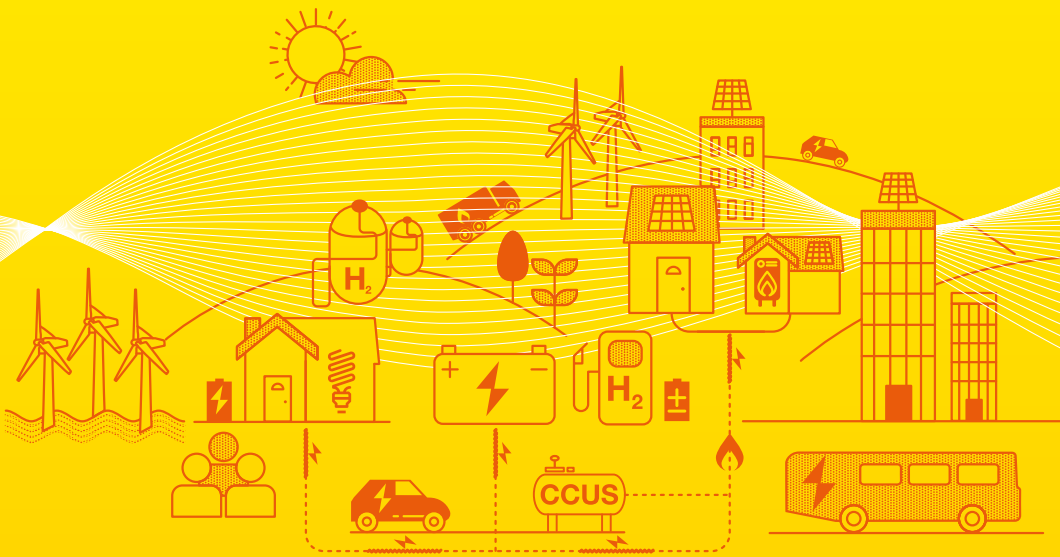


Future Energy Scenarios

July 2019



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.



A to Z

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



Arrows

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



Hyperlinks

Hyperlinks are underlined and highlighted in black throughout the document. You can click on them to access further information.

Welcome to our *Future Energy Scenarios*

Decarbonising energy is fundamental in the transition towards a sustainable future. Our *Future Energy Scenarios* aim to stimulate debate to inform the decisions that will help move us towards achieving carbon reduction targets and, ultimately, shape the energy system of the future.

Our energy system is already transforming as the trends of decarbonisation, decentralisation and digitisation revolutionise how we produce and use energy every day. This summer the electricity system operated coal free for over two weeks and carbon intensity of generation last winter reached a new low. We will continue to facilitate the energy transformation and, by 2025, our ambition is to be able to operate the electricity system at zero-carbon. These are significant milestones in the sustainability transition that will be required to meet the 2050 carbon target.

The UK government has responded to growing public focus on climate change by committing to a shift from the 2050 target of an 80 per cent reduction in CO₂ from 1990 levels to a net zero target. Policy changes combine with rapid technological progress and market forces to create a swiftly changing landscape, where it is impossible to accurately forecast a single energy future out to 2050. Instead, our *Future Energy Scenarios (FES)* creates a range of credible futures which allow us to continue supporting the development of the energy system that is robust against different outcomes. Following clear feedback from our stakeholders, we have kept the scenario framework the same as in *FES 2018*. Two of our scenarios meet the 2050 target¹, and we have also included a new, standalone sensitivity analysis on how net zero carbon emissions could potentially be achieved by 2050.

National Grid Electricity System Operator (ESO) became a legally separate entity within the National Grid Group on 1 April 2019. Separating the ESO business from National Grid's Electricity Transmission Owner business provides transparency in our decision-making and gives confidence that everything we do will promote competition and is ultimately for the benefit of consumers. While the *FES* is an ESO publication, our analysis continues to consider the whole energy system – ensuring the implications for, and interactions across, electricity, gas, heat and transport are fully considered.

Our scenarios reflect the year-round feedback received from all of our stakeholders right across the energy landscape and beyond. Please continue to share your views with us using the details on the Continuing the conversation page at the back of the document. This year, for the first time, we will also be building on the issues highlighted in our key messages through a series of industry discussions and collaborative analysis. Look out for the first of these in Autumn 2019.

Thank you for your continuing support and I hope you enjoy *FES 2019*.



Fintan Slye
Director, Electricity System Operator

¹ Throughout *FES* we refer to the '2050 target'. This is the original Climate Change Act 2008 target of achieving 80 per cent reduction in greenhouse gas emissions by 2050, compared to 1990 levels.

Key messages

Reaching net zero carbon emissions by 2050 is achievable. However, this requires immediate action across all key technologies and policy areas.

- Our analysis is aligned with that of the CCC and provides an approach to achieve net zero emissions by 2050.
- The 80 per cent decarbonisation target can be reached through multiple technology pathways, but **Net Zero** requires greater action across all solutions. Action on electrification, energy efficiency and carbon capture will all be needed at a significantly greater scale than assumed in any of our core scenarios.



Homes in 2050 will need to use at least one third less energy for heating than today.

What this means

- **The electricity system will need to operate using only zero carbon generation and the power sector will need to deliver negative emissions (e.g. biomass with CCUS).**
- **The gas system will need to be transformed to accommodate hydrogen.**
- **Gas appliance standards must require boilers to be “hydrogen-ready” in order to leverage replacement cycles.**



37 million tonnes of CO₂ removed from atmosphere. Residual emissions will be offset by negative emissions from biomass power generation paired with carbon capture and storage.

Heat decarbonisation pathways are uncertain and vary by region. However, there are clear, urgent no regrets actions that can remove barriers to deploying solutions at scale.

- There are immediate steps to decarbonise heat which are common across all scenarios. These include improving the thermal efficiency of homes so that the majority are rated at EPC Class C or higher by 2030, raising appliance efficiency standards and rolling out at least 2.5m domestic heat pumps by 2030.
- Multiple heat decarbonisation pathways are possible including electrification, decarbonised gas, and hybrid systems. But optimal solutions will vary by region and the combinations and interaction of these technologies must be considered to provide a flexible, operable and sustainable whole energy system.



More than 23m homes will need to install new low-carbon heating solutions by 2050².



By 2050², up to 85% of homes need to be very thermally efficient (at EPC class C or higher).

What this means

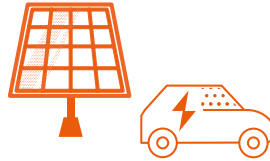
- **Strong, no regrets policy action must be taken immediately to improve the thermal efficiency of housing, and to accelerate the rate of heat pump installation. This will have a direct impact on end consumers and so positive engagement and support measures will be key to ensuring uptake at scale.**
- **The current policy timeline of setting a clear heat strategy by 2025 can meet the 2050 target, but there is no room for delay. A regional plan will be required to optimise low-carbon heating solutions.**

²Community Renewables and Two Degrees

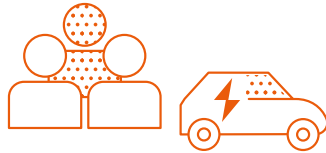
Key messages

Electric vehicles can help decarbonise both transport and electricity supply for Great Britain. The market needs to align vehicle charging behaviour to complement renewable generation and meet system needs.

- The charging of over 35m electric vehicles in 2050 will provide flexibility and integrate a higher level of renewable generation on the system. This amplifies the positive impact of electric vehicles on decarbonisation.
- The timing, location, and frequency of electric vehicle charging varies more than previously assumed and many factors influence this. This variability has positive implications for the operation of the electricity system.



Smart charging vehicles could enable the storage of roughly one fifth of GB's solar generation for when this energy is needed.



Over 75% of EVs could be using smart charging by 2050.

What this means

- **A smart flexible system will need new business models and services to match system needs with vehicle charging requirements and consumer preferences.**
- **The investment in infrastructure to support increasing numbers of electric vehicles indirectly benefits all energy consumers through lower prices and lower carbon generation intensity, as smart charging of EVs can support increased renewable generation.**

A whole system view across electricity, gas, heat and transport underpins a sustainable energy transformation. Widespread digitalisation and sharing of data is fundamental to harnessing the interactions between these changing systems.

- Existing interactions between gas and electricity networks will increase as gas generation provides more flexibility, and new technologies such as electrolysis and hybrid heat systems create new interfaces between electricity and gas systems.
- The complexity of the whole system is increasing, but so is the ability of data and technology to understand and manage this complexity.
- Investment decisions around potential new systems such as hydrogen and carbon transportation must be made on a whole energy system basis.



Over seven million hybrid heat pumps could be installed by 2050 with gas providing continued flexibility.



Well over 2.8 trillion data points will be collected in 2050 to understand where EVs are charging on the electricity system.

What this means

- **Significant digitalisation of legacy infrastructure is required to provide visibility and enable optimisation of the whole energy system. This must be done in a way that ensures data and systems are interoperable.**
- **Data must be made accessible to decision makers across interdependent systems such as gas, electricity, and transport.**
- **Appropriate governance and standards will be required in order to ensure a joined up and digitalised energy system.**

Contents

Foreword	01
Key messages	02

Chapter 1

Introduction	08
1.1 What is <i>FES</i> ?	08
1.2 What <i>FES</i> is not	09
1.3 What is <i>FES</i> for?	09
1.4 How is <i>FES</i> created?	12
1.5 What's new in <i>FES</i> ?	12
1.6 How to use the <i>FES</i> document suite	13

Chapter 2

The scenarios	16
2.1 The scenario framework	16
2.2 Extended analysis and spotlights	16
2.3 An overview of the Future Energy Scenarios	18

Chapter 3

Decarbonisation and decentralisation	30
3.1 Speed of decarbonisation	30
3.2 Level of decentralisation	34

Chapter 4

Energy demand	44
4.1 Energy demand	44
4.2 Industrial and commercial demand	50
4.3 Residential demand	60
4.4 Transport demand	76
4.5 Gas demand for electricity generation	93
4.6 Demand for hydrogen production	95

Chapter 5

Energy supply	110
5.1 Energy supply	110
5.2 Electricity supply	113
5.3 Gas supply	139

Chapter 6

Net zero	150
6.1 Net zero	150

Chapter 7

Glossary	162
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Chapter 1

Introduction	08
1.1 What is <i>FES</i> ?	08
1.2 What <i>FES</i> is not	09
1.3 What is <i>FES</i> for?	09
1.4 How is <i>FES</i> created?	12
1.5 What's new in <i>FES</i> ?	12
1.6 How to use the <i>FES</i> document suite	13

Introducing the Future Energy Scenarios



Introduction

1.1 What is *FES*?

The energy system is rapidly transforming, driven by political, economic, environmental, technological and consumer pressures. Our *Future Energy Scenarios* document (*FES*) includes a set of pathways that capture what the future of energy may be, a future we must navigate together as an industry.

Climate change is the challenge of a generation. Decarbonising our energy system is a critical element in the response to this challenge. Technological advances, policy decisions and consumer behaviour may also lead to greater decentralisation of the energy system. *FES* uses the lenses of decarbonisation and decentralisation to explore uncertainty and opportunity in the future of energy.

These drivers for change provide the context for our *Future Energy Scenarios* (*FES*), produced each year to identify a range of credible scenarios for the next 30 years and beyond. They help us to better understand the range of uncertainties, and assist our customers and stakeholders as they make long-term decisions.

As the energy industry faces key challenges, we expect to see greater interactions between gas and electricity markets, along with significant changes in the heat and transport sectors. National Grid ESO are in a privileged position that enables us to draw on insight and data that cut across both fuels in developing our *FES* publication. We develop a whole system view of energy, helping the industry to understand how low-carbon solutions can be delivered reliably and affordably for the consumer of the future.

1.2 What *FES* is not

FES includes four scenarios. These are not in themselves forecasts of expected pathways. The actual pathway could be a combination of each of these four scenarios and the scenarios should be used as a set.

Having a range of scenarios allow us to explore different options and opportunities for the future. Our projections of energy demand and supply are not limited by capability or operability issues for either the distribution or transmission networks. They are simply based on a view of underlying demand. Our scenarios are technology neutral, and reflect a mix of technology options.

1.3 What is *FES* for?

Our stakeholders use *FES* in a variety of ways, and for a variety of purposes:

- for investment and pre-investment decisions
- to gain insight into the industry
- to see where potential future opportunities lie
- as a reference point and/or comparison with other forecasts
- as a starting point for academic studies.

FES is the starting point for planning long-term regulated investment in gas and electricity systems. It defines a path for delivery of low cost energy for the consumer of the future and for meeting the energy industry's contribution to carbon reduction targets.

FES also provides a sound, consistent and visible reference point for a range of different published reports. You can see using figure 1.1 how these documents link together, providing our stakeholders with greater analysis of key topics, ranging from long-term views of the future through to short-term operational plans.



Introduction – Industry publications informed by *FES*

Figure 1.1

Industry publications informed by *FES*



Future Energy Scenarios

July

A range of credible pathways for the future of energy from today to 2050. Scenarios are unconstrained by network issues.

The ETYS and GTYS take the unconstrained scenarios in *FES* to develop requirements for planning and operating the electricity and gas transmission systems over the next 10 years.

Needs case



Electricity Ten Year Statement

November

The likely future transmission requirements on the electricity system.

Options



Network Options Assessment

January

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



Gas Ten Year Statement

November

How the gas network is planned and operated, with a ten-year view.



Ten Year Network Development Plan

Overview of the European gas and electricity infrastructure and its future developments.

Ad-hoc reports that develop shorter-term plans for more specific elements of operational assets and services, where the need arises.



System Needs and Product Strategy

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



Product Roadmap for Restoration

Our plan to develop restoration products.



Transmission Thermal Constraints Management

Our plan for the management of thermal constraints.



Wider Access to the Balancing Mechanism Roadmap

Our plan to widen access to the balancing mechanism.



Product Roadmap for Reactive Power

Our plan to develop reactive power products.



Future Energy Scenarios

July

A range of credible pathways for the future of energy from today to 2050. Scenarios are unconstrained by network issues.



The operability publications consider the unconstrained scenarios in FES to explore operability risks and associated requirements of the transmission networks and services.



System Operability Framework

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



Gas Future Operability Planning

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

Ad-hoc, insights led productions and reports



Operability Strategy Report

Highlights the challenges we face in maintaining an operable electricity system, and summarises the work we are undertaking to ensure we meet those challenges.



Future Gas Supply Patterns

How variability in supply pattern seasonally and day-to-day has changed, and could change in the future.

Annual short-term reports that explore any security of supply or operational challenges anticipated over the summer and winter periods.



Winter Review and Consultation

June

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



Summer Outlook Report

April

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



Winter Outlook Report

October

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



Electricity Capacity Report

Capacity Market auctions for delivery in a year ahead and four years ahead.

Introduction

1.4 How is FES created?

FES is the product of in-depth analysis by our team of experienced analysts. Collaborating with stakeholders plays a hugely important role in the development of FES. We take stakeholder insight and combine it with the expertise of industry specialists and our own insights, resulting in the breadth and depth of knowledge we need to produce credible pathways for the future of energy.

Creating our scenarios is a continuous process throughout the year which is detailed in figure 1.2. At each stage we use our expertise to create scenarios that are relevant and credible. Each year we rigorously review and develop our scenarios to make sure they reflect the changing energy landscape.

Figure 1.2 shows the main stages in the FES process and key engagement points that stakeholders can be involved in during the year.

During 2018, we implemented several changes to our engagement approach, carrying out a Call for Evidence and actively seeking additional insights from our evolving stakeholder base. We engaged

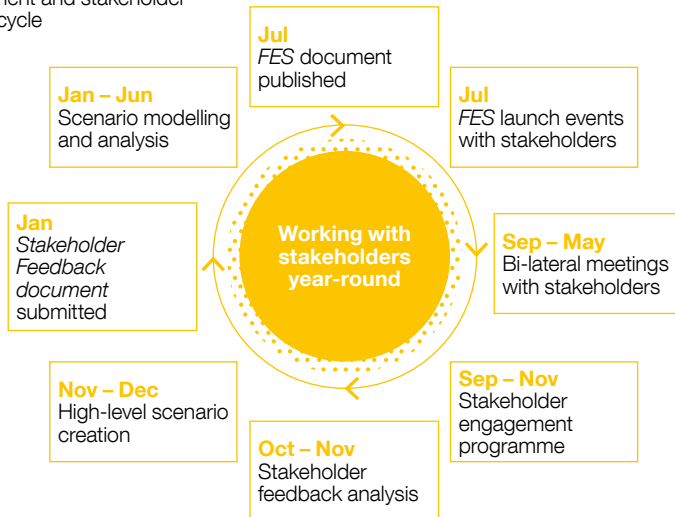
with over 630 individual stakeholders from 415 organisations from the UK, continental Europe and beyond; many were new to our engagement processes. Our *Stakeholder Feedback* document provides further information about the *Scenario Framework* and our engagements. You can find it in our *Stakeholder Feedback* section on the FES website: [fes.nationalgrid.com](https://www.fes.nationalgrid.com)

1.5 What's new in FES?

This year, we share a five-year forecast in the *Data Workbook* to provide more clarity on the shorter-term view requested by stakeholders. We include a standalone sensitivity analysis on how net zero carbon emissions could potentially be achieved by 2050, extending the evaluation published in the Committee on Climate Change report and providing our expert view on these policy developments. Alongside the GB level information in the *Data Workbook*, we have added a *regional breakdown* of electricity demand. We continue to develop our modelling and this year we have included the outputs of a Network Innovation Allowance project to further enhance the analysis of electric vehicle charging behaviour in our transport section.

Figure 1.2

FES development and stakeholder engagement cycle



1.6 How to use the FES document suite

This 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.

We also publish:

- *FES in 5*, a summary document with key headlines and statistics from FES
- *Scenario Framework* which details all the assumptions used as inputs into our models
- *Data Workbook* which contains the outputs from the numerous models, including detailed tables, full sets of graphs and charts, beyond those included in the main document
- *Modelling Methods* which contains information on our modelling methodology and assumptions
- *Key Changes* that summarises the most significant changes since the last FES publication
- *Regional breakdown* which splits GB-level electricity demand data into regional sets
- *Frequently Asked Questions* (FAQs).



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 1.3

Future Energy Scenarios document suite



Future Energy Scenarios



FAQs



Modelling Methods



Data Workbook



Scenario Framework



Key Changes



Regional breakdown



FES in 5

Chapter 2

The scenarios	16
2.1 The scenario framework	16
2.2 Extended analysis and spotlights	16
2.3 An overview of the Future Energy Scenarios	18

The scenarios



The scenarios

2.1 The scenario framework

***FES 2019* uses the scenario framework we introduced last year. We received positive feedback from our stakeholders about the level of insight it provided; and the use of a consistent framework to support year-on-year comparisons in a rapidly changing market.**

The framework is based on two drivers, the speed of decarbonisation and the level of decentralisation.

Two Degrees and **Community Renewables** meet the UK's 2050 carbon reduction target but feature different levels of decentralisation. **Steady Progression** and **Consumer Evolution** do not meet the 2050 target.

All scenarios:

- are GB wide. The scenarios include regional variations in how the energy landscape could develop, where evidence is available.
- take a whole system view. They explore a future where the different parts of the energy market work together in new ways to maximise efficiency and value for consumers.
- include a mix of technologies, but show different levels of adoption.
- model progress from today to 2050.

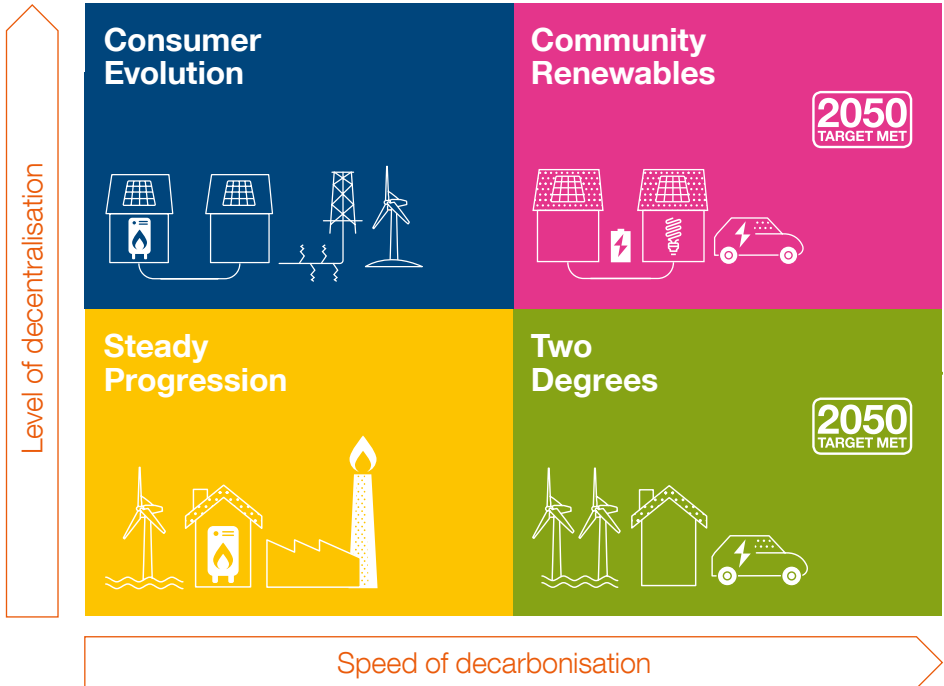
2.2 Extended analysis and spotlights

We extend our analysis to examine uncertainties or consider more extreme cases. This covers two areas.

Chapter six includes **a sensitivity analysis of how net zero carbon emissions** could be achieved by 2050.

We use **spotlights** to supplement the main text, explaining some of the technologies and concepts.

Scenario matrix



Speed of decarbonisation

Take up of low-carbon solutions driven by policy, economic and technological factors, and consumer sentiment.

Level of decentralisation

How close energy supply is to the end consumer, moving up the axis from large scale central to smaller-scale local solutions. We explore this axis in more detail in the scenarios, for example, by differentiating between centralised and decentralised electric vehicle charging options.

More information about how *FES* is modelled is included in the *Modelling Methods* document on the *FES* website.

The scenarios

2.3 An overview of the Future Energy Scenarios

This section provides a brief overview of each scenario.

A pathway graphic for each scenario rates the development across five overarching external factors from low to high to support the scenario's progress to 2050.

Policy support

The level of support mechanisms to encourage low-carbon solutions.

High: Clear, robust and timely policy direction including tax and incentive regimes, market frameworks and other subsidies such as for technology innovation and support for consumers to choose low-carbon solutions.

Low: Delayed policy direction and/or lack of appropriate tax and incentive regimes, corresponding market frameworks or other subsidies.

Economic growth

The overall economic climate.

High: Strong, sustainable increase in the production of goods and services, measured by the annual rate of growth of the UK Gross Domestic Product (GDP).

Low: Slow GDP growth.

Consumer engagement

The level of consumer interest in modifying their behaviour in response to price signals or reducing their carbon footprint by choosing alternative heat and transport options.

High: Consumers proactively choosing low-carbon alternatives, such as electric cars and alternative heat solutions, as well as engaging with ways to manage their energy demand e.g. through digital solutions and smart vehicle charging.

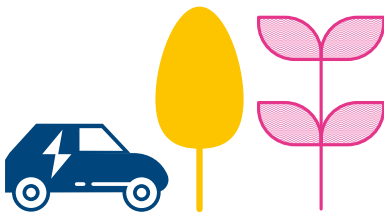
Low: Consumers with little interest or limited means to choose alternative energy solutions or proactively manage their energy demand.

Technology development

The pace of innovation for developing new or existing technology.

High: Rapid progress for proven technologies moving to large-scale deployment (e.g. storage solutions and new digital solutions); and accelerated demonstration of other technologies that have high potential for decarbonisation (e.g. carbon capture, usage and storage (CCUS)).

Low: Delayed demonstration of proven technologies at scale and slow introduction and development of new innovative solutions.



Energy efficiency

The energy efficiency of appliances and thermal efficiency solutions for new and existing buildings.

High: Energy efficient products and services (e.g. thermal insulation) widely accessible and adopted for existing buildings. High quality and regulation of new build thermal efficiency.

Low: The lack of a strong marketplace for energy efficient products and services limiting accessibility and adoption. Poor quality and regulation of new build thermal efficiency.

More information on the assumptions used for the scenarios can be found in the ***Scenarios Framework Document***¹.

¹ <http://fes.nationalgrid.com/fes-document/>



The scenarios

Community Renewables

This scenario achieves the 2050 decarbonisation target in a decentralised energy landscape.

In **Community Renewables**, local energy schemes flourish, consumers are engaged and improving energy efficiency is a priority.

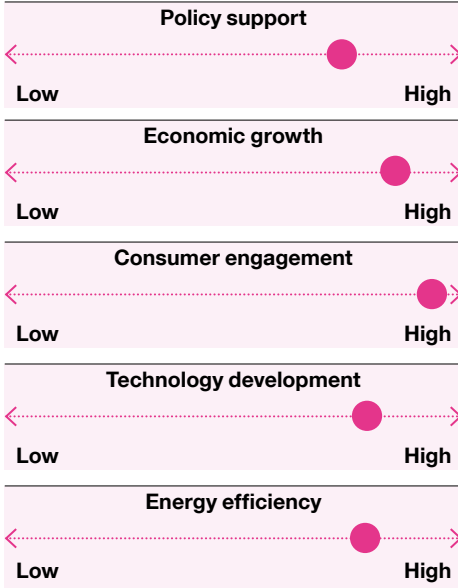
UK homes and businesses transition to mostly electric heat. Consumers opt for electric transport early and simple digital solutions help them easily manage their energy demand.

Policy supports onshore generation and storage technology development, bringing new schemes which provide a platform for other green energy innovation to meet local needs.

Key changes for 2019

- Larger role for district heat and hybrid heat pumps.
- Earlier growth in electricity storage capacity.
- Reduced solar capacity.
- Increased offshore wind capacity and decreased nuclear capacity, as well as lower thermal efficiency is common across all scenarios.

Community Renewables pathway



2017 emissions

503 MTeCO₂

2050 emissions

165 MTeCO₂

Scenario reaches 80% emissions reduction target

Community Renewables pathway

1

By 2050, 58 per cent of total generation capacity is decentralised i.e. not transmission connected.

2

Over 80 per cent uptake of low-carbon heat solutions in homes by 2050, including electric heat pumps, hybrid heat pumps, district heat and biofuels.

3

High appliance and thermal efficiency in new and existing homes have supported a 26 per cent drop in residential heat demand.

4

Electric vehicles are the most popular form of transport by 2035.

5

Over 75 per cent of electric vehicle owners engage in smart vehicle charging (e.g. off peak) by 2050.

6

Rapid growth in storage capacity from the early 2030s with the highest installation of residential battery systems by 2050.

7

Decentralised wind generation grows to over four times 2018 levels.

8

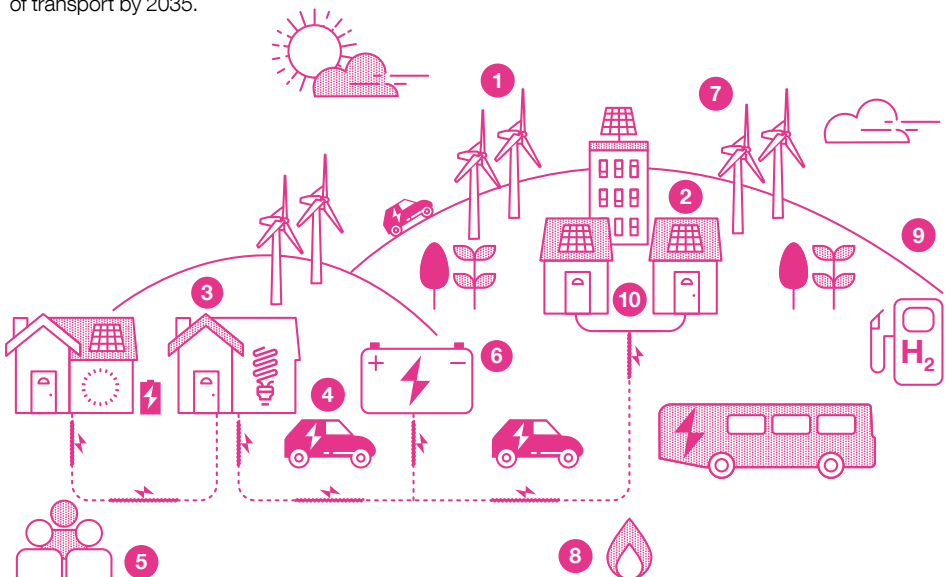
Green gas is 46 per cent of the total natural gas supply by 2050.

9

Multiple onshore renewable energy schemes support other energy production (e.g. hydrogen from electrolysis for commercial vehicles).

10

Lowest total annual energy demand scenario by 2050, approximately two thirds of 2018 levels.



The scenarios

Two Degrees

This scenario achieves the 2050 decarbonisation target with large-scale centralised solutions.

In **Two Degrees**, large-scale solutions are delivered and consumers are supported to choose alternative heat and transport options to meet the 2050 target.

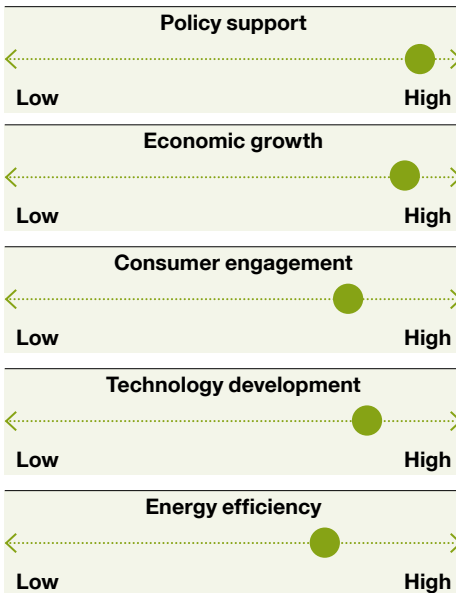
UK homes and businesses transition to hydrogen and electric technologies for heat. Consumers choose electric personal vehicles and hydrogen is widely used for commercial transport.

Increasing renewable capacity, improving energy efficiency and accelerating new technologies such as carbon capture, usage and storage are policy priorities.

Key changes for 2019

- Now the highest peak and annual electricity demand scenario.
- Higher hydrogen demand for heat and commercial transport and hydrogen from electrolysis introduced.
- Small modular nuclear reactors introduced.
- Increased offshore wind capacity and decreased nuclear capacity, as well as lower thermal efficiency is common across all scenarios.

Two Degrees pathway



2017 emissions
503 MTeCO₂

2050 emissions
165 MTeCO₂

Scenario reaches 80% emissions reduction target

Two Degrees pathway

1

Strong growth in renewables and other centralised technologies, with offshore wind generation growing to over six times 2018 levels.

2

Regional roll-out of hydrogen for heat, with over a third of homes heated by hydrogen by 2050.

3

Appliance and thermal efficiency improves in new and existing homes.

4

Electric vehicles are the most popular form of transport by 2035.

5

Public vehicle charging points become more popular, leading to less smart vehicle charging (e.g. peak avoidance).

6

Growing storage capacity and interconnection provide flexibility.

7

312TWh annual hydrogen demand by 2050, mostly produced via methane reforming supported by carbon capture, usage and storage.

8

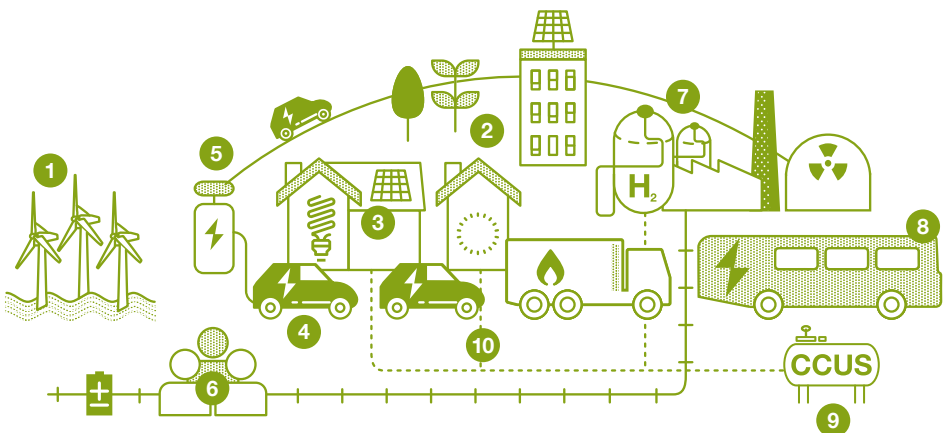
Over 1m hydrogen or natural gas vehicles by 2050.

9

Carbon capture, usage and storage is commercialised, having developed at scale from 2030.

10

Total energy demand has reduced slightly from 2018 levels. Around a 50 per cent increase for electricity, with about 30 per cent less gas than today.



The scenarios

Steady Progression

This scenario makes progress towards decarbonisation through a centralised pathway, but does not achieve the 2050 target.

In **Steady Progression**, the pace of the low-carbon transition continues at a similar rate to today but then slows towards 2050.

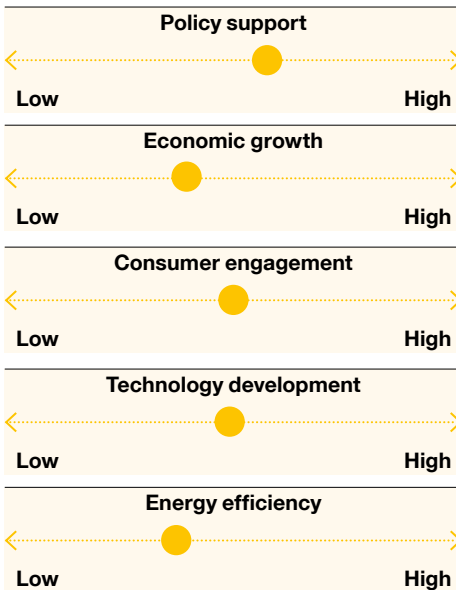
Consumers are slower to adopt electric vehicles and take up of low-carbon alternatives for heat is limited by costs, lack of information and access to suitable alternatives.

Although hydrogen blending into existing gas networks begins, limited policy support means that new technologies such as carbon capture, usage and storage and battery storage develop slowly.

Key changes for 2019

- Higher hydrogen supply with roll-out of blended hydrogen into the gas network.
- Increased offshore wind capacity and decreased nuclear capacity, as well as lower thermal efficiency is common across all scenarios.

Steady Progression pathway



2017 emissions
503 MTeCO₂

2050 emissions
345 MTeCO₂

Scenario reaches 58%
emissions reduction

Steady Progression pathway

1

Some growth in large-scale renewable electricity generation and other centralised technologies, particularly offshore wind.

2

Some hydrogen blending into the gas network, but less than 20 per cent low-carbon heat solutions in homes by 2050.

3

Low levels of appliance and thermal efficiency in new and existing homes and low engagement with smart appliances.

4

Slower take up of electric vehicles, becoming the most popular form of transport only by the early 2040s.

5

Public vehicle charging points become more popular, leading to less smart vehicle charging (e.g. peak avoidance).

6

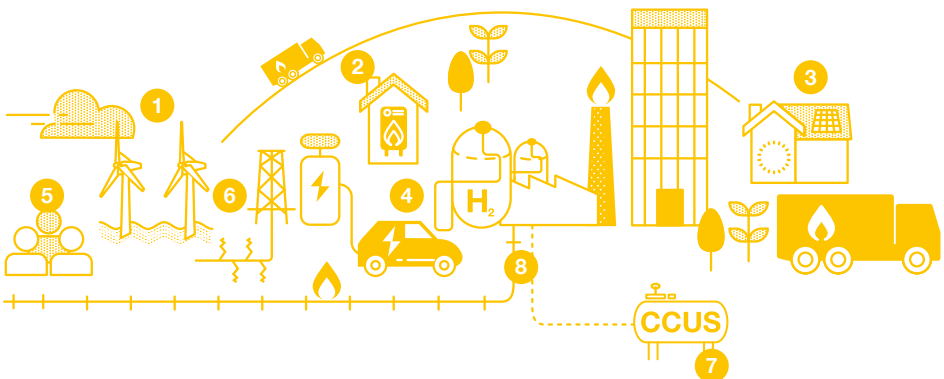
Over 60 per cent of overall energy demand is provided by natural gas at 2050, with high reliance on imported gas, including LNG.

7

Carbon capture, usage and storage is commercialised and used for power generation and hydrogen production via methane reforming.

8

Highest total energy demand scenario by 2050, slightly increasing from 2018 levels.



The scenarios

Consumer Evolution

This scenario makes progress towards decarbonisation through decentralisation, but does not achieve the 2050 target.

In **Consumer Evolution**, there is a shift towards local generation and increased consumer engagement, largely from the 2040s.

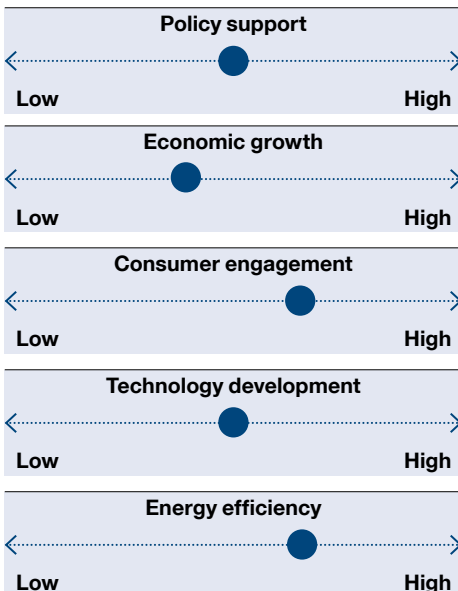
In the interim, alternative heat solutions are taken up mostly where it is practical and affordable, e.g. due to local availability. Consumers choose electric vehicles and energy efficiency measures.

Cost-effective local schemes are supported but a lack of strong policy direction means technology is slow to develop, e.g. for improved battery storage.

Key changes for 2019

- Now the lowest peak and annual electricity demand scenario.
- No small modular nuclear reactors.
- Increased offshore wind capacity and decreased nuclear capacity, as well as lower thermal efficiency is common across all scenarios.

Consumer Evolution pathway



2017 emissions
503 MTeCO₂

2050 emissions
344 MTeCO₂

Scenario reaches 58% emissions reduction

Consumer Evolution pathway

1

55 per cent of total generation capacity is decentralised by 2050 (i.e. not transmission connected).

2

Around one third of homes using low-carbon heat solutions by 2050, such as district heating schemes and electric and hybrid heat pumps.

3

Some appliance and thermal efficiency improvements for new and existing homes.

4

Slower take up of electric vehicles, becoming the most popular form of transport only by the early 2040s.

5

Over 70 per cent of electric vehicle owners are engaged in smart vehicle charging by 2050 (e.g. off peak).

6

Local renewable electricity generation grows gradually, with the lowest interconnector and nuclear capacity of all scenarios.

7

Greatest reliance on gas-fired generation of all scenarios.

8

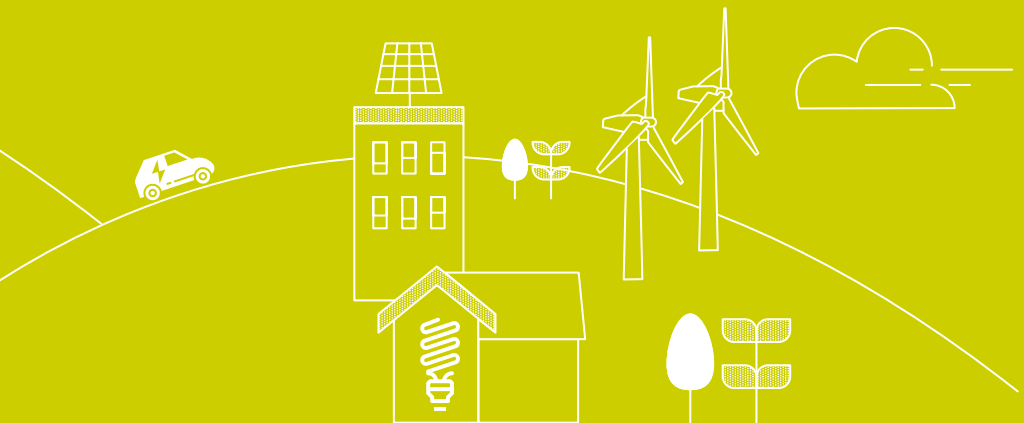
Overall energy demand stays similar to 2018 levels. Over 60 per cent is still provided by natural gas at 2050, including distribution connected shale gas and green gas.



Chapter 3

3.1 Speed of decarbonisation	30
3.2 Level of decentralisation	34

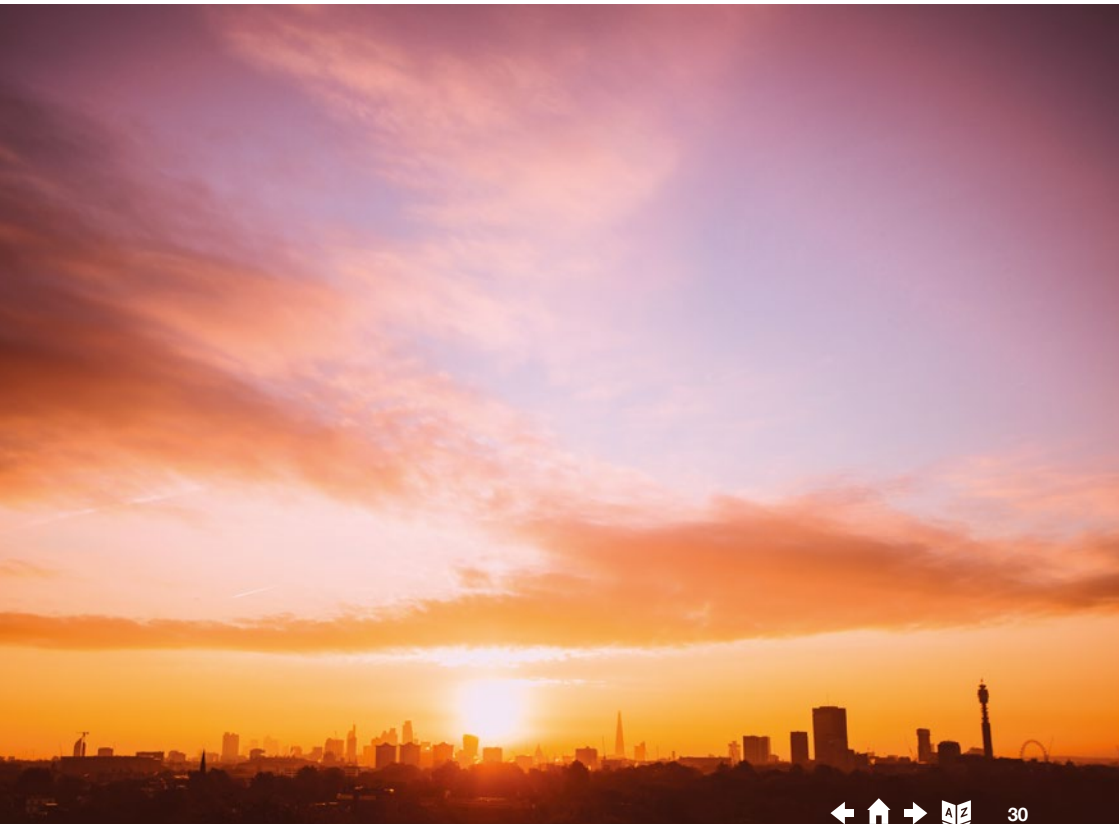
Decarbonisation and decentralisation



Decarbonisation and decentralisation

3.1 Speed of decarbonisation

Decarbonisation is an important driver in determining what the future of energy could look like, and speed of decarbonisation is one of our two scenario axes in *FES 2019*. Two of our scenarios meet the UK's 2050 carbon reduction target, and two do not. All four scenarios achieve decarbonisation in distinct ways across the sectors of heat, electricity and transport. In this section, we explore how recent trends and policy developments relate to our core scenarios, and how carbon emissions could reduce across different sectors.



More than ever before, climate change is at the forefront of public consciousness. There is increasing coverage of environment related issues in mainstream media and, across Europe, direct citizen action calling on governments to act now to protect our planet. In March 2019, UK Government research¹ found that around 80 per cent of the public were either 'fairly' or 'very' concerned about climate issues, the highest proportion since this research began in 2012.

One of the main drivers in reducing the UK's carbon and other greenhouse gas emissions to date has been environmental legislation. A key focus for our *FES 2019* scenarios is the Climate Change Act 2008. This is the UK's contribution to the global Paris Agreement that seeks to keep the increase in global temperatures to less than 2°C above pre-industrial levels. As well as this commitment, the **Paris Agreement** also noted the need to limit temperature increase even further, to 1.5°C. We discuss this further in chapter six where we consider the implications of the UK Government's recent decision to move to a net zero carbon emissions target by 2050.

The Climate Change Act legally bound the UK to reduce carbon emissions and associated greenhouse gases by at least 80 per cent from 1990 levels by 2050 (the '2050 carbon reduction target') via a series of five-yearly carbon budgets. So far, the Government has set carbon budgets up until 2032, and these progressively reduce the amount of greenhouse gases the UK can legally emit in each five-year period.

FES 2019 refers to the **Community Renewables** and **Two Degrees** scenarios, that meet the 80 per cent reduction by 2050 target, as the '2050 compliant' or 'faster decarbonising' scenarios. Both scenarios meet all current carbon budgets.

Further legislation and policy measures support the achievement of the carbon budgets, and seek to reduce the emissions of other greenhouse gases that contribute to both climate change and to health concerns. For example, the **UK Clean Growth Strategy**, published in 2017, sets out policy measures to enable economic growth whilst also decarbonising the economy. And the **Road to Zero Strategy**, published last year, focuses on the reduction of emissions from existing vehicles as well as measures to rapidly drive the uptake of low-carbon vehicles.

All four *FES* scenarios approach decarbonisation in distinct ways, and to differing extents, across the energy landscape. Our analysis focusses on decarbonisation in the electricity, heat and transport sectors. Other sectors, such as aviation and agriculture, contribute to greenhouse gas emissions as well, and we incorporate research by expert organisations into our modelling to account for these sectors. So, for example, we do not model developments in the agricultural sector ourselves, but use research from other organisations to account for how greenhouse gas emissions from this sector might change over the next 30 years.

Decarbonisation policy in the UK

As *FES 2019* was being written, the UK Government had just announced its intention to commit to a net zero emissions target. The Climate Change Act 2008 legally committed the UK to reducing greenhouse gas emissions by 80 per cent compared to 1990 levels. Section two of the Act allows the Secretary of State the power to amend the target (either by amending the percentage, or the baseline year) 'by order' (i.e. through secondary legislation). At the end of June 2019, the House of Commons and then the House of Lords approved the UK

Government's proposed net zero legislation, thereby moving the legally binding target to net zero emissions by 2050. You can read more about this at <https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law>. In *FES 2019*, where we refer to the '2050 target' we are referring to the original Climate Change Act target of an 80 per cent reduction in emissions by 2050. We discuss the implications of a net zero target in chapter six.

¹ BEIS public attitudes tracker, Wave 29.

Decarbonisation and decentralisation

Carbon accounting methods

There are many ways to measure the carbon emissions resulting from a specific process. For example, some methods consider the carbon emissions across the whole life of a project. These would include emissions from the output of a generation plant, for example, but also emissions associated with its construction and decommissioning.

Other methods consider upstream aspects – the greenhouse gases associated with extracting and transporting a fuel, as well as the emissions produced when it is burnt. Further differences could result from accounting for issues such as network energy losses.

In *FES 2019*, we only consider the direct carbon emissions from a specific process, rather than whole life cycle or upstream approaches.

However, electricity imported via interconnectors and used in this country is counted as zero carbon from a UK perspective. This reflects the agreed approach for electricity of accounting for emissions in the country of production.

We also discuss carbon dioxide equivalent when discussing emissions. This approach considers all types of greenhouse gases, and accounts for their impact on climate change, compared to a unit of carbon dioxide. For example, the release of one unit of a greenhouse gas such as methane, that warms the planet 25 times more quickly than carbon dioxide, would be counted as 25 units of carbon dioxide equivalent. This approach means we can account for the impact of different gases on climate change consistently.

In all scenarios, we expect continued decarbonisation of the electricity sector as new low-carbon generation comes online. Consequently, both the carbon intensity of electricity, and the overall emissions associated with its use and production, reduce in all scenarios. It's essential to reduce the carbon intensity of electricity generation ahead of other sectors – otherwise demand is simply being shifted from other carbon intensive sources of energy to electricity that is also carbon intensive.

By 2050, the greatest decarbonisation of the electricity sector is in **Two Degrees**, thanks to the high growth of renewable generation, nuclear capacity and interconnection as well as the use of carbon capture usage and storage (CCUS) with gas-fired generation. By 2050, this sector emits less than seven megatonnes of carbon dioxide equivalent per year. This compares to approximately 73 megatonnes in 2017.

The road transport sector is significantly decarbonised compared to today in every scenario. This is thanks to clear policy direction, such as the Government's Road to Zero goal to ban the sale of conventional vehicles by 2040, and the falling total cost of ownership for electric vehicles (EVs). Although the Road to Zero ambition is not met in **Consumer Evolution** and **Steady**

Progression, there is still a marked growth in EVs, leading to a very large reduction in carbon emissions from road transport.

Finally, heat is the most challenging sector to decarbonise. As explored in chapter four, all the main technologies available to decarbonise heating in GB today involve some additional cost, consumer disruption and energy infrastructure development. As a result, decarbonising heating will require co-ordination at a national scale, with clear policy and resourcing. The variety of technologies also means there is no one leading pathway to decarbonise heat. The best choice is likely to vary across the country, depending on factors such as existing infrastructure, geography and housing stock.

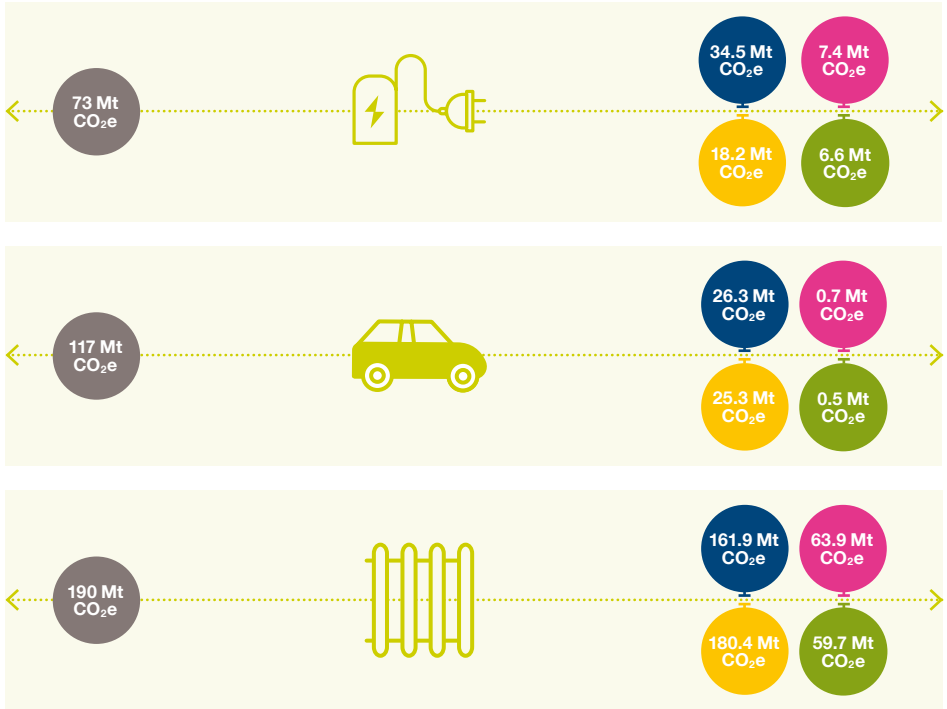
Heating has the greatest variation in decarbonisation across the four scenarios, with little progress in **Steady Progression** as the number of gas boilers remains almost unchanged, but a small amount of hydrogen is blended into the gas network. In contrast, the roll-out of hybrid and air source heat pumps, district heating and, in **Two Degrees**, pure hydrogen heating, means that both 2050 compliant scenarios achieve considerable progress in decarbonising heat, though with significant emissions remaining.

Figure 3.1

Carbon emissions from the electricity, transport and heat sectors by scenario

2017

2050



Decarbonisation and decentralisation

3.2 Level of decentralisation

The level of decentralisation indicates how close the production and management of energy is to the end consumer. Decentralisation creates closer links between sources of energy supply and demand via local networks, and consumers take a more active part in managing their energy needs.

In a decentralised world, far more small-scale energy supplies connect to the distribution networks, including renewables and small-scale green gas. On a yet smaller-scale, consumers access technology to manage their own electricity needs in a more localised manner. Residential solar panels provide a direct source of energy for domestic use, and EV owners tap into the storage capacity of their vehicle's battery to help to power their homes. New technology and business models help make this more easily accessible to all consumers.

With increased decentralisation, as the number and diversity of those involved in the energy market grows, so too does the complexity of operating the system. The increasing quantity of distribution connected energy supplies reduces the visibility of network assets for the transmission system operator.

No longer do large transmission connected electricity and gas supplies dominate. Instead there is a transition to more distributed supply patterns, varying in terms of scale and location, and more complex flows of energy around the country. Since many of the distribution connected electricity supplies are renewable, the generation patterns become more weather dependent. It is possible to see significant swings in both scale and location of supply, dependent upon weather conditions.

This also results in far more interaction between gas and electricity supply and demand. Currently, when output from renewable electricity generation is low, one of the primary sources of flexibility is provided by gas-fired power stations and other thermal peaking plant. In this way, the weather dependent, intermittent nature of renewable generation has a knock-on effect on gas demand, increasing its variability and uncertainty.

In a decentralised world, it is essential to adopt a more integrated, whole system approach across the gas and electricity transmission and distribution systems. New ways of designing and operating the energy system will increasingly be needed. To manage the system in the most cost-efficient way, new markets for operability products must be 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.

There are many different approaches as to how the concept of decentralisation applies to the energy market. In the following sections, we explore how we apply the concept of decentralisation in our scenarios.

Electricity decentralisation

Electricity generators are connected to either the transmission network or to the distribution network, or can be located on customers' own sites. There has also been increasing growth in the number of microgenerators (those with a capacity of 1 MW or less) in recent years.

In our scenarios, we consider electricity generation connected to the transmission system as being centralised, and generation connected to the distribution system or at lower voltages (including microgeneration) as being decentralised. Figure 3.2 shows the split across our scenarios out to 2050.

Currently there is 108GW of generation capacity on the system, split as 71 per cent transmission connected, 24 per cent distribution connected and five per cent microgeneration.

In our decentralised scenarios, **Community Renewables** and **Consumer Evolution**, we assume continued growth in distribution connected generation, increasing steadily from

its current levels to 36 per cent of total generation in both scenarios by 2050. These connections are predominantly renewables, but distribution connected peaking plants provide smaller-scale forms of flexibility.

By 2050, **Community Renewables** has the highest proportion of microgeneration, rising to 22 per cent of total generation capacity. This equates to 53GW, whereas the more centralised **Two Degrees** scenario has only has 22GW of microgeneration by 2050.

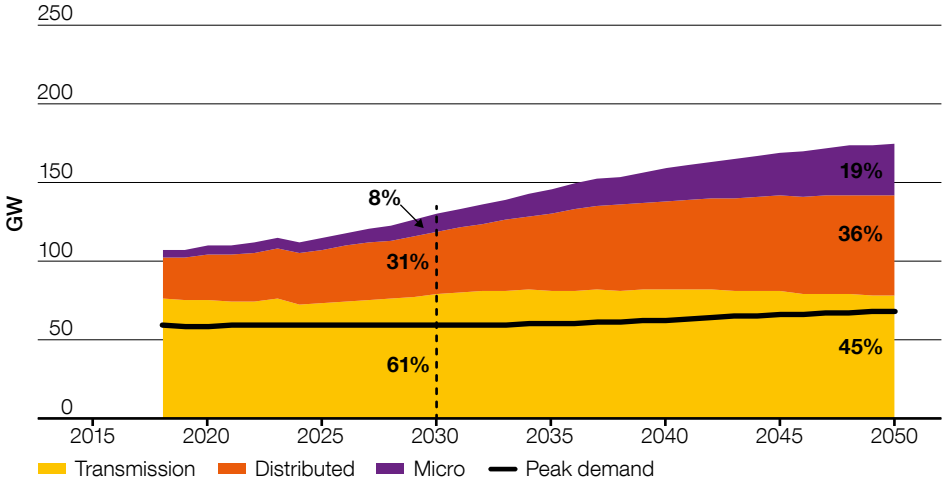
In all scenarios, the decentralisation of generation increases, and new microgeneration develops, including small wind turbines and solar panels. Our decentralised scenarios also reflect the growth in battery storage, more typically connecting to the network at distribution level due to their scale. In addition, we consider the impact of vehicle-to-grid (V2G) technology, where electricity stored in the battery of an EV can be supplied back into the network. V2G is higher in the decentralised scenarios (see the transport demand section for more details on [page 76](#)).

Decarbonisation and decentralisation

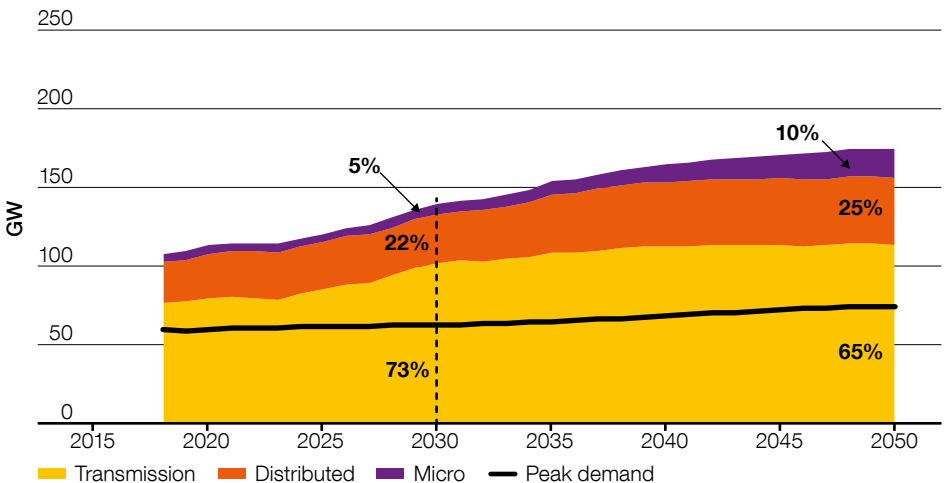
Figure 3.2

Connection location of installed generation capacities and peak demand

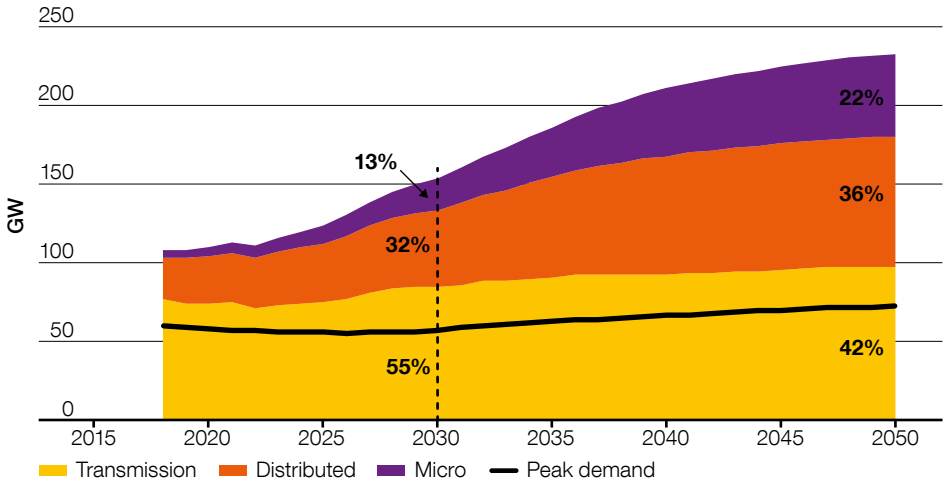
Consumer Evolution



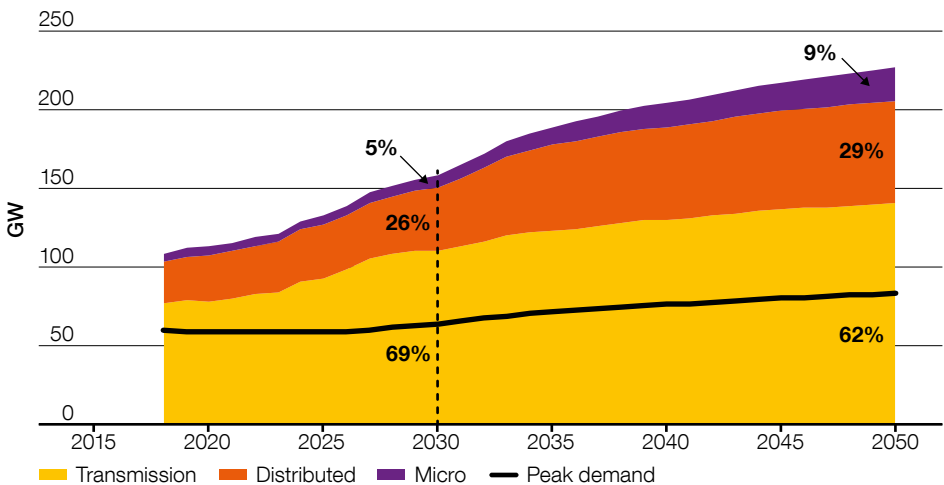
Steady Progression



Community Renewables



Two Degrees



Decarbonisation and decentralisation

Although annual demand is broadly similar in each of the two faster decarbonising scenarios, figure 3.3 shows the shift to decentralisation

in **Community Renewables** by illustrating the scale of the top four installed generation capacity types based on where they are connected.

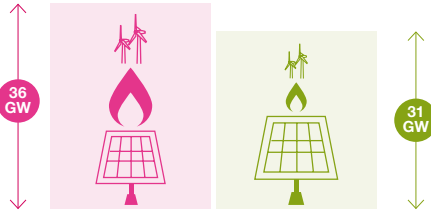
Figure 3.3

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

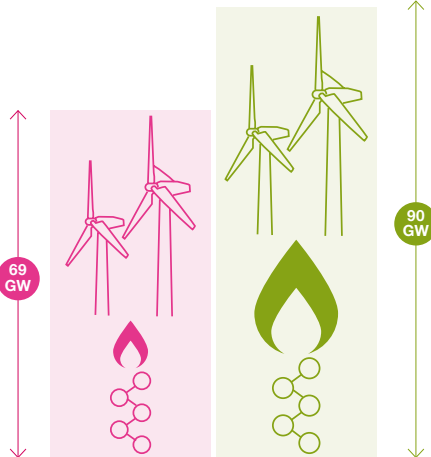
Micro connected



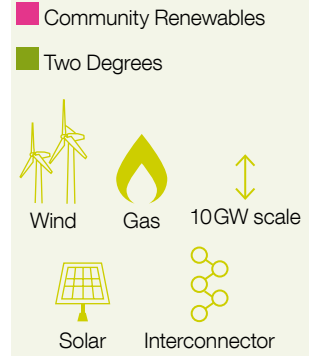
Distribution connected



Transmission connected



Key



There are many views on how demand differs in a decentralised world. In *FES 2019*, we have changed our assumptions in a couple of areas. This year we have assumed that district heating would be higher in a more decentralised world. Whilst it would need some degree of coordination to establish, the fact that this is established by local communities has made it, in our view, more aligned to a decentralised world where consumers are more engaged with their energy needs. The average size of such schemes (typically around 30 buildings) is also more aligned to a decentralised world.

We have also made some changes to energy efficiency across the four scenarios, in order to capture a wider range of uncertainty. We have assumed that in a more decentralised world, consumers are more engaged with their energy use and so are likely to choose more efficient options where available. However, government energy policies and legislation are also influenced by the decarbonisation axis, as this would capture aspects such as efficiency legislation.

In our decentralised scenarios, most charging of EVs will be done at or close to home. There is less use of public charging facilities and public transport than in centralised scenarios. Decentralised solutions for transport demand could include small-scale, dedicated wind and solar plant, built where charging demand is greatest, for example in supermarket car parks, with co-located battery storage.

Gas decentralisation

The current proportion of gas supplies connected at distribution level is less than one per cent of total gas supply. Growth in distribution connected supplies is expected across all scenarios out to 2050, and much of this growth comes from green gas connections (gases created from organic

materials, domestic waste etc). Many types of green gas are created in much smaller-scale plants. These are better suited to connecting to the lower pressure distribution network, as compressing small amounts of gas to a high pressure could be costly. Some distributed gas connections will also result from the introduction of shale gas.

GB mainly relies on centralised forms of gas supply. Most of the GB gas supplies still come from the UKCS and Norway, with additional flexibility of supply provided by LNG and imports from Europe. As production of green gas increases, we see dependency on LNG and interconnection reducing in our scenarios, most significantly in **Community Renewables**.

Figure 3.4 shows the split of supply connections across all scenarios².

Community Renewables is the scenario with the lowest dependency on gas by 2050. There is 56TWh per year of distribution connected supplies in 2050, which is 19 per cent of total supply, and all of this is green gas.

Consumer Evolution has 109TWh per year of distribution connected gas supply in 2050. This scenario has the highest level of shale gas, much of which is likely to be connected at distribution level with production beginning from around 2026. Some of the distribution connections will also be green gas (18TWh per year in 2050), but far less than in the faster decarbonising scenario, **Community Renewables**.

In the more centralised scenarios, the distribution connected supplies are less than ten per cent of total gas supply. **Two Degrees** has 49TWh per year by 2050, all of which is green gas. In **Steady Progression**, most of the distribution connected supply is shale gas, and by 2050 this reaches 24TWh per year.

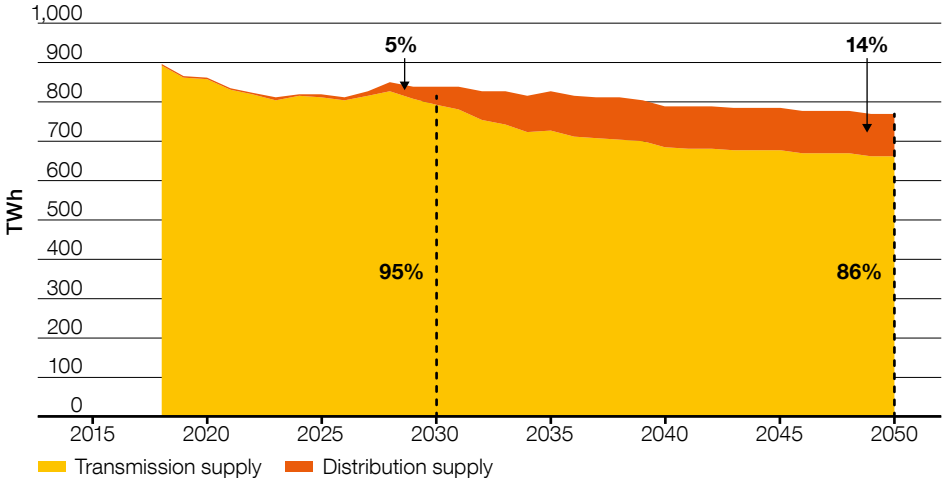
² Gas supply is represented in TWh in this section, for easier comparison with electricity supplies. To convert gas TWh units to billions of cubic metres (bcm) units, divide by 11.

Decarbonisation and decentralisation

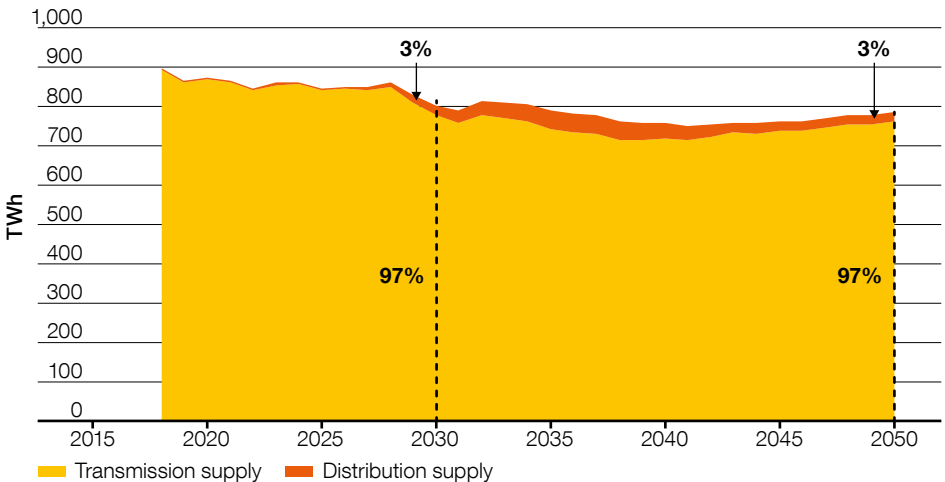
Figure 3.4

Connection location of gas supplies

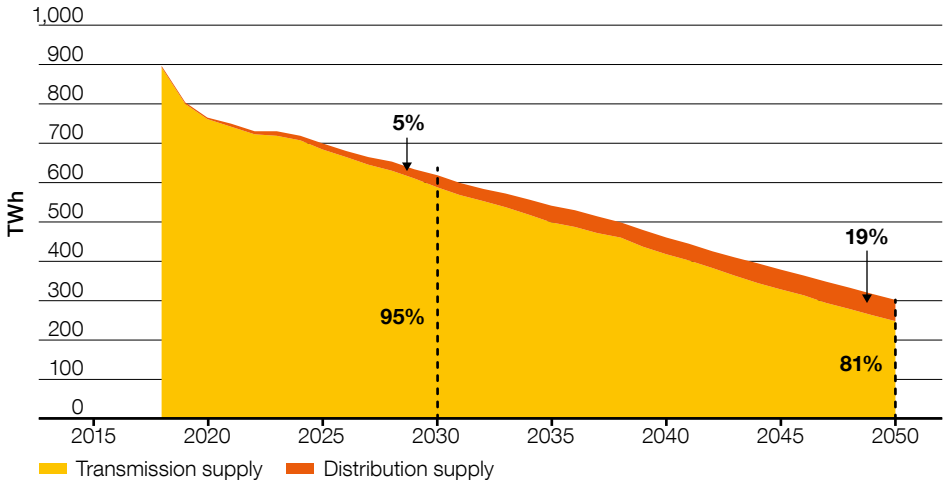
Consumer Evolution



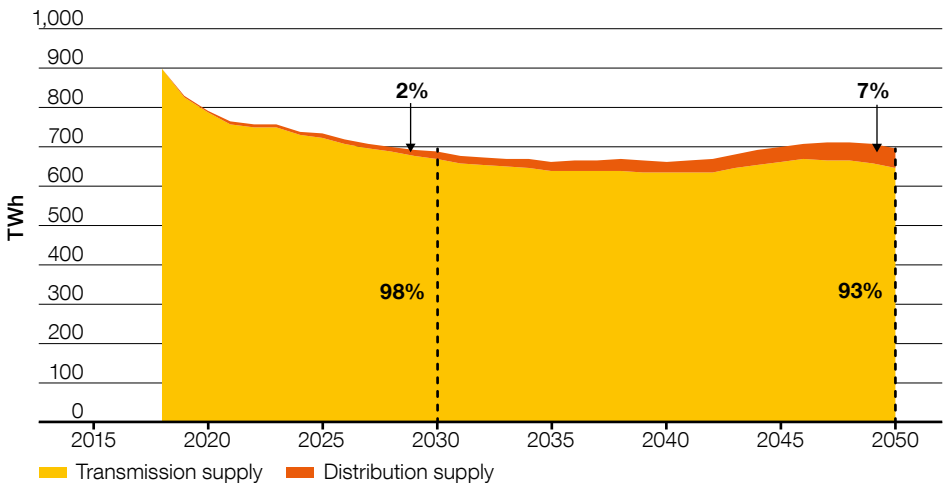
Steady Progression



Community Renewables



Two Degrees



Chapter 4

Energy demand	44
4.1 Energy demand	44
4.2 Industrial and commercial demand	50
4.3 Residential demand	60
4.4 Transport demand	76
4.5 Gas demand for electricity generation	93
4.6 Demand for hydrogen production	95

Energy demand

Spotlights



Demand changes in a hybrid heat pump home [Pg 70](#)



Electric vehicle charging behaviour [Pg 89](#)



Hydrogen production [Pg 100](#)



Hydrogen: Building the evidence [Pg 104](#)

Energy demand

4.1 Energy demand

Energy is a basic requirement for everyday life. The electricity and gas components of this energy demand¹ interact very closely and this will increase as technologies such as hybrid heat systems and hydrogen production are developed further.

In addition, energy needs traditionally met by fuels such as petrol and diesel in the transport sector will increasingly switch to electricity, gas or hydrogen, further broadening the scope of overall energy demand across gas and electricity. In general, demand will also become more active in response to the increasing need for flexibility on the gas and electricity systems.

¹In FES we consider the underlying, or actual, demand of consumers within GB and, in this section, we do not include electrical network losses or gas shrinkage unless otherwise stated. More information on our assumptions can be found in the *Modelling Methods* document. <http://fes.nationalgrid.com/fes-document/>

Key insights



Across all the scenarios, although to different extents, demand initially reduces due to increased levels of energy efficiency. However, this starts to be offset by a fuel switch as transport moves from oil-based fuels to electricity, gas or hydrogen.



The demand for gas as it is used today reduces in all scenarios. However, total demand for gas in 2050 remains high in scenarios where it is used to produce hydrogen or for electricity generation with CCUS.



Demand side flexibility from activities such as electric vehicle charging could play a significant role in managing peak electricity demand and weather dependent generation output. Smart charging and vehicle-to-grid technology enable this flexibility across all the scenarios.



Of the total gas and electricity demand of 1,089TWh in 2018, 74 per cent was met by gas and 26 per cent by electricity. By 2050, total demand is highest in **Steady Progression** at 1,092TWh, where electricity demand has increased to 34 per cent but gas still provides 66 per cent. **Community Renewables** sees the lowest total demand in 2050 at 617TWh. Here, however, electricity now contributes 66 per cent with gas only providing 34 per cent.

Annual demand

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

- residential
- industrial and commercial
- transport
- gas demand for electricity generation
- electricity and gas demand for hydrogen production.

Annual energy demand has reduced year-on-year from 2010; largely as a result of improved energy efficiency². Figure 4.1 illustrates the extent to which this trend continues across the scenarios and highlights the contributions of each of the different energy sectors.

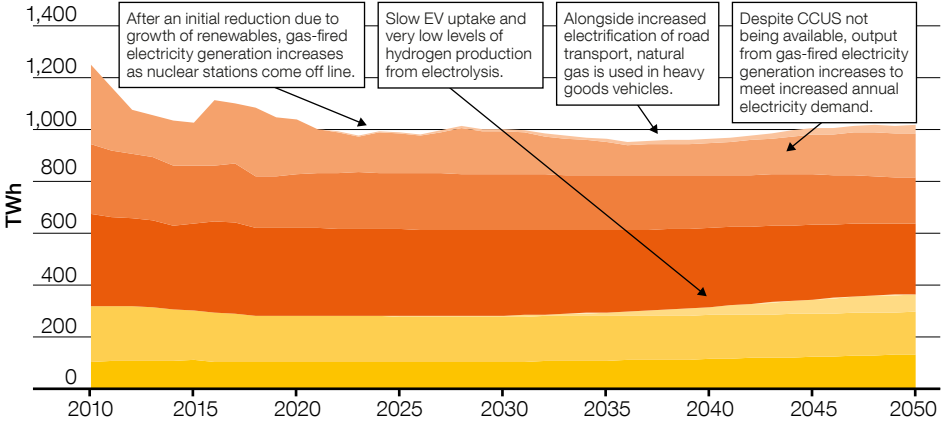
²The increase in 2016 was when gas replaced coal as the preferred fuel for electricity generation.

Energy demand

Figure 4.1

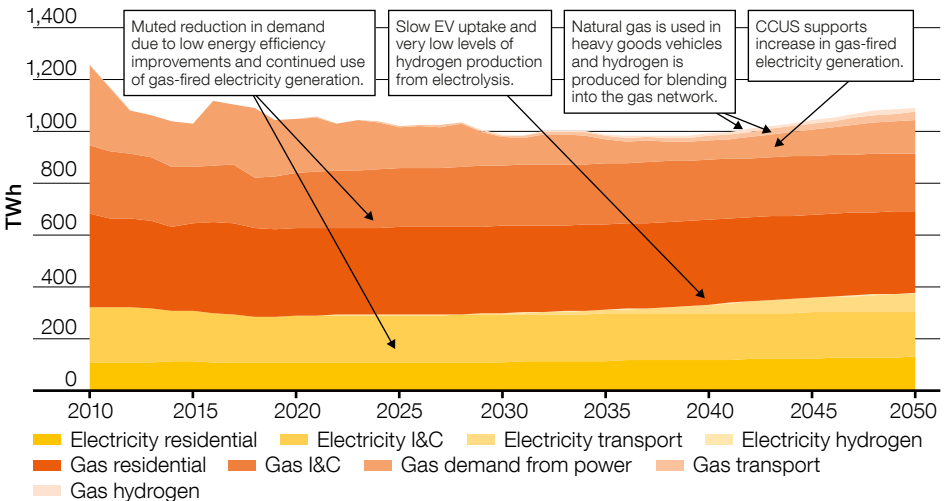
Gas and electricity annual demand by sector

Consumer Evolution



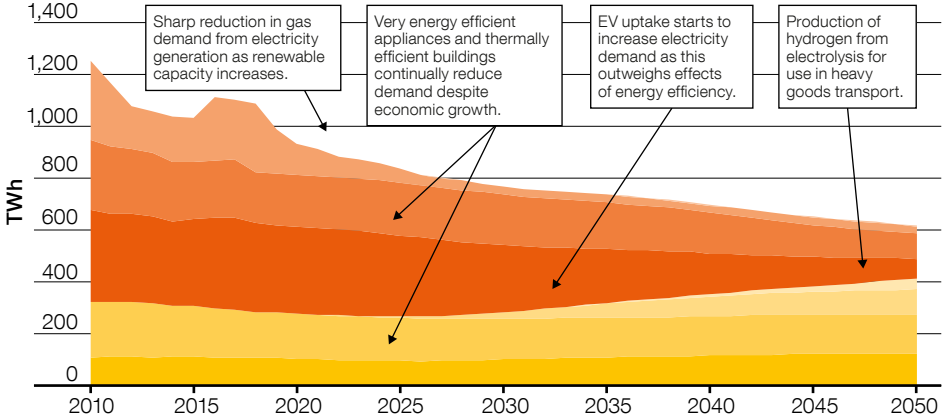
In **Consumer Evolution**, total energy demand stays relatively constant to 2050.

Steady Progression



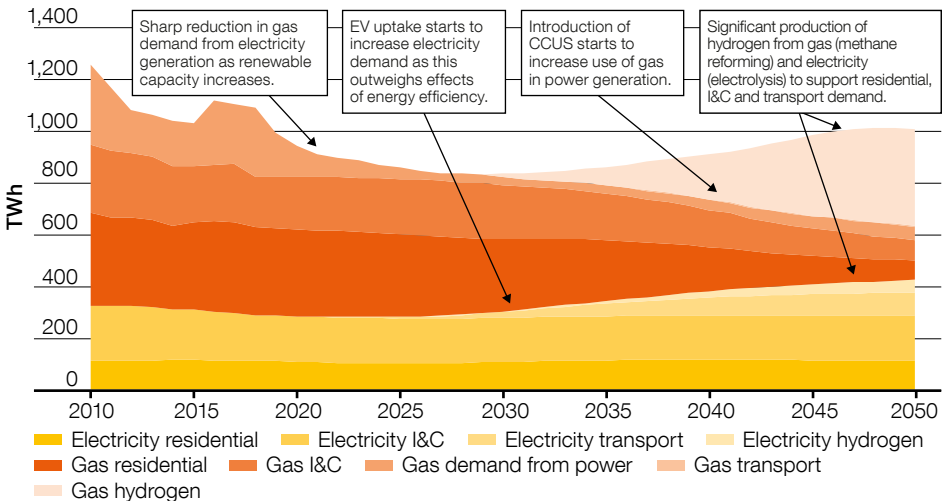
Total energy demand increases in **Steady Progression** compared to today's level. Here, increases in electricity demand due to electrification of transport are not sufficiently offset by improvements in energy efficiency.

Community Renewables



Community Renewables sees the greatest reduction in total energy demand, falling to just over half of the 2010 value by 2050.

Two Degrees



Two Degrees initially sees large reductions but, from 2030, demand starts to increase again as both electricity and natural gas are used to produce hydrogen.

Energy demand

Electricity peak demand

At present, the highest demand for electricity, called peak demand, is generally on a winter weekday evening at around 5:30pm. As the adoption of technology like smart meters and smart devices increases, the daily demand profile may change as flexible demands like electric vehicles (EVs) take advantage of cheaper prices when system demand is lower or renewable output is high³.

Underlying peak demand is currently around 60GW. Moving further into the future, the effects of electrifying first transport and then heat become apparent as these outweigh the improvements in energy efficiency and peak avoidance.

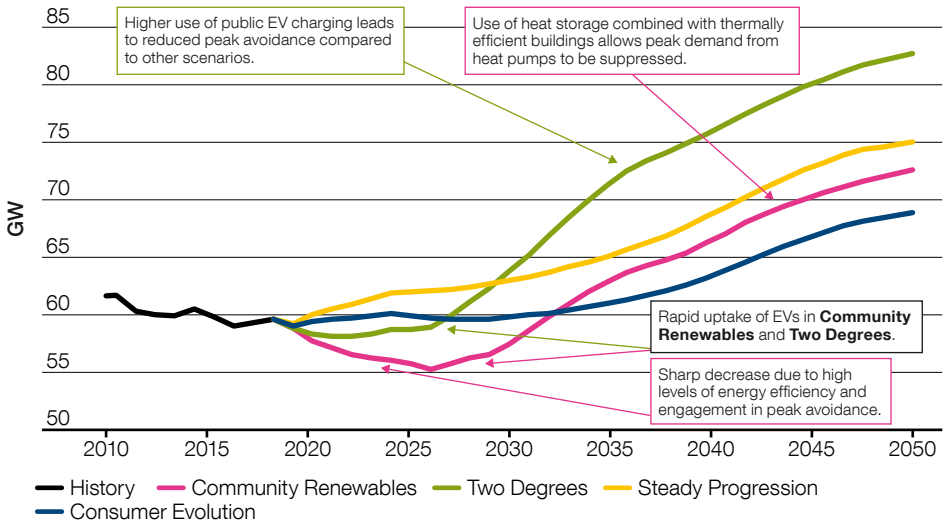
EV growth is highest in **Two Degrees** and **Community Renewables** and, even though

they also have the highest energy efficiency and peak avoidance, demands start to increase as a result of consumers who do not use smart charging buying EVs. Decentralisation also plays a large role in avoiding charging at peak. In **Two Degrees** and **Steady Progression** there is far more centralised charging of EVs which restricts peak avoidance as consumers want to charge there and then. In **Community Renewables** and **Consumer Evolution**, there is more decentralised residential charging which is more suited to smart charging.

In terms of heat, thermal storage and insulation suppress peak electricity demand in **Community Renewables** while, across the scenarios, increased use of hybrid heating means that other fuels provide heat energy during peak electricity demand.

Figure 4.2

Electricity peak demand (including losses)



³Our assumptions on smart charging and consumer behaviour are discussed later in this chapter.

Electricity minimum demand

Minimum electricity demand is generally on a summer's weekend day at around 6am. In all the scenarios this remains relatively static, around 20GW, out to the early 2030s. These relatively stable minimum underlying demands mask more complex flows across the network caused by embedded generation such as solar.

However, demand in these minimum periods could increase significantly due to the opportunities provided by storage and the smart charging of EVs to take advantage of low prices.

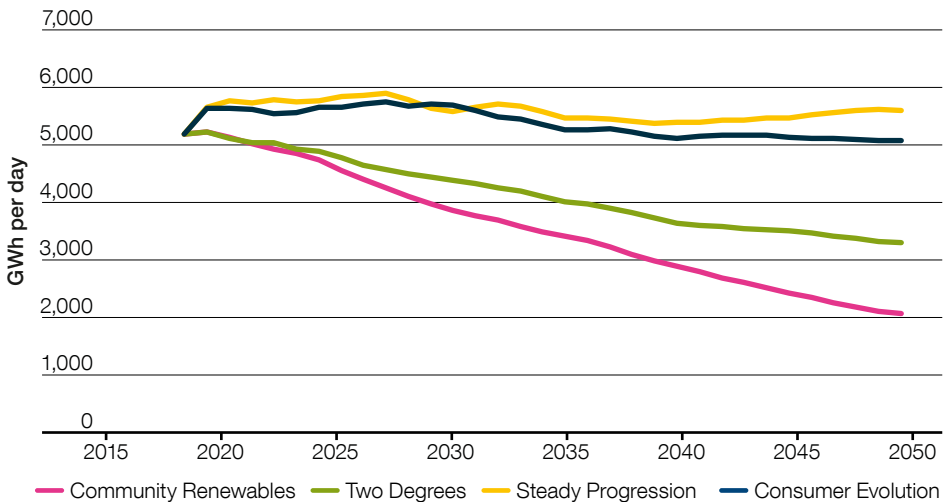
Gas peak day

Gas peak demand⁴ is illustrated in figure 4.3. Generally, it mirrors the movement of annual gas demands in each scenario as many of the factors which influence annual demand also influence peak demand, but the declines are not as rapid. For instance, if a property converts from a gas boiler to an electric heat pump, this will reduce both the annual and the peak demands. Similarly, energy efficiency measures impact peak demand, as well as annual demand, as a better insulated property would retain heat better during winter and require less gas in cold snaps.

However, if properties move to hybrid heating systems, the annual demand for gas is likely to be reduced as the electric heat pump contributes a large share of the energy; but on a peak day, the gas boiler would fire up and peak demand could stay relatively high even as annual demand decreases.

Figure 4.3

Gas 1-in-20 peak demand



⁴This is a 1-in-20 demand which means that statistically, in a long series of winters, it would be exceeded in one out of twenty winters.

Energy demand

4.2 Industrial and commercial demand⁵

Key insights

173TWh electricity

2018 annual electricity demand

147TWh–170TWh electricity

2050 demand range



I&C electricity demand reduces in all scenarios by 2050.



Changes in demand are due to two main factors:

1. Improved energy efficiency

For buildings and processes, this offsets rising I&C demand associated with economic growth.

230TWh gas

2018 annual gas demand

103TWh–247TWh gas⁶

2050 demand range



I&C gas demand reduces in two of the scenarios by 2050.



2. New fuels and technology

A switch to alternative fuels and technologies, such as hydrogen and air source heat pumps, disrupts I&C demand.

Figures above exclude energy demand for hydrogen production, as this is considered in section 4.5.

⁵ In this section, gas industrial demand includes the demand for combined heat and power (CHP) and CCGTs connected to the gas distribution network; gas commercial demand excludes demand for flexible or peaking generation connected to the gas distribution network.

⁶ Gas demand range does not include natural gas demand for hydrogen production.

Industrial and commercial (I&C) businesses currently account for about 25 per cent of all gas used in GB and around 60 per cent of electricity. Most of this demand is to heat and light buildings, and to run industrial processes. The industrial and commercial sector is also currently responsible for about 30 per cent of total UK greenhouse gas (GHG) emissions.

In all scenarios by 2050, electricity demand is relatively close to today's levels. Gas demand reduces in two of the scenarios.

The demand in each scenario is based on the interaction of three main factors⁷ economic growth, energy efficiency and the adoption rate and type of low-carbon technology.

The UK⁸ is currently the world's ninth largest industrial nation. The UK Government's Industrial Strategy recognises the challenge and importance of I&C decarbonisation to sustain the economy and deliver future prosperity.

Economic growth and energy efficiency

More than two thirds of the I&C GHG emissions come from a small number of energy intensive

industries (for example steel, chemicals, glass and cement) which are very important to the economy. They support employment both directly and through their supply chains which underpin regional economies. As an example, manufacturing, which is largely energy intensive, was 10 per cent of UK output and 45 per cent of total UK exports in 2018.

The scenarios continue the trend of the last ten years where, in many I&C sub-sectors, the relationship between high economic output and increased energy demand has broken down. This is mainly due to energy efficiency improvements. However, in sub-sectors where energy is a significant part of the cost base, our modelling shows that demand remains linked to economic output in the long term.

Table 4.1

A summary of the key economic levers used in *FES*

	Average GDP growth	Electricity prices	Gas prices
Community Renewables	1.9%	High	High
Two Degrees	1.9%	High	High
Steady Progression	0.8%	Low	Low
Consumer Evolution	0.8%	Low	Low

⁷ Further detail on the models and their outputs can be found in the accompanying *Modelling Methods and Data Workbook*.

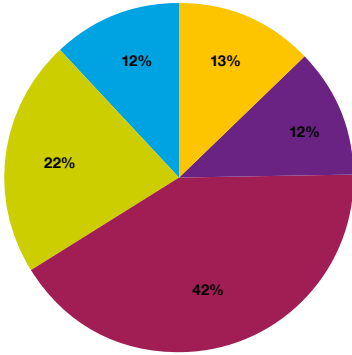
⁸ Whilst modelling in *FES* is based on GB energy demand and supply, in some areas (such as economic growth), it is necessary to talk in terms of the UK.

Energy demand

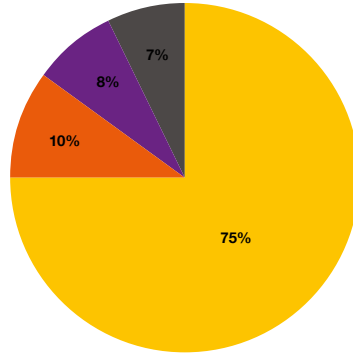
Figure 4.4

End uses for gas and electricity in the industrial and commercial sector⁹

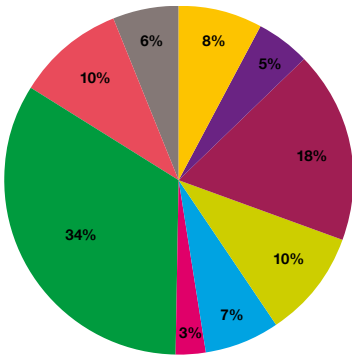
Industrial end uses for gas



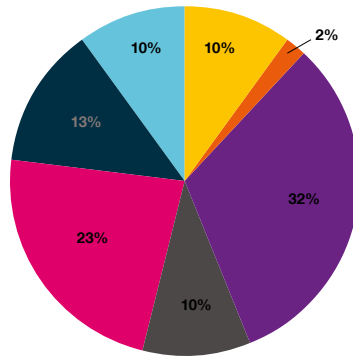
Commercial end uses for gas



Industrial end uses for electricity



Commercial end uses for electricity



Space heating

Water heating

Other

Cooking/catering

Low temperature process

High temperature process

Drying/separation

Lighting

Cooling/ventilation

Motors

Compressed air

Computing

Refrigeration

⁹FES modelling assumptions for end uses of gas and electricity based on BEIS ECUK 2018 data. Further detail on the models and their outputs can be found in the *Modelling Methods and Data Workbook*.

Our modelling accounts for energy efficiency gains in the I&C sector to 2050, and we have used broader application of energy efficiency than in previous years. We also include more detailed variation in how quickly energy efficiency improvements are introduced between now and 2050.

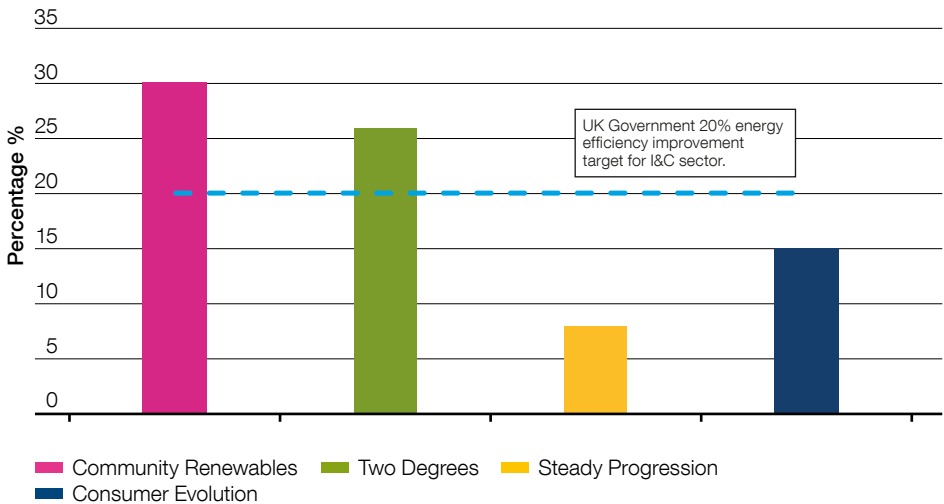
These changes build on the energy efficiency gains of recent years and the UK's Government's

drive for further improvements. A key part of the **UK Government's Clean Growth Strategy** (2017¹⁰) is a proposal for a 20 per cent energy efficiency improvement by 2030 for the I&C sector, from 2015 levels.

New measures to support the change include simplified efficiency reporting tools and funding for innovation programmes which explore a switch from fossil gas to low-carbon fuels.

Figure 4.5

Energy efficiency improvements at 2030 in FES



¹⁰ HM Government Clean Growth Strategy (2017) <https://www.gov.uk/government/publications/clean-growth-strategy>.

Energy demand

Industrial demand

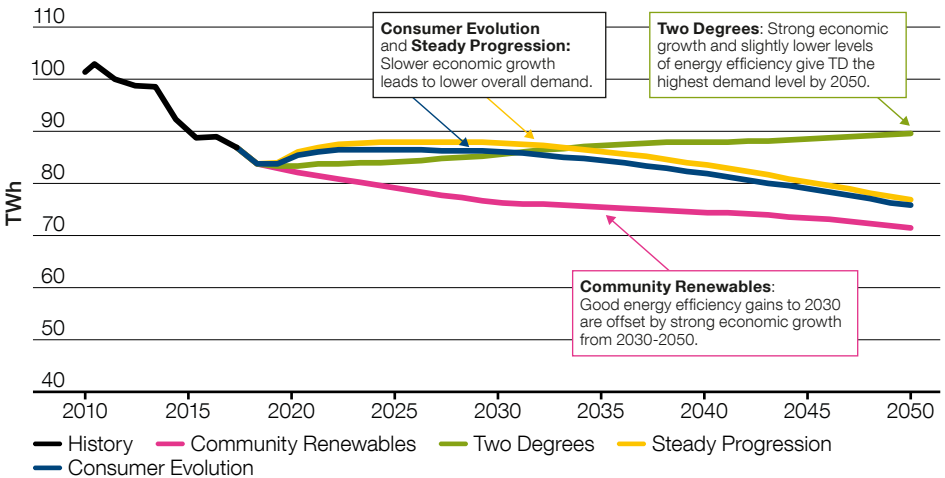
Electricity

Demand in all scenarios up to 2025 is flat or reduces as progress is made towards 2030 energy efficiency targets. The biggest fall in demand is in **Community Renewables** which has the strongest energy efficiency gains. By 2050, demand grows in **Two Degrees** due to high economic growth and slightly

less energy efficiency progress than **Community Renewables** which has similar economic growth but higher energy efficiency gains. Both **Steady Progression** and **Consumer Evolution** show a decrease in electricity demand at 2050 due to slower economic growth.

Figure 4.6

Annual electricity demand from industry



Gas

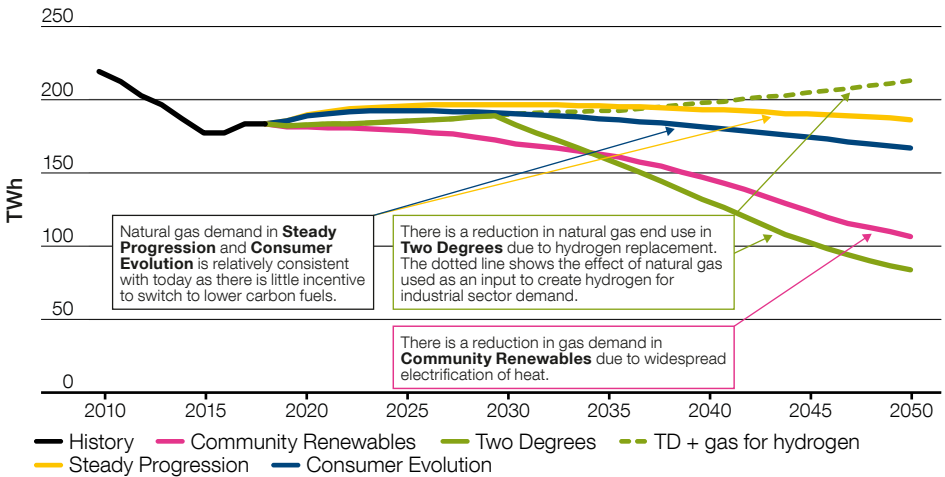
Industrial gas demand in all scenarios is steady to 2025 as efficiency gains offset the effect of an expanding economy.

After 2030, **Two Degrees** shows the sharpest reduction in direct natural gas demand, as it is replaced by hydrogen. The effect of natural gas used as an input for hydrogen production for I&C demand (e.g. for manufacturing processes that require high heat) is shown by the dotted line on figure 4.7.

Community Renewables also shows a decline in demand which is achieved mostly through the electrification of heat for low temperature processes and heating buildings (e.g. via air source heat pumps (ASHPs)), and use of biomass combined heat and power after 2030. This process is similar but slower in **Consumer Evolution**. Both scenarios do show continued natural gas demand for high temperature I&C processes.

Figure 4.7

Annual gas demand from industry



Energy demand

Commercial demand

Electricity

Community Renewables and **Two Degrees** show the sharpest decline in demand due to energy efficiency improvements. **Community Renewables** has the lowest demand by 2050 as strong efficiency gains offset an increased demand from the electrification of heat (e.g. ASHPs). Figure 4.9 shows the take up of ASHPs

in the commercial sector. The demand levels in **Steady Progression** remain similar to today.

Consumer Evolution has some electrification of heat and energy efficiency improvements leading to an initial drop in demand by 2030 when levels become steady to 2050.

Figure 4.8

Annual electricity demand from the commercial sector

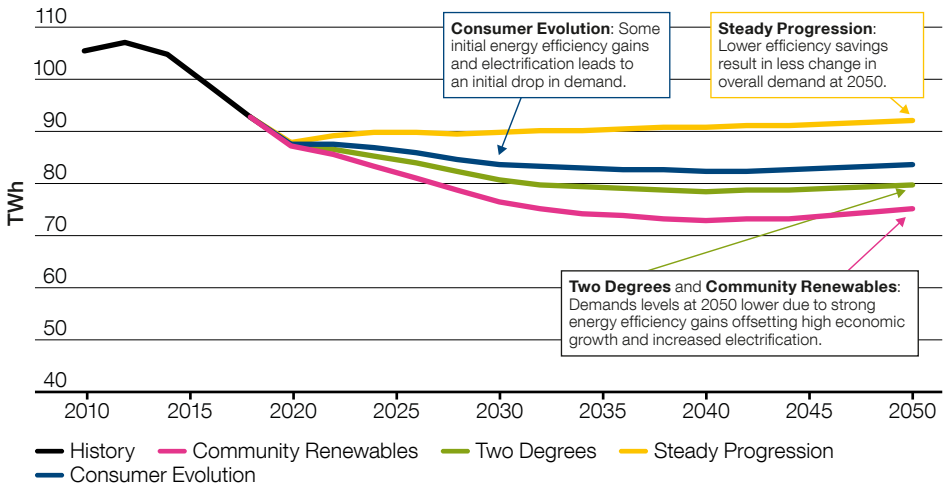
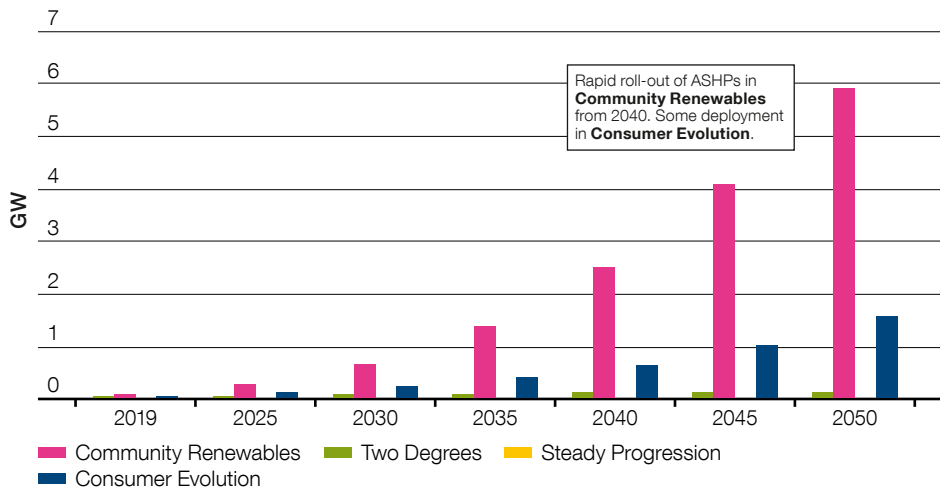


Figure 4.9

ASHP installed capacity in the commercial sector



Energy demand

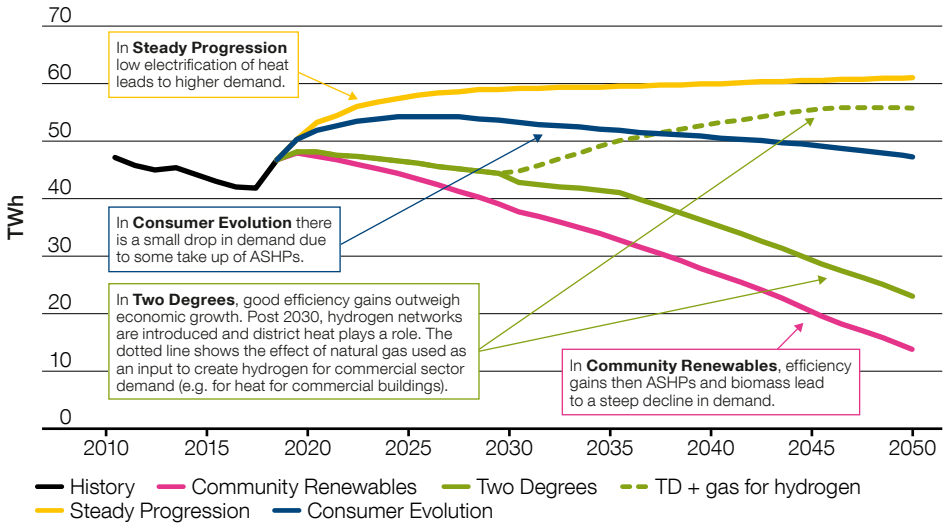
Gas

From 2025, commercial gas demand declines in **Community Renewables** and **Two Degrees** with increased use of alternative technologies such as hydrogen, biomass, combined heat and power (CHP), district heat and ASHPs. Limited energy efficiency gains for gas use means demand initially

rises in **Steady Progression** and **Consumer Evolution**. Slower economic growth then keeps demand steady through to 2050. The least electrification of heat in **Steady Progression** at 2050 gives it the highest demand level.

Figure 4.10

Annual gas demand from the commercial sector



Industrial and commercial demand side response (DSR)

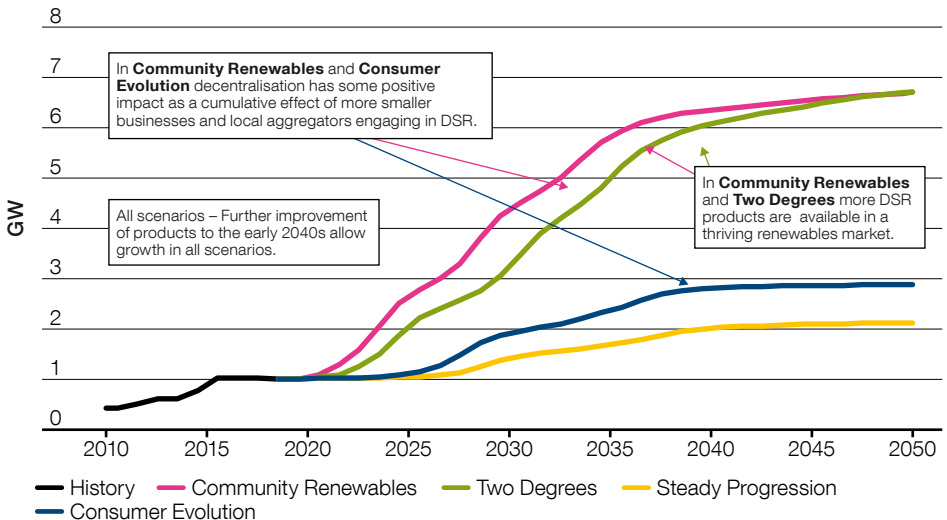
In *FES* we define I&C DSR as the turning up or down, or turning off or on, of electricity consumption in response to external signals. In our scenarios we model end use demand. If a consumer chooses not to reduce their demand but instead switches to an alternative energy source such as an onsite diesel generator or batteries, this is captured in other areas of the modelling (for example, distributed generation and storage). So, to avoid double counting, this is not included in our definition of I&C DSR.

DSR in the I&C sector has an important role to play as one of the tools that support flexibility in a future energy system. Other flexibility options such as back-up generators and on-site storage are covered in Chapter Five Electricity Supply.

In all scenarios, DSR increases in the early 2020s with a noticeable upturn by 2025 as the market framework and products become more streamlined. This trend continues through to the early 2040s. Figure 4.11 shows the impact of DSR use for the scenarios.

Figure 4.11

Industrial and commercial demand side response



This year's *FES* includes increased longer term DSR potential. This does vary across the scenarios due to different overall demand levels. The adoption of low-carbon technologies is the main driver of the differences. In a thriving

renewable energy market, more DSR products are expected to become available for businesses to use as income generators as they are flexible with their demand.

Energy demand

4.3 Residential demand

Key insights



2050

In the 2050 compliant scenarios, there is a huge change in the way we heat our homes. This transformation requires technology and infrastructure development as well as action from consumers and government.



Smart technology and new ways of heating homes could significantly change patterns of residential energy demand across the day and across the seasons.



26%

The thermal efficiency of buildings improves out to 2050 – but not as quickly as in *FES 2018*. Thermal efficiency improvements mean that by 2050, homes could use up to 26 per cent less energy for heat compared to today.

Homes in Great Britain use energy for many different things, such as heating, lighting and powering appliances like fridges, TVs and washing machines. We expect residential energy demand to fundamentally change over the coming years:

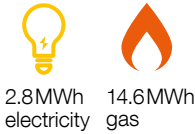
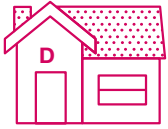
- First of all, we expect people's homes and the appliances they use to become more energy efficient. This means that a household could use less energy overall, but without having to reduce the use of appliances, or lower the temperature in a home. Over the past few years, there has been a drop in energy demand due to these factors.
- Secondly, the types of energy used in homes will change, particularly for heating, with a shift away from mainly natural gas boilers today, to lower carbon heating in the future. This could include electric heat pumps, hybrid heat pumps, hydrogen boilers and other technologies. In the two 2050 compliant scenarios, the majority of homes make this shift. This will need government intervention and changes

in housing infrastructure, as well as widespread consumer acceptance of new technologies. In contrast, there is little change in types of residential heating in the slower decarbonising scenarios.

- And thirdly, we'll see a change in how people use energy both across the day and over the year. Smart technology will move energy use to when electricity is cheaper and greener with minimal input from consumers, and technologies such as hybrid heat pumps could change how we use gas and electricity across the seasons.

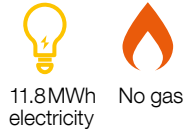
Residential charging of electric vehicles is considered in the transport demand section. The graphic overleaf shows homes today, and then some examples of the different types of homes that could exist in the **Two Degrees** scenario. You can see how different factors such as efficiency and new heating technologies could change the amount and type of energy used by homes in the future.

2018



An average home (EPC band D) in 2018, with a combustion gas boiler, used 2.8MWh of electricity a year for appliances, lighting etc and 14.6MWh of gas for heating and hot water.

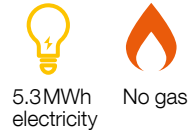
There are 22 million homes like this today.



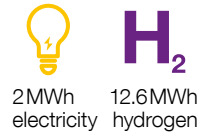
An average home (EPC band C) in 2018, with electric heating (such as storage heaters), used around 11.8MWh of electricity a year for appliances, lighting, heating, etc.

There are three million homes like this today.

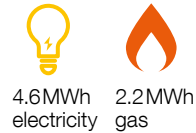
Two Degrees (2050)



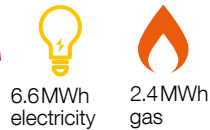
Electric heat pump home around 5.7m.



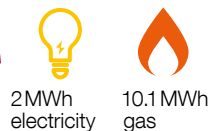
Hydrogen home around 11m.



Hybrid heat pump home around 2.7m.



District heat home around 3.4m.



Gas boiler home around 5.9m.

Energy demand

Residential heating

The two main trends in residential heating are the improved thermal efficiency of buildings, which reduces the energy needed to heat a home, and a move towards new types of heating. These could be more efficient than today's heating technologies, and may use lower carbon sources of energy.

Thermal efficiency

This year, we have updated our assumptions about the future thermal efficiency of buildings to reflect stakeholder feedback and new data and research. In particular, slower than expected changes in policy have led us to reduce anticipated thermal efficiency improvements for buildings compared to *FES 2018*. We have also included a greater range of thermal efficiency assumptions across our scenarios, with the **Community Renewables** scenario having the best thermal efficiency improvement, and **Steady Progression** the lowest.

We have used the Energy Performance Certificate (EPC) rating as a proxy measure for a home's thermal efficiency performance. Buildings rated as EPC band A are the most efficient, and band G the least. In all scenarios, there is an improvement in thermal efficiency compared to today, and this assumes further policy development to raise and enforce minimum building standards.

For example, by the early 2030s legislated changes such as the Energy Efficiency (Private Rented Property) Regulations will mean that there are very few F and G rated homes. We assume similar legislation is introduced later to markedly reduce the number of category E properties as well. However, some properties will be more challenging to upgrade to a higher EPC rating, for example listed buildings.

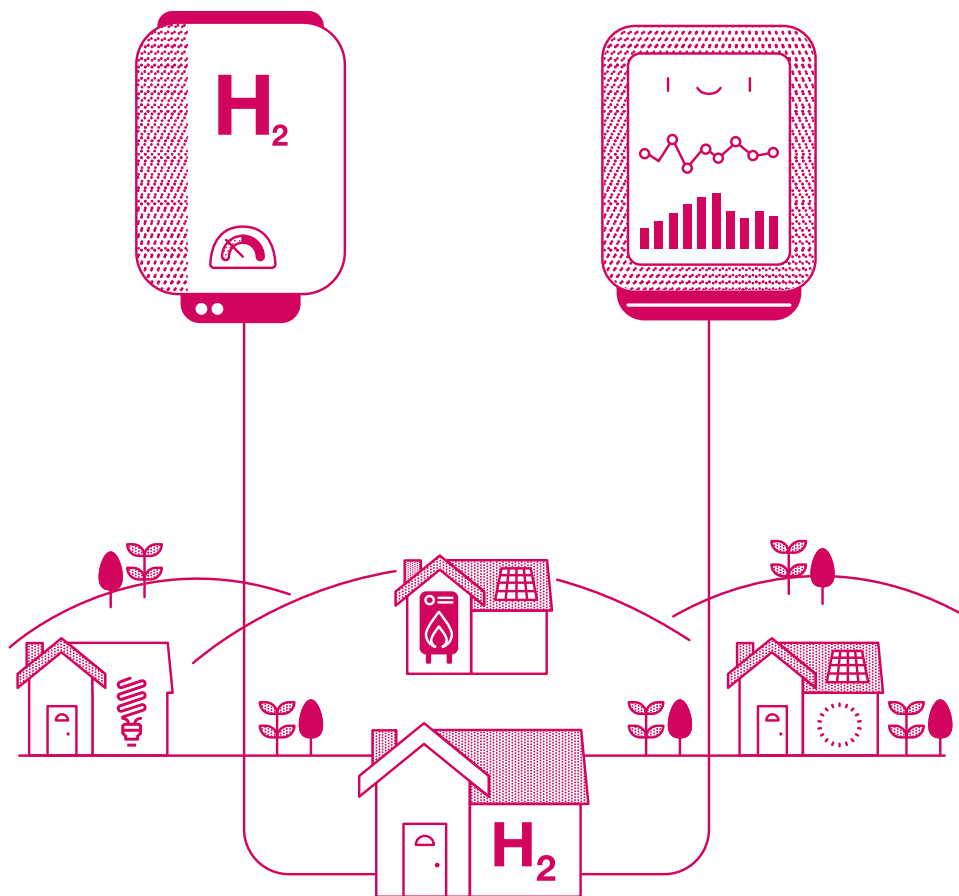
As noted in the **Clean Growth Strategy**¹¹ published in 2017, the UK Government's aspiration is that 'as many homes as possible are improved to EPC band C by 2035, where practical, cost-effective and affordable'. Our two 2050 compliant scenarios meet this aspiration, with the majority of homes rated EPC band C or higher by 2035. In **Consumer Evolution** and **Steady Progression**, the aspiration is not met, but **Consumer Evolution** comes closer to achieving this goal.

The combined effect of more efficient buildings, and more efficient heating technologies (discussed below) means that overall energy demand for residential heating falls in all scenarios, but to a different extent. By 2050, the energy demand for residential heating falls by 26 per cent compared to today in the **Community Renewables** scenario, and by nine per cent in the **Steady Progression** scenario.

Heating technologies

Across all scenarios, population growth in GB means the overall number of homes increases out to 2050. However, as well as becoming more thermally efficient, the way these homes are heated will change. Today natural gas boilers dominate residential heating, with around 22 million in use. A smaller number of homes use appliances such as oil boilers or electric storage heaters. Figure 4.12 shows how residential heating technologies could change between now and 2050, across the four scenarios.

¹¹ <https://www.gov.uk/government/publications/clean-growth-strategy>

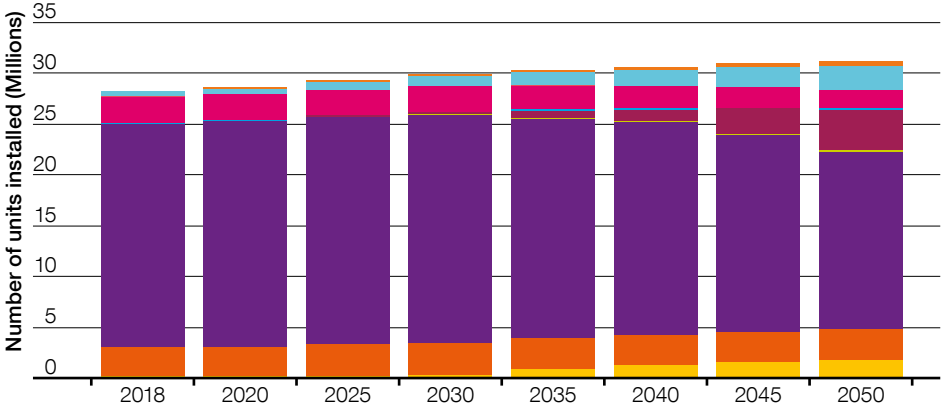


Energy demand

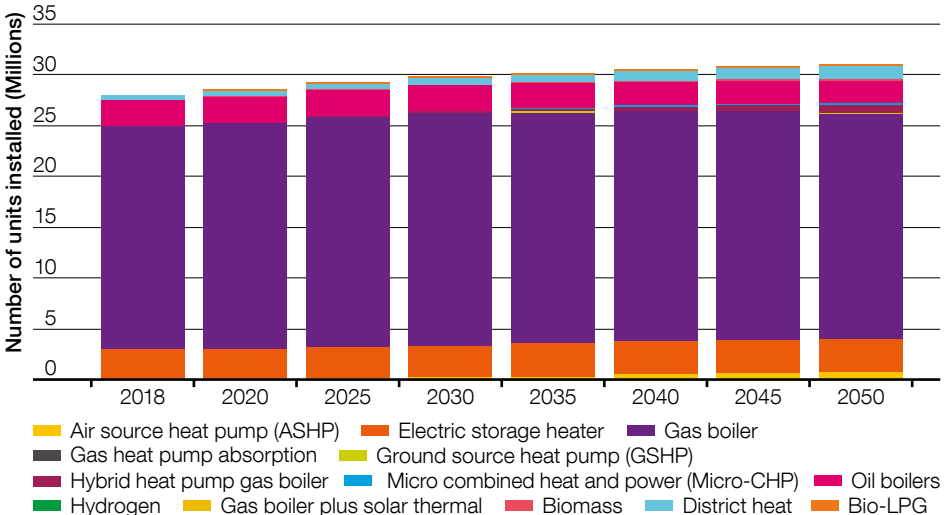
Figure 4.12

Heating technology roll-out across the scenarios

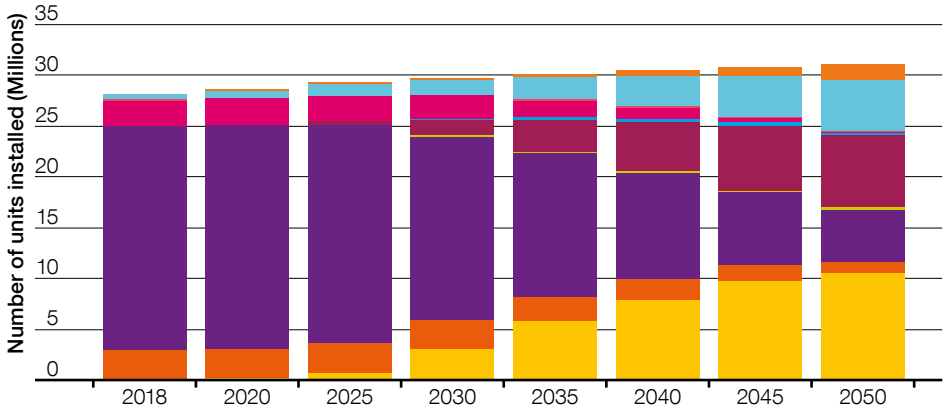
Consumer Evolution – Some reduction in oil and gas, particularly after 2035. By 2050, gas boilers still dominate but there is a limited roll-out of hybrid and air source heat pumps, plus district heat.



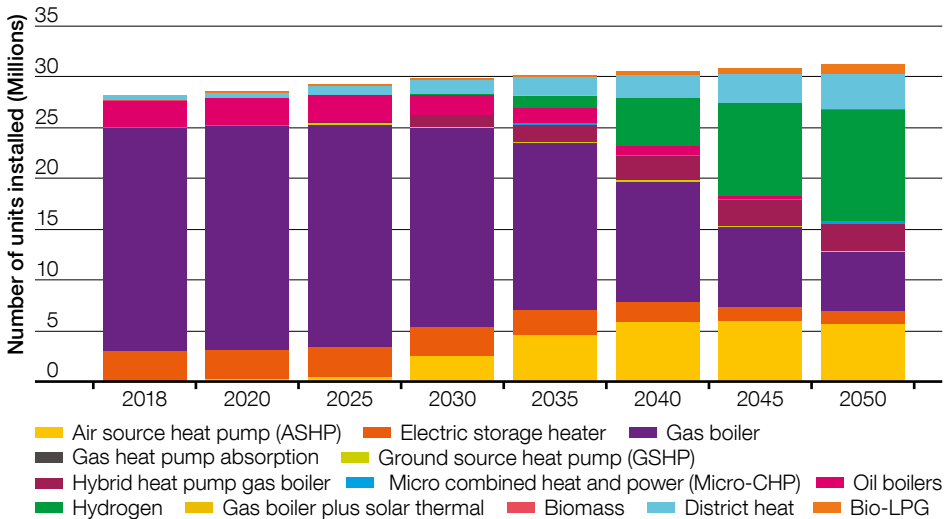
Steady Progression – Virtually no reduction in oil and gas boilers compared to today, with very small roll-out of air source and hybrid heat pumps. Some growth of district heat schemes.



Community Renewables – Oil and gas reduce significantly, particularly after 2035, and are mainly replaced by air source and hybrid heat pumps, plus district heat.



Two Degrees – Large reduction in oil and gas boilers, due to large-scale hydrogen roll-out starting in 2030, and installations of air source and hybrid heat pumps, plus district heat schemes.



Energy demand

In the two 2050 compliant worlds, there is a marked shift away from natural gas boilers. In March 2019, the UK Government announced that by 2025 a 'future homes standard' would be in place. Although subject to consultation, it will ensure that new build UK homes will be built to high efficiency standards and without fossil fuel heating from 2025 onwards, in line with an earlier recommendation from the Committee on Climate Change. We have captured this future standard in our modelling of the two faster decarbonising scenarios. In these scenarios, around two million homes will have been built to new standards by 2050, approximately seven per cent of the future housing stock.

As well as the direct effect of the future homes standard on new buildings, this clear policy direction provides certainty for the market. We can therefore expect an indirect effect, as the standard should accelerate the development of a supply chain for low-carbon heating technologies. Indeed, across the faster decarbonising scenarios, the pace of change (away from fossil fuel heating) increases as we move towards 2050. This is due to our assumption that prices fall as markets grow across all new heating technologies – with improved installation proficiency, more efficient supply chains and economies of scale.

The types of new heating differ across the scenarios, and figure 4.13 explores some of the more prominent technologies in more detail.

Figure 4.13

Low-carbon heating technologies



Electric heat pumps

Heat pumps extract heat from the air or ground using technology similar to reverse refrigeration.

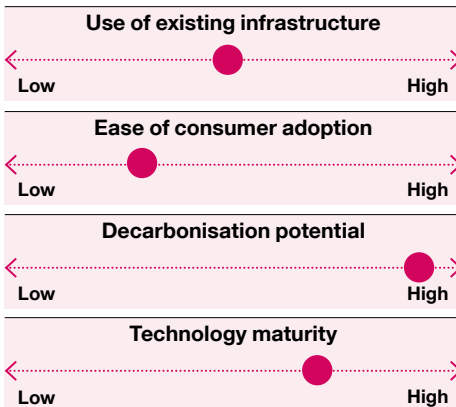
Features strongly in Community Renewables and Two Degrees. Most suited for:



Off gas grid home



Thermally efficient homes



Electricity network upgrade/generation build required to accommodate increased demand. Heat storage may be required. Possibility of high demand peaks on colder days.

If retrofitting, substantial disruption as heating systems may need to be replaced. New build or some more thermally efficient homes = no disruption.

Systems are very efficient and can use low carbon electricity.

Heat pumps in use today but anticipate continued efficiency improvements.



Hybrid heat pumps

Hybrid heat pumps feature a smaller electric heat pump alongside a gas boiler.

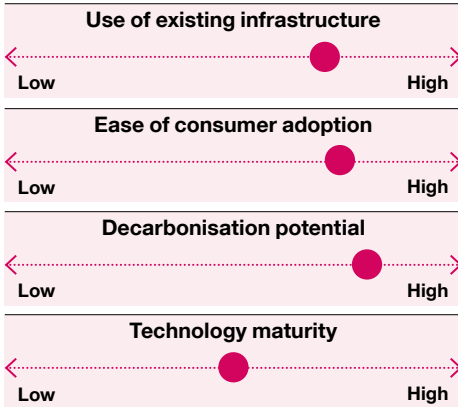
Features strongly in Community Renewables and Two Degrees. Most suited for:



Homes on the gas grid



Less thermally efficient homes



Electricity network upgrade/generation build required, but less than for electric heat pumps. Use of gas should avoid large cold day peaks in electricity demand.

Potentially less installation disruption than purely electric heat pumps.

Around 20 per cent of annual heat demand still met by gas, but hydrogen hybrids may be available in the future.

Hybrid heat pumps being trialled today.



Biogases

Biogases are gases created from organic matter and are low-carbon. They can be mixed into the gas network alongside natural gas.

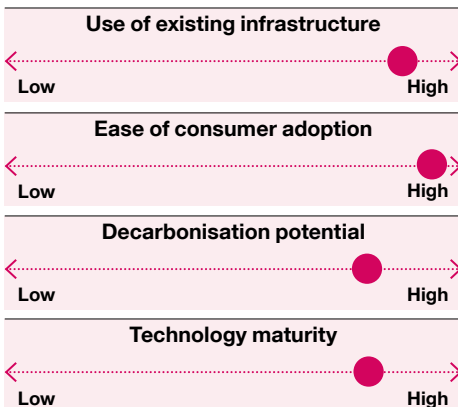
Features strongly in Community Renewables. Most suited for:



Homes on the gas grid



Less thermally efficient homes



Uses existing gas network.

No change to homes or appliances required.

Biogases have a very low-carbon footprint, as discussed in our spotlight in chapter five. However, there is not enough biogas to meet heat demand in GB.

Biogas is injected into the gas network today. As this increases, some challenges need to be overcome (e.g. gas specification).

Energy demand



Hydrogen boiler

Hydrogen boilers operate in a similar way to gas boilers but use hydrogen as a fuel.

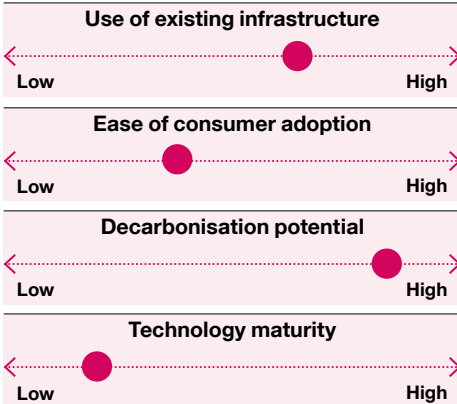
Features in Two Degrees. Most suited for:



Homes on hydrogen network



Less thermally efficient homes



Requires conversion of a whole region to hydrogen so significant planning and co-ordination. Potential for conversion of an area's gas distribution network.

Co-ordination across a region means little consumer choice as to switch date. New appliances may be needed but consumers are familiar with using gas for heating.

High if using low-carbon hydrogen e.g. that produced via methane reforming +CCUS (see spotlight on [page 100](#)).

Various projects are examining the technical challenges of using hydrogen.



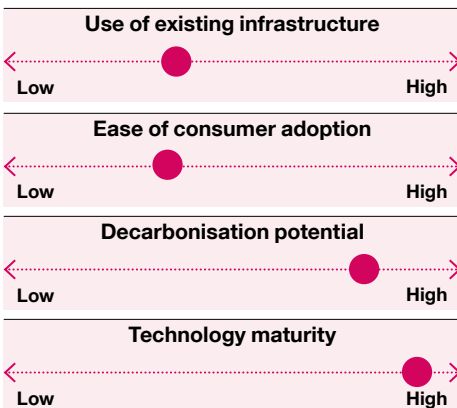
District heat

These schemes distribute heat from a central location into buildings via insulated pipes.

Features strongly in Community Renewables. Most suited for:



Denser urban areas, potentially near a source of (waste) heat



Requires installation of pipework from source of heat to each building.

Requires co-ordination across several buildings and limited opportunity for switching once connected.

This is dependent on the scheme using a low-carbon source of heat. Not all locations will be suitable for a district heat scheme.

Technology in use today.

In **Community Renewables**, there is significant electrification of heating. Electric air source heat pumps grow quickly, reaching more than 10 million by 2050, and there are also around seven million hybrid heat pumps installed by 2050. These combined units feature a smaller electric heat pump alongside a gas boiler, with the latter providing additional heat to meet demand on colder days when electricity demand is high. We have increased the number of hybrid heat pumps in our scenarios this year, as evidence suggests the potential to retrofit some systems (adding a heat pump to an existing gas boiler) which would reduce cost. In addition, some more efficient properties would also not need to replace their current radiators with low temperature radiators when installing a heat pump.

By the early 2030s, up to 400,000 air source heat pumps, mainly in off gas grid properties. Over 200,000 hybrid heat pumps are also being installed every year. A further advantage of some heat pumps is their ability to provide cooling as well as heating for homes, which is likely to make them attractive to consumers if temperatures rise or more extreme weather events increase.

As noted in figure 4.13, a large-scale heat pump roll-out would require an upgrade of the electricity network to accommodate increased demand, as well as the development of skills to install heat pumps, and effective incentives for consumers to accept and use new technologies. In **Community Renewables** we assume that government policy and motivated consumers will overcome these issues.

In **Two Degrees**, there is some growth in electric and hybrid heat pumps to replace gas boilers. However, the biggest change is the large-scale roll-out of hydrogen heating, which begins in 2030. By 2040, around 4.5 million homes are heated by hydrogen, rising to just over 11 million by 2050. We have increased the number of homes that could be heated by hydrogen in **Two Degrees** compared to 2018 to reflect latest research. You can read more about the latest projects considering the use of hydrogen for heating in our spotlight on [page 100](#).

All of the hydrogen used for heating homes in the **Two Degrees** scenario is produced via methane reforming, using natural gas and combining this process with carbon capture, use and storage (CCUS) so that minimal carbon dioxide is emitted during hydrogen production. As a result, the direct use of gas for heating in homes falls in **Two Degrees** as the number of gas boilers falls, but the use of natural gas to produce hydrogen for heating increases natural gas demand across GB.

An important aspect of heating transformation in both the faster decarbonising scenarios is the regional variation in adoption of new kinds of heating. The best choice for each area is likely to vary across different areas of the country, dependent on factors such as existing infrastructure, geography and existing housing stock, as noted in figure 4.13. This means that there will be diversity in heating technologies both across different regions of GB, and within them.

For example, in the **Two Degrees** scenario in 2050, Scotland has a widespread roll-out of hydrogen heating, with some installation of electric and hybrid heat pumps, and around a fifth of the population still using gas boilers. By contrast in North Wales, electric and hybrid heat pumps are more dominant, with no installation of hydrogen due to factors such as distance from infrastructure.

In the slower decarbonising scenarios of **Consumer Evolution** and **Steady Progression**, the technologies used to heat homes do not change substantially. By 2050, gas boilers are still the dominant heating technology. However, legislation means the efficiency of boilers improves in all scenarios, notably the recently introduced BoilerPlus legislation mandating that all boilers manufactured and installed in England must have an efficiency of 92 per cent, compared to the current average of 82 per cent. There is also a more marked reduction in oil boilers in the **Consumer Evolution** scenario, and greater growth of district heating schemes and electric and hybrid heat pumps compared to **Steady Progression**.



Spotlight

How might gas and electricity demand change in a hybrid heat pump home?

The installation of hybrid heat pumps could help to reduce the additional generation and electricity network upgrade required to meet electricity demand on the coldest days. This is because on very cold days, hybrid heat pumps use a gas boiler to warm a home rather than a heat pump, helping to reduce large increases in electricity demand – and hence the need to build electricity network and generation that is only used on a few days each year.

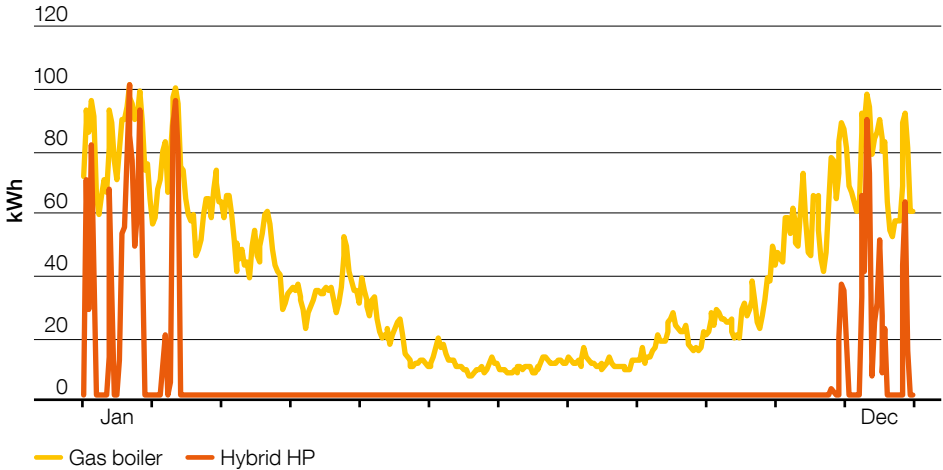
Currently, homes that use a gas boiler for heating will use the most gas on very cold days. There is a marked difference in gas use across the seasons, with little gas consumed over the summer and much more in winter. This pattern of gas demand across the year is shown by the yellow line in figure 4.14.

Overlaid onto this, shown by the orange line, is how gas demand could potentially change for a home using a hybrid heat pump rather than a gas boiler. A hybrid heat pump features an electric heat pump alongside a gas boiler. In these homes, no gas is used for heating across a large part of the year, as the continuous, lower temperature heat provided by an electric heat pump is sufficient to keep a house warm. However, on colder days the gas boiler ‘kicks in’ to provide additional heat. So on the coldest days of the year, heat in a hybrid heat pump home is still provided almost exclusively by gas. Then across the rest of the year, gas demand is very low. Overall, between 20 and 35 per cent of a hybrid heat pump home’s annual heat demand could be met by gas, and the rest by electricity.

Residential

Figure 4.14

Modelled gas use with hybrid heat pumps¹²



This would have important impacts for the operation of the gas network, as residential gas demand patterns for hybrid heat pump homes would become much more volatile and dependent

on the weather. There would also be close to zero use of the network by these homes over warmer months, but gas demand patterns similar to today's winter season on colder days.

¹² Insights derived from Project Freedom.

Energy demand

District heating

In 2019, we made a change to our scenario framework to assume that the more decentralised scenarios would see increased growth of district heating schemes. Previously we assumed that district heat schemes would be more aligned to centralised scenarios, given that they require some level of co-ordination and joint planning across a number of buildings. However, we now believe that the likely size of such schemes (average of 30 buildings) means they are more suited to decentralised scenarios where regional and local actors are more engaged in energy developments. **Community Renewables** has the highest number of homes connected to such schemes, around five million dwellings by 2050. We have assumed that some district heating projects use fossil fuels to begin with, but later transition to low-carbon technologies.

Homes on the natural gas network

In the faster decarbonising scenarios, although up to six million homes continue to be heated primarily by natural gas, more houses will stay connected to the natural gas network – for example those using hybrid heat pumps. In fact, 13 million homes are still connected to the natural gas network in 2050 in the **Community Renewables** scenario, and around nine million in **Two Degrees**¹³. And in the slower decarbonising scenarios, a much greater number of homes will continue to be heated by natural gas.

As explored further in a spotlight in the gas supply section, the carbon intensity of the gas network could change in the future. We anticipate increasing amounts of low-carbon biogas, particularly in the more decentralised scenarios, and in the **Steady Progression** scenario there is some hydrogen blending into the gas main network. This begins in the late 2020s and rises to around four per cent of residential gas demand by 2050. As a result, carbon emissions associated with residential gas heating could fall compared to today, as the inclusion of lower carbon gases within the gas network lowers the overall carbon footprint.

Residential appliances

Today the average home in Great Britain has around 30 electrical appliances – including fridges, washing machines, TVs and laptops. We have looked at a wide range of research that examines how consumers might use different types of services and appliances in the future, and how appliance efficiency could change.

To capture a wider range of uncertainty, this year we have explored four separate appliance pathways for the four scenarios:

In the non 2050 compliant scenarios, there is a slower rate of improvement in appliance efficiency, with the least improvement in **Steady Progression**. The increase in appliances per household outweighs improvements in their efficiency. This leads to an increase in the amount of electricity used by each home to power appliances.

In the faster decarbonising scenarios, there is a much more rapid improvement in appliance efficiency, with the greatest improvement in **Community Renewables** where consumer choice and legislation mean that people buy the best available technology from an efficiency perspective. Consequently, overall electricity demand for appliances reduces in both **Two Degrees** and **Community Renewables**.

Detailed output data by appliance type can be found in the *Data Workbook*.

Total residential demand for energy

All of these changes will have significant impacts on how much energy households of the future will need. Figure 4.15 considers total annual residential electricity demand by scenario, from now until 2050 (excluding electricity for electric vehicle charging).

Figure 4.16 looks at annual residential gas demand and shows the impact of various factors across the four scenarios.

¹³ This figure does not include homes heated by hydrogen, which could be connected to a gas distribution network that has been re-purposed to carry hydrogen.

Figure 4.15

Annual residential electricity demand (excluding electric vehicle charging)

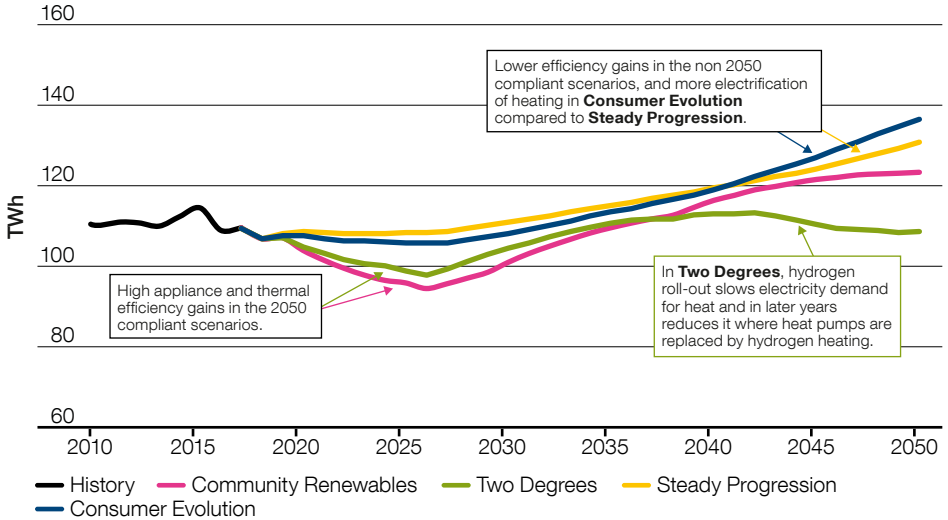
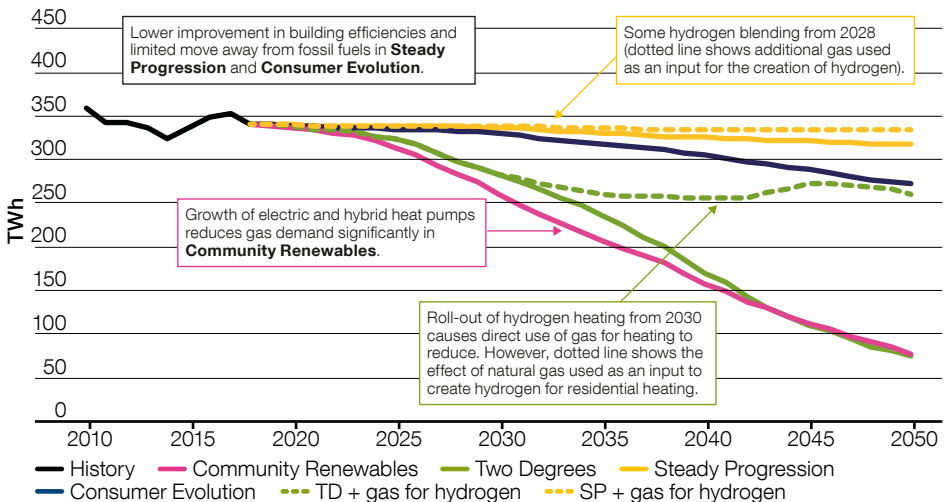


Figure 4.16

Annual residential gas demand



Energy demand

Residential flexibility

As the previous graphs show, annual demand for electricity and gas in homes could change significantly over the next 30 years. But the way that these homes use energy over the course of a day could also look quite different.

As we discuss later in chapter five, flexibility is defined as the extent that parties are able to, and incentivised to, respond to changing market conditions – potentially by quickly changing the amount of electricity they produce or use. In a residential context, residential flexibility is the extent to which consumers will alter their electricity use across the day in response to factors like price or the carbon intensity of electricity.

Flexibility is becoming increasingly important in the efficient operation of a decarbonised energy system. As intermittent or less flexible low-carbon generation grows, a smart flexible energy system allows for demand to be moved to times when there is a plentiful supply of low-carbon electricity. This allows greater growth of low-carbon generation, and reduces the amount of additional infrastructure required to meet demand at all times – meaning cheaper and less carbon intensive electricity.

Developments in smart technology mean that it is becoming easier for all consumers to change when they use electricity, with little or no disruption to their lives. But how quickly residential flexibility grows will depend on a number of factors, including:

- how quickly time of use tariffs become common place, with smart meters and half hourly settlement allowing time of use billing
- the range of smart appliances available, and how easy they are to use
- the number of residential battery systems in place that allow customers to, for example, store electricity generated by solar panels during the day and use it in the evening
- the number of heat storage systems in homes, such as hot water tanks.

Time of use tariffs are electricity tariffs where the price changes across time periods, and can include dynamic tariffs (where the price is set in real time and can change quickly) or static tariffs (where the price for a certain time period is set in advance).

Smart meters can capture energy consumption data in real time and send this to an energy supplier. The UK Government has set a target to install smart meters in all households by the end of 2020. However, the smart meter roll-out programme has encountered some challenges and it may be difficult to meet this target. We have assumed that in the two 2050 compliant scenarios the vast majority of homes have smart meters (gas and electricity) by the end of 2020. In the non 2050 compliant scenarios, we have assumed that the roll-out of smart meters continues at the current rate, and is not complete until around 2024.

Smart appliances are able to switch on and off in response to an external signal. For example, a smart freezer could adjust its temperature very slightly in response to data that forecasts when electricity is likely to be cheaper and/or less **carbon intensive**¹⁴. Our modelling considers smart appliances in two categories – smart wet appliances (such as washing machines) and smart cold appliances (for example, fridges and freezers). We have assumed a greater use of smart cold appliances as compared to smart wet appliances across all our scenarios as the former can flex energy demand with little consumer impact.

The highest installation of residential battery systems is in the **Community Renewables** scenario. We have also assumed that in the faster decarbonising scenarios, around 25 per cent of homes have some means of heat storage. This is equivalent to the proportion of homes today that use hot water tanks. In the faster decarbonising scenarios, we have assumed that legislation and technology develop from the mid 2020s and heat pumps are used alongside this heat storage to reduce heat demand at peak. By 2040 in these scenarios, homes with heat storage do not use any electricity for heating over peak periods, instead drawing all heat from storage systems.

¹⁴ <https://carbonintensity.org.uk/>

Taken together, these factors mean that across the four scenarios, we see the greatest residential flexibility in **Community Renewables**. Here, high roll-out of smart meters and a large number of smart appliances means that peak electricity demand from homes (excluding EV charging, and electricity and heat storage impacts) is suppressed by 10 per cent by the late 2030s, and 13.5 per cent by 2050. This equates to around 1.6GW of peak electricity demand. Residential battery systems, heat storage and smart EV charging will also further reduce demand.

The **Consumer Evolution** scenario has high consumer engagement as well, and in this scenario, peak electricity demand is reduced by 11.5 per cent by 2050. However, as this scenario has higher absolute peak electricity demands, this reduction has a greater total effect, reducing peak electricity demand by

around 2GW by 2050. The lowest residential flexibility is in **Steady Progression**, as consumers are less engaged with energy usage and have fewer smart appliances and residential battery systems.

This section only considers residential flexibility for electricity. This is because the wholesale price for gas is set daily, rather than every half hour, as for electricity. As a result, there is less incentive to move gas demand across the course of a day. Similarly, the carbon intensity of gas from the gas grid can also change, but this is much longer term due to, for example, increasing injection of low-carbon biogases or hydrogen blending. So again, unlike electricity, moving gas demand from one part of the day to another will not significantly affect a consumer's bill or the associated carbon emissions. For these reasons, flexibility for the gas system is more likely to be provided by other solutions.

Energy demand

4.4 Transport demand

Key insights



By 2050 there will be over 35 million electric vehicles on the road, with minimal use of petrol and diesel in two of the scenarios.



Daily peak demand for electric vehicle charging is expected to be later in the day than overall peak system demand.



Heavy duty vehicles continue to use liquid and gaseous fuel out to 2050, which is mostly hydrogen in the faster decarbonising scenarios.



Smart charging and vehicle-to-grid, led by growth in technology and policy drivers, provides demand side flexibility and additional choice for consumers.

Transport is now the largest sector for UK greenhouse gas emissions (27 per cent), of which road transport accounts for over 90 per cent¹⁵. Road transport is fundamental to the way people, goods and services move across the UK. More than 60 per cent of UK journeys are by car. More than 75 per cent of the goods we consume travel across the UK in vans and trucks.

Within this section of *FES* we cover both road and rail transport. We do not explicitly model developments in aviation and maritime transport in our Future Energy Scenarios, but these sectors are included in our assessment of carbon emissions.

¹⁵ Department for Transport: Road to Zero Strategy

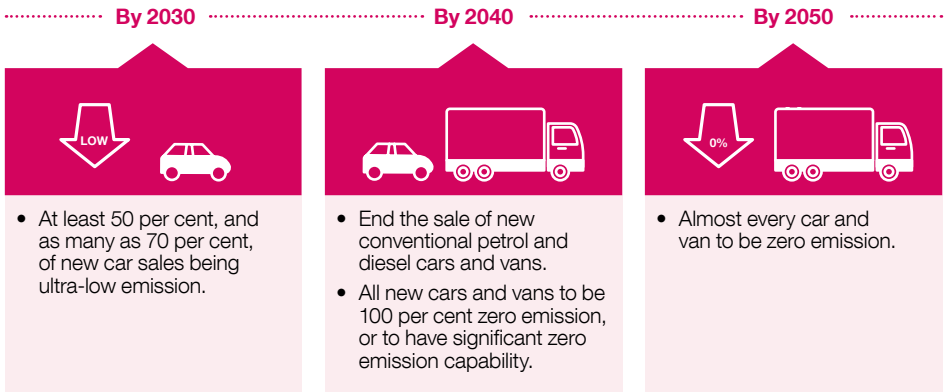
Road transport

In July 2018, the Government published its Road to Zero strategy, which sets out plans to enable a massive expansion of green infrastructure across

the country, reduce emissions from the vehicles already on the UK's roads, and drive the uptake of zero emission cars, vans and trucks.

Figure 4.17

Key milestones from the Government's Road to **Zero strategy**¹⁶



There are also stretching ambitions and incentives for charging point installation and technology. The Automated and Electric Vehicles Act of 2018 states that from July 2019 all home charge points for electric vehicles funded by grants must use innovative 'smart' technology.

Our scenarios reflect the direction set by these policy changes, their consequences on technology advancements and the extent to which consumers engage with these technologies.

Our FES scenarios

In **Community Renewables** and **Two Degrees**, most road transport is powered by electricity by 2050. Heavy-duty vehicles (high mileage, heavy loads) begin to use hydrogen as fuel from the mid-2030s, especially in **Two Degrees** where there is larger scale generation of hydrogen and the introduction of hydrogen networks.

In **Steady Progression** and **Consumer Evolution**, electricity usage for road transport increases, however petroleum-based products are still used out to 2050. Heavy-duty vehicles will continue to use a gaseous fuel, most likely natural gas. Hydrogen remains a niche fuel.

Total energy demand is similar across scenarios, but the speed at which vehicles shift from petrol and diesel to electricity, natural gas or hydrogen varies across scenarios. Total annual energy demand for road transport is currently around 500TWh. By 2050 it has reduced, in all scenarios, to below 200TWh. This is due to the shift from petrol/diesel vehicles to electric vehicles, which use less energy per mile; causing a significant drop in total energy used for transport.

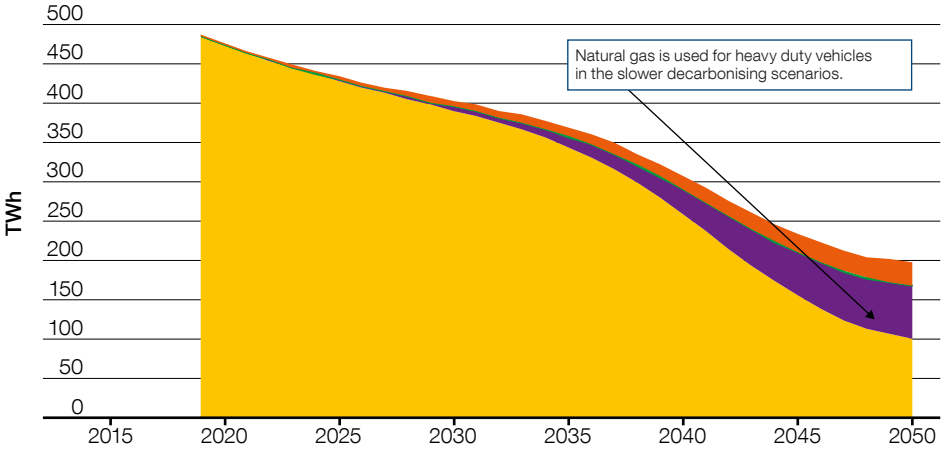
¹⁶ Road to Zero strategy document can be found at <https://www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy>.

Energy demand

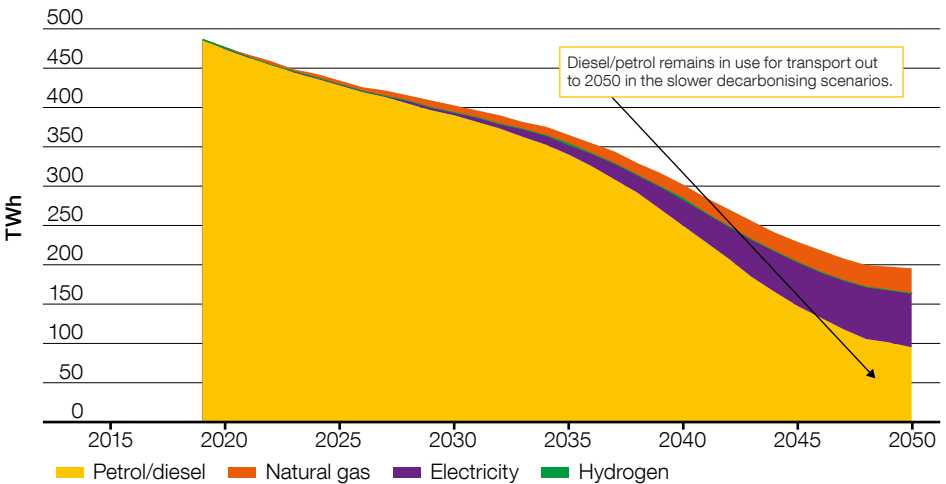
Figure 4.18

Annual road transport energy demand – by fuel type (TWh/year)

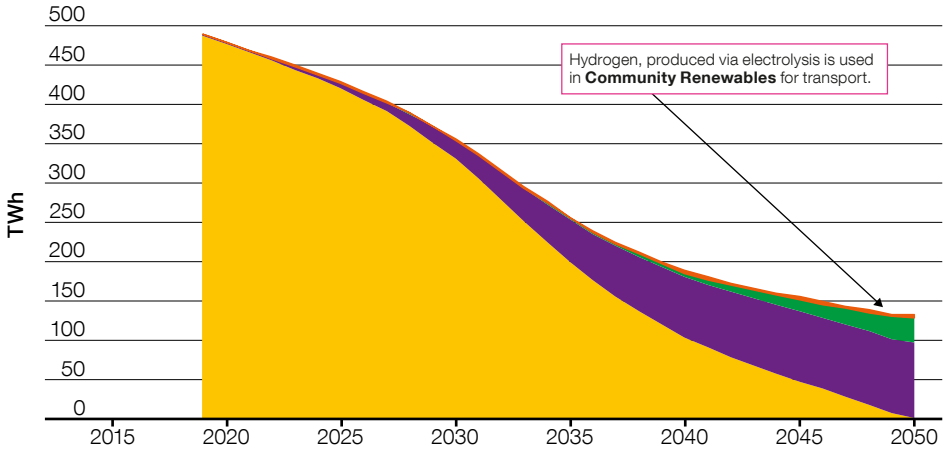
Consumer Evolution



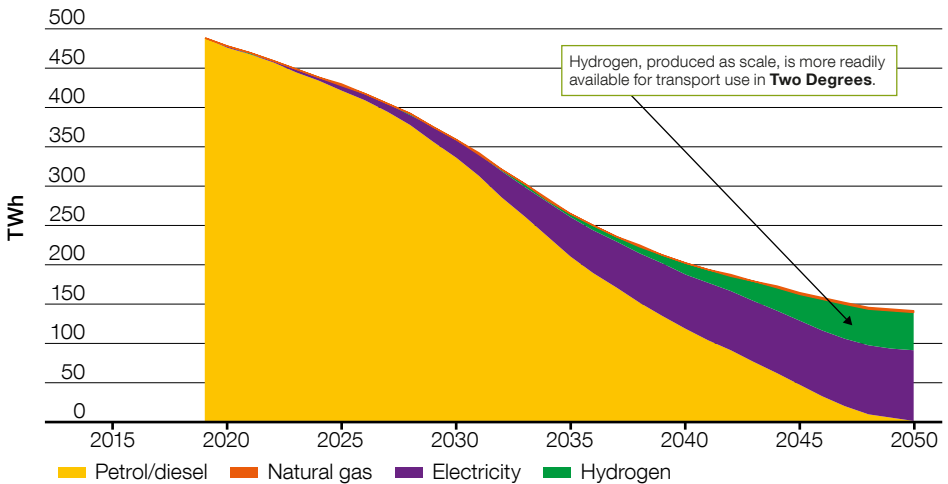
Steady Progression



Community Renewables



Two Degrees



Energy demand

Annual road transport demand

Annual road transport demand is influenced by both vehicle use and fuel technology.

Vehicle use

Our modelling considers all major forms of road transport, including cars, motorbikes, light goods vehicles (vans), heavy goods vehicles (HGVs), buses and coaches. Cars continue to account for over 80 per cent of all road vehicles in all scenarios. Whilst the relative proportion of vehicle types remains largely unchanged across all scenarios, by 2050 the total number of vehicles will have reduced slightly. This is due to two main factors:

- There is higher use of autonomous vehicles in the faster decarbonising scenarios, **Community Renewables** and **Two Degrees**. With autonomous vehicles, it is likely that the mileage per vehicle will rise significantly, while the number of vehicles per person falls. For example, a single autonomous vehicle may move between users.
- There is higher use of public transport in **Two Degrees** and **Steady Progression**, due to regional and national coordinated transport policies. So our **Two Degrees** and **Steady Progression** scenarios have a higher number of buses year-on-year than their decentralised equivalents.

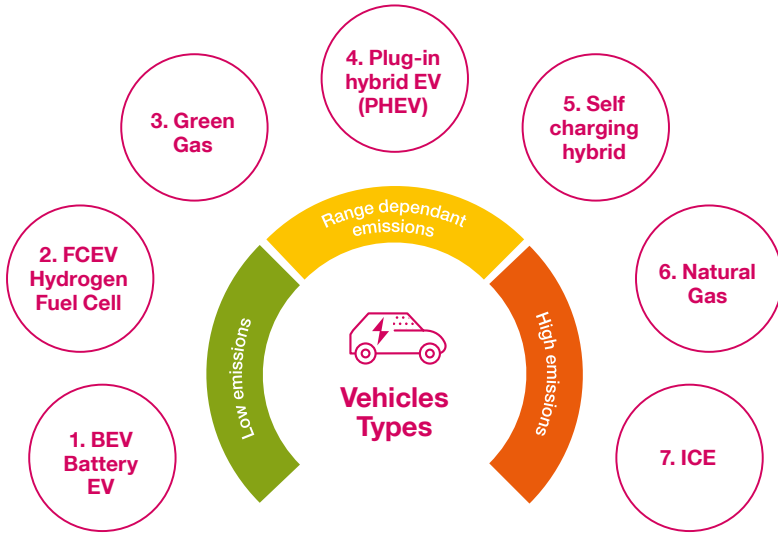
Fuel technology

We model four different fuel types:

- **Petrol/Diesel** – used by vehicles with an internal combustion engine (ICE). This also includes hybrids which combine a conventional combustion engine with an electric motor, where the battery is charged by the combustion engine.
- **Electricity** – used by electric vehicles (EVs), of which we also distinguish between plug-in hybrid EVs (PHEV) and battery EVs (BEV).
- **Hydrogen** – used by hydrogen fuel cell vehicles (HFCV) which are classed as ultra-low emission vehicles (ULEVs).
- **Natural gas** – also used by vehicles with an internal combustion engine, as either CNG (compressed natural gas) or LNG (liquefied natural gas). There also could be increasing amounts of green gas.

Figure 4.19

Low emission vehicles in FES

**1**

- Electricity
- Zero tailpipe emissions
- Low emissions¹⁷.

2

- Hydrogen
- Zero tailpipe emissions
- Low emissions¹⁸.

3

- Biomethane or bioSNG
- High tailpipe emissions
- Low emissions.

4

- Petrol/diesel and electricity
- Zero tailpipe emissions at short range
- High tailpipe emissions at long range
- High emissions¹⁹.

5

- Petrol/diesel
- Zero tailpipe emissions at very short range
- High tailpipe emissions at long range
- High emissions.

6

- Natural Gas
- High tailpipe emissions
- High emissions.

7

- Petrol/diesel
- High tailpipe emissions
- High emissions.

¹⁷ Assuming renewable power generation.

¹⁸ Assuming low or zero carbon production of hydrogen.

¹⁹ Emissions may be lower depending on range and charging behaviour.

Energy demand

In **Community Renewables**, almost all road transport is powered by electricity by 2050; however, some hydrogen or natural gas is still used by vehicles which do very high mileage, or carry very heavy loads. Limitations in battery capacity could prevent their use of electricity, even by 2050. The hydrogen in this scenario is generated via localised, smaller-scale production using electrolysis. This is of sufficient purity to be used directly by road transport.

In **Two Degrees**, most road transport is electric powered by 2050, but with more hydrogen used for heavy duty vehicles with greater access to hydrogen produced at scale either via electrolysis or via methane reforming with carbon capture, usage and storage (CCUS). Hydrogen produced via methane reforming/CCUS typically requires additional purification before use in fuel cell vehicles.

Consumer Evolution and **Steady Progression** see a much slower take-up of alternative fuels, with most car users retaining their petrol or diesel vehicles until after 2030. In these scenarios, over four million petrol or diesel vehicles are still in use by 2050, with most of those being vans and motorcycles. Heavy goods vehicles (HGVs) switch away from petrol and diesel to natural gas.

In **Two Degrees** and **Community Renewables**, we no longer expect plug-in hybrid EVs (PHEVs) to be used as a stepping stone to battery electric vehicles (BEVs). Changes in the Government's plug-in car grant scheme encourage the purchase of lower-emission vehicles than PHEV. These

scenarios assume no new conventional petrol or diesel cars are sold after 2040, and by 2050 no petrol or diesel cars remain on the roads.

In *FES 2018*, we assumed that natural gas would typically be used by heavy duty commercial vehicles as a stepping stone towards decarbonised fuels like hydrogen (in **Community Renewables** and **Two Degrees**) and electricity (in **Steady Progression** and **Consumer Evolution**). In *FES 2019*, this is no longer assumed to be the case. There have been improvements in diesel emissions, and we recognise the additional costs to this two-step approach. Some may use natural gas, but we assume this will be kept at low levels by the availability of other low-carbon fuels and as part of a transition to renewable/green gas.

Electrification of heavy use, long-range vehicles

Potential solutions include electrification of sections of roadway, with overhead systems similar to those used by railways. Another approach could include an electric rail built into the roadway, to which the vehicle can connect. Currently the cost of hydrogen refuelling appears more viable. While the uncertainty associated with these immature technologies means that they do not currently feature in our scenarios, we will continue to monitor developments for future analysis.

The following figures show how each energy component contributes to annual road transport demand across each of the four *FES* scenarios.

Figure 4.20

Annual road transport electricity demand – TWh/year

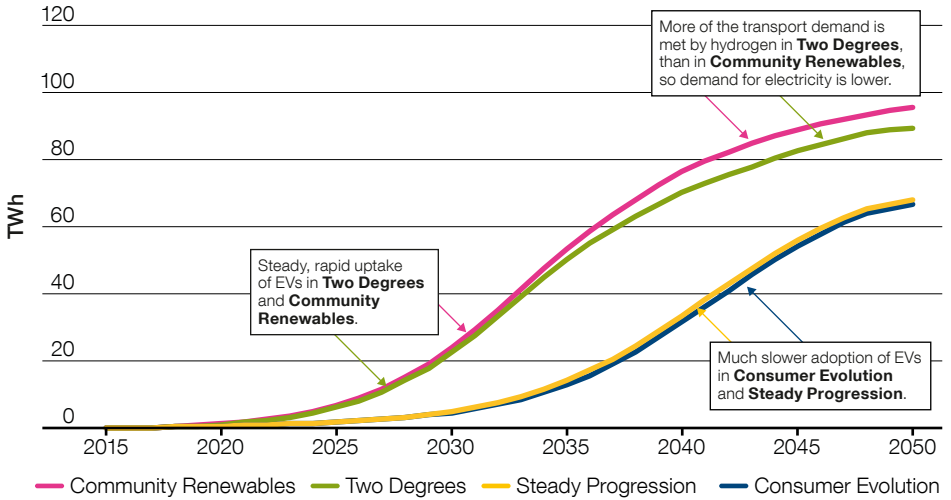


Figure 4.21

Annual road transport hydrogen demand – TWh/year

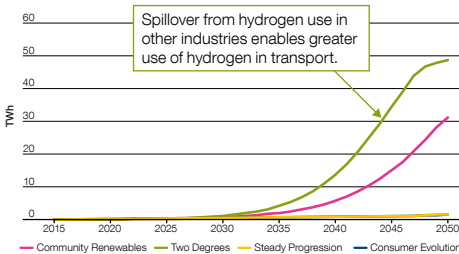
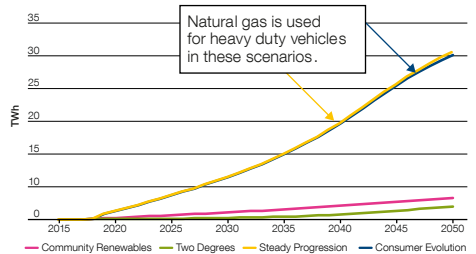


Figure 4.22

Annual road transport gas demand – TWh/year



Energy demand

Road transport demand at peak

How and when electric vehicles are charged during the day can have a significant impact on the profile of electricity demand for road transport. This year, we commissioned a Network Innovation Allowance project to improve our understanding of current charging behaviour, details of which are explored in our spotlight on [page 89](#).

- **Residential** chargers are located in people's homes and will mostly be used at the end of the day on return from work. These typically have a rated capacity of 3 kW–7 kW and will charge slowly over a number of hours.
- **Work** chargers are installed in workplaces, for use by employees who commute to work using an EV. These typically have a rated capacity of 3 kW–22 kW.
- **Slow/Fast public** chargers are publicly accessible with a charging capacity ≤ 22 kW and exclude those classified as work or residential. These may be based at supermarkets, large car parks, service stations and other public locations where people temporarily leave their cars. They are more likely to be used throughout the day, dependent on their location.
- **Rapid public** chargers are publicly accessible, with a charging capacity ≥ 43 kW. These can charge most vehicles in around 30 minutes. They are typically located on major transport routes, for people to top up their vehicle during a longer journey.

More powerful chargers are already being installed that can charge a vehicle in as little as five minutes (similar to filling up with petrol).

Smart phone mapping applications help EV owners manage their energy needs

As more map applications begin to include information about where electric vehicle charging stations are located, EV owners will have increased confidence in planning for longer journeys. The information provided is also becoming more comprehensive. Users can not only see which chargers are available before heading to a station, but they can also find out how many ports are currently available, port types and charging speeds.

Vehicle use will affect the opportunity to charge a vehicle. Cars and light vans are usually plugged into a residential charger once the owner has returned home from work. They are, however, increasingly being charged during the day, using workplace charging facilities. Commercial vehicles, on the other hand, are more likely to be in use, and not charged, during the traditional evening peak of 4pm–6pm.

In **Community Renewables** and **Consumer Evolution** most charging will be done at or close to home, with flats and shared properties providing dedicated charging. In **Two Degrees** and **Steady Progression**, more people will have and use shared charging facilities, either in the workplace or in public locations (service stations, supermarkets).

Two Degrees has rapid charging hubs at key locations, for example at service stations on major transport routes, existing petrol station sites and supermarkets. These can be used for shorter periods of time to top up on a longer journey. **Community Renewables** and **Two Degrees** assume greater investment and intensification to provide charging facilities for sustaining growth in electric vehicles.

Charging behaviour

Technology can enable the active management of vehicle charging and patterns of energy use. We explore future charging behaviour and what may encourage consumers to proactively manage their energy consumption.

Electric vehicle demand management

Smart charging enables consumers to manage the time when their vehicle is charged. This could be to take advantage of lower prices or lower carbon electricity or to respond to external signals from third parties such as aggregators or network companies. One approach, that is widely available today, involves consumers seeking out and actively accessing the financial benefits of various tariff options and scheduling their charging accordingly. A more dynamic form of smart charging would be where a consumer simply leaves their vehicle plugged in whilst not in use, and the time and duration of charging could be actively managed on their behalf with minimal interaction on their part. To make best use of this approach, cars must be plugged in for longer than needed for their own charging needs. There are a growing number of such opportunities for consumers.

Electric vehicle batteries as storage

Vehicle-to-grid (V2G) technology allows electric vehicle batteries to supply power to, or take it from, the electricity network. This gives the potential to help balance the electricity system at times of high demand or generation and provide operability services to network operators. This process may be managed by an aggregator, who would likely have large portfolios of vehicles contracted to deliver this capability. On a smaller-scale, individuals or businesses could use this option to take advantage of variable rate tariffs.

Vehicle-to-home (V2H) technology allows electric vehicle owners to charge their batteries when prices are low, and use that power for their own household needs when prices are higher. This could also alleviate pressure on electricity consumption in periods of high demand.

Our scenarios consider how engaged vehicle owners are likely to be with smart technology and V2G and build these assumptions into our modelling of peak demand. We classify a consumer as participating in smart charging if they do not charge their EVs at peak times, wherever possible. In the decentralised scenarios, **Community Renewables** and **Consumer Evolution**, consumers are more closely connected with their energy demand and so are more motivated to manage the factors affecting it. From a transport perspective, there is greater access to residential charging in these two scenarios. Consumers will be more likely to manage their charging behaviour as they can directly manage their overall demand.

In **Two Degrees** and **Steady Progression**, with increased access to workplace and public charging, the benefits of smart charging are not so directly attributed to the individual consumer. In this case we expect charging and demand management to be driven more by the technology, automating demand management on the consumer's behalf. It is also more difficult to apply smart behaviour to rapid chargers given their short-term nature.

Energy demand

We assume greater policy incentivisation in **Two Degrees** and **Community Renewables** will have a positive effect on engagement. For example, under plans to boost EV infrastructure and ease pressure on the UK power grid, the Government has stated that all home charge points for electric vehicles funded by grants must use smart technology from July 2019.

We assume that only 2 per cent of vehicle owners engage in V2G through to 2030, as the technology is still evolving. That number then steadily increases through to 2050, with the highest levels in **Community Renewables**. In the decentralised scenarios, consumers are more actively engaged in managing their demand.

Figure 4.23

EV consumer participation levels for smart charging and vehicle-to-grid technology in 2050

Smart charging

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

Vehicle-to-grid

Consumer Evolution 13%	Community Renewables 14%
Steady Progression 10%	Two Degrees 11%

How do electric vehicles impact operation of the electricity system?

Electric vehicle batteries can be considered as a form of storage within the wider energy system, though the impact of EVs is fundamentally different to other forms of storage. This is because not all vehicles are connected to the system at any point in time, meaning that the available storage capacity from EVs is constantly varying. The behaviour of connected vehicles is also different to other storage which is used purely for charging and discharging in response to electricity system demand and supply signals. Transport and lifestyle

needs may influence or override system signals and incentives, where use of EVs as storage capacity is concerned.

These factors create natural diversity in availability and charging behaviour for EV batteries, as discussed in our spotlight on [page 89](#). This also means that the potential for electric vehicles to increase, shift, or decrease demand (via smart charging or otherwise) varies and is a fraction of the total capacity of EV batteries in GB at any one time.

Figure 4.24 shows our assumptions on how much EV capacity may be available for smart charging and V2G during times of peak demand.

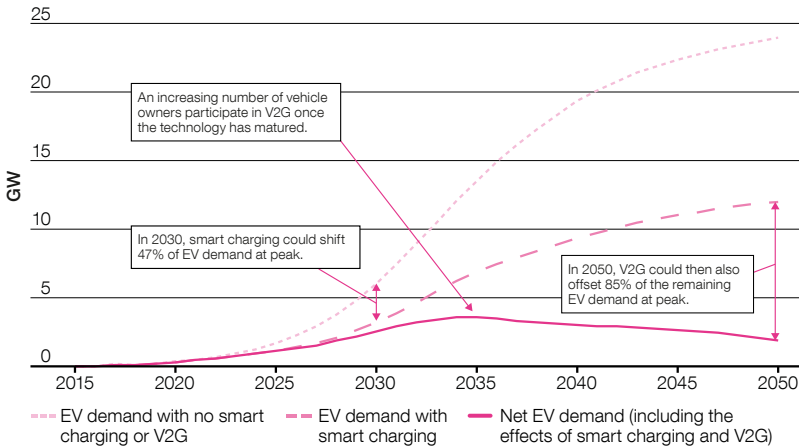
In these figures, the solid line shows peak EV demand after taking account of both smart charging and V2G. This is the impact we include in our scenarios. The dashed line represents what peak EV demand would look like if smart charging (but not V2G) was adopted. The dotted line represents what peak EV demand might

theoretically look like if there were no smart charging or V2G (which is not the case in any of our scenarios, as we believe that the combination of smart technology and innovative tariffs supports the assumption that smart charging will take place).

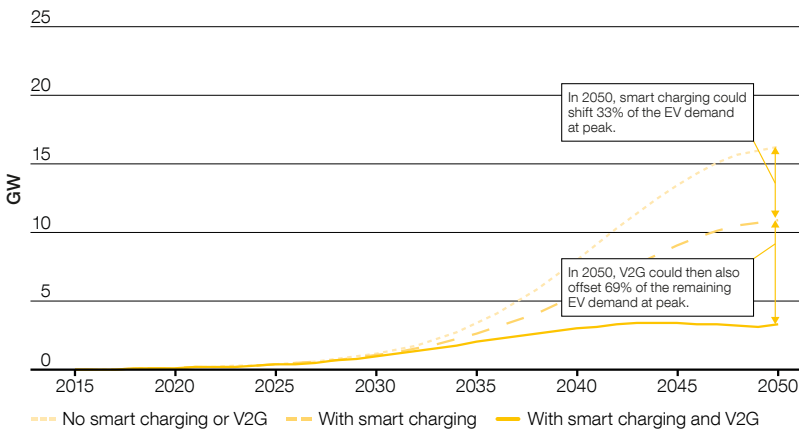
Figure 4.24

Electric vehicle charging behaviour at system peak

Community Renewables



Steady Progression



Energy demand

As vehicle owners engage with smart charging, V2G, V2H and other emerging technologies, these consumers will have increased flexibility and choice when it comes to managing their own electricity demand. They can not only manage the demand for the vehicle they own, but they can also utilise the vehicle's storage capacity for their domestic energy requirements.

Electric vehicles also provide opportunities that are complementary for renewable generation. During periods of oversupply, EVs could be used to store the excess electricity. This will require the introduction of new business models. For example, aggregation service providers may trade on behalf of individual consumers, extending this capability to provide demand side response services to network operators, such as frequency response. This is explored in more detail in our spotlight on oversupply of electricity (see [page 125](#)).

Rail transport

The rail sector of transport is also under scrutiny for its response to the challenge of a low-carbon economy. In April 2019, the Parliamentary Committee on Transport launched the 'Trains fit for the future?' inquiry. Evidence and views have been requested on topics such as bi-fuel locomotives, batteries and hydrogen.

Some opportunities for decarbonising rail transport are being explored.

- Electrification of certain routes is being considered but full electrification of the whole network is still unlikely.
- Opportunities for hybrid engines are being tested. Recent tests with liquid biofuel show that a 10 per cent blend with diesel does not affect engine performance.
- Hydrogen is being assessed as a potential fuel, but there is uncertainty over scale.
- Options for using batteries are being explored, looking at the impact of additional weight, location and recharging.

However, any investment in this sector would need to be significant, so our scenarios assume that growth in demand will be linked to GDP. In **Community Renewables** and **Two Degrees**, we assume that the majority of passenger miles are electrified by 2050. We assume growth of 2.0 per cent per year in **Community Renewables** and 2.5 per cent per year in **Two Degrees**, recognising that there are greater levels of investment in rail infrastructure in a centralised world. In **Steady Progression** and **Consumer Evolution**, we assume a lower growth in demand of 1.5 per cent per year as the economy slowly decarbonises.



Spotlight

Electric vehicle charging behaviour

This year, we have added data from over eight million charging events to improve our analysis and understanding of consumer behaviour. To do this, we commissioned a Network Innovation Allowance (NIA) project to develop a comprehensive picture of current charging profiles. This evaluation has delivered an improved understanding of charging behaviour and enabled us to generate a more nuanced and informed view of the future impact of electric vehicle growth on electricity demand. The trends explored in this spotlight are based on that current data set. The insight explored in this spotlight has informed our scenario analysis which is covered in the main transport section.

Why did we commission the study?

With electricity demand for road vehicles growing at a significant rate, we wanted to assess where and when EV charging currently occurs throughout the year at a national level; and whether this pattern of charging differs by location and size of charger.

What did we find out?

The study successfully gathered together a database of over eight million real world charging events and generated a representative full year charging demand profile at hourly resolution across a range of different location types and charger sizes. It has enabled significant improvements to the modelling of EV charging load on the electricity system. In this spotlight, we share the insights gained about different categories of charging behaviour and what this may mean to our understanding of peak system demand on the electricity network. Several categories of charging types were identified and the patterns of demand were assessed. The final NIA report can be accessed in full at https://www.smarternetworks.org/project/nia_ngso0021

Key charging characteristics identified were:

- at GB level, charging demand peaks between 7pm–8pm on weekdays and is dominated by residential charging demand

- public charging contributes to a smaller secondary peak on weekdays in the mid-morning between 9am–10am
- overall demand on weekend days is on average about 25 per cent lower than weekdays and shows a broader demand profile shape that peaks an hour earlier.

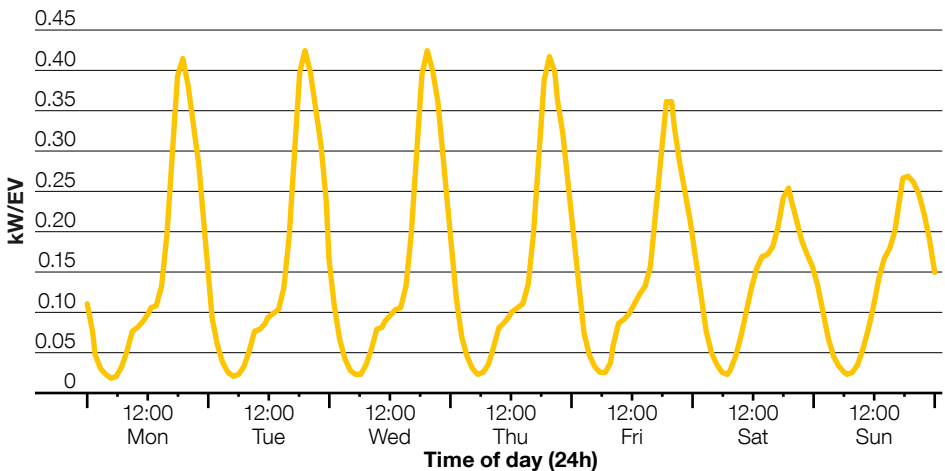
Residential charging

There is a regular pattern in daily demand between Monday and Thursday, but that changes across Fridays and the weekend. The shape of the residential demand profile shows a large evening peak on weekdays,

with a maximum between 7pm–8pm. This same peak is not visible on weekends, which suggests that it is largely due to commuters plugging in to charge after returning home from work.

Figure 4.25

Average residential charging profile (typical week)



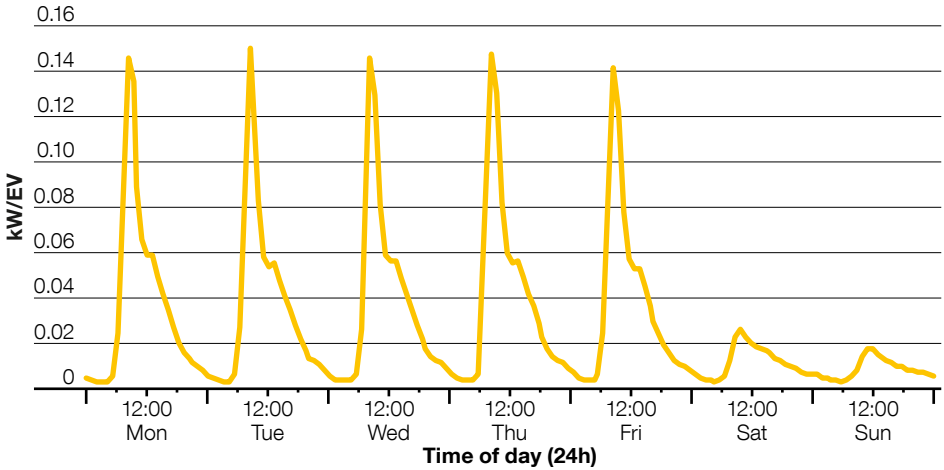
Charging at work

Charging at work takes place almost exclusively on weekdays, with daily demand on Saturdays and Sundays far lower than an average weekday. The shape of the charging profile shows a strong morning peak with a maximum between eight and 9am. The sharpness of this peak suggests that

most EVs need only 1–2 hours to finish charging but remain plugged in for the rest of the day, potentially blocking use by other employees. The small secondary peak between 1pm–2pm may be due to some employees vacating the charge point at lunchtime and others plugging in at that point.

Figure 4.26

Average work charging profile (typical week)



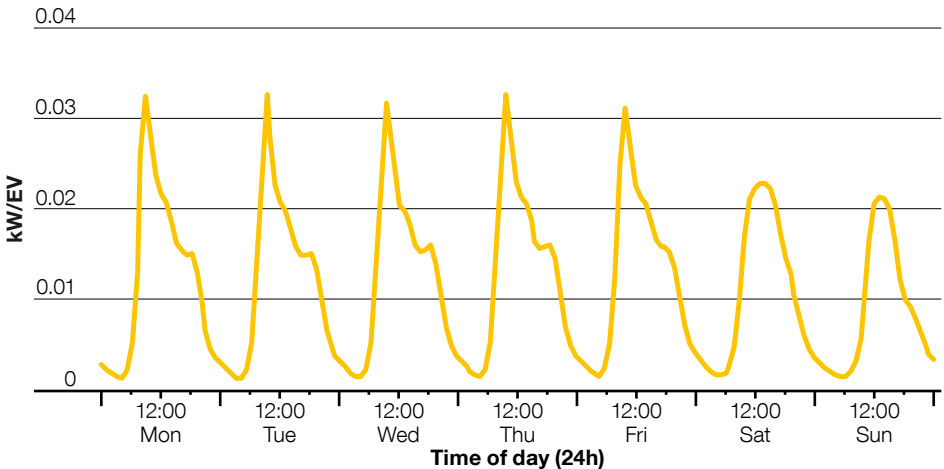
Public charging points

Demand remains very similar during Monday to Friday before falling over the weekend. On weekdays, charging demand is found to peak in the morning, showing a similar shape to work charging, however, the peak occurs an hour later between 9am–10am. It is likely that some of these charge points are used by commuters,

perhaps being located at train stations, or publicly accessible locations where commuters work, such as hospitals or educational establishments. There are also secondary peaks between 1pm–2pm and 6pm–7pm. The earlier one coinciding with lunch breaks, the later one when making their last trip of the day, or for overnight charging.

Figure 4.27

Average public charging point profile (typical week)



What does this mean for peak electricity demand?

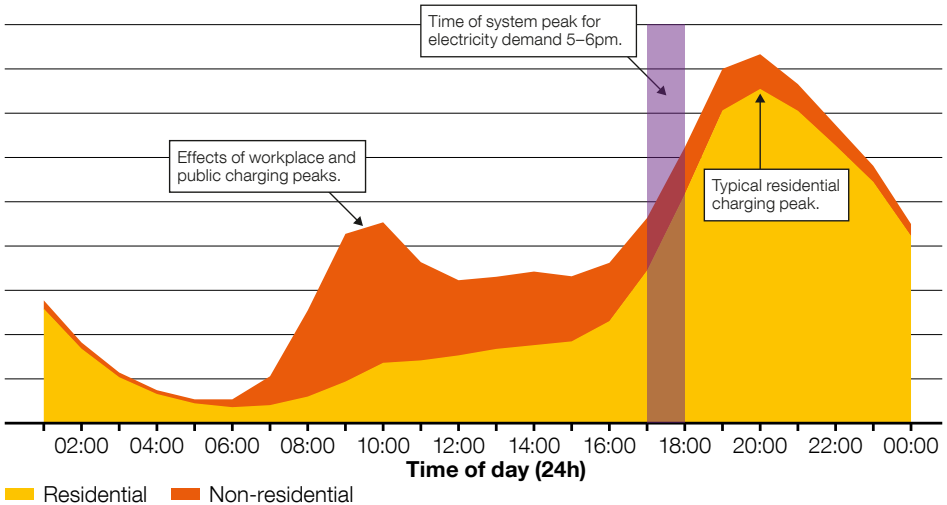
Residential is the most significant element of EV charging, making up around 75 per cent of total charging demand. Workplace charging is around 15 per cent of total demand with the remainder

being split fairly evenly across other types of public charging.

When considered as a whole, we can see that the level of EV charging is less than anticipated between 5pm–6pm, with a far higher peak a couple of hours later between 7pm–8pm.

Figure 4.28

Typical weekday profile (based on EV charging project data 2017/18)



Into the future?

As growth in electric vehicle ownership begins to drive up the proportion of overall demand that the transport sector is responsible for, the peak in EV charging could, in time, result in a new overall system peak later in the evening, or at an entirely different time. There are many uncertain factors that could influence this:

- Will residential charging continue to be the preferred method of charging going forward as the electric vehicle market grows?
- How will developments in charging infrastructure modify charging behaviour going forward?
- How will time-of-use and other charging tariffs influence consumer behaviour?
- How will smart charging, vehicle-to-grid (V2G) and vehicle-to-home (V2H) affect patterns of electricity demand and supply?
- Will there be significant uptake of autonomous vehicles and ride sharing business models?

It is inevitable that there will be advancements in the technology used in EV charging going forward; allowing consumers to proactively manage the time when they use electricity and to use the capacity within vehicle batteries to store electricity when incentivised.

With appropriate incentives, vehicle owners could benefit financially from the management of their own demand through their charging behaviour. Consumers, as a whole, benefit more generally through the flexibility provided to the system from EVs.

Through this capability, there is clear potential for management of peak demand, as well as opportunities to manage the intermittency of electricity supply.

We are seeing rapid uptake of EVs and, as this continues, increasing amounts of real world data will become available, helping to test assumptions and reduce the uncertainty in future analysis.

Energy demand

4.5 Gas demand for electricity generation

Key insights:



By 2050, gas demand for electricity generation has reduced in comparison to today's levels in all scenarios.



Following an initial decline, there is an upturn in this demand in three scenarios. In **Two Degrees** and **Steady Progression**, CCUS is used to decarbonise the generation process.

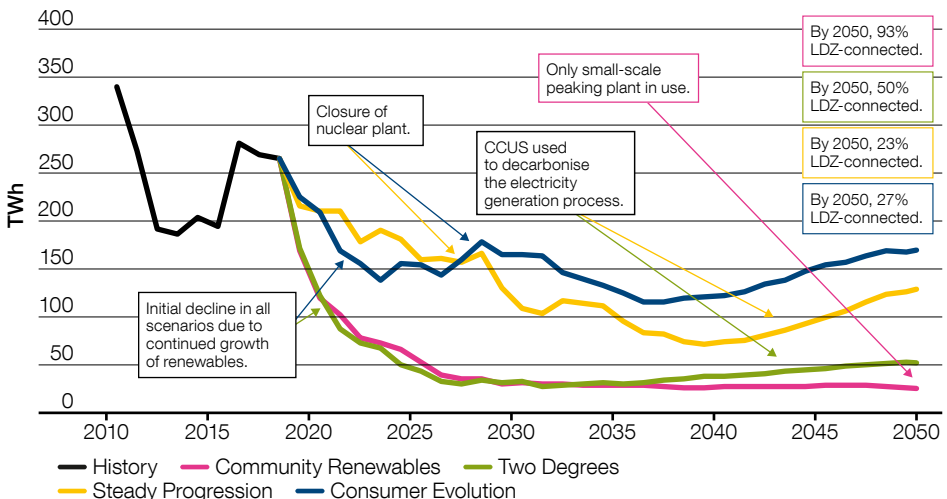
One of the most significant components of gas demand is for the generation of electricity. In recent years, gas demand for NTS connected power stations has typically made up around 25 per cent of the total annual gas demand.

Gas-fired power stations continue to play an important part in the GB electricity generation mix, both in terms of larger plants like transmission

connected CCGTs, as well as distribution connected or onsite small gas reciprocating engines. With the recent and continuing growth in renewable, intermittent forms of electricity generation, thermal plant offer flexibility services as they are able to provide extra generation at very short notice. For further details, see section 5.2, Electricity Supply.

Figure 4.29

Gas demand for electricity generation across all scenarios to 2050



Energy demand

Initially, gas demand for electricity generation is seen to decline in all scenarios because of continued growth in renewable generation. This is even more marked in the faster decarbonising scenarios, **Two Degrees** and **Community Renewables**, with clear policy direction driving investment in key technologies such as offshore wind.

Closures in nuclear plant can have marked effect on gas demand for electricity generation. Typically, when closures occur, the supply is replaced by output from gas-fired generation until other forms of generation capacity become available. The lowest level of nuclear capacity is in **Consumer Evolution**, as this scenario would favour smaller-scale technologies. In this scenario, there are closures that amount to around 3GW of capacity between 2026 and 2028. In **Steady Progression**, there are closures seen around 2032, but not at the same scale. The resultant effect can be seen on power generation demand.

Across all scenarios total electricity demand continues to rise steadily from 2040 onward,

and in three of the four scenarios gas-fired generation plays an important role in meeting this demand. **Community Renewables** is the only scenario to meet almost all electricity demand from other sources of generation capacity by 2050, with gas demand for electricity generation typically just from small-scale peaking plants. Flexible generation in this decentralised scenario is provided instead by other technologies, such as storage and interconnection.

From 2030 onward, commercialisation of CCUS plants in the centralised scenarios, **Two Degrees** and later, **Steady Progression**, begins to grow and is used to decarbonise gas-fired power generation in these scenarios.

In **Consumer Evolution**, there is insufficient renewable generation capacity being established to meet overall electricity demand in 2050. Therefore, output from gas-fired power stations starts to increase as they generate at higher load factors. In this scenario, decarbonisation of generation capacity progresses at a much slower rate since CCUS as a centralised technology is not available at scale.

4.6 Demand for hydrogen production

Key insights:



There is significant demand for hydrogen in **Two Degrees** by 2050, which requires 377 TWh of gas and 40 TWh of electricity to produce.



Transformation of electricity into hydrogen provides the potential for longer-term energy storage.



The centralised scenarios include transportation of hydrogen. In **Two Degrees**, this is via a dedicated hydrogen network and, in **Steady Progression**, hydrogen is blended with natural gas in the existing gas network.

Our *FES* scenarios show that hydrogen has a clear and growing role in a decarbonising energy system. In this section, we describe how gas and electricity are used in the processes for producing hydrogen.

Hydrogen can be produced from water using electricity via a process called electrolysis and from natural gas via steam methane reforming (SMR) and autothermal reforming (ATR), both of which must also include carbon capture, usage and storage (CCUS) to decarbonise production.

We refer to SMR and ATR as methane reforming throughout the document.

For a more detailed explanation of the various methods of hydrogen production, their maturity and the challenges faced in scaling the production, see our spotlight on [page 100](#). We also explore the benefits of CCUS in our spotlight on [page 135](#).

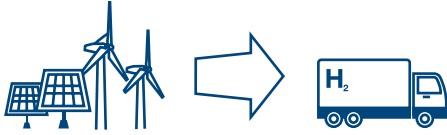
The demand for hydrogen across all the scenarios, and their associated consumption of electricity and gas in 2050, is illustrated in figure 4.30.

Energy demand

Figure 4.30

Hydrogen use across all scenarios by 2050

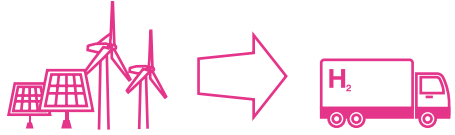
Consumer Evolution



⚡ 2.1TWh
Electrolysis

1.6TWh

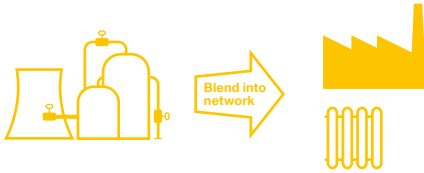
Community Renewables



⚡ 41.4TWh
Electrolysis

31TWh

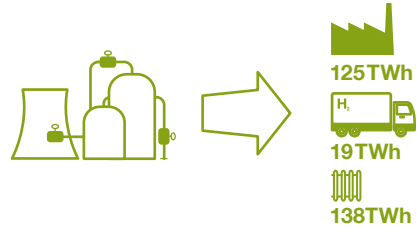
Steady Progression



🔥 17TWh
Methane reforming

12.4TWh

Two Degrees



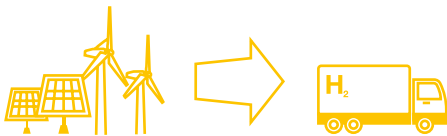
🔥 377TWh
Methane reforming

125TWh

H₂ 19TWh

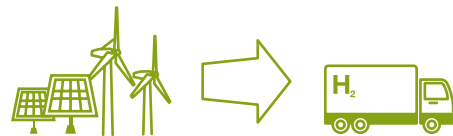
138TWh

282TWh



⚡ 2.1TWh
Electrolysis

1.6TWh



⚡ 40TWh
Electrolysis

30TWh

In *FES 2019*, we assume that more widespread use of electrolysis is driven by decarbonisation, both from the growth in renewable generation which drives down the cost of electricity required for this process, and due to increasing demand for hydrogen from the transport sector. This upturn in use of electrolysis is anticipated in the mid-2030s. We consider smaller-scale electrolysis, located at or close to sources of hydrogen demand, a decentralised solution. For example, an electrolyser at a motorway service station can provide fuel for hydrogen vehicles, without any need for transportation. Also, if a wind turbine or solar panel generates the electricity to directly power the electrolyser, it is not always necessary to connect to the electricity distribution network.

Production of hydrogen at scale using methane reforming and transportation via networks are considered centralised solutions, due to the scale of production methods and the level of investment required to build them.

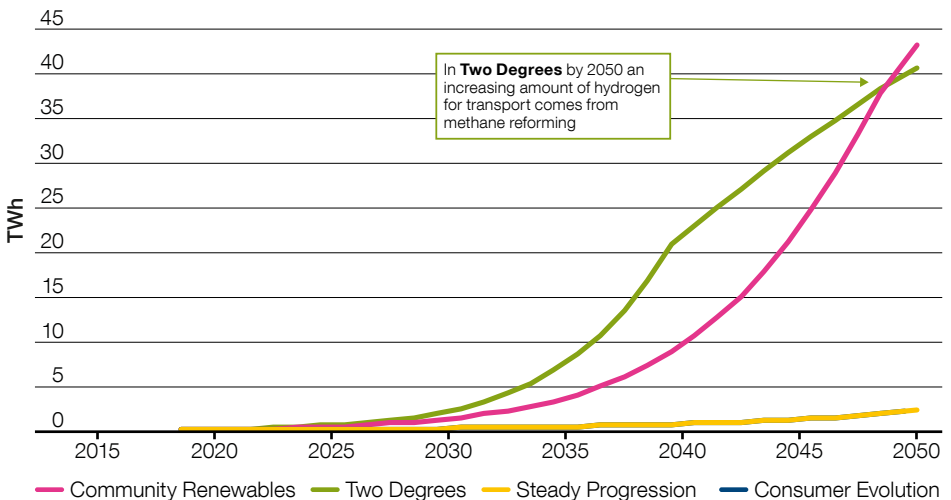
In the faster decarbonising scenarios, **Community Renewables** and **Two Degrees**, there is more widespread use of hydrogen, particularly in heavy use vehicles, and increased investment in hydrogen refuelling infrastructure. Over 40TWh of electricity is used in these scenarios to produce hydrogen for transport needs.

In the slower decarbonising scenarios, **Steady Progression** and **Consumer Evolution**, electrolysis is relatively localised and demand for hydrogen is lower, with many heavy use vehicles still using petrol, diesel or natural gas out to 2050.

Our scenarios assume that no hydrogen produced via electrolysis is injected into a network for transportation. It would lose some of its value if blended with lower purity hydrogen or natural gas and hydrogen of sufficient purity is needed for hydrogen fuel cell vehicles.

Figure 4.31

Annual electricity demand for producing hydrogen via electrolysis



Energy demand

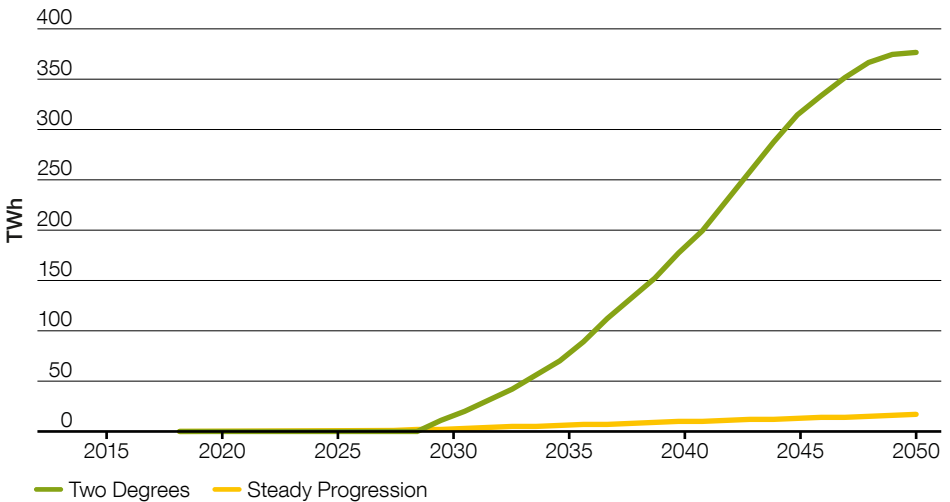
Natural gas²⁰ is used to produce hydrogen via methane reforming in just two of the scenarios, see figure 4.32.

Two Degrees and **Steady Progression** include larger scale production of hydrogen via methane reforming to coincide with increased commercialisation of CCUS from around 2030, and associated growth in demand. In **Two Degrees**, hydrogen is transported via dedicated hydrogen networks and it begins to replace natural gas in commercial and industrial processes in locations where these are built. Hydrogen also begins to be used for domestic heating.

As a result, 377 TWh of gas is required to produce hydrogen by 2050 in this scenario. In **Steady Progression**, hydrogen is injected into the natural gas network and the blended fuels are transported to meet demand needs. This represents a more gradual evolution to low-carbon energy for domestic consumers and industrial processes. No specific network changes are required to enable this²¹. If blending of hydrogen is carried out at relatively low concentrations²², it can safely be used in household appliances or connected industrial plants without any need for conversion or replacement of appliances. Here, 16 TWh of gas is needed to produce hydrogen by 2050.

Figure 4.32

Annual gas demand for producing hydrogen via methane reforming



²⁰ Methane reforming and CCUS rely on both gas and electricity for the production process, although some units are self-contained, extending the steam production to meet electricity needs of the plant as well. Our scenarios assume that this is the case.

²¹ Current assumption under trial by HyDeploy project.

²² Concentration is assumed to be a blend ratio of seven per cent by energy volume of total residential gas demand in some LDZ networks, which is equivalent to about 4 per cent to 5 per cent of hydrogen blend in the affected LDZs.

Hydrogen storage

There is not yet a consensus across the industry about the necessary level of hydrogen storage, nor the preferred solutions.

Both **Two Degrees** and **Steady Progression** assume that hydrogen storage will mostly be in salt caverns, but in **Two Degrees** additional forms of storage may be needed.

Community Renewables and **Consumer Evolution**

assume hydrogen, produced via electrolysis, will be stored local to production in pressurised tanks. This also offers opportunities to store energy when there is an oversupply of electricity. This topic is discussed in more detail in our associated spotlight (see **page 104**).

There is potential for more innovative solutions, for example, converting hydrogen to energy-dense ammonia for storage or transportation. The use of ammonia in the energy supply chain is discussed in more detail in the Net zero spotlight on **page 158**.

Energy storage innovation: Rutherford-Appleton Lab, Oxford

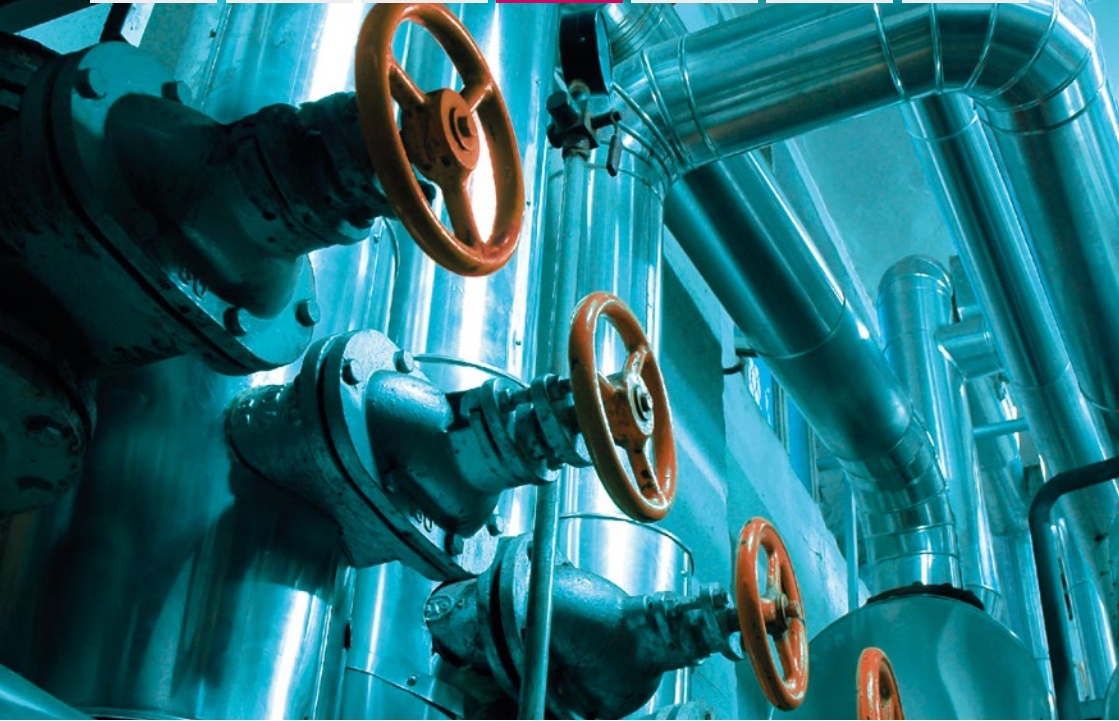
In a project supported by Innovate UK, Siemens has built an energy storage demonstration system to explore the possibility of using ammonia in the energy supply chain via a low-carbon production process. The pilot system uses a wind-powered electrolyser to produce hydrogen, followed by the synthesis of ammonia using the Haber-Bosch process. The ammonia is then stored for conversion back to electricity when required.

Ammonia, NH_3 , is a toxic gas but is essential in the production of fertilisers, notably ammonium

nitrate, NH_4NO_3 . With a long history of safe storage and transportation and a large infrastructure network, ammonia could be a useful and flexible energy carrier. Its energy density by volume is nearly double that of liquid hydrogen.

Ammonia offers a number of options. It can be burned to make electricity when renewable output is low, or turned back into hydrogen for different end uses.

This type of energy storage is an example of a new way for different markets to work together to meet the 2050 carbon reduction target.



Spotlight

In this spotlight, we look at the two leading ways to produce hydrogen, and the innovation programmes which are building the evidence for consumer use of hydrogen for heat and transport.

Hydrogen production, use and delivery

Hydrogen production methods

Hydrogen is already safely produced, largely for use in industrial processes and some transport. If hydrogen demand for heat and transport increases significantly, a bulk supply of low-carbon hydrogen would need to be established, supported by a full supply chain.

The two leading methods of hydrogen production are electrolysis and steam methane or autothermal reforming (SMR/ATR)²³, both of which are also modelled in *FES*.

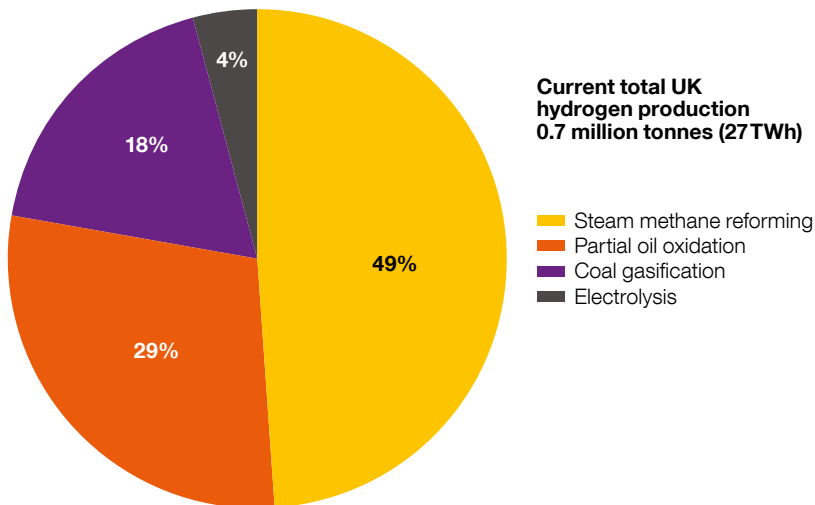
BEIS Hydrogen Supply Programme

As part of a funding programme to support the development of low-carbon industries, the Department for Business, Energy and Industrial Strategy (BEIS) have launched a hydrogen supply programme which aims to accelerate the development of bulk low-carbon hydrogen supplies. It is looking to support programmes which can demonstrate low-carbon hydrogen production at competitive costs.

²³ Methods not considered in this spotlight include biohydrogen, photolytic processes and gasification.

Figure 4.33

Current UK hydrogen production methods

**Table 4.2**Hydrogen production methods in summary²⁴

SMR/ATR (with CCUS)	Electrolysis
Potential for significant emissions savings	Zero carbon production method
Lower overall costs	Can be co-located with local generation
Best efficiencies for large-scale production	Best efficiencies for direct fuelling for hydrogen transport

²⁴ Based on current evidence.

Steam methane or autothermal reforming (SMR/ATR)

Applications



Industrial heat



Electricity generation



Domestic heat



Transport

Process

SMR comprises several processes.

1. Initial purification of feedstock e.g. methane.
2. Methane from natural gas is heated with steam at a high temperature with a catalyst to produce synthetic fuel (a mixture of hydrogen, carbon monoxide (CO) and carbon dioxide (CO₂)).
3. A further process converts the CO and the steam to produce more hydrogen and CO₂.
4. The waste CO₂ is captured with CCUS technology.
5. Different levels of purification can then be applied depending on how the hydrogen will be used e.g. a higher purity is required for hydrogen fuel cells for transport.

ATR is a similar process but uses a pure stream of oxygen to drive the reaction and increase the yield of hydrogen production and CO₂ capture. If targeting CO₂ capture rates above 90 per cent, the ATR route is more cost effective as the capture technology is lower cost than for SMR.

SMR/ATR and CCUS

Using SMR/ATR to produce large amounts of low-carbon hydrogen requires supporting carbon capture, usage and storage infrastructure (CCUS). Read more about CCUS in our spotlight on [page 135](#).

Transporting the hydrogen

For industrial use, dedicated pipelines are already in operation. Wider distribution could be via the gas network. Further purification could be applied locally e.g. for transport fuelling.

Scale/maturity

Large scale potential by 2030 (potential for up to 1.5GW per plant). SMR is proven technology currently in wide use for hydrogen production across the world, largely for industrial processes.

ATR is currently used to make synthetic gas for other products (e.g. methanol) and is also a proven technology.

Efficiencies and cost factors

70 per cent–82 per cent²⁵ efficiency, based on the energy that is retained from the gas used as an input into the process. This is impacted by the choice of SMR/ATR technology and capture technology. For instance, ATR is more cost effective than SMR due a single CO₂ capture point.

Other relevant cost considerations include:

- scale of production
- gas prices
- storage costs
- level of purification require
- grid/network connection.

Looking ahead

Large-scale application of SMR/ATR could develop quickly on demonstration of full supply chain evidence. The main component of this is the cost-effective demonstration of CCUS with high capture rates.

UK projects designed to provide this evidence base are centred in 'industrial cluster' areas. These are areas where there is likely to be a high hydrogen demand, as well as existing infrastructure which supports the most cost-effective development of a full hydrogen and CCUS chain.

²⁵ An efficiency rate of 70 per cent has been used for SMR/ATR in FES.

Electrolysis

Applications



Transport



Domestic heat



Electricity generation



Industrial heat

Process

Uses an electrical current to split water into hydrogen and oxygen over a catalyst. There are several different types of electrolysis:

- **Polymer membrane electrolysis (PEM)** – currently the most popular method with increasing efficiency levels.
- **Alkaline electrolysis** – most developed and demonstrates good stability.
- **Solid oxide electrolysis** – currently in development for industrial use.

Scale/maturity

Small-scale electrolyzers (< 1 MW) are successfully operating around the world, mainly for transport fuelling.

Mass electrolysis production needs to demonstrate it can be commercially competitive. Projects are underway to prove the commercial and technical viability of units up to 250 MW.

A zero carbon production method

Electrolysers can be powered by renewable generation and could absorb renewable energy at times of high output or low demand, by acting as a form of energy storage.

Transporting the hydrogen

Most electrolysis production is currently close to the point of use, which is an advantage of this type of technology. The *FES* modelling is based on this type of decentralised electrolysis production, co-located with renewable electricity generation.

Efficiencies and cost factors

70-90 per cent²⁶ efficiency, based on the energy efficiency of the amount of electricity required per unit of hydrogen produced.

Efficiency for electrolysis also depends on supply running conditions e.g. is the unit able to run with a continuous supply or paired with an **intermittent renewable source**²⁷.

Other relevant cost considerations include:

- electricity prices
- scale of production
- grid connection if required
- storage costs.

Looking ahead

The levelised cost of hydrogen (LCOH) for electrolysis is currently double that of SMR/ATR. This is due to electricity prices, efficiency levels, unit costs and other charges, e.g. grid connection. Long-term forecasts of operations at scale in the right market conditions indicate that the LCOH could ultimately match SMR/ATR.

To achieve this, electrolysis production needs to demonstrate technical viability and commercial competitiveness at large scale. There would also need to be significant investment in renewable generation and supporting infrastructure to support electrolyser production at the potential demand levels required for hydrogen in the future. Several innovation programmes are underway that aim to demonstrate the future potential of the technology.

²⁶ In *FES*, we have assumed small electrolysis plants initially installed alongside renewable generation with efficiency beginning at 45 per cent and growing to 75 per cent by 2050.

²⁷ Our modelling is based on the results of the Aberdeen Hydrogen Project <https://www.ssen.co.uk/DistributionInnovation/ahp/>.



Hydrogen:

Building the evidence for delivery and use

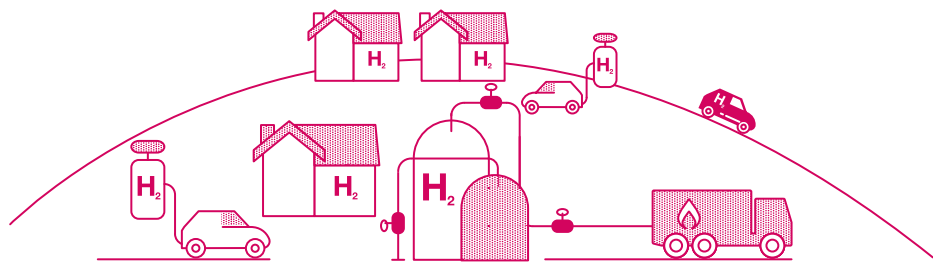
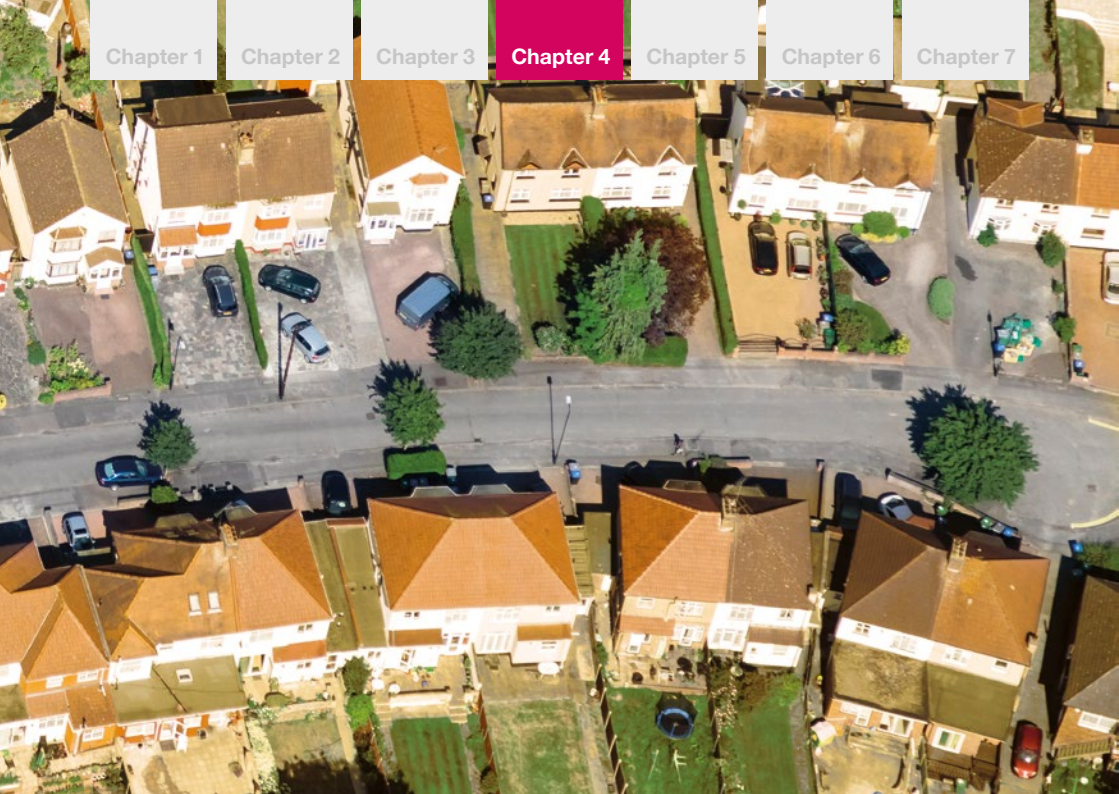
Research and development into the safe and efficient production and delivery of hydrogen is gathering pace around the world.

Hydrogen delivery and use

Hydrogen (2 per cent–20 per cent volume) blended into the existing gas network could offer a way to reduce carbon emissions from heat using the existing gas pipe network, without changing consumer appliances. Trials are now underway to demonstrate that this level of hydrogen injection is safe and practical. Hydrogen blending features in the **Steady Progression** scenario.

Delivery of higher hydrogen volumes (up to 100 per cent) would require significant infrastructure upgrades, a mature supply chain and changes to consumer gas appliances. Several projects are developing evidence to support the delivery of up to 100 per cent hydrogen in the future, potentially starting in the late 2020s. A future with high hydrogen delivery is explored in the **Two Degrees** scenario.

Hydrogen fuel cell vehicles could play a vital role in the decarbonisation of transport, particularly in the commercial sector (e.g. HGVs and buses, trains, shipping and aviation). Hydrogen for commercial transport features in all **FES** scenarios, with higher levels in **Two Degrees** and **Community Renewables**.



Hydrogen heat and transport projects in the UK

2017

Timeline

Project completion end dates range from 2018 to full delivery beginning in the late 2020s.



Safe delivery and consumer acceptability for hydrogen as a new fuel is a central focus of these projects.

20%+



Project Cavendish³⁰ (part of HyNTS programme)

A project to examine the potential for utilising existing energy infrastructure in the Isle of Grain area of Kent for hydrogen production and storage. The goal is to explore how this infrastructure could provide a pathway for future hydrogen injection into London and the South East of England.

2%+



20%+



Aberdeen Vision²⁸

This project is intended to demonstrate the commercial viability of injecting hydrogen into the gas grid. Hydrogen would be exported down to Aberdeen both as a 2 per cent blend into the NTS and potentially in the future via a dedicated hydrogen pipeline. Hydrogen piped into Aberdeen will supply refuelling for their fleet of hydrogen buses, could be blended into the local natural gas network at 20 per cent, as well as offer further opportunities for 100 per cent hydrogen in the future.

HyNet North West³¹

A detailed project concept to deliver hydrogen for heat and transport, along with supporting CCUS infrastructure in the 2020s. Drawing on the strengths and requirements of a particular region, HyNet proposes the UK's first dedicated hydrogen pipeline providing high hydrogen for industrial use, blended hydrogen for homes and enabling future transport fuelling. The first phase is now in progress to develop the costs and delivery evidence for the full project.

20%



HyDeploy²⁹

The UK's first practical demonstration of blended hydrogen (up to 20 per cent vol.) into a live gas network. The first trial for around 130 homes and buildings on a private gas network has been approved by the Health and Safety Executive to begin in 2019. Planning is underway for larger public network trials in the early 2020s.

Hydrogen transport innovation projects

Several other projects are underway to explore barriers and opportunities for hydrogen transport. By the early 2020s, together these will provide the knowledge needed on issues such as engine combustion and fuel purity to facilitate market growth.

20%–100%



²⁸ SGN, National Grid Gas Transmission: smarternetworks.org/project/nia_sgn0134

²⁹ Cadent, Northern Gas Networks, Keele University, Progressive Energy, UK Health & Safety Laboratory, ITM Power: hydeploy.co.uk

³⁰ Project Cavendish: smarternetworks.org/project/nia_nggt0143

³¹ Cadent, Progressive Energy: hynet.co.uk

Late 2020s

100%

**Hy4Heat³²**

A BEIS-funded initiative to establish if it is technically possible, safe and convenient to replace methane with hydrogen in residential and commercial buildings. A number of parallel work packages are underway including those for the development of domestic appliances and meters for demonstration in 2020.

100%

**H21 North of England³⁴**

A comprehensive concept for the conversion of the gas networks and over 3.5 million homes and businesses across the North of England to hydrogen. H21 is based on a regional roll-out between 2028–2034. The study sets out the engineering, economic, market and infrastructure changes required for a conversion, as well as the impact on consumers. Early stage innovation projects are underway to provide evidence for the full concept.

100%

**Hydrogen for Transport Programme (HTP)³⁵**

Sponsored by the Office for Low Emission Vehicles, the HTP is funding a range of projects which lays the groundwork for a UK hydrogen vehicle market. Running until 2020/21, its main focus areas are the expansion of the UK's hydrogen re-fuelling infrastructure and the deployment of HFC electric vehicles.

H100³³

H100 builds on prior work to develop site specific evidence to support the construction of a physical 100 per cent hydrogen demonstration. The project's aim is to develop quantitative evidence that will advise government policy, HSE and regulation and ultimately allow the construction and operation of the first 100 per cent hydrogen network in Scotland. Two workstreams include detailed feasibility and FEED studies which will bring together all elements of the programme.

Hydrogen in the National Transmission System (NTS)³⁶
(Part of HyNTS programme)

A feasibility study which aims to determine the capability of the NTS to transport hydrogen. Includes a review of relevant assets, pipeline case study and draft scope for offline trials.

100%



100%

**Key:**

- Homes/business
- Industry
- Transport

³² Department for Business, Energy & Industrial Strategy, Arup, Kiwa Gastec, Progressive Energy, Embers and Yo Energy: hy4heat.info

³³ SGN: sgn.co.uk/Hydrogen-100/

³⁴ Northern Gas Networks, Cadent, Equinor: H21 final project report (www.h21.green)

³⁵ OLEV, E4 Tech, Ricardo ee.ricardo.com/htpgrants

³⁶ Hydrogen in the NTS: foundation research and project roadmap innovation project https://www.smarternetworks.org/project/niu_nggt0139

Chapter 5

Energy supply	110
5.1 Energy supply	110
5.2 Electricity supply	113
5.3 Gas supply	139

Energy supply

Spotlights



Oversupply of electricity
Pg 125



Carbon capture, usage and storage (CCUS) Pg 135



Carbon intensity of gases
in FES 2019 Pg 147

Energy supply

5.1 Energy supply

The drive towards decarbonisation will transform the energy landscape over the next 30 years. Growth of renewable generation, reduction in use of fossil fuels, and use of low-carbon fuels such as hydrogen and biomethane, will result in significant changes in the way energy is supplied to meet the evolving profile of GB demand.

Across all scenarios out to 2050, supply patterns are changing, resulting in more complex and volatile flows of electricity and gas across the whole energy system. Whilst only part of the story, increased intermittency from renewables and diversification of supply sources play their role in this.

Since our last publication of *FES*, the energy industry in Great Britain has continued to evolve at a rapid pace in terms of electricity generation and gas supply. New milestones continue to be reached. We have seen the lowest ever carbon intensity winter, running for over 18 days without coal generation and, at times, seeing over a third of national electricity demand supplied by wind.

Supply patterns are increasingly influenced by the drive for decarbonisation. Technology is evolving in response to market signals, enabling more diverse forms of energy supply across the industry.

From an electricity perspective, generation will continue to decentralise as government targets phase out coal generation by 2025 and the majority of nuclear plants reach end-of-life and close by 2030. There has been huge growth in solar generation in recent years and government support for the offshore wind sector through the recently signed Sector Deal. Investments are being made in technologies such as carbon capture, usage and storage (CCUS) to decarbonise

generation, and numerous projects are being commissioned to extend the range of storage solutions within the system. These technologies will continue to mature and deploy at greater scale, and this wide variety of generation sources will collectively offer the range of capabilities needed to meet changing demand.

From a gas perspective, flows from the UK Continental Shelf are expected to decline, although the world market for liquefied natural gas (LNG) production will remain strong. Following recent government proposals to increase the proportion of green gas in the grid, investment in technology for green gas production is expected to grow, both for small-scale localised producers, and larger industrial scale bioSNG plants.

Supply is also affected by the way consumers engage with energy. More and more consumers meet their own demand, with use of solar panels. Also, as electric vehicle owners engage with V2G they can offer storage capability to the system, becoming part of the energy supply chain.

Looking across the whole energy system

Operation of the electricity and gas systems has become more complex, not only because of the increased intermittency of generation requiring flexibility across the whole energy system, but also due to the growing diversity of supply. This diversity plays out in terms of both technology and location. In our scenarios, more and more small-scale suppliers feed gas and electricity directly into the distribution networks and, in some cases, meet localised demand without any network connection. There is a wide range of new technologies entering the supply chain, such as residential batteries and production of green gas. There will be increasing diversity in the type and specification of gas in the networks going forward. With biomethane, shale gas and even hydrogen being blended into the network, there will be new challenges to face in managing the resulting profile of supply.

There are also complexities associated with the growing inter-dependency between fuels. Significant levels of electricity will continue to be generated from gas across all scenarios, and hydrogen is produced from both electricity and gas. Supplies must be responsive to changing patterns of both demand and supply across all fuels.

There remain several challenges to be resolved. For example, there are currently limited quantities of bioresources available. Whilst they can be used to decarbonise industry, transport or heating, the use in one sector may limit availability in another. The growing use of hydrogen could bring additional flexibility, with electrolysis scheduled to help balance electricity supply and demand, but it could also introduce additional operational complexity.

To manage these challenges, a suitable range of supply capabilities need to be in place to ensure efficient operation under all conditions. A whole energy system approach, that considers cross sector and cross fuel impacts, is crucial to optimise our energy use across GB.

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. Our *FES* analysis is unconstrained by network considerations, assuming that the networks have enough capacity to meet supply and demand requirements. Network development and operability is discussed in other published documents. See chapter one figure 1.1 Industry publications informed by *FES*.

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 (LOLE¹). For gas, there is no direct equivalent to LOLE, however the following test (meeting the N-1 condition²) is used as a guide. There must be enough supply to meet the peak demand on a very cold day (a 1-in-20 peak winter day³), even if the single largest piece of supply infrastructure were to fail.

¹ An approach used to describe electricity security of supply. For detailed definition, please refer to glossary on page 162.

² A risk assessment to demonstrate that UK gas supply infrastructure is resilient to all but the most extreme and unlikely combinations of severe infrastructure and supply shocks.

³ Peak demand for gas is 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.

Energy supply

Use of 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 power⁴; Megawatts (MW) or Gigawatts (GW). A 1 GW power station generating for one 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 of cubic meters per day or billions of cubic metres per year (mcm/d or bcm/y). 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 gas industry.

For gas, in 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.

⁴Electricity peak demand is discussed in the electricity demand section.

5.2 Electricity supply

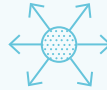
Key insights



All scenarios have much higher levels of both overall generation and decarbonised generation compared to today. However, the increase is more marked in **Community Renewables** and **Two Degrees**.



All scenarios require greater flexibility as the amount of intermittent renewable generation increases, but requirements are higher in the decarbonised scenarios.



All scenarios see an increase in decentralised generation. Up to 58 per cent of all generation (around 136GW) could potentially be decentralised by 2050.



In the 2050 compliant scenarios, there are some periods of excess electricity generation from around 2030 onwards. This rises to 20TWh–25TWh (around six per cent of total annual output) in **Community Renewables** after 2040. This is explored in our spotlight on **page 125**.

This section of *FES 2019* looks at GB electricity generation capacity, and how the annual output from this generation could change over the next 30 years. We examine how various technologies could develop between now and 2050, considering renewable and nuclear generation, thermal plant, the use of carbon capture, usage and storage (CCUS) in electricity supply, electricity interconnectors and storage.

The way that electricity is supplied in GB is undergoing radical change. Previously, electricity generation was dominated by thermal plant, and the majority of electricity flowed through the transmission and then distribution networks onto consumers. Today, a large range of technologies are being used to generate electricity, located on the transmission and distribution networks and on customers' own sites. Each of these has different attributes and can bring distinct benefits to the energy system.

Technologies such as wind and solar have zero fuel costs, with their output dependent on weather patterns. Electricity storage enables the use of electricity at different times, with long and short

duration storage providing different benefits as explored on **page 134**. Many types of thermal plant can be switched on and off quite quickly, whereas nuclear generation may be better suited to providing stable levels of electricity output over long periods of time. And interconnectors mean that electricity can be imported from other countries, dependent on the price differential between markets.

Throughout this chapter, we discuss the need for greater flexibility on the electricity system, particularly as the amount of weather dependent or less flexible generation increases. Supply and demand of electricity on a network must remain in balance on a second by second basis to keep networks stable. We define flexibility as the ability to easily and quickly respond to changing market conditions. From a supply perspective, this could mean a generator rapidly increasing output to ensure demand is met in a period of low wind or no sun, for example. Or electricity storage could store electricity at a time when renewable generation is abundant, and release it later when needed. Demand side flexibility is discussed in chapter four.

Energy supply

GB electricity generation capacity

Figure 5.1 shows how installed electricity generation capacity could change in GB over the next 30 years.

In all scenarios overall capacity grows, but this is particularly noticeable in **Two Degrees** and **Community Renewables** where installed generation more than doubles by 2050.

The proportion of renewable capacity also grows in every scenario, but much more quickly in the 2050 compliant scenarios.

These two developments are interrelated; **Two Degrees** and **Community Renewables** both have a higher proportion of renewable generation, and much of this capacity is intermittent, only producing electricity when weather conditions are favourable. This means more generation capacity has to be built to meet overall energy requirements and times of high demand, particularly in winter.

Figure 5.1

Installed electricity generation capacity, plus storage and interconnection (no vehicle-to-grid)

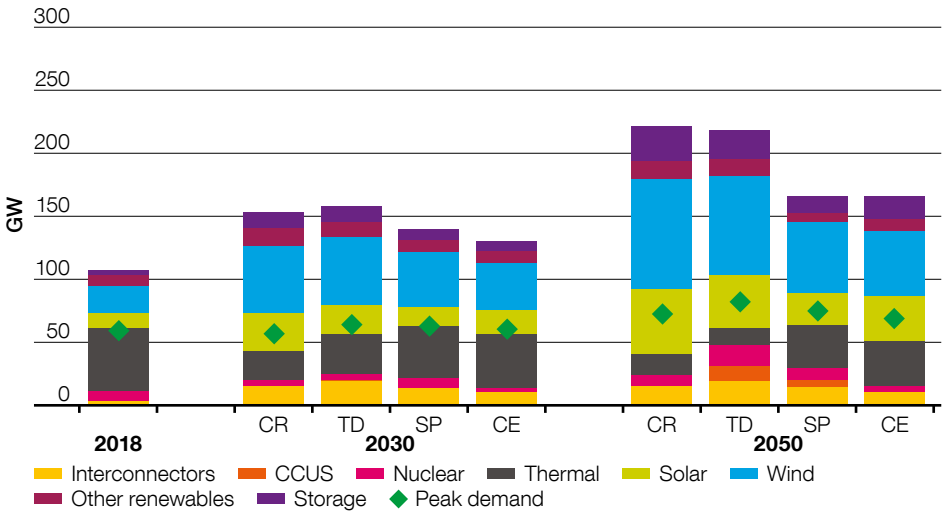


Table 5.1

Installed generation capacity; centralised and decentralised⁵

	Decentralised	Centralised
2018	29%	71%
2030		
Community Renewables	45%	55%
Two Degrees	31%	69%
Steady Progression	27%	73%
Consumer Evolution	39%	61%
2050		
Community Renewables	58%	42%
Two Degrees	38%	62%
Steady Progression	35%	65%
Consumer Evolution	55%	45%

All scenarios also eventually see an increase in the proportion of decentralised capacity, but in **Steady Progression** this does not happen until the early 2030s. By 2050, 58 per cent of all generation is decentralised in **Community Renewables**, compared to 35 per cent in **Steady Progression**.

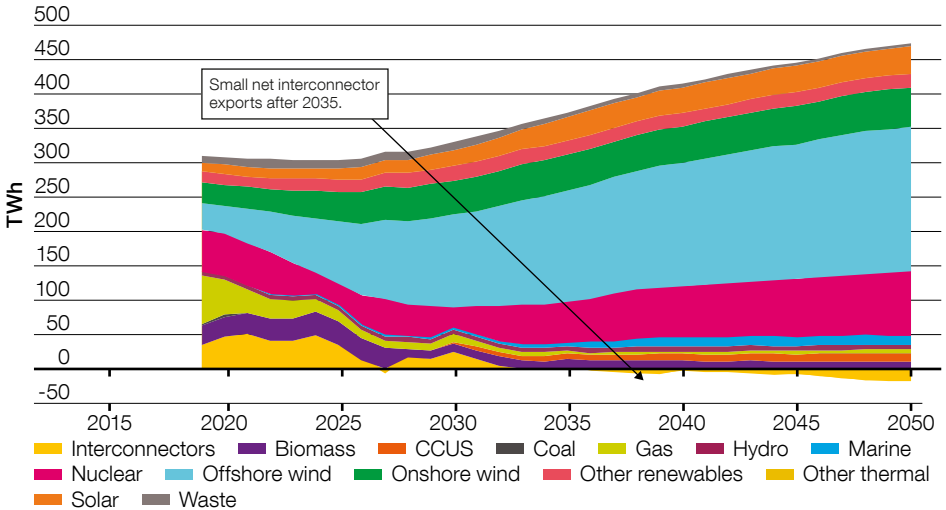
More discussion and data considering the decentralisation of electricity generation can be found in chapter three.

⁵ Percentages include vehicle-to-grid.

Energy supply

Figure 5.2

Electricity output by technology, **Two Degrees**

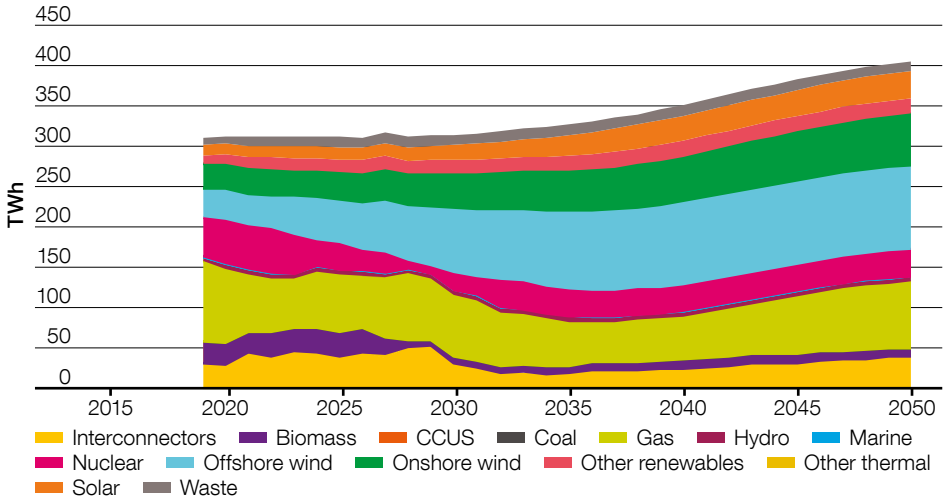


In **Two Degrees**, the electrification of transport and partial electrification of heat increases electricity demand from the mid 2020s. The large increase in output from wind, particularly offshore, and an increase in solar, means that by 2030, renewable generation could potentially account for almost 80 per cent of total electricity output. Nuclear output also begins to increase by the mid 2030s, as new nuclear plant is built.

Over the next 30 years, gas-fired generation moves from providing a significant proportion of electricity supply to providing a small proportion of overall output, particularly when there is high demand or less renewable output. In this way, it takes on more of a peaking plant role. As the output from this type of generation decreases, load factors⁶ decrease, and plant will increasingly be reliant on the selling of flexibility services to remain competitive. From the late 2030s, this scenario also moves to small net export of electricity via interconnectors.

⁶ Load factors are an indication of how much a generation plant or technology type outputs across the year, expressed as a percentage of their maximum possible generation.

Figure 5.3

Electricity output by technology, **Consumer Evolution**

In **Consumer Evolution**, the electrification of transport increases electricity demand. However, the pace of change is slower than the 2050 compliant scenarios. There is also much less electrification of heat. As a result, demand does not grow as quickly as in **Two Degrees**.

A large increase in output from offshore wind, and later some growth of solar and onshore wind,

helps to meet this demand. Gas also provides much more output than in the faster decarbonising scenarios, particularly in the late 2020s as nuclear capacity drops when older plants close ahead of new ones opening.

Output data for the **Steady Progression** and **Community Renewables** scenarios can be found in the *Data Workbook*.

Energy supply

Renewable generation

Key insights



Across all scenarios, renewable generation grows substantially, with growth most pronounced in the faster decarbonising scenarios. This mainly stems from cost reductions and technology improvements rather than subsidy support. Co-location with electricity storage also allows access to other revenue streams.



Offshore wind dominates the future growth of renewables, thanks to continued reductions in cost, turbine and supply chain developments and government support through the recently signed Sector Deal.

Looking back over the past year, there has been a continued increase in many forms of renewable generation⁷ in GB, and further milestones reached for renewable output, periods with no coal generation and low-carbon intensity

of electricity. However, some technologies have not grown as rapidly as in the past, with growth becoming more reliant on cost reductions as subsidy support reduces.

⁷ Our *FES 2019 Data Workbook* includes a breakdown of scenario data for all generation by technology type, plus five year forecasts for growth.

Solar

Following very rapid growth, the installation of solar capacity in GB has slowed in the past 2 years to 3 years after the loss of subsidy regimes. Consequently, we do not anticipate more rapid growth of solar until the late 2020s, when cost reductions in solar technology and co-location with increasingly cheaper storage will boost solar growth. New business models are emerging, such as suppliers offering home owners solar panels with discounted batteries when they sign up to participate in certain services.

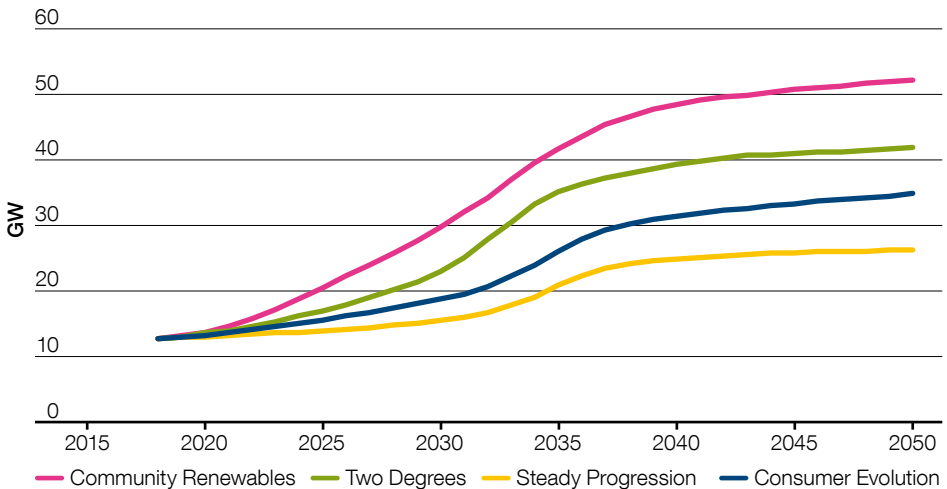
Growth in solar capacity is greatest in **Community Renewables**. This is due to falling costs and high consumer interest in technologies like residential solar plus storage systems. However, we have reduced maximum levels of solar in this scenario compared to *FES 2018* to reflect recent

stakeholder feedback. In contrast, solar growth is much more limited in **Steady Progression** where there is limited consumer engagement with energy and a slower drive to decarbonise.

Beyond 2040, growth in solar slows across all scenarios. Effectively, as solar generation output tends to rise at similar times across GB, the market for electricity at these times becomes saturated. Prices at times of high solar output will fall to the extent that it no longer becomes commercially viable to build new solar plants. However, co-location with electricity storage can improve revenues for solar projects, enabling them to avoid grid curtailment and benefit from price arbitrage, and to divert solar power to storage when the network is congested or prices are low or negative. It can then be sold at a different time of day when networks have capacity or prices are higher.

Figure 5.4

Solar capacity by scenario



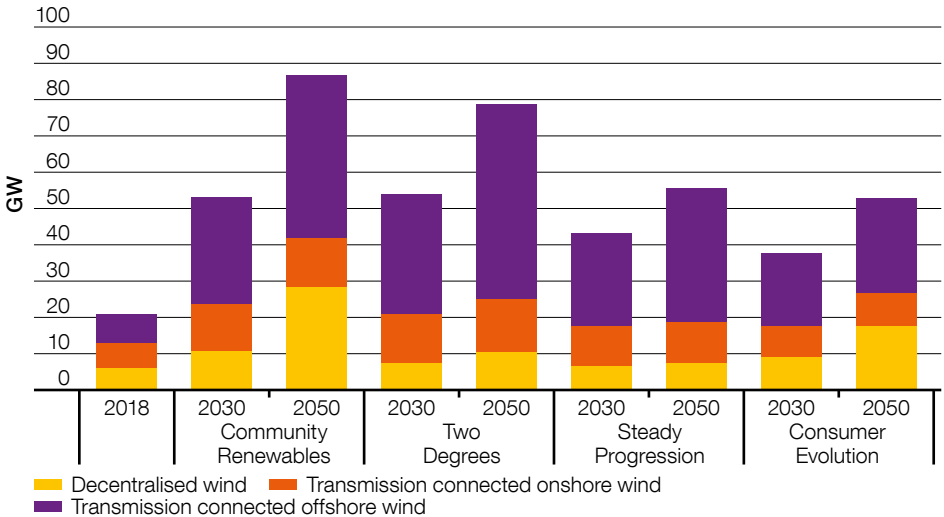
Energy supply

Wind

Overall wind capacity increases significantly in all scenarios, with capacity almost doubling by 2030 even in the scenarios with lowest growth.

Figure 5.5

Wind capacity by scenario



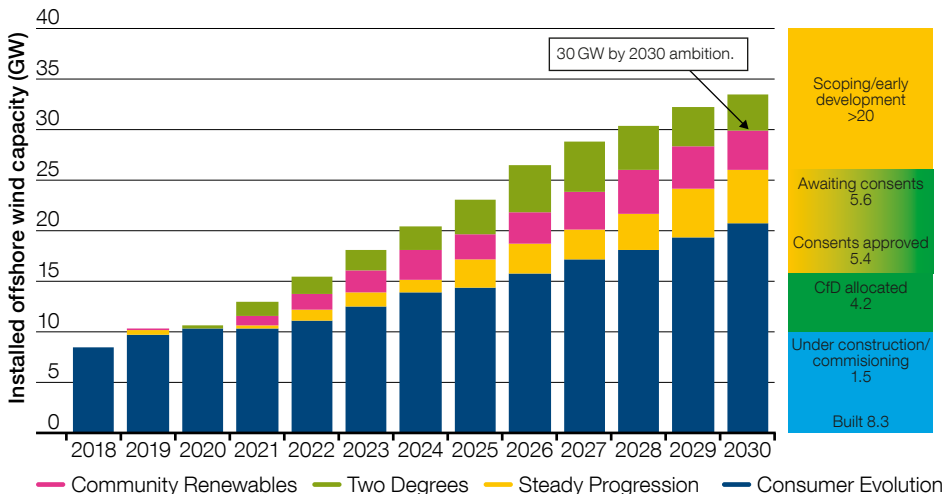
Most onshore and offshore wind sites are assumed to re-power in all scenarios. This is when a site is re-fitted with new, sometimes higher powered, equipment when the original assets reach the end of their life. This can make use of existing connection assets and likely favourable planning conditions. In **Steady Progression**, there are very few new onshore wind projects installed besides existing site re-powering. So, there is minimal growth in onshore wind generation in this scenario. In contrast, in the more decentralised worlds there is moderate growth in decentralised onshore wind. This is due to factors such as the increased consumer acceptance of wind turbines, co-located storage and a favourable policy and planning environment for smaller scale wind schemes.

Offshore wind has strong growth in all scenarios, due to factors such as turbine improvements and falling costs. Most notably the development of a **Sector Deal**⁸ has led us to increase the anticipated capacity of offshore wind across all scenarios compared to *FES 2018*. The Sector Deal is a partnership between the Government and the offshore wind sector to support continued growth of offshore wind technologies, and “maximise the advantages for UK industry from the global shift to clean growth”. The deal gives more certainty on the timing of future **Contract for Difference**⁹ (CfD) rounds, increasing investor certainty. It targets the installation of 30 GW of offshore wind generation by 2030, and we assume this is met or more than met in the 2050 compliant scenarios.

Figure 5.6 shows the strong pipeline of offshore wind projects until 2030.

Figure 5.6

Potential offshore wind projects by scenario



⁸ <https://www.gov.uk/government/publications/offshore-wind-sector-deal/offshore-wind-sector-deal>

⁹ A contract between the low-carbon Contracts Company and a low-carbon electricity generator, designed to reduce its exposure to volatile wholesale prices. For further information see <https://www.gov.uk/government/collections/contracts-for-difference-cfd-third-allocation-round>.

Energy supply

As shown in figure 5.6, our scenarios capture a wide range of uncertainty. Only projects already built or being built, or those with future subsidies and/or consents are included in **Consumer Evolution**, whereas **Two Degrees** includes some projects only in early development.

The Sector Deal includes a further target to install 50GW of offshore wind by 2050, which is met in **Two Degrees** and almost met in **Community Renewables**.

Other renewable technologies

As part of our *FES 2019* analysis, we examine other types of renewable electricity generation, including marine generation and electricity created from organic materials by burning biomass or biogases.

Electricity can be generated from organic materials in two ways. Matter like wood pellets or certain crops can be burnt to run a turbine that generates electricity. For gasification technologies, low-carbon biogas is produced from organic matter by allowing it to break down in the absence of oxygen. This is then burned to run an engine or turbine. In both cases, the resulting electricity is low-carbon – the carbon released by burning plant materials is equal to the carbon captured by the plant during its growth phase.

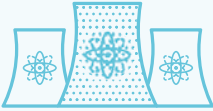
In considering likely levels of biomass and biogas generation in our future energy scenarios, we take into account other factors. Firstly, we consider realistic levels of organic materials that can be grown in GB or imported for the purposes of energy generation. Secondly, this limited supply of bioresources could be used in a number of ways across different sectors. For example, biofuels could be used to decarbonise the transport and aviation sectors, and biogases can be used in industry, electricity generation or injected into the main gas network and used for heating. For these reasons, we have limited the use of bioresources in electricity generation to take account of other competing uses.

To reflect uncertainty around its future development, marine generation (including technologies such as wave and tidal) is very low in the **Consumer Evolution** scenario, but reaches around 4GW by 2050 in **Two Degrees**. The majority of this capacity is large tidal lagoon projects, but there is also the potential for smaller tidal stream projects across GB.

A full breakdown of all renewable technologies can be found in the *Data Workbook*.

Nuclear generation

Key insight



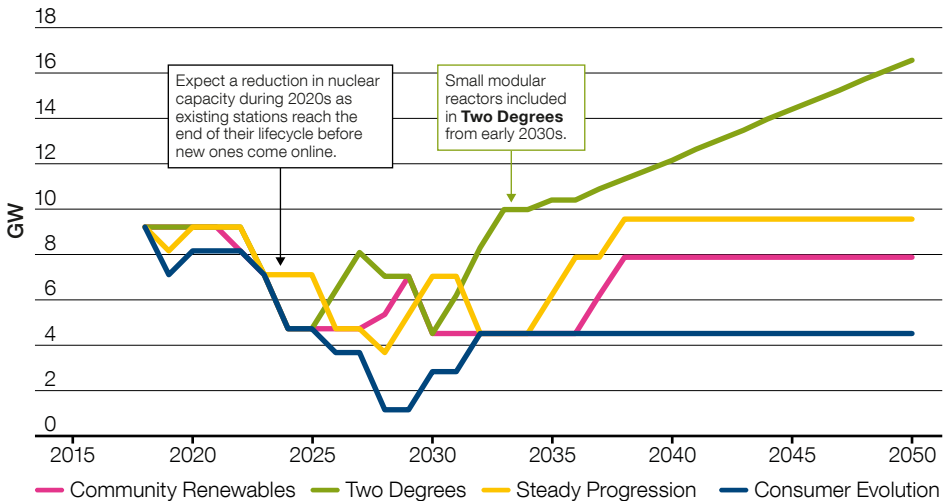
We have revised nuclear projections downwards across all scenarios, to reflect uncertainty of new project delivery. This is due to the recent terminations or suspensions of nuclear projects in GB in the past year.

Most existing nuclear plants in GB are more than 35 years old, with all but one plant expected to close before 2030. As a result, we expect an ongoing reduction in GB nuclear capacity during the 2020s, as stations start to close before new plant is ready to generate.

Since *FES 2018*, a number of nuclear projects in GB have been cancelled or suspended. This has led us to revise nuclear projections downwards across all scenarios. The lowest level of nuclear capacity is in **Consumer Evolution** as a slower decarbonising, decentralised scenario favouring smaller-scale technologies. Here nuclear capacity drops to below 2 GW in the late 2020s and rises back to just over half of today's levels by the mid 2030s.

Figure 5.7

Installed nuclear capacity



Energy supply

The highest level of nuclear capacity is in the **Two Degrees** scenario, reaching 16GW by 2050. This year, we have included small modular reactors in the **Two Degrees** scenario only, where they provide 7GW of nuclear capacity by 2050. These reactors have been included in a more centralised scenario because, although they are smaller and

more standardised than large nuclear plants, they are large enough to always connect to the transmission network. No small modular reactor projects are currently contracted to connect in GB, but there is a UK consortium seeking to develop this technology.



Spotlight

Oversupply of electricity

In the faster decarbonising scenarios of **Two Degrees** and **Community Renewables**, the growth of low-carbon capacity will contribute to periods of oversupply of electricity, particularly in the summer months beyond 2030.

A large amount of low-carbon generation is built in **Two Degrees** and **Community Renewables**, some of which is less flexible (difficult or costly to turn on and off) or intermittent (produces more or less electricity, dependent on weather conditions). The amount of low-carbon capacity needed to meet annual energy requirements and times of high demand means that, at other times, this capacity produces more electricity than total demand. However, from a system operation point of view, supply of electricity on a network needs to equal demand at all times to keep networks stable.

In **Two Degrees** and **Community Renewables**, we begin to see longer periods of excess electricity generation from around 2030 onwards. The annual amount of excess electricity rises to 20TWh–25TWh (around six per cent of total annual output) after 2040 in **Community Renewables**. Our modelling shows that at times of likely oversupply, excess electricity

cannot be exported, as other countries that have decarbonised are likely to be facing similar issues. Nor can it be stored, as available storage is full.

Our modelling shows that there could be short-term 'spikes' of excess electricity, and some more prolonged periods of oversupply. Ultimately, future markets will determine how this electricity could be used, stored or curtailed in the most efficient way, potentially with different solutions for different time periods:

- With dynamic time of use tariffs in place, some industries or consumers might be incentivised to use this excess supply (for example to charge up EVs) – potentially via negative electricity prices so they are paid to do so.
- Longer-term availability of zero or negatively priced electricity could also influence the development of hydrogen production via electrolysis, discussed in chapter four.
- Balancing markets are evolving to become accessible to all provider types. Future developments in technology may also make it easier for traditionally inflexible generation to change output. All of these factors mean that in the future, more types of generation could be incentivised to reduce output at times of oversupply.
- Other new innovative solutions could develop to make efficient use of remaining excess electricity.

Energy supply

Thermal generation

Key insight



In all scenarios, the economics of thermal generation will increasingly rely on their ability to provide flexibility and network services as their overall output falls. However, this changing role does not necessarily imply a reduction in capacity in the slower decarbonising scenarios, where there is little change in the amount of gas generation capacity compared to today.

Thermal generation refers to electricity generation that uses fossil fuels such as diesel, gas, oil or coal. Previously, thermal generation provided most of the electricity in GB. However, in the last five to ten years, its role has changed due to the growth of zero fuel cost, intermittent renewable generation, and carbon pricing policies. Increasingly, thermal generation is used as peaking plant, providing electricity at times of high demand and/or when renewable output is low, rather than all day long. We are seeing longer and longer periods of time without any coal-fired generation at all.

The Government is committed to phasing out all unabated¹⁰ coal generation by 2025. All of our scenarios achieve this goal, but with the faster decarbonising scenarios seeing earlier coal closures, and **Consumer Evolution** and **Steady Progression** seeing all coal closing by 2024 and 2025 respectively.

Gas-fired generation will continue to play an important part in the GB generation mix, both larger plants like transmission connected combined cycle gas turbines (CCGTs), as well as distribution connected or onsite small gas reciprocating engines.

In the last 12 months, growth in distribution connected gas engines has outpaced expectations. New sites are being built in advance of their Capacity Market (CM) delivery year, and many have also installed more capacity than their CM contracts, indicating that they are able to make revenue from other sources. Ofgem's most recent 'minded to' position in the Targeted Charging Review (seeking to create a level playing field across network charging for different types of distribution and transmission connected generation) could also change the balance of CCGTs and onsite generation.

We have therefore increased our projections for distribution connected gas generation across all scenarios, with the greatest growth in the more decentralised scenarios of **Consumer Evolution** and **Community Renewables**. One of the key factors for growth will be this plants' competitiveness against other forms of flexibility such as storage. In addition, new emissions regulations came into force in 2018¹¹. These have led us to predict no further growth in small diesel reciprocating engines beyond currently contracted projects, and so we anticipate that most distribution connected thermal plant growth will be from gas projects.

¹⁰ Unabated generation is generation where emissions have not been treated to remove carbon dioxide or other pollutants.

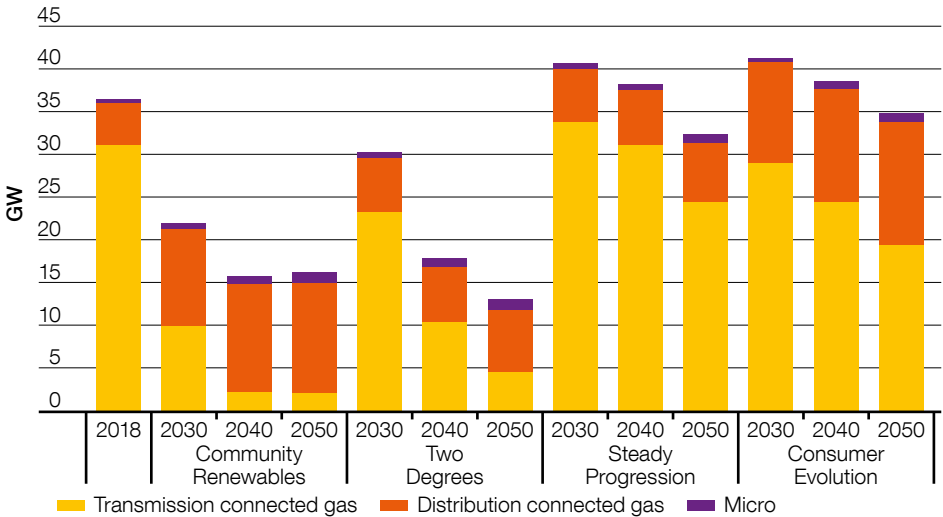
¹¹ The European Medium Combustion Plants Directive came into force from the end of 2018 for smaller generators, subject to transitional arrangements. In addition to this, the UK government has added further oxides of nitrogen limits for smaller generators with a capacity or balancing agreement.

Considering transmission connected gas generation, there are few new transmission connected CCGT plants in the faster decarbonising scenarios. At the same time, existing CCGTs are closing, meaning that there is a rapid overall reduction in CCGT capacity in **Two Degrees** and **Community Renewables**. The slower

decarbonising scenarios of **Consumer Evolution** and **Steady Progression** have a slightly slower rate of closure, and more new CCGTs after the late 2020s. This means transmission connected gas capacity sees some small initial growth, and does not begin to reduce compared to today until 2040. This is shown in figure 5.8.

Figure 5.8

Total gas-fired generation capacity



Energy supply

Carbon capture, usage and storage (CCUS) in electricity generation

Key insights



Carbon capture, usage and storage (CCUS) features in two scenarios in electricity generation, but growth could be influenced by the use of the technology in other sectors such as hydrogen production.

Carbon capture, usage and storage (CCUS) is a process in which carbon dioxide, usually emitted from burning fuels, is captured and then either recycled or stored safely so it is not released into the atmosphere. This is discussed in more detail in our spotlight on [page 135](#). CCUS, as a large-scale technology, appears in electricity generation in our two more centralised scenarios of **Two Degrees** and **Steady Progression**.

In both scenarios, we assume that CCUS is used with gas-fired generation to provide low-carbon electricity. It can also be paired with other generation methods, for example biomass, and we explore this in our **Net Zero** sensitivity in chapter six. However, in our core scenarios we assume that gas is most likely to be paired with CCUS at a large scale in GB, as there is existing gas infrastructure, and also there are limitations on the amount of biomass that can be grown or imported in large quantities.

In **Two Degrees**, the use of CCUS across multiple industries (hydrogen production

as well as electricity generation) helps to build a market more quickly. There could also be benefits in co-locating hydrogen production with CCUS gas-fired generation. This is because the CCUS process itself is more efficient to run at a constant output, so co-locating hydrogen production with electricity generation could allow more flexibility (with the CCUS used to produce hydrogen when electricity is not required). In **Two Degrees**, gas-fired generation with CCUS is rolled out at scale from 2030 and 12GW of capacity is installed by the late 2040s.

In **Steady Progression**, CCUS is also used in hydrogen production but at much smaller volume than in **Two Degrees**. As a result, there is less of a positive spillover effect for using CCUS in other sectors. In **Steady Progression**, CCUS with gas-fired electricity generation therefore develops at a later date, beginning in 2039. As there are fewer opportunities to co-locate hydrogen production and electricity generation, we assume that the electricity output from these plants is less flexible than equivalent plants in **Two Degrees**.

Electricity interconnectors

Key insights



Electricity interconnector capacity increases in all scenarios but with no additional growth beyond the late 2020s, as price differences between connected markets reduce.

Developments over the last 12 months mean the outlook for interconnector capacity growth remains fairly strong. Additional regulatory certainty has developed thanks to cap and floor regimes that limit the potential profit and loss from interconnector projects, helping to reduce investment risk. In the last year, a new interconnector connecting GB and Belgium, Nemo Link, has begun commercial operation and a further project has received a final investment decision. Two additional interconnector projects also received Capacity Market (CM) agreements for 2021/22.

In *FES 2018*, we introduced a range of European scenarios into our dispatch modelling, to better model uncertainty in the electricity markets directly

connected to GB. This year we have extended these scenarios over a wider geographical area, to model potential decarbonisation pathways in the next set of neighbouring countries such as Spain, Sweden and Italy.

Our scenarios assume that after the UK's exit from the European Union, the UK remains part of the internal energy market (IEM) or agrees a deal that closely replicates these arrangements. We assume that the GB carbon price continues to be a combination of the EU Emissions Trading Scheme (EU ETS) and the GB carbon price support (CPS). If or when the UK no longer participates in the EU ETS, we assume that the Government carbon tax would replace this aspect of the overall carbon price¹².

¹² For further detail on our modelling changes, European scenario sources and assumptions please see the Modelling Methods document.

Energy supply

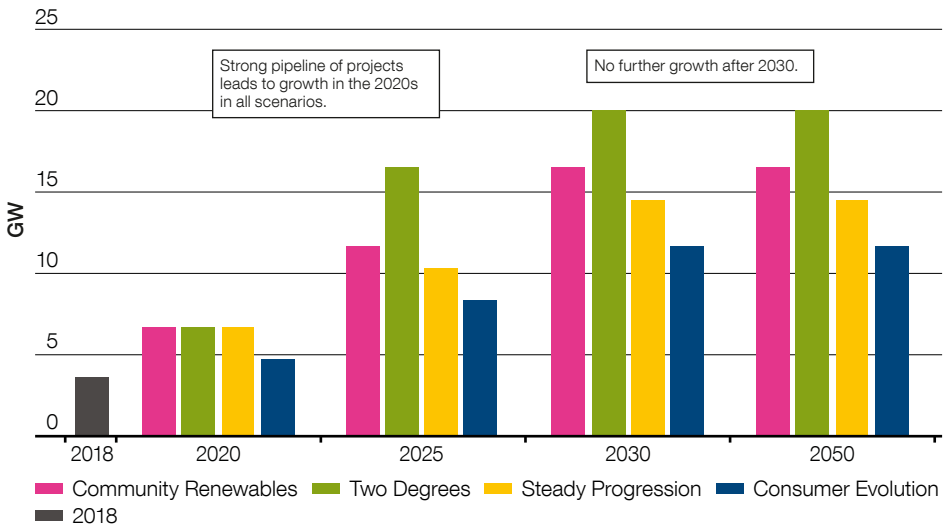
Electricity interconnector capacities

All the above developments mean that our outlook for interconnector capacities is similar to *FES 2018*, but with the lowest interconnector scenarios revised upwards to reflect latest projects. Capacity Market agreements, cap and floor regimes and projects beginning construction all give greater short-term certainty for interconnector projects.

As shown in figure 5.9, interconnector capacities are higher in the faster decarbonising scenarios, as more flexibility is needed to complement the intermittent output from renewable generation. However, in the more decentralised worlds, flexibility is more likely to be provided by smaller projects, for example decentralised thermal generation. Consequently, the highest interconnector capacity can be found in the faster decarbonising and more centralised scenario of **Two Degrees**, where capacity more than trebles by 2030.

Figure 5.9

Installed interconnector capacity



In all scenarios, no new interconnectors are built after the late 2020s, as we assume that the difference in electricity price between connected markets narrows as more interconnector projects come on line and more trading takes place. This reduces the value of additional interconnection.

In the slower decarbonising scenarios, there is also less policy support for interconnectors, and greater competition from the growth of domestic technologies in GB that can provide flexibility services. This is likely to reduce the potential profits for interconnector projects.

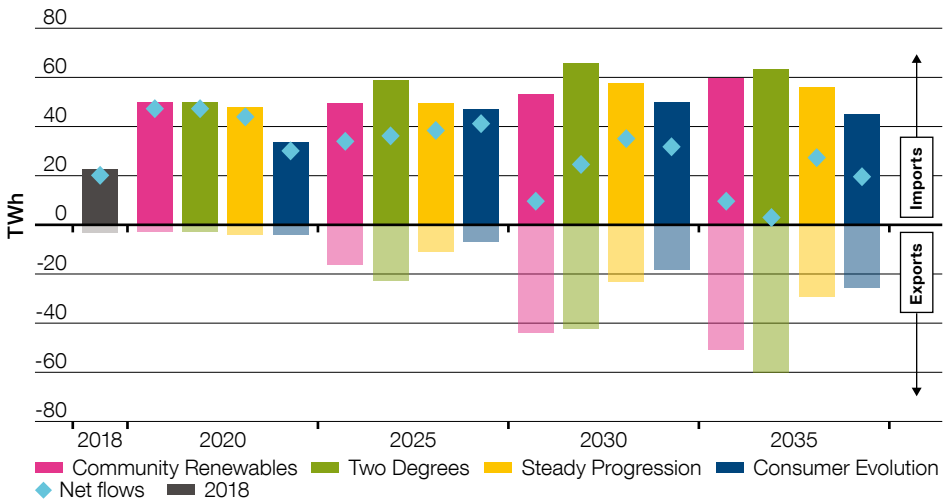
Net annual electricity interconnector flows

For most of the 2020s, we anticipate that GB will import more electricity than it exports in all scenarios, mainly due to higher electricity prices in GB as a result of carbon pricing policy. After the late 2020s, flows become more variable as other connected countries decarbonise and build more

intermittent generation. In the more decarbonised scenarios, interconnector flows move closer to net balance. This is due to interconnectors helping to balance the greater volumes of renewable generation across Europe, with prices responding to intermittent output in different countries. Although the net import position is close to zero, a large volume of energy is traded across interconnectors in these scenarios.

Figure 5.10

Interconnector annual flows



Interconnector flows at peak

In all scenarios, we expect GB to be a net importer of electricity at peak times, typically 5pm–8pm on weekdays in winter. This is when GB prices are likely to be higher than in connected markets, and cheaper hydro and nuclear electricity is likely to be available in Norway and France. The lowest peak flows are seen in **Consumer Evolution**, as this scenario has the lowest interconnector capacity. Highest flows are in **Community**

Renewables and **Two Degrees** as these scenarios have higher flexibility requirements and higher interconnection capacities.

Expected flows at peak could vary considerably from period to period, and this does not necessarily mean every peak period will see net imports. As renewable generation output, plant availability or demand changes in connected markets, this will affect prices on each side of the interconnector, which will respond by moving power from cheaper to more expensive markets.

Energy supply

Electricity storage

Key insights



Electricity storage capacity increases in all scenarios. This is needed to support intermittent output from renewables, with growth facilitated by continued falls in battery costs and developments in other storage technologies. In particular, there is a need for larger, longer duration storage to support decarbonisation.

The last 12 months have seen continued growth and developments in electricity storage. This section considers a number of electricity storage technologies, including batteries, liquid and compressed air projects and pumped hydro. Whilst hydrogen can also be used to convert and store energy, we do not consider it in this section as it is not electricity specific. This section does not include EV batteries that can be used for vehicle-to-grid (V2G) purposes. These are discussed in chapter four.

In the last year, around 50 storage projects have been commissioned in GB, providing around 500MW of capacity. Many of these are short duration batteries, but also include other technologies such as a new liquid air facility. This is where off peak electricity is used to cool air to a liquid state, which is later warmed and pumped to run a turbine. Around 80 per cent of these new projects are being installed on the distribution network or at a lower voltage, for example alongside onsite generation. There has been continuing co-location of storage with generation, so projects can access a broader range of markets. Most co-located projects are with solar and wind generation,

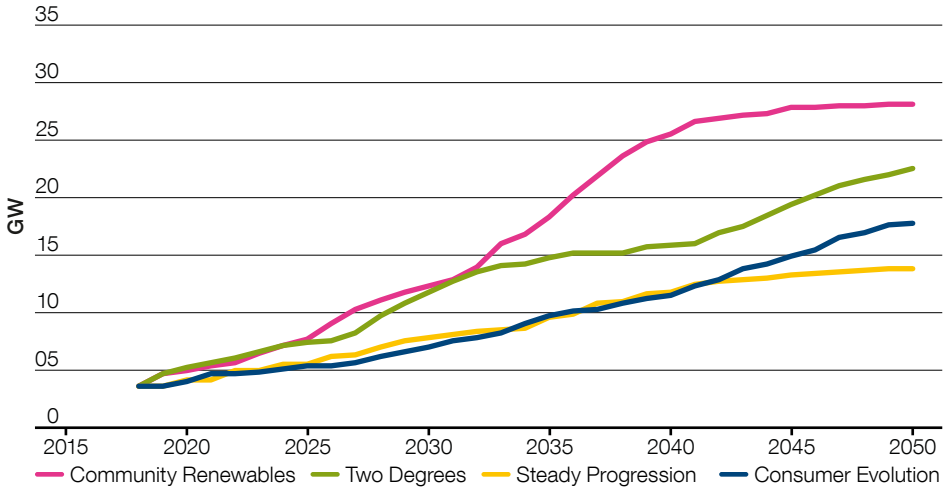
but there are co-located gas, hydro or tidal projects as well. This rapid development of projects in the past 12 months has led us to increase our projections of storage growth in the 2020s in most scenarios, as we see the development of a robust project pipeline.

Across all scenarios, we assume electricity storage projects will need multiple income streams to be commercially viable. Potential revenues could include price arbitrage, or balancing and ancillary services, and providing services to network operators. There is also an increasing number of new customer tariffs and business models in the electricity storage market. These include:

- Discounted residential battery packages, where the battery is used (potentially alongside domestic solar PV) to provide grid services. Consumers are able to benefit from a reduced price for purchase and installation, whilst also using the battery to reduce more expensive electricity use, or to store and use solar output.
- Trials to use batteries alongside solar PV to create local virtual energy markets via blockchain trading.

Figure 5.11

Installed electricity storage capacity



There is steady growth in storage in all scenarios, but a greater and more rapid increase in the faster decarbonising scenarios, as intermittent output from rising renewable generation increases the need for flexibility. In both faster decarbonising scenarios, storage plays an important role in helping to absorb excess renewable generation, so that it can be used at different times. In contrast, **Consumer Evolution** and **Steady Progression** have lower flexibility requirements due to lower renewable growth. This means there

is less need to store excess renewable electricity for use at a different time.

There is particularly rapid storage growth in the **Community Renewables** scenario from the early 2030s onwards as both demand and renewable generation (particularly solar and wind) increases. However, unlike **Two Degrees** there is less interconnection to provide flexibility services, and smaller-scale generation is often co-located with storage.

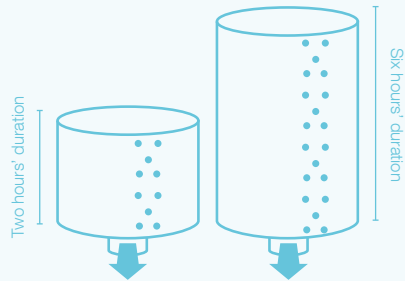
Energy supply

Long and short duration of electricity storage – what’s the difference?

Much of the storage capacity in the **Community Renewables** scenario consists of smaller, shorter duration projects. Two electricity storage projects can have the same connection capacity (measured in MW) but different durations, meaning that they can discharge energy at the same speed, but for different amounts of time. For example, a 5MW battery that can discharge energy for up to two hours could release a maximum of 10MWh from one charge. In contrast, a 5MW longer duration project could discharge the same amount of energy per hour, but for six hours – making its maximum release of electricity from one charge 30MWh.

These different types of storage can be used in distinct ways. For example, shorter duration projects could meet small periods of increased demand, or provide flexibility services such as frequency response. Longer duration storage is well suited to covering longer periods of, for example, high or low wind, potentially co-located with generation.

In the **Two Degrees** scenario, although less storage capacity is installed, more of these projects are bigger, longer duration projects such as transmission connected pumped hydro¹³.



Both storage projects release energy at the same rate, but one can continue to do so for a longer time period – rather like a sink and a bath tub emptying through the same sized plughole.

¹³ Further detail on modelled storage technologies by network connection and storage durations can be found in the *Data Workbook*.



Spotlight

Carbon capture, usage and storage (CCUS)

Carbon capture, usage and storage (CCUS) refers to technologies which capture carbon dioxide (CO₂) emissions from sources such as industrial processes to prevent them from entering the atmosphere. The captured CO₂ is then transported and stored, or re-used.

CCUS is versatile, large-scale technology and could be used to reduce CO₂ emissions across several different processes, including:

- industrial processes which use natural gas e.g. steel mills and cement plants
- large-scale hydrogen production from methane reforming
- biomass, gas and coal-fired electricity generation.

CCUS in FES

CCUS is essential to support low-carbon hydrogen production in **Two Degrees** (chapter four – Demand from hydrogen production), as well as reduce carbon emissions and support electricity generation (chapter five). It is used at lower levels in **Steady Progression**.

CCUS is also central to our **Net Zero** analysis, coupled with other generation, specifically biomass considered in chapter six.

CCUS has up to a 90% CO₂ capture rate depending on process design



Energy supply

CCUS UK outlook

2017/18	2018/19	2019/20	early 2020s	mid-2020s	2030s
<p>Clean Growth Strategy¹⁴ states an ambition to deploy CCUS at scale in the UK subject to costs coming down. CCC¹⁵ supports CCUS as ‘<i>crucial to meeting the UK’s long-term climate targets at least cost</i>’.</p> <p>CCUS Cost Challenge Taskforce formed.</p>	<p>CCUS Cost Challenge Taskforce report¹⁶ presents industry view on progressing CCUS in the UK to give the option for deployment at scale in the 2030s.</p> <p>Government CCUS Action Plan¹⁷ sets out a pathway to plan development of the UK’s first CCUS project, linked to Industrial Strategy¹⁸ goals. Plant to be operating from the mid 2020s to support 2030s ambition.</p> <p>CCUS Advisory Group formed.</p>	<p>CCUS Advisory Group to provide expert view on the cost structures, risk sharing and market mechanisms needed for an investment framework to deliver the first CCUS projects.</p> <p>Innovation funding awards for CCUS technologies.</p> <p>Oil and gas industry co-ordination on potential use of infrastructure for CCUS projects.</p>	<p>Indicative timescales (UK Government CCUS Deployment Pathway: Action Plan)</p> <p>Frameworks development Industry and government work on facilitating market delivery.</p> <p>First CCUS demonstration facility construction Location of potential initial CCUS sites:</p> <ul style="list-style-type: none"> • Humberside • Merseyside • Scotland (two sites) • South Wales • Teeside. 	<p>Target date for first operational UK demonstration plant.</p>	<p>Target date for large-scale UK commercialisation and deployment of CCUS.</p> <p>Several operational sites and world-leading deployment of the technology.</p>



c.50% higher
costs to meet the 2050
target without CCUS



43
projects operating/in
development worldwide



**Five leading
UK sites**

The best economies of scale could be achieved by developing CCUS in regional areas known as ‘clusters’ where existing infrastructure and high demand mean lower per unit cost for constructing and operating CO₂ pipelines

¹⁴ HM Government: The Clean Growth Strategy (2017) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

¹⁵ Committee on Climate Change: Independent Assessment of the UK’s Clean Growth Strategy (2018) <https://www.theccc.org.uk/wp-content/uploads/2018/01/CCC-Independent-Assessment-of-UKs-Clean-Growth-Strategy-2018.pdf>

¹⁶ CCUS Cost Challenge Taskforce report: Delivering Clean Growth (2018)

¹⁷ Clean Growth: The UK Carbon Capture Usage and Storage deployment pathway - An Action Plan, 2018 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759637/beis-ccus-action-plan.pdf

¹⁸ Department for Business, Energy & Industrial Strategy: UK’s Industrial Strategy: Building a Britain fit for the future (2017) <https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future>

Table 5.2

The CCUS value chain in brief

Transportation	Storage	Usage
<p>The captured CO₂ is compressed and transported via:-</p> <ul style="list-style-type: none"> • new or re-purposed pipelines, similar to those used to transport natural gas • shipping • road tanker. 	<p>CO₂ is injected into deep underground rock formations, usually at depths of one kilometre or more. Suitable storage sites include re-purposed oil and gas fields and deep saline formations. The UK has a number of potential offshore storage sites including oil and gas fields at Merseyside, Humberside and Scotland. Early moves to re-purpose sites due for decommissioning in the 2020s would maximise value from existing infrastructure.</p> <p>Widespread cross-border shipping of CO₂ for re-use or storage elsewhere could be an area of growth for the CCUS chain.</p>	<p>The captured CO₂ can be used as a source of carbon for products. Product innovation is responding quickly to the desire for a more sustainable economy and new uses are being found for CO₂. For instance, it could be mineralised into solid products for building materials. Advances could open a valuable market for large-scale CO₂ re-use.</p>

Energy supply

Table 5.3

Current CCUS technologies

Pre-combustion	Post-combustion	Oxy-fuel
<p>CO₂ is captured during a combustion process, when a fuel (e.g. natural gas) goes through gasification and partial oxidation to produce CO₂ and hydrogen. Steam methane reforming or autothermal reforming for hydrogen production are examples of this.</p> <p>Best for:</p> <ul style="list-style-type: none"> hydrogen production retro-fitting or as part of new power plants direct use with industrial processes needing high temperatures. 	<p>CO₂ is captured from the exhaust of a combustion process by absorbing it in a suitable chemical. The absorbed CO₂ is recovered using heat. It is the most mature CCUS technology.</p> <p>Best for:</p> <ul style="list-style-type: none"> retro-fitting to combustion processes e.g. at power plants direct use with industrial processes that need high temperatures. 	<p>In the process of oxy-fuel combustion oxygen is separated from air and combined with recycled flue gas to burn a fuel (e.g. coal or gas). This process can achieve high capture levels and no nitrogen oxide (NOx) pollutants but is currently limited to smaller processes and requires additional equipment.</p> <p>Best for:</p> <ul style="list-style-type: none"> smaller combustion processes e.g. at power plants (currently up to 30 MW). Further technology development will widen the scope.

5.3 Gas supply

Key insights



UK Continental Shelf (UKCS) production declines in all scenarios, but with more support for extended use in the centralised scenarios.



Green gas (biomethane and bioSNG) makes up 46 per cent of the total gas supply by 2050 in **Community Renewables**.



Gas demand in **Two Degrees** is similar to current levels in 2050 but over 73 per cent is transformed into electricity or hydrogen, via processes decarbonised by CCUS.



Shale gas replaces UKCS as the primary indigenous source of gas by 2050 in **Consumer Evolution**.



Imported gas makes up between 49 per cent and 87 per cent of total gas supply by 2050.

The UK is becoming increasingly reliant on imported gas from continental Europe and from worldwide sources of liquefied natural gas (LNG). This is largely down to the decline in production from the UK Continental Shelf (UKCS), but imported gas also provides greater flexibility to help manage the operational challenges of a rapidly-changing gas system.

In recent years, the discovery of new fields has resulted in a short-term increase in UKCS production. However, the challenges of decarbonisation are expected to reduce investment in exploration for new fields. Production from UKCS will therefore decline as existing fields are depleted, but not replaced.

Future availability of shale gas remains highly uncertain. In July 2018, BEIS launched a consultation on including major shale gas projects in the Nationally Significant Infrastructure Project regime. The consultation recognised that the development of onshore gas resources could

reduce UK reliance on imported gas and deliver substantial economic benefits to the UK economy, but relies heavily upon support from local communities. The proportion of people opposed to fracking reached its highest point since first surveyed, increasing from 35 per cent in December 2018 to 40 per cent in March 2019, and only 12 per cent of people support fracking, according to the **BEIS public attitudes tracker (March 2019)**.¹⁹

Whilst production of biomethane is growing rapidly worldwide, significant investment and innovation is still needed for it to become a major source of gas supply in the UK. The Chancellor's 2019 spring statement included new proposals to advance the decarbonisation of gas supplies by increasing the proportion of green gas in the grid, helping to reduce dependence on burning natural gas in homes and businesses. The consultation is expected to consider continued support for biomethane after funding for the Renewable Heat Incentive comes to an end in 2021.

¹⁹ https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/800429/BEIS_Public_Atitudes_Tracker_-_Wave_29_-_key_findings.pdf

Energy supply

Table 5.4

Sources of gas

Indigenous sources

UK Continental Shelf

Production on the UKCS has been declining for several years, but has more recently recovered as new fields were identified and brought into production. New production is dependent on the economic viability of exploring for new fields, future gas demand and prices. Production is expected to start in a number of fields in the next few years.

In **Two Degrees** and **Steady Progression**, we expect a small increase in production into the early 2020s. Production then steadily falls in all scenarios through to 2050, ending by 2044 in **Community Renewables**, and by 2047 in **Consumer Evolution**.

Shale gas

Production of shale gas has progressed this year. The first well has been fracked with steady gas flow rates reported. But there are continuing technical issues and public support is still low. There has been no indication that the overall volume of shale expected to be produced will change.

Consumer Evolution has the highest level of shale out of all the scenarios. **Steady Progression**, has some development in the early 2030s which is not sustained, and production steadily falls out to 2050. Across the scenarios, we assume shale gas will connect to both the distribution and transmission networks.

Biomethane

Biomethane is considered a low-carbon emission fuel because its production involves capturing methane biogases emitted by decomposing organic wastes, which would otherwise be released into the atmosphere. Biomethane can be created by a larger, more industrial process, in which case it is known as bioSNG. Biomethane and bioSNG are collectively referred to as green gas in our scenarios²⁰.

Community Renewables has the greatest level of green gas, reaching over 12 bcm per year by 2050. Growth in the use of biofuels is highly dependent on the availability of suitable types and quantities of feedstock. Current biomethane supplies are mostly connected to the distribution network.

²⁰We do not include biogas that is used for small-scale local electricity generation and not connected to the gas network in our scenarios.

Imported gas

Norway

Norway supplies gas through pipelines to Germany, Belgium, the Netherlands and France as well as to GB. No new large fields have been discovered in Norway this year, and projections of gas production have changed very little since *FES* was published last year. In scenarios with low gas demand in GB, we assume demand is similarly low across Europe and that production in Norway falls in response.

Production in Norway declines in all scenarios as gas demand falls. It reaches very low levels in **Community Renewables** as gas from continental Europe and LNG meet much more variable demand.

Liquefied natural gas (LNG)

Predicting LNG flows in the world market continues to be challenging. Worldwide production is increasing, but supply to UK is highly sensitive to global market costs. For example, supplies of LNG since October 2018 have far exceeded expectations due to unexpected changes in market conditions. In recent years, there has been competition for LNG between European and Asian markets, affected not only by the price of gas, but also by shipping costs.

LNG is a very flexible supply, so in our modelling we have used more LNG in scenarios where demand for gas is expected to be more variable through the year. Highest levels are seen in **Two Degrees** and **Steady Progression**.

Interconnection

The GB gas market is connected to Belgium by the IUK interconnector, and to the Netherlands via the BBL interconnector. Flows across the interconnectors are highly influenced by gas prices. In all our scenarios, we expect gas to be flowing both to and from continental Europe through the IUK and BBL²¹ interconnectors.

As well as including volumes of imported LNG and gas from continental Europe, our scenarios also include a volume of 'generic import'²², which could either be LNG or gas from continental Europe, or a mixture of both.

²¹ BBL Company plan to flows gas both to and from the Netherlands from 2019.

²² This approach has been used for several years, providing ranges for LNG and gas from Continental Europe in each scenario.

Energy supply

Scenario overview

In **Two Degrees** and **Community Renewables**, the factors which help us to meet the 2050 carbon reduction target result in very different gas supply profiles for these scenarios.

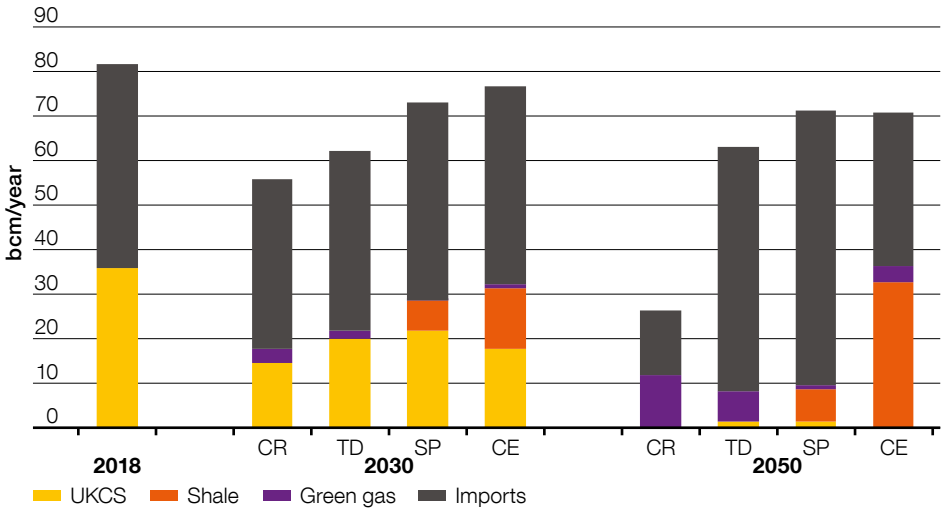
In **Community Renewables**, gas demand is the lowest of all the scenarios by 2050, with a large proportion met by local sources of green gas connected to the distribution network. Import dependency is relatively low.

In **Two Degrees**, total gas demand in 2050 is much the same as today, but gas is used to produce hydrogen as well as electricity with the processes being decarbonised via CCUS. Far more gas is imported from Europe than in **Community Renewables**.

In **Consumer Evolution**, the decline in UKCS production is replaced by shale gas connected to both distribution and transmission networks. However, **Steady Progression** has less shale and higher overall demand for gas, with an increasing reliance on imported gas from Europe and Norway, and worldwide supplies of LNG.

Figure 5.12

Summary of gas supply across all scenarios

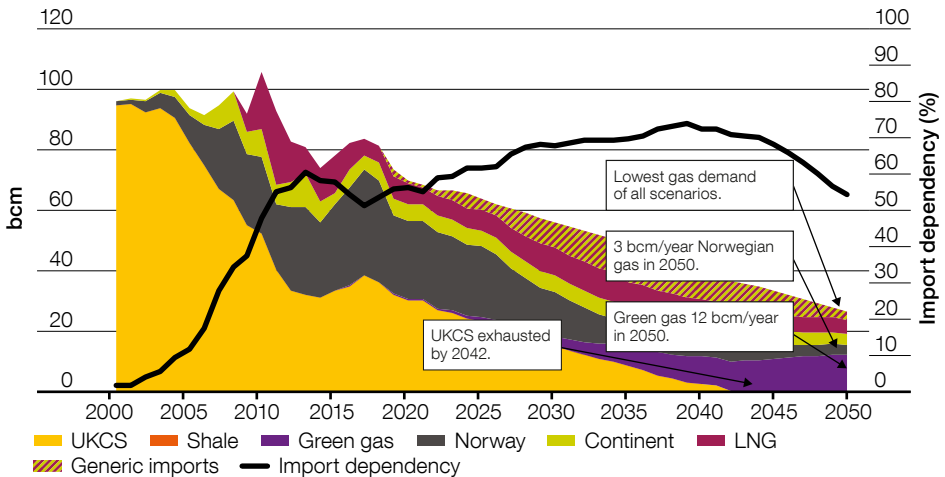


By 2050, **Community Renewables** has the lowest gas demand of all scenarios, as seen in figure 5.13. Natural gas is no longer so heavily relied upon to generate electricity to manage the intermittency of renewables, as greater levels of storage are available in this scenario. Gas boilers are displaced by electric and hybrid heat pumps, biomass combined heat and power is widely used within industrial and commercial processes and overall energy efficiency improves.

Production of green gas begins to grow through the 2030s, reaching 12 bcm per year by 2050 which is 46 per cent of the total gas supply. This includes biomethane production, typically connected to the distribution network in this scenario, as well as supplies from larger scale bioSNG plants. There is limited investment for developing new fields in the UKCS, so supplies are depleted by the early 2040s. Gas from Norway also reduces steadily out to 2050. More flexible supplies of gas are required to meet the remainder of UK demand. In this scenario, this flexibility comes from LNG and imports from continental Europe.

Figure 5.13

Annual gas supply pattern in **Community Renewables**



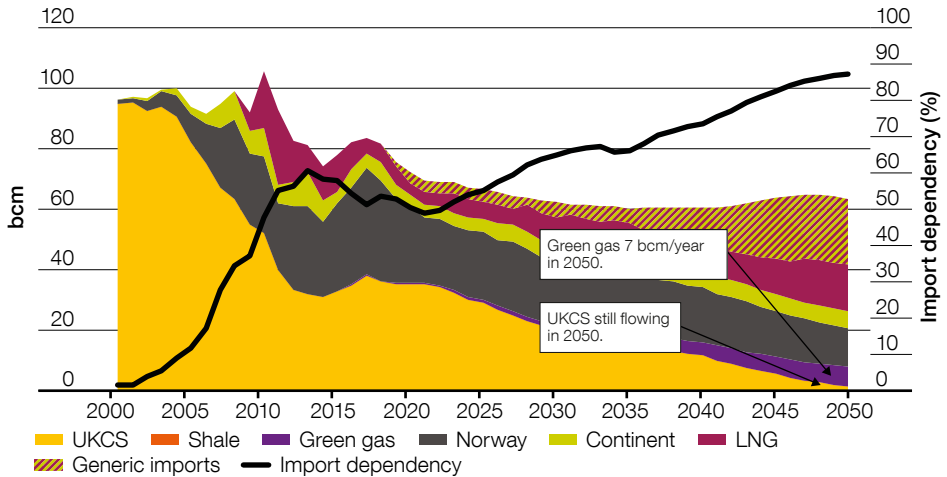
Energy supply

In **Two Degrees**, hydrogen is produced at scale, using natural gas for steam methane reforming (SMR) with CCUS to decarbonise the process. So by 2050, demand for gas is still 63 bcm, see figure 5.14. There is also continued reliance on gas for flexible generation as this process can also be decarbonised via CCUS. The UKCS receives more support than in **Community Renewables**, and so there is still some UKCS production in 2050. Green gas production levels

are lower than in **Community Renewables**; however, a greater proportion of the biomethane is produced via larger scale bioSNG plants in the scenario. Supplies from Norway still make up 20 per cent of total supply in 2050. Norway is assumed to focus on the most cost-effective operations in line with continuing demand. **Two Degrees** has the highest dependency on imported gas, reaching 87.2 per cent by 2050.

Figure 5.14

Annual gas supply pattern in **Two Degrees**

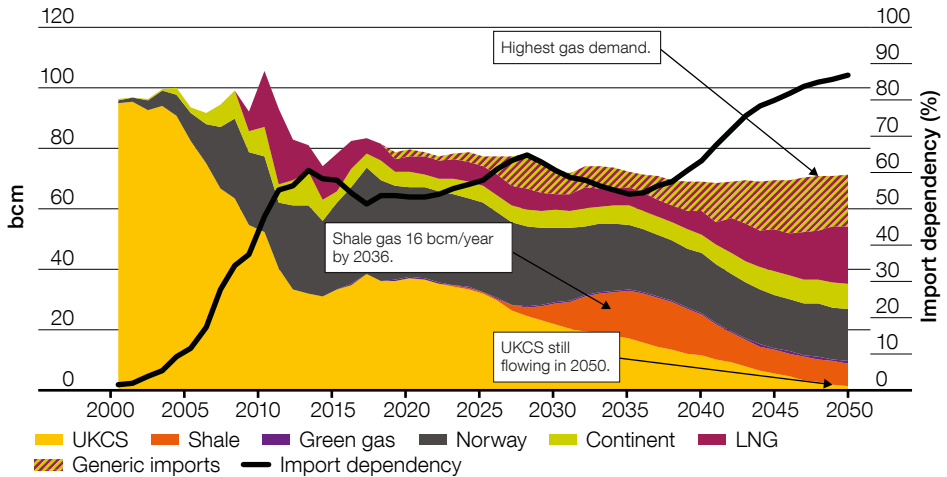


Overall, **Steady Progression** has the highest demand for gas of all the scenarios, see figure 5.15. There is still a significant demand for gas-fired generation, with CCUS used to decarbonise the process.

By 2050, 71 bcm per year of gas is still being supplied to GB, 90 per cent of the 2019 level. The UKCS is still producing around 1 bcm in 2050. Investment in innovation for green gas production is less than in the faster decarbonising scenarios, so we assume minimum growth out to 2050. There is only limited development of shale gas. Import dependency rises to 86.8 per cent by 2050.

Figure 5.15

Annual gas supply pattern in **Steady Progression**



Energy supply

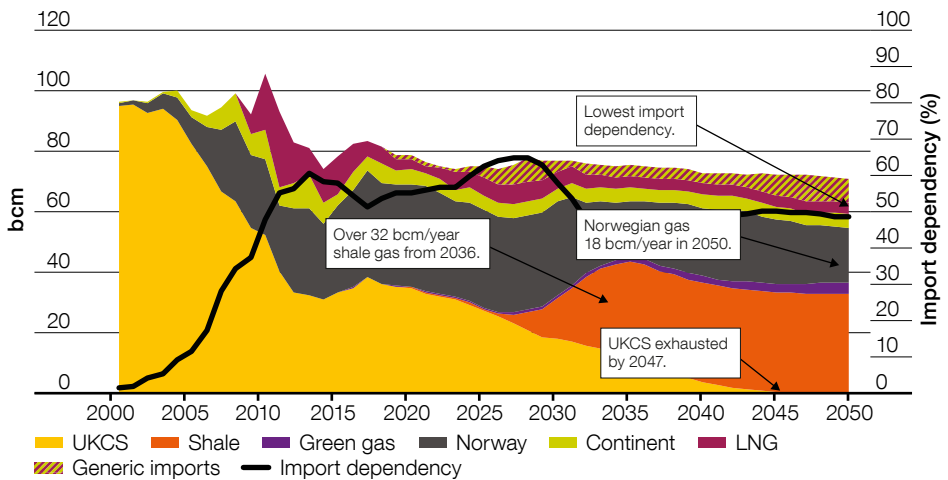
In **Consumer Evolution**, figure 5.16, gas supply is higher than the two 2050 compliant scenarios, but still slightly lower than in **Steady Progression**. This is mainly because of reduced demand as energy efficiency increases in residential, industrial and commercial properties.

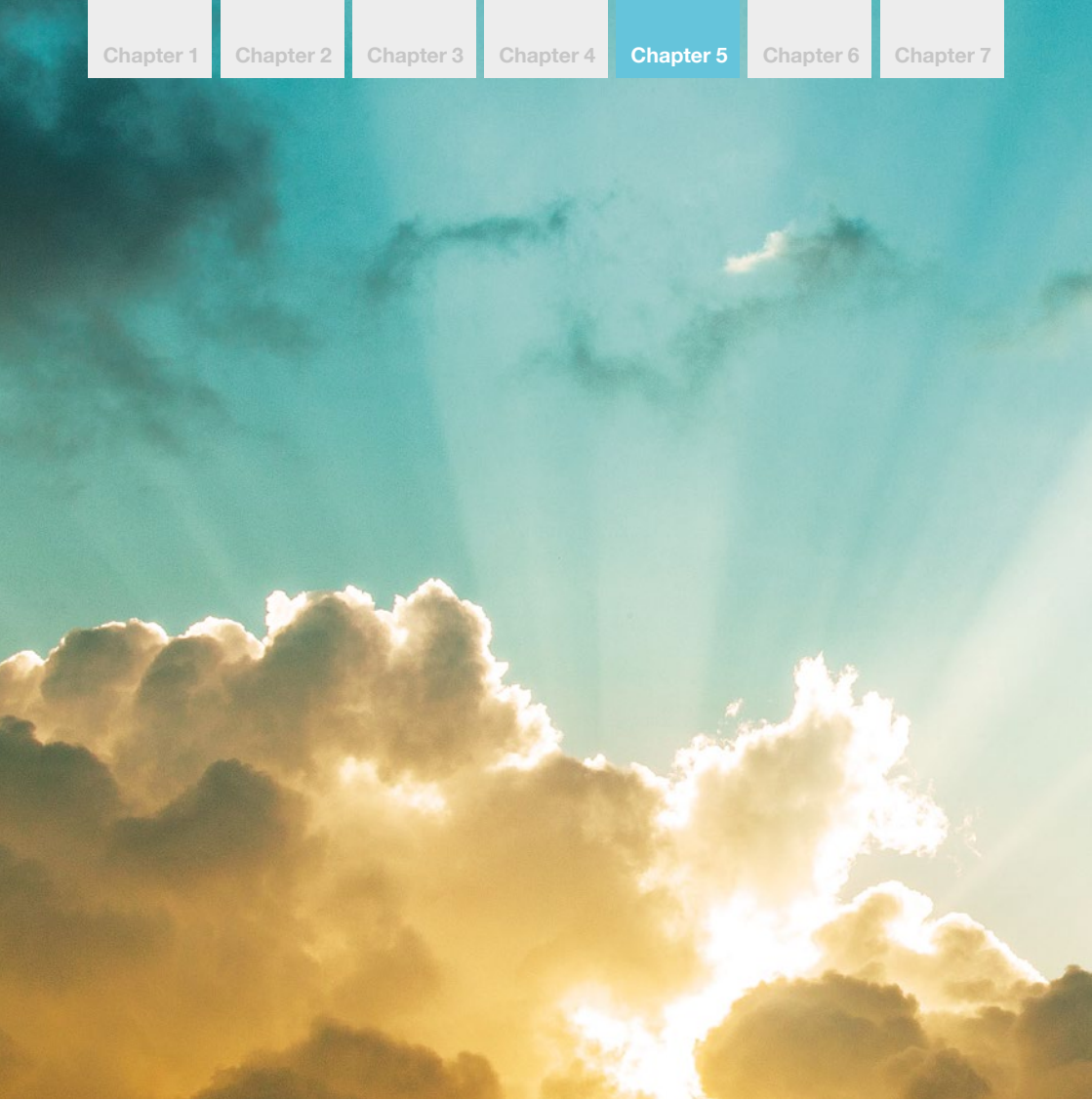
This scenario assumes increasing support for shale gas and includes extensive exploration and production in comparison to the other scenarios. Shale gas will be supplied to both the distribution and transmission networks, with regular

production from around 2026. In comparison, support for UKCS is much lower and supplies are assumed to be depleted by 2047. Although this is not a 2050 compliant scenario there is moderate development of green gas, connected mostly to the distribution network rather than the transmission network. There is still a need for imported gas, and Norwegian supplies reach their highest level in this scenario, being impacted less by market forces. This is the scenario with the lowest import dependency, at 49 per cent in 2050.

Figure 5.16

Annual gas supply pattern in **Consumer Evolution**





Spotlight

Carbon intensity of gases in *FES 2019*

The gas network of the future could carry gas from many different sources. What are these and what does this mean for the carbon intensity of the gas network in the future?

Carbon intensity is a way of examining how much carbon dioxide or carbon dioxide equivalent is emitted in different processes. Table 5.4 explores some examples of the gases that feature in *FES 2019*, and describes their relative carbon intensities in greater detail.

Table 5.5

Carbon intensity of gases in FES 2019

Carbon footprint	Type of gas	Description	Features in
Negative carbon footprint	Biogases created via anaerobic digestion or gasification of organic materials and then reformed with CCUS to create hydrogen.	This process is carbon negative – the organic materials capture carbon as they grow and this carbon is then captured and stored, and not released back into the atmosphere.	No direct use in any scenarios.
Zero or low carbon footprint	Hydrogen created via electrolysis using low-carbon electricity.	May sometimes be referred to as ‘green’ hydrogen. Low or zero carbon as long as the electricity required to create the hydrogen is from a low or zero carbon source (e.g. solar, wind).	All scenarios, highest in Community Renewables .
	Biogases (including biogas, biomethane and bioSNG, also called ‘green gases’) typically created via anaerobic digestion.	Organic materials capture carbon as they grow. When gas created from organic materials is burnt, this carbon is released back into the atmosphere. Therefore, biofuels in general are usually assumed to be close to carbon neutral, but actual footprints can vary widely depending on the type of biomass and processing method used.	All scenarios, highest in Community Renewables .
	Hydrogen created via steam methane reforming using natural gas as an input plus CCUS.	The exact amount of carbon emitted by this process will depend on the efficiency of the SMR process and the amount of carbon captured by CCUS. May sometimes be referred to as ‘blue’ hydrogen.	Highest in Two Degrees , also features in Steady Progression .
Higher carbon footprint	Natural gas	The carbon intensity of natural gas can vary depending on aspects such as inputs and methods of production, as well as carbon accounting method (discussed on page 32). For example, there are additional upstream carbon emissions associated with the liquefaction and transportation of LNG compared to domestically produced gas.	All scenarios

Currently, the European Federation of Local Energy Companies (CEDEC) is leading work with stakeholders to look at naming conventions for gases from different sources, and considering

in particular how to categorise lower carbon and decarbonised gases. This work will be further discussed at the European Commission’s 2019 Madrid Forum in summer 2019.

Chapter 6



Net zero
6.1 Net zero

150
150

Net zero

Spotlight



Net zero technologies
Pg 158



Net zero

6.1 Net zero

This chapter explores some of the background to a net zero emissions target, and summarises the results of our Net Zero sensitivity modelling.

To consider what a net zero emissions goal could look like, we wanted to examine how we could stretch the ambition of our core scenarios to reach this goal. In doing so, we looked at a number of key areas, including improved energy efficiency, consumer behaviour, new technologies and electrification. For each of these, we took our 2050 compliant scenarios as a starting point for analysis, and then further flexed assumptions to achieve net zero.

Other net zero pathways could use these levers in a different way, to give greater or lesser weight to certain aspects, for example attributing

a greater role to new or speculative technologies or to increased electrification. However, it is clear that early action will be necessary across each of these important areas if net zero emissions are to be achieved.

As sensitivity analysis, the focus of our modelling in *FES 2019* has been on reaching the end goal of net zero greenhouse gas emissions. We would like to further develop our work over the coming year with input from stakeholders to consider the transition to net zero in greater depth and use our sensitivity analysis as a catalyst for further debate.

Summary of our Net Zero sensitivity analysis

Reaching net zero greenhouse gas emissions in GB is possible by 2050.

This will require co-ordinated policy changes, alongside technology and infrastructure development and significant behaviour change.

In our **Net Zero** sensitivity, **electrification is greater** than in any core scenario, mainly due to greater electrification of the industrial and commercial sector. Consequently, peak electricity demand is much higher than our core scenarios. There is also **a small increase in the production and use of hydrogen** compared to **Two Degrees**, and hydrogen heating dominates in the residential sector.

Carbon capture, usage and storage (CCUS) technologies are essential in our **Net Zero** sensitivity to enable decarbonisation across several sectors, particularly:

- the widespread production of low-carbon hydrogen in GB
- the use of low-carbon heat for industrial processes
- the use of negative emissions technology to offset carbon emissions for processes that are very difficult to decarbonise.

The role of natural gas fundamentally changes, but it remains crucial to energy supply. It is used only with CCUS, as a key input to hydrogen production and industrial processes, and to generate electricity.

A further key assumption in our modelling is **a substantial improvement in the thermal efficiency of GB buildings.** This means the overall amount of energy needed to heat buildings is reduced.

The remaining residential heating demand can be largely met using hydrogen and electricity. **No natural gas boilers are used to heat homes by 2050.** The widespread roll-out particularly of hydrogen heating and better building efficiency implies an **even more significant infrastructure transformation** (both homes and networks) than that anticipated in our 2050 compliant scenarios.

There is an increase in the use of bioenergy resources compared to the core scenarios. **The majority of available bioenergy is used with CCUS in electricity generation to achieve negative carbon emissions, limiting the use of bioenergy in other sectors.**

Why net zero emissions?

As discussed in chapter three, the UK previously had legally binding targets, via the Climate Change Act, to reduce carbon and associated greenhouse gas emissions by 80 per cent by 2050 compared to 1990 levels. However, in the past 12 months, there has been an increasing focus on a 'net zero' emissions target.

In October 2018, the Intergovernmental Panel on Climate Change (IPCC) released a report noting that a global temperature rise of no more than 1.5°C would prevent 'long lasting and irreversible changes' to the global climate. This is more challenging than the goal of the Climate Change Act, which targets a 'less than 2°C' rise. In order to achieve this lower temperature target, the IPCC report outlines that the world would need to reach a point of 'net zero' greenhouse gas emissions by 2050. This would mean emitting no more greenhouse gases into the atmosphere than those removed.

After the release of the IPCC report in 2018, the Government asked the Committee on Climate Change (CCC) for advice on whether there was a need to review our current 2050 carbon reduction target to consider the achievement of net zero greenhouse gas emissions.

The CCC's report, released on 2 May 2019, concluded that reaching a net zero target in GB is largely achievable with known technologies, alongside changes in people's behaviour. However, new policies would be required as soon as possible to further reduce emissions, and getting to net zero would need 'concerted effort and action by all'. In response to this, at the end of June 2019, the House of Commons and then the House of Lords approved the UK government's proposed net zero legislation, thereby moving the legally binding target to net zero emissions by 2050.

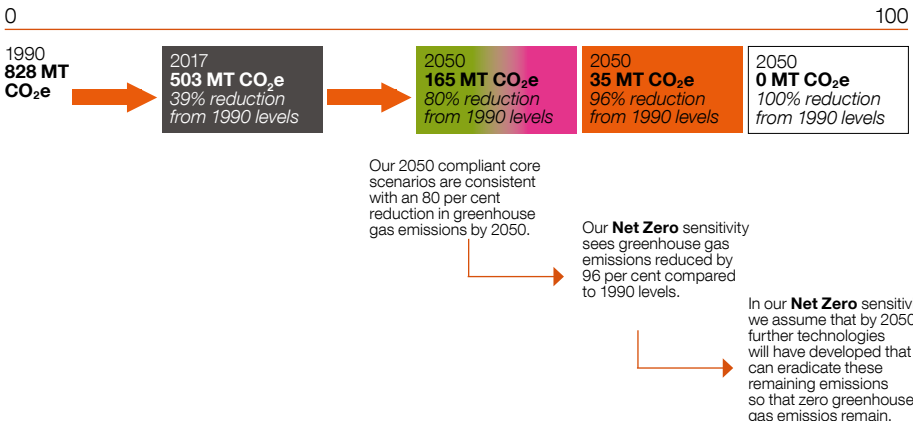
What do we mean by net zero?

Our definition of net zero carbon emissions is that by 2050, there will be close to zero (see below) emissions of all greenhouse gases, expressed in our analysis in terms of each gas's carbon dioxide equivalent.

In line with the approach taken by the CCC, our modelling reduces carbon and other greenhouse gas emissions by 96 per cent compared to 1990 levels using known technologies. Our assumption is that other, as yet commercially unproven, technologies would develop to enable the reduction or removal of remaining residual emissions, potentially alongside widespread behaviour change.

Figure 6.1

Reduction in greenhouse gas emissions (includes emissions from international and domestic aviation and shipping)



Net zero

Net Zero sensitivity

We committed to including a **Net Zero** sensitivity analysis in *FES 2019*, in response to stakeholder requests and to reflect latest climate research.

The following represents our early analysis in this area, which we will refine with relevant stakeholders over the coming year. The focus of our detailed modelling is on areas that impact the electricity and gas systems. However, activity in other sectors can heavily influence greenhouse gas emissions and we will continue to incorporate findings from other areas into our modelling as appropriate. Consistent with our *FES 2019* core scenarios, we consider Great Britain only in our modelling.

Setting the scene

Our initial modelling indicated that it would be very challenging to reach net zero emissions without the use of CCUS. For this reason, we used **Two Degrees** as a starting point for analysis, as this scenario has the highest use of CCUS. We then stretched assumptions and included some features of the **Community Renewables** scenario as well in order to reach net zero emissions.

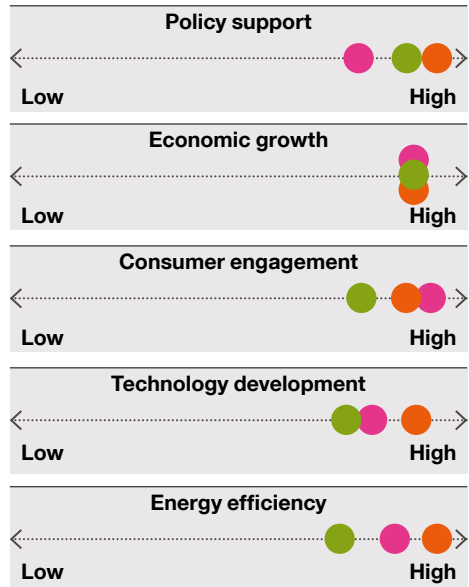
Notably, there is high electrification of the economy, as in **Community Renewables**, but in our **Net Zero** sensitivity this is more prevalent in the industrial and commercial sector rather than in residential heating. In homes, hydrogen is the dominant heating technology.

In line with assumptions for **Community Renewables**, consumers are highly engaged in energy matters, and buy high efficiency appliances.

An important difference is the use of negative emissions technologies. In **Two Degrees**, CCUS is used with natural gas in industry, hydrogen production and electricity generation. This is also the case in our **Net Zero** sensitivity, but in addition, biomass is paired with CCUS to achieve negative carbon emissions in electricity generation.

Key socio-economic assumptions (population growth, economic growth, housing numbers etc.) are the same as the 2050 compliant scenarios.

Net Zero sensitivity



A typical home in our Net Zero sensitivity

In our **Net Zero** sensitivity, a key difference compared to our 2050 compliant scenarios is that we see an even faster improvement in the thermal efficiency of homes, so the amount of energy needed to heat the nation's housing stock falls quickly from the mid 2020s onwards. By 2050, an average¹ home in **Net Zero** uses 36 per cent less energy for heating than a typical home today.

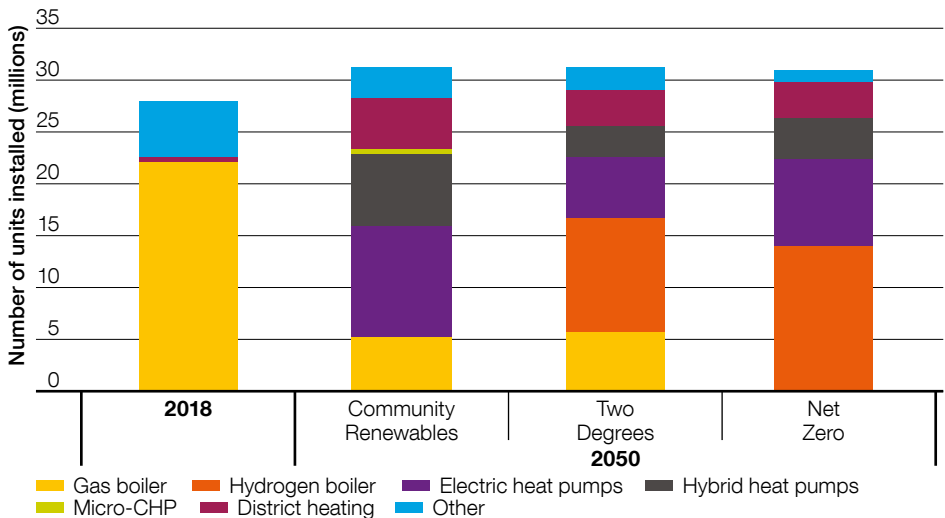
This reduction in each home's heating demand is key, as it means that remaining heat demand can be almost completely met with electricity and hydrogen. In our **Net Zero** sensitivity, installation of hydrogen heating also begins in 2030. Slightly

more hydrogen is used in residential heating compared to **Two Degrees**. However, thanks to the improved efficiency of houses, this small increase in hydrogen is enough to heat a lot more homes, as each requires less energy for heating. By 2050 in our **Net Zero** sensitivity, 13.9 million homes are heated by hydrogen, which is around 3 million more than in **Two Degrees**.

There is also a large roll-out of electric heat pumps in our **Net Zero** sensitivity, but slightly less than in **Community Renewables**. We assume that around a third of these are hybrid heat pumps which, along with new boilers, would need to be hydrogen-ready to leverage replacement cycles. Installing hydrogen-ready boilers could also help in the transition to hydrogen, building the supply chain for hydrogen heating in other homes.

Figure 6.2

Residential heating technologies in **Two Degrees**, **Community Renewables** and **Net Zero**



Taken together, electric and hydrogen heating are able to meet heat demand in the majority of homes in GB. As a result, by 2050 the five to six million gas boilers that remained in the 2050 compliant scenarios have been completely phased

out. It is clear that the infrastructure and transition challenge to decarbonise heating in a **Net Zero** sensitivity is even greater than our 2050 compliant scenarios, and would be significant.

¹ This is an average figure across many different home types, using various heating sources.

6.1 Net zero

A small number of homes in 2050 may be unsuitable for electric heating but also not on a hydrogen network (for example those not currently on a gas network). These could include rural homes such as those that are currently heated by liquefied petroleum gas, stored in an onsite tank. For this small minority of homes, other solutions could be developed, such as biofuels or biomass boilers.

In considering consumer behaviour, we have mainly taken assumptions around consumer engagement from the **Community Renewables** scenario. Consumers are highly engaged in energy matters, and buy only very efficient appliances, due to stringent efficiency standards being in place². The majority of households use smart appliances to shift their electricity demand to times when renewable generation is plentiful. In considering the number of EV owners that take part in smart charging and vehicle-to-grid we have used assumptions from **Two Degrees**.

In line with both the 2050 compliant scenarios, we have assumed 25 per cent of homes have some form of thermal storage. We have also assumed that legislation and technology develop from the mid 2020s so that this heat storage starts to be used to reduce heat demand at peak.

Industrial and commercial energy demand

By 2050 in our **Net Zero** sensitivity, the service sector is completely decarbonised, with more efficient buildings heated entirely by low-carbon sources. Natural gas for heating is mostly replaced by electric heating.

The industrial sector sees an increase in the use of hydrogen and electricity as well, alongside gas paired with CCUS, plus some use of bioenergy,

such as biogas in combined heat and power (CHP) stations. However, there are some industrial processes, for example those involving certain chemical reactions, that are more difficult to decarbonise. As a result, by 2050 the industrial sector still has 10 Mt CO₂e of emissions in our **Net Zero** sensitivity, about 10 per cent of today's levels.

Road transport

Our **Net Zero** sensitivity looks very similar to **Two Degrees** and **Community Renewables** from a road transport point of view, with a large growth in electric vehicles. There is a slight difference when considering heavy goods vehicles, as all of these shift to electric or hydrogen powered engines, in contrast to the 2050 compliant scenarios where some of these are still using natural gas in 2050. As a result there is an increase in the amount of hydrogen used for transport. To accommodate this increase, there is more electrolysis to produce high purity hydrogen for use in vehicles. As in **Community Renewables**, no hydrogen from methane reforming is used for transport.

In our **Net Zero** sensitivity, the Government's ambition to ban the sale of conventional vehicles by 2040 is met, and by 2050, there are no conventional or hybrid vehicles on the road at all (compared to a small number in **Two Degrees** and **Community Renewables**). To support this transition, there is a large-scale roll-out of domestic, workplace and public rapid charging points across GB.

In line with our assumptions for **Two Degrees**, we have assumed that in our **Net Zero** sensitivity the use of public transport increases, and vehicle sharing grows as a result of an increase in the number of autonomous vehicles.

²We assume a 32 per cent improvement in appliance efficiency by 2030, and continued improvement at reduced rates assumed thereafter. This is the same as the appliance efficiency improvements assumed for **Community Renewables**.

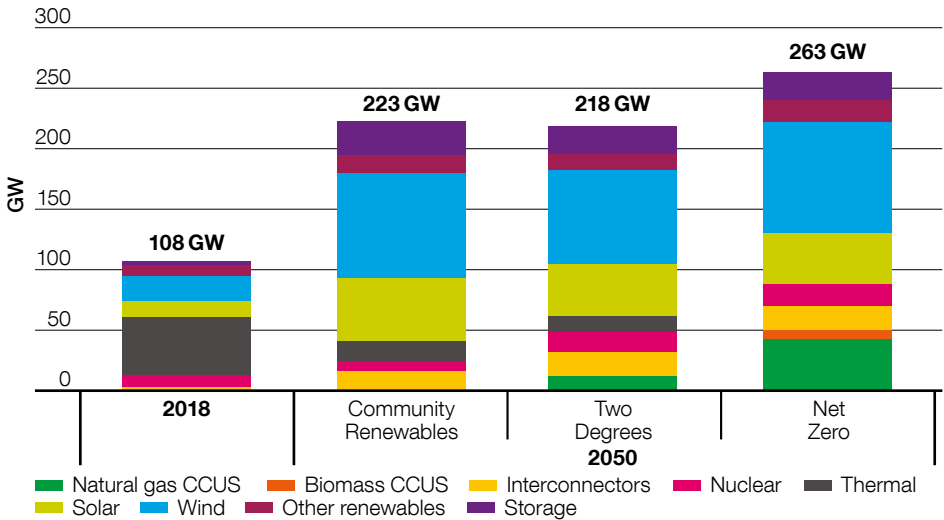
Electricity

In our **Net Zero** sensitivity, annual demand for electricity increases considerably, reaching 491 TWh per year by 2050, higher than the 422 TWh seen in **Two Degrees**. Consequently, approximately 20 per cent more electricity generation capacity needs to be built. Renewables

and gas-fired generation paired with CCUS play a key role helping to meet increased demand. CCUS in electricity generation is paired with biomass (to achieve negative carbon emissions – see below) and also with natural gas. By 2050, 43 TWh of electricity is produced via biomass paired with CCUS each year, and gas-fired generation is only used in conjunction with CCUS.

Figure 6.3

Installed electricity generation capacity: **Community Renewables, Two Degrees and Net Zero** in 2050



In the **Net Zero** sensitivity, increased electrification of the economy increases peak demand for electricity, with this peak gradually increasing to around 115 GW in 2050, almost twice today's level. As in our 2050 compliant scenarios, smart charging, appliances, and vehicle-to-grid play a key role in system flexibility and managing peak demand. Heat storage and smart heating help to shift heat demand away from peak times.

When considering the industrial and commercial sector, we have assumed a higher level of I&C demand side response (DSR) than in the highest core scenario. This is important as the industrial and commercial sectors have a greater level of electrification in our **Net Zero** sensitivity. This increased DSR further helps to manage peak demand.

Net Zero assumptions compared to core scenarios

Smart charging of EVs:

65%
(as Two Degrees)

Smart appliance use is:

c.85%
(as Community Renewables)

Vehicle-to-grid participation:

11%
(as Two Degrees)

I&C DSR:

13GW
(higher than Community Renewables/Two Degrees)

6.1 Net zero

Natural gas and hydrogen

To achieve net zero emissions, by 2050 natural gas is no longer burnt without the use of CCUS, and so natural gas can no longer be used for residential heating³. However, in our **Net Zero** sensitivity, there is an increasing reliance on hydrogen, which can be burnt without the release of carbon. Here, hydrogen is produced using two different methods: electrolysis (using electricity as an input) and via methane reforming with CCUS (using natural gas as an input). You can read more about hydrogen production in our spotlight on **page 100**. We assume that the majority of hydrogen production in our **Net Zero** sensitivity would be via methane reforming as this method has been proven at a large scale and is currently cheaper than other methods of hydrogen production.

The decline in direct use of unabated gas is partially but not completely offset by the use of natural gas:

- as an input for the increasing production of hydrogen, via methane reforming with CCUS
- with CCUS in industry for heating processes
- with CCUS in gas-fired electricity generation.

Consequently, overall annual demand for natural gas slowly drops, reaching 406TWh by 2050, which is around half of today's annual demand.

Alongside this, we have also assumed more electrolysis to produce hydrogen in our **Net Zero** sensitivity (68TWh by 2050, compared to around 40TWh in **Community Renewables** and **Two Degrees**). The high purity hydrogen produced in this way is primarily used in transport.

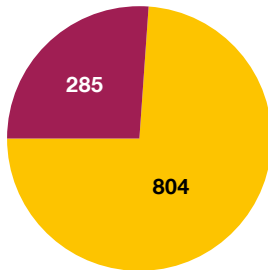
Figure 6.4

Gas and electricity use today, and in **Two Degrees** and **Net Zero** in 2050

Today

<1TWh of hydrogen produced

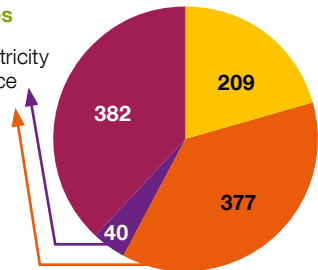
**Total
1,089 TWh**



Two Degrees

Gas and electricity inputs produce 312 TWh of hydrogen

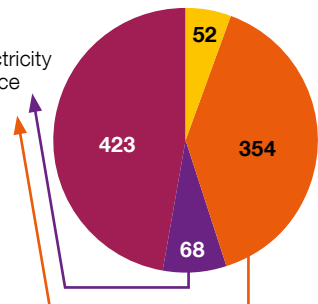
**Total
1,008 TWh**



Net Zero

Gas and electricity inputs produce 324 TWh of hydrogen

**Total
896 TWh**



■ Gas ■ Gas for methane reforming
■ Electricity for electrolysis ■ Electricity

³CCUS is a large-scale technology and so could not be deployed in individual homes.

Use of bioenergy for negative emissions

There are some sectors where it may be very difficult to fully reduce the amount of greenhouse gas emissions to zero for certain processes, for example industrial processes that involve certain chemical reactions. In addition, we assume that technologies such as carbon capture, usage and storage (CCUS) will remove the majority of greenhouse gas emissions, but some residual emissions are likely to remain. So, to reach a net zero position, some removal of greenhouse gases from the atmosphere is likely to be necessary. This could include:

- **natural climate solutions** such as reforestation. Trees absorb carbon dioxide as they grow and so planting a significant number of additional trees helps to reduce the carbon dioxide in the atmosphere
- **negative emissions technologies** – for example, the combination of bioenergy with carbon capture and storage (BECCS). Organic materials capture carbon as they grow, and if this carbon can be captured when the organic material is burnt or processed, then the overall impact on the atmosphere is a removal of carbon.

Negative emissions technologies are explored in further detail in our net zero technologies spotlight on [page 158](#).

In our **Net Zero** sensitivity, negative carbon emissions are achieved through the use of BECCS, used solely in electricity generation. By 2050, 43 TWh of electricity from BECCS is being produced, using 117 TWh of bioresources. The use of this technology means that by 2050, the use of BECCS removes 37 Mt CO₂e from the atmosphere.

As the use of bioenergy is focused on electricity generation, there is less use of bioenergy elsewhere in the economy. This is because the absolute amount of bioenergy available for use in GB is limited by what can be physically grown or imported. The main other use of bioenergy that we have considered is in industry, with around 25 TWh of biogas being used in industrial combined heat and power plants in 2050. Further bioresources are used in aviation and shipping. We also assume, in line with CCC assumptions, increased reforestation and changes in land use which have the effect of reducing emissions in the agricultural sector (captured within the 'other' category).

Table 6.1

Carbon emissions – tracking the journey to **Net Zero**

(Mt CO ₂ equivalent)	2017	Net Zero 2050
Heat for buildings	85	0
Electricity before BECCS	73	0.35
BECCS in power sector	0	-37
Industry	105	10
Road transport	117	0
Hydrogen production	0	3
Other (non energy related)	123	59
Total	503	35
Relative to 1990 Emissions (% reduction)	39%	96%

By 2050, residual emissions in industry, hydrogen production and other sectors are partially offset by negative emissions from BECCS.



Spotlight

Net zero technologies

This spotlight looks at two of the large-scale options to achieve negative greenhouse gas emissions. It also considers other elements relevant to the net zero ambition, including some of the innovative solutions that could offer new, unexplored ways to cut emissions in the future.

Bioenergy with carbon capture and storage (BECCS)

Bioenergy from specially grown feedstocks can be used:

- in place of fossil fuels for electricity generation;
- for hydrogen production; and
- biofuel.

Crops and plants used for feedstocks draw CO₂ from the atmosphere as they grow, so when they are burnt for energy the CO₂ they emit is offset by the CO₂ they have absorbed over their life. Coupling bioenergy with carbon capture technology (see [page 135](#)) to capture the CO₂ produced on combustion means that the process, known as BECCS, is carbon negative. BECCS could be valuable to offset the emissions produced in processes that are harder to decarbonise.

BECCS technology is making progress in the UK with the launch of a programme to capture CO₂ from the combustion of a 100 per cent biomass feedstock to generate electricity. The programme could make Drax power station in Yorkshire the world's first **negative emissions power station**⁴.

The pilot programme is capturing one tonne of CO₂ per day, using innovative technology developed by C-Capture. An organic solvent is used to isolate the carbon dioxide from the flue gases that are released during the combustion of biomass. Data collected during the pilot will be used to understand the potential for scaling up the technology as early as the mid 2020s, as well as storage and re-use of the CO₂.

In our **Net Zero** sensitivity analysis, all negative carbon emissions are achieved through the use of BECCS in electricity generation.

Annual potential carbon emissions savings from BECCS

**Up to 200
MT CO₂e**

If UK became a hub for BECCS, due to the availability of geological CO₂ storage.

**Up to 50
MT CO₂e**

Royal Academy of Engineering Royal Society

**37
MT CO₂e**

FES analysis

Agriculture and feedstock sustainability

Agriculture makes up 10 per cent of UK greenhouse gas emissions, and it's a challenging sector for a net zero emissions target. Exploring the potential of soil carbon storage, reforestation and fertilizer production are all potential areas where carbon emissions reductions could be made.

Agriculture can also take an active role in supporting decarbonisation in other sectors including by the growth of sustainable feedstocks like those required for BECCS, as well as timber for homes. A constant supply of feedstock needs to be sustainable, ethical and balanced with other demands on land use such as food production.



⁴ Drax, Equinor and National Grid Ventures Explore (https://www.drax.com/press_release/world-first-co2-beccs-ccus/)

⁵ Royal Society and Royal Academy of Engineering (2018): Greenhouse Gas Removal (<https://www.raeng.org.uk/publications/reports/greenhouse-gas-removal>).

Direct air capture and storage (DACs)

DACS is technology which captures CO₂ directly from the air using a chemical process. DACS is in the early stages of technology development but is considered feasible to support meeting a net zero target by offsetting CO₂ emissions from any continued fossil fuel use.

Situated in modular units, it has good potential for a fast roll-out. The main challenge with DACS is that it is a highly energy intensive process. Removing 25 Mt of CO₂e is estimated to add 50TWh to electricity demand, although use of waste heat could help to reduce this.

The CO₂ captured by DACS can be used for zero emissions synthetic fuel production or DACS could be combined with carbon capture, usage and storage (CCUS).

DACS is not modelled in our **Net Zero** sensitivity analysis, as it is currently considered to be an immature technology.

CO₂ removal levels with DACS

**25
MT CO₂e
By 2050**

Royal Academy of
Engineering Royal
Society

**1
MT CO₂e
By late 2030s**

annual removal.
Feasibility requires
demonstration at
this level

Opportunities

- Tackles residual emissions.
- Modular units with a small footprint and fast roll-out.

Challenges

- Highly energy intensive process including significant electricity demand increase.

Italy (Climeworks)

A recently commissioned DACS plant in Italy filters up to 150 tonnes of CO₂ from air per year. The new plant is part of a **Horizon 2020 research project**⁶, which demonstrates the technologies that can be used for large volume energy storage. The air-captured CO₂ is used to produce methane as a fuel for natural gas lorries.

Climeworks operates several DACS plant in various countries. Apart from the plant in Italy, it operates a plant with an annual capture capacity of 50 tonnes of CO₂ in Iceland. Here, the CO₂ is dissolved in water and then pumped underground, where it reacts with the local basaltic rock and eventually turns into stone. Thus, the CO₂ is permanently and safely removed from the atmosphere. The largest Climeworks plant to date is located in Hinwil, Zurich, consisting of 18 CO₂ collectors capturing 900 tonnes of CO₂ per year.

Synthetic fuels

Synthetic fuels can be carbon neutral and could be used for aviation. Captured CO₂ from a process like DACS could be used to produce aviation fuel. This does require significant processing but could provide a solution for the challenge of emissions from the aviation sector.



⁶Horizon 2020 research project: STORE&GO (<<https://www.storeandgo.info/>>) (<<https://ec.europa.eu/programmes/horizon2020/en/>>).

Chapter 7



Glossary

Glossary

Word	Acronym	Description
2050 carbon reduction target		To reduce carbon emissions by at least 80 per cent of 1990 levels by 2050.
2050 compliant scenarios		Those scenarios that achieve the 2050 carbon reduction target i.e. Community Renewables and Two Degrees .
2050 non compliant scenarios		Those scenarios that do not achieve the 2050 carbon reduction target i.e. Steady Progression and Consumer Evolution .
Air source heat pump	ASHP	Heat pump which absorbs heat from the outside air. This heat can then be used to produce hot water or space heating.
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 vehicles		A vehicle that is capable of driving without human input.
Autothermal reforming	ATR	A form of methane reforming (converting natural gas into hydrogen) which uses a pure stream of oxygen to drive the reaction and increase the hydrogen production and CO ₂ capture.
Biomass		Plant or animal material used for energy production, heat production or in various industrial processes as a raw material.
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.
BioSNG		Biomethane which is created by larger, more industrial processes.
Blockchain		A non-centralised digital (internet) transaction ledger that is public.
Carbon capture, usage and storage	CCUS	A process by which the CO ₂ produced in the combustion of fossil fuels is captured and 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.
Cap and floor		This is a form of revenue regulation applied to electricity interconnectors in GB. Where interconnector revenue falls within a specified range it can be retained by the interconnector operator. Any revenue over and above the top of this range (cap) is returned to customers and if any revenue is below the bottom of the range (floor) it is supplemented from customers.
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 dioxide	CO ₂	The main greenhouse gas. The vast majority of CO ₂ emissions come from the burning of fossil fuels.
Carbon footprint		The amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organisation or community.
Carbon intensity		A way of examining how CO ₂ is emitted in different processes. Usually expressed as the amount of CO ₂ emitted per km travelled, per unit of heat created or per kWh of electricity produced.
Carbon price floor	CPF	A UK Government policy which sets a target for the minimum price of carbon that is applied to carbon polluters to encourage low-carbon investment. It consists of the EU ETS allowance price and the carbon price support (CPS).
Carbon price support	CPS	The CPS is effectively a carbon tax that tops up the EU ETS allowance prices, as projected by the Government, to the UK carbon price floor target.
Climate change		A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.
Climate Change Act 2008		The Climate Change Act 2008 (c 27) is an Act of the Parliament of the United Kingdom. The act makes it the duty of the Secretary of State to ensure that the net UK carbon account for all six Kyoto greenhouse gases for the year 2050 is at least 80 per cent lower than the 1990 baseline, toward avoiding dangerous climate change.

Word	Acronym	Description
Combined cycle gas turbines	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.
Conventional vehicles		Conventional vehicles use gasoline or diesel to power an internal combustion engine.
Decentralised generation		Electricity generation that is connected to power networks below the high voltage transmission system. Includes distributed generation and onsite generation.
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.
District heating		Using a single shared 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.
Electrolysis		Electrolysis is the process of using electricity to split water into hydrogen and oxygen.
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 32.5 per cent (compared to projections).
EU Emissions Trading Scheme	EU ETS	An EU wide system for trading greenhouse gas emission allowances which effectively sets an EU carbon price. The scheme covers more than 11,000 power stations and industrial plants in 31 countries.
European Union	EU	A political and economic union of 28 member states in Europe.
Five-year forecast		A short-term view of the transition to low-carbon energy.
Flexible generation		Types of generation that can respond quickly to requests to change their output.
Gigawatt	GW	1,000,000,000 watts, a unit of power.
Gigawatt hour	GWh	1,000,000,000 watt hours, a unit of energy.
Great Britain	GB	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
Green gas		In our scenarios this is used to cover both biomethane and bioSNG.
Greenhouse gas	GHG	A gas in the atmosphere that absorbs and emits radiation within the thermal infrared range.
Grid curtailment		This is when the output from a generation unit connected to the electricity system is reduced due to operational balancing.
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 pump which absorbs 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. Can be ground source or air source.
Heavy goods vehicle	HGV	A truck weighing over 3,500 kg.
Hybrid heat pumps		An integrated system using a heat pump alongside a traditional installation such as a gas boiler to provide year-round efficient and flexible heating.

Glossary

Word	Acronym	Description
Hydrogen blending		When hydrogen is injected into the gas network and mixed with natural gas.
Inflexible/less flexible generation		Types of generation that require longer notice periods to change their output or have obligations that influence when they can generate.
Interconnector		Transmission assets that connect the GB market to Europe and allow suppliers to trade electricity or gas between markets.
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 energy market	IEM	The internal energy market (IEM) is a common market for energy across the EU and some additional countries. Members of the IEM aim to develop common or harmonised energy market rules to enable greater energy trading between IEM members.
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.
Load factor		Load factors are an indication of how much a generation plant or technology type has output across the year, expressed as a per centage of maximum possible generation. These are calculated by dividing the total electricity output across the year by the maximum possible generation for each plant or technology type.
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 three 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.
Megawatt	MW	1,000,000 watts, a unit of power.
Megawatt hour	MWh	1,000,000 watt hours, a unit of energy.
Million cubic metres	mcm	A unit of volume, used in the gas industry. 1 mcm = 1,000,000 cubic metres.
Microgeneration		Microgeneration is the small-scale generation of electric power by individuals, small businesses and communities to meet their own needs, as alternatives or supplements to traditional centralised grid-connected power.
Natural gas		A mixture of gases, primarily methane, suitable for transport through gas transmission and distribution networks.
Network Innovation Allowance	NIA	A set allowance each R10 network licensee receives as part of their price control allowance. Its aim is to fund projects directly related to the licensees network that have the potential to deliver financial benefits to consumers.
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.
Paris Agreement		An agreement within the United Nations Framework Convention on Climate Change, dealing with greenhouse gas emissions mitigation, adaptation, and finance, signed in 2016.
Passive demand		In relation to electricity, this is taken to mean demand that does not respond to external factors such as prices or carbon intensity.
Peak demand, electricity		The maximum electricity demand in any one fiscal year. Peak demand typically occurs at around 5:30pm on a weekday 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.
Plug-in hybrid electric vehicle	PHEV	A vehicle which has 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.
Road to Zero strategy		The Road to Zero strategy outlines how government will support the transition to zero emission road transport and reduce emissions from conventional vehicles during the transition.

Word	Acronym	Description
Shale gas		Natural gas that is found in shale rock. It is extracted by injecting water, sand and chemicals into the shale rock to create cracks or fractures so that the shale gas can be extracted.
Small modular reactor		Nuclear reactors, generally 300MW equivalent 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.
Steam methane reforming	SMR	A method for producing hydrogen, ammonia, or other useful products from hydrocarbon fuels such as natural gas.
System Operator		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 ESO operates the electricity transmission system in Scotland, which is owned by Scottish Hydro Electricity Transmission and Scottish Power Transmission.
Terawatt hour	TWh	1,000,000,000,000 watt hours, a unit of energy.
Time of use tariff	TOU	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		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.
UK Clean Growth Strategy		The Government's comprehensive set of policies and proposals that aim to accelerate the pace of clean growth by delivering increased economic growth and decreased emissions.
Unabated generation		Unabated generation is electricity generation where emissions have not been treated to remove carbon dioxide or other pollutants.
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	Enables energy stored in electric vehicles to be fed back into the national electricity network (Grid) to help supply energy at peak times of demand.
Whole energy system		A collective term that is used to cover transmission and distribution systems for both gas and electricity.
Whole system		A collective term that is used to cover all interdependent systems associated with provision of energy, such as transport, water, waste, hydrogen.
Whole gas system		A collective term that is used to cover transmission and distribution systems for gas.
Whole electricity system		A collective term that is used to cover transmission and distribution systems for electricity.

Legal notice

Pursuant to its electricity transmission licence, National Grid Electricity System Operator Limited is the system operator of the national electricity transmission system.

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Write to us at:
Strategic Insights
Electricity System Operator
Faraday House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA





National Grid Electricity System Operator

1-3 Strand
London
WC2N 5EH
United Kingdom

Registered in England and Wales
No. 11014226

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