disaggregate them to create scenarios specific to UK Power Networks' region.

[52] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.
[53] Drax, *Electric Insights – Quarterly*, 2019

We assume 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, we subtract the capacity of I&C batteries, co-located batteries, and capacity obtained from vehicle-to-grid services (see **Section 3.6.2**) from the total storage capacity requirements. We assume that Consumer Transformation and Leading the Way require high total battery capacity, System Transformation medium and Falling Short low.

Figure 33 shows the resulting uptake of standalone grid-connected batteries in UK Power Networks' region. In Leading the Way and Consumer Transformation, we expect a high uptake of standalone batteries in the near term. In the long term, alternative storage options enter the market in Leading the Way, and the overall storage demand will be met by vehicle-to-grid services, I&C batteries, and co-located batteries, diminishing the need for standalone batteries. Falling Short has a lower deployment of these alternative batteries and therefore sees a higher demand for standalone battery storage in the long term. The overall need for battery storage in Falling Short, however, is not as pressing in the near term as in the Net Zero scenarios, due to the slower adoption of intermittent renewable generation.

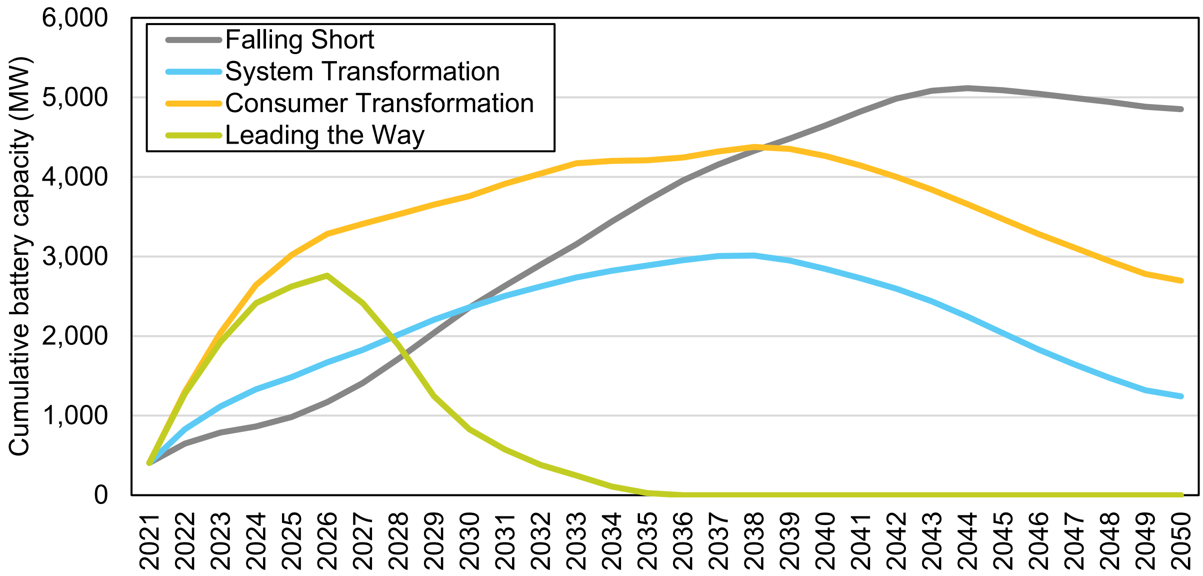


**Figure 33: Capacity of grid-connected standalone batteries in UK Power Networks' region.**

## 3.6 Flexibility

**Key Messages**

- Smart meter rollout is based on the latest Government plans, published in June 2021.
- The rollout of smart charging is in line with the recent Government mandate requiring all public charge points to be smart charging capable.

We modelled different sources of flexibility 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 18: 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 |

### 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. We model three scenarios for smart meter deployment rate and consider the BEIS smart meter policy framework[54] as a high scenario. The approach for forecasting the low scenario is kept the same as last year, starting from the March 2022 values from BEIS on smart meter roll-out[55] values.

Based on the scenarios that we adopt for the smart meter rollout, and expected ToU tariff availability, we developed the ToU uptake curves for domestic customers and small/medium I&C customers shown in Figure 34, 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.

[54] BEIS, *Smart meter policy framework post 2020,* 2021
[55] BEIS, *Smart meters in Great Britain, quarterly update March 2022,* March 2022

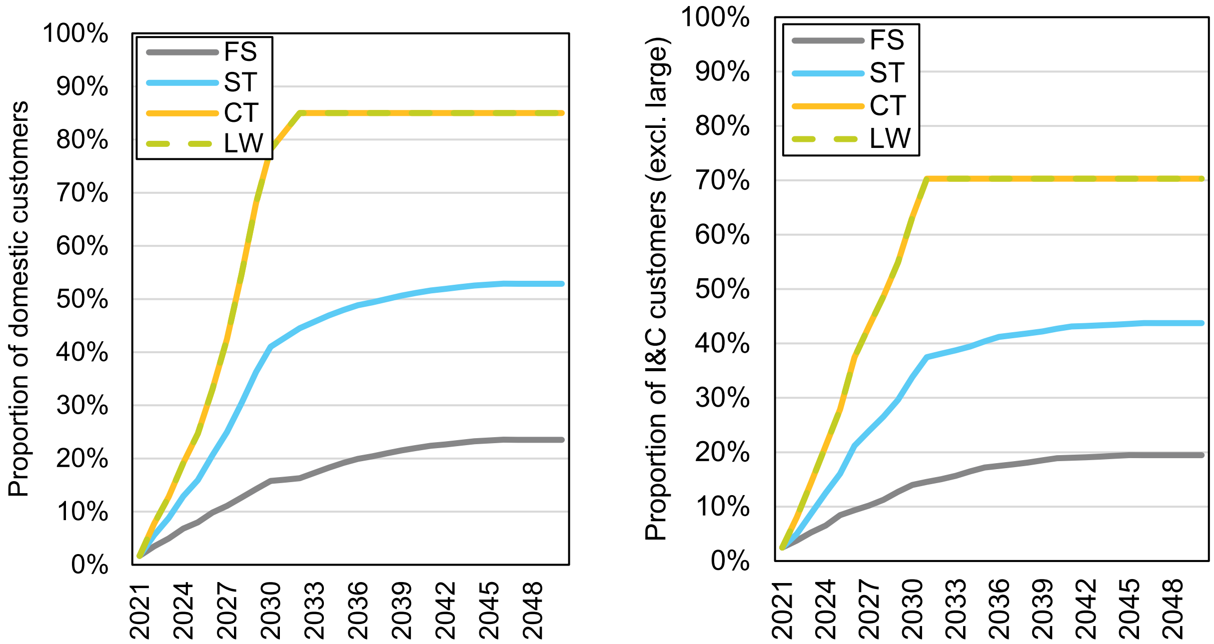


**Figure 34: Uptake of Time-of-use tariffs (ToUT) in the domestic sector (left) and in small and medium I&C customers (right).**

### 3.6.1 Demand side response

We developed two models 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 are both consistent with those published in the previous DFES[56].

### 3.6.2 Battery-based flexibility

#### Domestic battery-based flexibility

In order to lower their bills, we assume 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, we assume that the remaining discharge capacity will be available to provide flexibility to third parties such as the distribution system operator (DSO). We model the battery-based flexibility accessible to a DSO by considering the uptake of domestic batteries, discussed in **Section 3.5.1**, and assume 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[57].

#### EV smart charging

We divided EV charging 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. This year we adapted the three scenarios for the distribution of EV owners into these charging categories developed using our EV Consumer Choice Charging Choice Model in the previous DFES. We continue to follow the proposed faster rollout of smart charging uptake proposed in Government legislation[58], mandating all new non-public

[56] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.
[57] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021.
[58] Department for Transport (DfT), *Electric vehicle smart charging consultation; summary of responses,* updated 2021.

charge points to be smart charging capable, with smart charging being the default option. We assume 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 56% uptake of smart charging technology in System Transformation and 78% uptake in Consumer Transformation and Leading the Way.

The scenarios still see some level of non-managed charging as consumer will be able to override the default smart settings, to operate the charge points in a 'non-smart' way. We base our assumption for the proportion of sessions overridden by consumers in System Transformation, Consumer Transformation and Leading the Way on the results from Shift[59], a UK Power Networks innovation project. The initial results from a smaller set of users, which had a higher degree of override, are used in System Transformation. While the full trial results, used in Consumer Transformation and Leading the Way, 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, we assume that most charging sessions will be overridden, and that the majority of charging sessions remain non-managed out to 2050 (Figure 35).

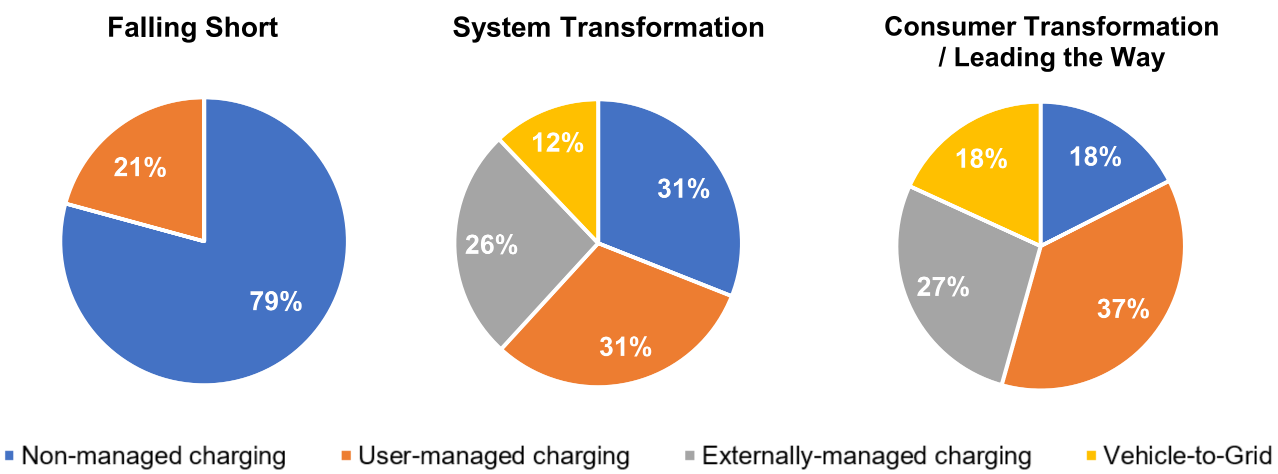


**Figure 35: EV residential charging distribution in 2050.**

To calculate the export capacity available from vehicle-to-grid at system peak we follow the same methodology as in the previous DFES. The available battery capacity assumed in System Transformation and Consumer Transformation is 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 V2G participation is assumed in Falling Short.

[59] UK Power Networks Innovation, *Shift*, 2021, available from: https://innovation.ukpowernetworks.co.uk/projects/shift/

# 4 Conclusions and future work

We developed scenarios for key drivers of demand and generation within UK Power Networks' three licence areas and brought them 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[60] but the scenarios were developed with a bottom-up approach to accurately reflect UK Power Networks' region.

The work was based on the previous iterations of the DFES, with carefully updated modelling based on the most recent available data, taking into account technology advancements and new policy frameworks, both of which have been evolving rapidly over the past few years. The publishing of new vehicle data, resolved at higher geospatial clarity, improved the baseline used for the vehicle uptake scenarios. Improvements in electricity generation data, bringing the categorisation of different generation types closer in line with ENA 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 updated projections for automotive OEM Li-ion battery prices, the new Boiler Upgrade Scheme and the second wave of funding for the Social Housing Decarbonisation Fund. These rapid developments within the sector highlight the value of continuing to develop the DFES in an iterative manner.

Furthermore, this work will feed into UK Power Networks' Strategic Forecasting System (SFS), an integrated set of software tools that will enable improved forecasting of load growth on the networks under different scenarios and analysis of what this means for network operation and investment, over RIIO-ED2 and beyond.

[60] National Grid ESO, *Future Energy Scenarios,* July 2022

# Appendix

## A. Electric vehicle uptake – taxis and private hire vehicles

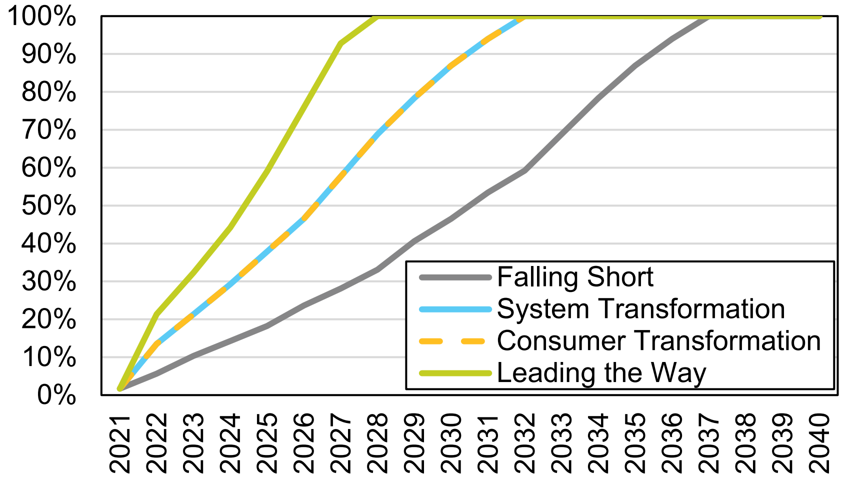


**Figure 36: Uptake of electric taxis outside the extended GLA boundary between 2020 and 2040.**

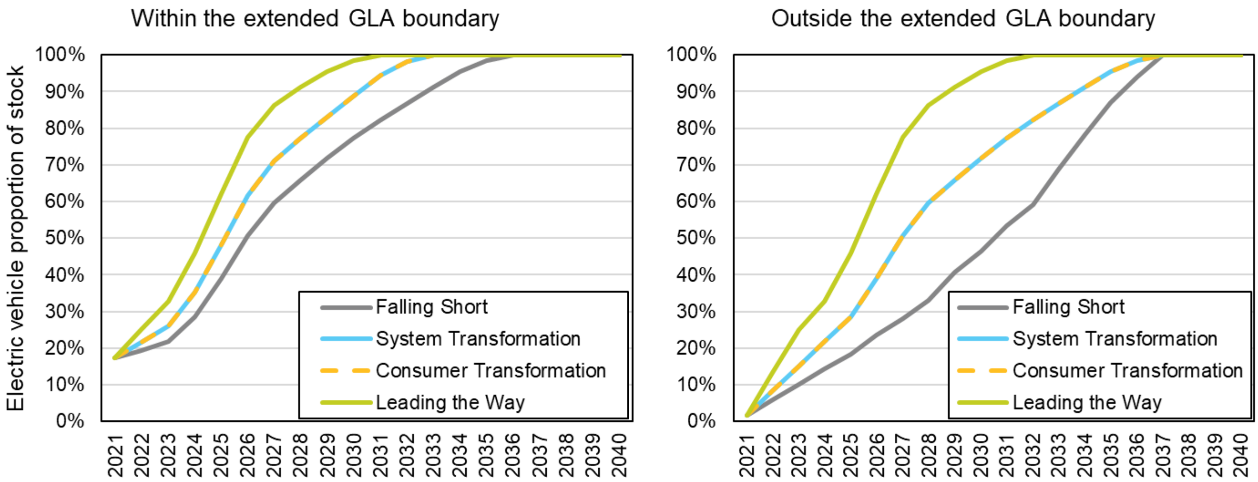


**Figure 37: Uptake of electric private hire vehicles within the extended GLA boundary (left) and outside the boundary (right) between 2020 and 2040.**

## B. Heating technology breakdown in the I&C sector

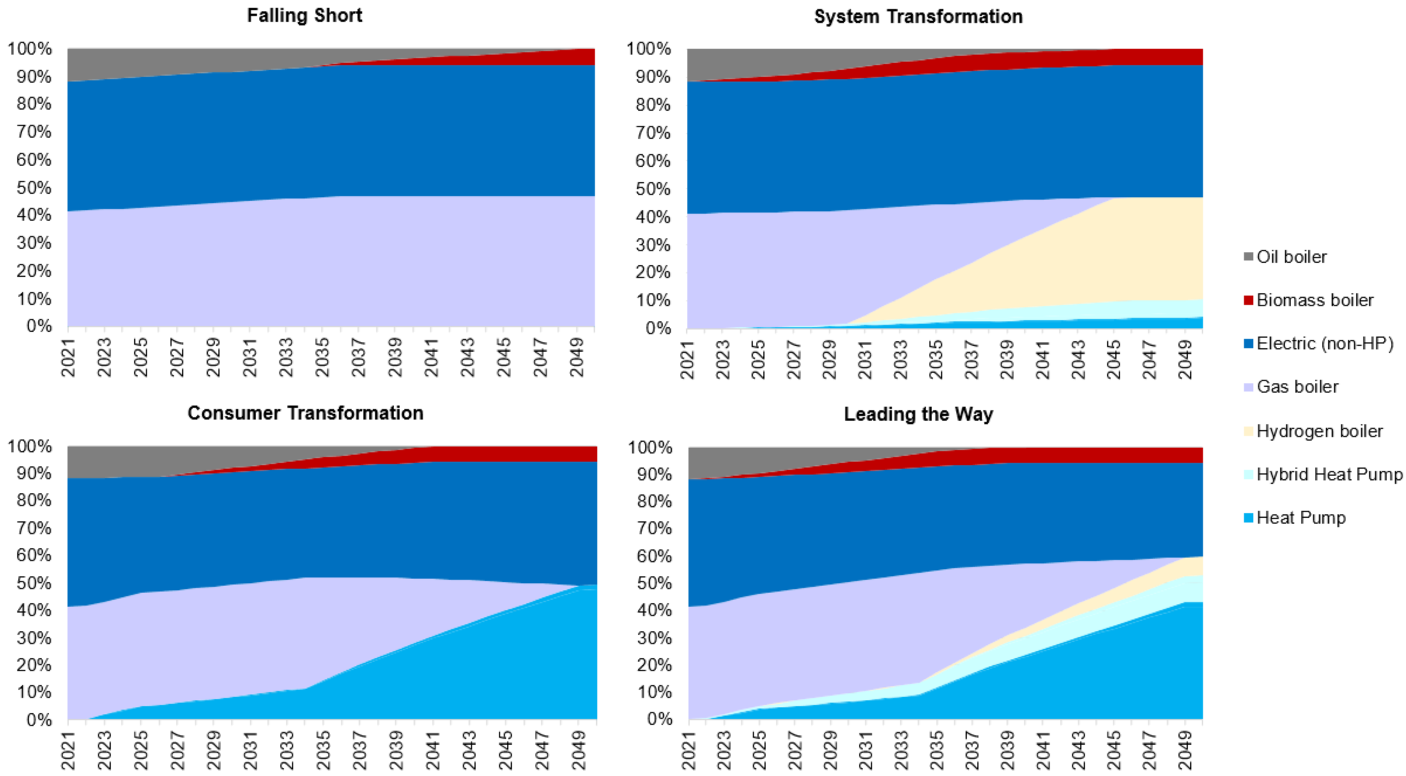


**Figure 38: Heating technology breakdown for I&C properties not on district heating in UK Power Networks' licence areas.**