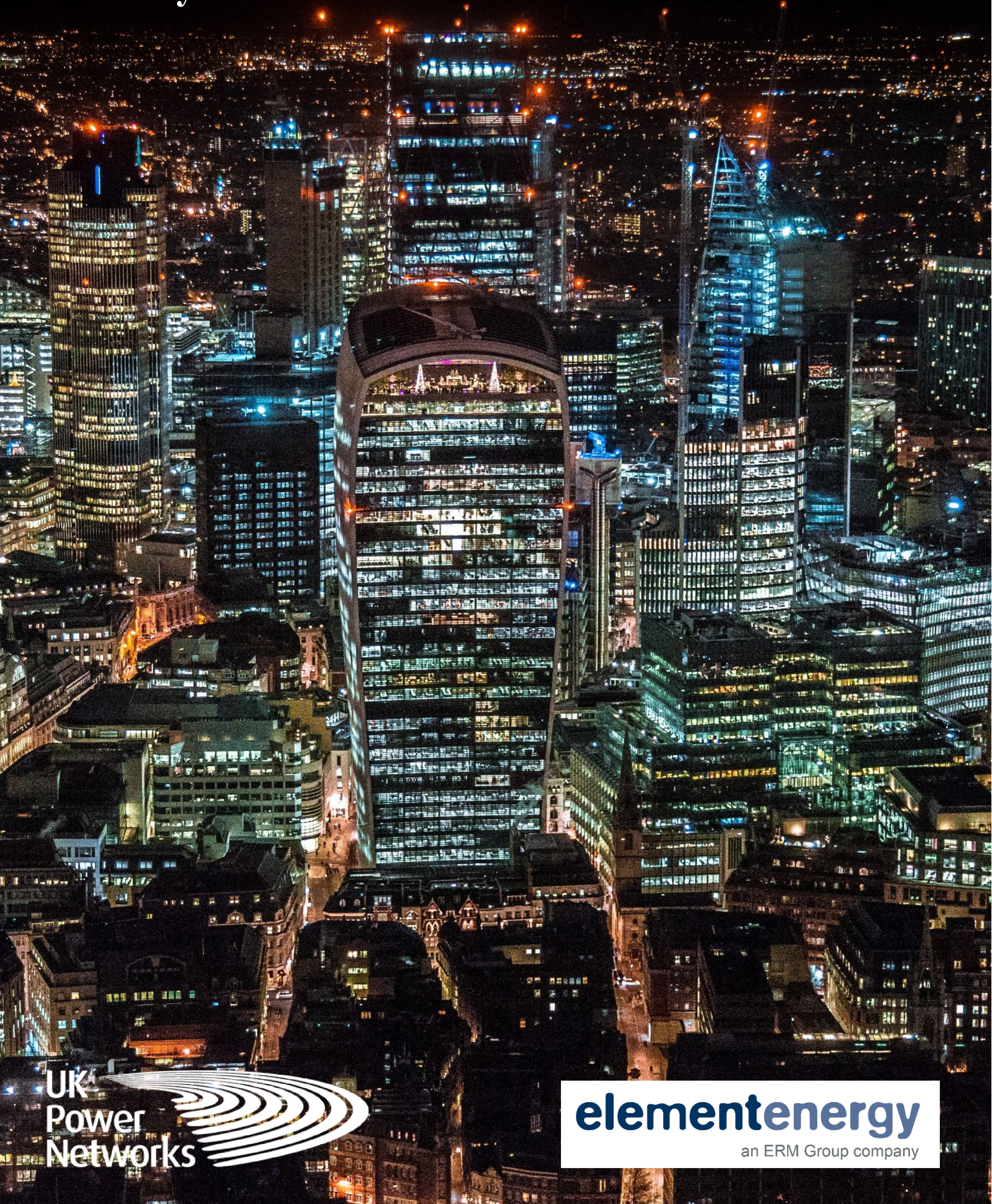
Distribution Future Energy Scenarios

Regional Outlook: UK Power Networks' projections
February 2022



UK Power Networks

elementenergy
an ERM Group company

Executive Summary

The urgent need for action to address climate change was highlighted by the recent UN Climate Change Conference (COP26) held in Glasgow in November. The United Kingdom is 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.

The recently announced Net Zero Strategy highlights the Government's ambition to reach these targets and indicates the rapid changes in policy that will be rolled out in the coming years.[1] The strategy highlights the key role that electrification will play in delivering Net Zero, and therefore, the crucial role that electricity networks have to play in helping to tackle climate change. Key messages from the report included that demand and generation across the electricity networks are expected to increase dramatically with the electricity distribution networks likely to *"require significant expenditures"* as a result. However, the report also highlights that this change *"means adopting a new approach to developing and delivering electricity networks".*[1] This new approach will require network operators to both operate the networks in a more flexible manner, as well as better predict the future need for additional capacity.

On 1st December 2021, UK Power Networks published its final business plan for the RIIO-ED2 period (2023-2028). This business plan outlined the expenditure that may be required to accommodate the demand and generation that could materialise across the UK Power Networks' network during the ED2 period under different possible futures. Those possible futures were underpinned by the 2020 Distribution Future Energy Scenarios (DFES), containing the same over-arching four scenario worlds as used by both National Grid and the other Great Britain Distribution Network Operators (DNOs).

In this update of the DFES, we present updated views for 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 cost projections and increasing consumer demand, as well as the practical limits of expected supply. We have also refreshed our projections for distributed generation, taking into account the Government's recent ambition to phase out fossil-fuel generation by 2035. Furthermore, we upgraded the modelling of decarbonised heating to align with the work done in the Heat Street innovation project undertaken by UK Power Networks and Element Energy in 2020[2].

The scenarios produced in this work will enable UK Power Networks to continue to effectively plan for the future across 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] Net Zero Strategy, BEIS, 2021
[2] UK Power Networks Innovation, Heat Street, 2021, available from https://innovation.ukpowernetworks.co.uk/projects/heat-street-local-system-planning/

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Disclaimer

Element Energy Limited has prepared this report in good faith, and has endeavoured to prepare it in a manner which is, as far as reasonably possible, objective. Whilst this report represents our best view at the time of issue, users should apply caution when using the contents of this report. The data in this report must be considered as illustrative only of what could occur under different possible futures and Element Energy Limited does not provide any view on the likelihood of these different scenarios coming to pass.

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	Future Energy Scenarios
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
SP	Steady Progression
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[3].

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

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".

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

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[4] as well as that used by the other UK 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). 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. **Steady Progression:** 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.

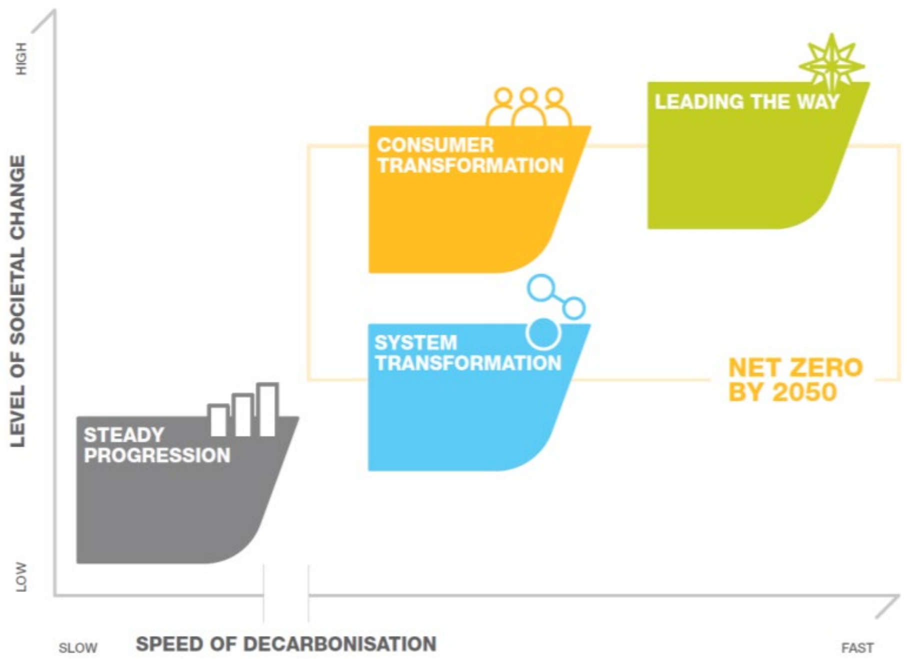

Figure 1: Scenario world framework overview (source: National Grid).

[4] National Grid ESO, *Future Energy Scenarios,* July 2021

2.1 Scenario world overview

SP

Steady Progression

The Steady Progression 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 and as a result the installed capacity of distributed generation, including solar PV and other renewable generation, increases steadily in this scenario . 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 available, and a nationwide refuelling network completed by 2045.

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 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 combines them with baseline data on the actual demand and generation on our network. This translates DFES to network assets such as substations.

In 2022, the DFES scenario assumptions in this document will be combined with substation demand profiles for the year April 2021 – March 2022 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 2022 demand forecast cycle from summer 2022 onwards. In 2022, we will also use the generation baseline in DFES 2022 (from end March 2021) 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. 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.

For each licence area, the "Best View" scenario is shown in the UK Power Networks' Long Term Development Statement (LTDS)[5] for 5 years ahead e.g. Table 3A and 3B in the LTDS show Grid and Primary substation peak demand forecasts. The "Best View" scenario is also the key input to the network developments shown in the LTDS for five years ahead. LTDS for all licence areas are published on our Open Data Portal, easily accessed in the 'document library' with type = LTDS.

For all substations in the LTDS, the "Best View" will be shown alongside other DFES demand and generation scenarios to 2050 at substation level in the new Network Headroom Report (NHR). The NHR must indicate existing and future network 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. This part of the new regulatory requirement for a Network Development Plan (NDP), due to be published for the first time on 1st May 2022 on our Open Data Portal. The 2022 NDP will reflect the 2021 demand and generation assessment with a baseline of the end of March 2021 – this means demand will be based on DFES 2021 (prior to the summer 2022 demand update to reflect DFES 2022 and a new baseline year of 2021/22), while generation will be based on DFES 2022.

[5] The most recent LTDS November 2021 tables are based on DFES 2021 (published January 2021), with the LTDS November 2022 to be based on this assumptions in this DFES document, DFES 2022.

The NDP will also contain development plans for the next ten years, informed by DFES. The “Best View” scenario will be the primary input to the development plans for the next ten years. However, in preparing the development plans for the NDP, the impact of the other DFES scenarios will be considered to ensure that no pathways are closed off and to reflect the greater level of uncertainty that exists towards the end of the ten-year period.

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

Parameter	Steady Progression	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
Non-renewable CHP / Decentralised biomass	High	Medium	Medium	Low
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
Flexibility				
Flexibility	Low	Medium	High	High

3 Scenario development

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[6]. Table 3 shows how the uptake scenarios that we have generated for the drivers of core demand maps to the scenario world framework.

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

Parameter	Steady Progression	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)[7] 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

[6] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021.
[7] Office for National Statistics (ONS), *2018-based Household projections for England (principal projection)*, June 2020

expected, we used UK Power Networks' analysis of local authority growth plans where available (see past DFES for more detailed methodology).

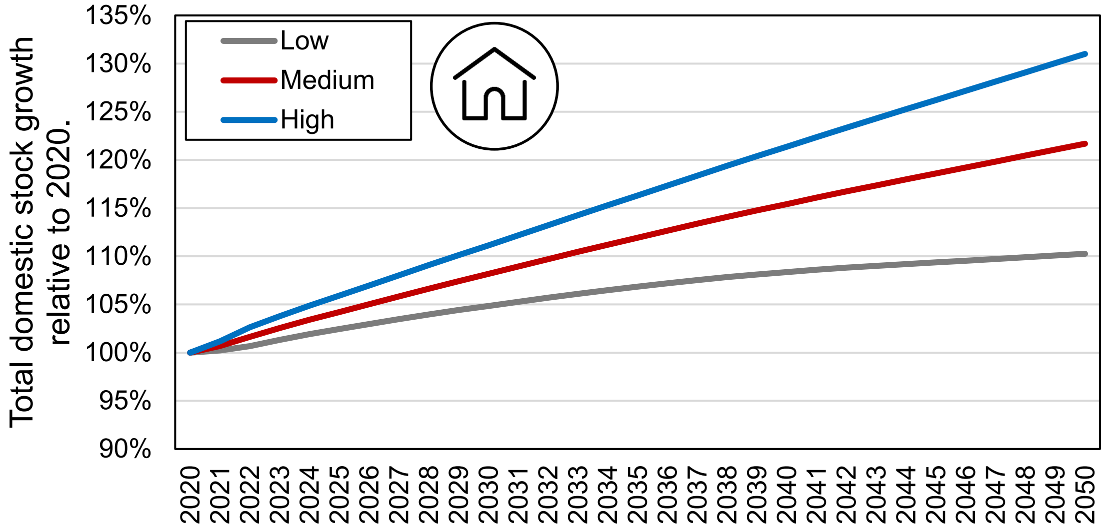

Figure 2: Domestic household growth in UK Power Networks' region out to 2050.

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 have been significantly impacted by the lockdown in response to the COVID-19 pandemic. GDP in the UK dropped in 2020, and according to latest projections from the Office for Budgetary Responsibility (OBR)[8], high growth is expected in 2021-2022 while the economy recovers to pre-COVID-19 levels. While economic growth can be an indication for growth in the I&C sector, we don't expect a rapid fluctuation in I&C floorspace over the next year, just as we didn't model a significant demolition of floorspace following the drop in GDP in 2020. Therefore, we modify the GDP projections from OBR by lowering the GDP growth in the recovery period over next few years. 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.

[8] Office for Budgetary Responsibility (OBR), Economic and fiscal outlook – October 2021, available from: https://obr.uk/efo/economic-and-fiscal-outlook-october-2021/

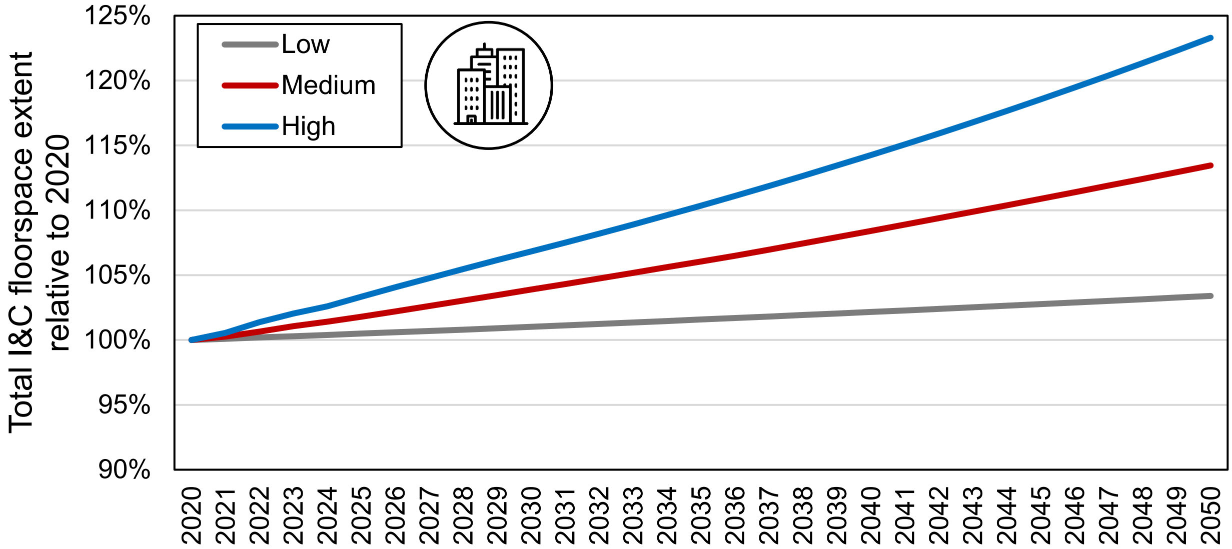

Figure 3: Total industrial and commercial (I&C) floorspace growth in UK Power Networks' region relative to 2020.

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[9], 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 2020 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.

[9] 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.

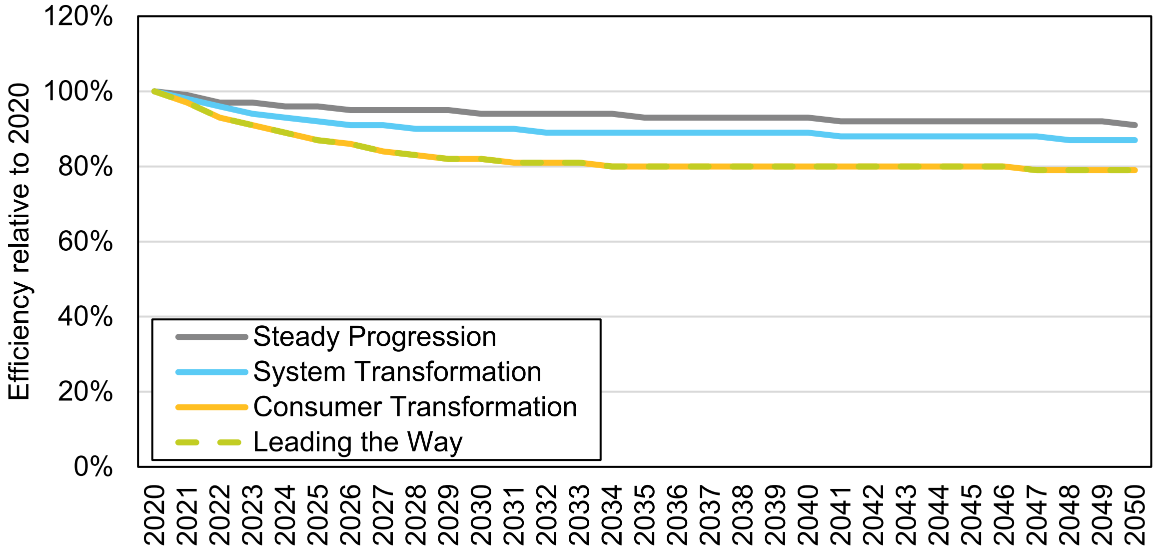

Figure 4: Domestic appliance efficiency, based on predictions from the Low Carbon London project

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[10]. Figure 5 shows the resulting energy efficiency projections for each different sector in the System Transformation scenario.

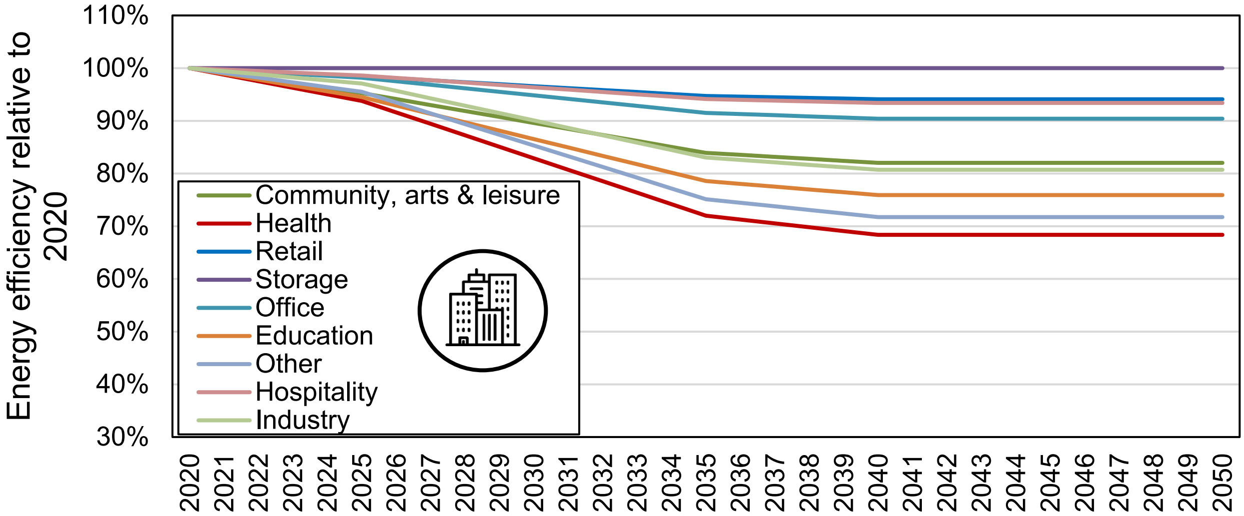

Figure 5: Energy efficiency in different I&C sectors out to 2050, System Transformation.

3.1.3 Air-conditioning

Due to climate change, hot summers are expected to become more common in the UK[11]. 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 2020 baseline, employing the methodology outlined in the previous DFES[12].

[10] Based on BEIS's Building Energy Efficiency Survey (BEES) that reports on the non-domestic building stock in England and Wales in 2014–15
[11] 'UK Climate Projections: Headline Findings', Met Office, 2019
[12] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.

3.2 Low-carbon transport

Key Messages

- Lower battery prices are expected to drive demand for EVs up, with supply being the limiting constraint in the near term.
- The modelling for uptake of electric taxis and private hire vehicles has been updated to reflect new studies.
- Ambition for decarbonising buses has increased in the GLA, resulting in more ambitious bus electrification scenarios.

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	Steady Progression	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 Ambition	MTS[13] Near Zero	MTS Near Zero	Max Ambition

3.2.1 Light vehicles

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

[13] Mayors Transport Strategy Near Zero – a scenario developed by TfL to forecast electric 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. We obtained a data extract from the Driver and Vehicle Licensing Agency (DVLA) and the Department for Transport (DfT), with a vehicle count at postcode sector level from Q1 2021. To obtain the desired geographic resolution, we used this data to find the vehicle count at Middle Layer Super Output Areas (MSOA) level, with subsequent data cleaning steps as detailed in the previous DFES.[14]

Once we have our baseline data, to commence uptake modelling we use the Element Energy Car Consumer (ECCo) model[15] 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 and Reduced Demand, public charging develops rapidly and consumers without access to off-street parking will have sufficient access to charging infrastructure, a ban on ICE vehicle sales is enforced in 2030 and in 2035 the sale of PHEVs is banned. Additionally, further policies to reduce vehicle stock and kilometres travelled are assumed in Reduced Demand.

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

<table>
<tr><th>Scenario name

(Scenario world)</th><th>Scenario description</th><th>Perceived access to charging for people without access to off-street parking?</th><th>ICE/PHEV ban enforced?</th><th>Stock and vehicle kilometres travelled trends</th></tr>
<tr><td>Limited Uptake

(Steady Progression)</td><td>The public charging market does not develop sufficiently to be seen as reliable by consumers (especially those parking on-street) and policy to remove conventional vehicles is not put in place.</td><td>✗</td><td>✗</td><td rowspan="2">Paused for 2 years (2020-2021) to account for COVID-19, then growth in line with DfT forecasts</td></tr>
<tr><td>ICE Ban

(System Transformation/ Consumer Transformation)</td><td>In addition to better public charging access, the government bans the sale of ICE vehicles in 2030 and PHEVs in 2035.</td><td>✓</td><td>✓</td></tr>
<tr><td>Reduced Demand

(Leading the Way)</td><td>As for ICE Ban scenario, with further policies assumed to reduce vehicle stock and kilometres travelled.</td><td>✓</td><td>✓</td><td>Paused for 2 years (2020-2021), then growth for cars in line with projected population growth rate. Growth for vans is twice growth in CCC Balanced Net Zero pathway</td></tr>
</table>

[14] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, February 2020 and January 2021.
[15] 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 2021Q1. It supports 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

Several updates were made to the ECCo model for this year's analysis, including a full recalibration of the cost and performance unit. As a result, price parity with ICE vehicles is reached sooner than in previous versions of the model and near-term demand for EVs is higher. However, due to the present chip shortage and a potential future global battery shortage[16], supply is likely to be a limiting factor when it comes to the uptake of EVs in the near term. Therefore, we have introduced supply constraints to these scenarios based on supply estimates, chip and battery shortage impacts and production capabilities of key EV manufacturers.

To estimate the supply of EVs over the next five years, we collected stated ambitions from the car manufacturers that make up a combined 90% market share in GB on when they expect EVs to reach a certain proportion of their sales. We then use these targets to create trajectories for EV proportion of sales by year for each car manufacturer and combine with our car sales projections to calculate the total expected EV supply in GB. In addition to the car makers that historically have had a high market share in GB, we estimate the GB EV supply from emerging players in the electric vehicle market. Emerging players are treated separately as they are already a large supplier of BEVs and their market share in GB is expected to grow over the coming years.

Supply constraints were then defined for each scenario in the following way.

- **Limited Uptake:** More conservative supply estimates, in the near term due to the chip shortage (2021-2023) and in the longer term due to battery shortages (2024-2025).
- **ICE Ban:** Equal to the manufacturer-stated supply estimates in 2021-2023; then in 2024 and 2025, we assume that an additional emerging car maker enters the market.
- **Reduced Demand:** The manufacturer-stated supply estimate plus an additional supply equivalent to Tesla sales in 2021.[17] From 2022, we assume additional supply from two additional emerging players entering the market, rising to three in 2023 with no constraints from 2024.

Figure 6 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.

[16] https://www.forbes.com/sites/neilwinton/2021/07/27/battery-scarcity-will-dwarf-chip-shortage-impact-on-global-auto-sales-report/?sh=68a14ca6363e
[17] This could be met by high production from existing manufacturers or additional suppliers, such as Chinese car manufacturers, coming into the market.

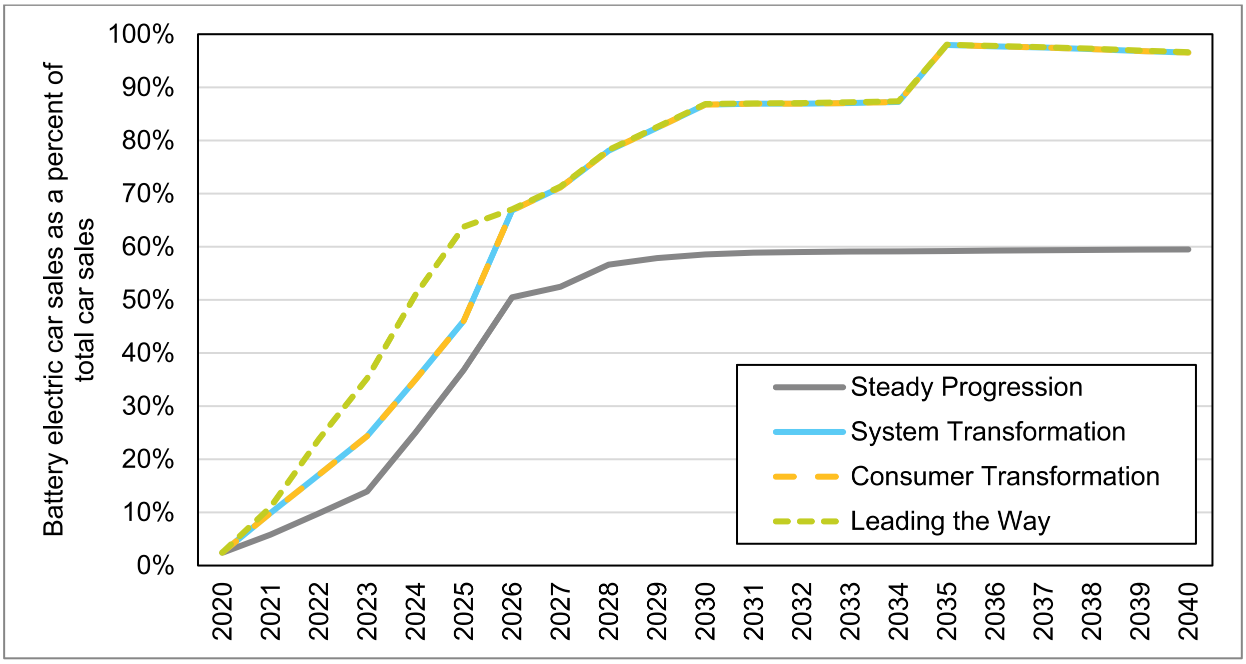

Figure 6: BEV sales as a proportion of total car sales to 2040. Modelled using the ECCo model with additional supply constraints at GB level applied over 2021-2025.

Figure 7 shows the resulting breakdown of the car and van stock in UK Power Networks' licence areas. We model the lowest uptake of BEVs in Steady Progression 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.

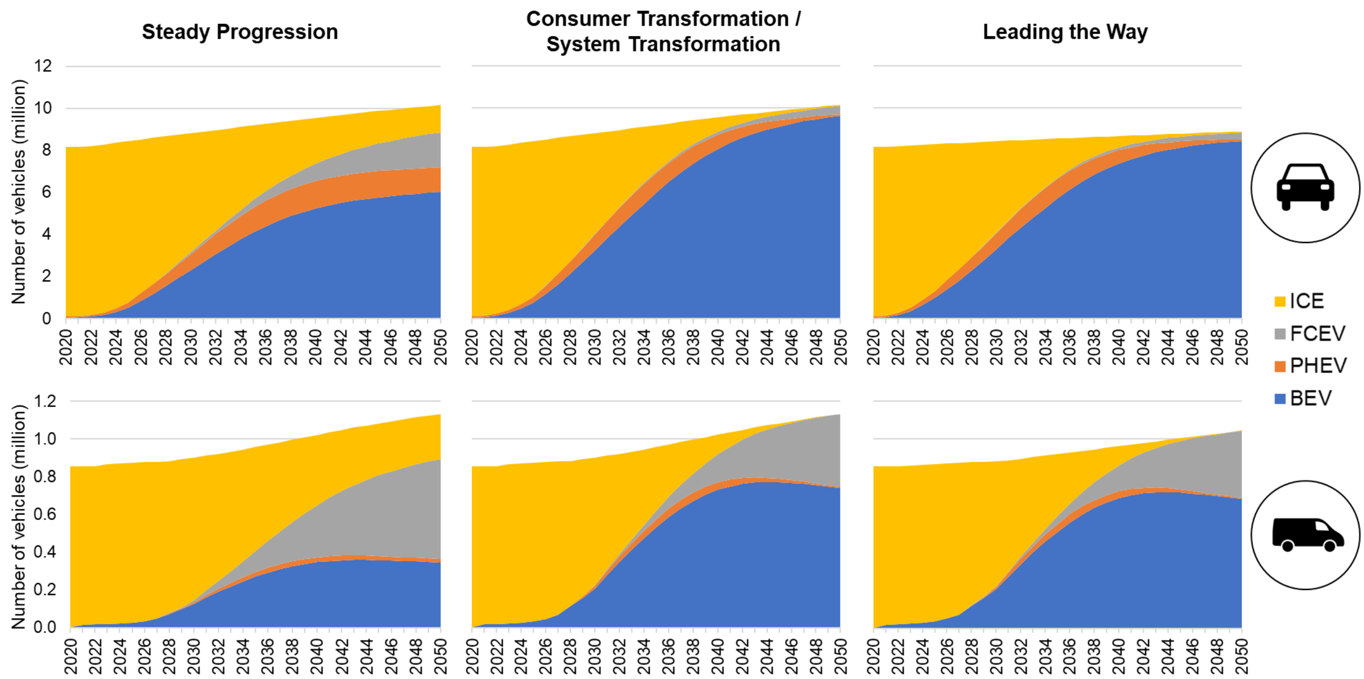

Figure 7: Breakdown of the vehicle stock in UK Power Networks' licence areas 2020-2050, cars (above) and vans (below).

We model between 3.2 and 4.3 million electric cars and vans in UK Power Networks' region by 2030[18], with the highest number of EVs in Leading the Way (Figure 8). Those figures are within the range modelled in the previous DFES (between 2.5 and 4.5 million EVs by 2030) with the most notable change in Steady Progression, which is the scenario with the lowest number of EVs by 2030 in both versions. By 2050, however, there are fewer total cars and vans on the road in Leading the Way compared to the other scenarios, resulting in a lower number of EVs than in Consumer Transformation and System Transformation, despite a very similar proportion of vehicles being electrified in these scenarios.

[18] The years refer to the regulatory year, so "2030" refers to the period from April 2030 - March 2031

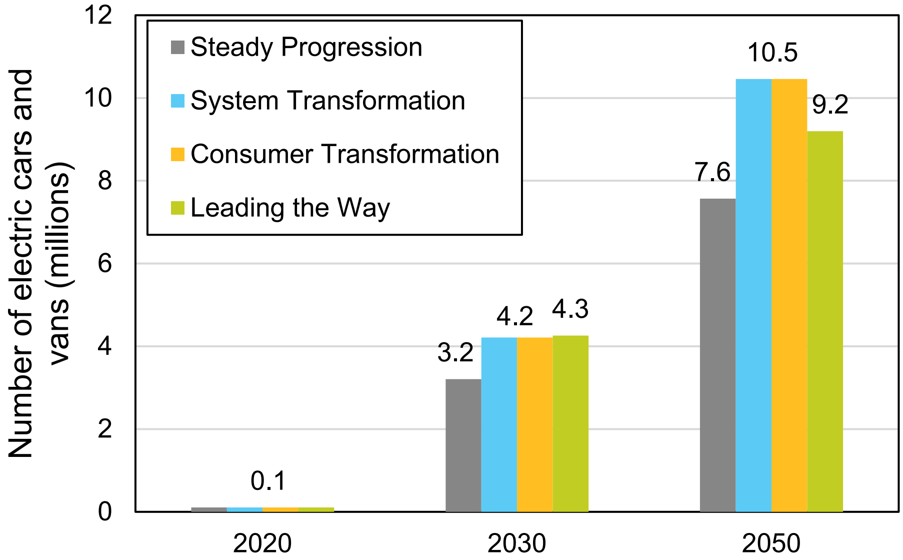

Figure 8: Number of electric cars and vans in UK Power Networks' region in 2020, 2030 and 2050.

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)[19], available at partial postcode resolution, and secondly the number of taxis and PHVs by local authority from the Department for Transport (DfT)[20]. 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 a part of the baseline, we establish which vehicles will be treated separately. In the previous DFES, we used the Greater London Authority (GLA) boundary as a barrier, and vehicles located within the GLA boundary (according to our baseline distribution) were on a higher electrification trajectory than those located outside of the boundary. In this update, we have expanded this boundary by 10 miles in all directions as a large share of vehicles registered by TfL are located outside of the GLA boundary (Figure 9). All taxis and private vehicles that we locate within this new extended boundary in our baseline, whether they are registered by TfL or not, will therefore have an accelerated decarbonisation trajectory as outlined in the following section.

[19] 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 October 2020, and electric taxi numbers dated September 2021, TfL licencing information, available from https://tfl.gov.uk/info-for/taxis-and-private-hire/licensing/licensing-information
[20] DfT/DVLA table TAXI0104, available from https://www.gov.uk/government/collections/taxi-statistics

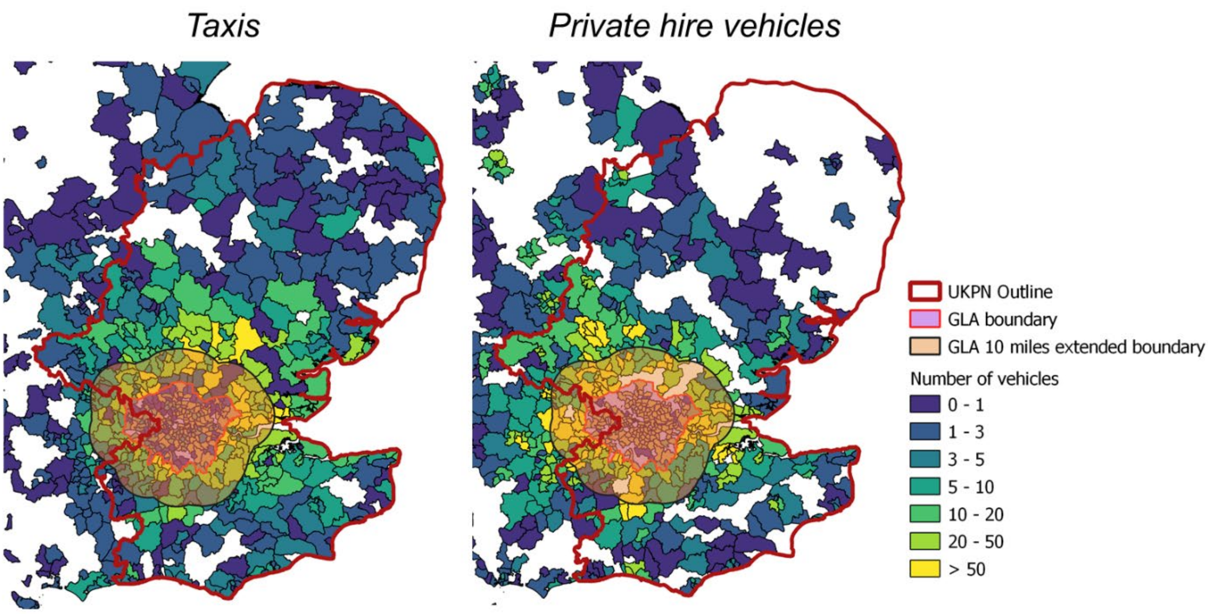

Figure 9: Number of taxis and private hire vehicles registered by TfL in 2020 by postcode district.

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[19], 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 "cars and vans" section.

In the previous DFES, uptake modelling was based on the Black Cab Green[21] (BCG) project which produced an uptake scenario that reflects the current ambitions of Transport for London (TfL) for taxis within the GLA to reach 100% electrification by the end of 2032.However, current uptake of electric taxis in the GLA is far higher than originally projected by the BCG study. Therefore, we have developed new, accelerated uptake scenarios for electric taxis within the extended GLA boundary (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 during the last DFES. 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, a five-year delay of the BCG scenario is assumed in Steady Progression 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.

[21] UK Power Networks, 2018, Black Cab Green project, info and reports available from: http://www.smarternetworks.org/project/nia_ukpn_0026

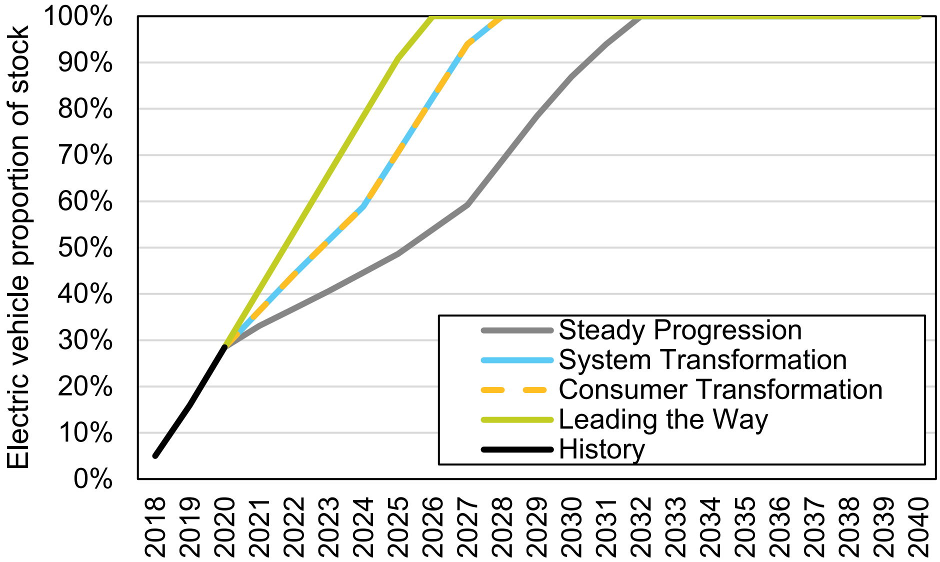

Figure 10: Uptake of electric taxis within the extended GLA boundary between 2018 and 2040.

For PHVs within the extended GLA boundary, we created three electrification trajectories using Element Energy's in-house modelling, a base scenario that reflects the current TfL licensing rules and stated ambitions from private hire vehicle operators[22], 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 Steady Progression, 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 2025, there could be up to 68,000 electric taxis and private hire vehicles in UK Power Networks' region, rising to up to 112,000 by 2030 (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 are due to stock growth. By 2050, we model between 105,000-130,000 electric taxis and PHVs.

[22] Several London private hire vehicle operators have stated an ambition to go electric, including Uber, Kapten, and Addison Lee.

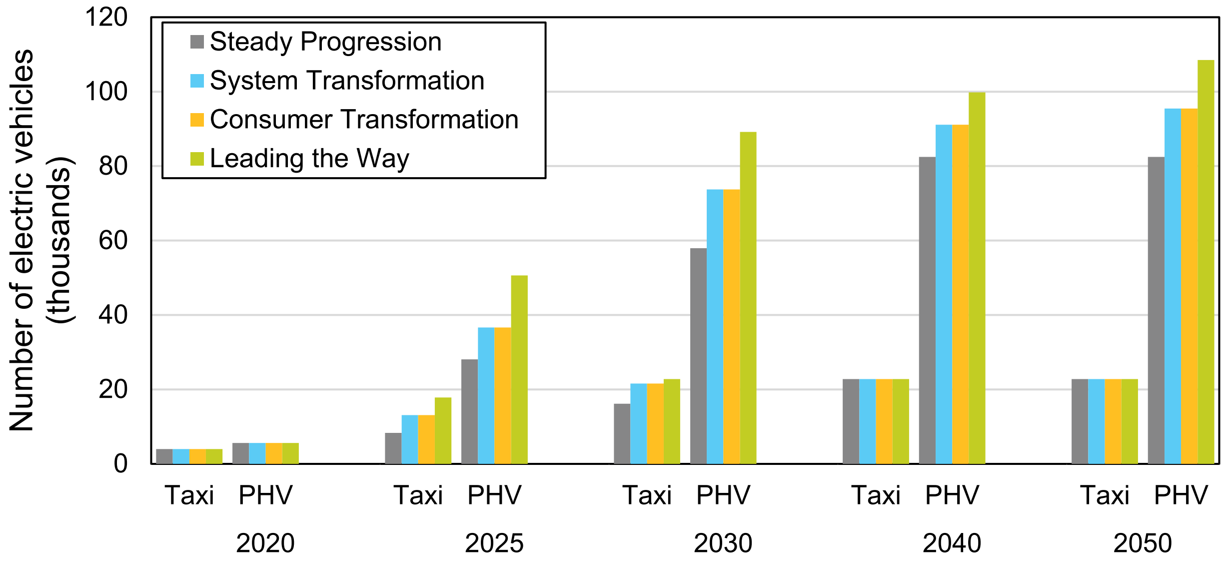

Figure 11: Number of electric taxis and private hire vehicles in UK Power Networks' licence areas at present (2020), in 2025, 2030, 2040, and 2050.

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 local authority level[23], and number of electric motorcycles at regional level[24].

To produce our uptake modelling we use the electrification scenarios for motorcycles developed by TfL, as reported in the London Climate Action Plan[25]. 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 Steady Progression, 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).

[23] Motorcycle data is extracted from the DfT/DVLA table VEH0105, 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.
[24] Baseline electrification proportion of motorcycles in the UK Power Network's region is assumed to be the same as the electrification proportion in the government regions East, London and South East, extracted from the DfT/DVLA table VEH0130 from Q1 2021, available from https://www.gov.uk/government/collections/vehicles-statistics.
[25] The London's Climate Action Plan Work Package 3: Zero Carbon Energy Systems, for Greater London Authority / C40 Cities, January 2019.

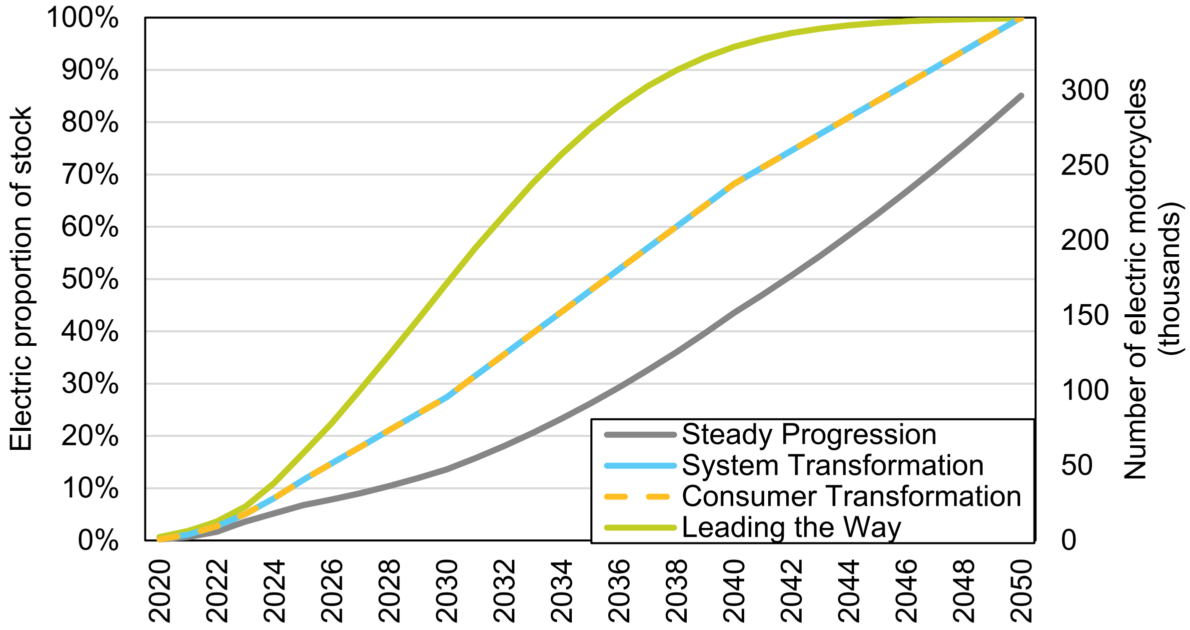

Figure 12: Uptake of electric motorcycles in UK Power Networks' region in 2020-2050.

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 use statistics from TfL[26] to determine the number of electric buses within Greater London and data from the DfT[27] to determine the electric proportion of buses outside London.

During the last DFES[28], we created three sets of four scenarios for the uptake of low emission heavy duty vehicles, using Element Energy in-house modelling. 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 were created to fit the narrative of the four scenario worlds outlined in this report and for this update we have realigned the baseline to match the latest available data. Based on recent announcements from the Mayor of London[29], committing to deliver a 100% zero-emission bus fleet in London by 2034, with further interest in reaching that target by 2030, we have accelerated the 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.

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[26] Transport for London (TfL) Bus fleet audit 31 March 2021, available from https://tfl.gov.uk/corporate/publications-and-reports/bus-fleet-data-and-audits.
[27] Baseline electrification proportion of buses outside the GLA, and within UK Power Network's region, is assumed to be the same as the electrification proportion in the government regions East and South East, extracted from the DfT/DVLA table VEH0130 from Q1 2021, available from https://www.gov.uk/government/collections/vehicles-statistics.
[28] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021.
[29] https://www.london.gov.uk/press-releases/mayoral/mayor-host-zero-emission-bus-summit-at-city-hall

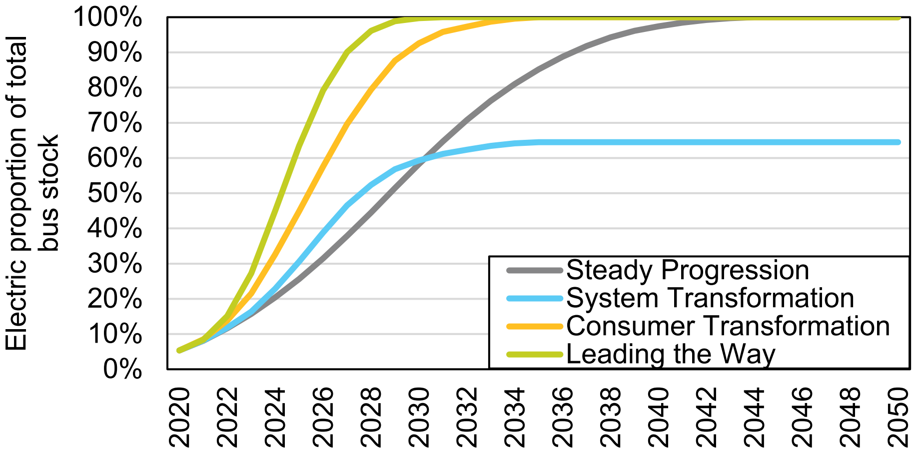


Figure 13: Electric bus uptake rates for the bus stock within the GLA.

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 first 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[30] and GLA-specific[31]) 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 13% (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.

[30] Department for Transport, *National Travel Survey: England 2017*, July 2018. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/729521/national-travel-survey-2017.pdf and Department for Transport, *Statistical data set: Mode of travel*, August 2020.
[31] Transport for London, *Travel in London, report 12,* 2019. Available from: http://content.tfl.gov.uk/travel-in-london-report-12.pdf and Transport for London, *Roads task Force. Thematic Analysis – Technical Note 14,* 2012

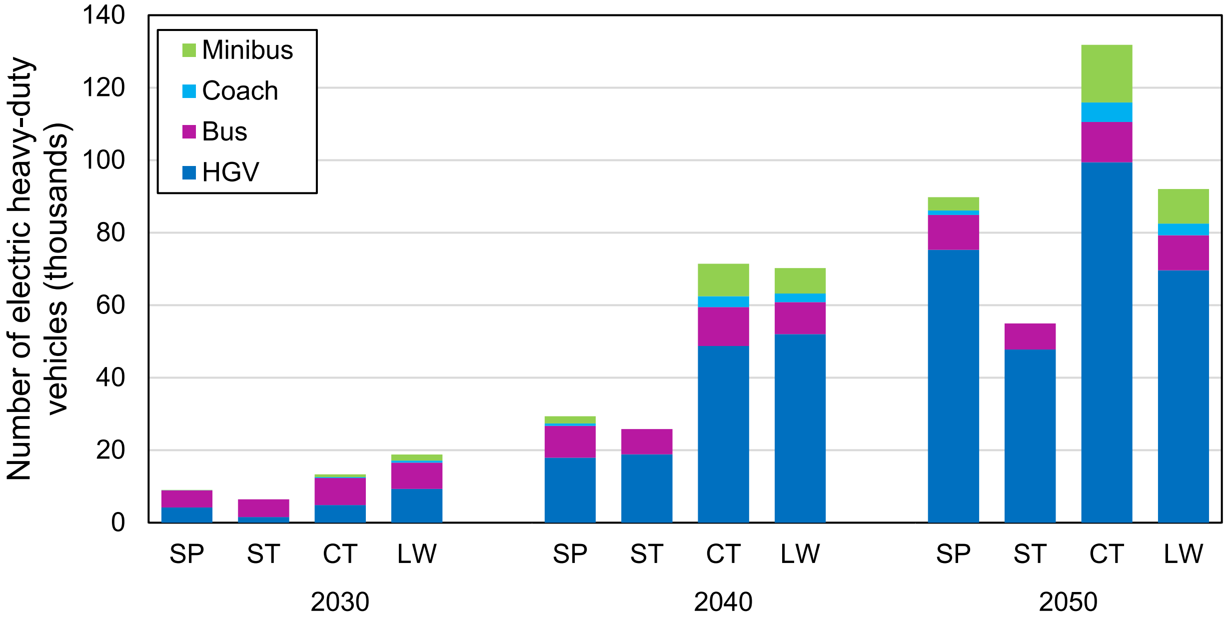


Figure 14: Number of electric heavy duty vehicles in UK Power Networks' licence areas in 2030, 2040 and 2050.

3.3 Decarbonised heating

Key Messages

- The modelling for decarbonised heating uptake has been updated to reflect the Heat Street innovation project.
- 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.

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 extremes are 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 represets a scenario world where high uptake of heat pumps is combined with a decarbonised gas grid, which sustsains a market for hybrid heat pumps. Steady Progression 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	Steady Progression	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[32]

[32] 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

Element Energy recently worked with UK Power Networks on a detailed study of decarbonised heating called Heat Street[33]. Heat Street was a Network Innovation Allowance (NIA) project that took a data-driven look into the future to understand, at a granular level, the options for decarbonisation of heat and the likely impact on consumers, local authorities, policy makers and the electricity network. The project analysed the building stock in UK Power Networks' licence areas, identified over 2,000 building archetypes, and then found the optimal thermal energy efficiency and heating technology package for each archetype in terms of suitability and cost. As part of this year's DFES we have built upon the outcomes of the Heat Street project and aligned them to the requirements for the DFES. A key additional element that was added for the DFES work is a consumer choice module that models when consumers are likely to switch to their optimal thermal efficiency and heating technology package. We then combined these findings with modelling of district heating, using the approach outlined in the previous DFES, to obtain a final picture of the heating sector in each LSOA out to 2050. Figure 15 outlines the modelling approach with the individual modelling components discussed below.

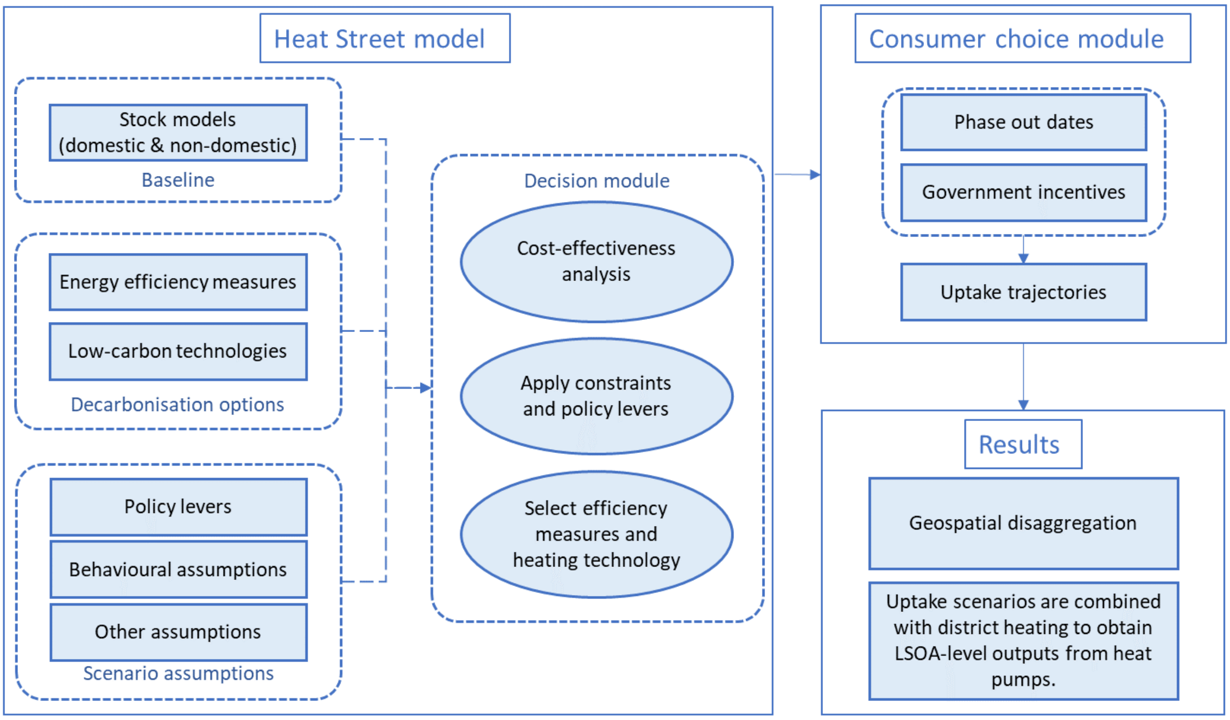


Figure 15: Schematic of the modelling approach for the uptake of low carbon heating.

Heat Street model: We used the decarbonised heating technology model, developed during the Heat Street project, to define the optimum heating technology for each building archetype. The model considers over 2,000 different building archetypes, present in UK Power Networks' region, and assesses the best option for a package of energy efficiency measures and a low-carbon heating solution, based on cost-effectiveness and the policy environment in each scenario. For example, the optimum heating technology for a domestic building in Consumer Transformation is not allowed to be a gas boiler as we assume they will be phased out in this scenario. Further detail on the policy environment in each scenario can be seen in the following section. We consolidate the outcome of this modelling by aggregating similar archetypes together before we feed the results into the newly added consumer choice module that determines the rate at which each consumer archetype adopts their selected heating technology.

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

Consumer choice module: Our approach for modelling the uptake rate of the thermal efficiency and heating technology packages, identified by the Heat Street model, is closely aligned to the methodology of our bespoke consumer choice uptake model for heating technologies, utilised in the previous DFES. We created a consumer choice module that adds onto the Heat Street work and produces the uptake rates for the heating technology and energy efficiency packages for each individual archetype. The consumer choice module cycles through each year and compares the business case for the optimum thermal energy efficiency and heating technology package against the counterfactual technology for each archetype and assesses the number of homes switching their heating system in each year out to 2050. The model takes into account technology prices (capex, opex), fuel costs, conversion costs (adding or removing a wet heating system or hot water cylinder, decommissioning gas boilers, adding hydrogen pipework etc.)[34], willingness to pay for each occupant type, grants, and Government policy.

In the domestic sector, we consider four different occupant types for each building archetype – 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. We consider the proposed Clean Heat Grant that is available to all consumers, the Social Housing Decarbonisation Fund, 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, decarbonised electrification or a mix of both – will rely on top-down Government intervention. Based upon the recent recommendation made by the CCC to ban gas boilers in new homes, 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	Steady Progression	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	Steady Progression	System Transformation	Consumer Transformation	Leading the Way
Gas boilers	No restrictions	All switch to H2 by 2050	2035	2035
Oil & LPG boilers	2035	2030	2027	2025

[34] Costs and technology prices are adopted from the Heat Street work.

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.

Steady Progression

- Low grant amount from schemes with no support for hybrids available.
- Low electrification.

In Steady Progression, 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 Clean Heat Grant will not be extended to last longer than the current proposed duration (from April 2022 until March 2024) and that the maximum grant amount available to each consumer will be £4,000. 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 timeframes proposed by each scheme.

System Transformation

- Medium grant amount from schemes with no support for hybrids available.
- 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 Standard, as well as a ban on fossil fuel heating in the off-gas sector from 2030. We assume that the Clean Heat Grant will be extended to last until 2026 with a grant amount of £5,000. 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 with no support for hybrids available.
- 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[35]. In 2035, a ban on gas boilers is enforced for existing buildings (Table 8). We assume that the Clean Heat Grant will be extended to last until 2029 with a grant amount of £6,000 and the Social Housing Decarbonisation Fund and Sustainable Warmth competition will also be extended further than in System Transformation.

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

Leading the Way

- High grant amount from schemes with support for hybrids.
- 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 in Leading the Way. To further encourage the deployment of hybrid heat pumps, the grants available will include support for hybrid heat pumps (unlike the other scenarios).

Figure 16 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.

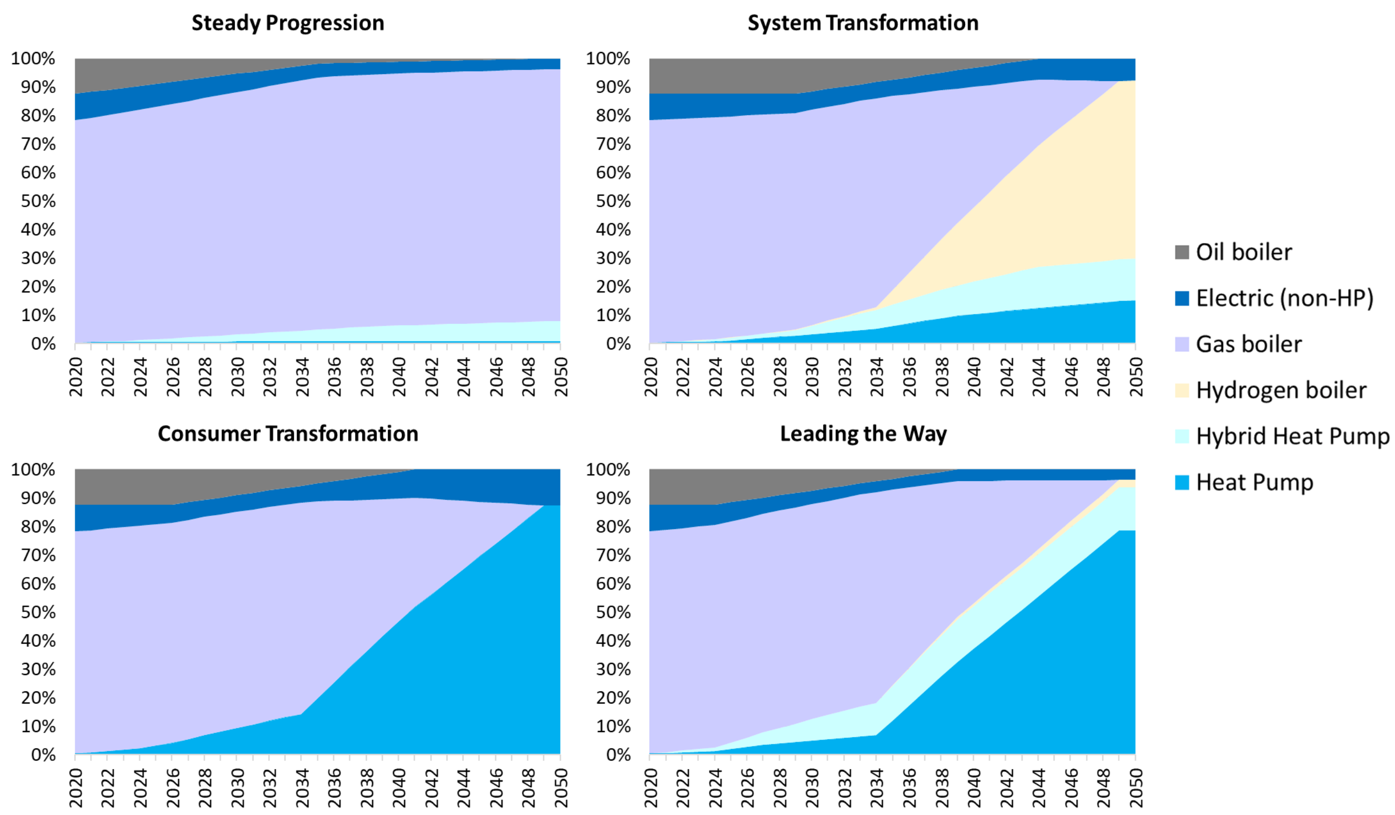


Figure 16: Heating technology breakdown for domestic buildings not on district heating in UK Power Networks' licence areas.

Steady Progression 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 17 shows the resulting number of total domestic heat pumps in each scenario. This figure indicates that by 2030, there could be between 250,000 and 985,000 heat pumps operating in UK Power Networks' licence areas, rising to between 660,000 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).

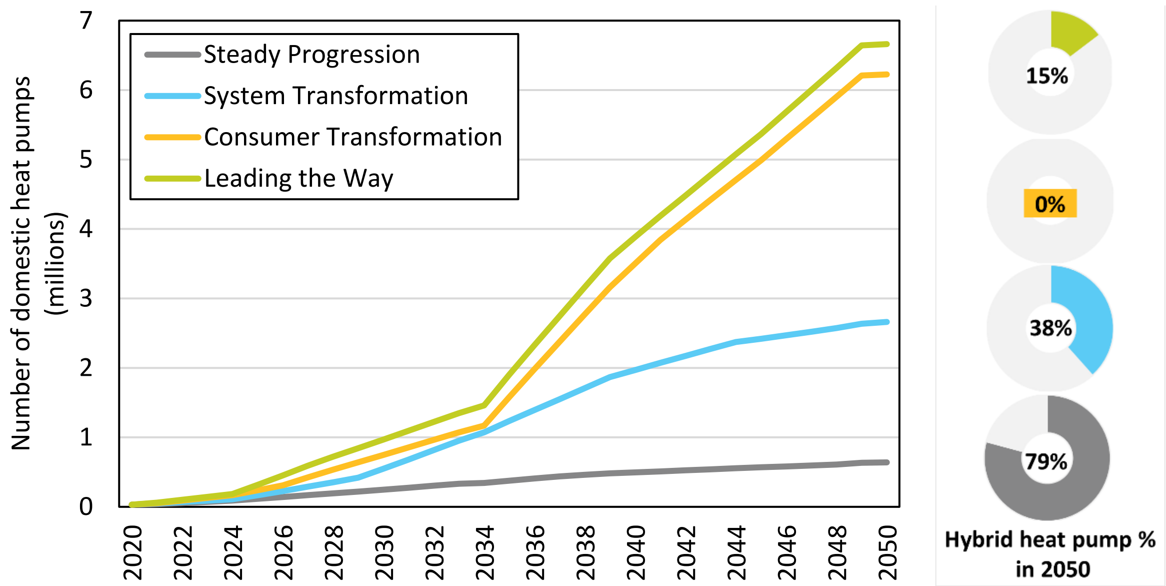


Figure 17: Total number of domestic heat pumps installed in UK Power Networks' licence areas and the proportion of heat pumps that are hybrids in 2050.

Similar trends are observed in the I&C sector and Figure 18 indicates that by 2030, there could be between 2,000 and 120,000 I&C heat pumps operating in UK Power Networks' licence areas, rising to between 4,400 and 405,000 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. Steady Progression 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.

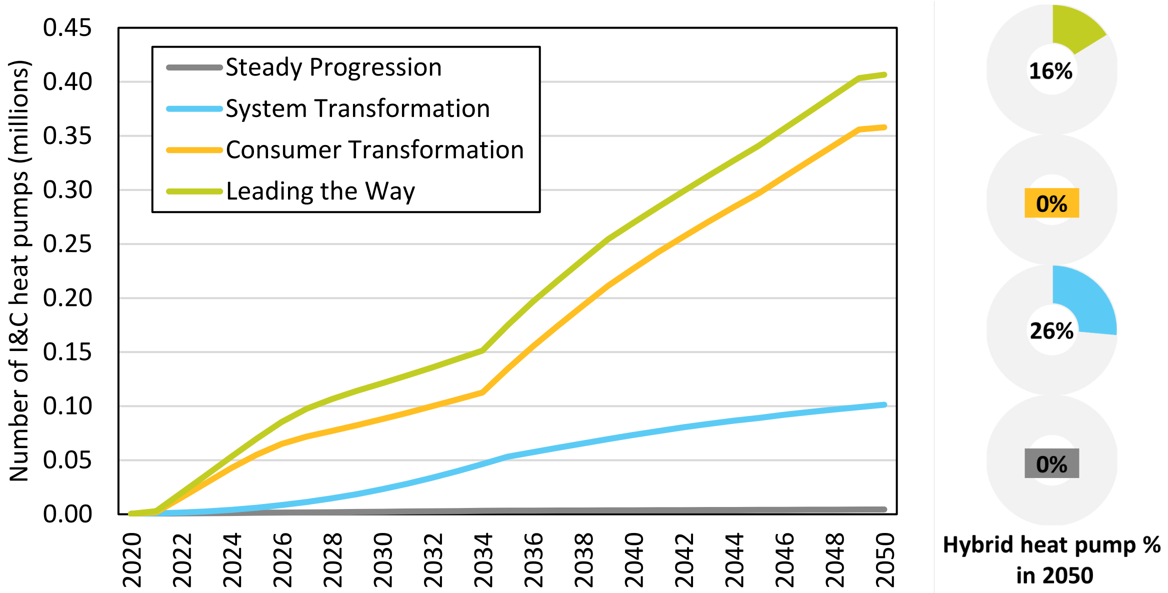


Figure 18: Total number of I&C heat pumps operating in UK Power Networks' licence areas and the proportion of heat pumps that are hybrid in 2050.

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 19).

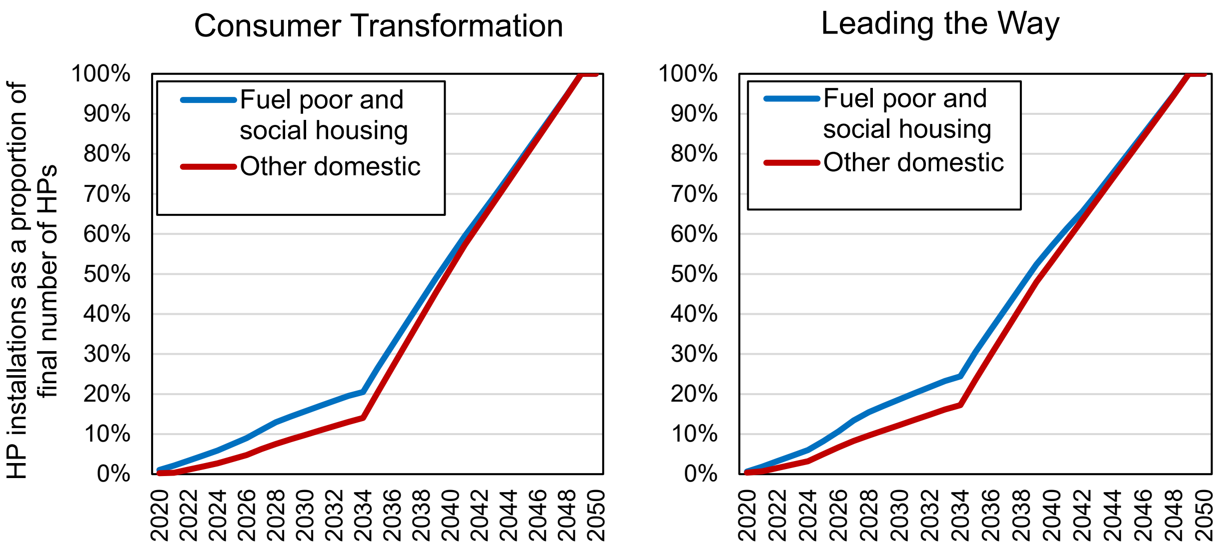


Figure 19: Heat pump rate of uptake for fuel poor and social housing compared to other domestic properties.

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 20 shows the resulting energy efficiency scenarios for the domestic building stock within UK Power Networks' licence areas.

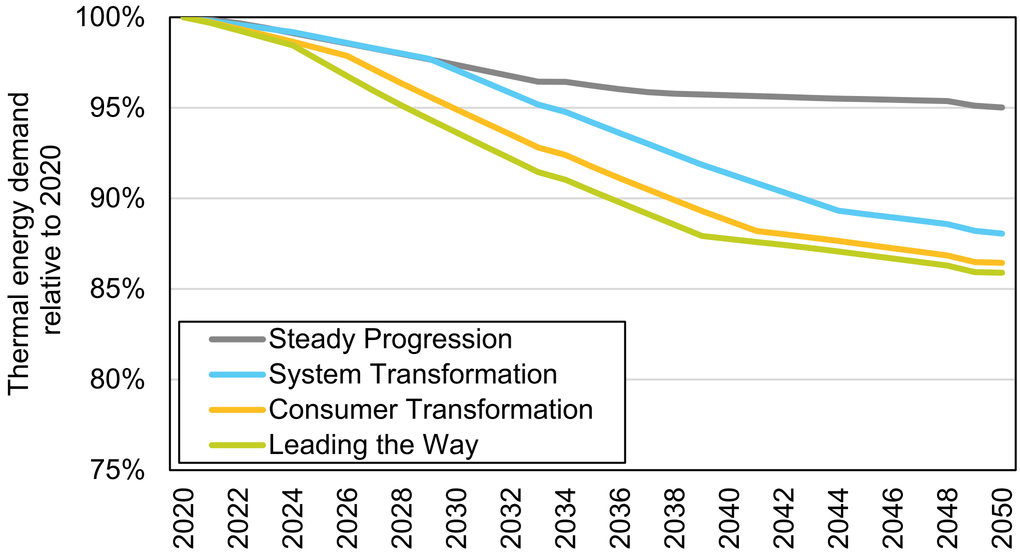


Figure 20: Thermal energy demand in the domestic building stock compared to a 2020 baseline.

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 based on the same principles as applied in the previous DFES and the results are closely aligned to those published in the last DFES report[36].

[36] Element Energy for UK Power Networks, Distribution Future Energy Scenarios, January 2021.

3.4 Distributed generation

Key Messages

- Scenarios for large-scale solar PV capacity are higher than previously due to revised technical potential for the region.
- Uptake of small-scale (rooftop) solar PV in Leading the Way is now higher than previously, following National Grid's narrative of the scenario.
- 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 9).

Table 9: Distributed generation uptake scenarios modelled in this work and their mapping to the scenario world framework.

Parameter	Steady Progression	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 21.

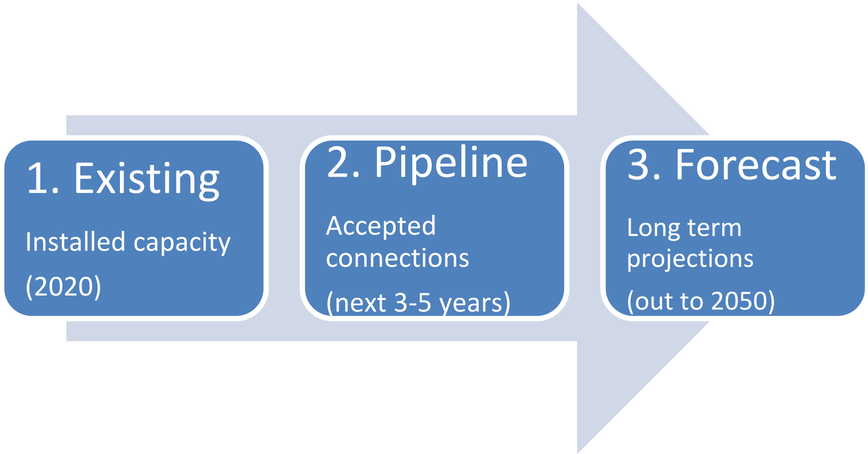


Figure 21: Pathway for modelling distributed generation.

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 10). Combined, these sources provide us with a detailed baseline for installed capacity, generation site locations and installation dates.

Table 10: 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) 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 has been updated to include additional generation detail; most notably the categorisation of different generation types was brought closer in line with ENA Building Blocks. This led to improved accuracy of the established generation baselines; for example, splitting fossil gas generation between large gas turbines, CHP and non-renewable engines could be done directly from the generation database in the ECR this year.

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 11).

Possible forthcoming changes to the Access & Forward looking charges through the Ofgem Charging Futures program were considered in the context of the uptake scenarios. If the proposed changes are adopted to facilitate easier connection of generation capacity through reduced costs, higher volumes of generation connecting to the distribution network could be observed. However, since UKPN has adopted Active Network Management connections in recent years, which already allow cheaper connections, the impact of changes to the Access & Forward looking charges is expected to be limited. Therefore, the scenario modelling has not been adapted specifically to reflect the expected shallower connection boundaries; however, the impact of any eventual changes to charging is something we will continue to monitor closely in future iterations of the DFES.

We analyse a range of sources for developing 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[37]. 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 two DFES) of suitability of UK Power Networks' region to different generation technologies 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.

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

Table 11: 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

Figure 22 shows the total distributed generation forecast in the UK Power Networks' region for all four scenario worlds in 2030 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 Steady Progression 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 2030 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.

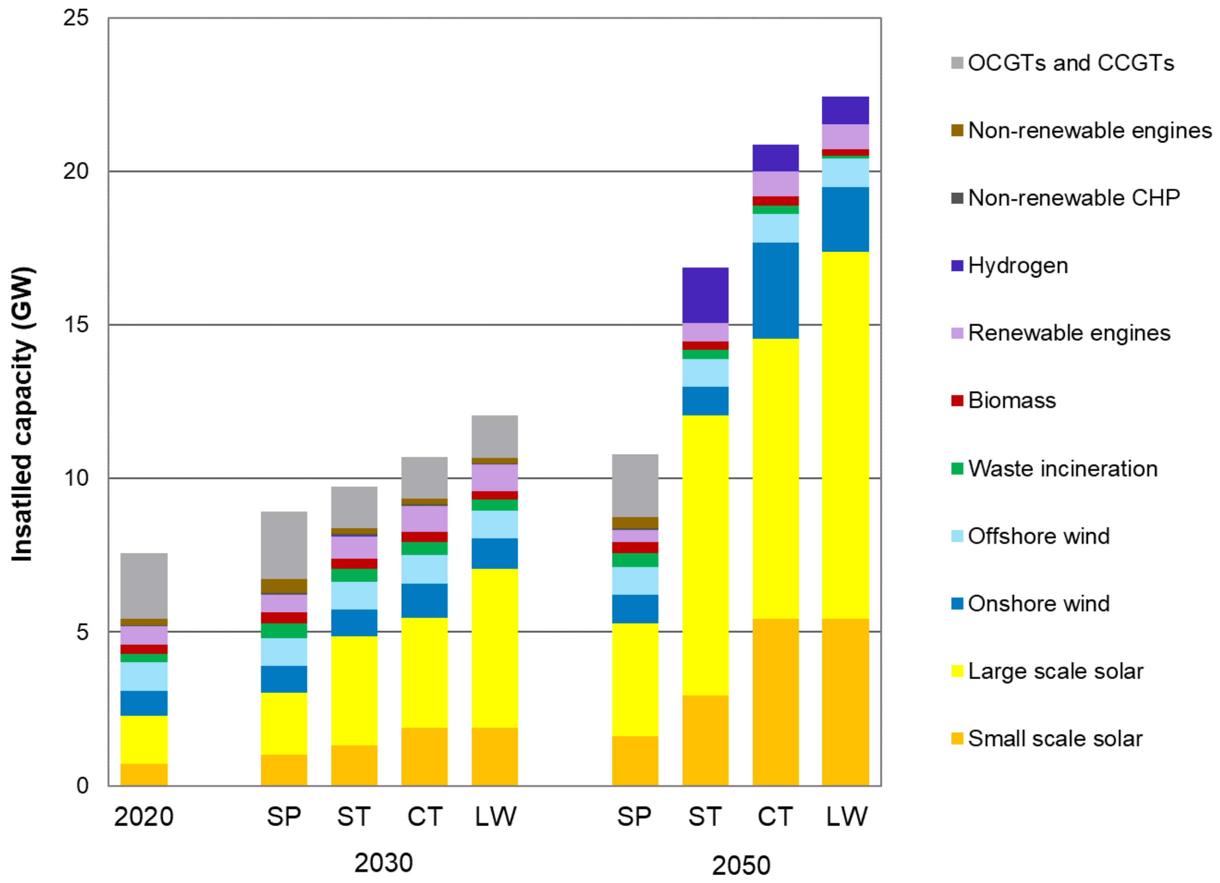


Figure 22: Capacity of distributed generation installed in UK Power Networks' licence areas in the base year of the scenarios (2020), in 2030 and 2050.

3.4.1 Renewable generation

We model a range of renewable generation technologies as listed in Table 11. 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 12 below, and different installation costs applied to each band.

Table 12: 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 12). Following National Grid's narrative of the scenarios, a key change this year was that a high uptake of small-scale solar PV was modelled in Leading the Way compared to a medium uptake last year. In the high uptake scenario, we also account for a shift in taxes on electricity, where environmental taxes on customer electricity prices are shifted onto gas prices (the same assumption is made in our scenarios for decarbonised heating in Leading the Way, see **Section 3.3.2**). This change in taxation results in lower forecasted electricity prices than previously, making the business case for rooftop solar PV weaker, causing a lower uptake of small-scale solar PV. Figure 23 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. We model the lowest uptake in Steady Progression 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 Steady Progression, when early installations reach the end of their life, assuming a 20-30 year lifetime of small-scale solar PV.

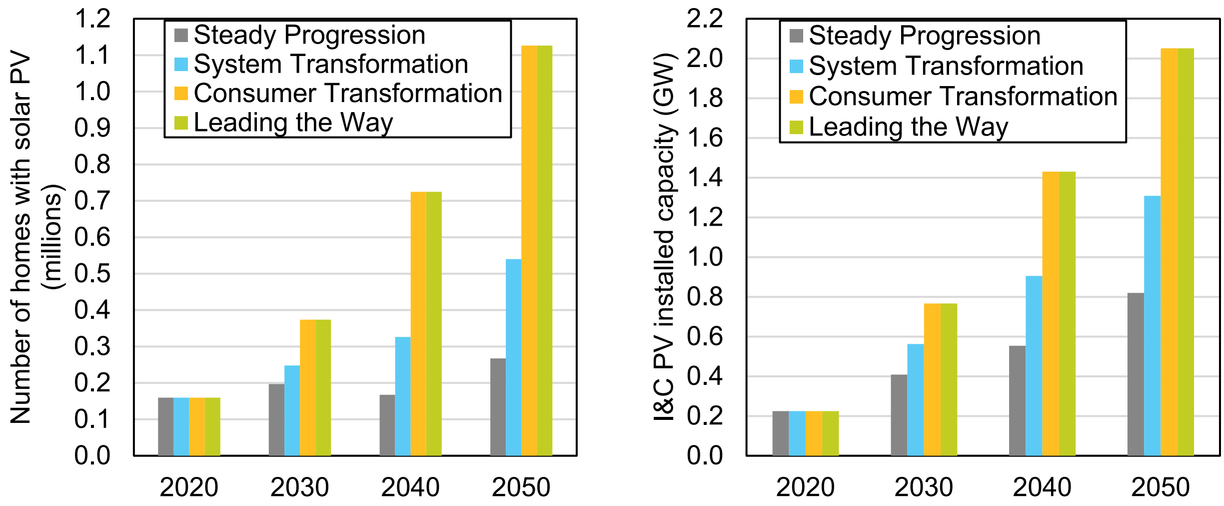


Figure 23: Small scale solar uptake. Number of domestic installations (left) and installed capacity of I&C solar PV (right).

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. We updated our definition for the technical potential of large scale solar in each licence area based on a re-evaluation of the land types suitable for ground mounted solar installations, land availability, and constraints such as areas of outstanding natural beauty. The technical potential evaluation is higher than in the previous DFES, resulting in a significant increase in large-scale solar forecasted in UK Power Networks' licence areas, particularly in Leading the Way (Figure 24). The uptake is sensitive to the technical potential because we assume that the installation rate slows downs as the total installed capacity approaches the technical potential. This assumes that developers will first choose the most suitable locations for solar PV and as more and more capacity is installed, the harder (more expensive) it becomes to find suitable locations for additional installations.

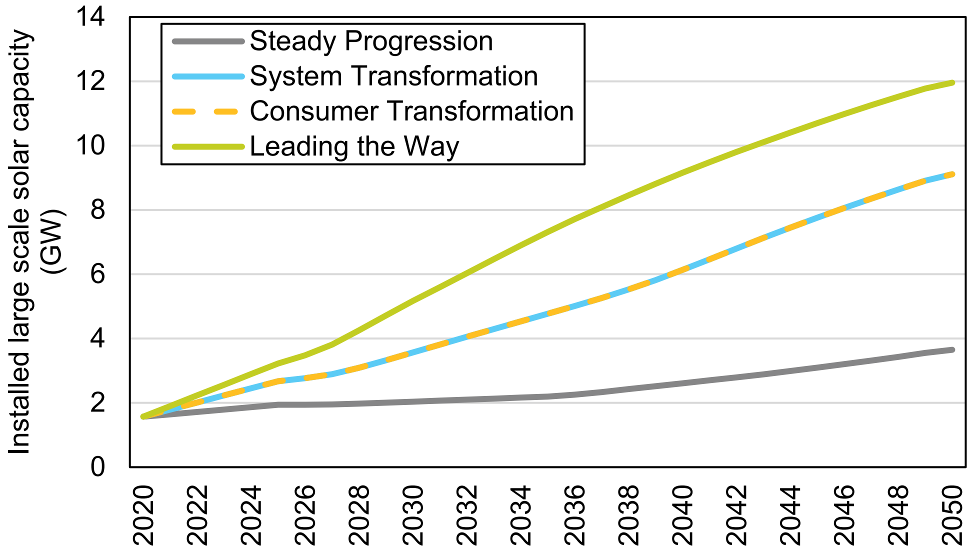


Figure 24: Installed capacity of large-scale solar PV in UK Power Networks' licence areas out to 2050.

Other renewable generation

Table 13 summarises the uptake of the renewable generation technologies across the four scenarios.

Distribution connected biomass generation (Figure 25) has been decreased in this year's DFES, reflecting 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. Our analysis has revealed that no existing biomass generator in the UKPN area is expected to be suitable.

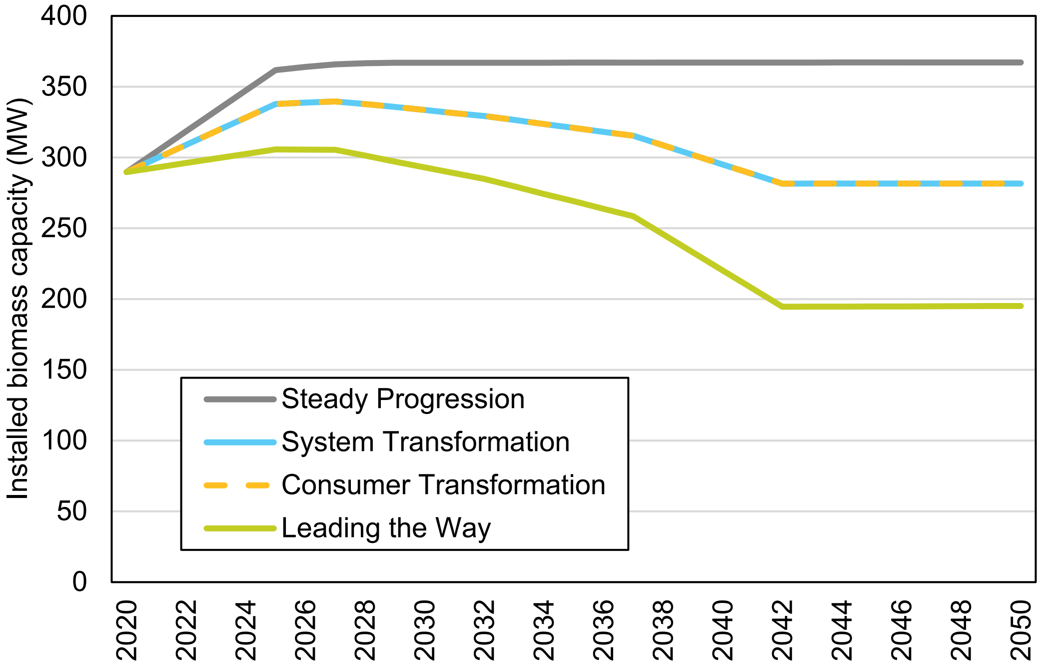


Figure 25: Biomass and energy crops (including CHP) distribution network connected generation capacity for the UKPN region

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 Steady Progression 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 13: Modelled outputs of renewable generation in 2050 by scenario world.

Technology	2050 Installed Capacity (MW)			
	Steady Progression	System Transformation	Consumer Transformation	Leading the Way
Onshore wind	935	935	3,143	2,105
Renewable engines (landfill-, sewage- and biogas)	379	610	818	818
Waste incineration (including CHP)	442	294	294	114
Biomass and energy crops (including CHP)	367	282	282	195
Hydrogen fuelled generation	0	1,782	891	891

Waste incineration

Our forecast for distribution connected generation from waste incineration (Figure 26) deviates from the NG FES for the Leading the Way scenario, and we do not incorporate an increase in waste incineration in line with National Grid's scenarios. The reason for deviating in Leading the Way is based on the 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 in the reduced uptake out to 2050.

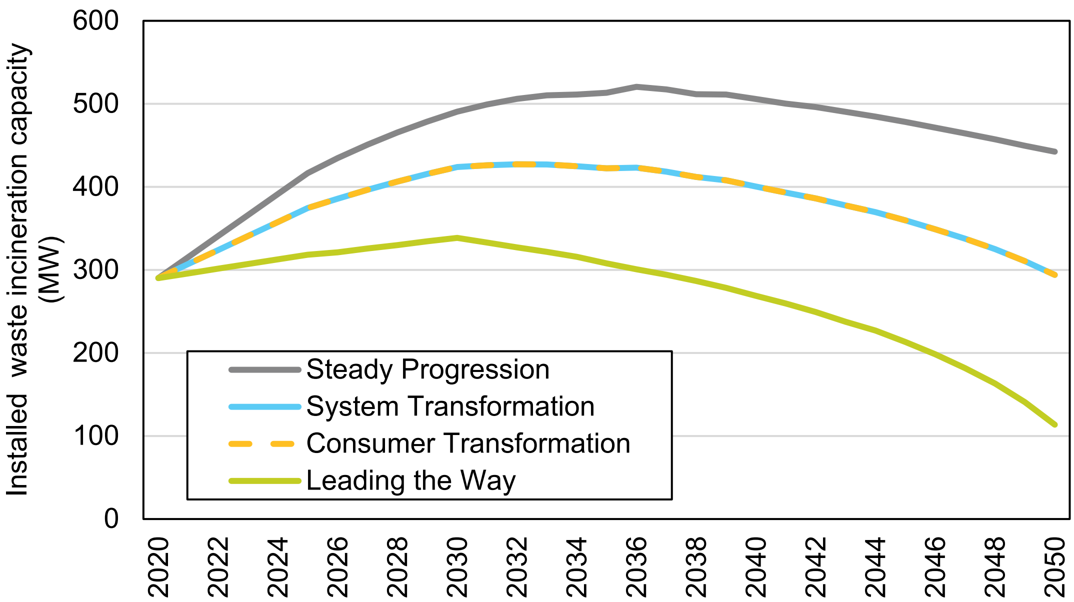


Figure 26: Waste incineration generation capacity for the UKPN region

3.4.2 Non-renewable generation

We model a range of distributed non-renewable generation technologies. In the three Net Zero scenarios, generation from non-renewable sources is phased out by 2035 (Table 14) by mapping them to the "low" uptake scenarios (Table 9). 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[38]. In contrast, National Grid's FES do not phase out unabated gas generation by 2035 in all Net-Zero pathways as this government policy was adopted after their publication; therefore, we have deviated from the NG FES mapping in this case to reflect the latest policy developments.

Table 14: Non-renewable electricity generation capacity in the UKPN region

Installed generation capacity (MW)	Steady Progression			Net Zero scenarios (ST, CT, LtW)		
	2020	2035	2050	2020	2035	2050
Non-renewable CHP	47	65	68	47	0	0
CCGTs and OCGTs	2,135	2,284	2,041	2,135	0	0
Non-renewable engines	208	446	364	208	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. This data allowed for more accurate classification of the installed fossil gas capacity, in particular as either large gas turbines, non-renewable CHP or non-renewable engines.

[38] 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 and lower battery prices.
- 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 15.

Table 15: Battery storage types modelled and their mapping to scenario worlds.

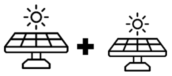
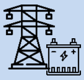
Scenario World	Steady Progression	System Transformation	Consumer Transformation	Leading the Way
Domestic battery storage	Low	Medium	High	High
I&C behind-the-meter battery storage	Low	Medium	High	Medium
Co-located battery storage	Low	Medium	Medium	High
Standalone grid-connected battery storage[39]	Progressive High	Medium	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 16 shows the different use cases, the relevant business case considered, and the modelling method used.

Table 16: 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** Maximise own use	Consumer choice modelling coupled with domestic solar PV uptake modelling
I&C battery storage	**Arbitrage and system balancing** Electricity price arbitrage, avoidance of network charges and provision of services to National Grid	Consumer choice modelling

[39] 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** 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** 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 27 shows the total battery storage capacity forecast in the UK Power Networks' region for all four scenario worlds in 2030 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 Steady Progression 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.

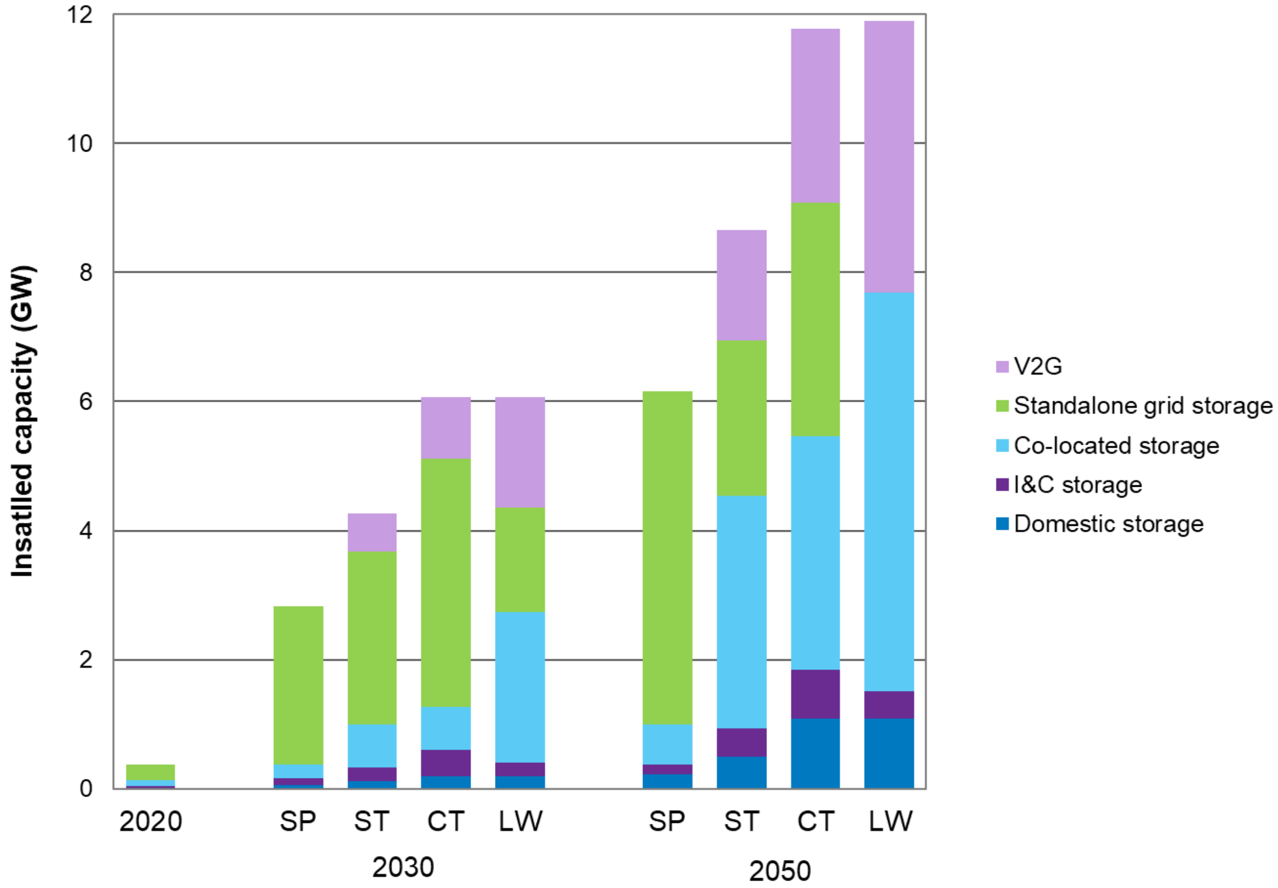


Figure 27: Distributed battery storage in UK Power Networks' region at baseline (2020), in 2030 and 2050.

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[40]. 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.

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

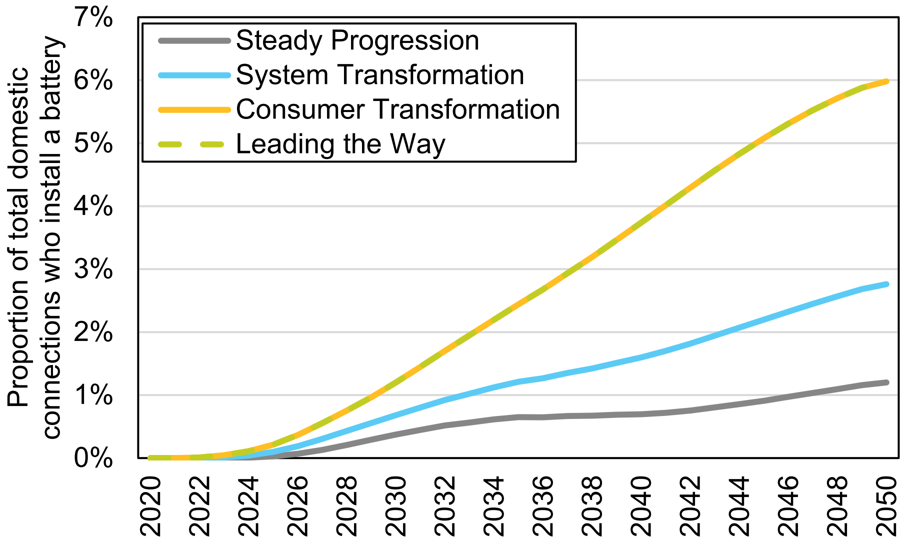


Figure 28: Proportion of all domestic customers who install a battery in UK Power Networks' region.

The results from our modelling (Figure 28) indicate that between 1% and 6% of all domestic customers (or between 41% and 49% 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 Steady Progression 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 for this year's update we have reviewed what revenues are available, as this is a rapidly changing space due to Ofgem's charging reforms[41] and new markets becoming accessible to smaller battery installations. These new options include the recent wider access to the Balancing Mechanism[42], which allows I&C customers to access high revenues from the scheme. Another update to the modelling this year was an overhaul of the assumed battery size for each I&C consumer archetype. We base the battery size on average modelled weekday peak demand and with this update, the average battery capacity for each customer is lower than what was modelled previously.

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

[41] Ofgem, *Electricity Network Access and Forward-Looking Charging Review: Open Letter on our shortlisted policy options,* March 2020.
[42] National Grid have recently made changes to the Balancing Mechanism, lowering the minimum threshold for participation, which allows for small and aggregated units to provide balancing services to the grid, see more here: https://www.nationalgrideso.com/industry-information/balancing-services/balancing-mechanism-wider-access

different revenues from these streams are available in each scenario. In Consumer Transformation, we assume that the current spike in electricity prices[43] 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 29). In Steady Progression, we assume that these revenues quickly drop after the electricity price spike in 2021, 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.

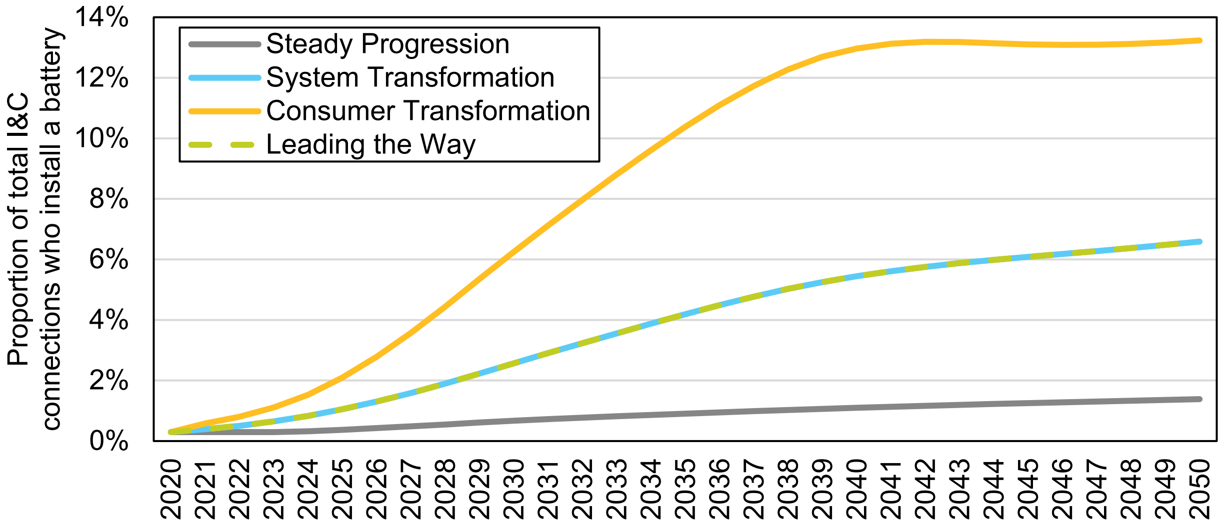


Figure 29: Proportion of all I&C customers who install a battery in UK Power Networks' licence areas.

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 last years' DFES. 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 30 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, lower forecasted battery prices than previously, 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 Steady Progression, the business case for co-located storage remains unfavourable and uptake remains low.

[43] https://www.theguardian.com/money/2021/oct/01/energy-price-cap-higher-gas-electricity-bills-fuel-suppliers

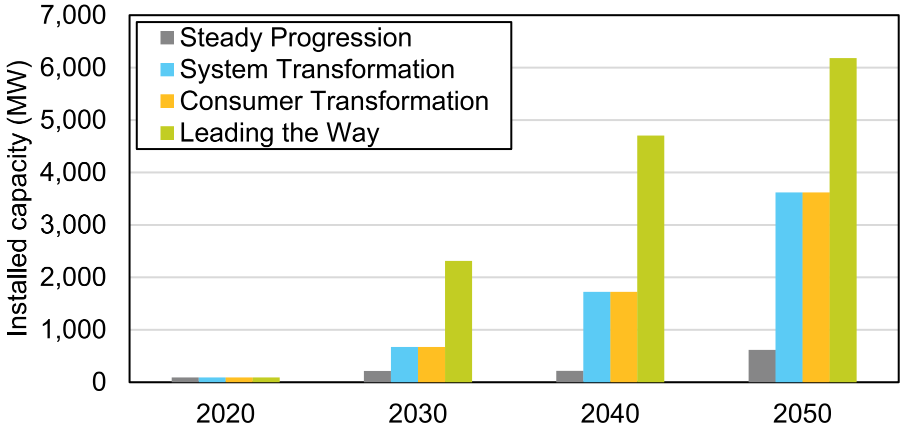


Figure 30: Capacity of battery storage co-located with solar generation in UK Power Networks' licence areas.

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[44]. 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.

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 Steady Progression low.

Figure 31 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. Steady Progression 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 Steady Progression, however, is not as pressing in the near term as in the Net Zero scenarios, due to the slower adoption of intermittent renewable generation.

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

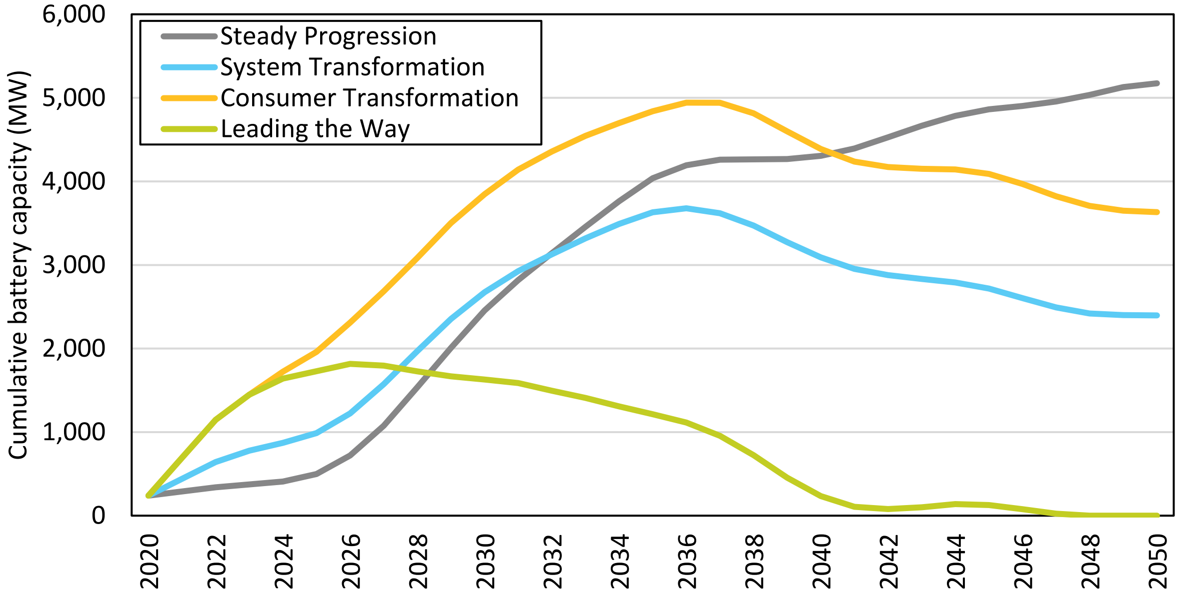


Figure 31: Capacity of grid-connected standalone batteries in UK Power Networks' region.

3.6 Flexibility

Key Messages

- Smart meter rollout is based on the latest government plans, published in June 2021.
- We model a faster rollout of smart charging due to new 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 17: Flexibility measures modelled and their mapping to scenario worlds.

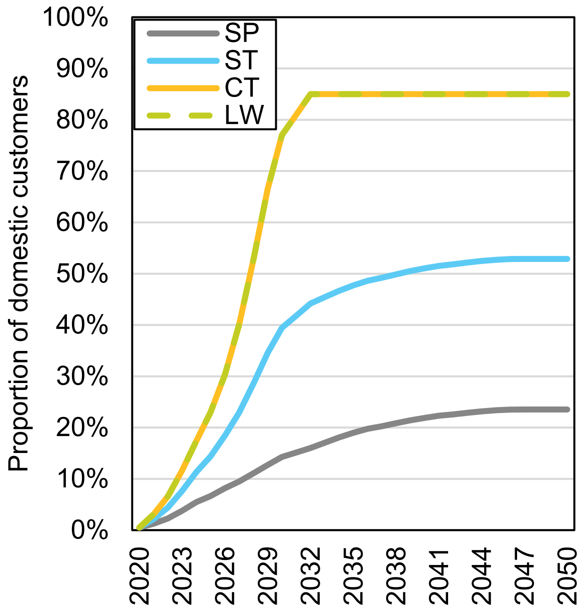
Scenario World	Steady Progression	System Transformation	Consumer Transformation	Leading the Way
Time-of-Use Tariff uptake	Low	Medium	High	High
Battery based flexibility	Low	Medium	High	High
EV smart charging	Low	Medium	High	High

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[45] as a high scenario. The approach for forecasting the low scenario is kept the same as last year, starting from the March 2021 values from BEIS on smart meter roll-out[46] 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 32, 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.

[45] BEIS, *Smart meter policy framework post 2020*, 2021
[46] BEIS, *Smart meters in Great Britain, quarterly update March 2021,* March 2021



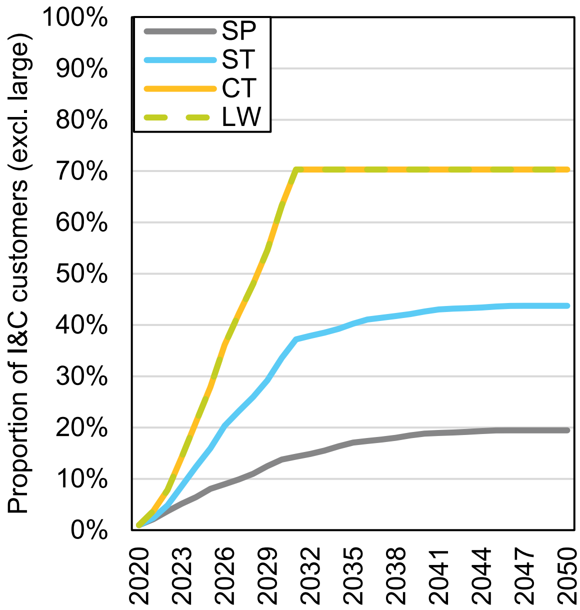


Figure 32: Uptake of Time-of-use tariffs (ToUT) in the domestic sector (left) and in small and medium I&C customers (right).

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[47].

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 last year's modelling[48].

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. A key update this year was a faster rollout of smart charging uptake due to proposed government legislation[49], mandating all new non-public charge points to be smart charging capable, with smart charging being the default option. We assume that all

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

new domestic chargers are smart from 2022 in Consumer Transformation and Leading the Way, and from 2024 in System Transformation. This has accelerated smart charging uptake for Consumer Transformation and Leading the Way compared to last year; 50% uptake of smart charging is now achieved in 2024 compared to 2027 in DFES20.

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[50], 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. In Steady Progression, we assume that the Government does not mandate the rollout of smart charging capable charge points and that the majority of charging sessions remain non-managed out to 2050 (Figure 33).

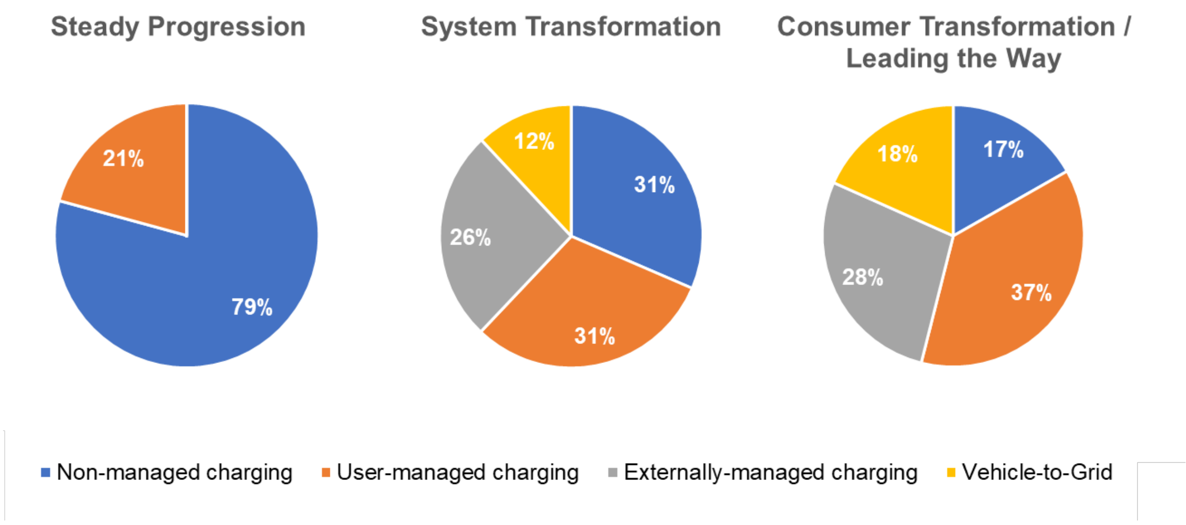


Figure 33: EV residential charging distribution in 2050.

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 Steady Progression

[50] 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[51] 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. Key developments since the publication of the previous DFES that were captured this year include a rapid drop in battery prices, limits in EV supply, and the Governments' ambition to phase out of fossil-fuel generation by 2035. Additional improvements made include a complete overhaul of the decarbonised heat modelling based on data from a new UK Power Networks Innovation project[52]. 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.

[51] National Grid ESO, *Future Energy Scenarios,* July 2021
[52] UK Power Networks Innovation, Heat Street, 2021, available from https://innovation.ukpowernetworks.co.uk/projects/heat-street-local-system-planning/

Appendix

A. Electric vehicle uptake – taxis and private hire vehicles

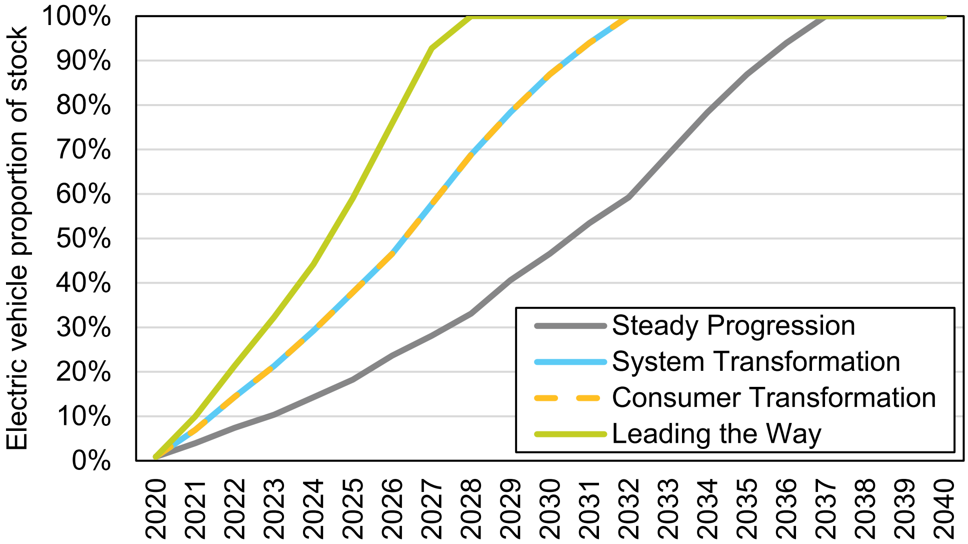


Figure 34: Uptake of electric taxis outside the extended GLA boundary between 2020 and 2040.

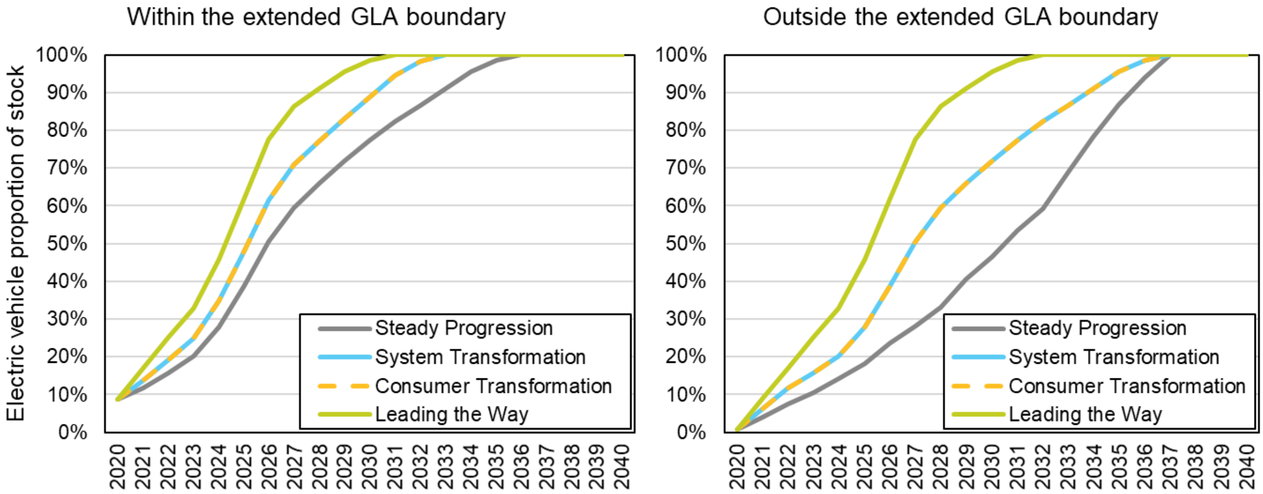


Figure 35: Uptake of electric private hire vehicles within the extended GLA boundary (left) and outside the boundary (right) between 2020 and 2040.

B. Heating technology breakdown in the I&C sector

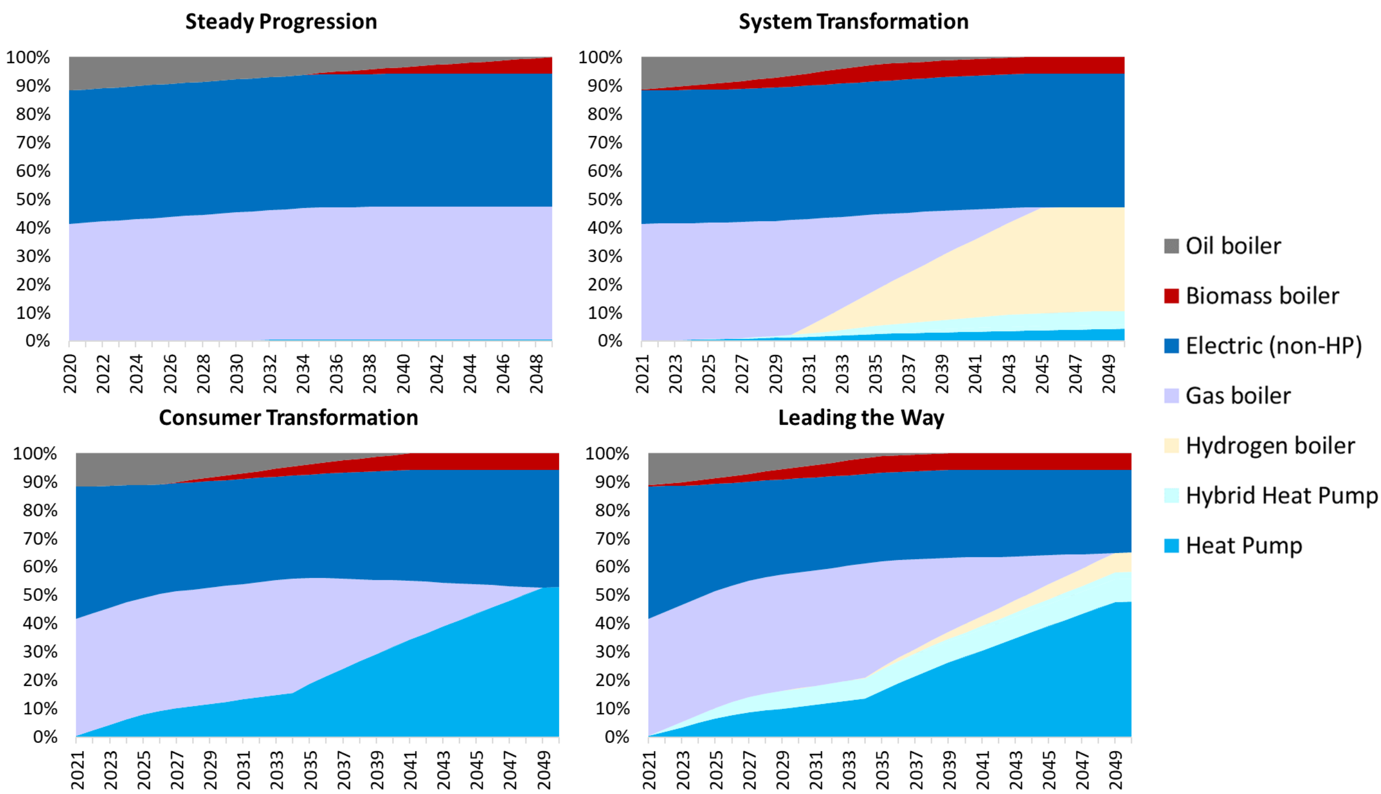


Figure 36: Heating technology breakdown for I&C properties not on district heating in UK Power Networks' licence areas.

C. Licence area Analysis

EPN, Steady Progression

Parameter **Low-carbon transport**	2020	2030	2050
Number of battery electric cars and vans	21,000	1,200,000	3,200,000
Number of plugin hybrid cars and vans	21,000	400,000	600,000
Number of electric cars and vans	42,000	1,600,000	3,800,000
Decarbonised heating			
Number of domestic heat pumps	22,000	34,000	61,000
Domestic district heat connections	20,000	56,000	120,000
Distributed generation			
Number of homes with solar PV	104,000	128,000	167,000
Small-scale solar PV capacity (MW)	450	640	1,040
Large-scale solar PV capacity (MW)	1,200	1,700	3,000
Onshore wind capacity (MW)	450	470	520
Biomass capacity (MW)	270	340	340
Hydrogen fuel cell capacity (MW)	-	-	-
Renewable engines (MW)	170	140	60
Non renewable CHP (MW)	20	30	30
Gas powered generators (MW)	1,500	1,400	1,100
Battery storage			
Domestic battery storage capacity (MW)	-	40	140
I&C battery storage capacity (MW)	20	30	40
Large battery storage capacity (MW)	240	1,900	4,100

EPN, System Transformation

Parameter Low-carbon transport	2020	2030	2040
Number of battery electric cars and vans	21,000	1,700,000	5,200,000
Number of plugin hybrid cars and vans	21,000	400,000	41,000
Number of electric cars and vans	42,000	2,100,000	5,200,000
Decarbonised heating			
Number of domestic heat pumps	22,000	165,000	717,000
Domestic district heat connections	20,000	91,000	219,000
Distributed generation			
Number of homes with solar PV	104,000	159,000	333,000
Small-scale solar PV capacity (MW)	450	830	1,860
Large-scale solar PV capacity (MW)	1,200	3,000	7,600
Onshore wind capacity (MW)	450	470	520
Biomass capacity (MW)	270	310	260
Hydrogen fuel cell capacity (MW)	-	30	1,250
Renewable engines (MW)	170	160	110
Non renewable CHP (MW)	20	20	-
Gas powered generators (MW)	1,500	1,400	-
Battery storage			
Domestic battery storage capacity (MW)	-	70	310
I&C battery storage capacity (MW)	20	90	200
Large battery storage capacity (MW)	240	2,300	4,300

EPN, Consumer Transformation

Parameter	2020	2030	2050
Low-carbon transport			
Number of battery electric cars and vans	21,000	1,700,000	5,200,000
Number of plugin hybrid cars and vans	21,000	400,000	41,000
Number of electric cars and vans	42,000	2,100,000	5,200,000
Decarbonised heating			
Number of domestic heat pumps	22,000	372,000	3,073,000
Domestic district heat connections	20,000	138,000	350,000
Distributed generation			
Number of homes with solar PV	104,000	237,000	678,000
Small-scale solar PV capacity (MW)	450	1,200	3,400
Large-scale solar PV capacity (MW)	1,200	3,000	7,600
Onshore wind capacity (MW)	450	620	1,730
Biomass capacity (MW)	270	310	260
Hydrogen fuel cell capacity (MW)	-	-	630
Renewable engines (MW)	170	180	150
Non renewable CHP (MW)	20	20	-
Gas powered generators (MW)	1,500	1,400	-
Battery storage			
Domestic battery storage capacity (MW)	-	120	650
I&C battery storage capacity (MW)	20	180	350
Large battery storage capacity (MW)	240	3,100	5,100

EPN, Leading the Way

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	21,000	1,700,000	4,600,000
Number of plugin hybrid cars and vans	21,000	400,000	38,000
Number of electric cars and vans	42,000	2,100,000	4,638,000
Decarbonised heating			
Number of domestic heat pumps	22,000	206,000	2,705,000
Domestic district heat connections	20,000	138,000	350,000
Distributed generation			
Number of homes with solar PV	104,000	237,000	678,000
Small-scale solar PV capacity (MW)	450	1,200	3,400
Large-scale solar PV capacity (MW)	1,200	4,400	9,900
Onshore wind capacity (MW)	450	550	1,160
Biomass capacity (MW)	270	270	180
Hydrogen fuel cell capacity (MW)	-	-	630
Renewable engines (MW)	170	180	150
Non renewable CHP (MW)	20	20	-
Gas powered generators (MW)	1,500	1,400	-
Battery storage			
Domestic battery storage capacity (MW)	-	120	650
I&C battery storage capacity (MW)	20	90	200
Large battery storage capacity (MW)	240	2,800	5,200

LPN, Steady Progression

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	16,000	400,000	1,100,000
Number of plugin hybrid cars and vans	20,000	200,000	200,000
Number of electric cars and vans	35,000	600,000	1,300,000
Decarbonised heating			
Number of domestic heat pumps	-	13,000	39,000
Domestic district heat connections	71,000	140,000	269,000
Distributed generation			
Number of homes with solar PV	9,000	11,000	17,000
Small-scale solar PV capacity (MW)	50	70	110
Large-scale solar PV capacity (MW)	10	10	10
Onshore wind capacity (MW)	-	-	-
Biomass capacity (MW)	-	-	-
Hydrogen fuel cell capacity (MW)	-	-	-
Renewable engines (MW)	210	260	260
Non renewable CHP (MW)	20	30	30
Gas powered generators (MW)	300	300	300
Battery storage			
Domestic battery storage capacity (MW)	-	4	14
I&C battery storage capacity (MW)	11	34	51
Large battery storage capacity (MW)	2	2	2

LPN, System Transformation

Parameter Low-carbon transport	2020	2030	2040
Number of battery electric cars and vans	16,000	600,000	1,800,000
Number of plugin hybrid cars and vans	20,000	200,000	14,000
Number of electric cars and vans	35,000	800,000	1,814,000
Decarbonised heating			
Number of domestic heat pumps	-	88,000	472,000
Domestic district heat connections	71,000	262,000	628,000
Distributed generation			
Number of homes with solar PV	9,000	14,000	36,000
Small-scale solar PV capacity (MW)	50	90	210
Large-scale solar PV capacity (MW)	10	10	10
Onshore wind capacity (MW)	1	1	1
Biomass capacity (MW)	1	2	2
Hydrogen fuel cell capacity (MW)	-	-	80
Renewable engines (MW)	210	360	380
Non renewable CHP (MW)	20	20	-
Gas powered generators (MW)	300	-	-
Battery storage			
Domestic battery storage capacity (MW)	-	7	34
I&C battery storage capacity (MW)	11	64	116
Large battery storage capacity (MW)	2	2	2

LPN, Consumer Transformation

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	16,000	600,000	1,800,000
Number of plugin hybrid cars and vans	20,000	200,000	14,000
Number of electric cars and vans	35,000	800,000	1,814,000
Decarbonised heating			
Number of domestic heat pumps	-	178,000	1,223,000
Domestic district heat connections	71,000	387,000	990,000
Distributed generation			
Number of homes with solar PV	9,000	23,000	86,000
Small-scale solar PV capacity (MW)	50	130	420
Large-scale solar PV capacity (MW)	10	10	10
Onshore wind capacity (MW)	1	1	1
Biomass capacity (MW)	1	2	2
Hydrogen fuel cell capacity (MW)	-	-	40
Renewable engines (MW)	210	450	500
Non renewable CHP (MW)	20	20	-
Gas powered generators (MW)	300	-	-
Battery storage			
Domestic battery storage capacity (MW)	-	13	84
I&C battery storage capacity (MW)	11	120	205
Large battery storage capacity (MW)	2	2	2

LPN, Leading the Way

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	16,000	600,000	1,600,000
Number of plugin hybrid cars and vans	20,000	100,000	13,000
Number of electric cars and vans	35,000	700,000	1,613,000
Decarbonised heating			
Number of domestic heat pumps	-	122,000	1,199,000
Domestic district heat connections	71,000	387,000	990,000
Distributed generation			
Number of homes with solar PV	9,000	23,000	86,000
Small-scale solar PV capacity (MW)	50	130	420
Large-scale solar PV capacity (MW)	10	10	10
Onshore wind capacity (MW)	1	1	1
Biomass capacity (MW)	1	2	1
Hydrogen fuel cell capacity (MW)	-	-	40
Renewable engines (MW)	210	450	500
Non renewable CHP (MW)	20	20	-
Gas powered generators (MW)	300	-	-
Battery storage			
Domestic battery storage capacity (MW)	-	13	84
I&C battery storage capacity (MW)	11	64	116
Large battery storage capacity (MW)	2	2	-

SPN, Steady Progression

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	15,000	800,000	2,100,000
Number of plugin hybrid cars and vans	14,000	200,000	400,000
Number of electric cars and vans	29,000	1,000,000	2,500,000
Decarbonised heating			
Number of domestic heat pumps	8,000	15,000	33,000
Domestic district heat connections	14,000	38,000	84,000
Distributed generation			
Number of homes with solar PV	46,000	58,000	84,000
Small-scale solar PV capacity (MW)	210	290	470
Large-scale solar PV capacity (MW)	300	400	600
Onshore wind capacity (MW)	370	380	420
Biomass capacity (MW)	20	30	30
Hydrogen fuel cell capacity (MW)	-	-	-
Renewable engines (MW)	210	170	60
Non renewable CHP (MW)	10	10	10
Gas powered generators (MW)	500	900	900
Battery storage			
Domestic battery storage capacity (MW)	-	20	70
I&C battery storage capacity (MW)	10	30	50
Large battery storage capacity (MW)	90	800	1,700

SPN, System Transformation

Parameter **Low-carbon transport**	2020	2030	2040
Number of battery electric cars and vans	15,000	1,100,000	3,400,000
Number of plugin hybrid cars and vans	14,000	200,000	26,000
Number of electric cars and vans	29,000	1,300,000	3,426,000
Decarbonised heating			
Number of domestic heat pumps	8,000	93,000	454,000
Domestic district heat connections	14,000	59,000	144,000
Distributed generation			
Number of homes with solar PV	46,000	74,000	170,000
Small-scale solar PV capacity (MW)	210	380	860
Large-scale solar PV capacity (MW)	300	500	1,500
Onshore wind capacity (MW)	370	380	420
Biomass capacity (MW)	20	20	20
Hydrogen fuel cell capacity (MW)	-	-	450
Renewable engines (MW)	210	200	120
Non renewable CHP (MW)	10	10	-
Gas powered generators (MW)	500	100	-
Battery storage			
Domestic battery storage capacity (MW)	-	30	160
I&C battery storage capacity (MW)	10	60	120
Large battery storage capacity (MW)	90	1,000	1,700

SPN, Consumer Transformation

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	15,000	1,100,000	3,400,000
Number of plugin hybrid cars and vans	14,000	200,000	26,000
Number of electric cars and vans	29,000	1,300,000	3,426,000
Decarbonised heating			
Number of domestic heat pumps	8,000	198,000	1,929,000
Domestic district heat connections	14,000	90,000	229,000
Distributed generation			
Number of homes with solar PV	46,000	113,000	361,000
Small-scale solar PV capacity (MW)	210	550	1,610
Large-scale solar PV capacity (MW)	300	500	1,500
Onshore wind capacity (MW)	370	500	1,410
Biomass capacity (MW)	20	20	20
Hydrogen fuel cell capacity (MW)	-	-	220
Renewable engines (MW)	210	220	170
Non renewable CHP (MW)	10	10	-
Gas powered generators (MW)	500	100	-
Battery storage			
Domestic battery storage capacity (MW)	-	60	350
I&C battery storage capacity (MW)	10	100	200
Large battery storage capacity (MW)	90	1,400	2,100

SPN, Leading the Way

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	15,000	1,100,000	2,900,000
Number of plugin hybrid cars and vans	14,000	200,000	24,000
Number of electric cars and vans	29,000	1,300,000	2,924,000
Decarbonised heating			
Number of domestic heat pumps	8,000	117,000	1,779,000
Domestic district heat connections	14,000	90,000	229,000
Distributed generation			
Number of homes with solar PV	46,000	113,000	361,000
Small-scale solar PV capacity (MW)	210	550	1,610
Large-scale solar PV capacity (MW)	300	700	2,000
Onshore wind capacity (MW)	370	440	950
Biomass capacity (MW)	20	20	20
Hydrogen fuel cell capacity (MW)	-	-	220
Renewable engines (MW)	210	220	170
Non renewable CHP (MW)	10	10	-
Gas powered generators (MW)	500	100	-
Battery storage			
Domestic battery storage capacity (MW)	-	60	350
I&C battery storage capacity (MW)	10	60	120
Large battery storage capacity (MW)	90	1,200	1,000

UKPN, Steady Progression

Parameter **Low-carbon transport**	**Latest DFES**	**Latest DFES**	**Latest DFES**
Number of battery electric cars and vans	51,000	2,400,000	6,400,000
Number of plugin hybrid cars and vans	55,000	800,000	1,200,000
Number of electric cars and vans	106,000	3,200,000	7,600,000
Decarbonised heating			
Number of heat pumps	31,000	62,000	133,000
Total district heat connections	104,000	234,000	473,000
Distributed generation			
Number of homes with solar PV	159,000	196,000	267,000
Small-scale solar PV capacity (MW)	700	1,000	1,620
Large-scale solar PV capacity (MW)	1,600	2,000	3,700
Onshore wind capacity (MW)	820	840	930
Biomass capacity (MW)	290	370	370
Hydrogen fuel cell capacity (MW)	-	-	-
Renewable engines (MW)	590	570	380
Non renewable CHP (MW)	50	70	70
Gas powered generators (MW)	2,200	2,500	2,300
Battery storage			
Domestic battery storage capacity (MW)	-	60	220
I&C battery storage capacity (MW)	40	90	140
Large battery storage capacity (MW)	330	2,700	5,800

UKPN, System Transformation

Parameter Low-carbon transport	2020	2030	2040
Number of battery electric cars and vans	51,000	3,400,000	10,400,000
Number of plugin hybrid cars and vans	55,000	800,000	100,000
Number of electric cars and vans	106,000	4,200,000	10,500,000
Decarbonised heating			
Number of heat pumps	31,000	347,000	1,644,000
Total district heat connections	104,000	413,000	990,000
Distributed generation			
Number of homes with solar PV	159,000	247,000	540,000
Small-scale solar PV capacity (MW)	700	1,300	2,930
Large-scale solar PV capacity (MW)	1,600	3,600	9,100
Onshore wind capacity (MW)	820	840	930
Biomass capacity (MW)	290	330	280
Hydrogen fuel cell capacity (MW)	-	40	1,780
Renewable engines (MW)	590	720	610
Non renewable CHP (MW)	50	50	-
Gas powered generators (MW)	2,200	1,500	-
Battery storage			
Domestic battery storage capacity (MW)	-	110	500
I&C battery storage capacity (MW)	40	220	430
Large battery storage capacity (MW)	330	3,300	6,000

UKPN, Consumer Transformation

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	51,000	3,400,000	10,400,000
Number of plugin hybrid cars and vans	55,000	800,000	100,000
Number of electric cars and vans	106,000	4,200,000	10,500,000
Decarbonised heating			
Number of heat pumps	31,000	748,000	6,225,000
Total district heat connections	104,000	615,000	1,569,000
Distributed generation			
Number of homes with solar PV	159,000	373,000	1,126,000
Small-scale solar PV capacity (MW)	700	1,890	5,430
Large-scale solar PV capacity (MW)	1,600	3,600	9,100
Onshore wind capacity (MW)	820	1,130	3,140
Biomass capacity (MW)	290	330	280
Hydrogen fuel cell capacity (MW)	-	-	890
Renewable engines (MW)	590	850	820
Non renewable CHP (MW)	50	50	-
Gas powered generators (MW)	2,200	1,500	-
Battery storage			
Domestic battery storage capacity (MW)	-	190	1,080
I&C battery storage capacity	40	410	750
Large battery storage capacity (MW)	330	4,500	7,300

UKPN, Leading the Way

Parameter Low-carbon transport	2020	2030	2050
Number of battery electric cars and vans	51,000	3,500,000	9,100,000
Number of plugin hybrid cars and vans	55,000	800,000	100,000
Number of electric cars and vans	106,000	4,300,000	9,200,000
Decarbonised heating			
Number of heat pumps	31,000	445,000	5,683,000
Total district heat connections	104,000	615,000	1,569,000
Distributed generation			
Number of homes with solar PV	159,000	373,000	1,126,000
Small-scale solar PV capacity (MW)	700	1,890	5,430
Large-scale solar PV capacity (MW)	1,600	5,200	12,000
Onshore wind capacity (MW)	820	1,000	2,110
Biomass capacity (MW)	290	290	190
Hydrogen fuel cell capacity (MW)	-	-	890
Renewable engines (MW)	590	850	820
Non renewable CHP (MW)	50	50	-
Gas powered generators (MW)	2,200	1,500	-
Battery storage			
Domestic battery storage capacity (MW)	-	190	1,080
I&C battery storage capacity	40	220	430
Large battery storage capacity (MW)	330	3,900	6,200