nationalgrid

Future Energy Scenarios

System Operator

JULY 2018

How to use this interactive document

To help you find the information you need quickly and easily we have published the *FES* as an interactive document.

Home
This will take you to the contents page. You can click on the titles to navigate to a section.

Arrows
Click on the arrows to move backwards or forwards a page.

A to Z
You will find a link to the glossary on each page.

Hyperlinks
Hyperlinks are underlined and highlighted in the chapter colour throughout the report. You can click on them to access further information.

Foreword

Welcome to our *Future Energy Scenarios*.
These scenarios, which stimulate debate and help inform the decisions that will shape our energy future, have never been more important – especially when you consider the extent to which the energy landscape is being transformed.

Factors include ambitious environmental policy and legislation, a dramatic growth in local generation, and the development of technologies that are allowing consumers to break away from the more traditional models of energy supply.

The pace of change was starkly highlighted this year when Britain had three consecutive days free of coal-fired power generation. And solar generation continues to set new records.

Against this backdrop, it's impossible to accurately forecast a single energy future over the long term. However, creating a range of credible futures allows us to continue supporting the development of an energy system that's robust against different outcomes.

And it's not just based on our own input – we've gathered the views of 430 organisations through meetings, workshops, webinars and our conference, so we could learn more about what our stakeholders thought the future of energy could look like.

Our new scenarios highlight some important themes and future developments. For example, gas will remain crucial for both heating and electricity generation in all scenarios for the coming decades. There will be a significant increase in electricity infrastructure, from new renewable generation to electric vehicle charging networks. And the decarbonisation of heating will be challenging, with multiple ways to achieve it – requiring both electricity and different types of gas.

We've refreshed our scenario framework to reflect the increasing importance of decentralisation and decarbonisation in our industry. We've also included, for the first time, the early results from our project to cost the scenarios. Our key messages highlight the insights from the scenarios and act as a call to action. They will help the industry to focus on how we could efficiently transition to a low carbon economy.

Another development is happening within our own business. National Grid's Electricity System Operator (ESO) will separate from our electricity transmission business in April 2019. Although the ESO will soon start to look and feel different, our *Future Energy Scenarios* will remain a whole system publication. It will also play an important role for the RIIO-2 process, providing valuable analysis and insight.

Of course, this publication is only the start of our work. Our expert analysts will be working on what the scenarios mean for network development, system operability and security of supply. Their findings will appear in our other System Operator publications.

Thank you for your valuable insight over the past year. Please continue to share your views with us. Details about how to contact us are on our website: fes.nationalgrid.com.

Fintan Slye
Director, UK System Operator

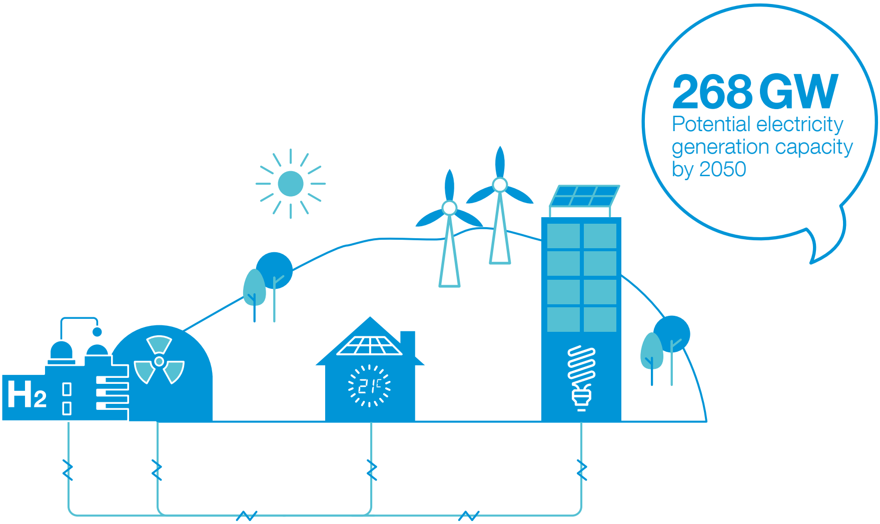
Key messages

We are entering a new world of energy. The expected growth of low carbon and decentralised generation means the electricity system will need to change.

- Capacity could increase from 103 GW today to between 189 GW and 268 GW by 2050, with the more decarbonised scenarios requiring the highest capacities. Up to 65 per cent of generation could be local by 2050.
- High levels of intermittent and inflexible generation will require high levels of new flexibility, and there may be some periods of oversupply. Interconnectors and electricity storage will play a key role in easing this.
- The changing generation mix also means new ways to maintain system balance will have to be found.

What this means

- The market will need to adapt to the changing plant mix. Key industry processes are likely to need reviewing, bringing with them opportunities for new services.
- Balancing security of supply, affordability and efficiency in a decarbonised world presents new challenges. We will work with industry, Ofgem and the Government to meet these challenges to deliver a reliable, efficient and operable low carbon system.



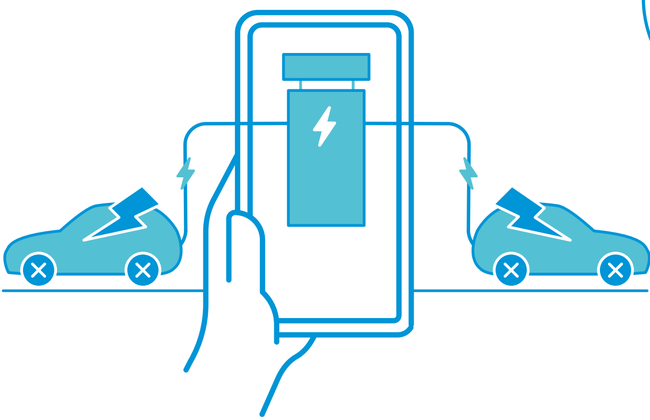
Electric vehicle growth goes hand-in-hand with electricity decarbonisation. Smart charging and vehicle-to-grid technology can actively support the decarbonisation of electricity.

- Electricity demand is expected to grow significantly by 2050, driven by increased electrification of transport and heating. There could be as many as 11 million electric vehicles (EVs) by 2030 and 36 million by 2040.
- Through smart charging technologies, consumers charging vehicles at off peak times and through vehicle-to-grid technology, the increase in electricity peak demand could be as little as 8GW in 2040.
- In turn, EVs can support the rollout of renewables by storing excess low carbon generation and by providing electricity back to the system when needed.

What this means

- Balancing demand and supply and power flows will become increasingly complex and need a coordinated approach across the whole industry.
- This presents opportunities for developers and suppliers, but data and information flows will become increasingly critical.

36m
Possible number of electric vehicles by 2040



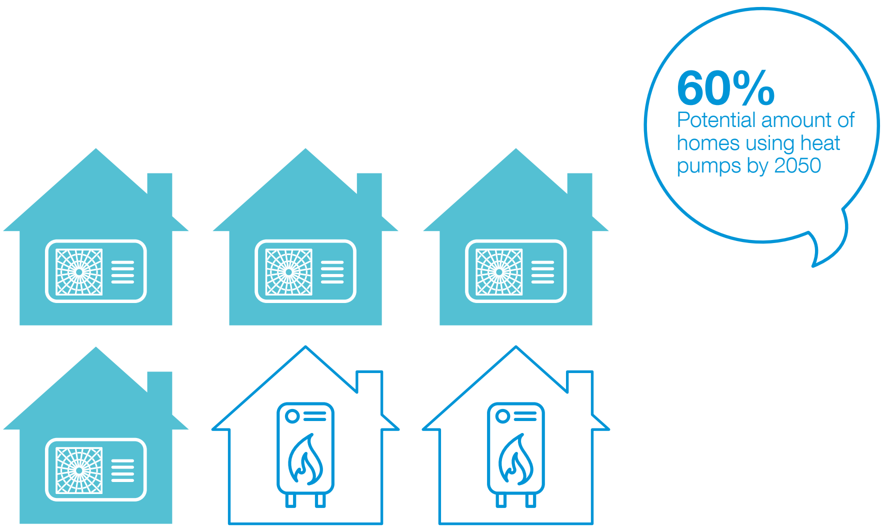
Key messages

Action on heat is essential and needs to gather pace in the 2020s to meet carbon reduction targets. A mix of low carbon heating solutions and better thermal efficiency of buildings is needed.

- We have identified different ways to achieve the decarbonisation of heating.
- Up to 60 per cent of homes could be using heat pumps by 2050. Green gas and smart technology for heating could help to suppress future electricity peak demand.
- Hydrogen could heat one third of homes by 2050. This would require coordinated action to develop city and regional hydrogen networks.
- Both options will also need other forms of heating such as low carbon district heating, hybrid heat pumps and micro combined heat and power.

What this means

- Decarbonising heat is crucial but needs to address significant technical and commercial challenges. A balance of technologies is needed to meet the heat challenge.
- Development of hydrogen and the rollout of heat pumps need to be driven by clear policy and supportive market arrangements.

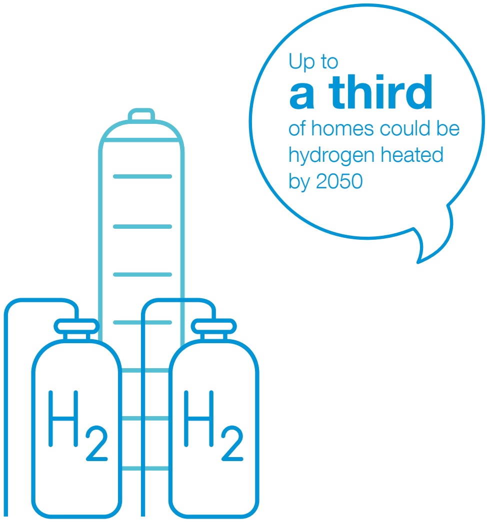


Gas will play a role in providing reliable, flexible energy supplies for the foreseeable future. New technologies and sources of low carbon gas can decarbonise the whole energy sector.

- Gas continues to provide more energy than electricity by 2050 in three of our four scenarios. It remains the dominant form of heating well into the 2030s. However, its usage patterns will change, providing flexibility for both heat and generation complementing renewables.
- Hydrogen could play a key part in a decarbonised energy world, either produced from natural gas alongside carbon capture utilisation and storage (CCUS) or by electrolysis using surplus renewable generation.

What this means

- Gas networks and markets will need to adapt to accommodate changing gas flows and reduced annual demand with more pronounced winter peaks.
- The development of hydrogen and CCUS needs innovation and demonstration projects to help overcome the technical, commercial and implementation challenges and to enable commercial rollout of CCUS and hydrogen in the 2030s.



Contents

Chapter one

Introduction

1.1 What is *FES*?

The three drivers of decarbonisation, decentralisation and digitalisation are transforming the energy landscape, alongside continuing technological advances and economic and political changes. Great Britain (GB) has the opportunity now to make sure it has the systems and capabilities in place to support the secure, sustainable and efficient delivery of energy in the decades to come.

We produce our *Future Energy Scenarios* (*FES*) each year to identify a range of credible scenarios for the next 30 years and beyond. These consider how much energy we might need and where it could come from. They look at what the changes might mean for the industry and for its customers.

All our scenarios consider energy demand and supply on a whole system basis, incorporating gas and electricity across the transmission and distribution networks.

To allow us to explore a full range of opportunities, we have not constrained levels of energy demand and supply because of any network capabilities or operability issues. These issues are explored in National Grid System Operator's network and operability documents. Our scenarios are also technology neutral and consider a range of potential options.

You have told us that you use *FES* in a variety of ways, including:

- as a foundation to build your own analysis and scenarios
- to inform investment decisions
- as a market view
- as a reference point
- as academic material.

For us, *FES* is the starting point for our regulated long-term investment and operability planning, as well as a reference for other reports we produce. You can see how these documents link together in figure 1.1.

Figure 1.1
System Operator publications

Network Options Assessment
January 2018

The options available to meet reinforcement requirements on the electricity system.

Winter Outlook Report
October 2018

Our view of the gas and electricity systems for the winter ahead.

Summer Outlook Report
April 2018

Our view of the gas and electricity systems for the summer ahead.

Electricity Ten Year Statement
November 2018

The likely future transmission requirements on the electricity system.

System Needs and Product Strategy
April 2018

Our view of future electricity system needs and potential improvements to balancing services markets.

Gas Ten Year Statement
November 2018

How we will plan and operate the gas network, with a ten-year view.

Winter Review and Consultation
June 2018

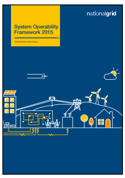
A review of last winter's forecasts versus actuals and an opportunity to share your views on the winter ahead.

Gas Future Operability Planning
November/December

How the changing energy landscape will impact the operability of the gas system.

Future Energy Scenarios
July 2018

A range of plausible and credible pathways for the future of energy from today out to 2050.



System Operability Framework

How the changing energy landscape will impact the operability of the electricity system.

Introduction

1.2 How we develop our scenarios

FES is the product of in-depth analysis by our team of experienced analysts. Stakeholder feedback is fundamental to the development of these scenarios. Combining the expertise of industry specialists with our own insights gives us the depth of knowledge we need to produce credible pathways for the future of energy.

Each year we rigorously review and develop our scenarios to make sure they reflect the changing energy landscape. This year, we have made some significant changes to our scenario framework, which includes our detailed assumptions. You can find out more about these in chapter two.

Creating our scenarios is a continuous process and incorporates several stages, including stakeholder engagement, data and intelligence gathering. This is followed by high level scenario creation and detailed modelling and analysis. At each stage, we apply our expertise and judgement to make sure we create scenarios that are relevant and credible.

Evidence gathered from our stakeholders is an essential part of the development of *FES*. This feedback is one of a number of inputs that inform our analysis, making sure our scenarios are independent, well informed and up-to-date.

We continually review our stakeholder base, to make sure we capture the depth and breadth of relevant knowledge from across the industry. During 2017, we engaged with 430 organisations from the UK and Europe; this is a 10 per cent increase from 2016.

We evaluate our modelling methods and data sources each year to make improvements to our processes. This year, we have used new and enhanced models and expanded our analysis to cover a wider range of factors.

For example, we have considered the production and use of greater volumes of hydrogen in two of our scenarios. For our carbon emissions analysis, a new model has provided us with more robust and higher quality data. We also used new models for our transport analysis, which covered total ownership of all road vehicles. For interconnector modelling, we extended our GB assumptions to include wider European scenarios. You can find out more about this in our *Modelling Methods* document. We are also exploring costing of the scenarios to develop further insight and richness from our analysis.

Our *Stakeholder Feedback* document provides further information about the *Scenario Framework* and our engagement. You can find it on our feedback section on the *FES* website: *fes.nationalgrid.com*.

1.3 How to use the *FES* document suite

This main publication gives an overview of our work in key areas. It is just one of a suite of documents we produce as part of the *FES* process.

To support this, we also publish:

- *FES in 5*, a summary document with key headlines and statistics from *FES*.
- *Scenario Framework* document which details all the assumptions used as inputs into our models.
- *Data Workbook* which contains the outputs from the numerous models, including detailed tables, graphs and charts, beyond those included in the main document.
- *Modelling Methods* document which contains information on our modelling methodology and assumptions.
- *Frequently Asked Questions (FAQs)* document.

For more information and to view each of these documents visit: *fes.nationalgrid.com*. If you'd like to get in touch, our contact details can be found on the last page of this document.

Figure 1.2
Future Energy Scenarios document suite


H2

Chapter two

The scenarios

2.1 A new scenario framework

Following extensive analysis and consultation, we have created a new framework for our scenarios this year. The scenarios are aligned to two new axes: ‘speed of decarbonisation’ and ‘level of decentralisation’. We now have two scenarios that meet the 2050 carbon reduction target: Two Degrees, based on centralised and transmission connected technology; and Community Renewables, based on more decentralised technology.

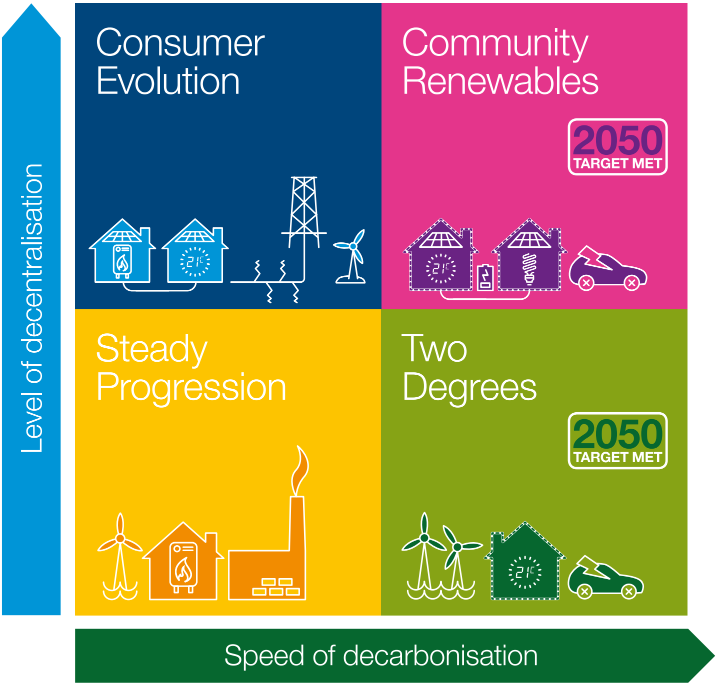
For several years we have based our scenarios around the axes of prosperity and level of green ambition. We feel these have served us well. However, following feedback from our stakeholders, we felt that changing conditions in the energy market meant that a new framework would provide greater insight.

The relationship between green ambition and prosperity has changed; for example, the cost of some renewable technology is reducing significantly. We also felt that it was important to focus more on scenarios that consider decentralisation to understand the greater use of local generation. Finally, we discussed how many scenarios should meet the UK’s 2050 carbon reduction target. The consensus was that having more than one scenario meet the target would allow us to explore a greater range of pathways that achieve this goal.

The Climate Change Act 2008 legally binds the UK to reduce greenhouse gas emissions by at least 80 per cent from 1990 levels by 2050. This is the UK’s contribution to the Paris Agreement, seeking to hold the increase in global temperatures to less than 2°C above pre-industrial levels.

As a result of our analysis, and following discussions with our stakeholders, we have developed four scenarios based on speed of decarbonisation and level of decentralisation. The scenarios and the axes are shown in figure 2.1. You can find more detail on how we developed the scenarios in this year’s *Stakeholder Feedback* document.

Figure 2.1
Scenario matrix for 2018



The speed of decarbonisation axis is driven by policy, economics and consumer attitudes. All scenarios show progress towards decarbonisation from today, with the two scenarios on the right meeting the 2050 target. We refer to these two as the '2050 compliant' scenarios throughout this year's *FES*.

The level of decentralisation axis indicates how close the production and management of energy is to the end consumer, moving up the axis from large scale central, to smaller scale local solutions. All scenarios show an increase in decentralised production of energy, compared with today.

The two new axes are a significant development since FES 2017, so we have devoted chapter three to discussing the concepts in more detail.

The scenarios

2.2 The scenarios in detail

In this section, we give an overview of each of the scenarios, focusing on developments in electricity demand, transport, heat, electricity supply and gas supply. We also explain how the new scenarios relate to *FES 2017*. There are similarities across the scenarios and so some of the commentary may seem repetitive. For example, there is little difference between the number of electric vehicles (EVs) in **Community Renewables** and **Two Degrees**.

Community Renewables

In this scenario, we explore how the 2050 decarbonisation target can be achieved through a more decentralised energy landscape.

Electricity demand: With the drive towards decarbonisation, together with the high use of EVs and use of heat pumps, smart technology is used extensively to manage peak electricity demand. Appliance efficiency improves to meet EU targets and we see greater use of demand side actions.

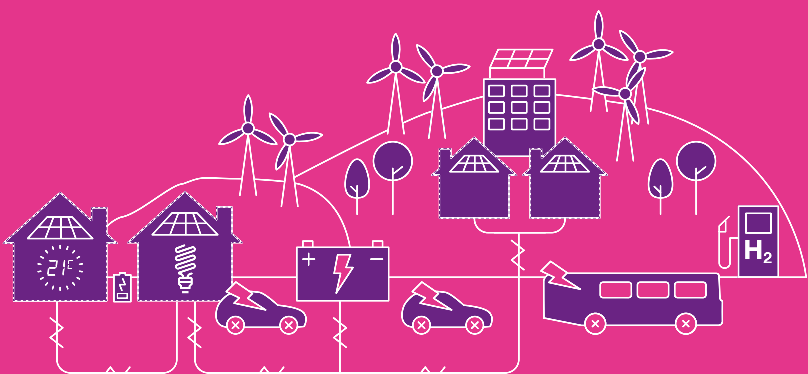
Transport: The Government's aspiration to end sales of conventional petrol and diesel powered cars and vans by 2040 is met. EVs become the most popular personal mode of transport. Natural gas is used in heavy goods vehicles but, by 2050, hydrogen becomes the fuel of choice in this sector to aid the decarbonisation target.

Heat: Homes become more thermally efficient, and heat pumps are the dominant technology. Green gas and increased use of district heating also have a role.

Electricity supply: Onshore wind and solar, co-located with storage, dominate the picture. This achieves the 2050 target without carbon capture utilisation and storage (CCUS). Flexibility is provided by small scale storage, small gas-fired plant, some interconnection, and hydrogen production by electrolysis.

Gas supply: Gas from the UK Continental Shelf (UKCS), Norway and liquefied natural gas (LNG) remain important in the short and medium term. However, in this scenario, where the 2050 target is met without CCUS, there is significant development of green gas. In **Community Renewables**, hydrogen is only produced by electrolysis.

Community Renewables builds on the consumer renewables sensitivity from *FES 2017*.



The scenarios

Two Degrees

In this scenario, we explore how the decarbonisation target can be achieved using larger and more centralised technologies.

Electricity demand: The use of hydrogen for heating helps reduce electricity demand, despite the widespread use of EVs. Smart technology is extensively used, alongside greater demand side actions to manage peak electricity demand. Appliances are more energy efficient to meet EU targets.

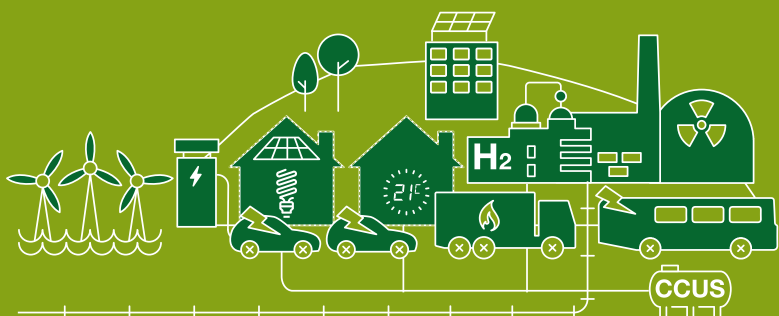
Transport: The Government's 2040 transport aspiration is met. EVs become the most popular choice for personal transport. Increased use of public transport features in this scenario. For commercial vehicles, use of natural gas, and then hydrogen, become more widespread.

Heat: As with **Community Renewables**, homes become more thermally efficient as there is a drive towards decarbonisation. By 2050 the dominant heat source is hydrogen, supported by a mixture of gas boilers, district heating and heat pumps.

Electricity supply: Generation, such as offshore wind and nuclear, is based more on the transmission network. Flexibility is provided by interconnectors, larger scale storage and later, some large scale gas-fired plants fitted with CCUS technology.

Gas supply: Gas from the UKCS, Norway and LNG remains important and we explore the use of steam methane reforming to produce hydrogen. Some green gas is available.

This scenario builds on Two Degrees from *FES 2017*, combined with hydrogen heating from the decarbonised gas sensitivity.



Steady Progression

This scenario is more centralised and makes progress towards, but does not meet, the 2050 decarbonisation target.

Electricity demand: With a slower drive to decarbonisation, there are slower improvements in appliance efficiency and little electrification of heat. However, there is significant use of EVs, so smart technology is important for managing peak demand.

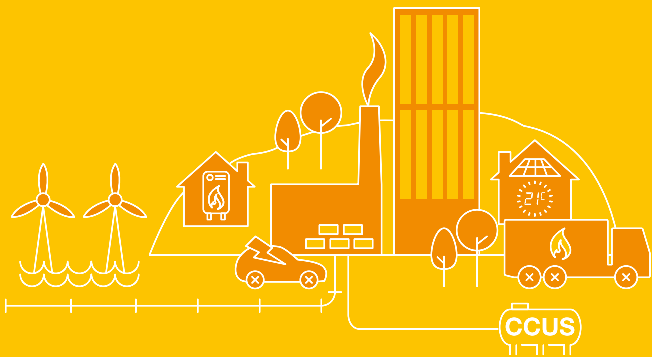
Transport: The Government's aspiration for transport in 2040 is not met, though EVs are still the dominant choice for personal transport by 2050. There is also more of a role for natural gas-powered vehicles, particularly in the commercial sector.

Heat: Most residential properties rely on gas boilers. There is limited use of heat pumps and smaller improvements in the thermal efficiency of houses. Decarbonisation of the heating sector is slow.

Electricity supply: There is greater emphasis on large scale, rather than local, generation. There is development of nuclear power and offshore wind. Gas plays an important role in providing flexibility and gas-fired generation fitted with CCUS develops through the 2040s.

Gas supply: Gas comes from the UKCS, Continental Europe, Norway and LNG, with additional supplies from shale gas.

This scenario combines elements from Steady State and Slow Progression from *FES 2017*.



Chapter two

The scenarios

Consumer Evolution

This is a more decentralised scenario which makes progress towards the decarbonisation target but fails to achieve the 80 per cent reduction by 2050.

Electricity demand: There is a moderate rollout of smart charging of EVs. There are some improvements in energy efficiency with homes, businesses and communities focused and incentivised towards local generation, notably roof top solar, and local energy management.

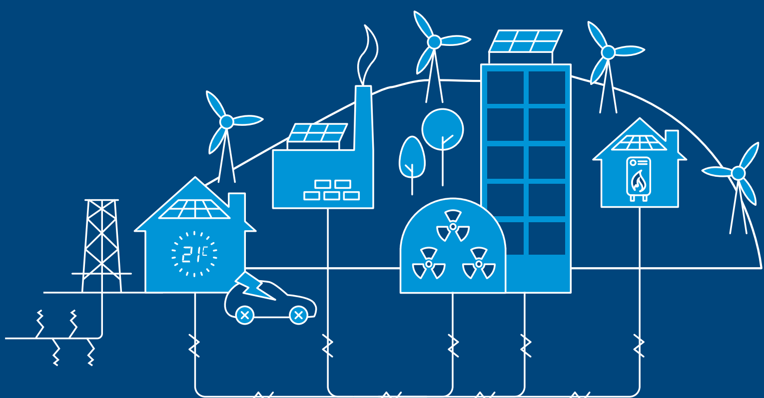
Transport: Private ownership of personal vehicles remains popular. The Government's aspiration for transport in 2040 is not met, though EVs are still the dominant choice for personal transport by 2050. There is a greater role for natural gas-powered vehicles, particularly in the commercial sector.

Heat: Limited progress is made towards decarbonising heat. There are only small improvements in thermal efficiency. There is some progress in the rollout of heat pumps, but current heating technologies remain dominant.

Electricity supply: Generation is focused on smaller scale renewables, with gas and batteries providing most of the system flexibility. Some new large scale nuclear power stations are built but there are also a number of small modular reactors. Greater emphasis on domestic and national energy solutions leads to lower levels of electricity interconnection.

Gas supply: Gas from the UKCS, Continental Europe, Norway and LNG remains important in this scenario. However, by 2050, shale gas is the largest source of supply.

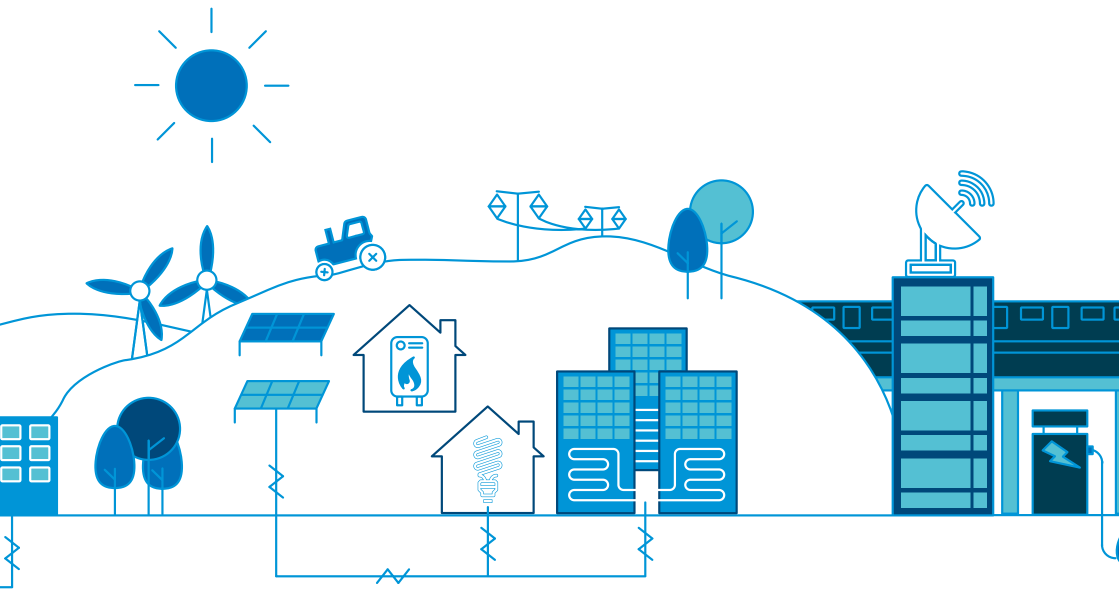
This scenario builds on a blend of Consumer Power and Slow Progression from *FES 2017*.



2.3 Sensitivities and spotlights

In some areas we want to expand our analysis, to examine uncertainties or consider more extreme cases, without creating a whole new scenario. These extensions to our core analysis are included as sensitivities in *FES 2018*. Unlike last year, we have embedded them in the main narrative, rather than giving them a chapter of their own.

We have provided further explanation of some technologies or concepts used in the scenarios. We call these spotlights.



Chapter three

Spotlights

Carbon intensity Pg 30

Power flows Pg 40

Decarbonisation and decentralisation

3.1 Speed of decarbonisation

The speed of decarbonisation is a key feature of our *FES 2018* scenarios, with two scenarios now meeting the 2050 carbon reduction target via distinct pathways. In each scenario, different elements influence the pace and scale of carbon reduction. In this section, we examine the key assumptions underlying our two 2050 compliant scenarios, and consider the important milestones in each journey to decarbonisation.

Environmental legislation has been an important driver in reducing the UK's carbon emissions. The UK is currently committed to a number of environmental targets. A key focus for our *FES 2018* scenarios is the Climate Change Act 2008. This is the UK contribution to the Paris Agreement that seeks to hold the increase in global temperatures to less than 2˚C above pre-industrial levels.

The Climate Change Act legally binds the UK to reduce carbon emissions by at least 80 per cent from 1990 levels by 2050, (the '2050 carbon reduction target') via a series of carbon budgets. This is underpinned by further legislation and policy measures. Many of these have been consolidated in the UK Clean Growth Strategy.

The European Union's 2030 Climate and Energy Framework also includes a number of decarbonisation targets for 2030, namely:

- at least a 40 per cent reduction in greenhouse gas emissions (from 1990 levels)
- renewable energy to make up at least 27 per cent of energy consumption in the EU
- energy efficiency – reducing energy use by at least 27 per cent (when compared to the projected use of energy in 2030).

The EU 2030 targets will continue to be binding on all EU member states. Although the UK's future relationship with the EU is yet to be determined in this area, the UK's current energy and climate policy is in line with the EU's 2030 targets, and in some cases is more ambitious. The targets therefore provide a useful benchmark for decarbonisation progress in each of our scenarios. For example, in **Two Degrees** and **Community Renewables**, we assume that the Government makes further ambitious advances in energy efficiency policy. As a result, there is an improvement in energy efficiency at least equivalent to the EU 2030 efficiency target.

UK and European policies have also addressed concerns about other greenhouse gases that contribute to climate change, as well as air pollution issues. We have seen measures such as the Medium Combustion Plant Directive (MCPD), which we discuss on page 111, and the UK Government's aspiration to ban the sale of conventional diesel and petrol cars and vans by 2040.

The graphics in this section illustrate how decarbonisation is achieved over time for both 2050 compliant scenarios, across the sectors of power, heat and transport. The amount of carbon emitted per kilowatt hour of electricity produced in Great Britain (GB) has decreased by almost 50 per cent between 2013 and 2017. This is mainly due to coal-fired plants running much less and more electricity being provided from low carbon sources such as wind and solar.

For electrification to be a way to decarbonise other sectors, it's essential that the carbon intensity of electricity generation continues to reduce before other sectors increase their reliance on electricity. Otherwise energy consumers are simply moving from one carbon intensive source of energy to carbon intensive electricity.

In all scenarios we anticipate that carbon emissions from transport will reduce. This is due to the falling cost of ownership for electric vehicles (EVs) and the clear policy direction set by the UK Government. However, in the slower decarbonising scenarios, the Government's aspiration to ban the sale of conventional diesel and petrol cars and vans by 2040 is not achieved. The growth in EVs takes place more slowly than in the faster decarbonising scenarios.

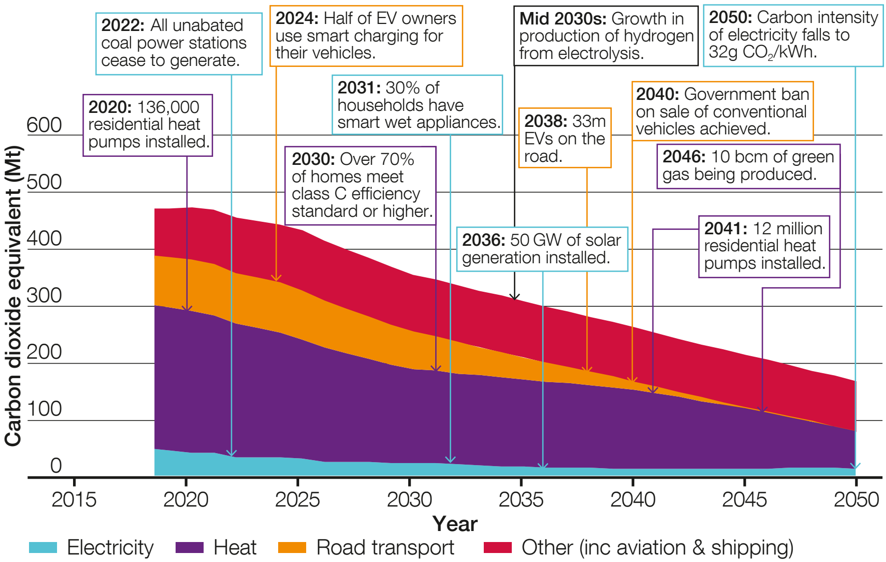
Heat is the slowest and most challenging sector to decarbonise. Firstly, the lead times for changing heating options are lengthy. For example, consumers may change their car every 3 to 5 years, but are unlikely to change their boiler more than once in a 10 to 15 year period. Many boiler replacements take place following a breakdown as a distressed purchase, so there is less opportunity to consider changing heat sources. Similarly, in the industrial sector there may be few opportunities to replace assets between now and 2050.

All of the current options to decarbonise heat at scale involve some level of consumer disruption, additional cost and a level of change to the UK's energy infrastructure. As a result, any move towards decarbonising heat will require clear policy direction, coordination and resource. The different challenges and opportunities may also mean that different solutions are better suited to various places across GB, in contrast to the dominance of gas boilers across the country today.

To reflect this, our 2050 compliant scenarios explore different heat decarbonisation options. These include electric heat pumps, hydrogen heating and district heating schemes. The figures illustrate the important milestones for each of these scenarios.

Decarbonisation and decentralisation

Figure 3.1
Decarbonisation in ***Community Renewables***



The figure above illustrates some key milestones in the journey to decarbonisation in **Community Renewables**. In the 2020s, electricity decarbonises rapidly as both wind and solar generation grow quickly. All unabated coal generation (where the plant is not fitted with technology to capture carbon emissions) closes by 2022, the earliest of all our scenarios. However, the early decarbonisation of electricity is not quite as rapid as in **Two Degrees**, as there is a slower rollout of nuclear and more use of unabated gas.

The **Community Renewables** world has the most consumers who avoid peak time energy use. As discussed on page 69, these consumers flex the time they use energy by using smart appliances, incentivised by time of use tariffs. In **Community Renewables**, there is a high and rapid take-up of smart charging technology for EVs. By the early 2030s, a third of households own a smart wet appliance like a washing machine.

At the same time, government policy drives improvements in energy efficiency and over 70 per cent of GB homes reach class C efficiency or greater, as in **Two Degrees**.

The rollout of residential heat pumps also gathers momentum in the 2020s. However, there are challenges in the widespread rollout of heat pumps. These include the fitting of heat pumps in properties, for example they require a certain amount of space and level of insulation. A further challenge is the upgrade necessary for electricity networks to accommodate increased demand, particularly at peak.

In the **Community Renewables** scenario, natural gas and green gas play an important role in minimising electricity peak demand. For example, the use of hybrid heat pumps means that these appliances can switch to gas at times of high demand. You can find out more about this technology on page 70. Without this, extra electricity generation and networks would be needed to meet peak demand from heat pumps. This would be very expensive to meet relatively short duration peaks.

From the early 2030s, hydrogen production from electrolysis starts to grow. The hydrogen is used in transport, predominantly in commercial vehicles. This is supported by increasing periods of time with excess inflexible or intermittent electricity output. This is described in more detail in chapter five, and in our hydrogen spotlight on page 89. Broadly speaking, the number of hydrogen fuelled vehicles grows at the same pace as in **Two Degrees**.

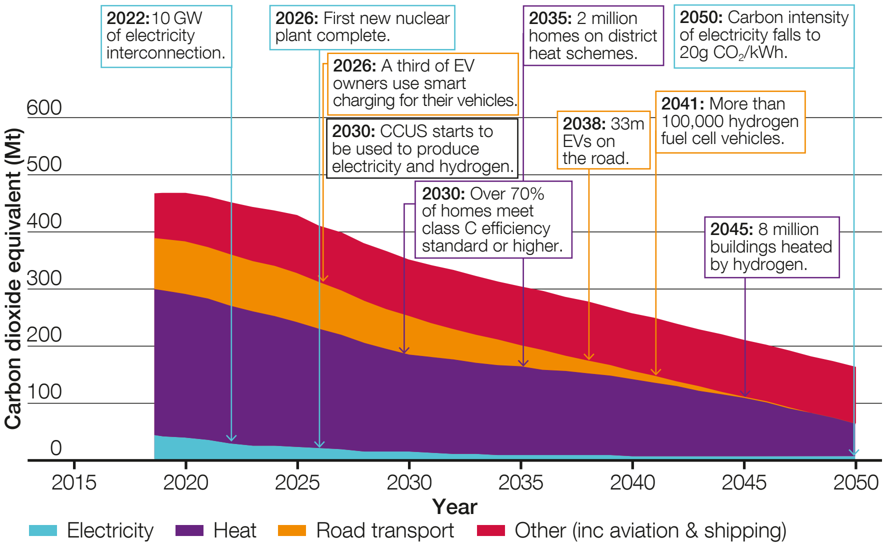
At the same time, both the number of EVs and renewable generation capacity continues to grow, with further flexibility provided by continued growth in electricity storage. The carbon emissions from both electricity and transport continue to fall over this decade. The Government's aspiration to ban the sale of conventional petrol and diesel cars and vans by 2040 is achieved. There is also increasing injection of green gas into the gas grid, meaning that the carbon footprint of remaining gas and hybrid appliances is lower than before. By 2050, carbon dioxide emissions from heat have reduced significantly. Transport is almost completely decarbonised and carbon emissions from electricity form only a small proportion of GB carbon emissions[1].

[1] Other emissions, including aviation and shipping, are slightly lower by 2050 in **Community Renewables** than **Two Degrees**. This is because there is greater development and use of biofuels in these sectors. However, this is not a main focus of our *FES* modelling.

Chapter three

Decarbonisation and decentralisation

Figure 3.2
*Decarbonisation in **Two Degrees***



In **Two Degrees**, electricity generation from coal ends in the early 2020s, new nuclear stations are being built and renewable generation is growing quickly. Consequently, the carbon intensity of electricity falls to less than 50 g CO_2/kWh by 2030. At the same time, new interconnector projects are developed. For the purposes of carbon accounting, imported electricity is counted as zero carbon from a GB perspective (see page 33).

By the end of the 2020s there are 10 million EVs on the road, with a strong take-up of smart charging. The cost of owning an EV has fallen to the point that they are now cheaper than conventional vehicles. There is widespread EV charging infrastructure. The emissions from transport reduce rapidly in the 2020s as EVs, powered by low carbon electricity, replace conventional vehicles.

The development of carbon capture utilisation and storage (CCUS) and hydrogen heating will need much work in the 2020s. For example, National Grid's *Future of Gas* report published in March 2018 illustrates how a number of actions must take place years earlier to support large scale low carbon hydrogen production. These include both infrastructure decisions and CCUS research and development.

In **Two Degrees**, as in **Community Renewables**, we also assume that ambitious government policy in the 2020s leads to improvements in energy efficiency at least equivalent to the EU 2030 target. Over 70 per cent of GB homes reach class C efficiency or greater.

Through action in the 2020s, we start to see more progress in the decarbonisation of heat from the early 2030s onwards. Buildings begin to connect to regional hydrogen networks instead of natural gas, and district heat schemes continue to be developed. By 2040, a regional programme of gas to hydrogen conversion is well underway, and there is also some take-up of electric heat pumps.

Although the number of new EVs continues to grow over this time, the reduction in carbon emissions is lower as some of the EVs are replacing other older EVs rather than much more polluting conventional vehicles. By 2040, the UK Government's aspiration to ban the sale of new conventional petrol and diesel cars and vans is achieved. At the same time, hydrogen use in commercial vehicles grows.

By 2050, there is significant decarbonisation across all sectors. Electricity generation has been almost completely decarbonised through renewable generation, interconnection, nuclear and gas-fired generation fitted with CCUS. In transport, 0.3 million hydrogen vehicles and more than 35 million EVs have contributed to the large reduction in carbon emissions.

Similarly to **Community Renewables**, by 2050 in **Two Degrees**, heat is still responsible for a large proportion of emissions, but transport is almost completely decarbonised. Carbon emissions from electricity have reduced slightly faster than **Community Renewables**, and form only a small proportion of GB carbon emissions.

Spotlight

Carbon intensity

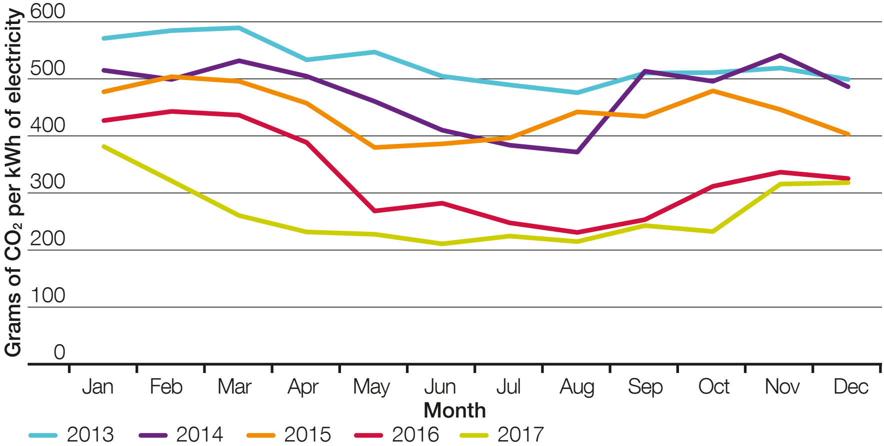
Carbon intensity is a way of examining how much carbon dioxide is emitted in different processes. It is usually expressed as the amount of carbon dioxide emitted per kilometre travelled, per unit of heat created or per kilowatt hour of electricity produced.

In the last five years, the GB carbon intensity of electricity has almost halved. This is measured by looking at grams of carbon dioxide (CO_2) emitted per kilowatt hour of electricity produced. Why has this happened? Across GB, there is a mix of electricity generation technologies, each with different patterns of production and CO_2 output. Fossil fuel technologies like gas or coal can be switched on or off easily, but emit more CO_2 for every unit of electricity produced. Nuclear generation is zero carbon, but is difficult to switch on and off – so it tends to stay switched on for long periods. Technologies like solar or wind can produce low carbon electricity with zero fuel cost, but only when the wind is blowing or the sun is shining.

So, less flexible low carbon technologies like nuclear generate electricity most of the time, with solar and wind running whenever conditions allow. More expensive and carbon-intensive units, like gas, run in periods of higher demand, or when renewable generation is unavailable. And with the amount of renewable generation in GB increasing each year, more and more electricity is being provided by these low carbon sources.

As can be seen in figure 3.3, there is a seasonal ‘shape’ to the carbon intensity of electricity. In winter, carbon intensity is higher as darker colder days mean increased demand for light and heat, and less solar generation. Similarly, carbon intensity flexes over the course of the day. This is in response to demand and different weather patterns that influence, for example, how much electricity can be produced by low carbon generation such as wind.

Figure 3.3
Carbon intensity of GB electricity generation 2013–2017



49.7% decrease from 2013 to 2017

2013	2014	2015	2016	2017
529 gCO_2/kWh	**477 gCO_2/kWh**	**443 gCO_2/kWh**	**330 gCO_2/kWh**	**266 gCO_2/kWh**

Spotlight

Carbon intensity

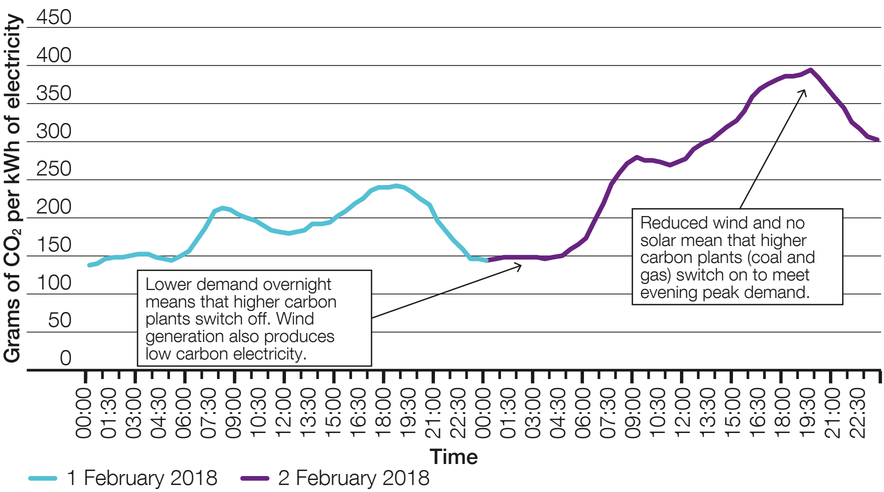
In 2017 National Grid, in partnership with the Environmental Defence Fund Europe and WWF, developed a carbon intensity forecast tool for the GB electricity system[2]. This forecast uses weather data provided by the UK Met Office, plus other data, to provide a 48-hour ahead forecast of the GB carbon intensity of electricity. Carbon intensity data is also available by region.

The goal of the tool is ultimately to influence how and when consumers use electricity. For example, a developer might be able to write a smartphone application that links the forecast data to a smart appliance, such as a smart freezer. The freezer can then slightly reduce its energy demand at times of high carbon intensity (allowing the freezer temperature to rise very slightly), and re-cool when electricity is less carbon intensive. The changes are small and don't impact food quality.

The difference this can make to a user's carbon footprint becomes even more apparent when considering devices with large energy demands. In figure 3.4, charging an EV overnight between 1 and 2 February 2018, rather than at 4pm on 2 February, could approximately halve the amount of associated CO_2. For more detail on our assumptions around smart appliances and consumer engagement, please see page 69.

All our scenarios project a continued decline in the carbon intensity of GB electricity, with a more rapid decline in scenarios with faster decarbonisation. This is detailed in the Data Workbook. For more information on how the carbon intensity of electricity is calculated please see the Modelling Methods document.

Figure 3.4
Carbon intensity of GB electricity, 1 to 2 February 2018 – www.carbonintensity.org.uk



[2] www.carbonintensity.org.uk

Decarbonisation and decentralisation

A note on carbon accounting methods

The reduction of carbon emissions can be achieved by reducing overall demand for energy. This could be done by making appliances and buildings more efficient, or by changing consumer behaviour. Another way to reduce carbon emissions is to use lower carbon energy sources. In the future, the development of CCUS technology may also make it possible to achieve 'negative emissions'. This is where organic materials are grown and in the process absorb carbon, before being burnt in a CCUS process that captures and stores the carbon.

Our scenarios do not currently include technologies that lead to negative emissions. However, in recent months the UK Government has said it would like to understand the implications of a 'net zero' carbon emissions target. Negative emission technologies would be necessary to achieve such a goal. We will explore this in future publications in line with any government announcements.

There are different ways to account for the carbon emissions from a specific process. Take gas-fired generation as an example. Some methods consider not only the carbon emissions from burning gas to produce electricity, but also the upstream emissions due to extracting and transporting the gas required. Whole life cycle assessments consider emissions associated with building a generation plant and safely disposing of it at end-of-life. Further differences in methods could include whether a measure accounts for network energy losses.

In *FES 2018*, our carbon emissions data includes only the carbon emissions produced as a result of a specific process, without considering other aspects. This approach is consistent with the method used for the UK's carbon budgets and by the Committee on Climate Change. Similarly, electricity imported through interconnectors is counted as zero carbon when calculating GB emissions. This reflects the practice of accounting for carbon dioxide emitted in producing this energy in the source country.

Lastly, the graphics in this chapter look at the amount of 'carbon dioxide equivalent' when considering future emissions pathways. This looks at all greenhouse gases and considers their impact on climate change as compared to a unit of carbon dioxide. So, one unit of a gas that warms the atmosphere twice as fast as carbon dioxide would be counted as two units of carbon dioxide equivalent. This approach allows us to quantify the impact on climate change consistently across different greenhouse gases.

Decarbonisation and decentralisation

3.2 Level of decentralisation

The more decentralised a system is, the more its supply and demand assets are linked to local networks and processes. Local energy solutions are developed to meet local requirements.

From the electricity supply side, we have witnessed a dramatic growth in smaller scale generators, such as solar, wind turbines and small peaking plant, which are not connected to the transmission network. Decentralised gas supplies will evolve, from a low base, out to 2050 in all the scenarios.

On the demand side, data exchange technologies and business models are developing. These allow consumers to break away from the more traditional models of energy trading.

Linking together this increasingly complex web of supply and demand will require close cooperation between all players within the energy industry.

How we apply the decentralisation axis

Decentralisation in electricity generation has been driven by the growth in smaller scale renewable generators, such as solar and wind farms. These do not connect directly to the high voltage transmission system, but rather to the medium voltage distribution system or the low voltage system (for generators connected directly to the consumer).

Smart technology and improved information communication technology (ICT) mean that a more fluid and localised approach can be developed for electricity demand, supply and trading. We anticipate, in our more decentralised scenarios, a stronger presence of third parties who will be able to buy and sell the collective resources of their clients as a virtual power station.

There is also a potential for peer-to-peer trading. In April 2018, the UK's first physical trade of energy took place using blockchain technology[3]. There is regulatory support for further developments in this area as Ofgem has "shortlisted the trial to participate in [its] Regulatory Sandbox"[4].

Such trading arrangements will become particularly important for the development of vehicle-to-grid technology (V2G), where consumers will be able to trade their EV's energy storage capabilities. You can find out more about this in the transport section on page 80. We see V2G and smart charging as significant enablers to reduce the impact of EV charging at peak times and to absorb excess renewable generation at times of high supply.

The development of localised trading platforms to handle commodities such as stored electricity means that more consumers will evolve into prosumers. These are people who will consume and produce energy and will have a much richer understanding of their energy world, helping them to make more informed energy decisions.

For the decarbonisation of heating, we consider the installation of heat pumps in residential buildings as a decentralised solution to reducing the number of residential gas and oil boilers. This is because they are installed by consumers on a case-by-case basis and not as a centralised, coordinated solution.

[3] https://verv.energy/news/weve-just-executed-the-uks-first-energy-trade-on-the-blockchain-as-we-look-to-power-a-london-social-housing-community-with-sunshine/

[4] https://www.ofgem.gov.uk/system/files/docs/2018/05/westminster-energy-forum-ceo-speech03-05.pdf

The location of gas connections

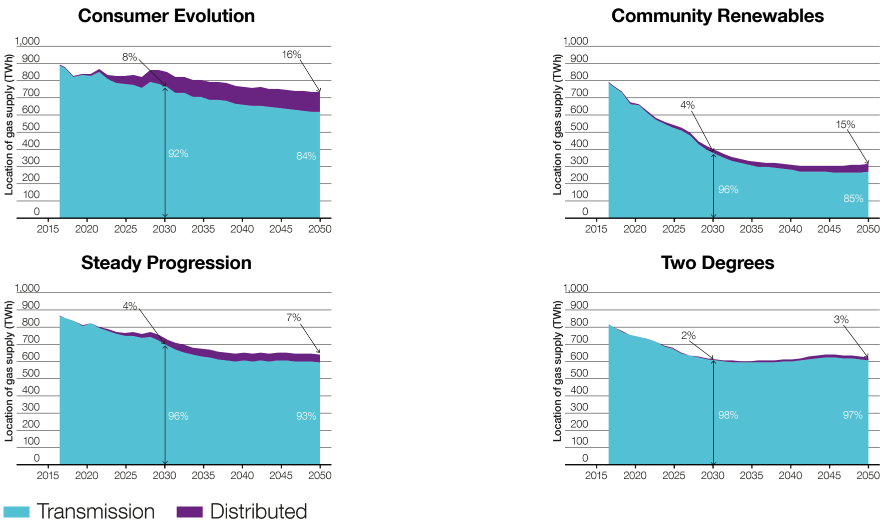
In all our scenarios, gas supply connections to the distribution networks (DN) grow steadily up to 2050, although by how much differs between scenarios. This is shown in figure 3.5. Gas supplies, in this section, are presented in TWh units so that they can be compared against electricity supplies. To convert gas TWh units to billions of cubic metre (bcm) units divide by 11.

By 2050, in the more decentralised scenarios, the proportion of gas supplies connected to the DN is similar, at around 15 per cent. In **Community Renewables**, which is a scenario that reduces dependency on gas, there is 47 TWh of DN gas supplies – most of which is bio-methane. **Consumer Evolution** has 114 TWh of DN connected gas, nearly all of which is shale gas. Almost three times as much shale gas is connected to the National Transmission System (NTS) than to the DN in **Consumer Evolution**.

By 2050, in the more centralised scenarios, the proportions of DN connected gas supplies range from 3 per cent in **Two Degrees** to 7 per cent in **Steady Progression**. These are less than in the decentralised scenarios. **Two Degrees** has the lowest absolute value of 18 TWh, the majority of which is bio-methane. Here there is a similar volume of NTS connected gas as there is in the less decarbonising scenarios. This is as a result of increased gas consumption, in conjunction with CCUS, for hydrogen production.

In **Steady Progression**, like **Consumer Evolution**, most of the DN connected supply is shale gas and by 2050 this reaches 46 TWh.

Figure 3.5
Connection location of gas supplies



Chapter three

Decarbonisation and decentralisation

The location of electrical generation capacity

The capacity of a generator is its maximum possible electricity output at any one time. How much electricity the generator actually produces (or supplies) will depend on a number of factors including how long and how 'hard' it is operating.

In the decentralised scenarios, there are more small scale intermittent electricity generators connected to the medium and low voltage networks. As they are intermittent, there is a need for more of them so that there is a balanced supply of electricity across the day; for example, when the sun sets, or there is heavy cloud cover, then solar generation will decline. This will be made up of generation elsewhere.

Figure 3.6 shows the split between transmission connected, distribution connected and microgeneration[5] capacities for our four scenarios. It illustrates how the decentralisation of electricity takes place to varying degrees across all four scenarios. It also shows peak demand.

Currently, there is 103 GW of generation capacity on the system, split as 73 per cent transmission connected, 23 per cent distribution connected and 5 per cent microgeneration.

By 2030, in our two 2050 compliant scenarios, there are broadly similar annual demand levels. Figure 3.7 illustrates where the top four installed generation capacity types are located. The totals of the illustrated capacities are similar. However, there is clearly a shift to decentralisation in **Community Renewables** with microgeneration connections being 23 GW. In **Two Degrees** it is only 7 GW.

As shown in figure 3.6, in **Community Renewables**, by 2050 there is 268 GW of installed generation capacity. This is more than double today's capacity. Over the same period, annual demand increases by 48 per cent and peak demand by 39 per cent.

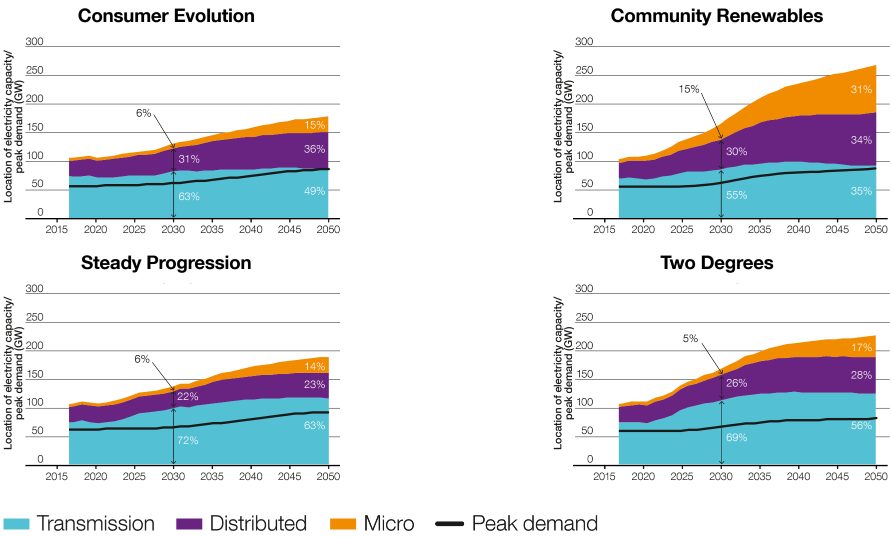
In all the scenarios, the decentralisation of generation increases and other microgenerator types develop. This is particularly evident within **Community Renewables**. In this scenario, in 2050, there is an additional 21 GW of V2G capacity, 14 GW of storage capacity and 3 GW of biomass.

In the non 2050 compliant scenarios of **Steady Progression** and **Consumer Evolution**, the difference between decentralisation of generation is less marked. In **Consumer Evolution**, the decentralised generation is connected more to the distribution network, rather than being microgeneration. However, the major contributing components remain wind and solar.

A full breakdown of electricity generation types and connection levels may be found in the *Data Workbook*.

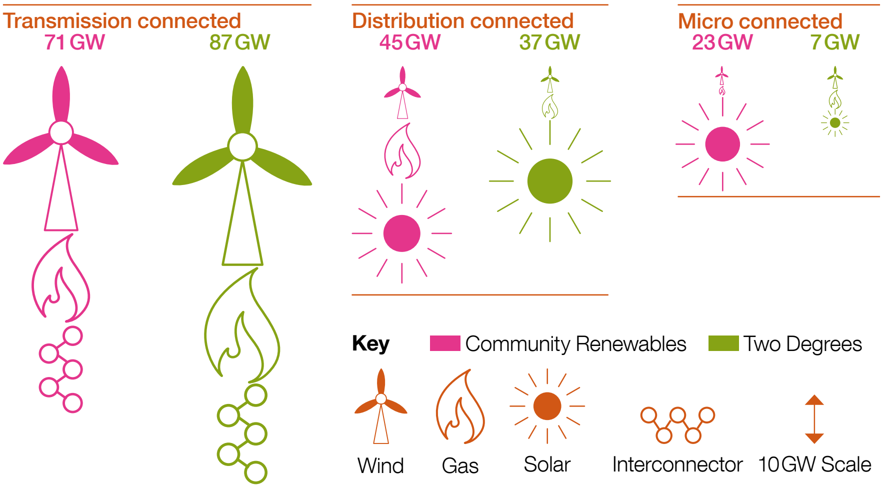
[5] Microgenerators have a capacity of 1 MW or less.

Figure 3.6
Connection location of installed generation capacities and peak demand



Decarbonisation and decentralisation

Figure 3.7
Top four generation capacity types by connection location for ***Community Renewables*** *and* ***Two Degrees*** *in 2030*



Minimum transmission electricity demand

Minimum electricity demand is the opposite of peak demand; it is when demand for electricity is at its lowest. This has historically been at 6am on a summer weekend day.

In *FES*, we focus on underlying electricity demand, which is the total amount of electricity needed by consumers in GB. It is also possible to distinguish between the amount of electricity flowing through the transmission network, and that flowing through the distribution network.

As the amount of generation connected to a distribution network increases, more local demand for electricity can be met by these generators.

We expect that minimum electricity demand on the transmission network will move from early in the morning to around 2pm on a summer weekend day. This happened for the first time in March 2017. We anticipate that this will become a regular occurrence as the amount of distribution connected solar generation grows. This is because local solar generation will be meeting demand on the distribution network, meaning less power needs to flow through the transmission network in these areas.

Exactly how quickly this shift happens is scenario specific. It depends on the amount of solar generation on the system, and for three of the scenarios it is spread within the 2020 decade.

Low levels of transmission connected generation have other impacts on the electricity network. Many large power stations, including nuclear plants, cannot be turned on and off quickly, and so balancing the system at times of low transmission demand can be challenging. You can find more detail on minimum transmission electricity demand in our *System Operability Framework*, *Network Options Assessment* and the *Electricity Ten Year Statement*.

Power flows

Considering transmission demand over the summer only tells part of the story of how the decentralisation of electricity is driving more complex changes to power flows. More broadly, as the network becomes more decentralised, so power flows become more complex and potentially more volatile.

In the past, with a centralised generation system, power flowed from remote large generators through the transmission system, down though distribution networks to the consumer. This dynamic is changing as generation becomes more decentralised and diversified.

For example, on cold windy nights the solar farms in the south west of England won't be generating, while small wind farms in Scotland will be generating significant quantities of electricity. On still sunny days the opposite could be true. So although neither type of generator is connected to the transmission system, it is still required to move power from where it is produced, to wherever it is needed. Moreover, flows of power can change quickly as weather conditions change, and so networks need to be designed and operated in a way that allows this. An illustration of potential power flows is given in figures 3.8 and 3.9.

As the generation mix evolves, we must continue to keep the transmission system balanced, including keeping voltage and frequency stable. So at a particular moment the majority of the power might be coming from solar generation in the south, while the frequency reserve keeping the grid stable could be coming from gas plants in the Midlands.

System operation

Decentralisation of electricity supply means it becomes more fragmented and some of the detail becomes less visible to a national system operator. The output of many newer generator types are also weather dependent. Weather forecasting has its limitations and exact prediction of generator output cannot be guaranteed. Balancing supply from wind farms in the Highlands and houses with solar panels in the South-West, with demand from EVs in London and factories in the West Midlands, will become even more complex in the future. In addition, system frequency and voltage stability characteristics, which are influenced by fluctuations in renewable sources of generation, have to be managed to keep networks stable and secure.

These developments mean that a more integrated, whole system approach across the transmission and distribution systems is required. New ways of designing and operating the electricity system will be increasingly needed. In order to manage the system at the most efficient cost, new markets for operability products are being developed with a wider range of providers. Clear flows of information and data across all parties will be vital, along with coordination across system boundaries to deliver the most efficient outcomes.
For example, a lower cost option such as a distribution network asset or battery storage could be used in place of a transmission asset in the long term, or to manage costs while the need for a transmission line becomes more certain. More active management of distribution networks may also be an efficient way to manage local issues.

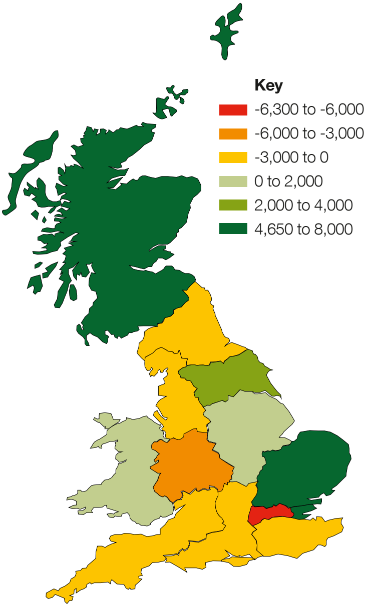
We recently set out how we plan to develop our network planning to maximise the opportunities in order to meet the challenges through our Network Development Roadmap consultation.

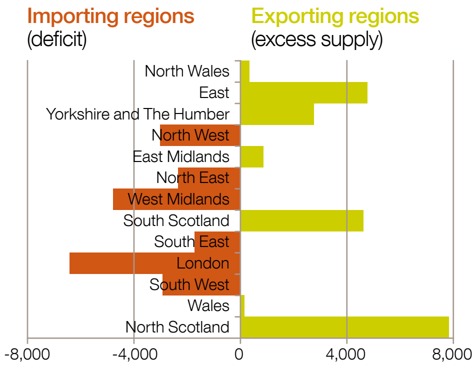
Spotlight

Power flows

The graphics on page 41 show net demand across GB in two different time periods in 2030 in the **Community Renewables** scenario. Some areas will have more generation than demand (coloured green). As a result, electricity from their area will be transported on the transmission network and used elsewhere where there is a deficit (coloured red).

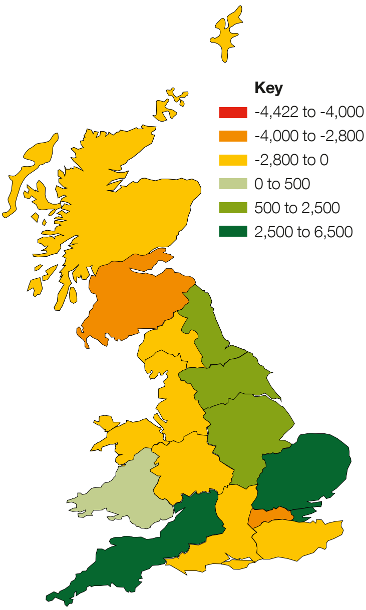
Figure 3.8
Net winter supply – demand (MW)

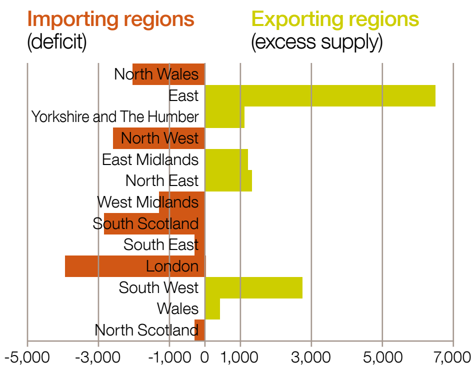




Winter 2030, Community Renewables
This map illustrates a time period with high wind output and high demand. Here some areas with high wind capacity, such as Scotland, have an excess of generation, and this flows south down the country to be used in areas of high demand such as London.

Figure 3.9
Net summer supply – demand (MW)





Summer 2030, Community Renewables
This map illustrates a time period with high solar output and medium demand. Here the areas with excess generation are different, and consequently we can see that flows of electricity across the country will be different to those in figure 3.8.

Chapter **three**

Decarbonisation and decentralisation

3.3 Costing the scenarios in *FES 2018*

Over the last few years, there has been increasing interest in understanding the costs of our different scenarios. Our stakeholders have told us that they would find this valuable. As such, we have initiated a project to explore the costs of the four scenarios in *FES 2018*.

Looking at our scenarios from a cost perspective provides a number of benefits to the wider energy industry. We believe it will provide us with a deeper understanding of the uncertainties in some areas of our analysis. It will also help to determine the biggest influences on the costs of the different scenarios. By determining which technologies have a significant impact on cost, we can examine these in greater detail.

Costings allow us to share a better understanding of the pathways to achieve the 2050 carbon targets. We can then compare different solutions from both a financial and carbon perspective. This insight will add to our existing processes to further refine and focus our efforts in future scenario development.

We are at an early stage in this project. So far, our analysis has focused on the two 2050 compliant scenarios, **Community Renewables** and **Two Degrees**. Our initial findings are detailed below.

Our approach

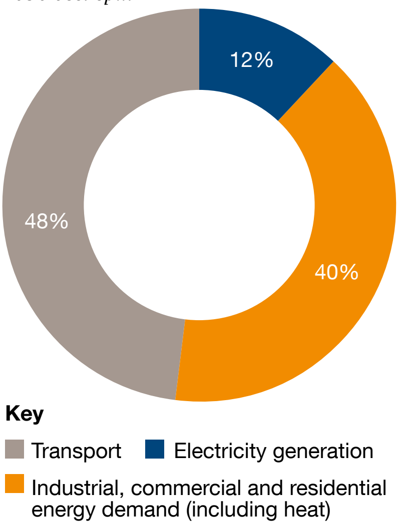
We are working collaboratively with academics from University College London to develop the UK TIMES Model (UKTM) as the basis for our costing analysis. This model looks across the whole energy system. Once a FES scenario is completed, we replicate it in the UKTM to cost the scenario. Predicting the future costs of technologies can be difficult. To allow for this we flex the cost assumptions to understand how sensitive the outcome is to the cost of key technologies.

This is just the start of the analysis we are planning. The whole energy system is complex so a single model, looked at in isolation, will not provide the information we need. It will necessitate a number of models used together. Therefore we intend to supplement the UKTM modelling with additional analysis. Over the next few months we will focus on representing the cost of network impacts across transmission and distribution. This will include the development of new networks and the costs of balancing the system.

Initial results

Our initial results indicate that in 2050, the costs for **Community Renewables** and **Two Degrees** are broadly similar overall. How costs are apportioned across the electricity generation, industrial, commercial and residential energy demand (including heat) and transport sectors is also comparable for both scenarios. However further work is needed to understand some of the wider implications of each pathway.

Figure 3.10
2050 cost split



Transport

There is little difference between the costs for transport in the two scenarios. This is not surprising considering their similar transport assumptions.

In the same way as today, the costs associated with road transport are dominated by the purchase and maintenance costs of cars. In chapter four, we discuss our modelling assumptions around total cost of ownership of vehicles. In all scenarios, we expect the total cost of ownership of electric cars to reach cost parity with conventional cars relatively soon. Therefore in the longer term, the decarbonisation of transport will not lead to increased costs for these vehicles.

However, our initial analysis does indicate that, without further research and development, there may be additional costs to decarbonise commercial vehicles. This is because some types of commercial transport are more difficult to electrify, due to their size and intensive use. Therefore other solutions will need to be sought to decarbonise these types of transport.

Residential heating

At present, the best way to decarbonise heat in the residential sector is unclear. It is a complex sector as the choice of technology drives different implications through the energy industry. Conventional heat pumps, for example, require high levels of insulation and may necessitate a change of central heating system. For district heating, the end consumer must be part of a collective heating system. For hydrogen, boilers and other appliances need to be upgraded and a network switchover required. Our analysis indicates that whichever technology solutions are developed, additional costs will be incurred.

The range of technologies in **Two Degrees** and **Community Renewables** provide a balanced approach to decarbonising heat. Our initial results indicate that including hydrogen in the mix has the potential to reduce overall costs, although further work is required to determine what an optimised group of technologies would be. The different challenges and opportunities may mean that different technologies are better suited to various places across GB. For example, in a densely populated area close to a low cost source of heat, district heating may be a cheaper solution than another technology. However this may not be the case in a rural environment. We therefore believe that a mix of low carbon heating options will have an important role to play.

Electricity generation

Our comparison of the electricity generation costs for **Two Degrees** and **Community Renewables** has shown both scenarios currently have similar results. As with heat, the power generation scenarios are a mixture of technologies with each having a greater emphasis for either centralised or decentralised generation.

This demonstrates that the cost difference between a greater amount of large scale generation (i.e. off-shore wind and large nuclear), as seen in **Two Degrees**, and higher volumes of smaller scale generation (i.e. solar and on-shore wind), as found in **Community Renewables**, could be relatively small. While **Community Renewables** has an additional 43 GW of installed generation capacity[7], **Two Degrees** contains more generation with a higher capital cost.

Further analysis is needed to understand the network and balancing requirements of the technologies in **Two Degrees** and **Community Renewables**. This analysis will provide more information to help us understand an optimal low cost pathway between these scenarios.

[7] Including capacity from interconnectors.

Decarbonisation and decentralisation

Next steps

This initial analysis is just the start of the work we are planning. After extending our analysis to cover all four scenarios, further model development will begin.

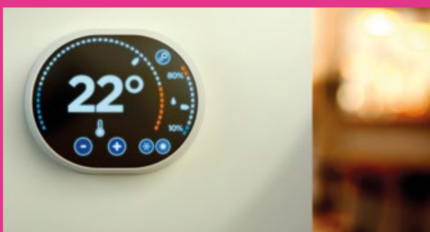
The big areas we will concentrate on over the next few months include:

- the impact of network and balancing costs on the two 2050 compliant scenarios
- continuing to explore all options and build on the learning highlighted here. This will include a better understanding about how the interaction between the heat and power sectors can be optimised.

Over the course of the year we will discuss this activity further with our stakeholders and share more detail of our modelling where possible.

Chapter four

Spotlights



EPCs Pg 63

Smart hybrid heat pumps Pg 70

How might autonomous vehicles affect electricity demand? Pg 83

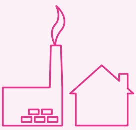
What is hydrogen and how might it feature in the future of energy? Pg 89

Energy demand

4.1 Energy demand

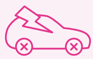
Great Britain's (GB) gas and electricity demand are highly interlinked, with gas currently supplying the highest proportion of energy delivered. However, in some scenarios, this balance will shift substantially over the next decades. This year, we have also considered the potential role for hydrogen in greater detail, discussed in our new transformation section.

Key insights
Commonalities and uncertainties across the scenarios

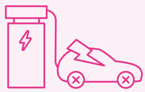


- The current annual energy demand for gas in GB is 810 TWh and for electricity 297 TWh. In all our scenarios, total energy demand is reduced by 2050. This is due to factors such as improved energy efficiency and a reduced output from gas-fired electricity generation.

- The rate of decline in gas use varies by scenario, and is particularly driven by the level of decarbonisation and the role of carbon capture utilisation and storage (CCUS) and hydrogen.



- Electricity demand grows in all scenarios, particularly from the 2030s onwards. This is due to the electrification of transport in all scenarios and then the electrification of heat in some scenarios. Electricity peak demands mirror this increase.



- In all scenarios, electricity demand to charge electric vehicles (EVs) is managed through smart charging and vehicle-to-grid technology (V2G).

In *FES* we consider the underlying, or actual, demand of consumers within GB. Within this section, we do not include electrical losses or gas shrinkage. We do not take account of any network constraints in our demand modelling. These issues are considered in our other System Operator publications.

Annual demand

Annual demand is made up from the sum of gas and electricity demand from the following sectors:

- industrial
- commercial
- residential
- transport
- transformation.

The transformation sector is where one energy source is used to create another. Within *FES 2018* transformation includes:

- gas to electricity
- gas to hydrogen
- electricity to hydrogen.

In all our scenarios, the total energy demand decreases from today's levels despite a rising population.

The sectors that drive this change in demand vary depending on the scenario. Figure 4.1 illustrates the changing energy demand levels for gas and electricity by sector.

The decarbonisation of electricity generation continues to reduce gas demand. However, in our 2050 compliant and centralised scenario of **Two Degrees**, the development of hydrogen production alongside CCUS means that the use of gas starts to increase again from about 2040.

The average thermal efficiency of buildings continues to improve. This means that the overall amount of energy required for heating homes reduces despite the population increase. This process is more pronounced in our 2050 compliant scenarios of **Community Renewables** and **Two Degrees**.

Government policy to rapidly decarbonise transport means a substantial increase in the number of EVs in all our scenarios. EV growth will lead to increased electricity demand and it becomes one of the dominant features in the overall energy demand mix. However, opportunities exist to harness the potentially large numbers of EVs, with their battery storage ability, to facilitate the integration of renewable intermittent generators. This is referred to as vehicle-to-grid technology (V2G).

Appliance efficiency savings partly offset the growth in demand we would expect from an increasing population.

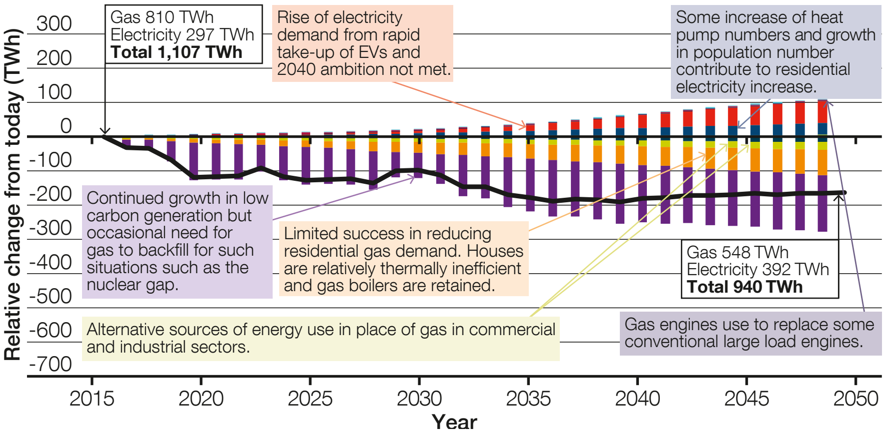
Finally, the production of hydrogen has been incorporated to a greater extent in our models this year. Hydrogen can be used within its own network as a fuel for heating. It can also provide some flexibility to the electricity system when created via electrolysis, potentially from excess renewable electricity.

The following sections of this chapter will discuss the contributions made by each sector.

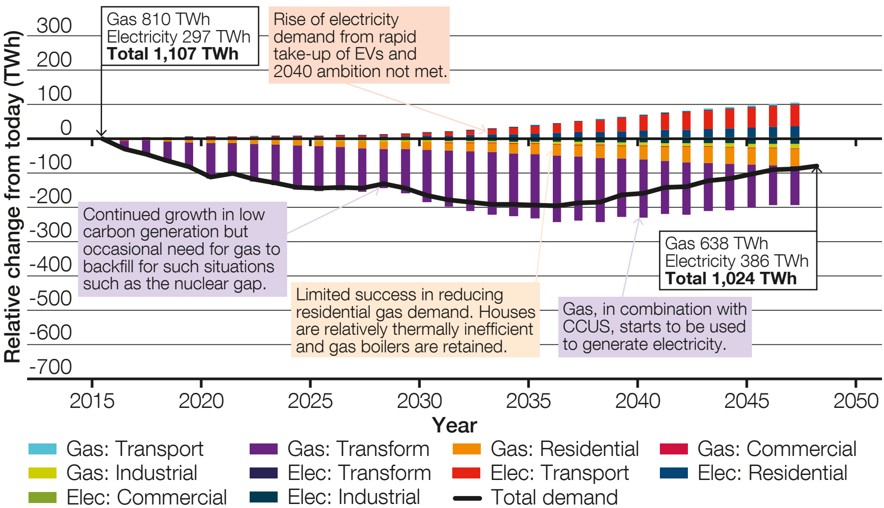
Energy demand

Figure 4.1
Gas and electricity annual demand by sector and variances from today

Consumer Evolution

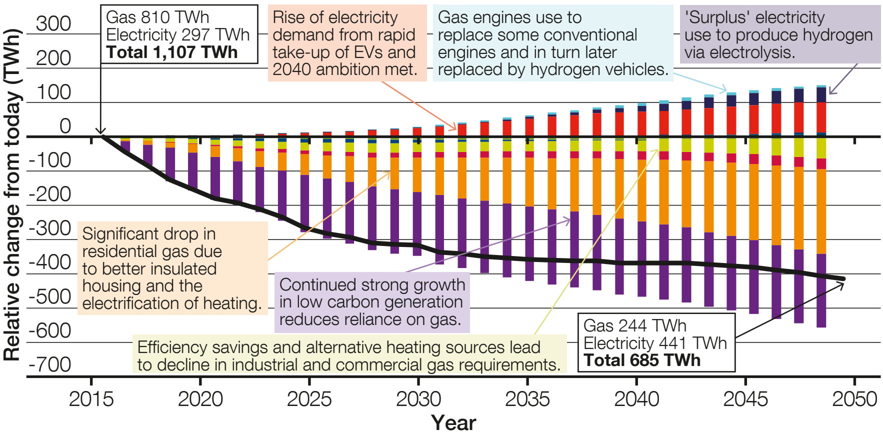


Steady Progression

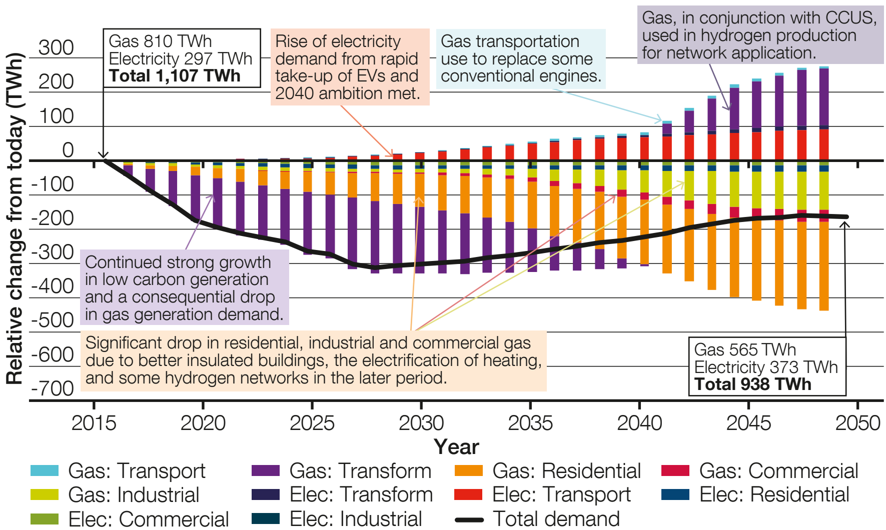


Chapter four

Community Renewables



Two Degrees



Chapter four

Energy demand

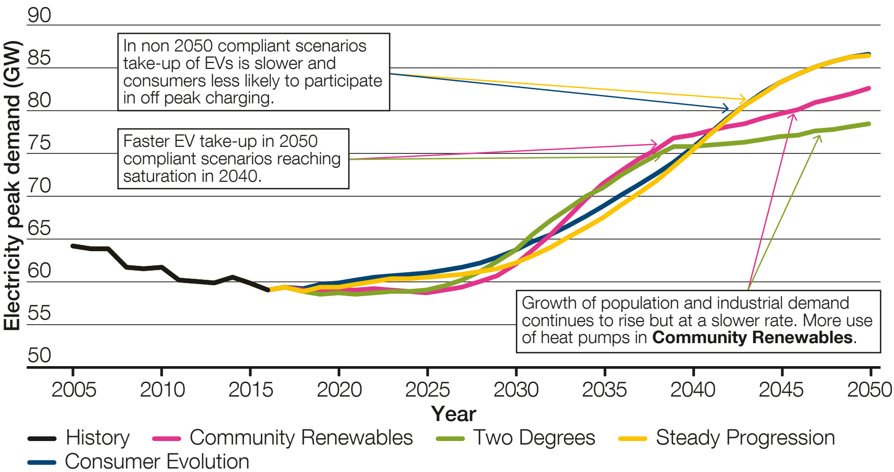
Electricity peak demand

The highest demand for electricity, referred to as peak demand, is generally on a weekday winter's evening at around 5:30pm. In all our scenarios, peak demand increases significantly from the 2030s, as shown in figure 4.2.

Appliance efficiency gains, despite a rising population, moderate the rise in peak demand for the next decade. Thereafter there is a steep rise caused mainly by the electrification of transport. This rise in peak demand would be much more severe without smart charging.

Our assumptions on smart charging and consumer behaviour are discussed later in the transport section of this chapter.

Figure 4.2
Electricity peak demand (including losses)

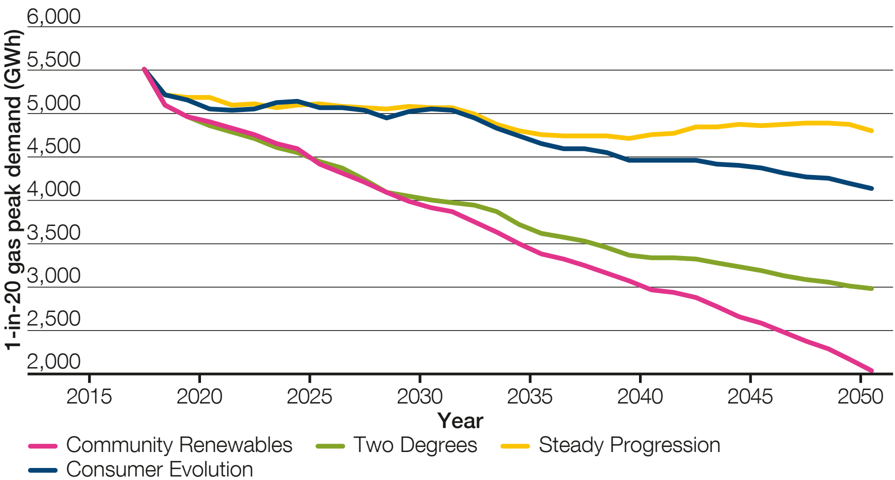


Electricity minimum demand

Minimum electricity demand is generally on a summer's weekend day at about 6am. The minimum electricity demand in all the scenarios remain relatively static, around 25 GW, out to the early 2030s. There is then a slow but steady rise out to 2050 when all the scenarios have a minimum demand between 27 and 28 GW. These relatively stable minimum demands mask more complex flows across the network. You can find out more in chapter three.

Gas peak day
Gas peak demand is illustrated in figure 4.3. Generally, it mirrors the movement of annual gas demands in each scenario but the declines are not as rapid. Gas is still required as a supporting electricity generation source when intermittent generation is producing less. It is also used for heat through gas boilers, hybrid heating or hydrogen production, depending on the scenario.

Figure 4.3
Gas 1-in-20 peak demand



Energy demand

4.2 Industrial and commercial demand

In 2017 the industrial and commercial (I&C) sectors accounted for 245 TWh of gas. Together this was about 30 per cent of all gas used in GB. The demand for natural gas from the I&C sectors drops from today's value in all our scenarios. There is little change in electricity demand for I&C by 2050.

The scenario with the most gas use in the I&C sector is **Steady Progression**, which sees 241 TWh used in 2030 and 225 TWh in 2050. The two 2050 compliant scenarios see a decline in gas demand. With the introduction of hydrogen networks after 2040, the reliance on natural gas reduces much faster in **Two Degrees**. In this scenario it drops from 229 TWh in 2030 to 94 TWh by 2050.

I&C electricity demand in 2017 was 183 TWh, making up 62 per cent of GB's total electricity demand. In all our scenarios, I&C electricity demand drops below this level from the mid 2020s to 2050, but by no more than 10 per cent.

Within the I&C sectors there are four dominant factors that interact to produce our scenario profiles. These are:

- the economy; a strong economy drives up energy demand
- appliance efficiency; the higher the efficiency level the lower energy demand
- decarbonisation; which dictates if low carbon technologies are adopted
- decentralisation; which indicates what technology is adopted and hence which energy source is required.

The change in this year's scenario framework and a convergence in the price of gas and electricity have made some significant alterations to our models' outcomes when compared to last year. In the following section we describe the results. Further detail on the models and their outputs can be found in the accompanying *Modelling Methods* and *Data Workbook*.

Economic outlook

The Gross Domestic Product (GDP) growth in 2017 was 1.8 per cent. The average growth rates we have used are 2.0 per cent for the high growth scenarios, which are **Community Renewables** and **Two Degrees**, and 0.9 per cent for the low growth scenarios, **Steady Progression** and **Consumer Evolution**. These growth rates are relatively stable over the period with only 2019, in the low growth forecast, deviating significantly from the general trend.

We have assumed the same population growth and, as a consequence, labour supply, across all our scenarios. As one of the main drivers of economic growth, this pan-scenario approach limits the amount of divergence between the scenarios.

Compared to last year, the relative retail price of gas has increased and the electricity price has decreased. This has meant that, for *FES 2018*, our projections for gas demand have decreased and the demand for electricity has increased in the industrial and commercial sectors for all the scenarios, when compared with *FES 2017*.

In the two 2050 compliant scenarios of **Community Renewables** and **Two Degrees**, the retail prices of both gas and electricity are higher than in the non 2050 compliant scenarios. For gas this is an imposed financial disincentive to its use, and for electricity it is a means of financing decarbonisation activities, such as subsidies.

A summary of these key points is given in table 4.1

Table 4.1
A summary of the key economic levers

Lever	Average GDP growth	Electricity retail prices	Gas retail prices
Community Renewables	2%	High	High
Two Degrees	2%	High	High
Steady Progression	0.9%	Low	Low
Consumer Evolution	0.9%	Low	Low

Energy demand

Industrial demand

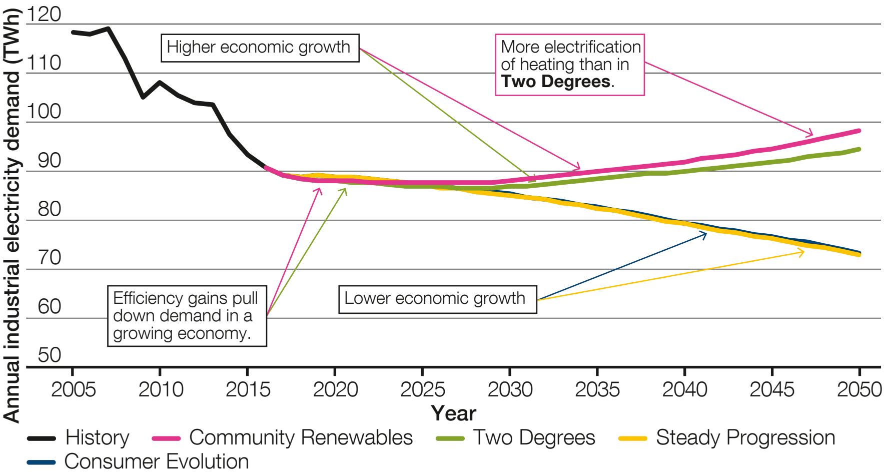
In figure 4.4 we show the annual electricity demand from industry.

Electricity demand is greater in the higher growth 2050 compliant scenarios. However, it is not until the 2030s that they exceed the 2017 level of 89 TWh. This initial reduction in demand is due to the 30 per cent efficiency improvements for appliances[1] resulting from the EU 2030 target. This offsets the demand increase due to economic growth.

Demand in **Community Renewables** reaches 98 TWh in 2050. This is the same level as in 2013. In **Two Degrees** it reaches 94 TWh, which is similar to 2015 demands. The main reason for the differences between these two scenarios is **Community Renewables'** greater reliance on electricity driven heat pumps. This contrasts with **Two Degrees**, where hydrogen is used for heating.

There is slower economic growth in **Steady Progression** and **Consumer Evolution**. In both of these scenarios there is a continual decline in industrial manufacturing output. This reflects the trends witnessed in the previous decade. As a result, their annual demand for electricity gradually decreases, reaching just above 70 TWh by 2050.

Figure 4.4
Annual industrial electricity demand



[1] https://ec.europa.eu/energy/en/topics/energy-efficiency

In figure 4.5 we show the annual gas demand from industry. Unlike electricity demand, economic growth is not the primary factor driving a difference across the scenarios.

The scenario which shows the greatest variability is **Two Degrees**. In this faster decarbonising and more centralised scenario there is an initial plateau caused by efficiency gains offsetting the effect of an expanding economy. This is followed by a steep decline, mainly as a result of hydrogen network installations, which occur over the 2030s and 2040s. As each network gets commissioned, hydrogen replaces natural gas in the pipes. All businesses on the network then swap to hydrogen, reducing the demand for natural gas.

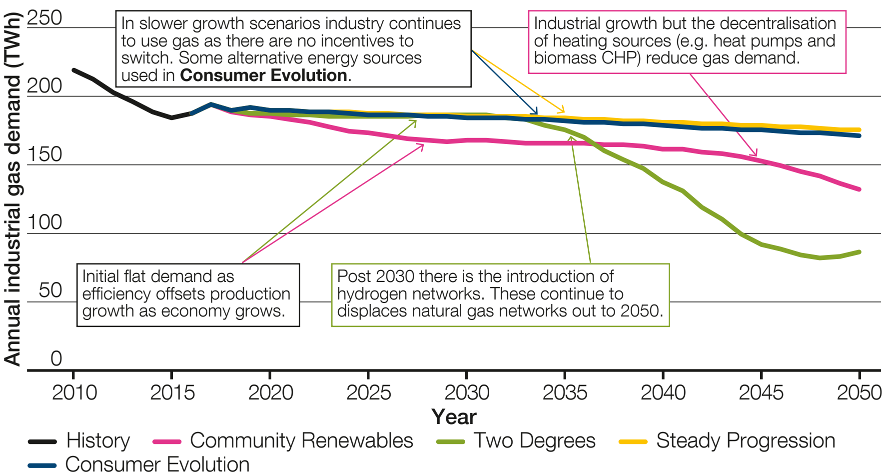
Natural gas demand also declines in **Community Renewables**. This decrease is achieved in a number of ways including the electrification of heating through the use of heat pumps. These appliances reduce gas demand by 20 TWh by 2050. Another significant factor is the large scale deployment of biomass combined heat and power (biomass CHP).

This reduces the demand for natural gas by about 12 TWh in 2050. However, for high temperature processes natural gas will still be relied upon.

Natural gas demand in **Steady Progression** stays relatively constant as there are no reasons or incentives to switch to alternative forms of heating.

In **Consumer Evolution**, being a more decentralised scenario, more local heating sources are used, similar to **Community Renewables**. However, the options are more limited as there are fewer low carbon incentives available.

Figure 4.5
Annual industrial natural gas demand



Chapter four

Energy demand

Commercial demand
Within the commercial sector, the EU's 2030 target of 30 per cent appliance efficiency gains is met in the two 2050 compliant scenarios of **Community Renewables** and **Two Degrees**. In figure 4.6, the effect of this can be seen in the steep drop in electricity demand out to 2030. Despite being the faster growing economies, the efficiency savings are sufficient to reduce the overall amount of electricity consumed.

The lowest demand for electricity is in **Two Degrees**, around 83 TWh in 2030 where it effectively remains out to 2050. In *FES 2017*, **Two Degrees** was the scenario with the highest commercial electricity demand. This change of position is a result of the changes to the scenario framework. Now, being a centralised, decarbonising scenario, there are fewer heat pumps. Instead use is made of hydrogen and combined heat and power (CHP) appliances.

Meanwhile the commercial sector in **Community Renewables** relies heavily on electrically driven air source heat pumps (ASHP) for heat.

The two non 2050 compliant scenarios have similar profiles. In both, energy efficiency gains are achieved, but the rate of change is similar to recently observed trends. Low efficiency gains cancel out the low demand growth for most of the period.

Figure 4.6
Annual commercial electricity demand

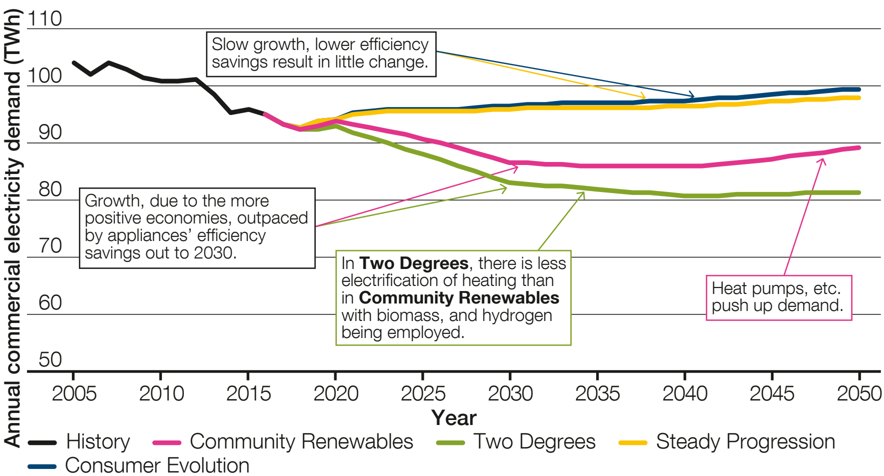


Figure 4.7 illustrates the profiles of the annual natural gas demands for the commercial sector.

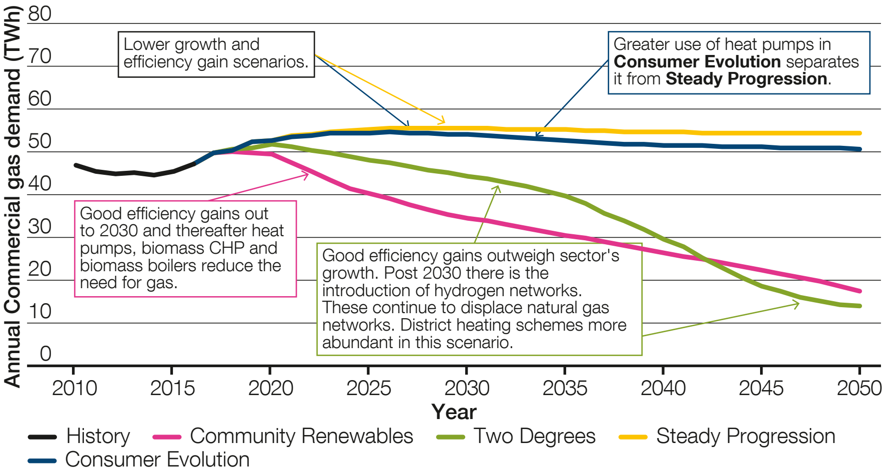
As we saw in the annual gas demand for industry, gas demand in **Two Degrees** drops significantly after 2030 because of hydrogen networks. For the commercial sector, district heating reduces gas demand.

In **Community Renewables**, less natural gas is used. Other forms of low carbon heating are used in this scenario such as ASHP, biomass boilers and CHP. Their effects are sufficient to offset the gas demands required of a faster growing economy.

As with the commercial electricity demand profiles, more gas is used in the non 2050 compliant scenarios. This is mainly due to heating and industrial processes being decarbonised more slowly.

Greater use of ASHPs, in the decentralised **Consumer Evolution**, decreases the demand for gas. The result is slightly lower demand levels than seen in **Steady Progression**.

Figure 4.7
Annual commercial natural gas demand



Energy demand

Industrial and commercial demand side response (DSR)

In *FES* we define DSR as the turning up or down, or turning off or on, of electricity consumption in response to external signals. In our scenarios we model end use demand. Therefore, if a consumer chooses not to reduce their demand but instead switches to an alternative energy source, such as an onsite diesel generator or batteries, then we do not regard this as DSR.

Figure 4.8 shows the effect of DSR on the I&C sectors. There is little change in the overall levels of DSR across all four scenarios for the next few years. Post 2020 some barriers, such as the complexity of the marketplace, ease off allowing for divergence in the scenario pathways.

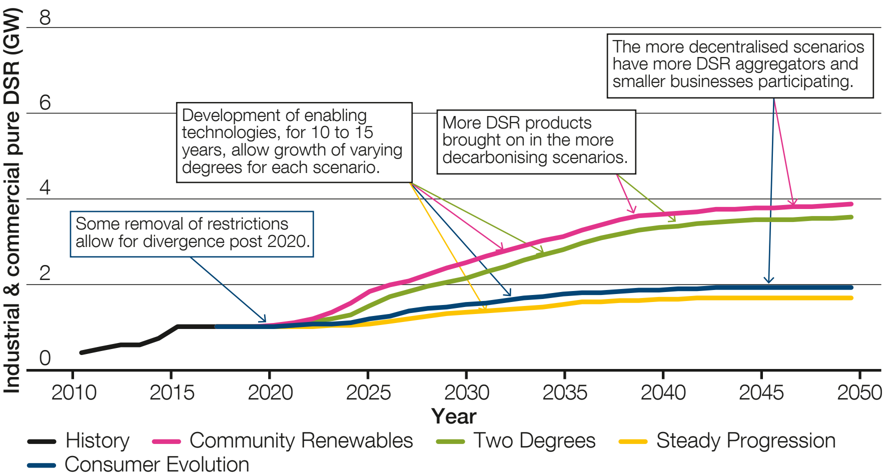
From the early 2020s through to 2040 there is a growth and development in enabling systems, such as information communications technology, which permit DSR to evolve in all the scenarios. After this, growth tails off, dampening the initial rate of growth.

The most significant differentiator between DSR take-up in the scenarios is decarbonisation. More DSR products enter the marketplace in the scenarios with more renewable generation, **Community Renewables** and **Two Degrees**. These products are used by businesses as income generators, for supplying balancing services, or as cost savings, by reducing their exposure to more expensive charges.

In the scenarios with lower decarbonisation there are fewer drivers for DSR and subsequently there are fewer DSR products in the marketplace.

A more minor component, which separates **Community Renewables** from **Two Degrees**, and **Consumer Evolution** from **Steady Progression**, is the effect of decentralisation. In the decentralised scenarios there are more smaller businesses and more local aggregators engaging in DSR, rather than just larger businesses. The effect of this is to increase the level of DSR in these scenarios above the levels seen in the more centralised scenarios.

Figure 4.8
Industrial and commercial demand side response



4.3 **Residential demand**

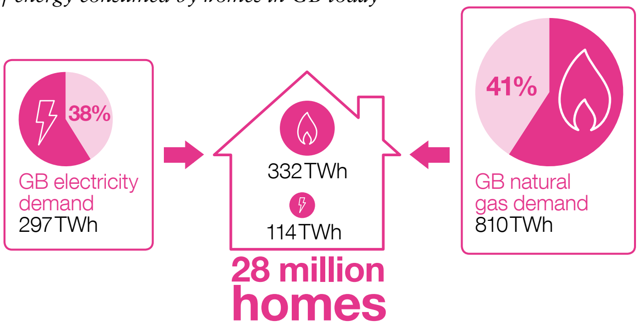
In order for the residential sector to contribute to the 2050 target, the direct use of natural gas for heating needs to reduce and energy efficiency needs to increase. These approaches are adopted in our 2050 compliant scenarios of Community Renewables and Two Degrees. In both, the same high level of appliance efficiency gains is assumed. Both scenarios also see significant changes to the building stock.

Heating demand
The decarbonisation of heat can be achieved through two processes, both of which must happen to reach the 2050 decarbonisation target. They are:

- increasing thermal efficiency and thereby reducing the energy needed to heat homes
- greater use of lower carbon emitting sources of heat.

The Government has stated its intention to tackle the decarbonising of heat in its recently published Clean Growth Strategy[2] and Grand Challenges[3]. The aspiration is to see the average home achieving a Band C Energy Performance Certificate (EPC) rating by 2035. For a more detailed description of EPC bands please see our spotlight on page 63. This is achieved by new building regulations and by retrofitting older buildings.

Figure 4.9
Proportion of energy consumed by homes in GB today



[2] https://www.gov.uk/government/publications/clean-growth-strategy
[3] https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/missions#clean-growth

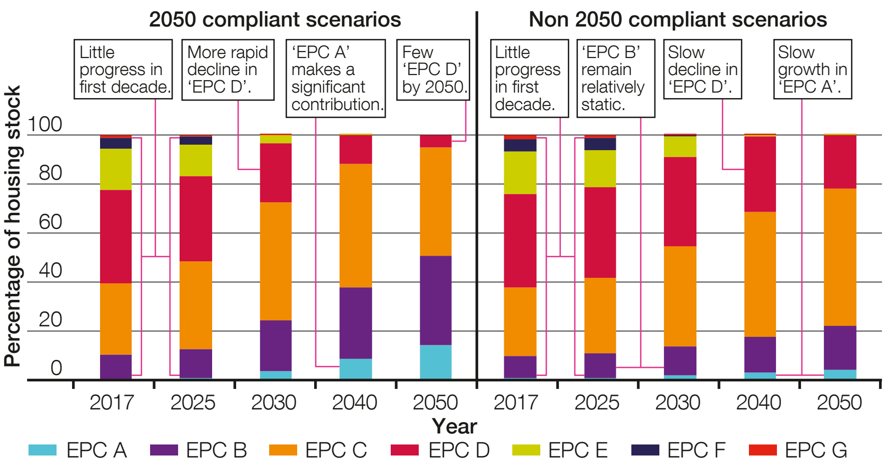
Energy demand

Thermal efficiency

In *FES 2017* we proposed that a significant proportion of the housing stock in our **Two Degrees** scenario would have to be EPC A band rated. Evidence gathered since then suggests that EPC A is a very difficult target to achieve. We have therefore assumed, in our faster decarbonising scenarios, an average rating between band B and C for the entire housing stock.

This year our scenarios follow two thermal efficiency development routes; one for the 2050 compliant scenarios, the high case, and an alternative low case for the non 2050 compliant scenarios. As shown in figure 4.10, the high case has a greater proportion of homes that are A and B rated, and a lower proportion of C and D rated homes as compared with the low case. For both the high and the low case the first few years are similar to historical trends. However, after the early 2020s, as the Government's Clean Growth Strategy takes effect, the high case diverges resulting in a more thermally efficient housing stock.

Figure 4.10
EPC rating for high case (left) and low case (right)



Chapter four

SENSITIVITY: What would happen to gas demand if we increased the thermal efficiency of homes?

Today the average home has an EPC rating of D. In our two 2050 compliant scenarios we have made the assumption that the thermal efficiency of the majority of homes will improve to a rating between B and C by 2050.

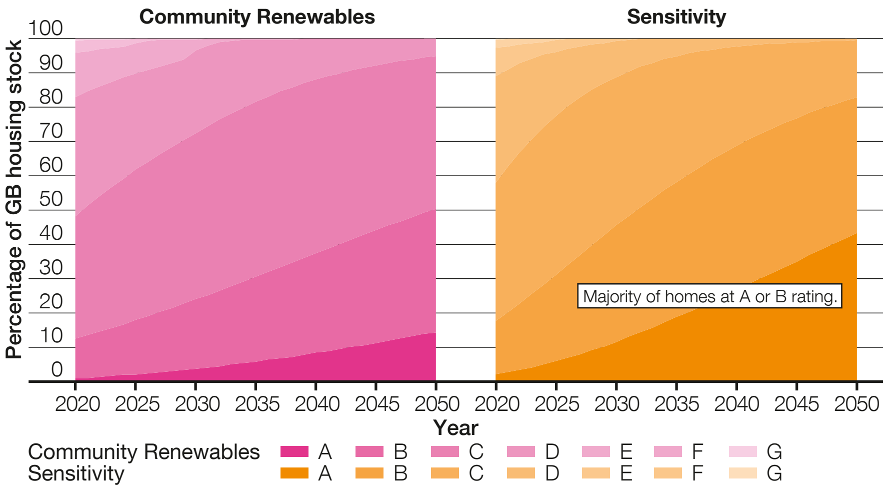
In this sensitivity, we investigate what would happen if the majority of housing stock were to achieve an EPC rating of between A and B. For this analysis we will look at increasing the EPC ratings in Community Renewables, although the two 2050 compliant scenarios both use the same housing efficiency assumptions. Figure 4.11 illustrates the differences in the EPC ratings of this sensitivity and **Community Renewables**.

With an increase in the thermal efficiency of the housing stock, homes heated by gas boilers need less gas to be warm, so gas demand reduces. In addition when houses need less heating, heat pumps become a more viable and cost optimal alternative to gas boilers, further reducing gas demand. Figure 4.12 illustrates the different gas demands.

Improving the thermal efficiency of most homes by one EPC rating gives the potential for a 14 per cent reduction in residential gas demand in 2030, a 17 per cent reduction in 2040, and a 23 per cent reduction in 2050. In 2050 this equates to 18TWh.

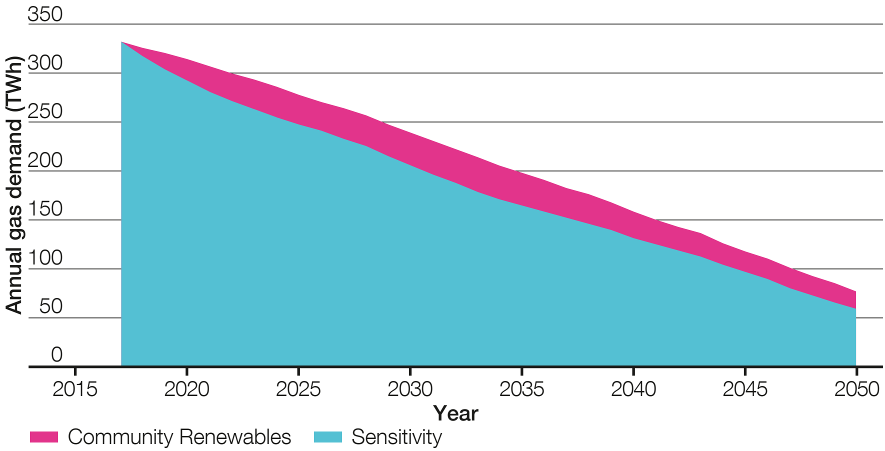
In this sensitivity we have assessed the impact on those homes connected to gas supplies. There will also be an electricity demand saving for homes that are more thermally efficient and that have decarbonised their heating source.

Figure 4.11
The EPC rating of ***Community Renewables*** *and the sensitivity*



Energy demand

Figure 4.12
Residential gas requirement differences between ***Community Renewables*** *and the sensitivity*



Spotlight

EPCs

Almost every home that has been sold or rented since 1 June 2007 must have an EPC.

Energy performance is assessed using the Standard Assessment Procedure (SAP). The EPC assigns a band to the home, based on the SAP score, which ranges from A, the best, to G, the worst.

The SAP calculation is based on factors that affect a building's energy efficiency. These include:

- materials used for construction of the dwelling
- thermal insulation of the building fabric
- air leakage from the building
- efficiency and control of the heating system(s)
- south facing windows
- the fuel used to provide space and water heating
- ventilation and lighting
- energy for space cooling
- renewable energy technologies.

Spotlight

EPCs

Figure 4.13
EPC bands for current housing stock and 2017 constructions

Figure 4.13 illustrates what the spread of EPC bands is for all of the current residential building stock in GB and what it is for 2017 new residential constructions.

We estimate that from the current stock of 28 million homes in GB, about 25 million would achieve a rating somewhere between band C and G.

There has been a slow shift in the EPC bands over the years. This has been primarily brought about by the evolution of building regulations and the inclusions of minimum SAP scores. Planning permission is only granted if building regulations are met.

Newer properties are generally more energy efficient. The real challenge is improving the energy efficiency of older properties.

The Energy Saving Trust has a useful Home Energy Check[4] from where we have drawn the following insights. However, it should be noted that in our building efficiency model we only consider the heating elements of EPC. Other factors that are considered in calculating the EPC band, for example appliance efficiencies, are not included.

A fifty year old two bedroom semi-detached house, which is about the median for GB, would probably have an EPC rating of band D. Coincidentally this is also the average for the GB housing stock.

There are many ways to upgrade a house's energy efficiency. We illustrate just one of them but apply the principle of installing the most cost effective measures first.

To improve the energy performance of this building to band C, would necessitate loft and cavity wall insulation. Solid floor insulation would also have to be laid and the doors and windows draught proofed.

Going even further, moving this building to band B would require additional installations including underfloor heating, solar panels, secondary glazing and insulated external doors. And finally, to get to band A, a low carbon heating source would also be required.

Implicit in the example given above is that moving up the EPC bands incurs additional upfront costs. Getting to band A is achievable, but is expensive and has a long payback period.

[4] http://www.energysavingtrust.org.uk/resources/tools-calculators

Energy demand

Alternative technologies

Gas demand, for residential heating, is currently 332 TWh. Almost 22 million homes, around 80 per cent, have gas boilers installed. A further 3 million homes have oil boilers, which are more polluting than gas boilers.

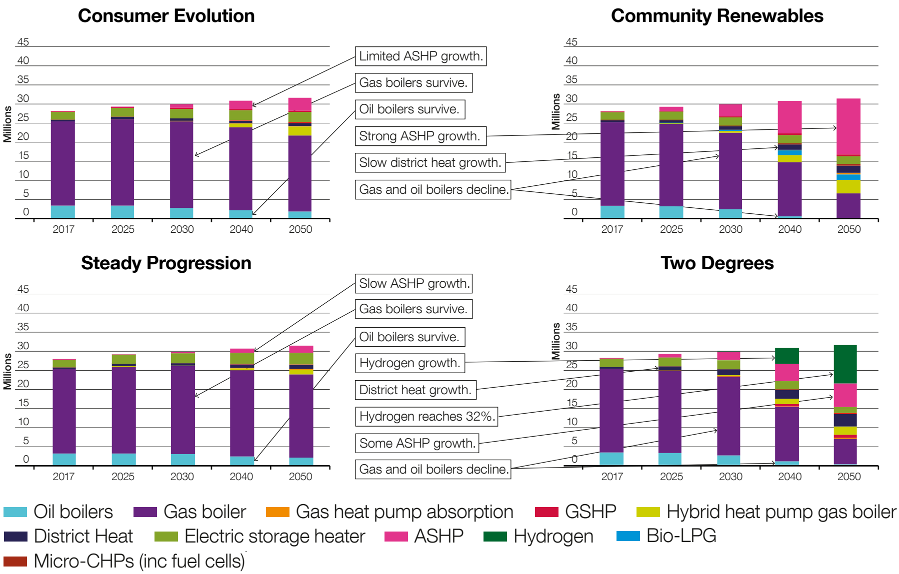
For our 2050 compliant scenarios, alternative forms of energy and technologies are employed to heat homes that are more thermally efficient. At the same time, population growth drives an increase in the number of homes, and therefore heating appliances. Figure 4.14 gives our views of changing heating technologies for all the scenarios out to 2050.

In both the non 2050 compliant scenarios, the development of alternative heating technologies is limited. Gas boilers remain dominant, although there are efficiency gains in this technology as older boilers get replaced.

The homes in **Consumer Evolution** do have more ASHP than in **Steady Progression**. This partly accounts for their slightly lower demand for gas and greater demand for electricity. About two million homes in these two scenarios continue to use oil. This contrasts with the 2050 compliant scenarios, where oil is phased out.

In the 2050 compliant scenarios gas boilers decrease significantly post 2030. However, they never fall below 20 per cent, or 6.5 million installations. Note though that some replacement low carbon appliances do use gas. These include smart hybrid heat pumps, fuel cells and micro combined heat and power units (mCHP). As a result the total number of gas dependent appliances could be up to around 10 million. Our spotlight on one of these technologies, smart hybrid heat pumps, outlines how they might operate. In our analysis the technologies that replace boilers differ by scenario.

Figure 4.14
Heating technologies by scenario



Chapter four

Energy demand

In *FES 2017* our **Two Degrees** scenario met the 2050 target by the application of large numbers of ASHP. This year it is **Community Renewables** that has the highest proportion of heat pumps. In this scenario heat pumps, of various types, are installed in almost 60 per cent of households by 2050. This occurs because there are fewer large scale coordinated actions to develop alternative heating technologies. There are some low carbon district heating schemes but these are fewer in number when compared to **Two Degrees**.

In a **Two Degrees** world, there are two significant low carbon technologies that are more highly developed than in any other scenario: hydrogen and district heating.

The potential for hydrogen networks has come more to the fore in recent years. In its Clean Growth Strategy, the Government highlights the potential for a Hydrogen Pathway[5]. It is investing in a £25 million project to explore its potential[6]. We describe the production of hydrogen, and what it may be used for in our spotlight on page 89.

In **Two Degrees**, by 2050, about 10 million homes are supplied by hydrogen, all of which are within conurbations. All of this hydrogen is initially supplied from steam methane reforming. For hydrogen to be considered as a low carbon fuel, the steam methane reforming process must be accompanied by CCUS.

District heating is also most developed in **Two Degrees** with 10 per cent of homes benefiting from this form of heating. This heat can either be from a dedicated low carbon source, or a by-product of industrial or commercial processes.

Both hydrogen networks and district heating schemes are centralised activities which are better suited to more densely populated areas. If homes are not in such areas, it is unlikely that there would be wide scale installations of these technologies. Therefore low carbon alternatives, such as ASHP, are taken up in order to decarbonise heating, as is seen in **Community Renewables**.

[5] https://www.gov.uk/government/publications/clean-growth-strategy

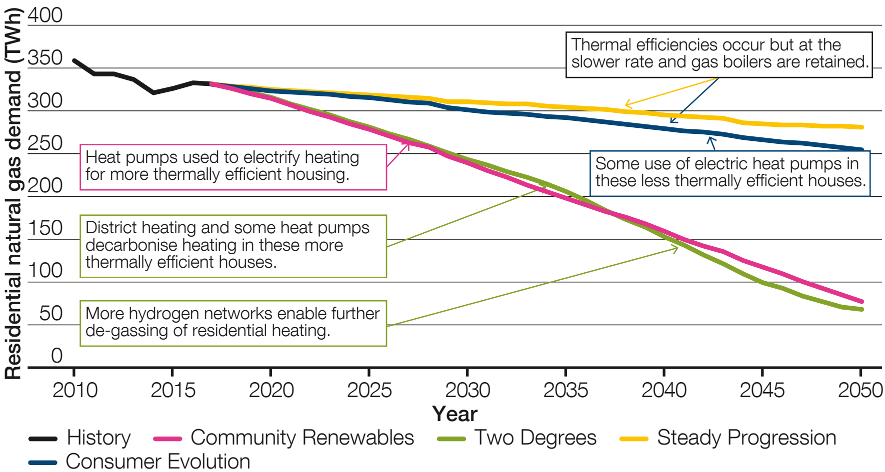
[6] https://www.gov.uk/guidance/innovations-in-the-built-environment#investing-in-hydrogen-innovation-for-heating

Natural gas demand

The vast majority of residential gas is used for heating homes. As outlined above, the two 2050 compliant scenarios reduce their use of gas as a heating source. Gas use does not reduce as quickly in the non 2050 compliant scenarios.

Figure 4.15 illustrates the gas demand in each scenario. There are two broad groups. Firstly the non 2050 compliant **Consumer Evolution** and **Steady Progression** scenarios. Both of these use more than 250 TWh of natural gas for residential demand by 2050. This demand is mainly from gas boiler use in low thermally efficient homes. The second group is the 2050 compliant **Two Degrees** and **Community Renewables** scenarios, where demand is less than 100 TWh of natural gas per year.

Figure 4.15
Residential gas demand



Chapter four

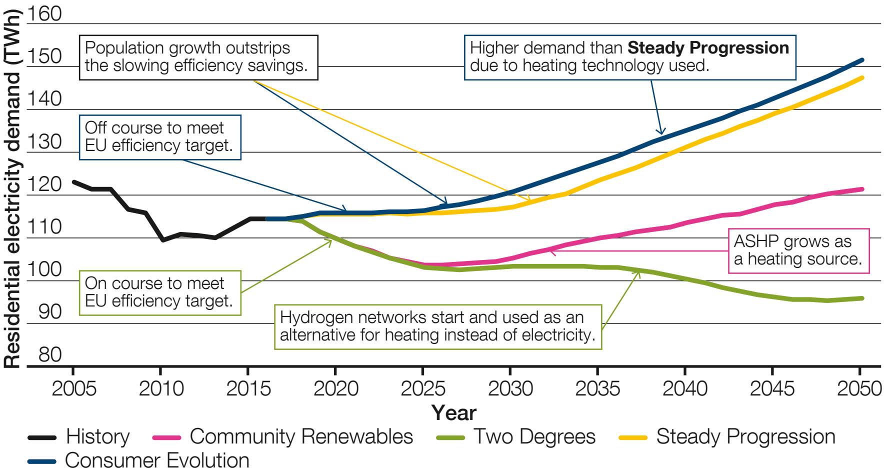
Energy demand

Electricity demand

Currently, in homes electricity is mainly used for appliances. These make up just over 61 per cent of residential electricity demand. Heating accounts for almost a quarter. The scenario profiles are illustrated in figure 4.16.

Within residential demand we have not included EVs charged at home; these are discussed in the transport demand section on page 72.

Figure 4.16
Residential electricity demand



Electricity heating demand

The technologies that use significant amounts of electricity for heating are mainly either resistive heaters (such as storage heaters and showers) or heat pumps, which consume less energy per unit. Of the two 2050 compliant scenarios it is **Community Renewables** that has the highest demand. This is because of the number of installed heat pumps.

Two Degrees does have an initial quicker drop in electricity demand for heating in the 2020s as efficiency savings are applied to the improving insulated housing stock. This continues as hydrogen networks and district heating schemes are instigated, and also as homes continue to become more thermally efficient.

Post 2030, **Consumer Evolution** and **Steady Progression** see a consistent rise in demand. This mainly is brought about by population growth. However, **Consumer Evolution** homes make use of more heat pumps, which contribute to the scenario's divergence from **Steady Progression**.

Electrical appliances' demand

We present two demand pathways for residential electrical appliances. The pathways are based on whether or not the scenario meets the EU 2030 target of 30 per cent savings for appliance efficiencies[7]. This occurs in the 2050 compliant scenarios irrespective of the UK's future energy relationship with the EU. The non 2050 compliant scenarios do not meet this target. They maintain their current, more limited, efficiency gain rates into the future. Electricity demand in the non 2050 compliant scenarios is greater than in their 2050 compliant counterparts.

Detailed output data from the modelling, including appliance type, can be found in the accompanying *Data Workbook*.

Residential flexibility

The extent to which consumers' demand will be flexible, i.e. they will choose to, and are able to, alter their electricity use pattern, is uncertain. This year, as a result of evidence gathered, we have modelled three different consumer participation profiles, for use within each scenario. These profiles are applied to:

- time of use tariffs (TOUTs)
- smart wet appliances, for example washing machines
- smart cold appliances, such as freezers.

These participation levels have been developed from Ofgem's consumer segmentation[8].

TOUTs can only exist where there is differential pricing. Also it is unlikely that this will develop fully until smart technologies are sufficiently rolled out.

There are two types of TOUTs: dynamic tariffs, where the price is set in real time, and static tariffs, such as Economy 7, where prices are set in advance for different time periods.

The smart meter rollout programme has some substantial challenges if its targets are to be met. In the 2050 compliant scenarios we have assumed that the rollout programme target of 95 per cent of homes having smart meters (gas and electricity) by the end of 2020 is achieved. This means that over 8.5 million electricity smart meters need installing in 2019 alone. For the non 2050 compliant scenarios, we have extrapolated the current rollout profiles so that they meet the 2020 target two years later.

For smart wet appliances, which can be turned off altogether and for hours at a time, we have slowed our deployment rates. We believe that manufacturers are making slower progress than we had thought last year. There are currently very few smart models available. Policy makers are just beginning to consider them, as indicated by this year's BEIS consultation on smart appliances[9]. The EU eco design forecast[10] predicts fewer deployments by 2030 than we used in our modelling for *FES 2017*. The maximum participation level we have given these in *FES 2018* is 70 per cent; this compares to last year's level of 85 per cent.

Evidence suggests that cold appliances are significantly different from other appliances in that their operational modes can be adjusted with no noticeable impact. For example, smart refrigerators can be adjusted to operate at slightly warmer temperatures. Our maximum participation level for these appliances is capped at 85 per cent.

[7] https://ec.europa.eu/energy/en/topics/energy-efficiency

[8] https://www.ofgem.gov.uk/system/files/docs/2017/10/consumer_engagement_survey_2017_report.pdf

[9] https://www.gov.uk/government/consultations/proposals-regarding-setting-standards-for-smart-appliances

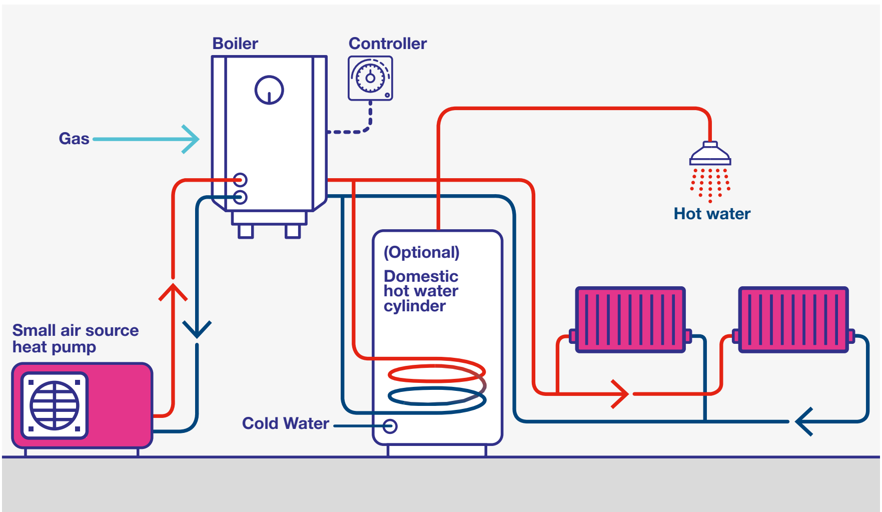
[10] http://www.eco-smartappliances.eu/Documents/Task_7_draft_20170914.pdf

Spotlight

Smart hybrid heat pumps

All our scenarios include hybrid air source heat pumps as part of the pathways to decarbonise heating. Here we explore how smart controllers are changing the industry's traditional approach to hybrid heat pumps.

Figure 4.17
An example of a smart hybrid heat pump system



Spotlight

Smart hybrid heat pumps

Figure 4.17 illustrates a smart hybrid heating system. As the name implies it uses both a gas boiler and, in this case, a small air source heat pump. The gas boiler uses gas from the local network. Where this includes green gas, the carbon footprint will be lower. You can read more about green gas in chapter five. The small heat pump can normally be incorporated into a traditional central heating system so many central heating systems can be adapted relatively easily.

The continuous low grade heat from the heat pump works alongside the quick responsiveness of the gas boiler. The gas boiler may also top up a home's heating if the heat pump is not providing enough heat.

The whole system is coordinated by a smart controller. The smart controller is able to switch between energy sources, gas and electricity, in order to maximise the benefits offered by each. This technology has several benefits:

- taking advantage of TOUTs and avoiding peak electricity prices
- using gas at electricity peak demand times to avoid the requirement for higher carbon emitting generators
- using electricity when low carbon emitting generation sources, such as renewables, are generating, thereby reducing overall carbon emissions
- avoiding more costly and disruptive changes to homes.

The concept is currently being tested by the Freedom project which plans to install 75 such installations this year[11].

[11] http://www.wwutilities.co.uk/media/2451/final-on-the-road-to-a-green-energy-uk-freedom-work-v2.pdf

Energy demand

4.4 Transport demand

If the Government's transport aspirations are met, then by 2040 there will be 34 million electric cars on the road requiring about 60 TWh of electricity per year. All our scenarios assume strong growth in EVs.

In all our scenarios, peak demand from EVs is managed through smart charging. This behaviour is more evident in our two 2050 compliant scenarios, reducing peak demand by 8 GW in 2030. By 2040 this saving would stabilise at 32 GW.

After 2030 V2G will provide useful levels of support. By 2040 the support to reduce peak demand could be as much as 8 GW, rising to 13 GW in 2050.

Table 4.2
Transport's additional annual electricity demand and net peak demand (and as percentage increases on 2017 values)

	2030	2050	2030	2050
Community Renewables	22 TWh (7%)	89 TWh (30%)	5.0 GW (9%)	3.3 GW (6%)
Two Degrees	19 TWh (6%)	88 TWh (30%)	8.1 GW (14%)	6.5 GW (11%)
Steady Progression	6 TWh (2%)	66 TWh (22%)	2.8 GW (5%)	12.7 GW (22%)
Consumer Evolution	5 TWh (2%)	65 TWh (22%)	2.6 GW (4%)	9.9 GW (17%)
	Total annual demand in 2017 297 TWh		Peak demand in 2017 59 GW	

Developments since *FES 2017*

Since we last published our modelling results on 13 July 2017 there have been a number of high profile announcements on transport that impact our assessment of the future. On 26 July 2017, the Secretary of State for Transport stated that nearly all new cars and vans sold by 2040 will be zero emission[12], and nearly every car will be zero emission by 2050[13].

These announcements have been followed up by funding arrangements for supporting initiatives. The Clean Growth Strategy[14], published in October 2017, summarises the Government's present policies and proposals for transport, as well as other sectors. As a result of these positive actions, we have significantly increased the number and the take-up rate of low emission vehicles in all our scenarios.

We have extended our model's range from only cars to now include motorbikes, light goods vehicles (vans), heavy goods vehicles (HGVs), buses and coaches. We have also considered non-residential fast and rapid charging impacts in our analysis. Expanding the range of vehicles being modelled and the types of charging allows us a much more comprehensive perspective on transport. For a more detailed description of the new model please refer to our accompanying *Modelling Methods* document.

In the last year we have gathered a large amount of evidence which has helped us formulate views on some of the more uncertain variables in our model, some of which are given below.

We believe that the majority of chargers will be smart. Smart chargers will enable vehicles to avoid charging at peak time. In addition, a number of energy suppliers have launched EV specific tariffs that have a time of use element.

As a result, we have significantly increased the consumer engagement levels for our two slower decarbonising scenarios of **Steady Progression** and **Consumer Evolution**.

Engagement levels help us to reflect the numbers of consumers who avoid charging their EVs at peak time. This may be by actively choosing to avoid charging their vehicle at peak times, or by passively allowing smart charging technology to make these decisions for them. Each scenario has been assigned different levels of engagement.

We have reduced our assumptions on the energy efficiency gains that vehicles achieve. Our revised view is that vehicles will not reduce in size, as assumed in some scenarios in *FES 2017*.

As policy, rather than consumer choice, will be the main driver of the take-up rates of low emission vehicles, we now believe that the annual mileage for low emission cars will be more or less the same as it is for today's petrol and diesel fuelled internal combustion engine (ICE) cars.

V2G, where EV batteries can consume from and supply electricity to the network, has also now been included in our modelling. V2G has minimal impact on the annual demand but it can play a significant role in the within day demand profiles. It has an important role to play in helping to manage times when the network experiences excess generation or demand. Again, we have seen some commercial developments in this area and a number of innovation projects that aim to prove the concept.

[12] https://www.gov.uk/government/news/government-gears-up-for-zero-emission-future-with-plans-for-uk-charging-infrastructure

[13] https://www.gov.uk/government/news/plan-for-roadside-no2-concentrations-published

[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651916/BEIS_The_Clean_Growth_online_12.10.17.pdf

Energy demand

Finally, evidence gathered suggests that the introduction and take-up of automation in vehicles will not be as rapid as we thought last year. This means the effect of removing vehicles and replacing them with fewer automated shared vehicles in our scenarios is only significant post 2040.

Vehicle fuel type numbers

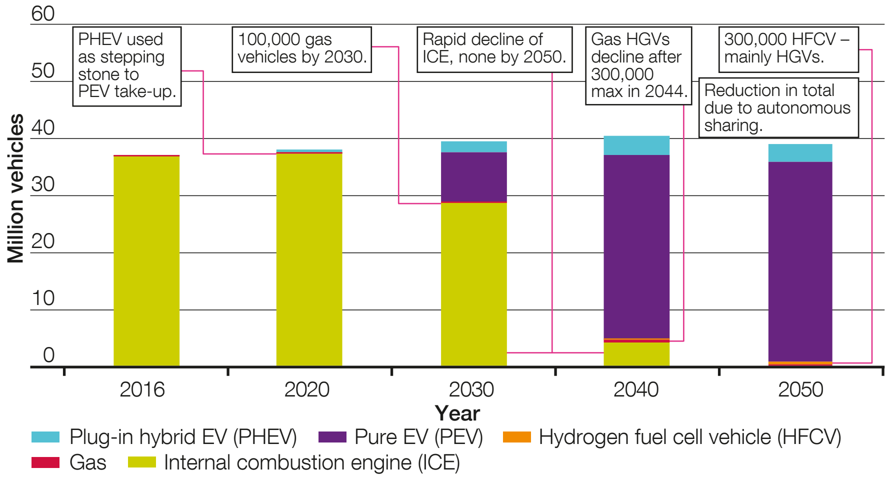
The numbers of vehicles in our two 2050 compliant scenarios are very similar, as they are in our two non 2050 compliant scenarios. However, there are more vehicles in the non 2050 compliant scenarios as they have fewer shared vehicles and less use is made of public transport. In every scenario cars account for approximately 80 per cent of vehicles.

A breakdown of vehicle technology types for the representative scenarios of **Community Renewables** and **Steady Progression** is given in is given in figures 4.18a and 4.18b. All the scenario data may be seen in the accompanying *Data Workbook*.

In the two 2050 compliant scenarios, plug-in hybrid EVs (PHEV) are used as a stepping stone to the take-up of pure EVs (PEV). PHEVs reach a maximum of 3.8 million in 2047 for **Community Renewables**, and 3.5 million in 2045 in **Two Degrees**. In both these scenarios there are no new conventional ICE cars sold after 2040 and they are totally removed by 2050, in line with the Government's aspiration. However, some PHEV are still on the road by 2050 and they still emit some carbon.

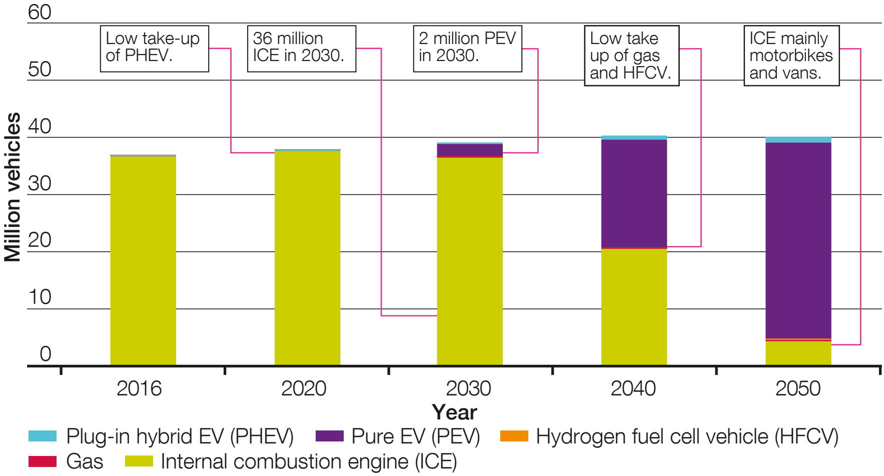
Other fuel types are present in these two scenarios but these are dwarfed by EV cars. Gas vehicles, mainly HGVs, are present and reach a maximum in the mid-2040s. After this time, they start to decline in favour of hydrogen fuel cell vehicles (HFCV). This growth is helped by the presence of hydrogen production in both the 2050 compliant scenarios.

Figure 4.18a
*Number of vehicles by fuel type in **Community Renewables***



Chapter four

Figure 4.18b
*Number of vehicles by fuel type in **Steady Progression***



In the same scenarios, the number of vehicles decline after 2040 as some sharing of autonomous vehicles comes into play. There is also more use of public transport, particularly in **Two Degrees** where centralisation enables the greater development of regional and national coordinated transport policies.

In the non 2050 compliant scenarios the take-up of alternative fuel types is much more muted. This includes the take-up of PHEVs. PHEVs only ever represent a small proportion of vehicles as most consumers stick to their ICE vehicles before switching to PEVs. The Government's aspirations on transport for cars and vans are not met. In these scenarios there are still over 4 million ICE vehicles left on the road by 2050, mainly in the form of motorcycles and vans.

Electric vehicle annual demand

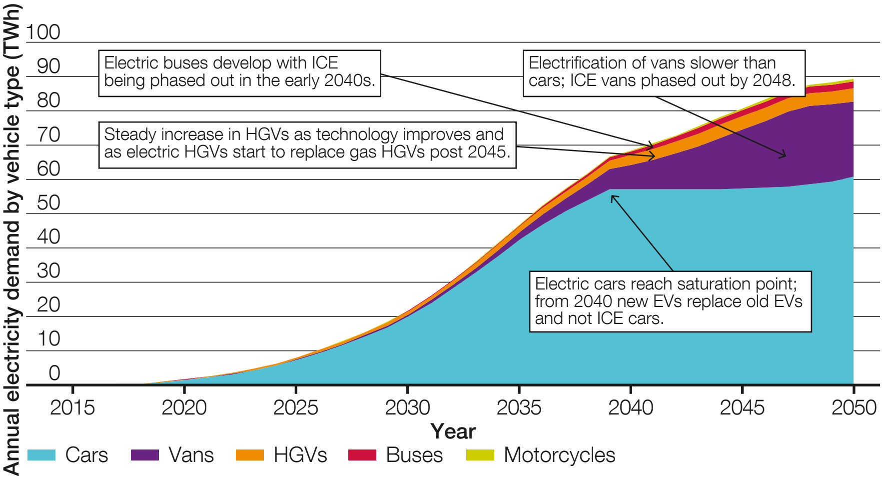
The annual electricity demand profiles for vehicles in the two 2050 compliant scenarios are very similar, as are the numbers in the two non-compliant scenarios. In 2050 it is 89 TWh in **Community Renewables**, 88 TWh in **Two Degrees**, 66 TWh in **Steady Progression** and 65 TWh in **Consumer Evolution**. Figure 4.19 gives the profiles for **Community Renewables** and **Steady Progression**. The other two scenario profiles may be found in the *Data Workbook*.

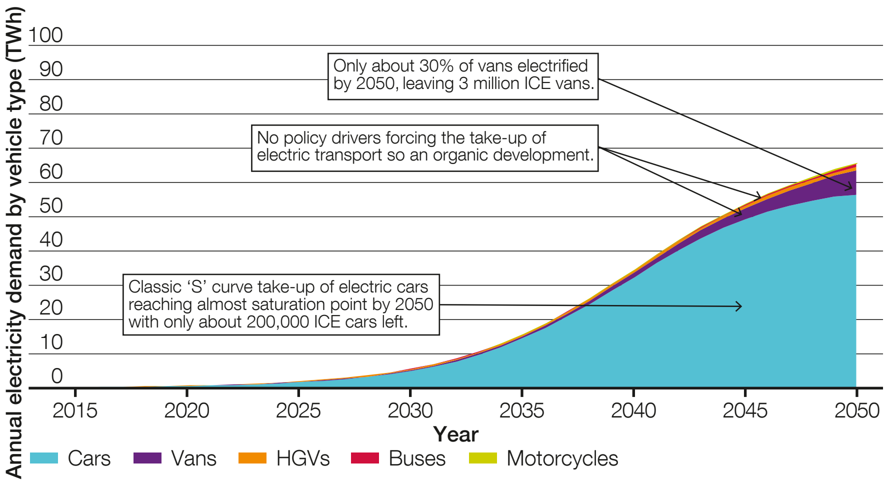
In the 2050 compliant scenarios there is an initial rise in electricity demand. This is caused by the rapid take-up of EV cars as they mainly replace ICE vehicles. Around 2040, the replacement of ICE vehicles is complete as new EVs are now replacing old EVs. Post 2040, electricity demand from cars stays relatively static, with the effects of car sharing and population growth effectively counteracting each other.

In these scenarios the electrification of vans is slower than it is for cars. This is partly as a result of the heavy loads that vans carry and having to wait for suitable technological advancements to accommodate this need effectively. Consequently, the impact of their electrification is not seen until later. Eventually ICE vans are phased out in the late 2040s.

Energy demand

Figure 4.19
*Annual electricity demand profiles, by vehicle type, for **Community Renewables** (top) and **Steady Progression** (bottom)*





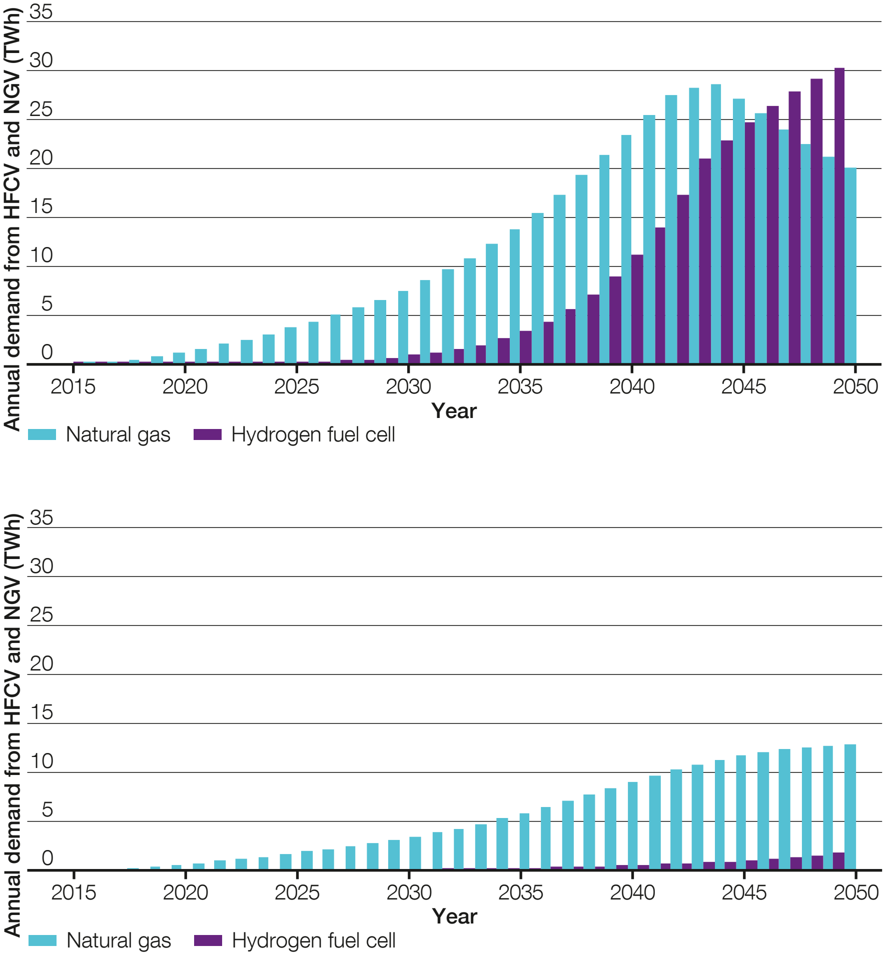
For the same reason, there is a delay in the demand from HGVs and buses. But from 2030 onwards their numbers, and hence their electricity demand, steadily increases. As the technology improves it becomes more economically advantageous to electrify heavy-load carrying vehicles. Gas fuelled HGVs and buses make a relatively short appearance. After the mid 2040s they are superseded by HFCVs, as seen in figure 4.20.

In the two non 2050 compliant scenarios, there is less impetus for the removal of petrol and diesel engines. Annual electricity demand increases follow the general profile of a new product take up, or S-curve. They almost reach maturity by 2050. The scenarios' annual electricity demand for transport in 2050 are about three quarters of those for the 2050 compliant scenarios, and for natural gas it is about two thirds.

Our accompanying *Data Workbook* gives a full breakdown of vehicle types by fuel and their demand, for each scenario, out to 2050.

Energy demand

Figure 4.20
Annual demand from hydrogen fuel cell vehicles (HFCV) and natural gas vehicles (NGV) for ***Community Renewables*** *(top) and* ***Steady Progression*** *(bottom)*



Peak demand

Within transport, there are a number of contributing factors that affect peak electricity demand. The three variables that have the greatest impact in our scenarios are:

- the number of EVs
- the number of consumers who participate in smart charging and avoid charging at peak times
- the number of consumers who participate in V2G and supply power at peak times.

There are other significant factors that play a part in our modelling, such as:

- size of chargers – 7 kW domestic chargers charge over several hours. They have a different impact on electricity demand profiles compared to the future 350 kW commercial fast chargers which will take only 5 minutes
- use of vehicles – if it is being used at peak times, it is more likely to be charged at a commercial fast charging facility rather than specific journeys to charging points
- parking facilities – on road parking will mean that the use of commercial chargers is more likely.

EV peak demand is mainly caused by non-commercial vehicles. These tend to be driven during the day, making charging at peak times convenient. Commercial vehicles will be in use at peak time and businesses will actively avoid peak time costs. In the 2050 compliant scenarios there are more EVs. These drive up peak demand but there is also increased participation in smart charging (shown in figure 4.21) and V2G. Together these partly reduce the rise in peak demand.

We classify a consumer as participating in smart charging if they do not charge their EVs at peak times, wherever possible. This peak time avoidance is done as a lifestyle choice and because there are more incentives, such as TOUTs, available to encourage this behaviour.

In the non 2050 compliant scenarios, consumers have fewer incentives and less desire to avoid peak time charging.

Energy demand

Figure 4.21
Electric vehicle (EV) consumer participation levels for charging away from peak times in 2050

Consumer Evolution	Community Renewables
65%	78%
Steady Progression	**Two Degrees**
61%	73%

Vehicle-to-grid technology
Ninety-six per cent of the time a non-commercial car is not being driven. During some of this time an EV could be connected to the electricity network and instructed to draw from or supply electricity to the system. These instructions would come from an aggregator who could have in their portfolio hundreds or thousands of vehicles. The aggregators would then sell the combined capabilities of the connected batteries to network operators in order to help balance the electricity system at times of high demand or high generation. A more in-depth explanation can be found on our Power Responsive website[15].

Table 4.3 shows, for each of our scenarios, the percentage of consumers who make use of V2G given the right situation, such as the availability of off-street parking and cars not being driven.

Table 4.3
Percentage of electric vehicle (EV) owners who participate in vehicle-to-grid (V2G), when appropriate

Scenario	2030	2050
Community Renewables	2%	13%
Two Degrees	2%	14%
Steady Progression	2%	10%
Consumer Evolution	2%	11%

[15] http://powerresponsive.com/how-smart-charging-can-help/

The net peak time demand for vehicles is illustrated in figure 4.22. The net peak demand is the overall demand from peak time charging minus the supply provided by V2G.

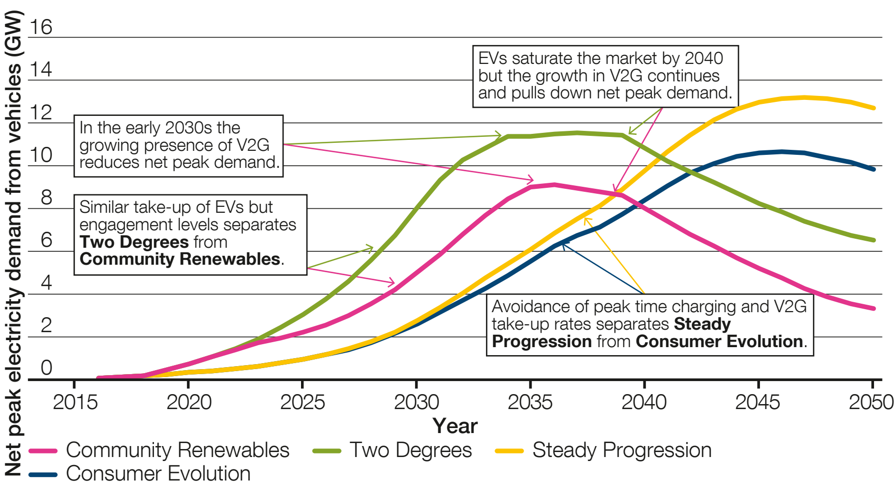
The two 2050 compliant scenarios start with a relatively steep increase in net peak demand. This is brought about by the rapid take up of EVs. The increase in **Community Renewables** is not quite as steep as that in **Two Degrees**. This is mainly due to more engaged consumers who avoid peak time charging.

These initial rates of growth start to slow down in the mid 2030s as the take-up rate of EV cars slows down, consumer peak avoidance increases and V2G begins to become more established. By 2035, in **Community Renewables**, and 2040, in **Two Degrees**, the net peak demand actually starts to decrease. By 2050 these demands are of the same order as those seen in the late 2020s.

For the two non 2050 compliant scenarios the net peak demand reflects the growth of EV cars. These demands are less well dampened, compared to the other scenarios, as consumers do not avoid peak time charging as much and fewer of them take up the V2G option.

By 2030 both the net peak demands are around 3 GW. For **Consumer Evolution** these demands reach their maximum in 2046. They are a year later for **Steady Progression**. After this they slowly decrease, so by 2050 their net peak demands are 10 GW and 13 GW, respectively.

Figure 4.22
Net peak electricity demand from vehicles

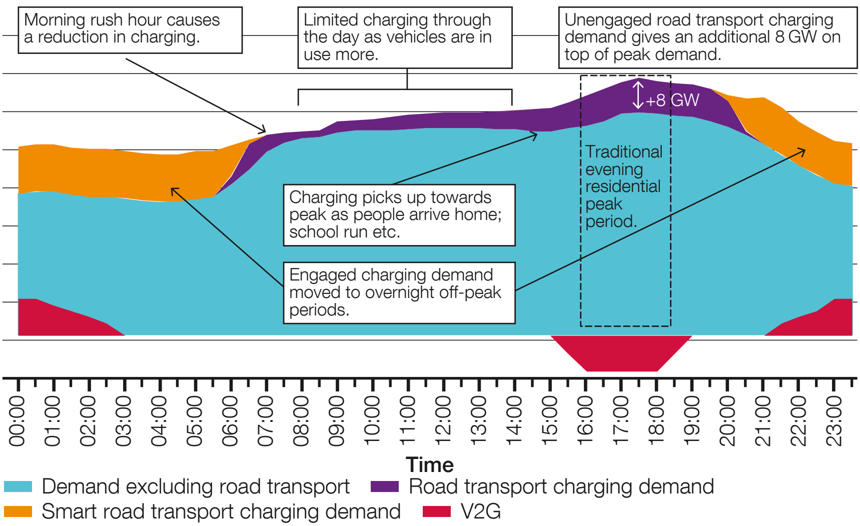


Energy demand

Figure 4.23 illustrates how consumer engagement levels and V2G might affect demand on a winter's day in our **Community Renewables** scenario. In this illustration we have overlaid the potential 2040 charging demand and V2G supply and demand on top of a winter's day profile from 2017/18. As a result of using smart chargers, much of the additional EV demand is moved to between 9pm and 6am. These are traditionally low demand times. At peak times additional demand would be 16 GW. However, V2G will be supplying electricity at this time. In this illustration V2G will provide 8 GW of supply, reducing the amount of generation required to 8 GW.

There is another advantage of V2G. As some vehicles will not, or cannot, charge overnight there is also an increase in daytime demand. This helps to smooth the within-day electricity demand profile.

Figure 4.23
Peak time charging and the effects of engaged consumers and V2G in 2040



Spotlight

How might autonomous vehicles affect electricity demand?

Growth in autonomous vehicles has the potential to dramatically change how people and goods are transported in the future.

In this spotlight we explore some of the ways this growth might affect energy demand. Exactly how autonomous vehicles could change energy use for transport is uncertain. It is likely that the mileage per vehicle will rise, while the number of vehicles per person falls. However, many different factors could impact whether this increases or decreases overall energy demand for transport. This is an emerging area of modelling. We would like to hear from stakeholders with views in this area to further refine our analysis.

The Society of Automotive Engineers defines autonomous vehicles by categorising them from 0 (no automation) through to level 5 (full automation with no human driver input in any situation). Between these two extremes, there are features that exist today such as adaptive cruise control and lane keeping assistance (level 1) and self-parking (level 2).

Shared and autonomous vehicles are not the same thing, but autonomous vehicles are likely to lead to greater sharing of vehicles. Firstly, consumers will be able to call an autonomous vehicle, with the vehicle able to move from one user to another easily. Secondly, autonomous vehicles will be internet connected so there will be better real-time data available, to show where local people are making similar journeys. This will enable easier sharing of journeys if consumers want this. In addition, it is likely that the business models for autonomous vehicles may look different in different environments. For example, there could be greater sharing in urban environments.

The timescales of when autonomous vehicles will be commerically available makes them highly likely to be electric. As the UK Chancellor noted in his autumn budget speech in 2017 "our future vehicles will be driverless, but they'll be electric first"[16].

[16] https://www.gov.uk/government/speeches/autumn-budget-2017-philip-hammonds-speech

Spotlight

How might autonomous vehicles affect electricity demand?

The illustration in figure 4.24 gives an example of a 'day in the life of' a level 5 autonomous EV and a conventional EV. It highlights some of the ways that automation could change how cars are used. In this example, data encourages a user to share journeys with a neighbour, and a single vehicle also provides mobility for the user's elderly parents. At first glance, this might suggest a much more efficient way of travelling for all. One car is doing more miles, but providing mobility for four people. In the long term, this might result in fewer cars per person on the road, but each of them doing more miles and serving more people.

However, this type of vehicle usage may not necessarily reduce the energy required for transport compared to today. For example, if the elderly parents had previously used public transport, calling a car instead would use more energy per person. As a result, it's difficult to say whether sharing cars in this way will increase or decrease the overall energy required for mobility. The fact that an autonomous car can make some journeys while empty could also increase its overall mileage compared to a conventional car. The computing power required for a vehicle to drive itself could use lots of energy too.

On the other hand, autonomous cars are likely to be able to drive more closely together due to better safety features, and can be programmed to drive in a smooth and efficient manner. As cars communicate between themselves and avoid traffic, this could enable better congestion management. All of these aspects should lead to improved vehicle fuel efficiency.

In addition, as figure 4.24 shows, autonomous vehicles could charge in a different way. Because it's easy to move these cars without a driver, these vehicles could quickly be moved to a convenient location to draw power from the grid when output from renewable generation is high, and the price of energy is cheaper. Similarly, autonomous vehicles may also be able to provide vehicle-to-grid services in a more flexible manner than conventional cars, due to their ability to drive themselves to different locations during the day. You can find out more about the impact of vehicle-to-grid services on page 80.

This year in our modelling, we anticipate that the use of private autonomous vehicles will increase the mileage per vehicle compared to a conventional car. However, it is likely to reduce the number of vehicles per person. For example, a household might move from two conventional cars to one private autonomous car. They would use the latter more intensively, alongside occasional shared vehicle use.

Shared autonomous vehicles further extend this trend. We anticipate such vehicles would have greater mileage than a conventional or a private autonomous vehicle. This would further reduce the number of vehicles per person. Effectively some of the population will choose to no longer own cars but rely solely on shared autonomous vehicles.

We have not currently made any assumptions about whether autonomous vehicles will be more or less efficient in terms of energy demand than conventional vehicles, as this remains uncertain. Similarly we have not modelled the impact of users moving away from public transport to use autonomous vehicles instead. We will seek to continually refine these assumptions as new data and stakeholder insight emerges.

In all scenarios, the rollout of autonomous vehicles begins in the late 2020s. Growth is faster in the 2050 compliant scenarios of **Community Renewables** and **Two Degrees**. These scenarios see 50 per cent of new private car sales being autonomous cars by 2050. This compares to only 25 per cent of new cars in the non 2050 compliant scenarios. In all scenarios the vast majority of autonomous vehicles are EVs. There are also a small number of hydrogen fuel cell autonomous vehicles in the 2050 compliant scenarios.

Figure 4.24
A day in the life of autonomous and conventional electric vehicles (EVs)

	8am	9am	12pm	4pm	6pm	10pm	
Autonomous EV	Car drives me to work while I catch up on emails. My car has calculated that my neighbour and I work in the same town and start work at a similar time, so he accompanies me	Car leaves my workplace, picks up my elderly parents and drives them to the bridge club	Car takes my parents home from bridge club, then heads to central depot to charge using excess solar power	I order a super-market shop, which my car collects before coming to pick me up from work	Car drops me home from work	I fancy going to the cinema. My car drives me there and back. It then drives itself to a central depot to provide balancing services overnight	**EV used by 4 people, drives 64 miles**
	10 miles	**14 miles**	**8 miles**	**12 miles**	**10 miles**	**10 miles**	
Conventional EV	Drive myself to work	Car stays in office car park all day		I drive home via supermarket and pharmacy	I plug my car in to charge	I drive to the cinema and back, then leave my car on the drive	**EV used by 1 person, drives 30 miles**
	10 miles			**14 miles**		**6 miles**	

Energy demand

4.5 Transformation demand

In all the scenarios gas is used to produce electricity and in some of the scenarios substantial amounts of gas or electricity are used to create hydrogen. This section considers the amount of gas and electricity that is 'transformed' into other kinds of energy.

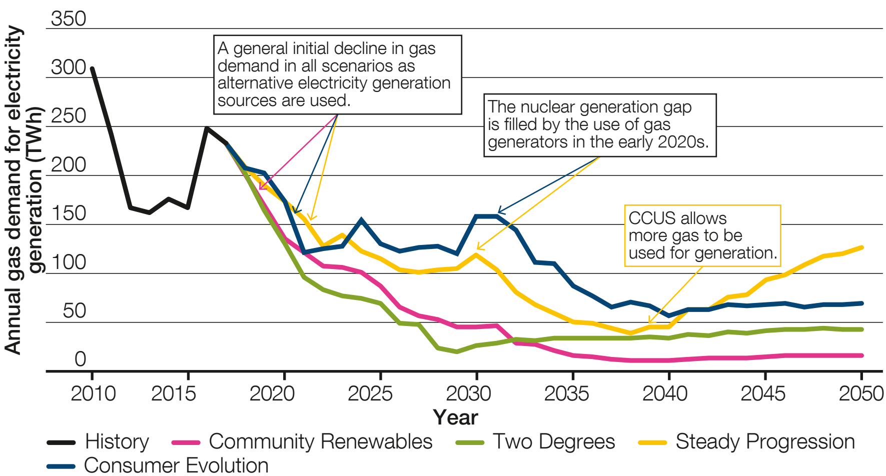
Gas for electricity generation

Gas for electricity generation has declined for a number of years, with the notable exception of 2016 when the price of gas was relatively low. This can be seen in figure 4.25.

As a rule, this decline continues out to the late 2020s. **Steady Progression** and **Consumer Evolution** see short-term spikes around 2030. This is caused by the temporary reduction in nuclear capacity, as older nuclear power stations close and are not immediately replaced by new ones. Gas-fired electricity generation is used to fill the energy gap.

After 2038 in **Steady Progression**, gas demand for electricity generation increases significantly. This is due to the use of CCUS with gas-fired generation, which permits power stations to continue to use gas while emitting less carbon.

Figure 4.25
Gas demand for electricity generation

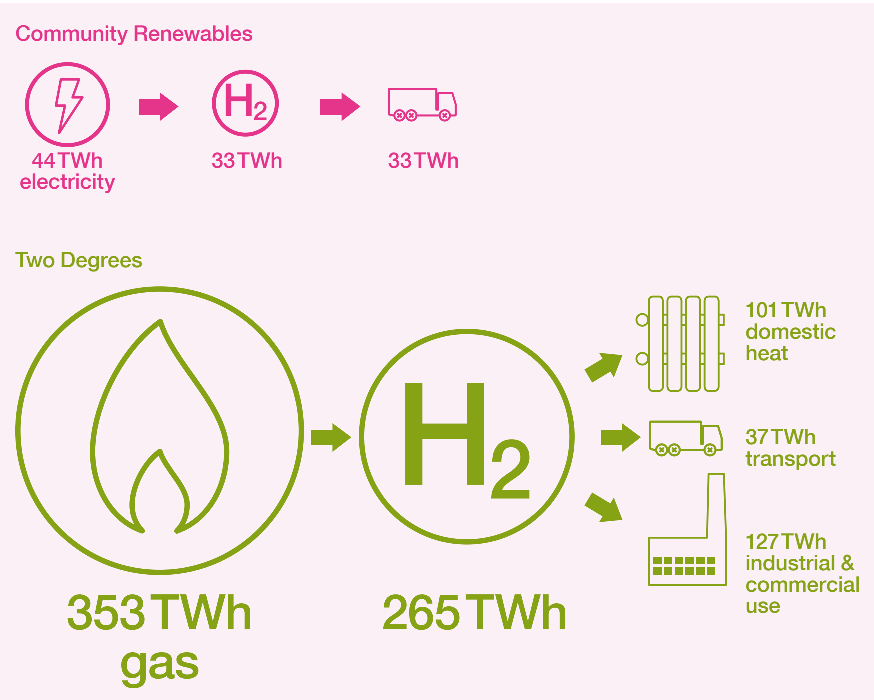


Hydrogen production

Hydrogen features most prominently in our two 2050 compliant scenarios in *FES 2018*. These demonstrate the potentially important part that hydrogen could play in a decarbonised future for GB. However, for this to happen a number of challenges need to be overcome in both the production of hydrogen, and the infrastructure and coordination required for its widespread use.

Our assumptions see hydrogen used primarily for transport in the **Community Renewables** scenario. In **Two Degrees** it is used for residential heating and industrial and commercial processes as well as transport. In addition, in the **Consumer Evolution** and **Steady Progression** scenarios, there are some very small amounts of hydrogen used for transport only, mainly heavy goods vehicles, by 2050. We do not currently include hydrogen blending with natural gas in our scenarios. You can find out more about this process in our hydrogen spotlight on page 89.

Figure 4.26
*Hydrogen production and use in **Community Renewables** and **Two Degrees***



Energy demand

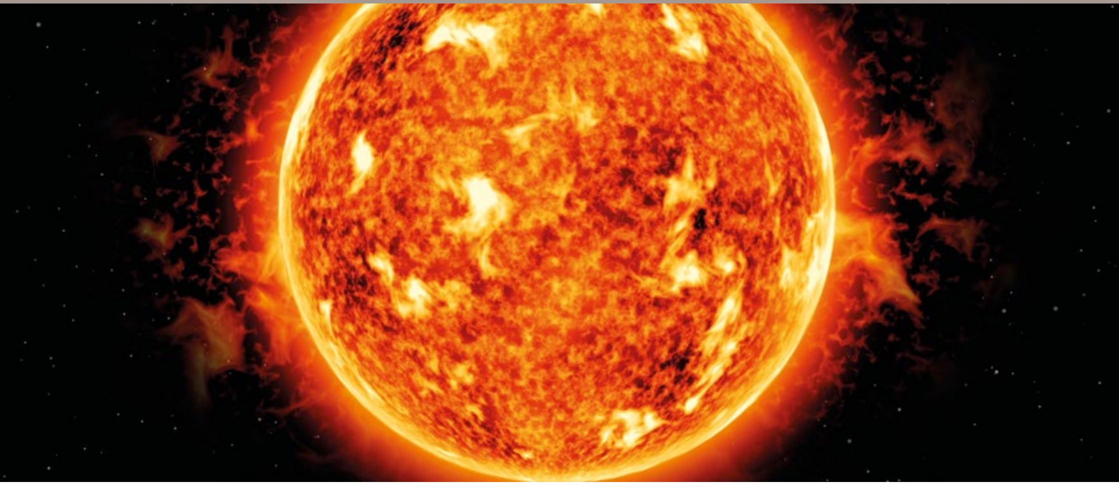
As can be seen in figure 4.26, we are assuming different means of hydrogen production in the scenarios. In **Community Renewables**, a high level of renewable generation capacity means that there is the opportunity to use electricity at times of excess generation to produce hydrogen via electrolysis. Hydrogen production begins to grow in the mid 2030s, coinciding with the rapid growth of solar capacity. By 2050, 44 TWh of electricity is used to produce 33 TWh of hydrogen. All of this is used for transport, mainly heavy goods vehicles.

Delivering hydrogen for transport at this scale requires significant investment in electrolysis and hydrogen refuelling capacity. This scenario requires either further innovation to bring down costs or policy support to encourage hydrogen production and use.

In **Two Degrees**, steam methane reforming converts natural gas into hydrogen at a larger scale. Hydrogen is used not only for transport but also for industrial use and domestic heating in some parts of the country. By 2050, 10 million homes are connected to a hydrogen network. Here, CCUS would be required to decarbonise this method of production.

Hence hydrogen production begins around 2030, coinciding with the large scale commercialisation of CCUS, and grows rapidly to reach 265 TWh by 2050.

The rollout of hydrogen heating systems would require buildings to be connected to a supply of hydrogen. Networks in a hydrogen region would therefore need to be converted to carry hydrogen instead of natural gas, with buildings no longer receiving a piped natural gas supply. Replacement of domestic boilers occurs at the same time. The conversion to hydrogen requires strong policy direction and support from government. It would be comparable to the conversion from town gas to natural gas that took place in the UK in the 1960s and 70s.



Spotlight

What is hydrogen and how might it feature in the future of energy?

Hydrogen is the most abundant element in the universe. At room temperature and pressure it is a colourless, odourless gas. Currently, the majority of the hydrogen being produced in the world is used in the production of ammonia and methanol and in oil refining.

In recent years, hydrogen is increasingly being discussed as a potential energy vector for such uses as heating and transport. An energy vector allows energy to be moved and converted into other forms of energy. Electricity is an example of an energy vector, as it connects primary sources of energy such as wind, sunlight and fossil fuels to end uses such as light, heat and transport. Hydrogen too can be created from other forms of energy and used in a variety of ways, as discussed below.

Hydrogen has some different physical properties compared to familiar fuels such as natural gas:

- When hydrogen reacts with oxygen it releases only energy and water. As no carbon dioxide is emitted at the point of use, hydrogen has a potential decarbonisation advantage.
- Hydrogen gas also has a very low energy density by volume. This means that to deliver a similar amount of energy as natural gas, hydrogen gas needs to be compressed to a higher pressure or delivered at a higher flow rate.
- Hydrogen is a very small and light molecule, meaning that it can leak rapidly through small holes and can diffuse into some metal structures making them more brittle. For this reason, some types of steel are unsuitable for transporting hydrogen. This may include some types of pipelines used in GB's gas networks. However large parts of the distribution gas network are replacing metal pipework with polyethylene pipes which are suitable for transporting hydrogen at lower pressures.
- Hydrogen has different burning characteristics to natural gas. This means that burners in heat appliances designed for using natural gas would have to be replaced. Hydrogen is more flammable than natural gas, but disperses more quickly in the event of a leak.

Hydrogen production

There are a number of methods to produce hydrogen:

Steam methane reforming combines methane and water and converts these to hydrogen and carbon dioxide. Steam methane reforming is currently significantly cheaper than any other method of hydrogen production. It is the most widely used method in the world today. However, unless this method is paired with CCUS, it still emits significant amounts of carbon dioxide. The hydrogen produced by this process is pure enough for most applications. The exception is hydrogen fuel cells, where hydrogen produced by steam methane reforming requires further purification before being used in fuel cells.

Electrolysis uses an electric current to split water into hydrogen and oxygen. Electricity and highly pure water are the only inputs of this process. This method has the potential to produce hydrogen with minimal carbon emissions provided that the electricity used in the process is from a low carbon source. However this is a much more expensive method of hydrogen production than steam methane reforming. Electrolysis produces a very high purity hydrogen gas which is suitable for fuel cell use.

Numerous other methods of hydrogen production exist or are in development. As these are not widely commercially available at this stage, we have not considered these in our *FES*.

Hydrogen use

Hydrogen can be used for heating in a similar way to natural gas. There have been a number of hydrogen boilers developed, including some combined with fuel cells. These would require the replacement of the boiler but little further modification to homes. Hydrogen cookers are also available, or conventional gas cookers can be converted to run on hydrogen.

Electricity produced from hydrogen using a fuel cell can power EVs, with a range and refill time similar to conventional vehicles. Heavy goods vehicles that need to drive for long distances are more difficult to electrify. Hydrogen fuel cells, with their increased energy storage capability, may be more suitable for this class of vehicles.

Hydrogen internal combustion vehicles have also been developed. These typically have significantly lower fuel efficiency and therefore a shorter mileage range than fuel cell vehicles.

There is also potential for hydrogen to be used in other applications, such as CHP units. Conversion of hydrogen to electricity in a fuel cell produces waste heat. With a CHP unit this can be used to heat buildings, improving fuel efficiency.

In addition, some studies are examining the possibility of injecting a proportion of hydrogen into the natural gas network alongside natural gas. This is known as hydrogen blending. The resulting gas mixture would have a lower carbon footprint than natural gas when burnt. At low concentrations of hydrogen, appliances do not need to be adapted. In contrast, gas mixtures with a higher concentration of hydrogen require the conversion of appliances and pipes, just as if pure hydrogen was being used. However, this approach leads to a smaller reduction in carbon emissions than if pure hydrogen were used.

Lastly, hydrogen production could offer a demand response service to the electricity system. For example, electrolysis uses a lot of electricity and so could be scheduled for periods of low electricity demand, or when there is an excess of renewable electricity. Some electrolysis technologies can be switched on and off very quickly so could potentially be used for flexibility services that require a fast response.

Chapter five

Spotlight

Changing gas flows Pg 120

Energy supply

5.1 Energy supply

When we discuss energy demand in chapter four, it makes sense to consider gas and electricity together, as in this context they are interchangeable. Houses can be heated by gas, electricity or a combination of the two, for example. When we consider energy supply, electricity and gas are not interchangeable. However, the interaction between them is extremely important and it is essential that we consider the two systems together in our planning.

The whole system view

Considering gas and electricity supply together allows us to create a better view of the whole energy system. For example:

- The gas national transmission system (NTS) supplies gas to local distribution networks for delivery to customers' homes. It also delivers gas to power stations for generating electricity. This electricity is ultimately delivered to the same customers for lighting, cooking and potentially heating. Electricity is also delivered to gas network operators for use in running their networks. When creating our scenarios, we have to meet the needs of all these different customers, while considering the interactions between electricity and gas.
- Increasing intermittent generation from renewable sources can lead to a greater need for flexible gas-fired generation and flexible supplies from the NTS. Interaction between the gas and electricity systems will need to increase as more renewable generation is connected.
- The developing use of hydrogen for both heat and transport is another area where we need to consider both the electricity and gas systems. Hydrogen can be created from natural gas or by electrolysis. It is then used in heating, industrial processes or for transport.

Energy balancing

The modelling for our scenarios considers energy balancing. Our models give a view of future demand and create patterns of electricity and gas supply to meet this. We do not consider all the detailed aspects of supply. In particular, we assume that the networks have enough capacity to meet supply and demand requirements. Network development and operability is discussed in other documents.

Security of supply in our scenarios

We have created scenarios where there is enough gas and electricity supply to meet demand. For electricity, this means meeting the reliability standard set out by the Secretary of State – currently three hours per year loss of load expectation (LOLE). For gas, there has to be enough supply to meet the peak demand on a very cold day, even if the single largest piece of supply infrastructure were to fail. This is called a 1-in-20 peak winter day.
We have sometimes been asked why we do not create a more challenging scenario where the security of supply standard is not met. The answer is that the scenarios support our planning for a secure and operable network. Therefore, none of our scenarios lead to a network that fails the security standards.

A word about units

Gas and electricity annual demands and generation outputs are discussed in units of energy; for example Gigawatt hours (GWh) or Terawatt hours (TWh). Electricity peak demand and generation capacity are discussed in units of power: Megawatts (MW) or Gigawatts (GW). A 1 GW power station generating for 1 hour will generate 1 GWh of electricity. Gas peak demands are usually measured as energy used in a day.

Gas supply is usually discussed in units of volume; millions or billions of cubic metres (mcm or bcm). This is because the physical operation of a gas network is governed by how much gas is being moved through pipes and compressors, not by how much energy the gas represents. When creating our supply and demand match, we convert gas demand from energy into volume. We have used volume for all discussion of gas supply, in common with the specialist energy press.

For gas, in Great Britain (GB), a good guide for converting from energy in watt hours to gas volume in cubic metres is to divide by 11. So, for example, 44 GWh approximates to 4 mcm and 880 TWh approximates to 80 bcm.

Energy supply

5.2 **Electricity supply**

Key insights
Commonalities and uncertainties across the scenarios

- All scenarios see high levels of generation growth, but this growth is greater in the 2050 compliant scenarios. All scenarios have higher levels of decentralised electricity than today.
- Offshore wind generation grows strongly in all scenarios. Solar capacity also grows rapidly, but the range across the scenarios is larger than for wind.
- Carbon intensity of electricity generation falls quickly in all scenarios. This happens most slowly in **Consumer Evolution** where carbon intensity falls to below 100g CO_2/kWh by 2035. In contrast, this happens around a decade earlier for the 2050 compliant scenarios.
- Greater levels of flexibility are needed in all scenarios leading to higher levels of storage than in *FES 2017*.
- Carbon capture utilisation and storage (CCUS) features in two scenarios, reflecting uncertainty around its deployment. Similarly hydrogen created by electrolysis features in one scenario, **Community Renewables**.

2017 has been another milestone year in electricity supply, with records broken and the reliance on high carbon fossil fuels continuing to fall.

Previously, electricity supply in GB was very much dependent on large thermal generation pushing power ‘one way’ to passive consumers. Today, this is being replaced by smaller, more localised and intermittent generation. Technological progress, an increasing focus on climate change, and evolving economic conditions have all contributed to this shift.

Consequently, the supply of electricity, rather than demand, will become an increasingly important driver of when electricity is used. At the same time, there is the potential for electricity demand to become more responsive and flexible with the advent of information communications technology (ICT). We have seen some of these areas explored in the demand chapter. For example, we discussed how electric vehicles (EVs) could become a big source of demand flexibility through smart charging. Similarly, smart appliances will enable much greater control over when energy is used with minimal consumer input.

With this evolution, we are seeing more complex flows of energy across networks. As a result, new commercial and technical solutions are emerging, and new parties are entering the energy market. While the move towards decentralised and lower carbon electricity supply is evident in all our scenarios, the pace of change differs. This year we have introduced a new scenario framework to make sure we are modelling the latest energy trends. These have raised new questions and challenges in our analysis as we seek to reflect what a highly decarbonised and decentralised world could look like.

One emerging area of complexity this year is how to optimise both security of supply and affordability when renewable generation makes up a large proportion of supply. Most of the renewable generation can only produce power under favourable weather conditions. As a result, a larger, more diverse, generation mix is needed to meet reliability standards and provide electricity when the wind isn't blowing or the sun doesn't shine.

However, this can also mean that when weather conditions are favourable, it's possible that too much electricity is generated. In our *FES* 2018 analysis, we are seeing times when electricity supply from intermittent or inflexible sources exceeds total demand for electricity in GB and connected markets. This is particularly evident post 2030 in the more decarbonised scenarios.

Supply and demand of electricity must remain in balance on a second-by-second basis to keep networks secure. Any excess of electricity could cause significant challenges for network design and operability. However, renewable and low carbon generation have low marginal costs or can be difficult to turn off, and so current commercial frameworks are unlikely to be able to fully address this problem. Market development, new technologies and new ways of designing and operating networks could all play a role in addressing this issue. They would make sure that any excess low carbon electricity is used, stored or curtailed in the most efficient way. We will discuss and explore operability challenges in more detail in other relevant System Operator documents, such as the *System Operability Framework*.

Another factor to consider is our increased connection with other countries. This year, we have begun to model potential decarbonisation in markets connected to GB. We anticipate that, in scenarios where GB decarbonises more quickly, connected markets will probably decarbonise rapidly as well. Our modelling has shown that there may be instances from around 2030 where connected markets have excess renewable electricity at the same time as GB. Therefore, it may not be possible to balance electricity supply and demand in GB simply by exporting energy to other countries.

This year an increased emphasis on the role of hydrogen has also highlighted potential new business models that span across different fuels. For example, electrolysis could make use of excess renewable output to produce hydrogen. This could then be stored. Gas-electric hybrid products could offer flexibility across different fuel types and networks. In **Two Degrees**, we have considered how CCUS used with steam methane reforming to produce hydrogen, could be run alongside electricity generation to lower the cost of producing flexible, low carbon electricity.

All this illustrates how flexibility of both demand and supply is becoming increasingly valuable to maintain a balanced and secure electricity system. This section examines potential developments in GB electricity generation capacity as a whole, before considering low carbon and renewable generation in greater detail. Following this, we look at flexible sources of electricity supply including electricity storage, interconnectors and thermal plant.

Energy supply

GB electricity generation capacity
Figure 5.1 shows how the technologies making up GB generation capacity could change in the next 30 years. The markers plot the amount of renewable generation capacity. In all scenarios, there is a marked increase in the amount of renewable and low carbon electricity generation up to 2050. At the same time, the proportion of decentralised generation capacity grows across all scenarios. The carbon intensity of electricity falls, as shown in table 5.1, and is below 100g CO_2/kWh in all scenarios by the mid 2030s.

The 2050 compliant scenarios of **Community Renewables** and **Two Degrees** have more renewable generation and a higher amount of generation capacity. This is because the majority of renewable generation is intermittent, only generating when weather conditions are favourable. Therefore, more generation capacity is needed to meet the reliability standard of three hours per year LOLE. Specifically, the scenario with the highest amount of generation, **Community Renewables**, has 78 GW more capacity by 2050 than **Steady Progression**, the lowest scenario.

The *Data Workbook* includes a full view of generation capacities for each scenario, by technology type and year. There is further detail on the decentralisation of electricity generation capacity in chapter three.

Figure 5.1
Generation capacity by technology type and amount of renewable capacity for 2030 and 2050

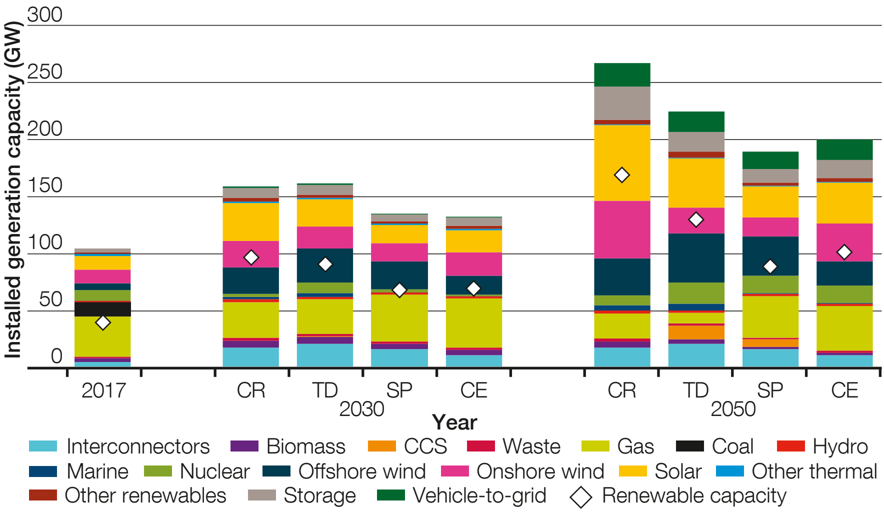


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Table 5.1
Carbon intensity of electricity (gCO_2/kWh)[1]

Scenario	2017	2030	2050
Community Renewables	266g	75g	32g
Two Degrees	266g	48g	20g
Steady Progression	266g	117g	52g
Consumer Evolution	266g	146g	72g

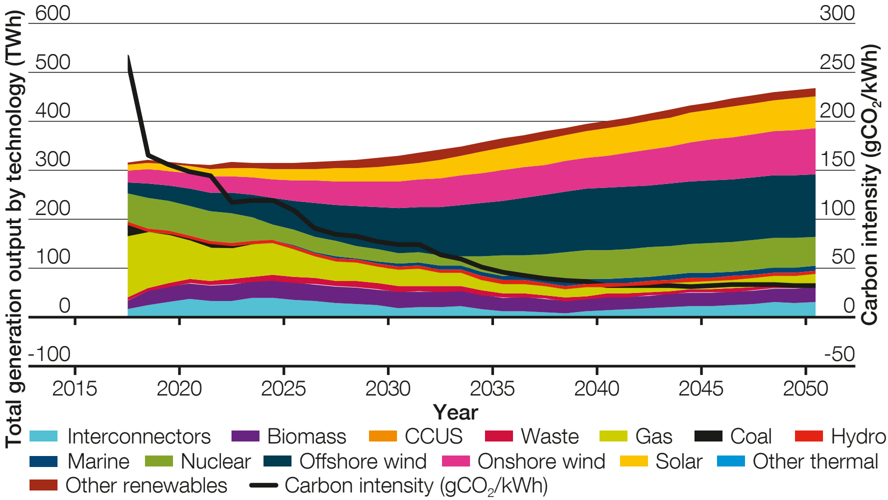
[1] The 2017 figure is from National Grid's control room, based on actual data from 2017, excluding some decentralised generation. Forward projections for 2030 and 2050 are based on BID3 modelling. Further details can be found in the *Modelling Methods* document.

Energy supply

Figure 5.2 shows the annual electricity output of different generation technologies and their carbon intensity in the **Community Renewables** scenario. Here, the electrification of transport and heat increases demand, leading to higher generation output being produced to meet demand.

By 2030, renewable generation, particularly wind and to a lesser extent solar, makes up more than 75 per cent of generation output. By 2030, the carbon intensity of electricity has fallen to 75 grams of CO_2/kWh, and then continues to fall to reach 32 grams of CO_2/kWh by 2050. Further information about the carbon intensity of electricity can be found in our spotlight on page 30.

Figure 5.2
Electricity output and carbon intensity of electricity, ***Community Renewables*** *scenario*



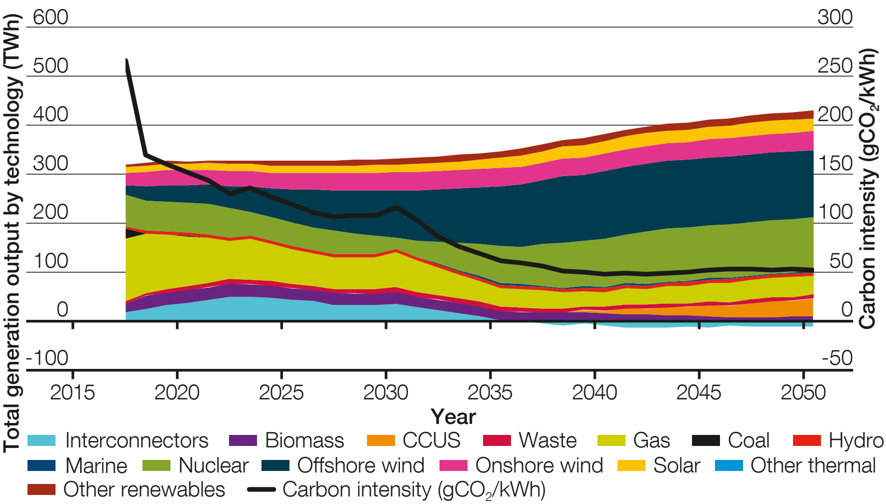
Chapter five

In contrast, in the **Steady Progression** scenario shown in figure 5.3, the slower electrification of transport and limited electrification of heat mean that electricity demand grows more slowly. More output is provided by thermal generation, particularly gas.

There is a temporary increase in carbon intensity of electricity at the end of the 2020s. This is due to a number of factors, notably the temporary decrease in nuclear capacity, discussed later in this section. This leads to an increase in gas-fired generation until new nuclear capacity becomes available. Consequently, the carbon intensity of electricity reduces more slowly than in the 2050 compliant scenarios, reaching 52 grams of CO_2/kWh by 2050.

The *Data Workbook* includes further information on generation output and carbon intensity of electricity for all scenarios.

Figure 5.3
Electricity output and carbon intensity of electricity, ***Steady Progression*** *scenario*



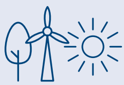
Chapter five

Energy supply

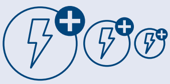
Renewable and low carbon generation

We have seen the continuing evolution of regulation and policy support for low carbon generation in GB in recent years. Despite subsidy support now reducing for many forms of renewable generation, GB has seen sustained growth in renewable output, leading many to name 2017 as the 'greenest year ever'. In this section, we look at renewable and low carbon generation in more detail.

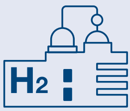
Key insights



- Subsidy support for renewable generation is reducing. However, continued reductions in cost, technology developments and the drive for decarbonisation mean that growth will continue at pace for most low carbon technologies.



- From 2030 onwards, particularly in the 2050 compliant scenarios, we anticipate time periods where there may be an excess of electricity in GB. In order to meet decarbonisation requirements, more inflexible and intermittent generation is built. However, the capacity required to meet security of supply standards at peak times means that there is an oversupply of output at times during the year. Market development, new technologies and new ways of designing and operating networks will be needed to address the operational challenges that arise as a result.

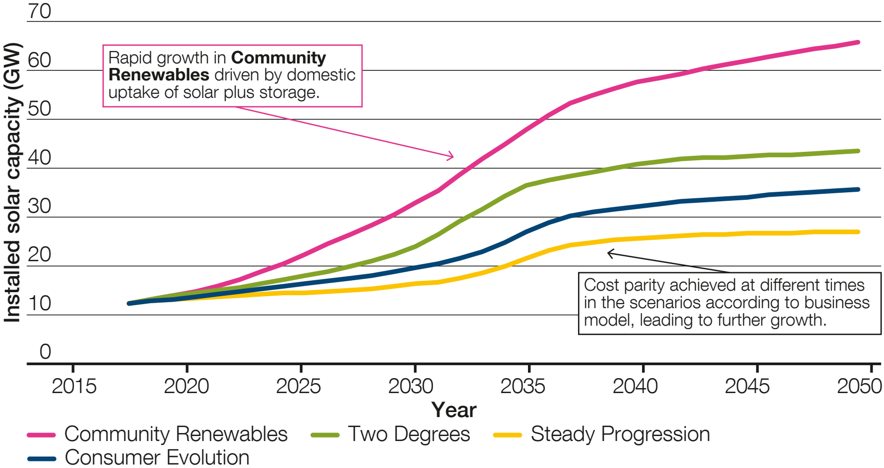


- In scenarios with a hydrogen economy, new business models could develop that provide greater flexibility for electricity.

Solar

The falling cost of solar technology and co-location with storage leads to significant solar growth in all scenarios. Even **Steady Progression** has more than double today's solar capacity by 2050.

Figure 5.4
Solar capacity



Energy supply

Growth in solar capacity is most pronounced in **Community Renewables**. This is due to falling costs, facilitative government policy and consumer desire to manage their own electricity supply. As a result, there is strong take-up of domestic solar and micro storage systems. By 2030, 33 GW of solar is installed. Around half of this is micro solar, such as rooftop installations on homes and industrial buildings. In **Two Degrees**, growth in solar capacity is lower than **Community Renewables**, but still substantial. In **Two Degrees**, there is greater development of larger scale solar farms connected to the transmission network.

With the growth in solar capacity, it will be challenging to manage at times of peak output in summer. During these months, some areas with high solar generation will see electricity supply exceed local demand. This will lead to power being exported back onto the transmission network for use elsewhere in GB. We anticipate that by the early to mid 2020s, the lowest demand on the transmission network will regularly coincide with periods of high solar output. This will typically be around 2pm on summer afternoons. This is discussed further in chapter three.

As noted previously, from 2030, in the 2050 compliant scenarios, total output from renewables, including solar, could exceed total demand in GB at certain times. In this context, co-located storage (where electricity storage is located on the same site as generation) will play an important role in absorbing excess solar power.

Co-located storage can help solar projects to access other revenue streams, for example price arbitrage. It can also help to avoid grid curtailment. Rather than stopping generation when the network faces constraints or when the price is low, solar energy can be diverted to storage. It can then be discharged at a later point, when networks are not constrained or prices are higher.

Trials are currently underway to investigate whether the purchase of some network services could be moved closer to real time[2]. Such a move would benefit some generation, such as solar and wind, where it is more difficult to predict output more than two days in advance.

Wind

Wind capacity increases across all scenarios as shown in figure 5.5. Much of this growth is in offshore wind. The prices bid by offshore wind projects in the 2017 Contracts for Difference (CfD) auction demonstrated how far offshore wind costs have fallen in recent years. This is as a result of factors such as larger turbines, maturing supply chains and new financing arrangements.

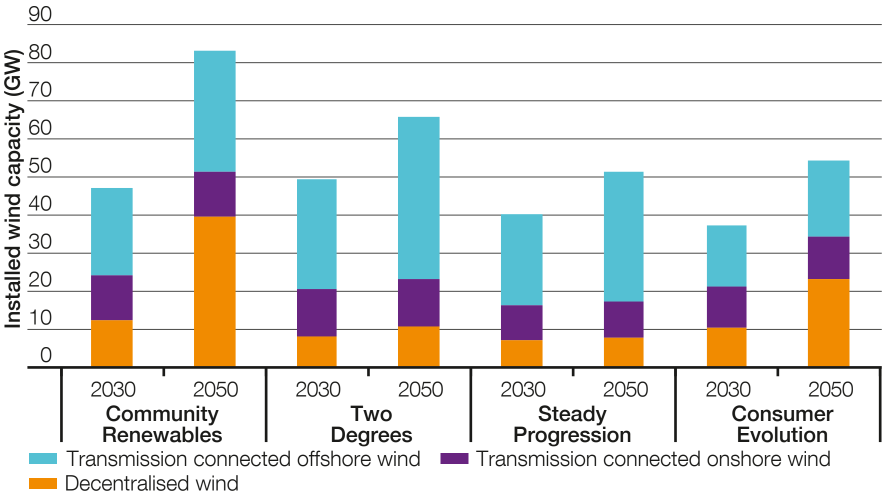
We also see growth of onshore wind in all scenarios. The majority of onshore wind sites are assumed to repower in all scenarios. This is when a site is re-fitted with new equipment when the original assets reach the end of their life.

A lot of onshore capacity growth is in Scotland. This is primarily due to favourable wind conditions and availability of land. In the more decentralised scenarios, a further driver for growth is the assumption that there will be more consumer acceptance of onshore wind. Alongside this, we have assumed a facilitative policy environment for local wind schemes. As a result, there is a dramatic growth in decentralised onshore wind in the **Community Renewables** scenario.

As a more mature technology, onshore wind is less likely to see further price falls compared to offshore wind. However, we anticipate some positive spill over effects from offshore wind developments. This could include innovation in maintenance and the further growth of supply chains. Co-location with storage is another factor which can enable developers to reduce connection costs and access other revenue streams, as described above.

[2] See for example https://www.nationalgrid.com/sites/default/files/documents/Product%20Roadmap%20for%20Frequency%20Response%20and%20Reserve.pdf

Figure 5.5
Centralised and decentralised wind capacity



Nuclear

The majority of existing nuclear plants in GB are approaching the end of their lives, and will be retired by the end of the 2020s. As in FES 2017, we anticipate a reduction in nuclear capacity in all scenarios in the next decade, as older nuclear plants close before new plants are ready to generate.

More than 7 GW of new nuclear is expected in all scenarios, with much of this new generation being constructed in the 2030s. **Two Degrees**, as a centralised, decarbonised scenario, has the highest level of installed capacity, with 17 GW of new nuclear by 2050. This compares to just less than 8 GW in **Community Renewables**.

This year, we have assumed the rollout of small modular reactors (SMRs) in **Consumer Evolution**. These reactors could offer the potential for faster build compared to larger nuclear projects, because such projects are smaller and more standardised. However, the size of these projects (typically 300–400 MW) means they are still large enough to connect to the transmission network.

Energy supply

Carbon capture utilisation and storage

CCUS, as a large scale technology, features in the two more centralised scenarios of **Two Degrees** and **Steady Progression**. In both cases, CCUS is used with gas-fired generation to provide low carbon electricity. CCUS can also be paired with other generation methods, such as biomass or coal. However, our scenarios assume that gas with CCUS is the most likely pairing in GB. This is because there are GB sources of gas, and coal-fired power stations will have stopped generating several years before CCUS is commercially viable. There are also constraints on the amount of biomass that can be grown or imported at large scale. This is discussed further below.

In **Two Degrees**, CCUS is also used with steam methane reforming to produce hydrogen with lower carbon emissions. This process is described in more detail in chapter four. As CCUS is used for both hydrogen production and electricity generation in **Two Degrees**, this helps to build a scalable market for the technology. Consequently CCUS reaches commercial viability in 2030 in this scenario. By 2050 there is 12 GW of CCUS gas-fired generation.

We assume that in **Two Degrees**, there are benefits to be gained by co-locating hydrogen production plants with CCUS gas-fired generation. CCUS technology can be used across both plants. This provides potential efficiencies, as well as allowing the generation to operate flexibly without disrupting the CCUS process. There is also the potential for excess hydrogen to be stored and burnt separately for electricity generation (although we have not currently modelled this in the scenario).

However, in **Steady Progression**, CCUS is only used with gas-fired electricity generation. It therefore develops at a later date, beginning in 2039, and the electricity output from these plants is less flexible than equivalent plants in **Two Degrees**.

Other renewable technologies

As part of our analysis, we also consider a number of other technologies, including marine generation, renewable combustion and renewable gasification technologies. For gasification technologies, low carbon biogas is produced and used to run a turbine. This provides electricity that is both low carbon and flexible. However, the biogas produced can also be processed further and fed into the gas network. Consequently we have included these technologies in our electricity supply analysis, but have limited their growth, as these resources may be better suited as a means to decarbonise heat in the future.

Biomass generation refers to electricity generated by burning organic matter, such as certain crops, wood pellets etc. This allows the production of electricity with lower carbon emissions than fossil fuels, but where it is possible to easily vary output. We have included biomass generation in our analysis, noting the physical limitations of this technology. For example, there may be limits on the amount of land available to grow suitable crops for burning. There may also be constraints on importing very large amounts of biomass materials. In addition, the burning of biomass materials, unless filtered, emits particulates and other pollutants. As a result, biomass generation is more likely to be situated away from population centres, providing a further limitation on growth.

The highest installed biomass capacity can be found in the 2050 compliant scenarios in the late 2030s. After this point some biomass capacity reaches the end of its life. Some, but not all, of these plants are replaced in **Community Renewables**. This compares to a much faster reduction in **Two Degrees**. Here biomass is supplanted by other low carbon generation. A full breakdown of all renewable combustion and renewable gasification technologies can be found in the *Data Workbook*.

Sources of flexibility

Flexibility refers to the extent that a party can respond to changing conditions. This could be by rapidly changing the amount of electricity they produce or use, or by providing flexibility services to network operators to keep systems balanced and secure.

This section explores supply side sources of electricity flexibility. It considers the future growth of electricity storage, interconnectors and thermal plant. Demand side sources of flexibility are discussed in chapter four.

Key insights

- Electricity storage capacities increase in all scenarios. This increase is driven by continued price falls for battery technologies, and the increasingly important role for storage in balancing renewable output.
- Electricity interconnector capacity increases in all scenarios, and this year we have modelled the impact of decarbonisation in connected countries.
- In all scenarios the economics of thermal plant will increasingly be reliant on their ability to provide flexibility and key network services. Particularly in the non 2050 compliant scenarios, gas continues to also provide some baseload power.

Electricity storage

Technological progress continues at pace for electricity storage. Globally, the accelerated move to electrify transport has helped to create economies of scale in battery production. In GB, the launch of the Faraday Challenge and the National Battery Manufacturing Development Facility in 2017, illustrates the continued interest and investment in electricity storage technology. In addition to batteries, our analysis continues to consider pumped hydro as well as compressed air and liquid air storage. Hydrogen can also be used to convert and store energy, but is not considered in this section as it is not electricity specific.

We have assumed that storage providers will need to obtain revenue from a number of sources to remain viable. This could include arbitrage, balancing and ancillary services, and providing services to network operators. In addition, our modelling of storage capacity and energy requirements is increasingly driven by the need for storage to absorb excess energy from inflexible or intermittent generation at times of low demand. A further development is the co-location of storage, not just with renewable technologies but also thermal plant. This combination means that a project can optimise across both generation and storage assets to sell a broader range of services.

Energy supply

As can be seen in figure 5.6, beyond 2030 there is a marked increase in electricity storage capacities in most scenarios. The range across the scenarios also broadens. This is due to a number of factors. In **Community Renewables**, beyond 2030 electricity demand increases, with a greater proportion of this demand being met by renewable generation. This leads to high flexibility requirements. The large amount of solar capacity in this scenario is often paired with storage. For example, residential solar plus battery systems can offer a number of benefits to households.

In a decentralised world, we assume that the costs of these continue to fall and become more widely available. Alongside smart metering, households can use batteries to reduce more expensive peak electricity use, as a source of back-up electricity, or to maximise the energy they use from solar systems.

High flexibility is also required in **Two Degrees**. This is due to the large proportion of renewable capacity. This flexibility is met, in part, by other sources such as CCUS generation and interconnectors. **Consumer Evolution** also has a high amount of thermal plant that can provide flexibility. However, in this scenario a relatively high amount of decentralised solar generation is paired with storage.

Beyond 2040, storage capacity only grows significantly in **Community Renewables**. In this scenario, there is less nuclear and no CCUS, but large amounts of solar and wind. Storage plays an increasingly important role. It not only provides energy at peak times, but also absorbs excess renewable generation for use at different times of the day. Additional information on the energy volume provided by storage in all scenarios can be found in the *Data Workbook*.

This section does not include EV batteries that can be used for vehicle-to-grid (V2G) purposes. These are discussed in chapter four.

Figure 5.6
Electricity storage capacity

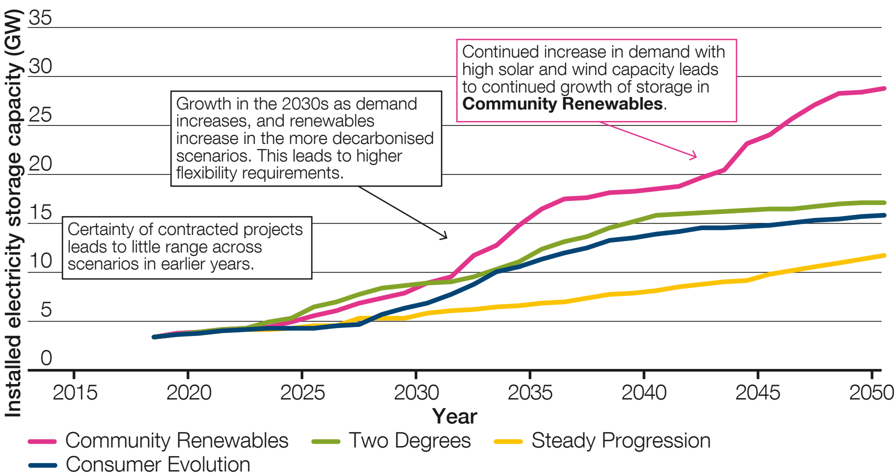
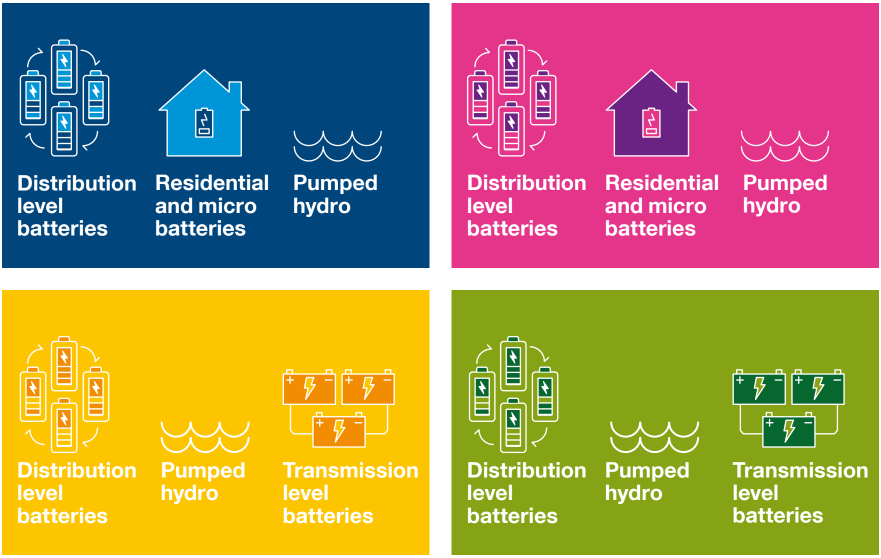


Figure 5.7
Top three electricity storage technologies by scenario



Electricity interconnectors

The UK's decision to leave the European Union in 2016 introduced some uncertainty around future energy trading. However, additional regulatory certainty has since developed in the area of interconnectors, with Ofgem holding a second 'cap and floor' regime in GB. Added to this was the success of interconnector projects in securing agreements in the Capacity Market. Cap and floor regimes essentially provide a limit on both the potential profit and the loss that can be made by an interconnector project. In doing so, they reduce the risk of the large capital investment required.

Last year, we began using a pan-European dispatch model to study interconnector flows. This year we have further refined our analysis by developing a range of European scenarios. These account for uncertainty in Europe as well as GB. They are based on scenarios developed by European system operators and the European Network of Transmission System Operators for Electricity (ENTSO-E).

Our analysis assumes continued market harmonisation between GB and Europe once the UK has left the European Union. This includes for example that GB continues to participate in the Internal Energy Market, or similar future arrangements are developed. For further detail on our modelling changes, European scenario sources and assumptions please see the *Modelling Methods* document.

This year, our outlook for interconnector capacity is similar to *FES 2017*. We see greater certainty in earlier years as a result of interconnector project success in the Capacity Market and the number of projects already under construction.

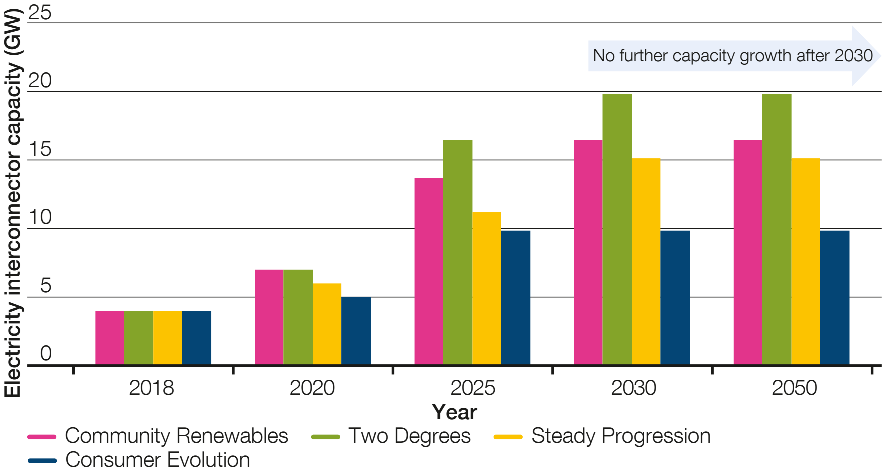
Energy supply

Interconnection is generally higher in the 2050 compliant scenarios, as shown in figure 5.8. This is because more flexibility is needed to balance intermittent output from renewable generation. However, in scenarios with greater decentralisation, capacity is likely to be lower. In these worlds, flexibility is more likely to be provided by smaller scale projects, such as domestic storage or distribution connected thermal plant. **Consumer Evolution**, as both a more decentralised and slower decarbonising scenario, sees the lowest level of capacity built, and **Two Degrees** the highest.

In all scenarios, no new interconnector projects are built after 2030. As more projects are built, the difference in electricity price between the connected markets will reduce. Buyers in more expensive markets can access cheaper electricity from other countries when required. In GB, the availability of other sources of domestic flexibility also reduces potential profit from interconnection projects.

Eventually a ‘saturation point’ is reached in each scenario. This is when an additional interconnector project will no longer benefit from a prolonged price differential across connected markets.

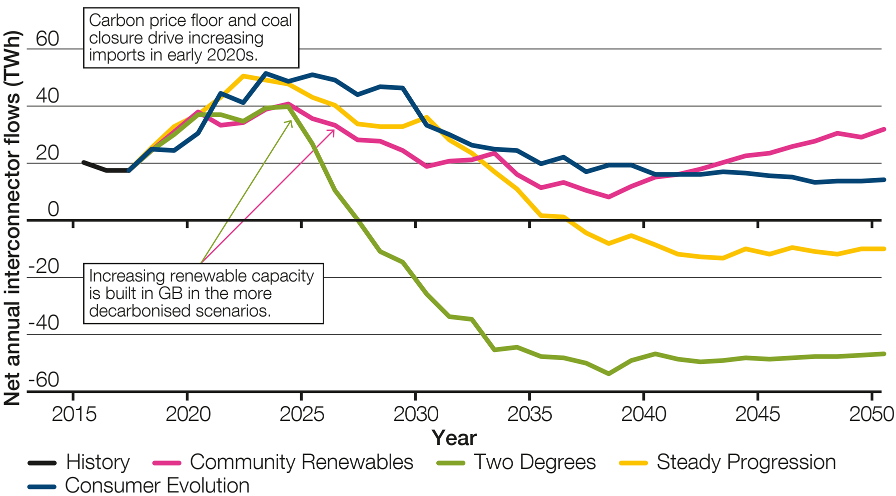
Figure 5.8
Electricity interconnector capacity



We anticipate that GB will be a net importer of electricity for most of the 2020s, as shown in figure 5.9. In this period, the GB carbon price floor plays an important part in driving imports from connected markets into GB. Currently, the Government has mandated that in GB an additional carbon support price is added to the carbon emissions price set via the European Union Emissions Trading Scheme (EU ETS). This sets a minimum total carbon price for GB, defined as the carbon price floor. This is currently higher than that set by the EU ETS. This means that the price paid to emit carbon in the UK is higher than in the rest of Europe, driving GB electricity prices upwards and leading to power flows into GB.

However, our carbon price assumptions mean that the EU ETS price then increases. Consequently the carbon price in Europe becomes similar to the UK. As a result, the UK's carbon price floor is less of a driver for energy trade after this point. This occurs in the 2020s in **Two Degrees** and **Community Renewables**, but not until the 2030s for **Consumer Evolution** and **Steady Progression**.

Figure 5.9
Net annual electricity interconnector flows



Energy supply

After the mid 2020s, **Two Degrees** starts to see net exports to connected markets. This is mainly due to increasing levels of nuclear and renewable capacity, that lead to excess power at certain times, which can then be exported.

The story is similar for **Steady Progression**. However, levels of both nuclear and renewable capacity are lower and built later. In the more decentralised scenarios, there is less baseload generation driving exports to connected markets. Imported electricity provides flexibility to support renewables, particularly in the **Community Renewables** scenario.

It is important to note that our projections are net annual flows. This can be the result of high flows counterbalancing one another. For example, our **Steady Progression** scenario sees a small level of net exports across many years, but underlying this net position is a higher level of both imports and exports. This implies a larger volume of energy being traded overall. Import and export flows for each scenario are detailed in the *Data Workbook*.

When looking at interconnector flows at peak, we expect GB to be a net importer in all scenarios. Imports at peak are predominantly driven by the fact that this is a time when GB prices will be high. This is likely to be when relatively cheap nuclear and hydro baseload generation will be available in France and Norway. Highest flows are seen in **Steady Progression**, as a more centralised scenario, with higher peak demand.

Again, peak flow analysis represents average or expected flows at peak, but this could vary considerably from period to period. This is because interconnectors respond to price signals, for example as renewable generation output, plant availability or demand varies in GB or in connected markets.

Thermal plant[3]

Historically, large coal and gas-fired plants connected to the transmission network provided the vast majority of electricity used in GB. However, since the start of the decade, the role of these large thermal plants has changed considerably. We are now, for example, seeing increasing periods of time when coal contributes no electricity at all to meet demand in GB. This has been driven by increasing competition from renewables, changes in fuel costs and the impact of government policies, such as the carbon price floor.

The flexibility and network services that can be provided by thermal generation are increasingly important in a world of growing intermittent generation. In this context, in our role as System Operator, we are undertaking work to clarify the value of services that have traditionally been provided by thermal plant, such as system inertia and reactive power. This work will look at how any future markets for these services could be accessed by new providers.

In line with government policy, our scenarios see all unabated coal generation phased out by 2025. Unabated generation means that emissions have not been treated to remove carbon dioxide and other pollutants. The earliest closure of all coal plant is in 2022 in **Community Renewables**, and the latest in **Steady Progression** in 2025.

The amount of transmission connected unabated gas-fired plant varies across the scenarios, according to our scenario framework assumptions. The highest amount of unabated large gas is in **Steady Progression**. Here there is a total of 35 GW of capacity in 2030, reducing to 30 GW by 2050. In this world, slower decarbonisation and greater centralisation means more reliance on larger thermal plant to meet demand and provide flexibility. In contrast, **Two Degrees** has 24 GW of unabated transmission connected gas plant by 2030. This then reduces to only 2 GW by 2050.

[3] For the purposes of this section, thermal plant refers to generation that uses diesel, gas, coal or oil as a fuel.

Compared to our assumptions in *FES 2017*, we have slightly delayed the closure of existing large unabated gas-fired plant. Consequently, we have delayed the building of new projects. This reflects the trends being seen for successful projects in the Capacity Market.

Decentralised thermal plant has been impacted by regulatory change in the last 12 months. Embedded benefits refer to the value that decentralised generation and storage can get from avoiding charges for the use of networks. For transmission charges, these benefits have recently been reduced, with a three year transition period beginning on 1 April 2018. The range of technologies included in the decentralised thermal plant group is detailed in the *Data Workbook*.

In addition, the European Medium Combustion Plant Directive will begin to come into force from the end of 2018 for smaller generators in this group (subject to transitional arrangements). The UK Government has gone further than the directive and extended oxides of nitrogen limits for smaller generators if they have a capacity or balancing agreement. Effectively this means that all small diesel generation and some gas generation that wish to participate in these markets will need to fit abatement technology. For some projects, the cost of this may outweigh future revenues, leading to project closure.

These new emissions limits have led us to predict no further growth in diesel reciprocating engines beyond currently contracted projects. Furthermore, some contracted projects may replace planned diesel with other technologies, such as storage or gas-fired plant. As a result of these regulatory changes, we have reduced the upper ranges of decentralised thermal plant compared to *FES 2017*. The highest installed capacity of these types of plant is in the more decentralised and slower decarbonising scenario of **Consumer Evolution**, with 16GW of capacity by 2050. In contrast, both of the more centralised scenarios, **Two Degrees** and **Steady Progression**, see only 8 and 7GW of decentralised thermal capacity respectively by 2050.

Energy supply

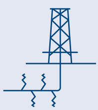
5.3 Gas supply

The pattern of gas supply in GB has changed dramatically in the past 15 years. We have gone from being self-sufficient in gas in 2000, to being dependent on imported gas for around half of our needs in 2017. Production from the UK Continental Shelf (UKCS) declined from 95 bcm in 2000 to 38 bcm in 2017. This has been replaced with gas from Continental Europe and liquefied natural gas (LNG) from the world market.

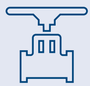
We can expect a similarly large change looking forward as, over the next 30 years, volumes of gas from the UKCS continue to decline.

Key insights
Commonalities and uncertainties across the scenarios

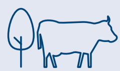
- The UKCS declines in all scenarios and is exhausted before 2050 in all except Steady Progression.



- The development of shale is still highly uncertain, leading to a wide potential supply range and two scenarios without any shale.



- In three out of four scenarios, imported gas will become even more important. In the scenarios without shale gas, import dependency rises to between 60 and 90 per cent by 2050.



- In some scenarios we consider the development of biomethane and bio-substitute natural gas (bioSNG).

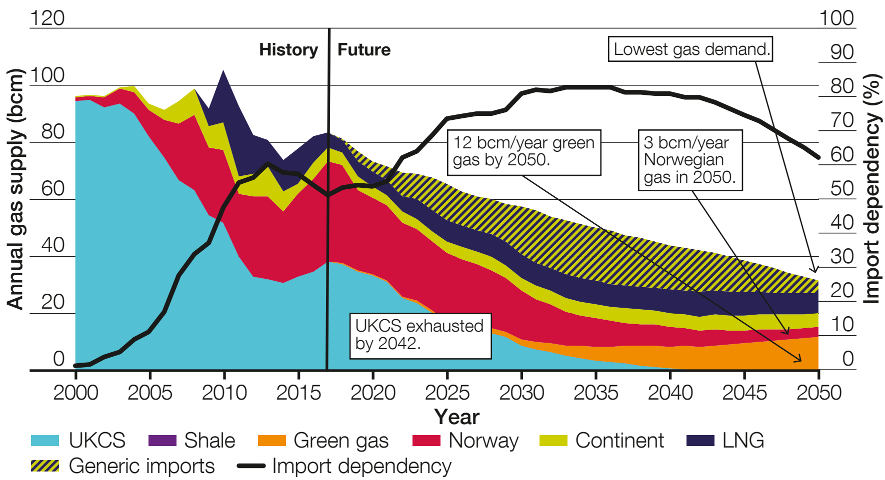
- On a year-to-year view it is uncertain whether imports will come from Continental Europe or from liquefied natural gas (LNG).

Scenario overview

The change in our scenario framework has led to patterns of gas supply that differ more between the scenarios than we have seen in recent years. Here we give a brief overview of supply in each scenario.

Gas demand in **Community Renewables**, shown in figure 5.10, is lower than in any of our other scenarios. In this world, with emphasis on decentralisation and decarbonisation, there is little policy support for continued development of the UKCS. There is greater support for green gas, which reaches nearly 12 bcm per year by 2050. To reach this level we have included over 7 bcm of bioSNG. In this scenario there is some gas used for heating and some for providing flexibility in electricity supply. To match the requirement for flexibility, the majority of the remaining gas supply is from LNG and Continental Europe. Supplies from Norway are low.

Figure 5.10
*Annual gas supply pattern in **Community Renewables***



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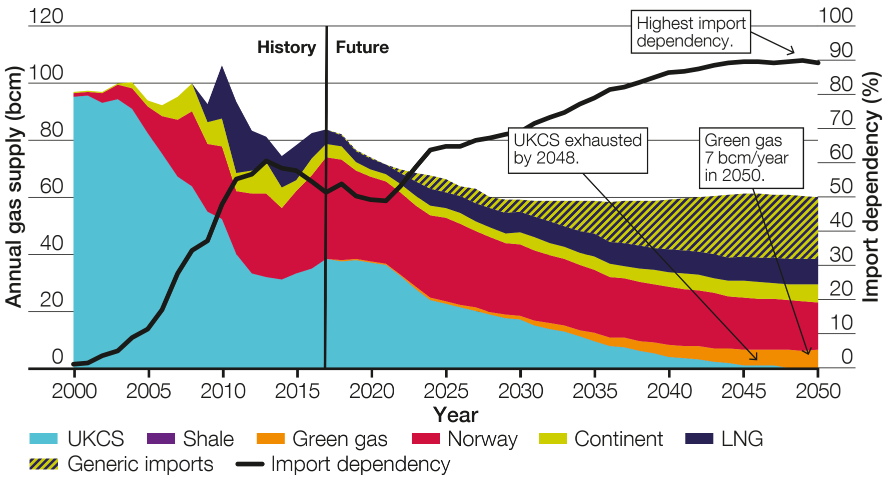
Energy supply

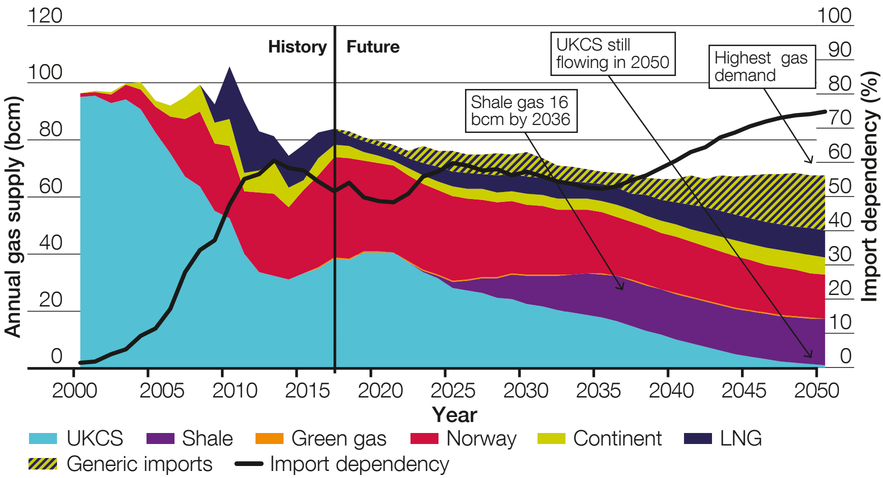
In **Two Degrees**, gas is used for conversion to hydrogen, leading to a much higher gas demand than **Community Renewables**. There is more emphasis on centralised solutions, so the UKCS receives more support than in **Community Renewables**, but production ends before 2050. There is moderate development of biomethane from anaerobic digestion (AD) but less bioSNG. Supplies from Norway, Continental Europe and LNG are all strong, and the dependence on imported gas is at its highest in this scenario, reaching nearly 90 per cent in the mid 2040s.

Figure 5.11
*Annual gas supply pattern in **Two Degrees***



Gas demand in **Steady Progression**, shown in figure 5.12, is higher than in our other three scenarios. This is because gas plays a major role in heating and power generation. Demand is still 68 bcm per year in 2050, 77 per cent of the 2017 level. In this scenario, with emphasis on centralised energy solutions, there is support for maintaining production on the UKCS, and there is still around 1 bcm being produced in 2050. There is less emphasis on decarbonisation, and so green gas receives no support for development greater than the current level, less than 1 bcm per year. There is some development of shale gas. Gas imports from Norway, Continental Europe and LNG are important. Import dependency rises to 75 per cent by 2050.

Figure 5.12
*Annual gas supply pattern in **Steady Progression***



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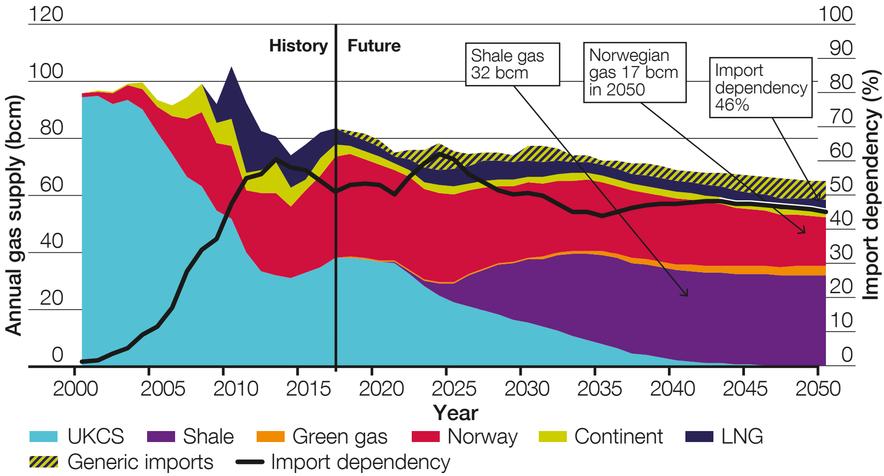
Gas demand in **Consumer Evolution**, shown in figure 5.13, is slightly lower than in **Steady Progression**, but higher than the two 2050 compliant scenarios. In keeping with the greater decentralisation in this scenario, there is more support for shale gas than for the UKCS. Shale gas will be supplied to both the distribution and transmission networks.

The UKCS is exhausted before 2050. Although this is not a 2050 compliant scenario there is moderate development of green gas, connected mostly to the distribution network rather than the NTS. There is still a requirement for imported gas, and Norwegian supplies reach their highest level. However extensive shale development means that overall import dependence is less than 50 per cent in 2050.

Figure 5.13
*Annual gas supply pattern in **Consumer Evolution***



Sources of gas

Indigenous sources

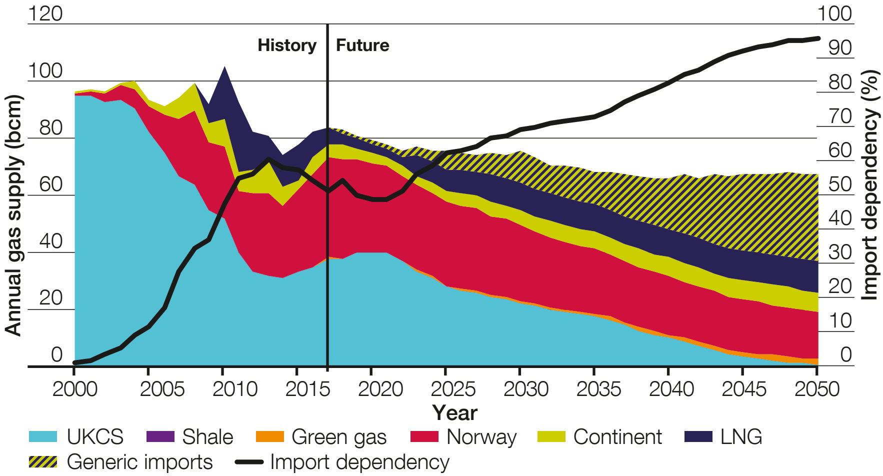
Production on the UKCS has risen over the last three years, after many years of decline. There are a number of fields where production is expected to start in the next few years. In addition, the former long-range storage facility at Rough has now been reclassified as a producing field. However, these cannot offset declines at other fields. We are expecting a small increase in production to 2020 in **Steady Progression** but production falls in all other scenarios from 2019 and from 2021 in **Steady Progression**. In **Community Renewables**, **Two Degrees** and **Consumer Evolution** the UKCS is exhausted before 2050. Even in **Steady Progression**, where production is highest, some receiving terminals will be closed before 2050.

There has been some high profile development in shale gas in the last 12 months. Two horizontal wells have been drilled and permission to hydraulically fracture (frack) these was being sought in July 2018. But there have been continuing protests against shale gas development, and public acceptability of the technology is still low. In recognition of this, and also recognising that the technology is in its infancy in GB, we have continued with our approach from previous years of having shale gas development in only two scenarios.

We have changed our modelling of shale gas development. For the first few years of development it uses a production profile that is similar to other new technologies, for example the early years of onshore wind generation. Our final production projections are unchanged from last year, but we now assume that it takes longer to reach full production. We are expecting shale gas to connect to both the distribution and transmission networks.

We use the term 'green gas' to include biomethane from anaerobic digestion (AD) as well as bioSNG. Some gas from biological sources is used for small scale local electricity generation but that is not included in the analysis in this chapter. Current biomethane supplies are all connected at distribution level, though there has been some interest expressed in connecting directly to the NTS through our project CLoCC[4] (Customer Low Cost Connections). In all our scenarios we expect to see most of the biomethane connected to distribution networks. On the other hand we are expecting that most of the bioSNG, which is expected to come from larger scale installations than biomethane for AD, will connect to the NTS.

Figure 5.14
Revised annual gas supply pattern for ***Steady Progression***



[4] http://projectclocc.com/news/project-clocc-pilot-customer-update/

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Energy supply

SENSITIVITY:
What happens if there is no shale gas?

In **Steady Progression** and **Consumer Evolution** we have included two levels of shale gas production. But what happens if shale gas development is not successful? Can gas demand still be met? In this sensitivity we have taken the two scenarios with shale gas, left the gas demand unaltered, and replaced the shale gas with other sources.

In **Steady Progression**, shown in figure 5.14, some of the money that had been used to support shale gas development is used instead for support for the UKCS, which lifts production slightly, particularly towards 2050. Supplies from Norway increase slightly but the most of the missing shale gas is replaced by other gas from Continental Europe, LNG and generic import. Import dependency rises to 96 per cent by 2050, in comparison to the 75 per cent in **Steady Progression** with shale included.

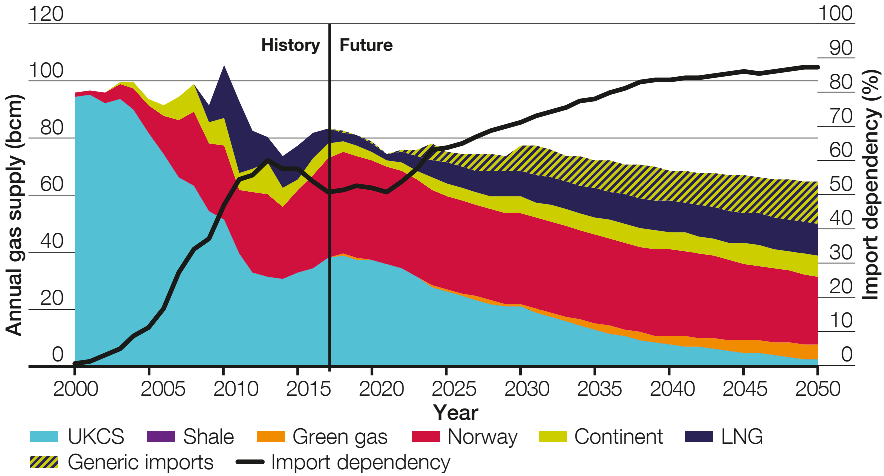
In **Consumer Evolution**, shown in figure 5.15, the loss of shale gas leaves a larger gap to fill. Some of the funds for shale gas development are directed to the UKCS, which is now still producing in 2050. There is some more support for green gas, as a decentralised supply connected to the distribution networks.

Supplies from Norway, already higher than in the other scenarios, increase further. As with **Steady Progression** the biggest increase is in the import of gas from Continental Europe, LNG and generic import. Import dependency reaches 88 per cent by 2050, compared to less than 50 per cent in **Consumer Evolution** with shale included.

In both scenarios in this sensitivity the demand is high but there is little indigenous supply left by 2050. The demand includes significant exports to Continental Europe.

With so little indigenous supply it is possible that exports would be reduced, leading to a lower requirement for imported gas.

Figure 5.15
Revised annual gas supply pattern for ***Consumer Evolution***



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Imported gas

Norwegian projections of gas production have recently been revised upwards. To reflect this, the upper end of our range is now higher than the input to our modelling in *FES 2017*. As a result, our projections for delivery of Norwegian gas to GB in the highest case, **Consumer Evolution**, are higher than last year's. In scenarios with low gas demand in GB, we assume that demand is similarly low across Europe. Production in Norway falls in response to reduced demand. Gas deliveries from Norway decline in all cases as gas demand falls, reaching very low levels in **Community Renewables** as gas from Continental Europe and LNG are selected to meet much more variable demand.

For some years our scenarios have included specific volumes of imported LNG and gas from Continental Europe, as well as a volume of 'generic import', which could be LNG, gas from Continental Europe, or a mixture. This approach effectively provides ranges for LNG and gas from Continental Europe in each scenario. Predicting LNG flows in the world market continues to be challenging. Production of LNG is increasing, but this gas is increasingly flowing to Asian markets where it attracts a higher price than in North West Europe. Set against that, on days of high demand and high gas price in winter 2017/18, LNG was delivered to the GB market. So although overall deliveries of LNG have been low, it has proved to be a very flexible supply. In our modelling we have used more LNG in scenarios where demand for gas is more variable through the year.

In all our scenarios we expect gas to be flowing both to and from Continental Europe through the IUK and BBL interconnectors. BBL Company has announced that they are expecting to be able to offer flows from GB to the Netherlands from 2019. Our projections take account of reductions in production at the Groningen field in the Netherlands.

Gas storage

Gas storage has an important role to play, alongside other flexible gas supplies, in supporting security of supply and providing flexibility in the operation of the gas market. The only long-range storage site in GB, Rough, closed in 2017 and the site has now been reclassified as a producing field. There has been some recent development of medium-range storage as capacity is increased at existing sites. However, the economics have not been favourable for the development of new storage for some years.

Spotlight

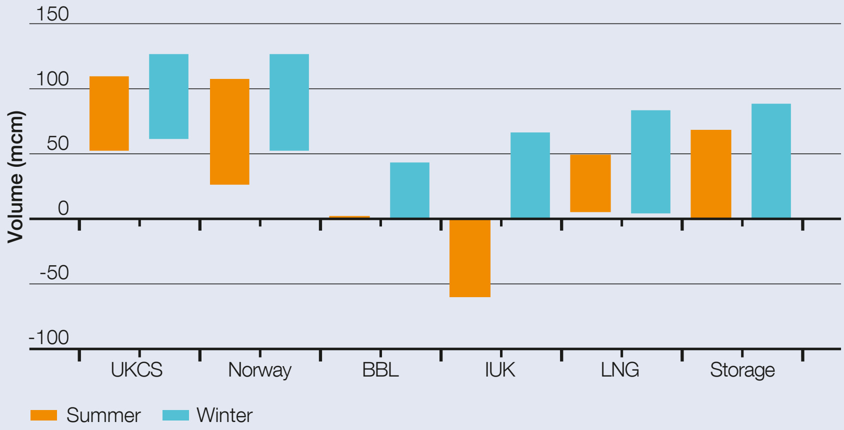
Changing gas flows

In all our scenarios we are expecting a decline in annual gas demand from 2018 onwards. As we explained in chapter four, we are not expecting peak demand to fall at the same rate as annual demand, especially in scenarios with high gas use for residential heating.

The pattern of gas supply from different sources will also change, as we have shown in figures 5.10 to 5.13. In particular, supply from the UKCS falls in all scenarios. However, although the total volume of gas transported through the National Transmission System (NTS) will be lower, this does not necessarily mean that flows will be easier to manage.

In figure 5.16 we show the range of daily gas supplies in both summer and winter from each supply type for the period April 2017 to March 2018, taken from our Winter Outlook and Summer Outlook reports.

Figure 5.16
Range of daily gas supply volumes in winter and summer 2017–2018



The maximum daily flow from each source, shown by the top of the bars in the chart, is higher in the winter than the summer, as we would expect. Although flows are lower in summer, the range in flow from each source, shown by the distance between the top and bottom of the orange bars, is still quite large for most supplies. For Norway, the summer range is larger than the winter range. IUK flows are shown as negative numbers in the summer as the pipeline operated in export mode, with gas flowing from GB to Belgium. BBL Company has announced that they will be offering the capability to export gas from GB to the Netherlands from 2019. In future years we can therefore expect to see exports through BBL in the summer, as well as through IUK.

As supplies from the UKCS decline, both the maximum and minimum UKCS flows will fall. However, supplies from Norway do not decline as fast as the UKCS. Supplies from Continental Europe and LNG increase in all scenarios. In this case it is likely that the range in supply volumes that must be handled during the year will remain high. Large changes in gas flow patterns from day-to-day need greater use of compressors on the network to make sure that we can deliver gas efficiently to our customers.

It is important that we ensure that the NTS continues to be capable of delivering the wide range of supply patterns expected, even in scenarios where overall gas demand is declining. You can read more about how we handle changing supply patterns in our Gas Future Operability Planning (GFOP) publication.

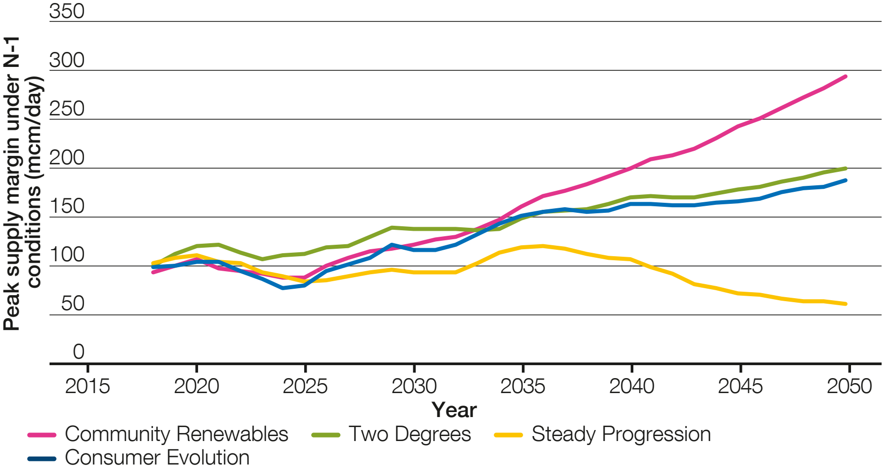
Energy supply

Peak gas supply
In all our scenarios we assess whether there will be enough gas to supply peak demand. To make sure that demand can be met even if there is a failure in the network, we carry out the assessment assuming that the single largest piece of infrastructure is not available. This means that in our analysis we remove the pipeline connecting the two LNG terminals at Milford Haven to the rest of the network.

This is known as the N-1 test and is used by the Government in assessing security of gas supply[6]. We describe our calculation in more detail in the *Modelling Methods* document.

In figure 5.17 we show the margin of supply over peak demand under N-1 conditions. This shows that supply capacity exceeds peak demand by more than 60 mcm/day in all scenarios.

Figure 5.17
Peak gas supply margin under N-1 conditions



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[6] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/560125/UK_Risk_Assessment_Gas_BEIS_template_Final__4_.pdf

Chapter six

Glossary

Word	Acronym	Description
2050 carbon reduction target		To reduce carbon emissions by at least 80 per cent of 1990 levels by 2050. This is taken from the UK's 2008 Climate Change Act.
2050 compliant scenarios		The scenarios that achieve the 2050 carbon reduction target i.e. Community Renewables and Two Degrees.
Air source heat pump	ASHP	Air source heat pumps absorb heat from the outside air. This heat can then be used to produce hot water or space heating.
Anaerobic digestion	AD	Bacterial fermentation of organic material in the absence of free oxygen.
Ancillary services		Services procured by a System Operator to balance demand and supply and to ensure the security and quality of electricity supply across the transmission system. These services include reserve, frequency control and voltage control. In GB these are known as Balancing Services and each service has different parameters that a provider must meet.
Arbitrage		In an energy context, this usually refers to the practice of buying energy when the price is low, storing this energy and then selling it when the price has risen.
Autonomous vehicle		A vehicle that is capable of driving without human input.
Balgzand Bacton Line	BBL	A gas pipeline between Balgzand in the Netherlands and Bacton in the UK.
Billion cubic metres	bcm	Unit of volume, used in the gas industry. 1 bcm = 1,000,000,000 cubic metres.
Biogas		A naturally occurring gas that is produced from organic material and has similar characteristics to natural gas. We use biogas to refer to gas that is not of pipeline quality.
Biomethane		Biogas that has been further processed to make it suitable for injection into gas transmission or distribution networks.
Bio-substitute natural gas	BioSNG	Pipeline quality gas created from waste.
Blockchain		A non-centralised digital (internet) transaction ledger that is public.
Capacity Market	CM	The Capacity Market is designed to ensure security of electricity supply. This is achieved by providing a payment for reliable sources of capacity, alongside their electricity revenues, ensuring they deliver energy when needed.
Carbon capture utilisation and storage	CCUS	A process by which the carbon dioxide (CO_2) produced in the combustion of fossil fuels is captured, transported to a storage location and isolated from the atmosphere. Capture of CO_2 can be applied to large emission sources like power plants used for electricity generation and industrial processes. The CO_2 is then compressed and transported for long-term storage in geological formations or for use in industrial processes.
Carbon dioxide	CO_2	The main greenhouse gas. The vast majority of CO_2 emissions come from the burning of fossil fuels.
Carbon intensity		A way of examining how CO_2 is emitted in different processes. Usually expressed as the amount of CO_2 emitted per kilometre travelled, per unit of heat created or per kilowatt hour of electricity produced.
Carbon price floor	CPF	A price paid by UK generators and large carbon intensive industries for CO_2 emissions.
Combined cycle gas turbine	CCGT	A power station that uses the combustion of natural gas or liquid fuel to drive a gas turbine generator to produce electricity. The exhaust gas from this process is used to produce steam in a heat recovery boiler. This steam then drives a steam turbine generator to generate more electricity.
Combined heat and power	CHP	A system where both heat and electricity are generated simultaneously as part of one process. Covers a range of technologies that achieve this.
Contract for Difference	CfD	A contract between the Low Carbon Contracts Company (LCCC) and a low carbon electricity generator, designed to reduce its exposure to volatile wholesale prices.
Decentralised generation		Electricity generation that is connected to power networks below the high voltage transmission system. Includes distributed generation and onsite generation.

Word	Acronym	Description
Demand side response	DSR	A deliberate change to an industrial and commercial user's natural pattern of metered electricity or gas consumption, brought about by a signal from another party.
Department for Business, Energy and Industrial Strategy	BEIS	UK Government department with responsibilities for business, industrial strategy, science, innovation, energy, and climate change.
Dispatch (or economic dispatch)		The operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognising any operational limits of generation and transmission facilities.
District heating		Using a single centralised source to heat a network of surrounding buildings.
Electric vehicle	EV	A vehicle driven by an electric motor. It can either be driven solely off a battery, as part of a hybrid system, or have a generator that can recharge the battery but does not drive the wheels. We only consider EVs that can be plugged in to charge in this report.
Electricity Market Reform	EMR	A government policy to incentivise investment in secure, low-carbon electricity, improve the security of Great Britain's electricity supply, and improve affordability for consumers.
Electricity Ten Year Statement	ETYS	A document published by the System Operator which illustrates the potential future development of the National Electricity Transmission System (NETS) over a ten year (minimum) period. It is published on an annual basis.
Energy Performance Certificate	EPC	An EPC gives a property an energy efficiency rating from A (most efficient) to G (least efficient).
EU 2030		Indicative target for an improvement in energy efficiency at EU level of at least 27 per cent, compared to projected use of energy.
EU Emissions Trading Scheme	EU ETS	An EU wide system for trading greenhouse gas emission allowances. The scheme covers more than 11,000 power stations and industrial plants in 31 countries.
European Network of Transmission System Operators - Electricity	ENTSO-E	An association of European electricity Transmission System Operators. ENTSO-E was established and given legal mandates by the EU's Third Legislative Package for the Internal Energy Market in 2009, which aims at further liberalising electricity markets in the EU.
European Union	EU	A political and economic union of 28 member states in Europe.
Flexible generation		Types of generation that can respond quickly to requests to change their output.
Frequency response		An ancillary service procured by National Grid as System Operator to help ensure system frequency is kept as close to 50Hz as possible. Also known as frequency control or frequency regulation.
Fuel cell		An electrochemical device than converts chemical energy from fuel into electricity.
Future Energy Scenarios in five minutes	FES in 5	A summary version of *FES*.
Gas absorption heat pump	GAHP	A heat pump powered by natural gas rather than electricity.
Gigawatt	GW	A unit of power. 1 GW = 1,000,000,000 watts.
Gigawatt hour	GWh	A unit of energy. 1 GWh =1,000,000,000 watt hours.
Gram of carbon dioxide per kilowatt hour	gCO_2/kWh	Measurement of CO_2 equivalent emissions per kWh of energy used or produced.
Great Britain	GB	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
Green gas		A term used to describe low carbon gas. In *FES 2018* this category includes biomethane and bioSNG.
Greenhouse gas		A gas in the atmosphere that absorbs and emits radiation within the thermal infrared range.

Glossary

Word	Acronym	Description
Gross domestic product	GDP	An aggregate measure of production equal to the sum of the gross values added of all resident, institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs).
Ground source heat pump	GSHP	Heat pumps which absorb heat from the ground. This heat can then be used to produce hot water or space heating.
Heat pump		A device that transfers heat energy from a lower temperature source to a higher temperature destination.
Heavy goods vehicle	HGV	A truck weighing over 3,500 kg.
Hybrid heat pump		An integrated system using a heat pump alongside a traditional installation such as a gas boiler, to provide year-round efficient and flexible heating.
Hydrogen fuel cell vehicle	HFCV	Fuel cell vehicles use hydrogen gas to power an electric motor.
Industrial and commercial	I&C	A category used for aggregating energy demand.
Inflexible generation		Types of generation that require long notice periods to change their output or have obligations that influence when they can generate.
Information and communication technology	ICT	Includes computing and digital communication.
Interconnector		Transmission assets that connect the GB market to Europe and allow suppliers to trade electricity or gas between markets.
Interconnector (UK)	IUK	A bi-directional gas pipeline between Bacton in the UK and Zeebrugge in Belgium.
Intermittent generation		Types of generation that can only produce electricity when their primary energy source is available. For example, wind turbines can only generate when the wind is blowing.
Internal combustion engine	ICE	A conventional petrol or diesel engine.
Liquefied natural gas	LNG	Formed by chilling natural gas to -161˚C to condense as a liquid. Its volume reduces 600 times from the gaseous form.
Long-range storage	LRS	A gas storage facility which mainly puts gas into storage in the summer and takes gas out of storage in the winter. There was one long-range storage site on the National Transmission System, Rough, situated off the Yorkshire coast. Rough was formally closed in June 2017.
Loss of load expectation	LOLE	Used to describe electricity security of supply. It is an approach based on probability and is measured in hours/year. It measures the risk, across the whole winter, of demand exceeding supply under normal operation. This does not mean there will be loss of supply for 3 hours per year. It gives an indication of the amount of time, across the whole winter, which the System Operator (SO) will need to call on balancing tools such as voltage reduction, maximum generation or emergency assistance from interconnectors. In most cases, loss of load would be managed without significant impact on end consumers.
Marine technologies		Tidal streams, tidal lagoons and energy from wave technologies.
Medium-range storage	MRS	Gas storage facilities designed to switch rapidly between injection and withdrawal to maximise the value from changes in gas price.
Megawatt	MW	A unit of power. 1 MW = 1,000,000 watts.
Megawatt hour	MWh	A unit of energy. 1 MWh = 1,000,000 watt hours.
Micro combined heat and power	mCHP	A subset of CHP, designed for domestic use.
Million cubic metres	mcm	A unit of volume, used in the gas industry. 1 mcm = 1,000,000 cubic metres.
N-1		Condition used in a security of supply test, where total supply minus the largest single loss is assessed against total peak demand.

Word	Acronym	Description
National Transmission System	NTS	A high pressure gas transportation system consisting of compressor stations, pipelines, multijunction sites and offtakes. NTS pipelines transport gas from terminals to NTS offtakes and are designed to operate up to pressures of 94 barg.
Natural gas		A mixture of gases, primarily methane, suitable for transport through gas transmission and distribution networks.
Natural gas vehicle	NGV	A vehicle which uses compressed or liquefied natural gas as an alternative to petrol or diesel.
non 2050 compliant scenarios		The scenarios that do not achieve the 2050 carbon reduction target i.e. Steady Progression and Consumer Evolution.
Office of Gas and Electricity Markets	Ofgem	The UK's independent National Regulatory Authority, a non-ministerial government department. Their principal objective is to protect the interests of existing and future electricity and gas consumers.
Open cycle gas turbine	OCGT	A combustion turbine plant fired by liquid fuel to turn a generator rotor that produces electricity.
Oxides of nitrogen	NOx	A group of chemical compounds, some of which are contributors to pollution, acid rain or are classified as greenhouse gases.
Peak demand, electricity		The maximum electricity demand in any one fiscal year. Peak demand typically occurs at around 5:30pm on a week-day between November and February. Different definitions of peak demand are used for different purposes.
Peak demand, gas		The level of demand that, in a long series of winters, with connected load held at levels appropriate to the winter in question, would be exceeded in one out of 20 winters, with each winter counted only once.
Peer-to-peer trading		Where individuals can buy and sell energy with each other.
Plug-in hybrid electric vehicle	PHEV	A vehicle with a battery which can be charged by plugging it in, as well as a petrol or diesel engine.
Pure electric vehicle	PEV	A vehicle which only has a battery for energy storage.
Renewable generation		Renewable generation creates electricity from natural resources that are quickly replaced. For example, wind, solar or biomass generation.
Repowering		Re-fitting a generation site with new equipment such as new wind turbine blades so that it can continue to generate electricity, usually more efficiently than previously.
Shale gas		Natural gas that is found in shale rock. It is extracted by injecting water, sand and chemicals into the rock to create cracks or fractures so that the shale gas can be extracted.
Shared vehicle		A vehicle that fulfils the transportation requirements of more than one person.
Small modular reactor	SMR	Nuclear reactors, generally 300MW or less, designed with modular technology using module factory fabrication.
Smart appliances		Residential electricity-consuming goods which are able to reduce their demand at defined times of the day, either by reacting to a signal or by being programmed.
Smart charging		Charging units which have two-way communication ability and that can react to external signals.
Smart meter		New generation gas and electricity meters which have the ability to broadcast secure usage information to customers and energy suppliers, potentially facilitating energy efficiency savings and more accurate bills.
Space cooling		Cooling an enclosed area.
Steam methane reforming		A method for producing hydrogen, carbon monoxide, or other useful products from hydrocarbon fuels such as natural gas.
Summer minimum		The minimum electricity demand on the transmission network in any one fiscal year. Minimum demand typically occurs at around 6am on a Sunday between May and September.
System inertia		The property of the system that resists changes. This is provided largely by the rotating synchronous generator inertia that is a function of the rotor mass, diameter and speed of rotation. Low system inertia increases the risk of rapid system changes.

Glossary

Word	Acronym	Description
System operability		The ability to maintain system stability and all of the asset ratings and operational parameters within pre-defined limits safely, economically and sustainably.
System Operator	SO	An entity entrusted with transporting energy in the form of natural gas or electricity on a regional or national level, using fixed infrastructure. The SO may not necessarily own the assets concerned. For example, National Grid operates the electricity transmission system in Scotland, which is owned by Scottish Hydro Electricity Transmission and Scottish Power.
Terawatt hour	TWh	A unit of energy. 1 TWh = 1,000,000,000,000 watt hours.
Time of use tariff	TOUT	A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high electricity demand times.
UK Continental Shelf	UKCS	Comprised of those areas of the sea bed and subsoil beyond the territorial sea over which the UK exercises sovereign rights of exploration and exploitation of natural resources.
Unabated generation		Electricity generation that is not fitted with carbon capture utilisation and storage.
United Kingdom of Great Britain and Northern Ireland	UK	A geographical, social and economic grouping of countries that contains England, Scotland, Wales and Northern Ireland.
Vehicle-to-grid technology	V2G	A system where an EV is connected to the electricity network and instructed to draw or supply electricity.
Wet appliances		Large electrical household appliances that use electricity and water, for example washing machines and dishwashers.

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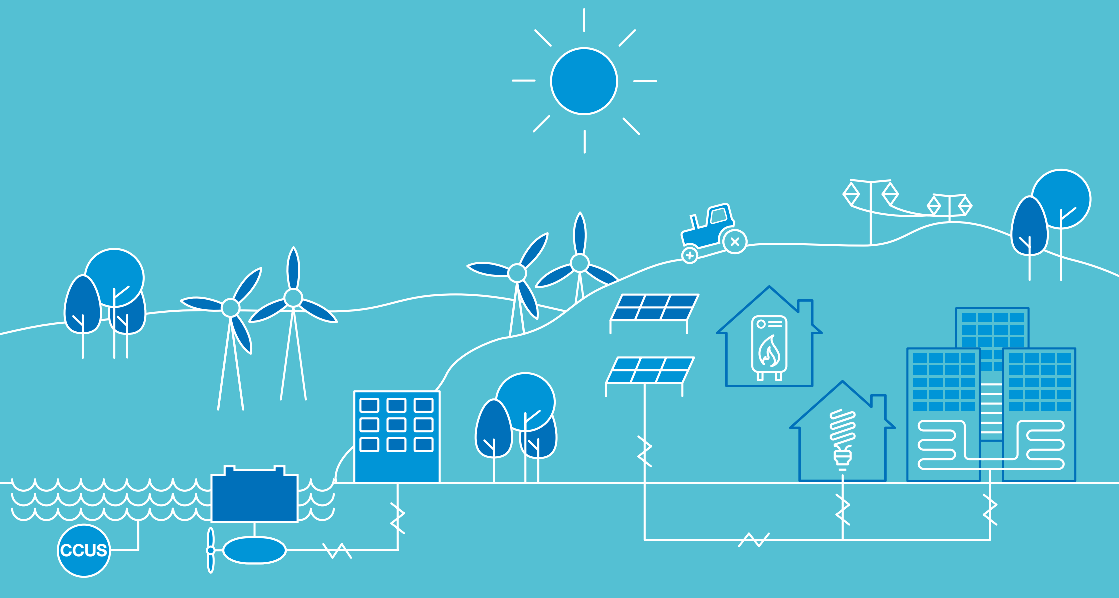

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