nationalgrid

Future Energy Scenarios

July 2017

How to use this interactive document

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

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

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

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

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

We are in the midst of an energy revolution.
The economic landscape, developments in technology, evolving business models and consumer behaviour are changing at an unprecedented rate, creating more opportunities than ever for our industry.

Our *Future Energy Scenarios*, along with our other System Operator publications, aims to encourage and inform debate, leading to changes that ensure a secure, sustainable and affordable energy future.

Last year I said that we were in the midst of an energy revolution, and this year it is even more evident. Since last year the political landscape has changed – we have seen the US withdraw from the Paris Accord, a general election in the UK and the continued uncertainty of the UK leaving the European Union. Coupled with this, we are seeing many developments which are disrupting the traditional energy status quo today, such as an ever changing and divergent energy mix. Plus developments in technologies such as electric vehicles, smart devices and consumer behaviour change, to name but a few, which will impact in the future. All of this leads to the requirement for more flexible energy systems.

Against this backdrop it is impossible to forecast a single energy future over the long term. By providing a range of credible futures in the *Future Energy Scenarios*, it allows us to support the development of an energy system that is robust against a range of outcomes. This year we have enhanced our modelling, have richer economic forecasts and have extended the use of our scenarios to 2050. We have also pushed the envelope wider by including a number of possible futures in our sensitivities that test hypotheses beyond our traditional range.

We remain focused on understanding the energy revolution, and this year our publication provides even greater insight than previously. I hope that you find this document, along with our other System Operator publications, useful as a catalyst for wider debate. For more information about all our publications, please see page 9.

Your views, knowledge and insight have shaped this publication, helping us to better understand the future of energy. Thank you for this valuable input over the past year and please continue to share your views with us; you can find details of how to contact us on our website: fes.nationalgrid.com

Marcus Stewart
Head of Energy Insights

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Executive summary

National Grid has an important role to play in leading the debate on the energy revolution across the industry and working with our stakeholders to ensure that we have a safe, secure and reliable energy future.

As System Operator (SO), we are perfectly placed to be an impartial enabler, informer and facilitator. The SO publications that we produce every year are intended to be a catalyst for debate, decision making, and change as well as providing transparency to the wider industry.

The starting point for our SO publications is the *Future Energy Scenarios (FES)*. The *FES* is published every year and involves input from stakeholders across the energy industry. This year we have enhanced our stakeholder engagement activities and we consulted 391 organisations, increasing our engagement from 362 in 2016. The scenarios are based on the energy trilemma (security of supply, sustainability and affordability) and provide credible pathways for the future of energy for Great Britain (GB) out to 2050. It is hard to have missed the significant amount of change on economic, political and technological fronts over the past year.

This year's analysis shows us electric vehicles (EVs) could drive large increases in peak demand if we continue to see the sharp uptake past the 2030s and if there is no management of when charging occurs.

Decarbonising heat remains an area that is difficult to progress and our scenarios cover a range of approaches to heating, from incremental to fundamental changes. There is no one solution for the heating dilemma but in our **Two Degrees** scenario, which meets the 2050 carbon reduction target, the use of gas boilers declines considerably by 2050 and is overtaken by heat pumps, supported by improved house heat retention.

We see an increasing diversity of generation sources becoming available and technology driving growth in the future. Innovation in information communication technology (ICT) is allowing new opportunities to emerge such as residential and commercial energy generation, and smart devices that use and provide data to communicate quicker and easier than ever before.

Our analysis points to some important themes and messages.

Executive summary

Key messages

An energy system with high levels of distributed and renewable generation has become a reality. This growth is set to continue, increasing the complexity of operating a secure and cost effective energy system.

- The total amount of renewable generating capacity was 34 GW in 2016, making up 34 per cent of total installed capacity. In **Two Degrees** this could increase to as much as 110 GW or 60 per cent in 2050.
- In 2016, installed capacity from distributed generation reached 26 GW or 27 per cent of total installed capacity. Looking forward to 2050, this could increase to a total of 93 GW or 50 per cent in **Consumer Power**.
- As traditional sources of energy supply are replaced by new ones, and demand becomes more dynamic, the energy system will be more complex to manage. Responsive balancing products and services will be needed to deliver flexibility across both the electricity and gas systems.

New technologies and evolving business models are rapidly transforming the energy sector. Market and regulatory arrangements need to adapt swiftly to support a flexible energy system with an increasing number of participants.

- There are rapid changes in technologies and approaches such as battery storage, electric vehicles and demand side response. Electricity storage capacity totalled 4 GW in 2016 and this could grow rapidly to almost 6 GW by 2020.
- The energy sector is becoming more diverse with a move away from a small number of large companies, to a wide range of smaller providers and innovators.
- Effective facilitation and investment will be required to achieve an agile, coordinated and accessible energy market that delivers value for consumers.

Electricity demand has the potential to increase significantly and the shape of demand will also change. This is driven initially by electric vehicles and later on by heat demand. It will require a range of solutions to deliver the best value for consumers, including a coordinated approach across the whole system; investment in smart technologies, transmission and distribution infrastructure; and commercial approaches such as consumer behaviour change.

- Electricity peak demand could be as high as 85 GW in 2050, compared to around 60 GW today, driven by a number of factors. Electric vehicles are projected to reach around one million by the early 2020s, and there could be as many as nine million by 2030. Without smart charging, this could result in an additional 8 GW of demand at peak times. Heat pump demand may also add to this.
- If weather patterns continue to change, air conditioning could raise peak demand in summer to a similar level to winter towards the end of the scenario period.
- Away from peak demand periods the increase in distributed generation, in particular solar, could lead to periods of very low demand on the transmission system.

Gas is critical to security of supply now and as Britain continues the transition to a low carbon future. It will have a long-term role as a flexible, reliable and cost-effective energy source favoured by many consumers.

- Gas provides value to consumers and the whole energy system. It supplies more than twice as much energy annually as electricity today and could still provide more energy than electricity in 2050.
- Gas infrastructure is ageing and the demands on it are also changing, requiring a more flexible system. It will need to be maintained or adapted, and it is likely that some upstream entry and further storage facilities will close over the scenario period.
- In order to meet the 2050 carbon reduction target, decarbonisation of heat needs to pick up pace now. Gas will continue to play an important role in this transition and beyond with new technologies and the potential use of hydrogen. It also offers worthwhile carbon reductions in the power sector in the interim.
- Traditional sources of gas are declining. There are plenty of options for providing a continuing supply of gas, from the world market and from novel sources within GB. Some of these may require innovative approaches to connecting and transporting gas.


H2

Chapter one

Introduction

We produce our *Future Energy Scenarios* each year to provide a credible range of energy futures for Great Britain. There are huge technological advances being delivered at an unprecedented rate and this is one of the key drivers in the evolution of our energy landscape. The possibilities are exciting.

The energy landscape has changed and continues to. There is innovation of new consumer technologies, advancements in alternative sources of gas and high levels of distributed generation. Great Britain (GB) needs to ensure it has the systems and capability in place to support this change. The *Future Energy Scenarios (FES)* outline a range of credible pathways for the future of energy out to 2050. The scenarios describe the possible sources of, and demands for, gas and electricity and their implications for consumers and the energy industry. All of our scenarios have considered energy demand and supply on a whole system basis, incorporating gas and electricity across the transmission and distribution systems. We have also not constrained the levels of demand and supply because of network capabilities or operability issues. These are explored further in our network and operability documents.

Our aim is to communicate the reality of each of the scenarios in a clear and concise way. Your feedback is a valuable tool that we use to continually improve the *FES*. You have told us that you use the *FES* in a variety of ways:

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

Our scenarios are used as a basis for a range of further National Grid activities. The *FES* is the starting point for our regulated long-term investment and operability planning as well as a reference point for other National Grid reports. As each of the subsequent processes has its own specific requirements, further detailed analysis is undertaken, building on the *FES*. You can see how these documents link together in figure 1.0.

Figure 1.0
System Operator publications

Nov/Dec 2017
Future Operability Planning
How the changing energy landscape will impact the operability of the gas system.

Nov 2017
Gas Ten Year Statement
How we will plan and operate the gas network, with a ten year view.

Jul 2017
Electricity Capacity Report
Contains recommendations for the capacity to secure for the Capacity Market T–1 and T–4 auctions.

Jul 2017
Future Energy Scenarios
A range of plausible and credible pathways for the future of energy from today out to 2050.

Nov 2017
Electricity Ten Year Statement
The likely future transmission requirements on the electricity system.

Regular
System Operability Framework
How the changing energy landscape will impact the operability of the electricity system.

Jan 2018
Network Options Assessment
The options available to meet reinforcement requirements on the electricity system.

System Needs and Product Strategy
Our view of future electricity system needs and potential improvements to balancing services markets.

Oct 2017
Winter Outlook Report
Our view of the gas and electricity systems for the winter ahead.

Apr 2018
Summer Outlook Report
Our view of the gas and electricity systems for the summer ahead.

May 2018
Winter Review
A comparison between the past winter's actual energy demand and supply and our forecast.

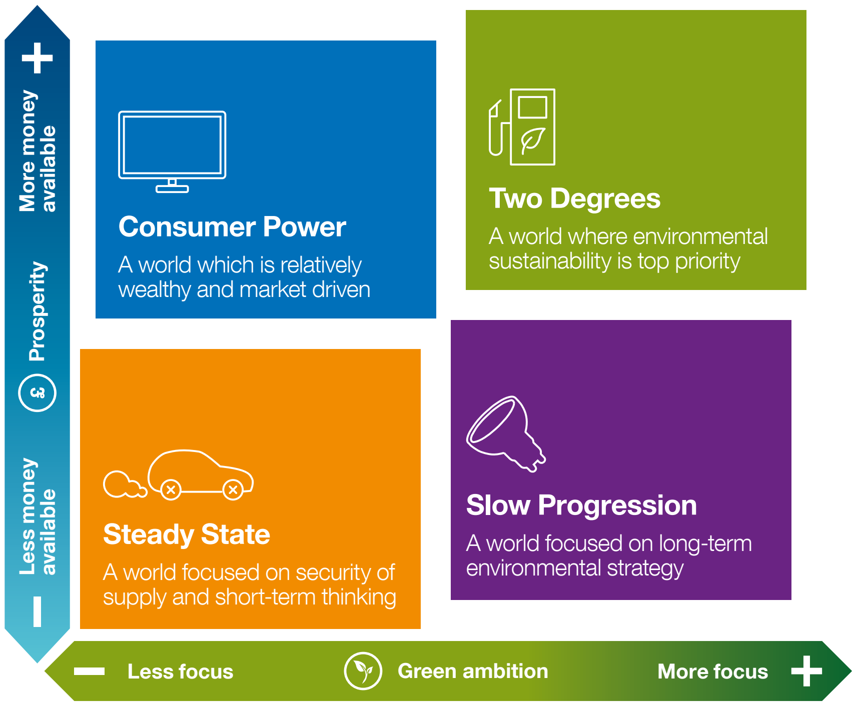
Jun 2018
Winter Consultation
An opportunity to share your views on energy demand and supply for the winter ahead.

Introduction

1.1 The 2017 scenarios

Our 2017 Future Energy Scenarios are **Two Degrees**, **Slow Progression**, **Steady State** and **Consumer Power**. They are an evolution from previous years and have taken into consideration valuable feedback from you, as well as our own analysis. We have continued to use our 2x2 matrix with the axes Prosperity and Green Ambition. Prosperity means the amount of money available in the economy for government expenditure, businesses to invest and consumers to spend. Green Ambition reflects the level at which society and policies engage with becoming environmentally friendly to help reduce our carbon emissions and increase sustainability. This year the relative positioning of the scenarios has changed. This reflects a wider range of economic forecasts and shows greater differences in levels of green ambition.

Figure 1.1
The 2017 scenario matrix



The scenario names **Gone Green** and **No Progression** have been retired. **Gone Green** has substantially changed since we first launched the *FES* in 2011. It has been renamed **Two Degrees** to reflect its focus on all forms of low carbon energy, rather than solely renewables. **Two Degrees** is built to show a cost optimal pathway to meet the UK's 2050 carbon emissions reduction target. The name reflects the ambition of restricting global temperature rise to below two degrees Celsius, above pre-industrial levels, as set out in the Paris Agreement[1]. **No Progression** has been renamed **Steady State** as your comments suggested that **No Progression** implied no movement. **Steady State** represents a world where current levels of progress and innovation continue.

In the next chapter we give a more detailed description of what each of the four scenario worlds look like and explain how they are developed. Throughout the document we will refer to the names of the scenario, however the description of each will not be repeated.

You have previously asked for a broader range of possible futures. This year we have produced a number of cases, which we have called sensitivities, to understand this broader range and the impact these could have on key areas of the energy landscape. These have not been modelled to the same level of detail as our scenarios; this simpler approach allows us to investigate more cases. You can find the sensitivities in Chapter 5.

1.2 EU Referendum

The UK vote to leave the European Union (EU) happened after we completed our analysis for last year's *FES*. For *FES* 2017, we have sought to take account of the potential impact of this decision. It is essential that the UK and the EU put in place the right arrangements, ensuring the best outcome for security of supply, affordable consumer bills and the ability to meet the UK's low carbon emission ambitions. We have dealt with uncertainty around the impact of leaving the EU in our modelling by using a wider range of economic growth forecasts, up from two forecasts in 2016 to four in *FES* 2017. Further consideration on the impacts is given throughout the document.

[1] http://unfccc.int/paris_agreement/items/9485.php

Introduction

1.3 How to use the *FES* document suite

This *FES* publication is just one of a suite of documents we produce as part of our *FES* process. A huge amount of work including modelling, analysis and interpretation goes into the production of the main document. For ease of use we have not included all of that data in the main *FES* document. Alongside it we have the *Scenario Framework* that details all the assumptions and levers that are used as inputs into our models. Our *Charts Workbook* contains all the outputs from the numerous models: the detailed tables, graphs and charts. We also publish information on our *Modelling Methods*, a summary document *FES in 5* and our *FAQs*. For more information and to view each of these documents visit: fes.nationalgrid.com

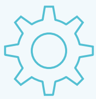
Future Energy Scenarios documents

Future Energy Scenarios

FAQs

Charts Workbook

Modelling Methods



Scenario Framework

FES in 5

Chapter two

Chapter two

Scenario descriptions

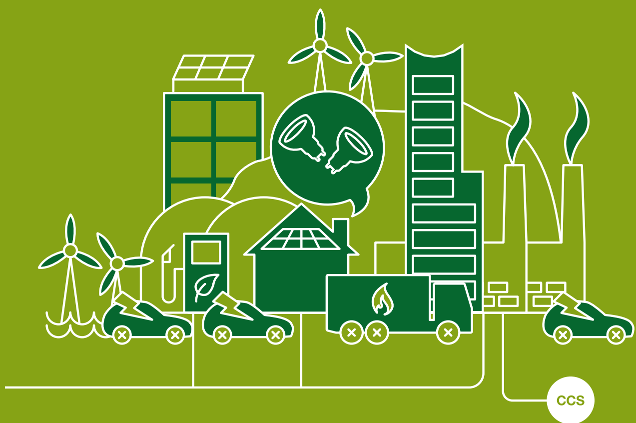
2.1 Two Degrees

Two Degrees has the highest level of prosperity. Increased investment ensures the delivery of high levels of low carbon energy. Consumers make conscious choices to be greener and can afford technology to support it. With highly effective policy interventions in place, this is the only scenario where all UK carbon reduction targets are achieved.

We see the highest economic growth of all the scenarios. There is a collective ambition to decarbonise the economy. High taxes are levied on those who continue to use carbon intensive options, such as conventional gas for heating. Policy and incentives are in place to reduce demand and increase renewable generation. This ensures progression towards the long-term green ambition.

Society is very conscious of its carbon footprint and is actively trying to reduce carbon emissions. Consumer demand for new green technologies is high and they are happy to spend money on home energy management systems, low carbon heating and insulation. There is also a drive to make transport greener.

Technology and investment are focused on low carbon generation, with the highest levels from sources such as solar, wind and nuclear generation. Investment in gas innovation continues as we look to produce more biomethane as well as other green gases.

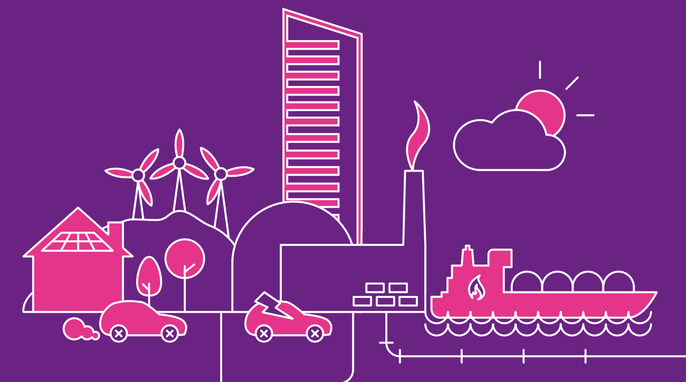


2.2 Slow Progression

In Slow Progression low economic growth and affordability compete with the desire to become greener and decrease carbon emissions. With limited money available, the focus is on cost efficient longer-term environmental policies. Effective policy intervention leads to a mixture of renewable and low carbon technologies and high levels of distributed generation.

Economically, conditions for growth are slow and gas prices rise significantly as a result of additional taxes. With limited money available to spend and invest, there is a focus on cost efficient long-term policies. Progress is made towards a low carbon world as government support and incentives are in place to grow renewable and low carbon technologies. This can be seen by the evolution in distributed generation. Although we see an increase in these technologies the lack of money available reduces the pace of their adoption.

Businesses are more aware of their carbon emissions and are prepared to spend more on low carbon investments than cheaper, less green options. Consumers are more proactive in engaging in an environmentally conscious way of life, but are limited in their choices by having less disposable income. They want to replace boilers and appliances to reduce emissions and be more efficient, but are more concerned with trying to keep costs down in a less prosperous world.



Scenario descriptions

2.3 Steady State

In Steady State business as usual prevails and the focus is on ensuring security of supply at a low cost for consumers. This is the least affluent of the scenarios and the least green. There is little money or appetite for investing in long-term low carbon technologies.

Steady State sees the slowest economic growth and subsequently there is the least investment in the longer-term future.

There is little ambition to move to a low carbon world, with policies that focus on the affordability of energy. No taxes are levied on the use of gas. There is limited intervention to encourage consumers to move towards greener sources of energy, as current technologies are favoured. Electricity prices are relatively low as subsidies for alternate low carbon sources are limited. The emphasis remains on ensuring security of supply at the lowest cost.

Consumers are very cost conscious and try to limit their spending and reduce their bills. With limited disposable incomes they are not tempted to buy expensive heating technologies or the latest gadget. They have no desire to move to a low carbon world.

Innovation continues as it does today. Businesses and consumers take a low risk, short-term value approach.

2.4 Consumer Power

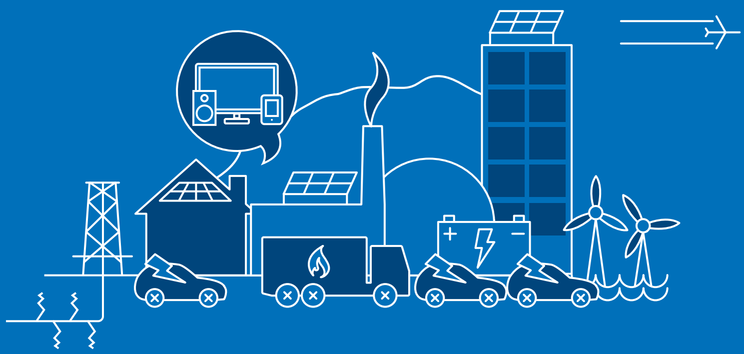
In a Consumer Power world there is high economic growth and more money available to spend. Consumers have little inclination to become environmentally friendly. Their behaviour and appetite for the latest gadgets is what drives innovation and technological advancements. Market-led investments mean spending is focused on sources of smaller generation that produce short- to medium-term financial returns.

Consumer Power has high economic growth, which means that society enjoys high levels of prosperity and has a high disposable income.

Government policies focus on indigenous energy supplies so in this world there is support for North Sea gas and the development of shale gas. Consumers and businesses benefit from low gas prices, it is cheap for them to use and they are not concerned with the cost or environmental impact of retaining high home temperatures.

There are fewer support mechanisms in place for renewable generation. Decisions are made at local levels as there are limited central government interventions and incentives.

Purchases of new and replacement residential appliances are high and, with the advances in technology, most will be smart and more energy efficient. As appliances tend to be larger and more are being bought, the energy savings are cancelled out by consumer demand. There is high uptake of electric and hybrid vehicles as desire increases for new and prestigious products.



Scenario development

Stakeholders are fundamental to the development of our scenarios. With industry specialists and our own expert knowledge, we have produced four core future energy scenarios and pathways for the future of energy. We bring energy to life.

Our scenarios described in the previous section are the foundation of our modelling activities. Each year we vigorously review and evolve them to ensure they are reflective of the changing energy landscape.

The production of our scenarios is part of an annual development process that has three key stages: stakeholder engagement, data and intelligence gathering, and analysis. At each stage we apply our expertise and judgement to ensure we create plausible and credible scenarios. Feedback from our stakeholders, such as industry experts, is an essential part of the development of *FES*. This feedback is one of a number of inputs that inform our analysis, making sure our scenarios are independent, well-informed and up-to-date.

Following engagement with stakeholders we create the scenario framework which includes our assumptions and levers. Each January, we share the details of our scenario worlds and engagement activities with Ofgem in our *Stakeholder Feedback Document*. This is in line with our Electricity Transmission Licence Standard Condition C11. You can find further information and access the 2017 document on our *FES* website: fes.nationalgrid.com

The scenario worlds give an overview of pathways to the future and are the foundation of our analysis. They describe the political, economic, social, technological and environmental (PESTE) landscape and they are placed within the two axes of Prosperity and Green Ambition. We have designed all of our scenarios to ensure security of supply is met.

The next layer of our framework is a more detailed consideration of the PESTE categories which are our assumptions. To each of the assumptions we apply levers that are fed into our models. These levers have a number of settings which vary depending on the scenario.

We then use the assumptions and levers as inputs for our various models. Details of the different modelling methods we use can be found in our *Modelling Methods*. The models produce the scenario outputs for the *FES* publication. The inputs, models and outputs take account of stakeholder feedback and are all subject to internal scrutiny and governance to ensure their credibility and accuracy.

Chapter three

Spotlight

Emerging technologies – energy demand Pg 46

Chapter three

Energy demand

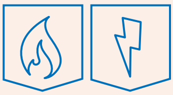
3.1 Energy demand

GB's gas and electricity demand are highly interlinked, with gas currently supplying the highest proportion of the energy delivered. However the balance is shifting and the rate of this change will be governed by green ambition and technological advances.

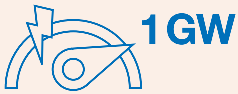
To meet the 2050 carbon reduction target, heating needs to move away from natural gas and use low carbon sources. This change needs to occur rapidly and will mainly result in the electrification of heating. Encouraging different buying habits by millions of consumers will require intervention from the government.

The growth in electric vehicles (EVs) will have a significant impact on demand. If not managed carefully the additional demand will create challenges across all sections of the energy system, particularly at peak times.

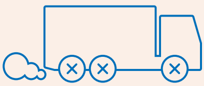
Key insights



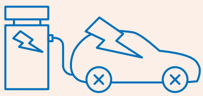
Overall the combined gas and electricity demand will fall in all of our scenarios, driven primarily by the decrease in gas consumption for power generation.



If not managed, peak time electricity demand in a prosperous economy could grow by almost 1 GW per year post 2030.



The cost optimal solution for reducing carbon emissions requires action now for transport and heating.



Technological advancement, such as EVs, will drive up the demand for electricity. However, technology is also a potential enabler for reducing demand, particularly at peak time, by the use of smart applications.

Annual Demand

Annual Demand comprises GB's underlying (end user) gas and electricity demand from residential, industrial and commercial, and transport sectors[1]. It also includes gas used in power stations to generate electricity.

The current usage of gas is 40 per cent for residential heating, 30 per cent for industrial and commercial heating, and 30 per cent for power station demand. If the 2050 targets are to be met in time to decarbonise our economy, heating needs to move away from gas and towards low carbon sources; this move needs to occur rapidly.

As gas demand for heat decreases, electricity demand for heat is expected to grow. At the same time other technological advances, particularly EVs, will further increase electricity demand. These new uses of electricity will need to be carefully managed in order to find a cost optimal, whole system solution for the consumer; particularly at peak time.

Figure 3.1 gives an overview of the overall gas and electricity demand and also the variation from today's values for all the scenarios.

A more detailed description of the various components follows later in this chapter and then Chapter 4 delves in more detail about the reasons for the fluctuations in power station demand.

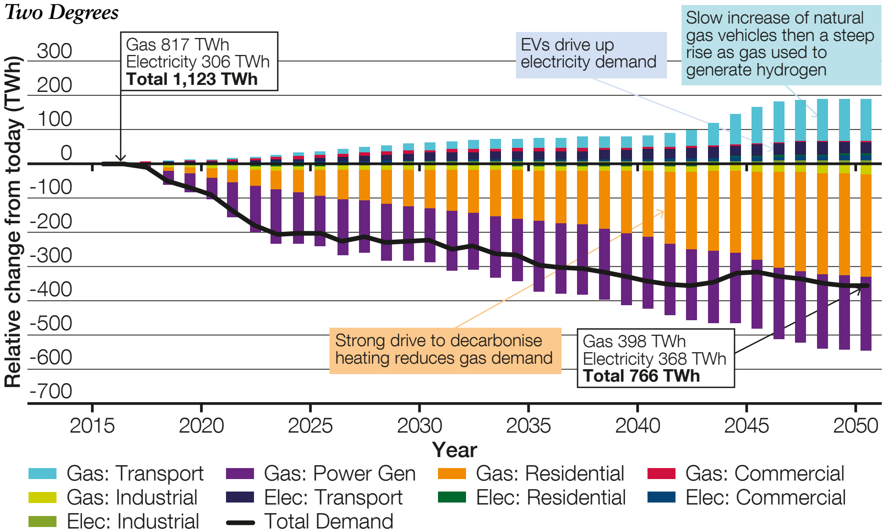
[1] We do not include exports in this demand section but details of Irish and continental exports may be found in the Charts Workbook.

Chapter three

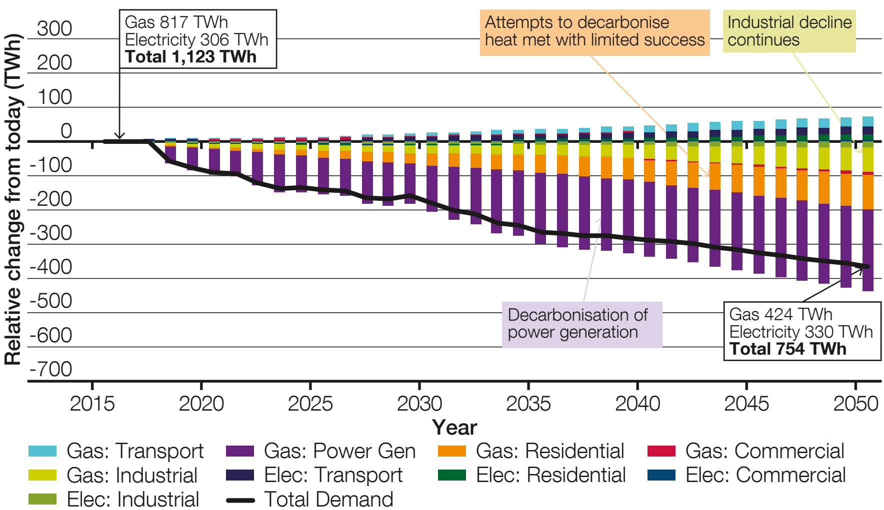
Energy demand

Figure 3.1
Scenarios: Gas and electricity annual demand and sector variation from today; excluding losses

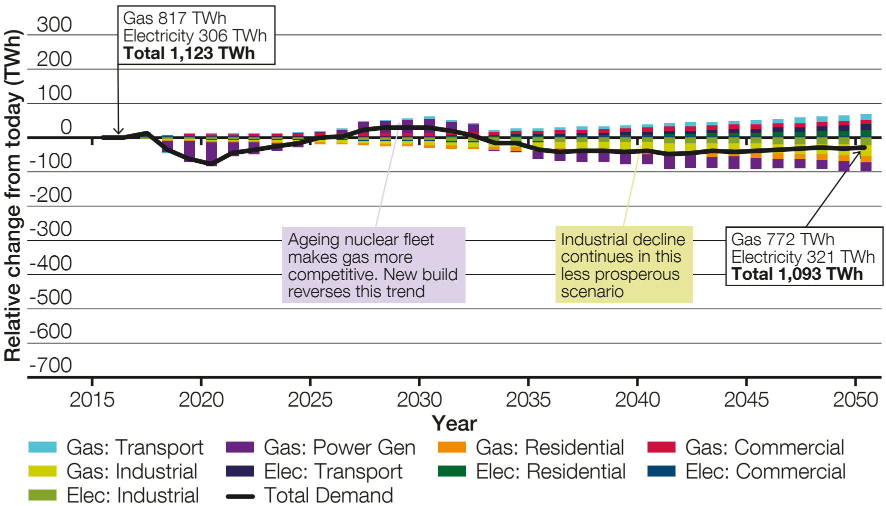
Two Degrees



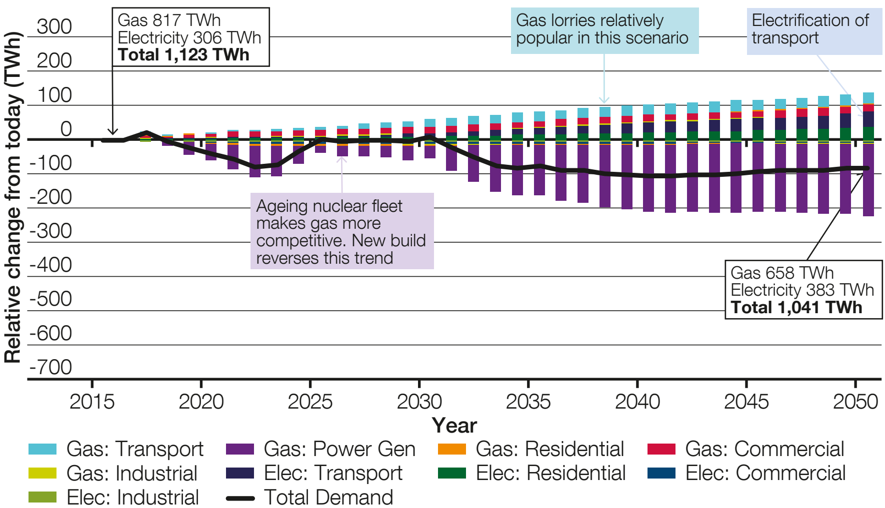
Slow Progression



Steady State



Consumer Power

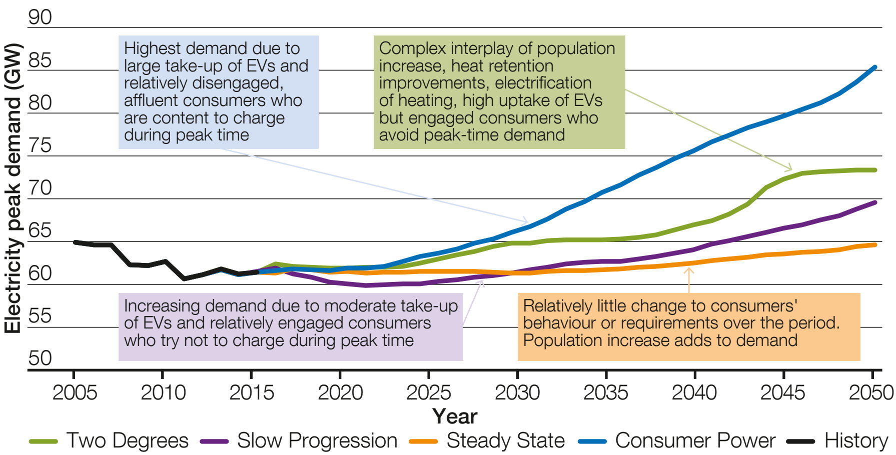


Energy demand

Peak electricity demand

Electricity peak demands are given in Figure 3.2 while peak gas is discussed within the gas supply section.

Figure 3.2
Electricity peak demand



In this year's *FES* our greenest scenario no longer has the highest peak. This has come about due to greater understanding of consumer behaviour change. In **Two Degrees**, consumers are highly engaged and they make use of efficiency gains, time of use tariffs (TOUTs), share EVs that are autonomous, and live in housing stock that is good at retaining heat. This manages what would have been, potentially, a very high peak demand that would not have been cost optimal for the whole system.

Consumer Power sees the most aggressive rise in peak demand. This is brought about by less engaged consumers who use electricity when it suits them. The potential impact that unmanaged mass EV charging, particularly at peak time, could create is significant. In such a scenario, challenges to operating the system, generation and network capability will need to be addressed if we are to have a network that is safe, secure, reliable and economical.

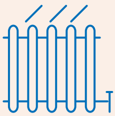
3.2 Industrial and commercial demand

Industry, and in particular heavy industry, continues to shrink and the commercial sector grows over the period. The electricity demand from industry will decline in all scenarios except Two Degrees where decarbonisation of heat will drive up demand for electricity.

In the commercial sector there is a more complex interplay of gas and electricity demand. The sector's growth is matched by an increase in gas demand except in Two Degrees. In this scenario decarbonisation suppresses gas demand and consequently increases electricity demand.

Key insights

Gas demand from industry, for all scenarios, declines over the *FES* period as does its electricity demand, with the exception of **Two Degrees**.



For the carbon reduction target to be met, in a cost optimal manner, space heating needs to be decarbonised, quickly.

Electricity demand from commerce has an initial rise in the short term in all scenarios except for **Consumer Power**. Thereafter all scenarios have a decline until the mid-2020s followed by a steady rise out to 2050.

Gas demand from commerce, for all scenarios, rises relatively steeply out to the mid-2020s; thereafter it slows down in the less green scenarios, or declines in the greener scenarios.

Energy demand

The economic outlook

In this year's *FES* we have used four economic conditions which have differing growth rates of Gross Domestic Product (GDP). We believe that these four economic pathways provide enough flexibility to model the potential consequences of the UK leaving the EU. The average GDP growths over the *FES* period are shown in Table 3.1.

Table 3.1
GDP average annual growth rate for each scenario

	Two Degrees	Slow Progression	Steady State	Consumer Power
Growth	2.1%	1.3%	1.0%	1.8%

Heavy industry generally continues its historical decline while industry with lower energy requirements is generally on the rise. As a result we see industrial growth in **Two Degrees** and **Consumer Power**. In **Slow Progression** it remains static and in **Steady State** it slowly shrinks.

In the commercial sector there is growth in all the scenarios, the degree of which is related to the prosperity of the scenario.

In the greener scenarios retail gas prices are higher than in the less green ones. This is because the government incentivises consumers to switch to a cleaner form of energy by using levies and taxes. This stimulates a move away from gas.

Industrial demand

In the first few years, for all of the scenarios, we see the effects of uncertainty in both gas (Figure 3.3) and electricity (Figure 3.4). This is the result of some postponement of investment in the industrial sector as businesses await clarity on the consequences of the UK leaving the EU.

Figure 3.3
Industrial sector's gas demand

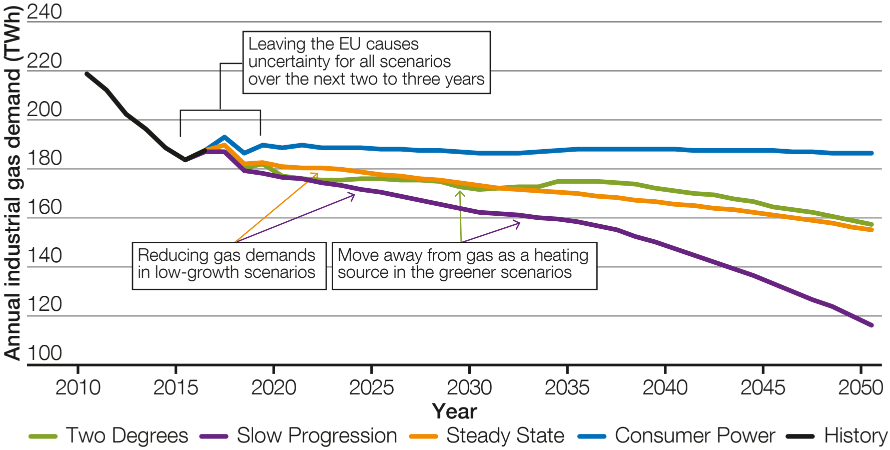
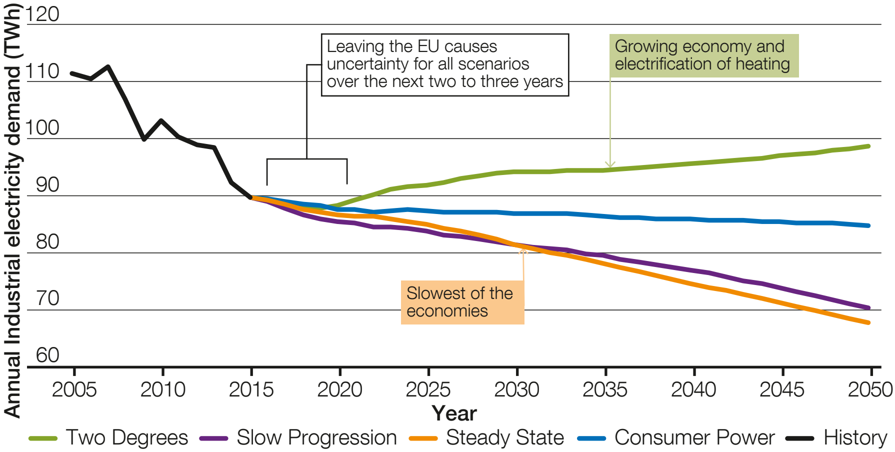


Figure 3.4
Industrial sector's electricity demand



Energy demand

There is more industrial output in the more prosperous scenarios but even so there is a total energy decline over the *FES* period for all the scenarios. Gas use is highest in **Consumer Power**. In **Two Degrees** and **Slow Progression**, the reduction in gas demand is due to the decarbonisation of heating, as described further on in this chapter.

Slow Progression ultimately has the lowest gas demand even though it is not the least prosperous scenario. It dips below **Steady State** because of additional downward pressures caused by higher gas retail prices and a shift towards decarbonisation.

In all but **Two Degrees**, there is a reduction in electricity use by heavy industry. This reduction is not offset by light industry's growth in demand. **Two Degrees** sees an increase in electricity demand due to a growth in industrial output and a move towards the decarbonisation of heating.

Commercial demand

As with the industrial sector we believe that there will be some short-term effects as a result of the uncertainties associated with the UK leaving the EU, but these will smooth out during the mid- to long-term. These effects are less pronounced than in the industrial sector, which is more open to international influences. Over the course of the *FES* period there is a general expansion of the commercial sector.

Gas use in the commercial sector is predominantly for heating and all the scenarios see an initial rise in demand as the sector grows (see Figure 3.5). Gas consumption rises in both the less green scenarios as it is a relatively cheap source of heat and environmental impacts are not a primary concern for consumers. **Two Degrees** sees less gas consumed as incentives drive the use of electricity. The same is true with **Slow Progression** to a lesser extent, both in terms of there being lower levels of incentives and less growth in the sector. Overall it sees the steepest decline in gas use.

Figure 3.5
Commercial sector's gas demand

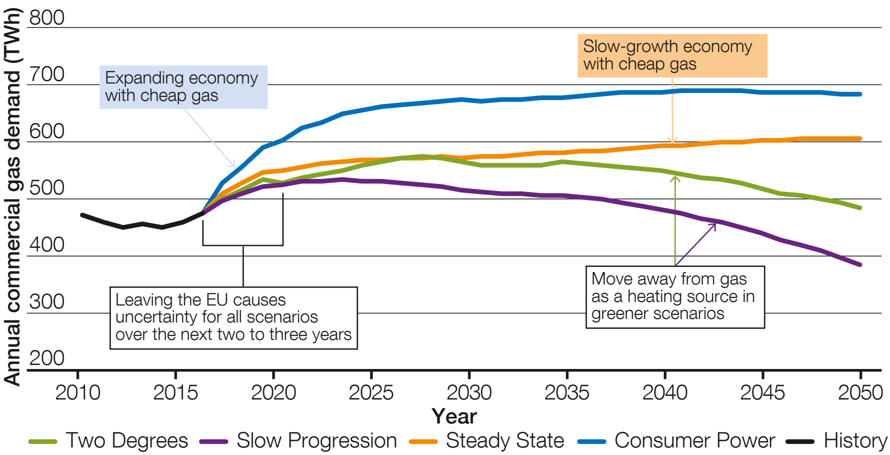
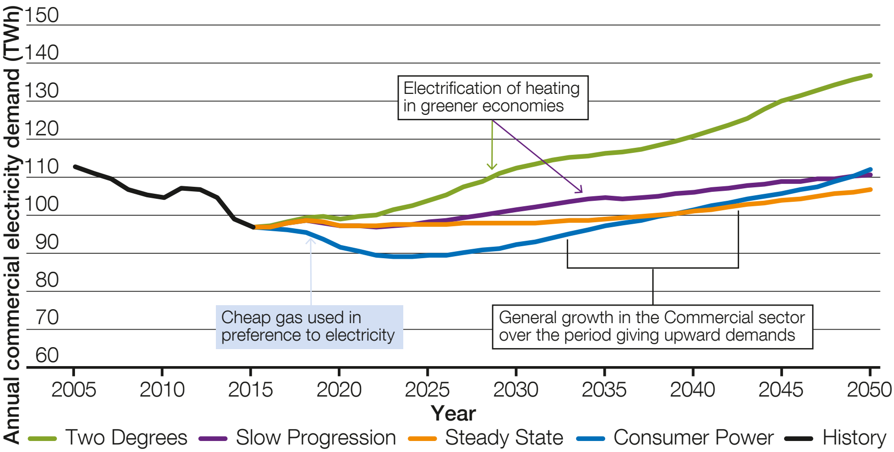


Figure 3.6
Commercial sector's electricity demand



In the less green scenarios of **Consumer Power** and **Steady State**, gas is relatively cheap and so it is not displaced. Its use continues to rise throughout the *FES* period as the commercial sector expands, albeit slowly after the mid-2020s.

Electrical appliances show efficiency gains in all the scenarios and these temper the electricity demand increase brought about by the expansion of the sector. The set of scenario profiles for electricity demands (see Figure 3.6) are almost a mirror image of the gas demand profiles with the exception of **Two Degrees'** relative position. The position of **Two Degrees**, relative to the other scenarios, differs between the two energy sources. Although it has the biggest movement towards the electrification of heating, its gas demand does not fall below **Slow Progression's** as it has the largest sector growth.

Industrial and commercial heating

As we will see in the residential sector, if the 2050 carbon reduction target is to be met in a cost optimal way then space heating must be decarbonised. The sooner this happens, the cheaper it will be for the whole system. If left too late the amount of decarbonisation that will have to be enacted in subsequent years will be more severe and more expensive solutions will have to be employed to play catch-up on missed opportunities. It is a short-term investment for a longer-term gain, which we see as being a cost optimal way of achieving the carbon reduction targets for the entire system. It is only in **Two Degrees** that this target is met. In this scenario air source heat pumps (ASHP) are the preferred early option as they are available. Their rate of growth slows in the late 2020s as gas absorption heat pumps (GAHP) become more competitive with technological advancements. However, ASHP make a comeback in the early 2040s as their efficiencies increase too.

Energy demand

The electrification of heating is almost non-existent in the less green scenarios of **Steady State** and **Consumer Power** as gas is relatively cheap. There is little or no green ambition to drive towards low carbon sources of heating. Other sources of heating, such as gas fired district heating, will play a role in these scenarios.

There are other means of heating, such as gas combined heat and power units (CHP). CHPs are discussed in Chapter 4; details of this and other heating options can be found in the *Charts Workbook* and in the Decarbonised gas sensitivity section.

Demand side response – electricity

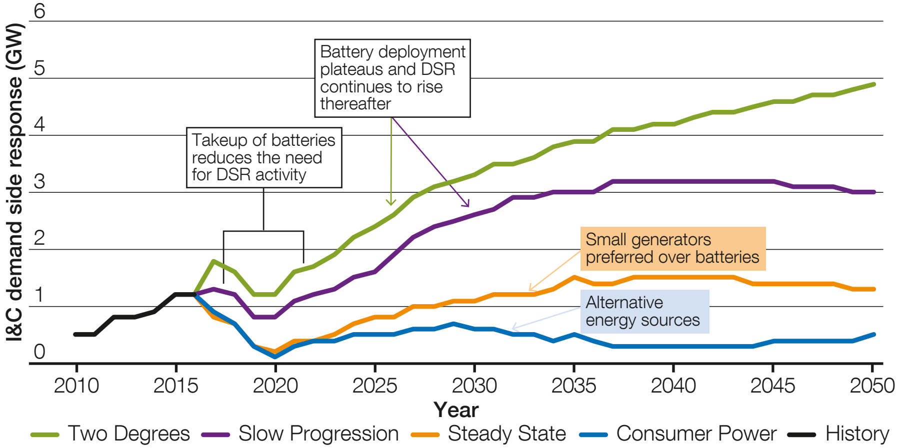
In *FES*, demand side response (DSR) is regarded as the turning down or off of electricity consumption. Generating sources and batteries are not counted as DSR, their growth is outlined in Chapter 4. Therefore *FES* does not consider switching from one source of supply to another as DSR. We take this position as *FES* looks at underlying demand.

We assume three interplaying parts which, if correctly combined, will produce the optimal outcome for businesses to make use of their flexible capability through DSR. These are:

- **income generation from supplying system services:** requirements may increase in the future, however new players may enter the marketplace
- **information communication technology (ICT):** this is a key driver. Businesses, or aggregators, with better access to data can make more informed decisions to reduce their consumption, particularly at peak times
- **savings from reduced system charges:** these can be made by reducing exposure to system charges or avoiding peak time tariffs. In the future smaller businesses, with the aid of aggregators with suitable ICT, could also take advantage of these schemes.

Figure 3.7 shows our projections for DSR in the industrial and commercial sector. The greener scenarios make more use of DSR as there are increased opportunities to make savings. **Consumer Power** sees the least DSR as it relies more on the use of alternative sources of electricity from both storage and small scale generators.

Figure 3.7
Industrial and commercial demand side response



Energy demand

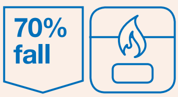
3.3 Residential demand

By 2030 there will be an additional 5 million people living in an extra 2 million homes in GB and by 2050 an additional 9 million people in an extra 4 million homes. Residential demand is a significant part of overall energy consumption and it currently accounts for about 40 per cent of gas and about 35 per cent of electricity demand.

Heat forms the largest proportion of demand in the residential sector but there are a number of other components. As a consequence of the population growth there will be more electrical appliances but they will be more efficient.

These efficiency gains will dampen the effects of the population growth on energy demand to some degree. In **Consumer Power** these gains are overridden by the use of larger appliances that consume more energy.

Key insights



In order to meet the carbon reduction targets at least cost:

- gas boilers will reduce from today's 22 million to 7 million by 2050 and heat pumps will predominate
- the housing stock will be around 40 per cent more efficient at retaining its heat by 2050.

Appliances become more efficient across all the scenarios – this is more prevalent in the greener scenarios as progress is aligned towards European targets.

There are 4 million fuel cells and micro combined heat and power units in Consumer Power by 2050.

Incentives, subsidies or other regulation will be needed to drive the required behaviours if Two Degrees is to be achieved.

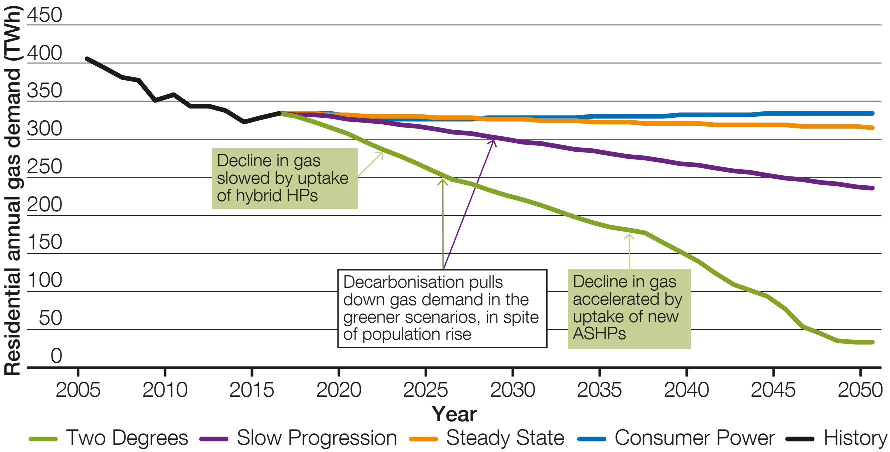
Residential heating demand

Due to the increase in population there is an associated increase in the housing stock. All homes in GB require heating and currently in 80 per cent of homes that heating is derived from gas. Natural gas is not a low carbon fuel and so our dependency on it is reduced in the greener scenarios.

In this year's *FES*, in response to your feedback, we have moved towards more of a whole house approach to our modelling rather than concentrating on just insulation. Now our modelling takes account of this and other thermal retention factors such as double glazing and draught proofing. These changes have resulted in a wider range of outputs (Figure 3.8) than we had last year. For residential gas demand we see a general decline in the greener scenarios and a rise in the less green ones. Cooking accounts for the majority of the rest of gas use and this slowly increases with population numbers.

In this year's *FES* we have improved our modelling and incorporated non-boiler gas heating appliances, which accounts for this year's higher gas annual demand figures.

Figure 3.8
Annual residential gas demand



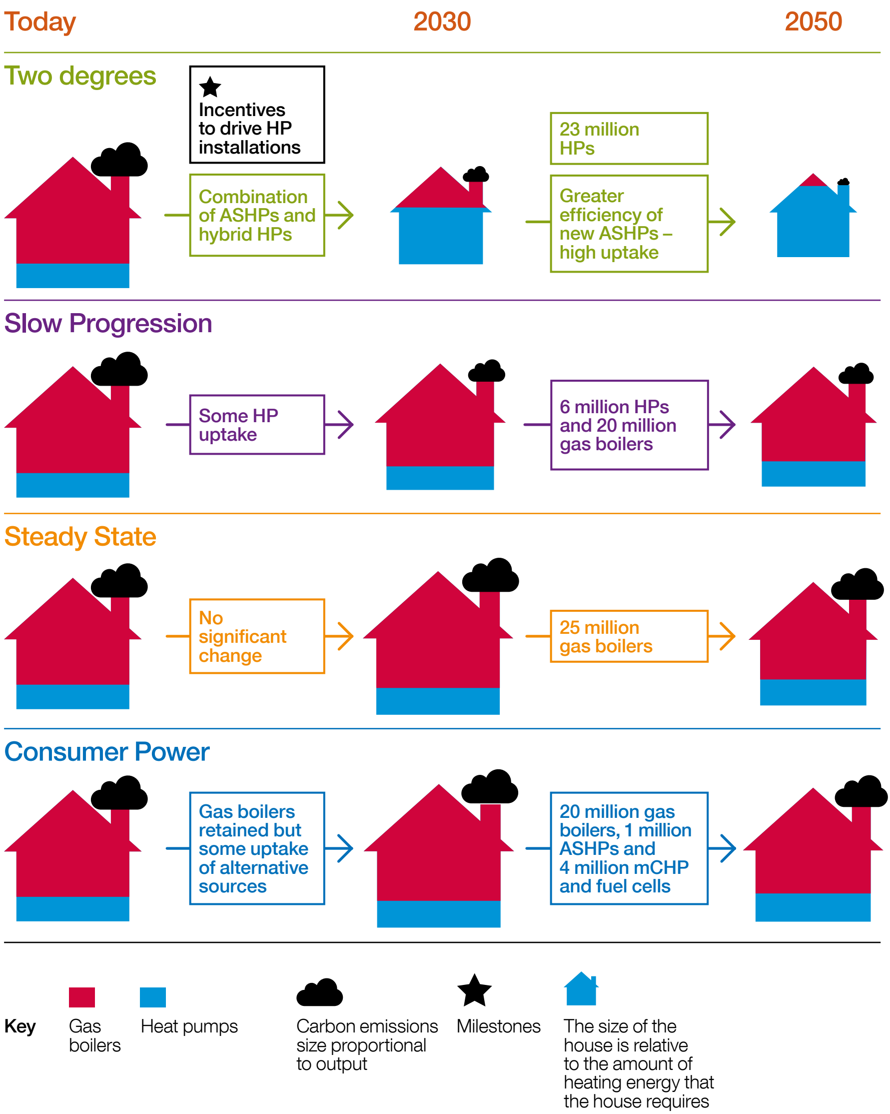
Energy demand

Two Degrees will require the most active involvement by consumers and government. There are a number of elements that need to come together if the carbon reduction target is to be met in the most cost optimal way. Firstly, there is a dramatic improvement in the ability to retain heat that is brought about by factors such as better insulation, double glazing and draught proofing.

Secondly, we see heat pumps (HPs) becoming the main alternative to gas boilers. Residential HPs come in a variety of forms but the more common types are; air source heat pumps (ASHPs), ground source heat pumps (GSHPs) and hybrid heat pumps.

In last year's *FES* there was an emphasis on decarbonising heat mainly through the growth of ASHPs. We have reassessed this assumption in order to minimise the impact across the entire electricity network system. Figure 3.9 illustrates our view of the heating elements for each scenario.

Figure 3.9
Residential heating



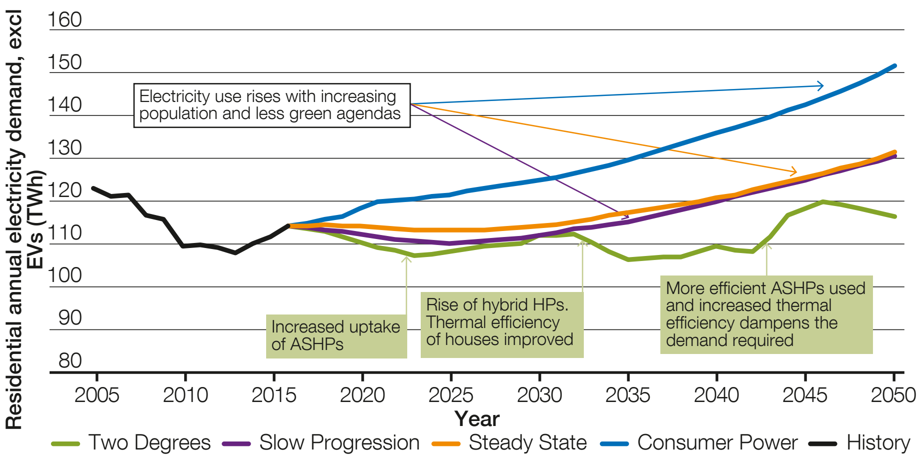
Energy demand

In **Two Degrees** the first HPs to be adopted are mainly ASHPs with some GSHPs because they are a known technology for consumers. In the mid-2020s, there is an increase in the use of hybrid HPs as they become more technologically advanced. Consumers accept hybrid HPs as they have the ability to rapidly inject heat into homes and heat water when required. We regard them as a stepping stone to the full decarbonisation of heating. After 2040, hybrid HPs are superseded by improved ASHPs that are more efficient and cheaper. Homes also benefit from much better heat retention.

Replacing gas boilers with HPs shifts demand from gas to electricity, though the effect is less pronounced in hybrid HPs. HPs' effect on electricity demand in **Two Degrees** is significant, and the influences of different HPs can be clearly seen on the overall annual demand profiles (see Figure 3.10).

Other means of heating are used, such as district heating and solar thermal heating, but these are often site-specific and not every location will be able to benefit from them. These have been modelled and the outputs may be viewed in the Charts Workbook.

Figure 3.10
Annual residential electricity demand



In order for **Two Degrees** to achieve the carbon reduction targets, there will need to be high levels of thermal retention in homes and growth in HPs. For this to happen incentives will be needed to; make homes more thermally efficient, quickly retire gas boilers and encourage the adoption of HPs.

Lagging behind **Two Degrees** is **Slow Progression** which has less money to spend on things such as home insulation and replacement of heating sources. However, HPs are still evident in this scenario and by 2030 there are one million hybrid HPs and one million ASHPs.

Steady State has the least money to insulate houses and invest in new technology. Also, as gas is relatively cheap, gas boilers remain the dominant heating source.

In **Consumer Power** insulation is less of a priority as consumers can afford to heat colder houses. Gas is relatively cheap and gas boilers remain the dominant heating source. However, in this world there is more adoption of other technologies such as micro-combined heat and power sources (mCHP) and fuel cells, of which there are over two million of each. These alternative heating sources are adopted more in this wealthy and consumer centric scenario.

Electrical appliances' demand

Currently, appliances and lighting account for 75 per cent of the residential electricity's annual demand. With the increase in population and households there is a growth in the total number of appliances but by how much and what type depends on the scenario.

In all our scenarios there are efficiency gains but these gains are more prevalent in **Two Degrees** and **Slow Progression**. However, since last year's *FES* the EU's aspiration to have in place a ban on class C halogen light bulbs, by the end of 2016, has not happened.

We have taken account of this change in our modelling and it has resulted in increased demand from light bulbs in all the scenarios.

In **Two Degrees** the level of green ambition means that the UK makes about 30 per cent efficiency saving by 2030. This would be in line with European targets[2]. It is a stretching target and some level of government intervention is required to ensure it is met. Being the most prosperous of our scenarios the number of appliances per household grows faster than recent historical rates. However, their demand is generally offset by their efficiency gains. For a more detailed breakdown of individual appliance groupings please go to the *Charts Workbook*.

In **Slow Progression** the appliances' efficiency savings are not as great as in **Two Degrees**, but efficiency still improves faster than today. The number of appliances per person is much the same as today but the population is growing. The overall effect is a gentle increase in appliance demand for electricity throughout the *FES* period.

Steady State has the same improvement rate of efficiency saving that we see today, but it has the weakest of the economies so the growth in appliances per person is less than in recent times. However, the population growth keeps appliance demand on the increase out to 2050.

In **Consumer Power**, consumers can afford more and larger appliances per person. When combined with population growth it gives the steepest increase in appliances' electricity demand of all the scenarios. This increase has been slightly suppressed by efficiency gains.

[2] http://ec.europa.eu/clima/policies/strategies/2030/index_en.htm

Energy demand

An appliance that makes a significant entrance in **Consumer Power** is the air-conditioner. In this prosperous world air-conditioners could be more readily adopted. Although their annual demand will be relatively low it is their peak day demands that will require attention. The additional demand from air conditioning could be as much as 17 GW by 2050 on very warm days. This demand is within the generation capacity of the system and will still be less than its winter peak. Demands will rise rapidly in the afternoon, which will require a steep ramp up of generation; this may coincide with output from solar generation falling. This is discussed in the operability spotlight. Further, the summer is traditionally a low demand period used for maintenance of generation and network assets; rising summer demand may create new complexities for maintenance schedules.

Consumer flexibility

We have applied the market segmentation characteristics for consumers, as used by Ofgem in its retail market review survey[3], as a measure of consumer engagement. The segments are 'Unplugged', 'On standby', 'Tuned in' and 'Switched on'. These have shown a trend in consumer engagement that we have continued. Then we applied the four categories' outcomes, to varying degrees, to our scenarios. We believe there are three other factors which must work in tandem to give the most flexibility at the lowest cost to consumers. These are smart meters, smart technology and smart pricing.

Smart meters only have a short-lived behavioural impact by themselves. Their impact is enhanced where they are supported by appropriate marketing and education around energy use. We see this happening more in the greener scenarios. The rollout of smart meters (see Figure 3.11) has a bearing on when their effect is felt. The Department for Business, Energy and Industrial Strategy's (BEIS) rollout programme is only met on time in **Two Degrees** and then only with strong support from all sectors of the energy industry.

Smart technologies flourish more in the prosperous scenarios. By smarter technologies we mean appliances that have two-way communication capability and interact with the consumer and other parties; for instance Hive or Nest. As the technology improves service providers such as aggregators have a greater role to play.

Finally, smart pricing is the appropriate use of time of use tariffs (TOUTs). TOUTs incentivise consumers to move those energy demanding activities, which can be moved, to off peak times. The more engaged consumers, energy suppliers and government are, then the greater the effects of TOUTs.

Some homes, and particularly those in the greener scenarios, start to install storage in order to reduce their peak time demand. Thermal storage units, which are similar to hot water tanks in size, allow consumers not to run their HPs at peak time. By 2050, in **Two Degrees**, 25 per cent of homes have thermal storage units.

The effect of these factors upon the scenarios' residential peak demand is given in Figure 3.12.

[3] https://www.ofgem.gov.uk/system/files/docs/2016/08/consumer_engagement_in_the_energy_market_since_the_retail_market_review_-_2016_survey_findings.pdf

Figure 3.11
Rollout of electricity smart meters, installations per year

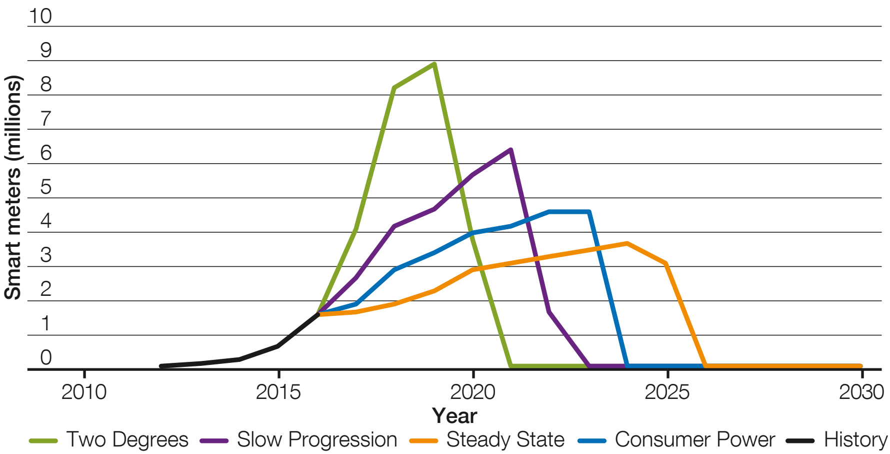
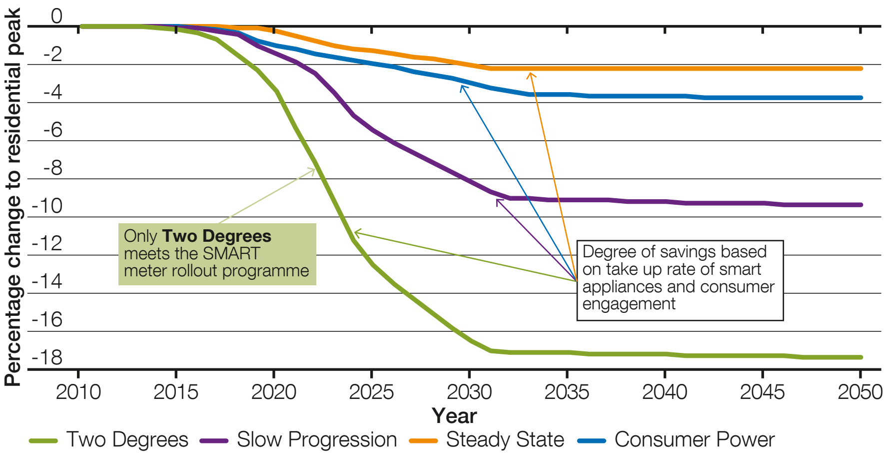


Figure 3.12
Smart appliance and TOUT effects on the residential peak demand



Energy demand

3.4 Transport demand

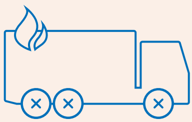
In all the scenarios but Steady State we see a dramatic rise in electric vehicles (EVs) with sales being more than 90 per cent of all cars by 2050. As their numbers increase, their peak time electricity demand could offer the most challenges. In a Consumer Power world EVs create an additional demand of 18 GW by 2050.

This is equivalent to an additional 30 per cent on top of today's peak demand. In **Two Degrees** there are two million more EVs than in **Consumer Power** by 2050, but through better use of smart technology, engaged consumers and use of vehicles with a lower energy demand, the additional peak demand is reduced to 6 GW.

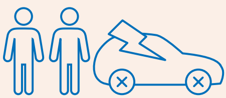
Similarly, natural gas heavy goods vehicles sales become more prevalent in the more prosperous economies of **Two Degrees** and **Consumer Power**. Here they achieve levels of around 200,000 by the early 2040s, compared to over seven hundred vehicles on the road today. This will represent about a third of the total heavy goods vehicle fleet.

Key insights

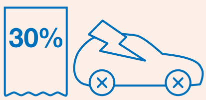
Consumer engagement is the highest in **Two Degrees.** Without this consumer engagement, this could result in an additional 8 GW of demand from EVs at peak times.



Two Degrees and **Consumer Power** see the most natural gas heavy goods vehicles used. Their demands are in the low 20 TWh in 2030 and in the mid-30 TWh in 2050.



Shared autonomous vehicles make up 50 per cent of EVs in **Two Degrees** and 5 per cent in **Consumer Power in 2050.**



Lowest growth is seen in **Steady State** where EVs only achieve 30 per cent of sales by 2050.

Electric Vehicles

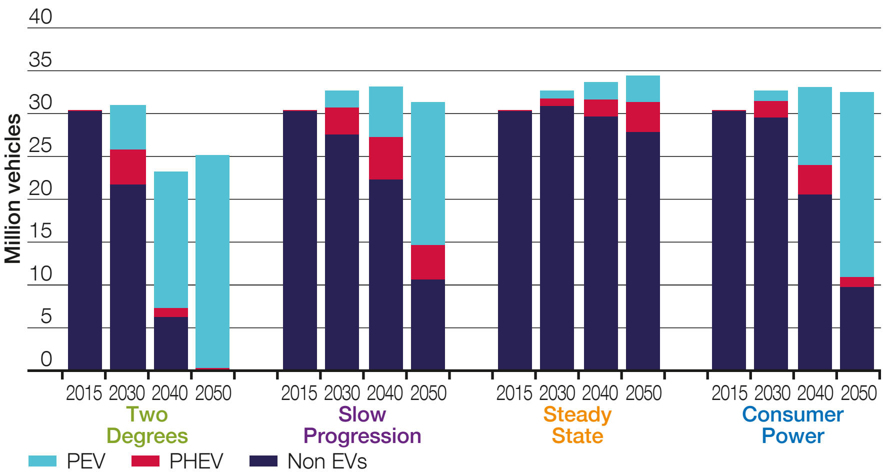
The context
In this section EVs refers specifically to plug-in electric cars. Plug-in EVs are categorised into two types in our analysis: Pure EVs (PEVs), those which are 100 per cent electric powered, and Plug-In Hybrid EVs (PHEVs), which combine an internal combustion engine (ICE) and an electric motor. PHEVs are less efficient than PEVs and also emit carbon due to their dual engines. Consequently they tend to be phased out in favour of the PEVs in the long term.

We assume technology will permit the introduction and growth of autonomous vehicles. An autonomous vehicle is one that is capable of driving without human input. These vehicles will more easily allow consumers the option of sharing journeys. How many are shared will depend on the scenario; the more green society is, the more it will embrace sharing. Sharing reduces the mileage a car travels per person as more than one person is picked up and dropped off in a single car journey. It is envisaged that shared autonomous vehicles will be centrally garaged and that the mileage per vehicle will be greater than today.

Exactly how the growth of EVs will be distributed through the country is not fully understood. It is likely that hotspots and clusters will develop. These will be in cities and urban settings where there are shorter commutes, more infrastructure developments, a greater prevalence of clean air zones and richer consumers.

In all our scenarios EV numbers will grow and so will the infrastructure needed to support them.

Figure 3.13
The growth of EVs



Energy demand

The growth of electric vehicles

The growth in EVs (see Figure 3.13) is fuelled primarily by advances in technology, such as battery capabilities and cost reductions, making them a viable alternative to ICEs.

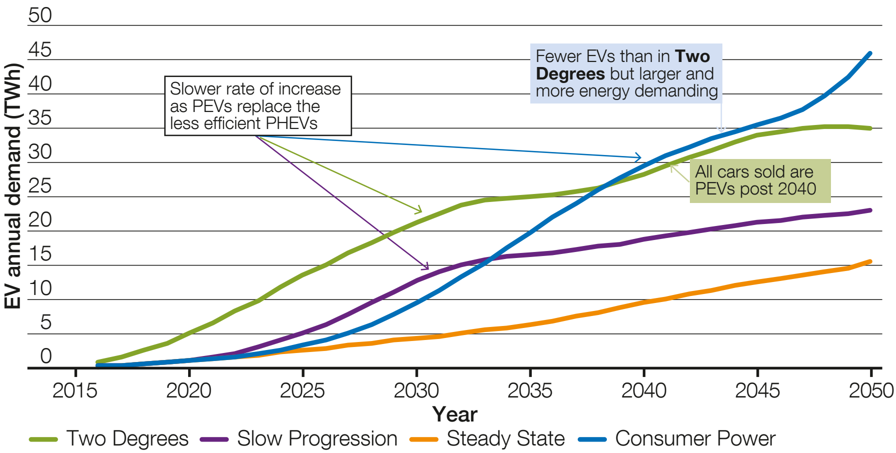
The take up rate within the greener scenarios is assisted by a variety of policy measures that incentivise EVs and discourage ICEs. In **Consumer Power** it is consumers' desire for the latest technology that helps drive the growth in EVs.

The lowest growth is seen in **Steady State** where both PEVs and PHEVs each achieve only 15 per cent of sales of all cars by 2050, that is 30 per cent in total. In all the other scenarios PEV sales finally overtake PHEV before 2040.

The scenario with the most EVs is **Two Degrees**. To meet the 2050 carbon reduction target 100 per cent of all cars sold are PEVs by 2045. Effectively this ensures that all cars on the road are purely electrically powered by 2050. To get to this fully committed position there is a transitional phase where some consumers purchase the less efficient PHEVs in the first instance, before progressing on to PEVs as battery performances improve. The PHEV phase is relatively short lived and there are virtually no PHEVs on the road by 2050. To achieve this there must be significant interventions to encourage the uptake of PEVs, discourage the use of ICEs and create clarity for investment in supporting infrastructure.

Without such interventions the other three scenarios have fewer ICEs on the roads in 2050. This is despite **Consumer Power** selling only EVs from 2045 onwards; residual ICEs and PHEVs still remain.

Figure 3.14
Annual demand from EVs



The growth of electricity demand from vehicles

With the growth of EVs there is a growth in annual demand (see Figure 3.14). Up to the late 2030s the EVs in **Two Degrees** use the most power annually of all the scenarios. Beyond that period the highest consumption is in **Consumer Power**. EVs in **Consumer Power** create an annual demand of 46TWh by 2050. This represents about 11 per cent of the 2050 national demand.

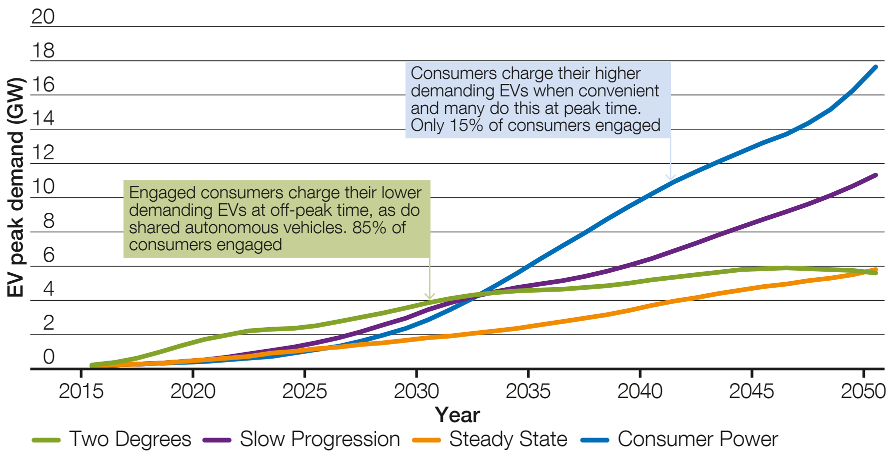
In all of the scenarios except **Steady State**, we see periods of steep increases in demand followed by slower growth. This is caused by the decline in less efficient PHEVs and their replacement with more efficient PEVs.

In **Two Degrees**, 50 per cent of the vehicles that are autonomous are shared and tend to be smaller and more economical to run. Technological advances have some indirect impacts as well, such as enabling activities like home-working, thus reducing the average mileage each person undertakes.

Slow Progression has a similar profile to **Two Degrees'** but lags behind by a decade.

The technological innovations are very similar in **Consumer Power** to **Two Degrees**. It is how they are applied that is different. Consumers in this world are buying EVs because they represent the latest technology, are seen as desirable, and because they have become the most economic option. The majority of cars are not shared as extensively as **Two Degrees**, making up only 5 per cent of the total vehicles on the road by 2050. Mileage per person does not differ from today's level. In this less green scenario the cars are larger and more powerful and therefore less efficient. Consequently, by the end of the 2030s, annual demand in a **Consumer Power** world has outstripped that in **Two Degrees** and it continues to rise.

Figure 3.15
Peak demand from EVs



Energy demand

Electric vehicles' peak demand contribution

How the peak time demand from EVs is treated has a significant effect on the electricity system. If left largely unmanaged, as in **Consumer Power**, it has the potential to be a challenge to the system but in particular to the distribution networks and for system operators post 2030.

Current peak demand is around 60GW so the additional contribution of 18GW from EVs in **Consumer Power** is significant (see figure 3.15). Its profile has a steep trajectory from the mid-2020s and shows no sustained slowing down throughout the next two decades. This is a world where consumers plug in and start charging their vehicles at their convenience. In this scenario we believe that about a quarter of the consumers are engaged with TOUTs. Consequently three quarters of those who charge their vehicles do not move away from peak time charging.

In contrast **Two Degrees** experiences a much more modest rise in its peak demand. Even though, effectively, all cars are PEVs by 2050 they make the least contribution to peak demand of all the scenarios – only 6GW. This is achieved by a mixture of high consumer engagement and the rise of shared autonomous vehicles which charge off-peak in central locations. Without this consumer engagement the peak demand in 2030 would be 6GW higher.

In this year's model we have made the assumption that 7 kW chargers become the standard whereas in last year's *FES* we assumed 3.5 kW. This change has been made as manufacturers are moving in this direction. We have also assumed that chargers will be smart enabled. That is, they can communicate with other devices that will allow consumers, and potential aggregation service providers, to optimise their demand management.

In all the scenarios we have assumed that at any one time only 21 per cent of the potential consumers who could be plugged in will be, due to natural activity diversity.

This is a rapidly developing field and there are a number of different models on how large-scale adoption of EVs may be integrated into everyday life. We plan to explore some of these issues and stimulate debate in our series of Thought Pieces[4].

Currently the electrification of heavy goods vehicles (HGVs) is not considered viable and other fuel types are considered more likely for these larger vehicles.

Natural gas vehicles

Three factors need to come together for natural gas powered heavy goods vehicles (NGVs) to significantly increase in numbers:

- technological development which increases the range on a single refuelling
- infrastructure developments to permit country wide refuelling
- price differentials between gas and diesel or petrol prices.

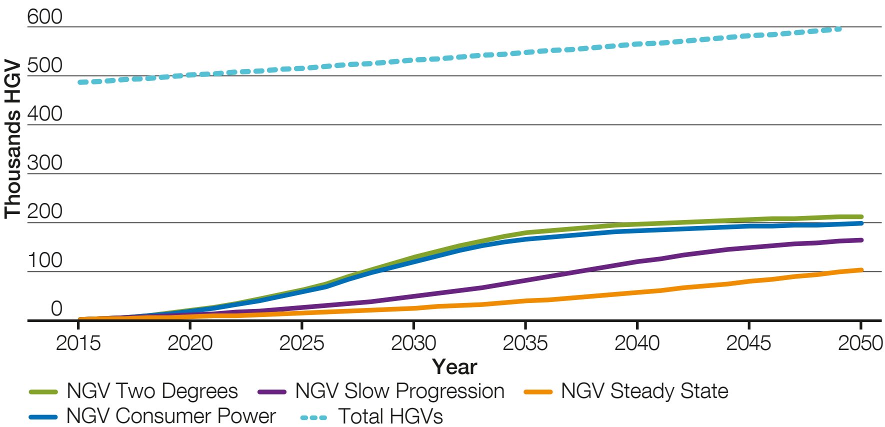
Technological and infrastructural developments are more likely to occur in the prosperous economies of **Two Degrees** and **Consumer Power**. A price differential is more likely in the greener scenarios, where incentives and levies are applied to move away from fossil fuels, and also petrol and diesel are regarded as high pollutants. Consequently we see the most NGVs in **Two Degrees** but this is closely followed by **Consumer Power**, see Figure 3.16. NGV uptake in **Two Degrees** is driven by the need to decarbonise transport, as part of the 2050 targets, whereas the rise in NGV in **Consumer Power** is driven by low gas prices. **Slow Progression**, after a relatively slow build up, starts to see more NGVs in the early 2030s as the price differential between gas and diesel or petrol starts to take effect.

[4] http://fes.nationalgrid.com/insights/

Gas demand for NGVs is a small proportion of total gas demand, which today is around 817 TWh. In **Two Degrees** NGVs account for about 23 TWh per year in 2030 and in 2050 it is about 37 TWh per year.

Additionally, we have included the development of hydrogen powered vehicles and their requirements from gas in our modelling; we also expand on this theme in our Decarbonised Gas sensitivity.

Figure 3.16
All heavy goods vehicles and NGVs



Other transportation

We have considered the impact that other forms of transportation, such as aviation and shipping, have on gas and electricity demand. These demands are incorporated into our annual demand estimates for each scenario.

Spotlight:

Emerging technologies – energy demand

Our Future Energy Scenarios consider a wide range of existing and newer technologies and look at how these might grow in the future. But what about technologies that are still early in development?

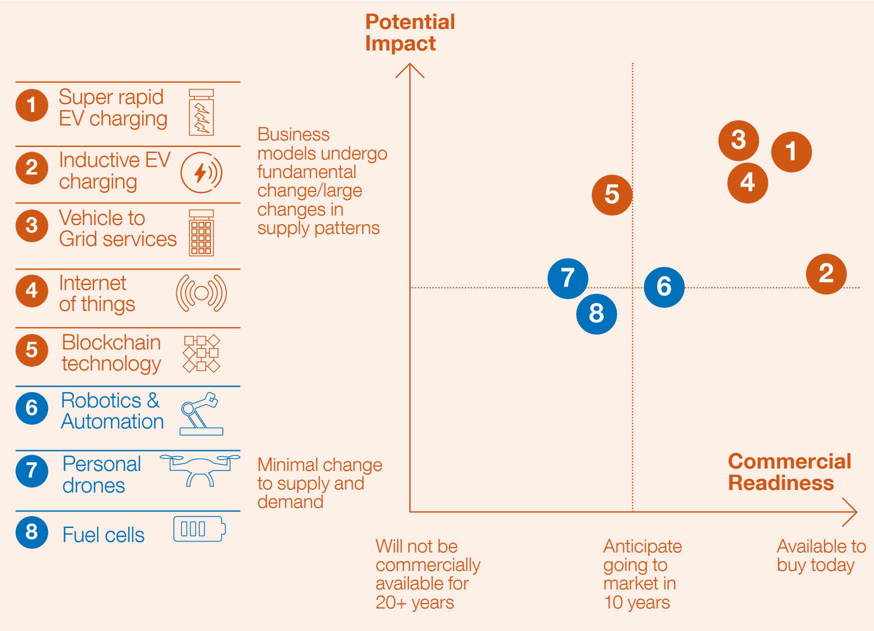
In this spotlight we explore a number of technologies that aren't yet widely available, and hence are not considered in detail in the Future Energy Scenarios. However, they have the potential to impact the traditional energy system, in particular demand for electricity and gas. In Figure 3.17, we have broadly categorised these technologies according to commercial readiness i.e. how soon they might be commercially available, and their disruption potential i.e. how much impact they could have on the energy system. Technologies which are expected to have the most impact on the energy system are coloured orange and are further described in this spotlight. Those circled in blue are not explored further here.

1. **Super rapid electric vehicle (EV) charging** A number of companies are developing flash battery technology that could allow an electric vehicle to run for a long distance from a five minute charge. This could change EV charging demand and infrastructure requirements. For example, centralised charging sites could be built, rather than vehicles being charged at home where super rapid charging could not be provided without significant grid reinforcement. The implications of different EV charging models are further explored in our Thought Piece series.

2. **Inductive EV charging** Inductive EV charging allows vehicles to charge without cables or wires. A current project in Milton Keynes has been trialling the use of inductive chargers at bus stops, to allow electric buses to top up batteries throughout the day. This could prolong battery life, and could mean less charging is required overnight when the vehicle is not in use, leading to different infrastructure reinforcement requirements.

5 min
Super rapid charging of electric vehicles

Figure 3.17
Emerging technologies



3. Vehicle to Grid (V2G) services By 2030, our scenarios predict there will be between 1.9 and 9.3 million EVs on the roads. If these vehicles were all to charge at the same time it would put significant strain on distribution networks and peak generation capacity. In *FES* 2017 we discuss smart approaches to vehicle charging that vary the rate of power transfer into a charging vehicle. However there is still debate over whether it will become commercially viable to flow electricity from a vehicle back onto the network to provide network services or to make money from price arbitrage in the electricity market. Some EV manufacturers are running UK trials to explore such services, but others are concerned that the battery degradation and connection costs required could make the solution unprofitable. We further explore large scale Vehicle to Grid services in our Thought Piece series.

4. Internet of things In the future, most electrical devices could be interconnected. This means that appliances will be able to be controlled via your phone or by an aggregator. As well as the convenience of switching, say, your oven on remotely, this also means heat pumps, lighting etc. could all contribute to demand response. This is already happening to an extent but it is still unclear how much flexibility this could deliver, how fast and at what cost.

5. Blockchain technology Blockchain is a distributed, digital transaction technology that allows the secure execution of smart contracts in peer-to-peer networks. This could further unlock the potential of distributed energy resources such as solar PV and batteries. For example, a US-based startup has enabled peer-to-peer electricity trading using smart contracts via Blockchain. This connects homes that produce energy through solar power with consumers nearby who can buy their excess energy.

We look forward to continuing this conversation with our stakeholders to monitor how these and other emerging technologies might impact the Future Energy Scenarios in years to come.


H2

Chapter four

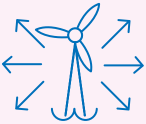
Spotlights

Energy supply

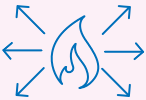
4.1 Energy supply

Electricity and gas demand are very closely linked. For example, in the heating market, an increase in one can lead directly to a decrease in the other. When we come to consider energy supply the interaction between electricity and gas is not quite as direct or obvious, but there are still many features in common, all of which we consider in this section.

Key insights



Increases in decentralised and renewable electricity generation will increase the complexity of operating a secure and cost effective energy system.



In some of our scenarios we are expecting an increase in decentralised gas supply.

Gas and electricity networks

Annual electricity demand in 2016, as reported in the demand chapter, was 306 TWh. By 2050 we expect electricity demand to be somewhere between 321 TWh in **Steady State** and 383 TWh in **Consumer Power**. Annual gas demand was 817 TWh in 2016 but by 2050 we expect it to have decreased to somewhere between 398 TWh in **Two Degrees**, to 772 TWh in **Steady State**, a greater range than in electricity. At the same time we see increasing levels of renewable and decentralised electricity supply. As gas supplies from the UK Continental Shelf (UKCS) decline GB will be more dependent on imported gas or on new indigenous sources such as shale gas or green gas.

With such significant changes it is clear that there may be a lot of work required to manage development and operation of the networks. *FES* is not the place for a detailed discussion of network operability. We have included two spotlights that consider operability issues and offer a view of how we will consider these in more detail in the *System Operability Framework (SOF)*[1] for electricity, and the *Gas Future Operability Planning (GFOP)*[2] documents. Network development is discussed in the *Electricity* and *Gas Ten Year Statements*, *ETYS*[3] and *GTYS*[4].

Decentralised and centralised supply

In electricity, the difference between centralised and decentralised supply is becoming increasingly important. More small-scale generation is being connected to the distribution networks, or possibly, not directly connected to the network at all. Sometimes this type of generation is referred to as 'behind the meter'. This is generation that is connected before a customer's meter, and which can provide electricity to be consumed by the owner without the power being metered on the distribution or transmission system. For many purposes this distinction is not important; at a national level a demand of x GW must be met by x GW of supply. However for network planning and operational purposes, the distinction is crucial.

[1] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/

[2] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas-Future-Operability-Planning/

[3] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-ten-year-statement/

[4] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas-Ten-Year-Statement/

Energy supply

In gas as well, we now have to give more consideration to decentralised supply. Currently there is some gas, from biomethane and small onshore fields, that is connected directly to the distribution networks at lower pressure than the transmission network. However the vast majority of supply is connected to the transmission network, although in the future this may not always be the case. For example, we expect that most new biomethane installations will continue to be connected to the distribution networks. In a large development of shale gas, as we have in **Consumer Power**, wells might be connected to either the distribution or transmission network. With our project CLoCC[5] (Customer Low Cost of Connections), we are working with customers and finding new ways of helping them to connect more efficiently and effectively.

Environmental targets

Development of both electricity and gas supply within our greener scenarios is driven, in part, by environmental legislation:

- The **2020 Renewable Energy Directive** commits the UK to produce at least 15 per cent of energy consumption from renewable sources by 2020.
- The **Climate Change Act 2008** legally binds the UK to reduce carbon emissions by at least 80 per cent from 1990 levels by 2050, via a series of carbon budgets. This is the UK contribution to the Paris Agreement, seeking to hold the increase in global temperatures to less than 2˚C above pre-industrial levels.

The electricity industry has responded well to this challenge, and in **Two Degrees** we have a large development of wind and solar generation. We have high solar generation in **Consumer Power** as well, though this is driven more by consumer choice than by a desire to meet environmental targets.

Gas makes a useful contribution to decarbonisation by replacing coal in electricity generation. We also have renewable biomethane in all scenarios, and bio-substitute natural gas in **Two Degrees**.

Introducing renewable technology into heat and transport has proved to be difficult. While **Two Degrees** meets the 2050 carbon reduction target, the earliest the renewable energy target is met is 2022, despite the progress made in renewable electricity generation.

[5] http://www2.nationalgrid.com/UK/Our-company/Innovation/Projects/Gas-T-Projects-CLoCC/

Security of supply and our scenario rules

In both electricity and gas we have created scenarios where there is enough supply to meet demand. For electricity this means meeting the reliability standard as prescribed by the Secretary of State for Business, Energy and Industrial Strategy – currently three hours per year loss of load expectation (LoLE). For gas there has to be enough supply to meet the peak demand in a very cold winter even if the single largest piece of supply infrastructure were to fail. We have sometimes been asked why we do not create a scenario in which the security of supply standard is not met. We use the scenarios to support our network planning and we only plan for a secure and operable network. As a result, none of our scenarios plan for a network that would fail.

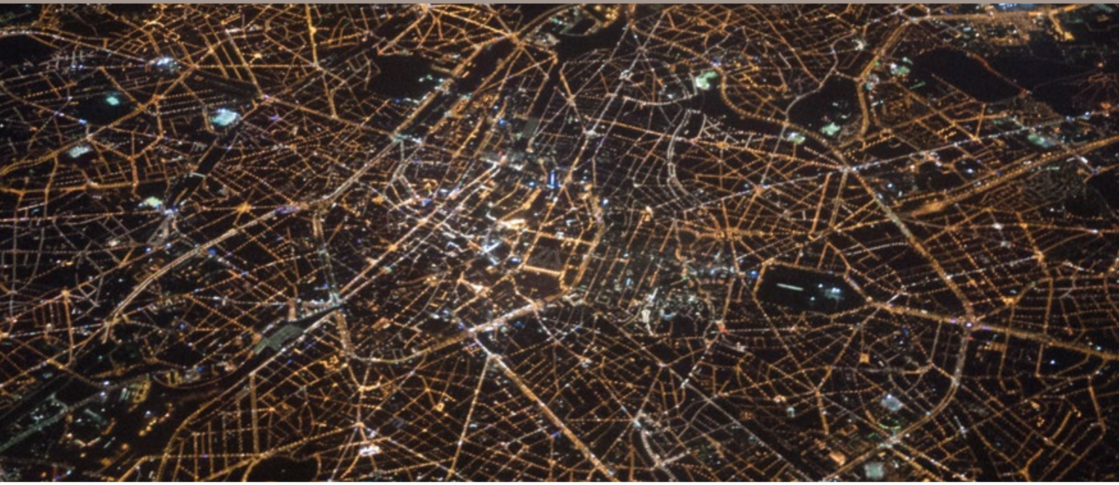
A word about units

Gas and electricity annual demands and generation outputs are discussed in units of energy: GWh or TWh. Electricity peak demand and generation capacity are discussed in units of power: MW or GW. A 1 GW power station generating for 1 hour will generate 1 GWh of electricity.

Gas supply is usually discussed in units of volume: millions or billions of cubic metres, mcm or bcm. This is because the physical operation of a gas network is governed by how much gas is being moved through pipes and compressors, not by how much energy the gas represents. When matching supply to demand we convert gas demand from energy into volume. We could discuss gas supply in energy terms, but that would be less familiar to those of our readers more interested in gas supply, so in common with the specialist energy press we have used volume for all supply.

For gas, in GB, a good approximation for converting from energy to volume is to divide by 11, so for example, 44 GWh approximates to 4 mcm and 880 TWh approximates to 80 bcm.

For further information on how these rules are applied please see our *Modelling Methods* document.



Electricity supply

4.2 Electricity supply

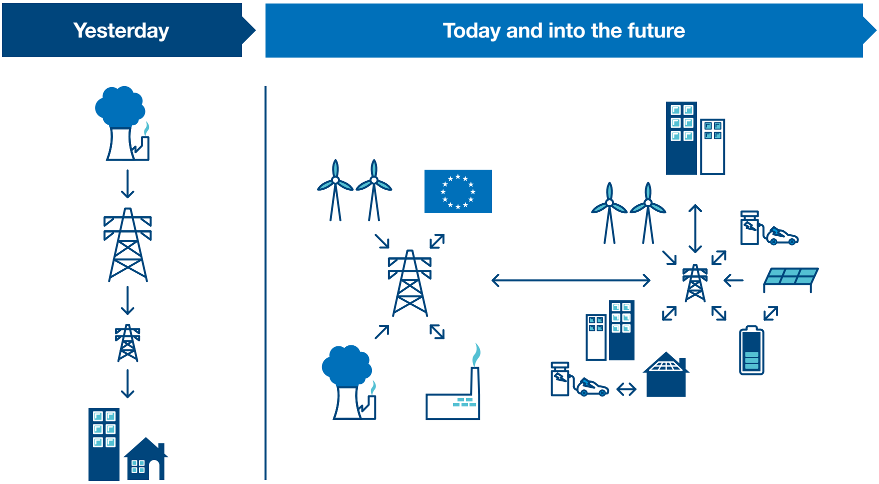
Much has been discussed in the energy industry regarding the speed and depth of transformation we are witnessing in electricity supply. Technical progress and significant cost reductions in technologies, such as storage and solar panels, have driven major change in a short space of time. We have seen a continued shift away from non-renewable generation sources, supported by energy policy. As information communications technology (ICT) develops and systems become smart enabled, new commercial opportunities are emerging, particularly for decentralised technologies.

In the past five years, we have seen technology developing and costs decreasing for small-scale and low carbon generation. At the same time, innovation in ICT has allowed new commercial opportunities to emerge, as generation sites, consumers and smart devices can access better data and communicate quickly and easily.

The growth of renewable generation has been supported through environmental and energy policy, including the 2020 Renewable Energy Directive and the 2050 carbon reduction target discussed earlier.

Previously, large thermal plants dominated GB generation. These were easily controllable and could be switched on and off in response to patterns of demand. Electricity broadly flowed from generation plants to the transmission network, through the distribution network and on to consumers.

Figure 4.1
Changing patterns of electricity demand and supply



Today however, we increasingly see much more complex flows of electricity, and a growing number of market players. Large thermal transmission connected plants in GB are becoming less competitive as a result of the changes outlined previously. Intermittent generation now provides a large proportion of electricity when weather conditions are favourable, but there are challenges in predicting this output. Decentralised generation (generation that is not located on the transmission network, but rather on the distribution network or on site) is changing the pattern of electricity flows. Interconnectors allow access to sources of supply from other countries. In addition, chapter three has already discussed demand side response, where users can flex demand in line with system requirements, facilitated by ICT.

These changes are set to continue. The shift towards decentralised and renewable generation is evident in all our scenarios, it is only the pace and extent of this change that differs. As a result, requirements for system flexibility are increasing as the amount of intermittent and decentralised generation grows. Electricity supply needs to match demand on a second by second basis to ensure the network remains safe and stable. Flexibility refers to the extent to which supply and demand technologies can respond to changing system conditions by quickly producing or using electricity, or by providing network services.

The diversity of generation sources becoming available, plus digital innovation, increasingly means that flexibility can be sourced from a number of different providers. More broadly, networks will need to upgrade and adapt to the changing nature of generation and demand connected to them, taking a whole electricity system approach to minimise costs to consumers.

This section looks at the broader changes in the GB generation mix, before considering renewable and low carbon technologies in more detail. We also explore the operability complexities that arise as a result of growing levels of intermittent and decentralised generation, noting the need for increased flexibility.

We then consider where this flexibility could come from on the supply side, looking at the future of large and small thermal plants, storage and interconnectors. Finally, we examine a number of emerging technologies that could fundamentally change energy supply in the coming decades.

Electricity supply

4.3 GB generation

All scenarios show an increase in renewable and low carbon generation over the next 30 years, alongside growth in the proportion of decentralised generation.

The generation mix
Figure 4.2 illustrates how installed generation capacity will change between now and 2050 across the four scenarios. The figures above each bar show the percentage of overall capacity that is decentralised generation.

The greener scenarios require a greater amount of generation capacity to be built compared to demand. This is because intermittent generation is not able to produce electricity when, for example, there is no sun or wind. A full view of generation capacities for each scenario by technology type and year can be found in the *Charts Workbook*.

Figure 4.2
Generation capacity by type and proportion of decentralised generation

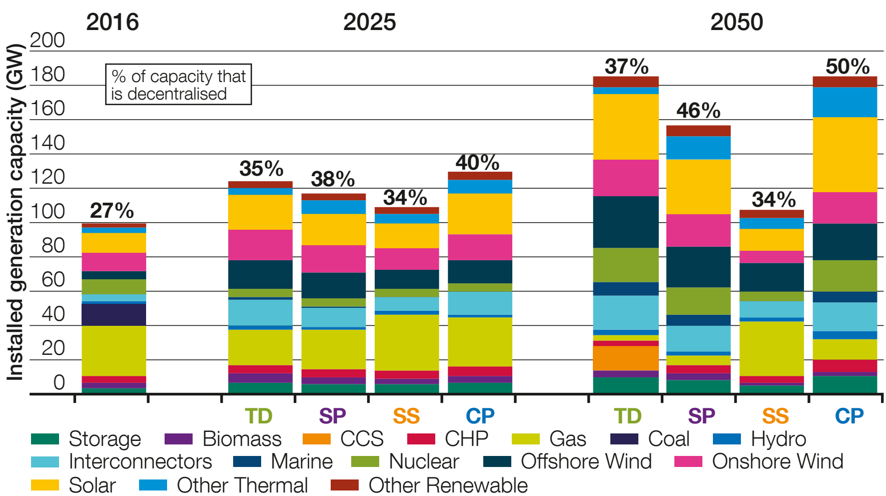


Figure 4.3
*Generation output and carbon intensity – **Two Degrees***

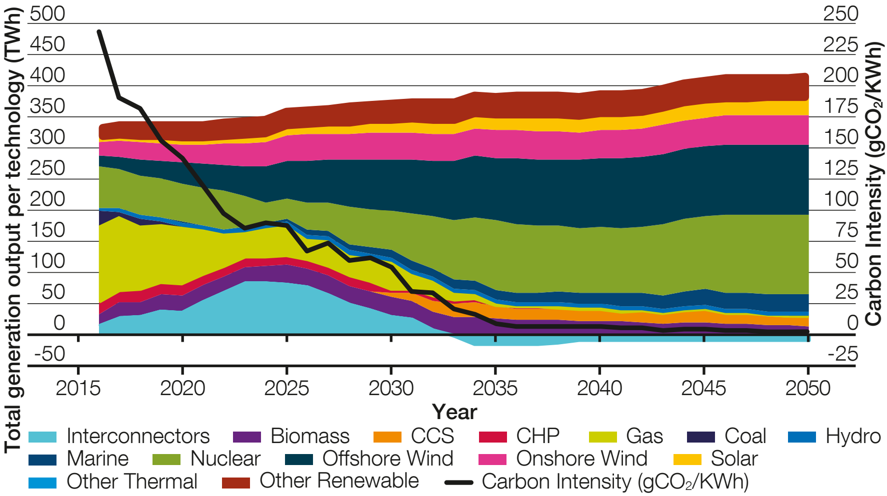
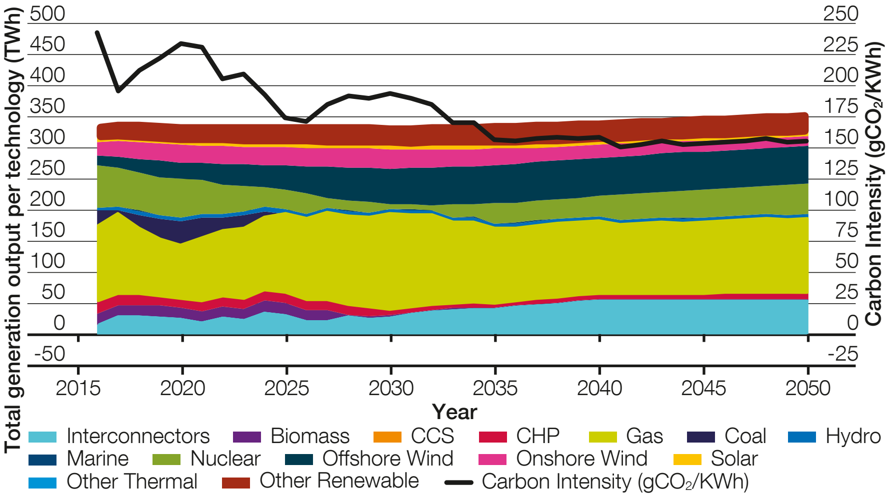


Figure 4.3 and Figure 4.4 show electricity output and carbon intensity for two scenarios, **Two Degrees** and **Steady State**. Under **Two Degrees**, the electrification of transport and heat (as discussed in chapter 3) leads to higher electricity demand and therefore output, produced mainly by low carbon sources. This results in the carbon intensity of electricity generation (the amount of CO_2 emitted for every unit of electricity generated) reducing to 2 grams of CO_2 per KWh by 2050. **Two Degrees** is the only scenario that achieves the 2050 carbon reduction target.

Electricity supply

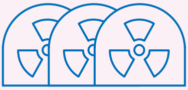
Figure 4.4
*Generation output and carbon intensity – **Steady State***



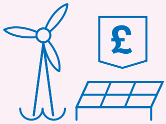
In contrast under **Steady State**, electricity demand and output grows at a slower pace. This growth is mainly due to population increase and a small expansion in the commercial sector. Society has less money to spend and less green ambition, leading to gas dominating the generation mix, as it remains a cheap and flexible method of generation. Consequently, the carbon intensity of electricity generation does not reduce at the same pace as in **Two Degrees**, and by 2050 is 155 grams of CO_2 per KWh.

Generation output and carbon intensity for all four scenarios can be found in the *Charts Workbook*.

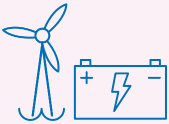
Key insights



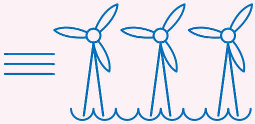
New nuclear build is required in all scenarios, and a gap is predicted between old plants being decommissioned and new nuclear stations beginning to generate.



Continued technological progress and associated cost reductions mean that the economic case for a number of renewable technologies, even with limited or no policy support, will continue to improve.



New opportunities will arise as storage is increasingly co-located with generation assets.



Offshore wind grows in all scenarios, with some built without subsidy in **Two Degrees.**

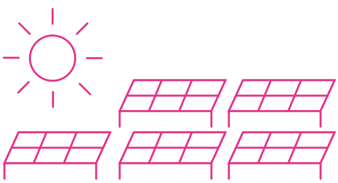
Renewable and low carbon generation

The past two years have seen a number of policy changes for renewable technologies. The Renewables Obligation (RO) scheme closed to all new generation capacity from March 2017, with earlier closing dates for onshore wind and solar. This has led to previously swift installation growth slowing for some technologies. However there is still potential for continued cost falls, and hence continued growth, in a number of areas.

All scenarios anticipate a growth in wind capacity, from approximately 15GW in 2016 to 26GW in **Steady State** and just less than 50GW in **Two Degrees** by 2040. Both onshore and offshore wind experience continued technological improvements, associated cost reductions, and new opportunities to co-locate assets with storage, all of which leads to growth. The majority of growth is seen in offshore wind which, as a less mature technology, has greater potential for further cost reductions. Offshore wind currently receives support through the Contracts for Difference mechanism, however **Two Degrees** assumes considerable offshore build without subsidy, reflecting falling costs.

The growth of onshore wind at both the transmission and distribution level is more muted, with some early growth until the mid-2020s. After this point, growth plateaus in all scenarios except **Steady State**, where limited repowering results in a decline in onshore wind capacity compared to today.

The earlier RO closing dates for solar in 2015 and 2016, alongside a reduction in feed-in tariff rates, led to a ‘solar rush’ as developers tried to install and accredit schemes before relevant closing dates. After this point, growth has slowed considerably. This change in support for solar now means that, for householders and businesses with rooftop solar, the saving from not needing to purchase electricity, rather than income from subsidy mechanisms, becomes key in considering the viability of future schemes.



Electricity supply

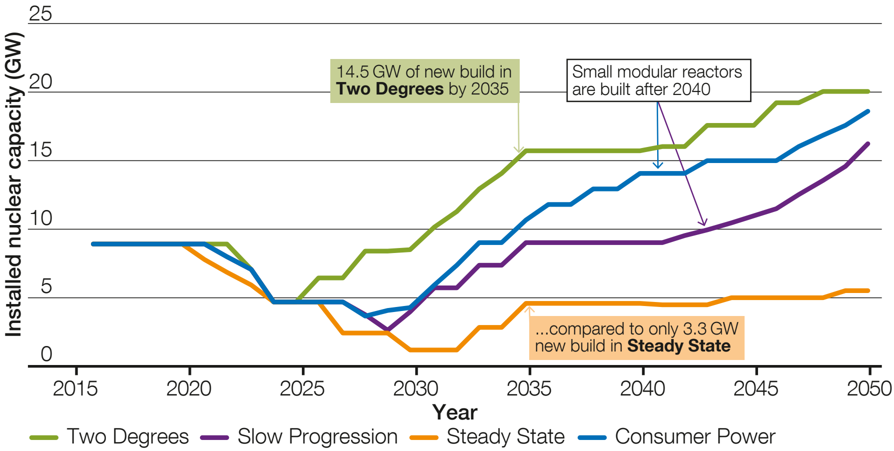
The growth of solar is highest under **Consumer Power**, with installed capacity of 44 GW by 2050, almost four times today's levels. This growth is driven by falling costs, consumer desire for newer technology, and co-location with storage. In this scenario we can expect to see high consumer interest in approaches such as local energy trading, which drives growth in residential generation systems. **Two Degrees** is not far behind with approximately 38 GW of solar generation, but with consumer desire for this technology primarily driven by green ambition rather than innovation.

The majority of solar projects are located on the distribution network or behind the meter. Therefore a fall in demand is seen on the networks as this type of generation increases.

As a result, growth in solar capacity at this scale is radically changing electricity demand seen at the network level, introducing new operability complexities. For example, on 25 March 2017 GB electricity demand on the transmission network was lower during the afternoon than it was overnight for the first time, due to high solar generation netting off demand. The implications of these major changes in network flows are explored further in our operability spotlight.

Nuclear generation features most prominently in **Two Degrees**. In all scenarios, the majority of the existing nuclear fleet is decommissioned by 2030. This leads to a dip in nuclear capacity from the early 2020s onwards, due to a gap between old plants decommissioning and new nuclear plants beginning to generate.

Figure 4.5
Nuclear capacity



In **Two Degrees**, the first new build nuclear plant comes online in 2026, with a total of 14.5GW of new nuclear capacity built by 2035. There are many challenges in building nuclear plants at such pace and scale. Financing for these large projects and political support can be assumed in a high prosperity, green world such as **Two Degrees**. However issues such as supply chain problems and legal challenges can all derail intended project progress. While this trajectory is plausible, a number of factors need to align for this amount of new nuclear build to progress. In **Slow Progression** and **Consumer Power**, a smoother build profile post 2040 can be seen due to the assumption that small modular reactors will have developed sufficiently to begin being built. The size and standardisation of these reactors make them quicker and easier to build than bigger nuclear plants.

Carbon capture and storage (CCS) captures the carbon emitted during another process, typically combustion, and transports the carbon to a storage facility that is usually offshore. It therefore enables technologies such as gas or coal fired generation to provide a flexible supply of electricity with minimal carbon emissions. CCS has been included in **Two Degrees** as it is essential to ensure the 2050 carbon reduction target is met. In this scenario, CCS is used in the production of hydrogen and gas powered electricity generation to minimise carbon emissions. Under **Two Degrees**, CCS for electricity generation begins to be rolled out around 2030, reaching around 8GW by the end of that decade and just under 15GW by 2050.

CCS currently only features in one scenario to reflect the present uncertainty around the commercial scalability of such projects. CCS technology is already well established and is typically used for enhanced oil recovery. However current costs are such that it is not commercially viable to extract carbon as part of the electricity generation process and the technology has not been extensively tested at scale.

Marine generation (such as tidal and lagoon) also features in our scenarios, reaching 8GW of installed capacity by 2050 under **Two Degrees**, but virtually no installed capacity under **Steady State**.

Our analysis also considers renewable gasification and combustion technologies as part of the GB generation mix. For a full breakdown of capacity by specific technology, please see the *Charts Workbook*.

Spotlight:

Electricity operability

By 2030 in Consumer Power, there will be 33 GW of solar panels connected to the electricity system in GB. What does this mean for how we operate the electricity system in ten years time? How will the operability requirements change? Here we give a flavour of how *FES* starts these conversations and leads through to our *System Operability Framework* and onto delivery of solutions.

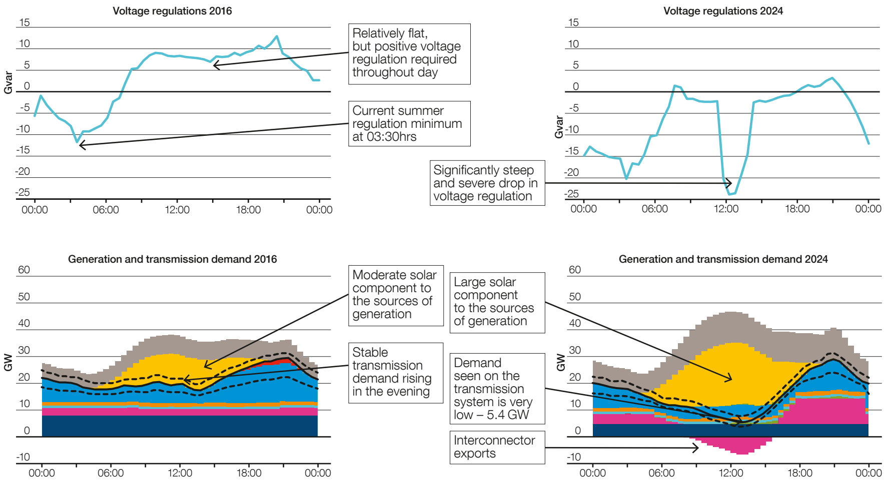
To operate the electricity system, generation and demand must be balanced second by second to maintain a set of parameters, with frequency and voltage being two of them. The *FES* gives four credible views of how generation and demand could change over time. The *System Operability Framework*[6] *(SOF)* is a follow up analysis that uses the *FES* information. Its aim is to understand how the system will need to be operated differently in the future in order to balance supply and demand, and to control voltage and frequency. As we move to a world where renewable generation continues to increase, the traditional tools we have always used to operate the system are becoming less available to meet operability requirements. Here we will explore a key operability challenge of low demand on the transmission system.

Low transmission demand

As discussed earlier in the chapter, the amount of solar generation has increased significantly in the past few years and it will continue to grow. The majority of solar generation is connected not to the high voltage transmission system but at the low voltage distribution level, much of it on people's rooftops. In summer when the sun is shining, people need less electricity for heating and lighting, therefore the electricity networks see a drop in demand. On the same days, at about noon, solar generation is at its maximum and is sufficient to meet most of this low demand. The combined result is very low demand on the transmission system. **Consumer Power** is the scenario with the most solar power generation. Transmission demand and voltage across a sunny day is illustrated in Figure 4.6, the first from 19 June 2016 and the second from a **Consumer Power** world in summer 2024.

[6] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/

Figure 4.6
Transmission voltage requirements and generation sources for summer 2016 and 2024



Comparing the two graphs, although the peak demands in the evening are very similar, the minimum demand in 2024 has shifted from early morning to midday and is much lower. This low midday demand causes the voltage regulation requirement to increase very sharply, almost doubling, which could make system operation more complex.

Figure 4.6 illustrates the significant effects that **Consumer Power** anticipates in 2024. We have already seen a period of low demand and sharply falling voltage in April 2017 showing that this is already a real phenomenon for system operation.

If left to continue, without intervention, the voltage on the system would go outside safe limits causing physical damage to equipment and, potentially, blackouts. Therefore, the transmission system will need to adapt in order to operate safely and securely in this future.

Traditionally voltage fluctuations were managed by using appliances such as combined cycle gas turbine (CCGT) generators. These were either already generating or were kept running to ensure that they were available to deal with such sudden changes.

Because non-transmission connected, intermittent, generation will increase, as will interconnectors, they will cause more variability. Consequently larger transmission connected generators and other interconnectors will have to operate more flexibly to accommodate this. This will be complemented by a growth in balancing tools and technologies such as energy storage and flexible demand. To manage the rapid changes in frequency and voltage caused by the newer type of low carbon generators, a holistic approach, which harnesses capabilities across energy and network resources, is required to address this shortage. What technologies will be utilised has yet to be established by the marketplace.

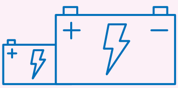
This movement in demand and voltage is one example of the changing operability requirements faced by the System Operator. To read more about the increasing complexity of operating a secure and cost effective electricity system see the SOF publications. These translate what the *FES* analyses mean for the future operability of the transmission system, along with new areas of study. We will be releasing information quicker than we did last year, with smaller more focused reports covering a single topic area throughout the year.

Electricity supply

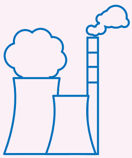
4.4 **Sources of flexibility**

As intermittent and less flexible generation grows at transmission and distribution level, the ability to flex generation and demand is becoming increasingly important to maintain a balanced and stable network. This section considers the potential growth in supply side sources of flexibility across the four scenarios. Demand side response was discussed in **Chapter 3.**

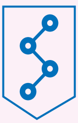
Key insights



Storage growth is projected to continue at a high rate to the early 2020s, driven primarily by technological progress and commercial factors.



The economics for large thermal plant continue to be challenging, and new gas plants are required in the next 15 years in all scenarios.



Interconnection capacity increases in all scenarios, although it is lower than last year as a result of stakeholder feedback and improved modelling. With some limited exceptions, we continue to anticipate a net import of energy annually and at peak.

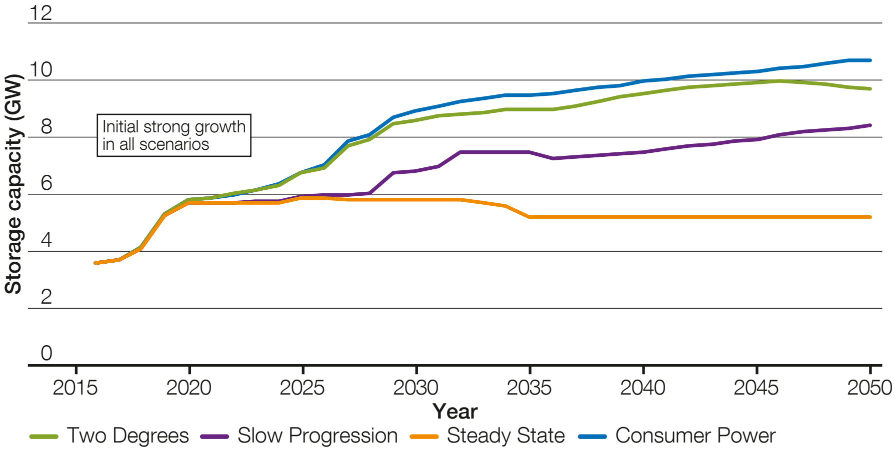
The Capacity Market has encouraged investment particularly in new small-scale thermal plants. However there is regulatory change and uncertainty for a number of decentralised technologies.

Storage

This year, new modelling methods, stakeholder feedback and increased availability of data have led us to assume a higher existing starting point and a faster build rate for storage projects than in *FES 2016*.

The greatest level of storage is in **Consumer Power**, with 10.7 GW by 2050. In this scenario high levels of distributed generation, particularly solar, create a favourable environment for storage to stack revenues. A large proportion of storage is either distribution connected or behind the meter.

Figure 4.7
Storage capacity to 2050



Under **Two Degrees**, growth in storage is almost as pronounced as in **Consumer Power**, with increased intermittent generation encouraging the development of storage for flexibility purposes. In contrast, the lowest level of storage is under **Steady State** with initial growth tapering after the early 2020s and reaching only 5.2 GW by 2050. Little money is available for innovation and investment, and there is less intermittent generation on the system, leading to lower system flexibility requirements. Existing pumped hydro therefore remains the main method of electricity storage in this scenario. There is low rollout of domestic batteries and some previously installed storage is not replaced at the end of asset life.

Electricity supply

All scenarios see strong initial growth in storage to the early 2020s. There have been a number of factors driving this faster growth. These include: a fall in the cost of relevant technologies, ICT advances allowing better communication and control of assets, and the emergence of commercial opportunities. Growth in the electric vehicle (EV) market has also encouraged greater production of batteries, driving technological improvements and economies of scale. The potential role of Vehicle to Grid will be explored separately as part of our Thought Piece series.

Our analysis assumes that storage requires the stacking of multiple revenues, for example, balancing and ancillary services revenues, asset services for Distribution Network Operators and Transmission Owners, and wholesale arbitrage opportunities in order to be commercially viable. In addition, storage will often be co-located with renewable generation, as this minimises capital and network costs and may enable owners to make savings by avoiding electricity purchase.

As can be seen in Figure 4.7, market saturation in storage is reached at different times in each scenario. We used dispatch modelling to determine the amount of storage capacity that is required under different scenarios to smooth generation across the day. For example, this could be to obtain arbitrage advantage or to fulfil various ancillary services requirements. Beyond this required capacity, any additional storage will absorb revenue from other storage or flexibility providers, meaning that projects are less likely to be economically viable.

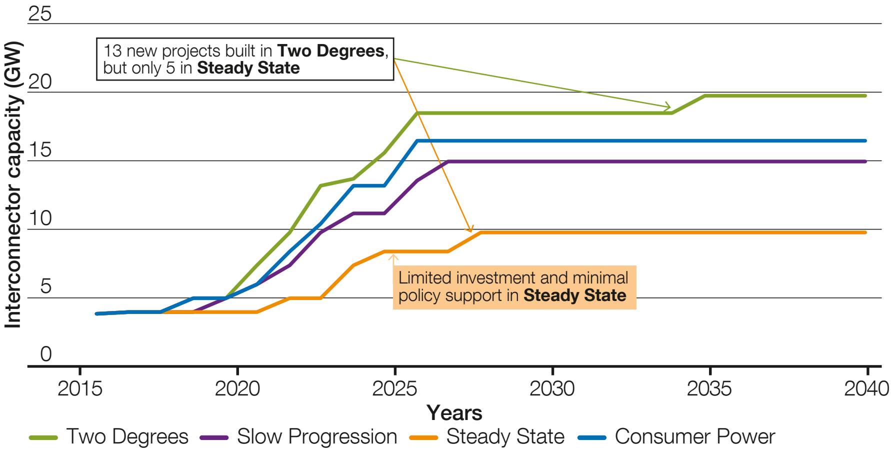
Greater rationalisation, standardisation and clarity in the flexibility market should benefit storage providers. However, we have seen limited progress in some of the relevant policy and regulatory developments for storage that were discussed in *FES 2016*. These included the removal of some potential elements of double charging, and a clearer definition of storage. Greater clarity on network charging arrangements for storage is anticipated as a result of Ofgem's Targeted Charging Review, discussed later in this section. However in the past year storage growth has been driven primarily by market opportunities and technological progress rather than regulatory evolution.

Interconnectors

The political and regulatory landscape for interconnection has continued to evolve. Ofgem's second cap and floor window for interconnection closed in October 2016, with three projects provisionally approved for cap and floor arrangements. At the same time the UK's decision to leave the European Union (EU) has brought uncertainty to the future of energy trading arrangements between the UK and EU member states. Given the lack of clarity on future trading provisions, our analysis currently assumes tariff free access to EU markets under all scenarios. Should further information on future European energy trading arrangements become available, we will consider how any such changes impact our analysis.

This year, interconnection capacity increases in all scenarios, although is lower than last year as a result of stakeholder feedback and improved modelling.

Figure 4.8
Total interconnector capacity



As can be seen in Figure 4.8, interconnector capacity is highest in **Two Degrees**. This is due to ample investment to deliver new projects, an enabling regulatory and political environment, and higher levels of GB intermittent generation increasing the requirement for system flexibility. In all scenarios, no new interconnectors are built after the late 2030s, due to market saturation or lack of available investment. Hence capacities are shown to 2040 only.

Reflecting the lower level of interconnector capacity, we also see lower net annual flows across all scenarios. There continues to be a net annual import of electricity in the 2020s. This is due to the fact that GB prices generally remain higher than neighbouring nations as a result of the GB carbon price floor and cheaper low carbon generation in other countries. However, post 2030 we see one scenario with sustained exports. In **Two Degrees** more GB renewable generation is built, leading to lower prices than other countries for long periods across the year.

Importantly, these net annual flow positions are made up of a considerable variability of flows on interconnectors, as markets respond to price signals driven by demand and supply movements. For example, the net export position seen in **Two Degrees** post 2030 is made up of a high export flow plus a moderate import flow – implying a high overall volume of electricity being traded. In **Consumer Power** in the late 2020s and early 2030s the growth of distributed generation, particularly solar, could lead to imports falling to zero or even small exports, as traded volumes react to changes in supply and demand in connected markets.

Electricity supply

Figure 4.9
Interconnector flows, consecutive weekdays in 2040

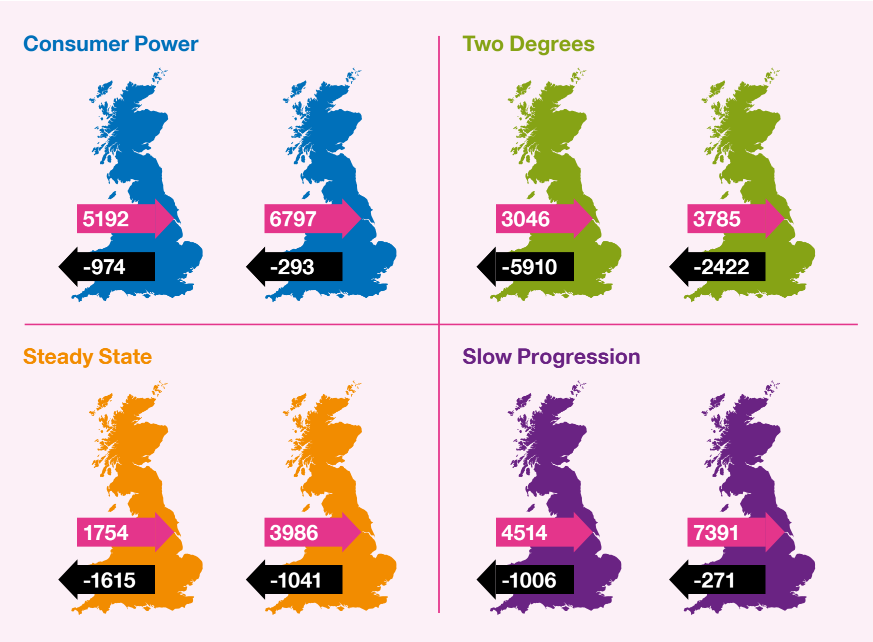
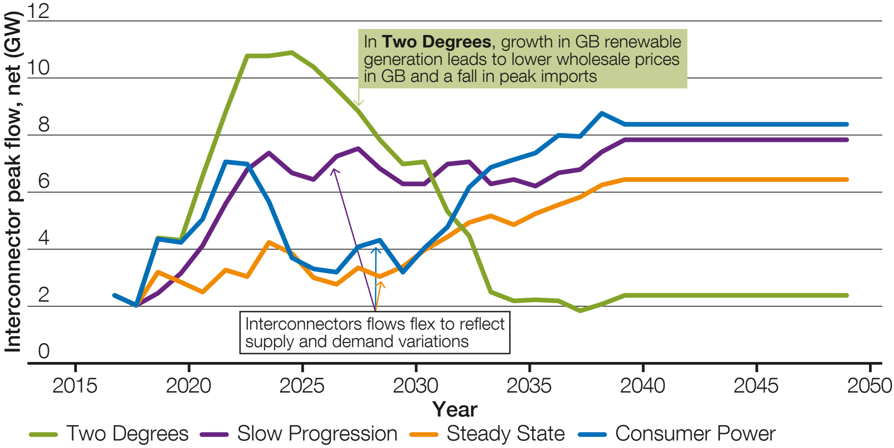


Figure 4.9 illustrates this variability of flows. Imports and exports on all available interconnectors were modelled for two consecutive weekday evenings in January 2040. In this analysis, GB demand is higher on the second day (e.g. due to lower temperatures). The second day also sees reduced output from renewable and thermal generation in GB (e.g. due to outages and lower wind). This is then reflected in changes in interconnector flows from one day to the next. As GB demand increases and production falls, the price increases and more electricity is imported. For a further breakdown of the export and import flows making up net annual flows please see the Charts Workbook.

Figure 4.10
Interconnector flows at peak



The net annual flow positions in Figure 4.10 show net imports at daily peak times (defined as 5–8pm on weekday evenings, November to February) for all scenarios until 2050. All scenarios except **Steady State** show a big increase in peak imports in the early 2020s due to high flows on existing interconnectors and new projects being delivered. In these scenarios, interconnectors can provide a lower cost source of flexibility while older, primarily thermal plants close, and new intermittent and nuclear plants are being built. The increase is particularly pronounced in **Two Degrees** as coal closes earlier than other scenarios, and a number of new interconnector projects are built. Later in **Two Degrees**, as more renewable generation is built in GB, the domestic price falls and imports reduce. The other wholesale scenarios show interconnectors flexing in response to changes in demand and supply over the period. For example in **Consumer Power** there is a dip in peak imports in the 2020s as more generation is built in GB. Later, imports increase again as GB demand increases (see Chapter 3).

Electricity supply

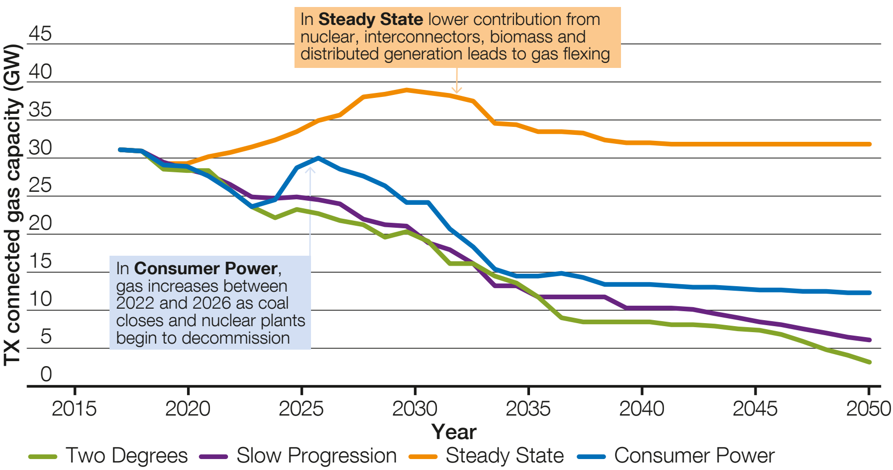
Thermal plants

Large thermal plants connected to the GB transmission network continue to face challenging economic circumstances. This is due to a combination of energy and environmental policy, such as the carbon floor price, and increasing competition from zero fuel cost generation.

There have been some important industry milestones in the past year, with no coal used for 24 hours in April 2017, and both wind and solar each providing more energy than coal for several months in 2016. However, slightly fewer large coal plants have closed this year than we anticipated in the *FES* 2016 scenarios, as some plants have received Capacity Market or ancillary services contracts. Our scenarios show all unabated coal plants closed by 2025 as a result of government commitments, but with the timing of closures differing according to scenario. The relative profitability of coal and gas generation will be a key factor impacting the timing of coal station closures in the next few years.

In contrast, large transmission connected gas plants remain an important part of the generation mix for a significant amount of time. Gas provides a flexible and low cost source of electricity for GB as we transition to a low carbon future. However the amount of gas varies considerably by scenario. The overall amount of transmission connected gas plants falls in all scenarios except **Steady State**. All scenarios also see irregular movements in the profile, illustrating how gas is likely to be the generation source that flexes to meet demand.

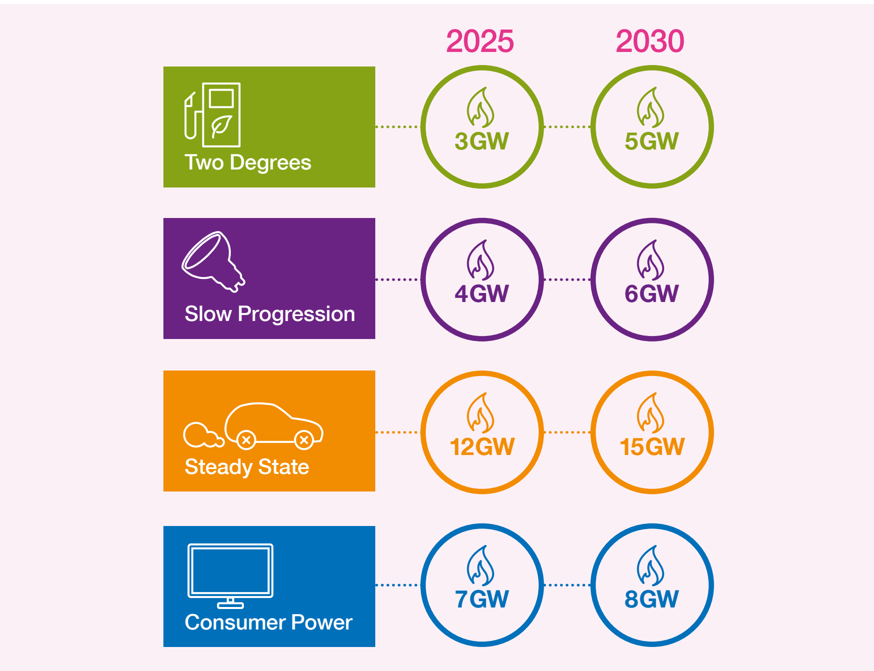
Figure 4.11
All transmission connected gas capacity to 2050 (includes Combined Heat and Power plants)



Underlying these movements are a number of plant closures and the build of new transmission connected gas plants. For example, in **Steady State** by 2040 transmission connected gas capacity is similar to today. However, between now and 2040, approximately half of the existing combined cycle gas turbine (CCGT) plants close, and a significant new build programme takes place with much of this build occurring in the early to mid-2020s.

Conversely in **Two Degrees** much less new CCGT build is required over this time frame, due to an increased proliferation of renewables supported by increased interconnection to provide flexibility. In this scenario most new build occurs in the mid- to late 2020s. The amount of required new CCGT capacity under each scenario is shown in Figure 4.12.

Figure 4.12
Total new transmission connected CCGT capacity



Electricity supply

Small-scale thermal generation can also be an important source of system flexibility as intermittency grows. Considered within this group are: CCGT, open cycle gas turbines (OCGT), diesel and gas engines, gas combined heat and power stations (CHPs), fuel cells and fuel oil generators, which are on site behind the meter or connected to the distribution network.

The results of the 2017/18 Capacity Market T-1 early auction have indicated that new small thermal plants are being built at a faster rate than anticipated in *FES* 2016. The highest proliferation of small-scale thermal plant takes place in **Consumer Power**, where local energy grows and convenience and innovation are valued but with lesser levels of green ambition. Under this scenario, distributed and micro thermal plant grows steadily to the mid-2030s, and then more slowly to reach over 24 GW by 2050.

Installed capacity is also high in **Slow Progression**, but the majority of this is peaking plants that run infrequently.

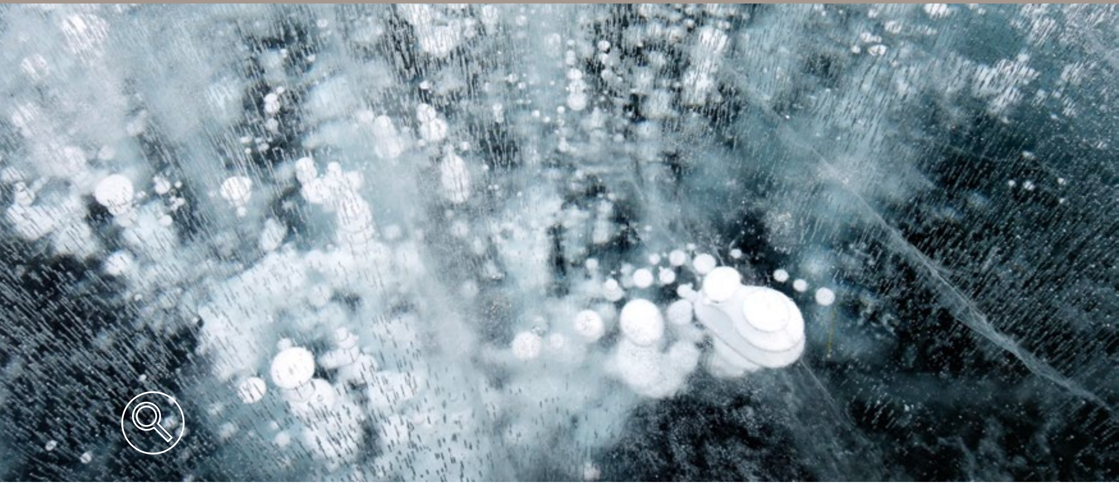
Figure 4.13
Decentralised thermal capacity by 2050

Two Degrees | Slow Progression | Steady State | Consumer Power

The lowest growth of smaller thermal plants takes place under **Two Degrees**, where there is less small-scale generation overall, and a much lower proportion of this is thermal due to green ambition.

A number of proposed regulatory changes will affect the growth of a number of decentralised technologies. In June 2017, Ofgem announced a major change to the value of embedded benefits, which will be implemented over a three-year time frame. Embedded benefits refer to the value that on site and distributed generators and storage can get from avoiding charges for the use of networks. Furthermore in March 2017 a Targeted Charging Review was announced which will consider transmission and distribution network charging arrangements in detail, with a specific focus on embedded benefits, behind the meter generation and storage. Various proposals have also been put forward to consider appropriate emissions limits for smaller-scale generation.

All of these regulatory factors will be significant in determining the future commercial profitability of various decentralised technologies, and hence their anticipated growth rate. We have accounted for this uncertainty in the wide range of installed capacities in our scenarios.



Spotlight:

Emerging technologies – energy supply

In Chapter 3, we explored a number of emerging demand side technologies that are still early in development. As these are not yet widespread, these technologies aren't considered in detail in our Future Energy Scenarios – but we discussed how they could have the potential to vastly change patterns of energy demand.

In this spotlight, we consider emerging technologies that could impact the energy system, but with a focus on energy supply. Again, we have categorised these technologies according to how soon they might be widely available and how much impact they could have. Technologies circled in pink, in Figure 4.14, are those that potentially could have the most impact on the energy system, and so these have been described in more detail. Those circled in blue are not explored further here.

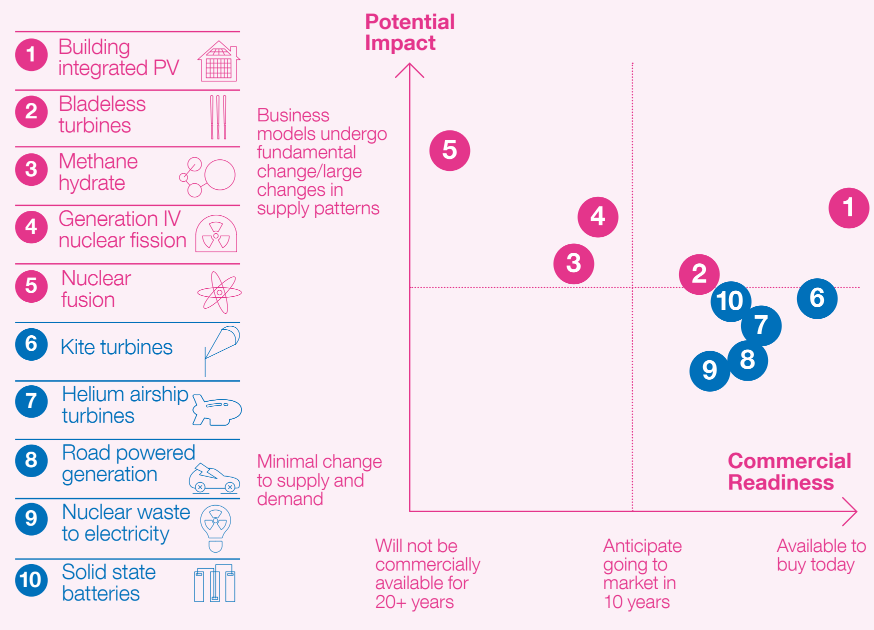
1. Building integrated photovoltaic

The ability to integrate solar PV into conventional building materials should increase widespread use as the incremental cost of installing PV is much reduced. For example, the Tesla solar roof launched in May 2017 is made up of solar roof tiles that produce significant amounts of electricity, yet can be installed at a comparable price to a high end conventional roof. We have explored some of the operational complexities and changes in demand as a result of high levels of solar PV in our operability spotlight.

2. Bladeless wind turbines

These turbines look like long poles, and they generate electricity by being shaken by the wind moving around them. They have the potential to provide energy in a way that is quieter, less visually and spatially intrusive, and safer for birds as compared to conventional wind turbines. This could mean they are more widely accepted than current wind farms, and more turbines can fit into a smaller space, allowing greater growth of onshore wind.

Figure 4.14
Emerging technologies



3. Methane hydrate Methane hydrate is a frozen mixture of water and methane where molecules of methane, the main element in natural gas, are trapped within a cage of ice. This is typically found under permafrost and near the ocean floor. Research is underway to develop safe and environmentally responsible ways to harvest the methane stored in methane hydrate. Some experts believe supplies of methane from this source could be greater than all of the world's other natural gas and oil resources combined, providing a huge new source of energy supply. However the environmental impacts of extraction will need to be carefully assessed.

4. Generation IV nuclear fission Currently, nuclear power is produced using a fission process, which involves breaking apart the nuclei of heavier elements. Generation IV nuclear fission describes a number of technological developments that could make the fission process considerably safer and more efficient, as well as reducing the environmental impact. Some of these technologies are already in small-scale use around the world, others are still at research stage. Generation IV technologies include: a) fast reactors, which deliver much more energy from the same amount of fuel, can use the waste from older reactors as fuel and produce much shorter lived waste products, b) very high temperature reactors which are more efficient, offer additional safety features and allow the direct production of hydrogen instead of electricity, and c) thorium reactors which produce less waste and use a more abundant source of fuel. If realised, these improvements could lead to much greater growth of nuclear power.

5. Nuclear fusion A fusion process releases energy when two lighter elements are combined. Fusion processes have important safety benefits and release much less radioactive material than fission processes. However research into using fusion to create energy has been in development for a long time, due to difficulties in starting and sustaining the required conditions for fusion, and the cost of research.

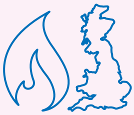
We look forward to continuing this conversation with our stakeholders to monitor how these and other emerging technologies might impact the Future Energy Scenarios in years to come.

Gas supply

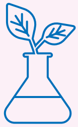
4.5 Gas supply

The pattern of gas supply in GB has changed dramatically in the past 15 years. We have gone from being self-sufficient in gas in 2000 to being dependent on imported gas for around half of our needs in 2016. Production from the UK Continental Shelf (UKCS) declined from 95 bcm in 2000 to 35 bcm in 2016. This has been replaced with gas from Norway, continental Europe, and the world market (delivered as liquefied natural gas (LNG)). We can expect a similarly large change looking forward. Over the next 30 years, the UKCS will continue to decline. In some scenarios we consider the development of other indigenous sources: shale gas, biomethane and bio-substitute natural gas (bioSNG). However, in three out of four scenarios imported gas will become even more important.

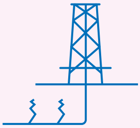
Key insights



There is sufficient gas available worldwide to meet GB demand throughout the scenario period.



Biomethane and bioSNG contribute around 13 per cent of total supply by 2050 in **Two Degrees.**



Shale gas is developed in the two scenarios with less green ambition.

Our requirement for imported gas in 2050 ranges from 51 per cent in **Consumer Power** to 93 per cent in **Slow Progression.**

Gas supply overview

Two Degrees has the lowest gas demand. In this world the green ambition drives investment in renewable and sustainable technologies. There is little incentive for maximising production from the UKCS and no support for shale gas. On the other hand, biomethane and bioSNG both feature strongly in this scenario.

Consumer Power has a high gas demand. Government policies are focused on indigenous energy supply, so both UKCS and shale development are at their highest. There is limited green ambition so little further development of biomethane over today's level. With the highest indigenous supply, this is the scenario with the lowest import dependency.

For **Slow Progression** and **Steady State** the future gas supply lies somewhere between the extremes of **Consumer Power** and **Two Degrees**. **Slow Progression** is not prosperous, and what money is available is directed toward green technologies. There is some development of biomethane but little investment in the UKCS. In common with **Two Degrees** there is no development of shale gas. **Steady State** is even less prosperous, but there is little green ambition and gas demand is high. Money is available for the UKCS and for moderate shale development.

The two extremes are shown in Figure 4.15 and 4.16.

Gas supply

Figure 4.15
Annual supply pattern in ***Two Degrees***

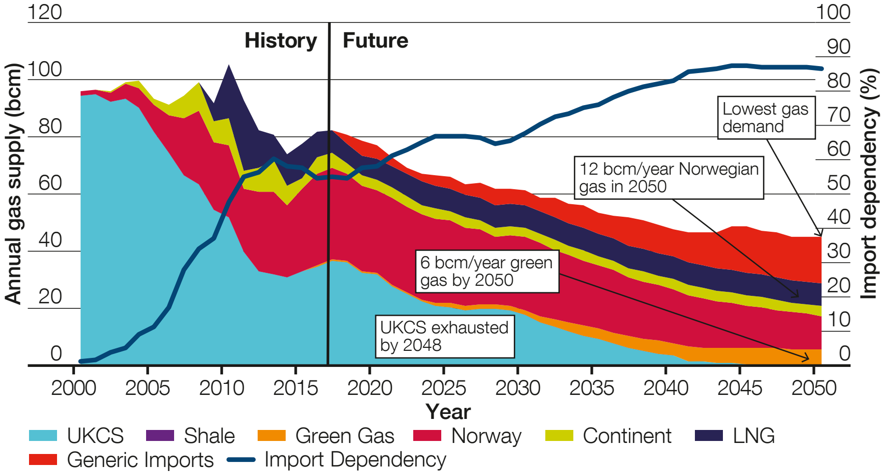
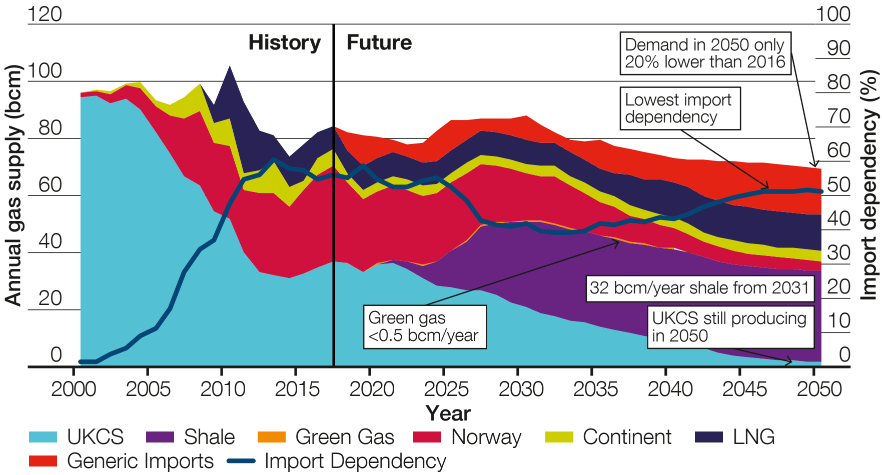


Figure 4.16
Annual supply pattern in ***Consumer Power***



Chapter four

4.6 Sources of gas

Indigenous sources
The UKCS has been enjoying a brief renaissance in recent years as new fields have come on line, and in all our scenarios we are expecting production in 2017 to be higher than 2016. However, in all scenarios except **Consumer Power**, production declines from 2017 onwards, and is exhausted before 2050. In all four scenarios production in some areas will decline to the point where receiving terminals are no longer financially viable and some will close. After consultation we have taken flows of less than one mcm/day as the threshold for closure.

There has been a lot of activity in shale gas development in the past year. Permission has been granted for exploration in a number of sites, though projects are meeting with local opposition. Public support for shale gas is currently very low, at 37 per cent in October 2016[7]. We have included shale gas in **Consumer Power** and **Steady State** but not in the two greener scenarios, where we have assumed that the green ambition will not support shale gas development. There is very little new information on shale gas prospects publicly available, so our projections for shale gas have not changed since last year. Our high case, in **Consumer Power**, reflects the current level of interest in shale development. In the medium case in **Steady State**, development starts two years later than in **Consumer Power**. However, successful development is not guaranteed, a view that is reflected by the absence of shale gas in **Two Degrees** and **Slow Progression**.

Our green gas category includes biomethane and bioSNG. Biomethane is produced principally by anaerobic digestion (AD) of organic material, either waste products or crops grown for this purpose. We are expecting several new AD installations to come on line every year until 2030. These will supply gas directly to the low pressure distribution networks rather than to the transmission network, though the total volume supplied remains low. In **Two Degrees** there is greater support for low carbon energy so we have included bioSNG. This technology is being developed to produce gas from household waste and should be able to produce gas on a larger scale than AD. We have grouped the two together as Green Gas in our charts and you can see from Figure 4.15 that in **Two Degrees** combined production reaches six bcm by 2050.

The use of hydrogen in place of natural gas is one way that heating can be decarbonised. As this option is not yet commercially proven we have not included it in our core scenarios, although some hydrogen is used for transport in **Two Degrees**. However, it is an interesting area and we have described a possible hydrogen future in our Decarbonised Gas sensitivity on page 94.

[7] https://www.nottingham.ac.uk/news/pressreleases/2016/october/support-for-fracking-is-at-an-all-time-low-says-new-survey.aspx

Gas supply

Imported gas

The supply of Norwegian gas in our scenarios is governed by assumptions on production. In the highest case, which we have used in **Steady State**, Norwegian production continues with little change into the 2040s, and even by 2050 Norway still supplies 24 bcm/year to GB. At the other extreme, in **Consumer Power**, production declines much more quickly. In this scenario there is support for development of the UKCS. This leads to a lower requirement for Norwegian imports which has a corresponding effect on the level of investment in production in Norway.

For some years our scenarios have included specific volumes of imported LNG and continental gas, as well as a volume of 'Generic Import', which could be LNG or continental gas or a mixture. This approach effectively provides ranges for LNG and continental gas imports in each scenario. Predicting LNG flows in the world market is challenging and you have told us that our approach is a sensible way of dealing with the uncertainty. However, global production of LNG is increasing and it seems likely that more LNG will be coming to North West Europe. We have recognised this by increasing the minimum LNG assumption in our calculations, and reducing the size of the unspecified generic import. Our view of minimum net imports from continental Europe is based on observed flows from the last six years. However, in all scenarios we expect gas to be flowing both to and from Europe.

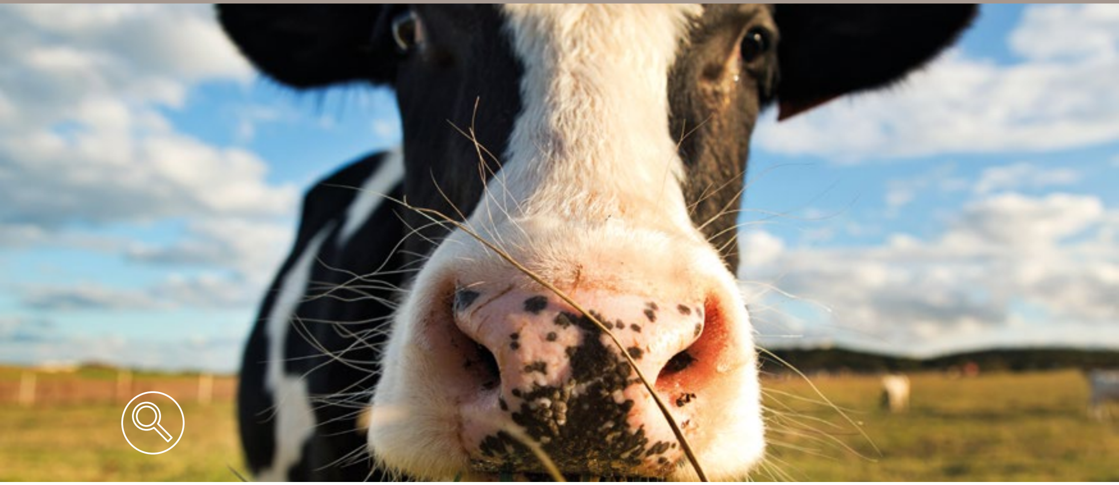
Storage

As part of our diverse range of supplies, gas storage has an important role to play in supporting security of supply and providing flexibility in the operation of the gas market. The role of flexible supplies, including but not limited to storage, will be increasingly important in **Consumer Power**. In this scenario at least half the annual supply will be from sources that are likely to deliver at the same rate throughout the year.

Some medium range storage has been developed in the last three years, but the economics, and particularly the winter to summer price spread, are very challenging for the development of new storage sites. There was only one long range storage site in GB, a depleted gas field, Rough, off the coast of Yorkshire. The capability of the site was reduced in 2015, while investigations were carried out into the condition of the wells used for injecting and withdrawing gas. In June 2017 after two years of testing and remediation the owners, Centrica Storage, announced the permanent closure of the site as a storage facility. For more details please see the Centrica Storage website[8].

The closure of Rough has removed around 70 per cent of the volume available for storage, known as space, and around 25 per cent of the daily storage supply capability, known as deliverability. We have looked at possible implications of the closure of further storage sites in our 'What if storage sites close' section on page 84.

[8] http://www.centrica-sl.co.uk/news/permanent-cessation-storage-operations-1



Spotlight:

Transit gas GB

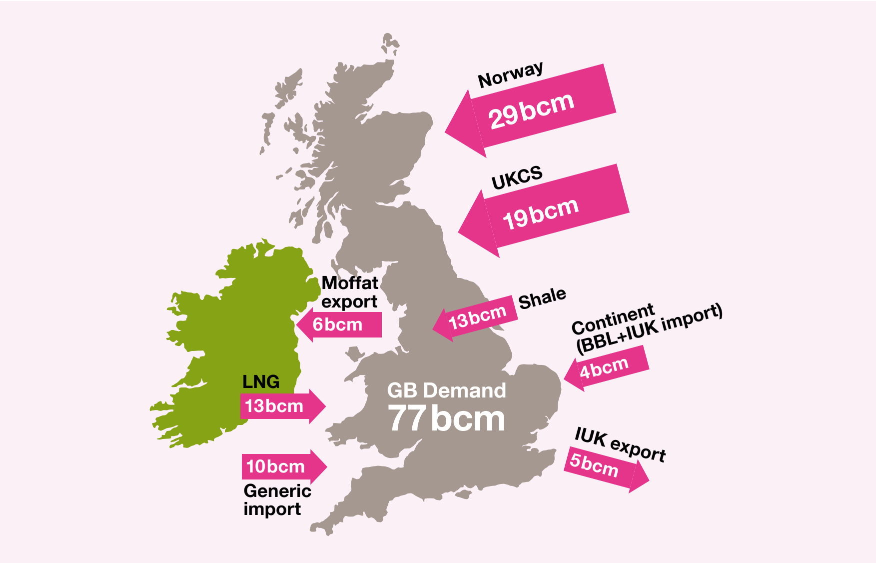
Gas is a global commodity. In a well-functioning market, gas traded internationally will land wherever it is most commercially advantageous to do so. GB has indigenous supplies of gas from UKCS and from shale and green gas in some scenarios, but is also well connected to Europe.

GB has pipeline connections for importing gas from Norway, and from the Netherlands – the BBL interconnector. Gas is exported to the Republic of Ireland and Northern Ireland via the Moffat interconnector, and there is also a bi-directional connection with Belgium – the IUK interconnector. The net flow between GB and North West Europe (Belgium and the Netherlands) is currently close to zero. In 2016 GB imported around six bcm from the Netherlands and Belgium through BBL and IUK, and exported around six bcm through IUK. Is this balance likely to continue? Could the exports increase so that GB becomes a regular transit point for gas entering Europe?

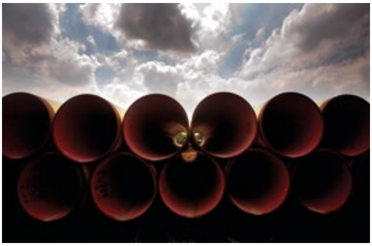
To gain some insight into possible future flows we have considered **Steady State** in 2030 in this spotlight. Gas demand in GB in this scenario is very nearly the same as today, but the pattern of supply is quite different. Figure 4.17 shows gas imports and exports. The generic import could be either LNG or continental gas, as discussed in the main gas supply section. In this example, if we assume that all the generic import arrives as LNG we have an LNG total of 23 bcm. This is much higher than today, but still far short of the capacity of the existing terminals, which is around 49 bcm. Similarly, IUK and BBL are not used at anything like full capacity, so there is physical capability for more import and more export.

23 bcm
Assumed total of all LNG imports in this spotlight

Figure 4.17
*Gas imports and exports. **Steady State** 2030.*



In the current commercial regime it would probably make more sense to land LNG directly in Europe than to land in GB and export through IUK. But if the commercial regime were different, perhaps as the UK seeks new trading arrangements with Europe, then transit may become more attractive.



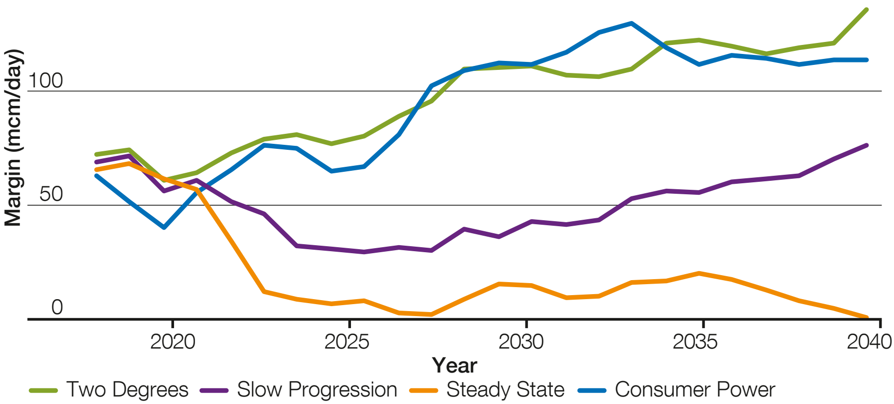
We do not model gas demand in Europe, but there are forecasts from other organisations that show an increase in gas demand there. This is especially true in greener scenarios where gas is used to replace coal in electricity generation. Norway provides gas by pipelines to France, Belgium, the Netherlands and Germany as well as to GB. Many of these pipelines are already quite heavily used. Figure 4.17 shows 29bcm of Norwegian gas, but in all our other scenarios the supply from Norway to GB is less than in **Steady State**. With rising gas demand in Europe, and lower demand for Norwegian gas in GB, it may become attractive in these other scenarios to land Norwegian gas in GB and export to Europe. The gas supply and demand patterns in our scenarios leave room for imported gas to use GB in transit to Europe. The National Transmission System (NTS) has enough physical capacity, though there may be operational challenges. The current commercial regime would not necessarily support this, but with new arrangements it could become an attractive proposition.

Gas supply

4.7 Peak gas supply

We assess peak gas demand against the supply capacity of the full range of supplies. Details of how we do this are in the *Modelling Methods* document. We also assess whether peak demand could still be met if the single largest piece of supply infrastructure fails, known as the N-1 test. Figure 4.18 shows the margin of peak supply over peak demand under N-1 conditions.

Figure 4.18
Peak supply margin under N-1 conditions



The closure of Rough has meant that **Steady State**, with its high gas demand and moderate supply, comes close to failing the N-1 test. Beyond 2040 new supply capacity will be needed to avoid breaching the condition. The N-1 test that we have used here is also used by the UK Government to assess the security of gas supply[9].

[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/560125/UK_Risk_Assessment_Gas_BEIS_template_Final__4_.pdf

Chapter four

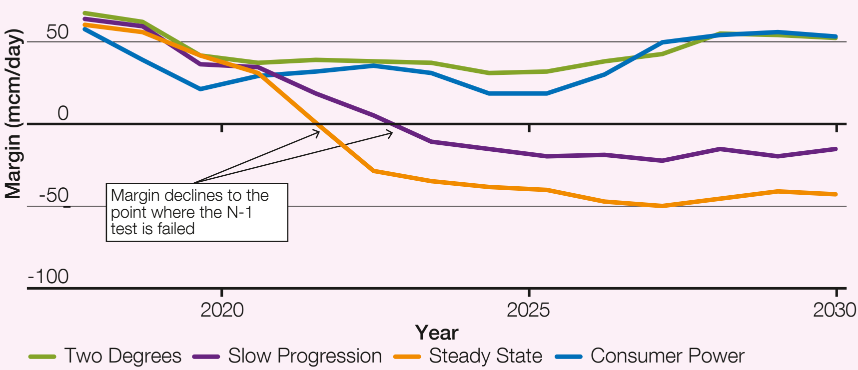
Gas supply

What if storage sites close?

The closure of Rough has highlighted the problems faced by ageing infrastructure in challenging economic conditions. Storage sites elsewhere in Europe are also facing similar problems and some have closed. It is too early to tell what effect the loss of Rough will have on the longer-term GB storage market, but we have investigated what might happen if further sites close here.

For this section, we have assumed that as well as Rough, further storage sites close, up to the point where the daily storage supply capability is reduced by half. As this is a high level investigation we have not modelled the closure of individual sites, but simply reduced the total deliverability by half to test the resilience of the market. Figure 4.19 shows the effect on the N-1 peak supply margins.

Figure 4.19
Peak supply margin under N-1 conditions with storage closures

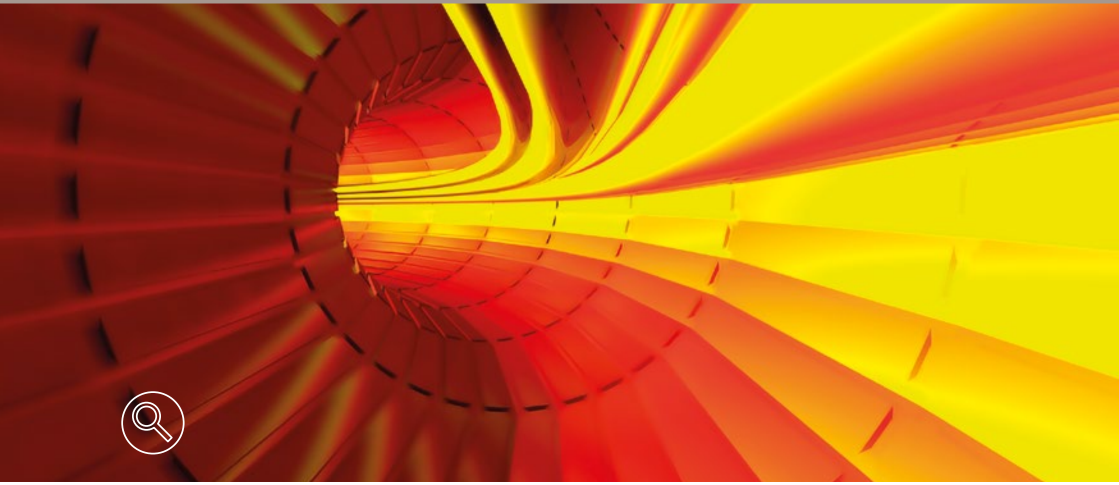


What if storage sites close? *(continued)*

In both **Steady State** and **Slow Progression** the margin of supply over demand declines to the point where new capacity would be needed by the early 2020s. No new capacity is needed in **Two Degrees** or **Consumer Power**. In **Consumer Power** demand and supply are both high, while in **Two Degrees** demand and supply are both low. In both cases there is currently sufficient supply capacity available to satisfy the N-1 test. However, a change in the economic environment could rapidly reduce the surplus, leading to a need for further development.

We have modelled this capacity reduction case as the loss of storage deliverability, but the results for the N-1 test would be the same regardless of the type of supply capacity that we considered.

In addition to the security of supply test, the reduction in the availability of flexible supply would also increase the complexity of operating the NTS, particularly at times of peak demand.



Spotlight:

Gas operability

As traditional energy sources are replaced by new ones and demand becomes more volatile, the within-day supply and demand patterns seen on the NTS are changing.

The gas and electricity networks have many interactions and in addition to changes on the gas network itself, the changes on the electricity network are also starting to have an increasing impact. As outlined in our key messages, an energy system with high levels of distributed and renewable generation has become a reality. As we continue to move to a more decentralised and decarbonised energy system it will need to be more flexible. We have already seen for electricity operability how solar generation is changing within-day electricity demand profiles.

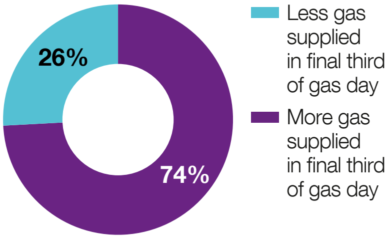
Combined cycle gas turbines (CCGTs) could play a key role in securing electricity supply by providing this flexibility. Such use of CCGTs could lead to increasingly variable within-day gas demand patterns, which if combined with unplanned gas supply losses and how gas is supplied, could create challenging operating conditions.

As the residual balancer of the GB gas market, we need to ensure that total supply equals total demand by the end of the gas day. However, throughout the gas day supply and demand are rarely in balance. The capacity of the pipelines to store gas means that our ability to meet localised demand is affected by the distribution of gas across the network.

The continuing tendency to put more gas onto the network in the final third of the day in response to market conditions – so called ‘backloading’ (see figure 4.20), can severely deplete gas stock levels, impacting our ability to meet customer demand.

Combined cycle gas turbines (CCGTs) could play a key role in securing electricity supply by providing flexibility.

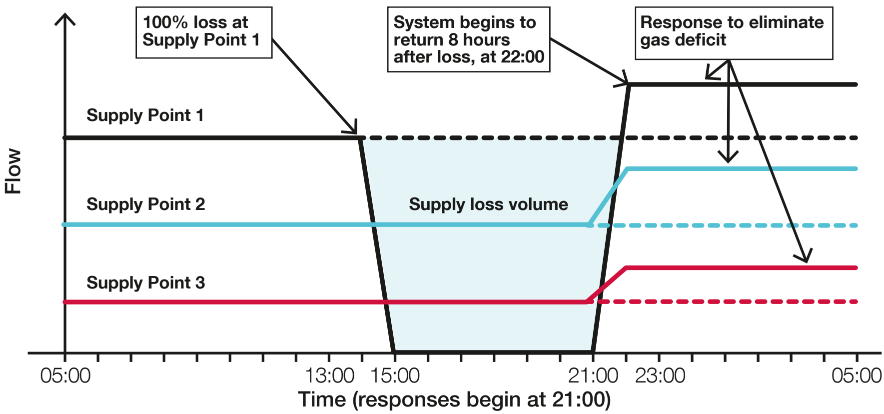
Figure 4.20
Percentage of days between 1 October 2012 and 30 September 2015 that more or less gas was supplied in the final third of the gas day



This challenge in meeting customer requirements is exacerbated in the event of an unplanned supply loss. Causes of such a loss can include offshore production problems or a fault at a terminal. Typically, the gas deficit caused by a supply loss is compensated by the affected supply point once it has been restored, as well as increased supplies at alternative supply points on the network. Figure 4.21 illustrates such a situation: an eight hour, 100 per cent supply point loss, occurring in a period of peak gas demand. The delayed response from alternative supply points shown would severely deplete gas stock levels making it challenging to meet customer demand.

In the near future, periods of high gas demand from CCGTs, coinciding with a supply loss event and 'backloading', could become more frequent. As supply and demand patterns continue to change, we are consulting with the industry and investigating how our models can be adapted to account for 'backloading' behaviour. The *Gas Future Operability Planning (GFOP)*[10] document provides a focus on longer-term uncertainty and the possible impacts on the transmission system, to help ensure we maintain a resilient, safe and secure network.

Figure 4.21
Illustrative example of a supply loss event



[10] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas-Future-Operability-Planning/

Chapter four

Chapter five

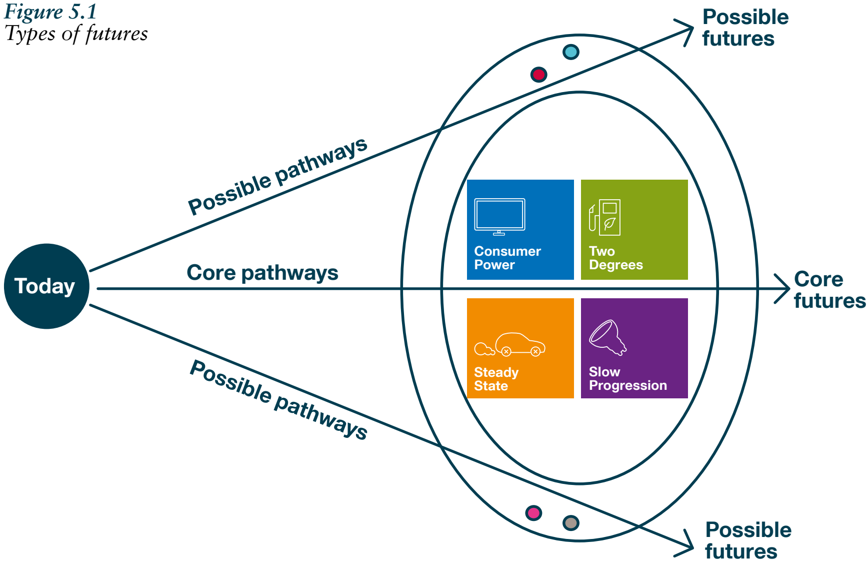
Sensitivities

5.1 Introduction to sensitivities

There is a lot of debate across the industry as to what the next technology breakthrough or future policy direction will be. We explore these uncertainties by developing sensitivities which consider a broader range of possible energy pathways. These sensitivities start with 'what if' questions – what if we rapidly adopted electric vehicles, or heat pumps, or chose to reduce fuel imports or there was a breakthrough in hydrogen technologies?

In *FES 2016* we produced a number of sensitivities around our 2050 carbon reduction targets; these were well received. From these you asked for a broader range of possible futures. For *FES 2017* we have considered four sensitivities, three of which meet our 2050 carbon reduction target and one that does not, which is focused on the electrification of transport. These sensitivities represent possible futures to give a broader view beyond the scenario envelope. They look to explore worlds where significant changes are required to realise them.

Figure 5.1
Types of futures

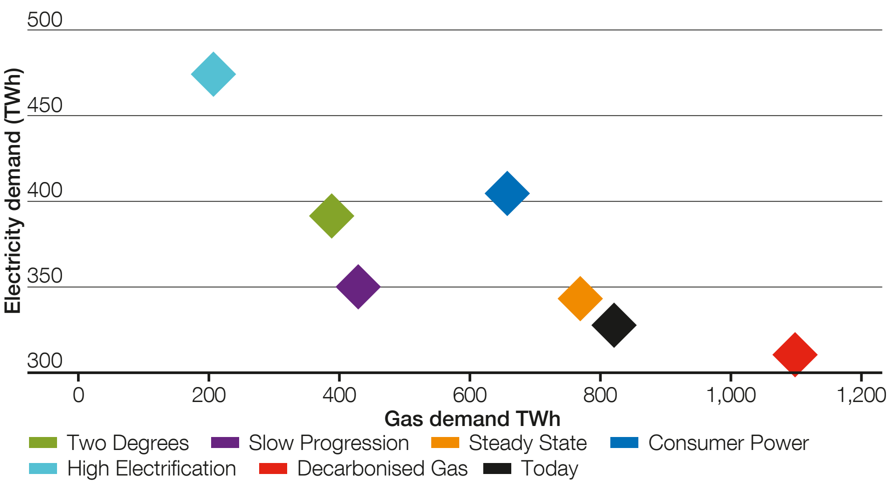


The sensitivities we have considered are set out in more detail later in this chapter and explore using decarbonised gas, high levels of electrification and large volumes of small scale generation. Additionally we investigate a rapid take up of electric vehicles (EVs). We have framed each of the sensitivities around questions the industry is currently debating and we are looking to add our insights to the potential answers.

Decarbonised Gas
What would happen if heat was decarbonised through an alternative approach to heat pumps, which still enabled the 2050 carbon reduction target to be met?

High Electrification
What would happen if society decided we should pursue a more electric future, with more renewable electricity, to help us reduce our dependency on fossil fuels?

Figure 5.2
Comparison chart to show gas demand vs electricity demand



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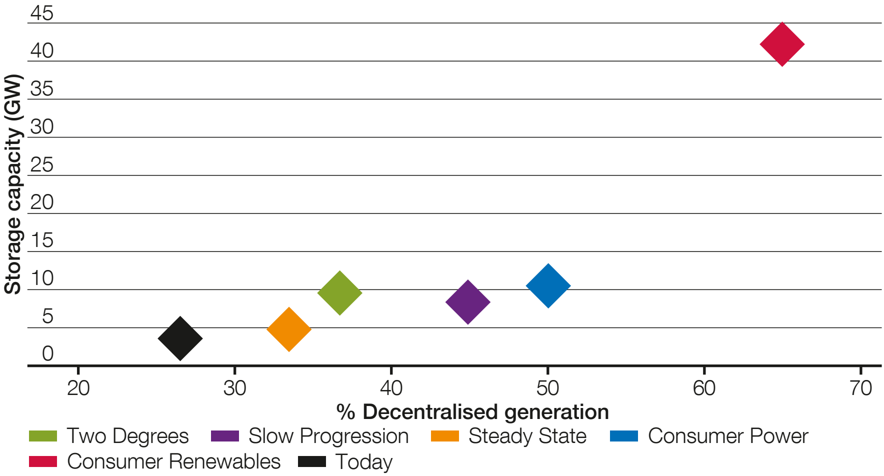
Consumer Renewables
What would happen if we saw millions of consumers and businesses installing small-scale renewable generation in their homes, offices and neighbourhoods – becoming 'prosumers'? Could we see a world where our 2050 carbon reduction target is met with a lot more decentralised rather than transmission connected generation?

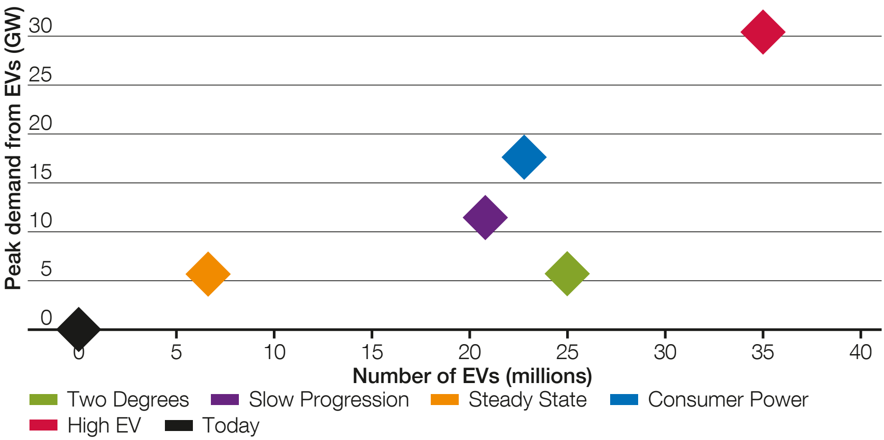
Figure 5.3
Storage capacity vs decentralised generation



High Electric Vehicles
The price of EV batteries has fallen by 65 per cent since 2010. What would happen if these cost reductions were to continue and the cost of EVs dropped significantly?

What if, at the same time, tail-pipe emissions were seen as the number one contributor to harmful pollution and vehicle pollution became one of the priorities for politicians and society?

Figure 5.4
Number and peak demand of EVs



Our sensitivities have been modelled using a high level, top down approach. Whereas the scenarios take a more detailed bottom up, holistic approach across gas and electricity. This lighter touch approach has allowed us to consider a broader range of futures than would have otherwise been possible.

As with all of *FES*, we value your feedback. We are particularly interested if you agree we have stretched our core scenarios sufficiently on the key topics currently being debated in the industry. If you have any comments or ideas for further sensitivities please get in contact with us.

Sensitivities

5.2 Decarbonised gas

Residential consumers have so far proved reluctant to switch from gas fired heating to the less familiar heat pump. Only around 60,000 heat pumps have been installed in residential properties, even with government support in the form of the **Domestic Renewable Heat Incentive** and the **Green Deal.**

Moving the entire heating demand from gas to electricity would have major implications for the generation and network capacity needed to meet the peak heating load. And yet, significant decarbonisation of heating will be required if we are to meet our 2050 environmental targets. What would happen if we found a way to reach the 2050 carbon reduction target that didn't involve a wholesale switch to electric heating?

We have created a sensitivity in which heating in some cities is provided by burning hydrogen rather than natural gas. The hydrogen is created from natural gas using a process that allows carbon to be captured, leaving a fuel with very low net carbon emissions. Using this low carbon fuel means that heating can be decarbonised without a large scale rollout of heat pumps. Hydrogen can also be used to decarbonise transport.

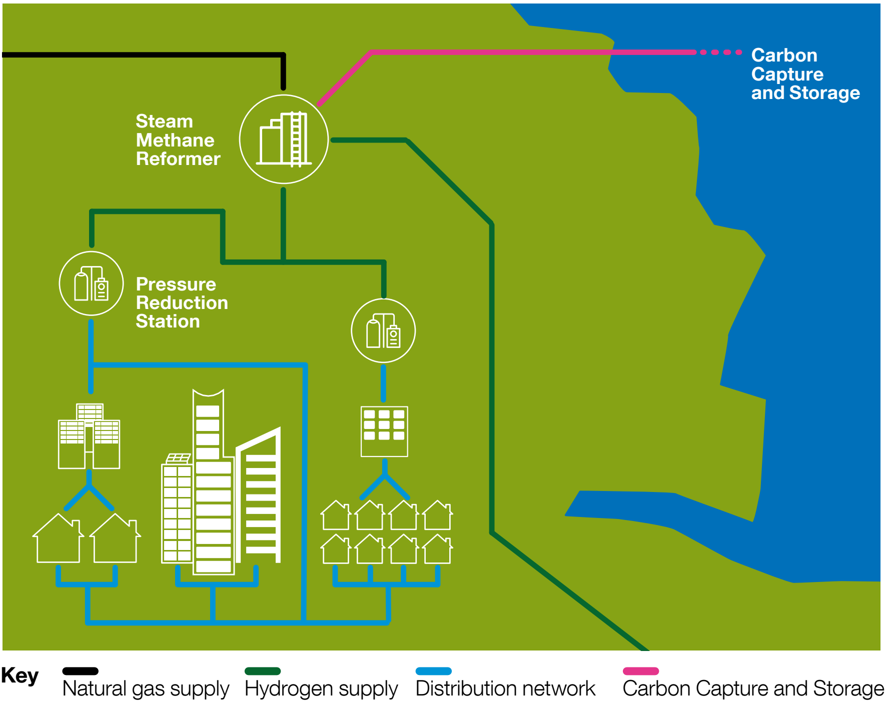
This sensitivity shares the green ambition of our Two Degrees scenario and would require considerable government support and intervention for it to be achieved.

Setting the scene

Using hydrogen for heating or transport has been discussed for many years. Fuel cell vehicles (FCV) use hydrogen as a fuel source and there have been investigations into whether hydrogen could be added to natural gas in transmission systems. Combustion of hydrogen produces no carbon dioxide, so if it can be produced without causing carbon dioxide emissions it can be very useful in assisting decarbonisation. Hydrogen can be produced by electrolysis of water and many projects are investigating using surplus electricity from renewable sources to generate hydrogen in this way. However, a well-designed energy system will tend to minimise this surplus electricity, so there is unlikely to be enough for large-scale use. Currently the most likely technology for large-scale production of hydrogen is steam methane reforming (SMR) – a chemical process that reacts methane (i.e. natural gas) with water to produce hydrogen and carbon dioxide.

Pure hydrogen cannot be transported through the steel pipes of the existing high pressure gas networks as it reacts with the type of steel used and makes the pipes brittle. However the polyethylene pipes that all distribution network companies are using to replace old, iron, low-pressure networks, are entirely suitable for transporting hydrogen. In this sensitivity we envisage that natural gas will be delivered to an SMR plant where it will be used to create hydrogen. Carbon dioxide will be removed from the waste gases using a carbon capture and storage (CCS) plant. Dedicated hydrogen pipelines are used to transport hydrogen to a city that has been completely isolated from the natural gas supply. The existing lower pressure network within the city is then used to distribute hydrogen to all consumers. Figure 5.5 shows how this might look.

Figure 5.5
Hydrogen production and supply



The concept has been developed in detail for the city of Leeds by Northern Gas Networks[1]. A rollout plan for 17 cities using four hydrogen production plants was included. We have used this as a starting point to create a sensitivity that meets the 2050 carbon reduction target.

Within the converted cities, hydrogen will be used in place of natural gas in boilers and cookers. Residential consumers will need new appliances, but the switch from a gas boiler to a hydrogen boiler should not be very disruptive. In contrast, the switch from a boiler to a heat pump frequently requires new radiators or under floor heating to be installed. Industrial and commercial users may be able to have their boilers modified rather than replaced. Once a city has been converted, there would be no option for consumers to continue to use natural gas and it is envisaged government support would be needed for the enforced upgrades. As only 17 cities are converted in this sensitivity, the size of the task would be far less than converting the whole country from town gas to natural gas as in the 1960s and 70s, but it would still be a major undertaking.

Outside the converted cities, the majority of residential and commercial consumers would continue using natural gas boilers for their

[1] http://www.northerngasnetworks.co.uk/archives/document/h21-leeds-city-gate

Sensitivities

heating. There are very few heat pumps in any markets in 2050, providing less than three per cent of the total heat requirement. In contrast, hydrogen supplies 28 per cent of the total GB heat demand by 2050.

With ready availability of hydrogen, fuel cells become a popular choice for powering HGVs, buses and vans and by 2050 have completely displaced all other fuels in these markets. Electric vehicles make some progress in the private car market, but in 2050 most cars are still powered by fossil fuels.

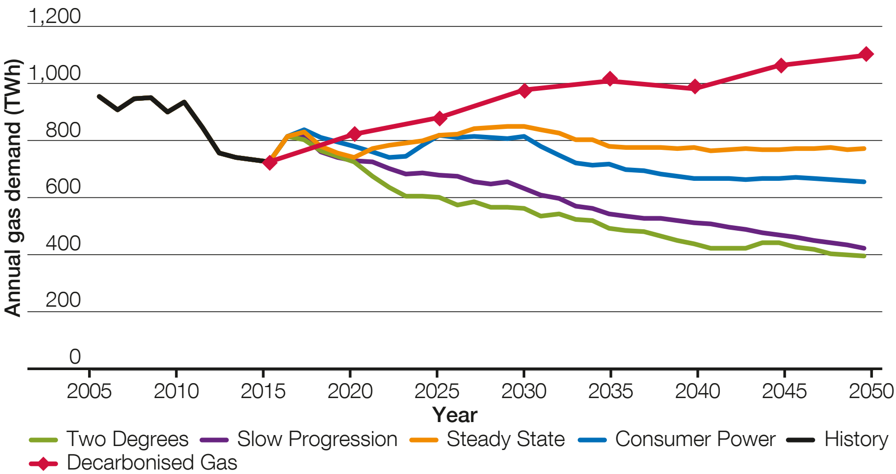
CCS is very important in this sensitivity. Successful development is needed for the low carbon hydrogen production. The infrastructure is then developed further to use with gas fired power stations. We have assumed that available funding is concentrated on this technology, so there is no further development of nuclear power. By 2050 there is 40 GW of gas fired generation with CCS on the system. This flexible plant is used to support very high deployment of renewable generation. For example, total installed wind capacity in 2050 is 61 GW, higher even than the 51 GW in **Two Degrees**.

What does this do for gas demand?

This sensitivity was designed to demonstrate an alternative to using electric heating, while still meeting the 2050 carbon reduction target. Figure 5.6 shows the effect on gas demand.

Gas demand by 2050 is around 1,100 TWh/year, comparable with the highest ever demands, which were seen in the early 2000s. Of this, 55 per cent is used for conversion to hydrogen.

Figure 5.6
Gas demand compared with scenarios



The pattern of gas supply in 2050 will be very different from 2010, when demand was last this high. In 2010 the UK Continental Shelf (UKCS) contributed around half of the total gas supply. By 2050 we are expecting the UKCS to be very nearly exhausted. We have useful contributions from biomethane and bio substitute natural gas (bioSNG), comparable with **Two Degrees**. There is also shale gas, but this still leaves a large requirement for imported gas. We are expecting that gas will be available from Norway, from continental Europe, and in the form of LNG. The current import infrastructure is large enough to cope with the volume of gas required, but it will be working at high capacity. This raises the possibility of more import infrastructure being developed, and potential reinforcement of the NTS.

Sensitivity summary

- The 2050 carbon reduction target can be met by developing hydrogen as a fuel for heating and for vehicles.
- There will be no need for an extensive rollout of heat pumps, which would require electricity network developments.
- Hydrogen supplies 28 per cent of the total heating demand by 2050.
- Outside converted cities, the majority of consumers can continue to use natural gas.
- Gas demand by 2050 is around 1,100 TWh/year
- CCS is essential for this sensitivity to work, both in hydrogen production and at gas fired power stations.
- A large deployment of gas fired generation with CCS (40 GW) supports a very high rollout of renewable capacity, without the need for nuclear generation.
- Although there will be a significant requirement for imported gas, the current import infrastructure should be large enough to handle it.

Sensitivities

5.3 High electric vehicles

The price of EV batteries has fallen by 65 per cent since 2010[2]. What would happen if this sort of price drop were to continue and the cost of EVs dropped significantly? What if, at the same time, tail-pipe emissions were seen as the number one contributor to harmful pollution and vehicle pollution became one of the priorities for politicians and society?

A recent report by the Royal College of Physicians has estimated that 40,000 deaths a year are attributable to exposure to air pollution and it is costing the UK £20 billion per year[3]. A desire to reduce vehicle pollution is beginning to gain momentum as indicated by the London Toxicity Charge[4] and the publication of the government's Draft UK Air Quality Plan for tackling nitrogen dioxide[5].

What might the rapid take up of pure electric vehicles (PEV) look like in this sort of world and how would it affect electricity demand and supply?

Setting the scene

In this sensitivity we see there being a rapid take up of PEVs. The cost of purchasing PEVs is reduced, particularly the battery element, so that overall PEVs are economically comparable with, if not cheaper than, petrol or diesel internal combustion engines (ICEs). At the same time, as a result of pollution concerns, polices are introduced to try and reduce tail pipe emissions. These could include high incentives, such as tax reliefs, pollution penalties and scrappage schemes. This desire for zero emissions is not about reaching the 2050 carbon reduction target, which has been abandoned in this sensitivity, but upon the need to improve air quality.

Consequently by 2040, 100 per cent of cars sold are PEVs. The sale of plug in hybrid electric vehicles (PHEVs) has ceased by 2025 as they have ICEs.

Drivers make up 46 per cent of the growing population throughout this sensitivity; this is the same as today's proportion. They continue to do approximately the same sort of trips, and they do not move towards smaller, more economical, vehicles. Nor do they share trips any more than today's drivers. Many cars will be autonomous but the changes this will bring to driving habits have not been modelled, although it is recognised that automation could change the volume of miles driven.

We have also assumed that the network infrastructure changes, which will undoubtedly be required to support such a rapid electrification of transport, are in place and so do not prevent consumers from owning EVs.

Other vehicles, such as heavy goods vehicles and public service vehicles, do not electrify en masse but switch to natural gas or hydrogen powered models.

[2] https://www.bloomberg.com/news/articles/2016-10-11/battery-cost-plunge-seen-changing-automakers-most-in-100-years

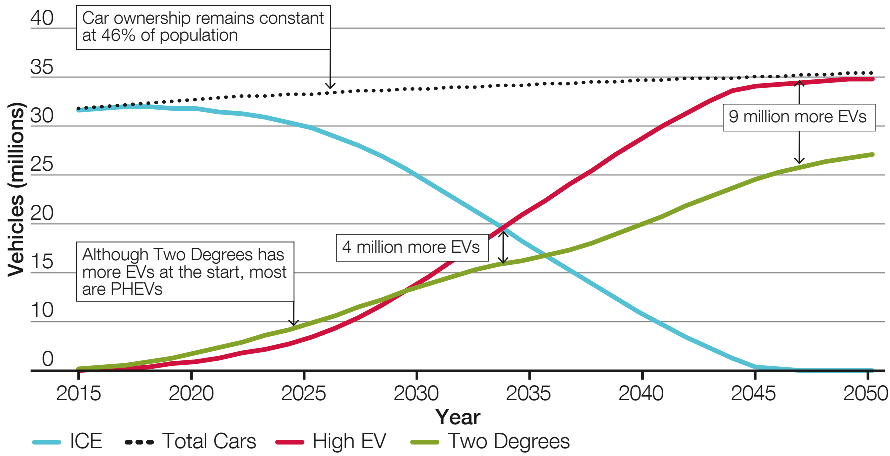
[3] https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

[4] https://www.london.gov.uk/press-releases/mayoral/mayor-introduces-10-toxicity-charge

[5] https://consult.defra.gov.uk/airquality/air-quality-plan-for-tackling-nitrogen-dioxide/supporting_documents/Draft%20Revised%20AQ%20Plan.pdf

Electricity demand
The take up rate of EVs for this sensitivity is given in Figure 5.7.

Figure 5.7
Electric vehicle uptake



By 2030 the annual demand required to supply just these EVs is 21 TWh. By 2040 this increases to 65 TWh and by 2050 to 88 TWh.

Electricity supply
Gas generation peaks, in 2040, at 223 TWh. Imports are the next largest source of electricity; the full make-up of the generation mix is illustrated in Figure 5.8.

Sensitivities

Figure 5.8
High EVs sensitivity: electricity generation sources

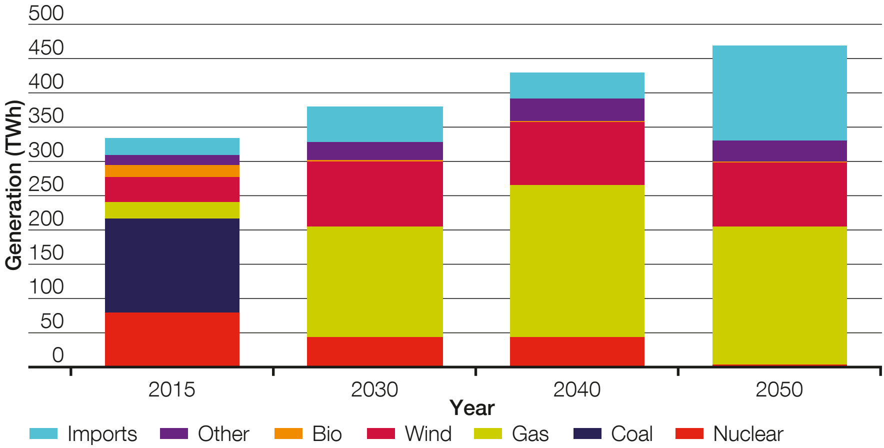
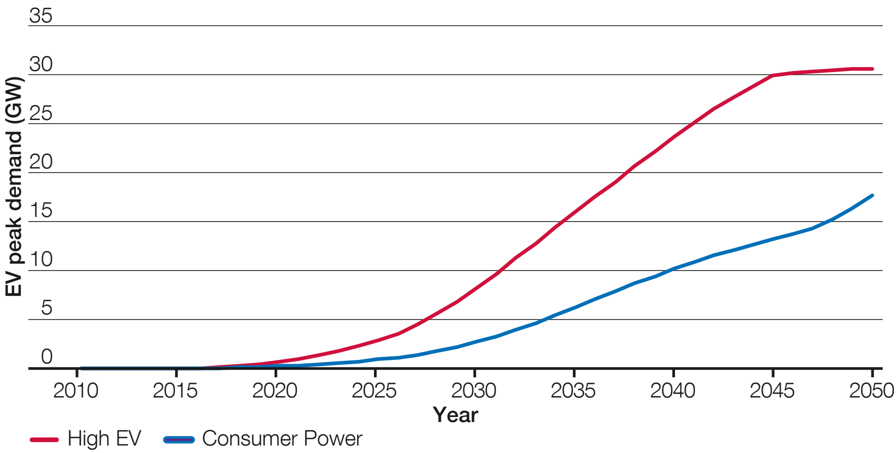


Figure 5.9
Additional peak demand required for EVs



We have applied a cost optimal approach to the generation sources. Being based on **Consumer Power** and its assumption of not meeting the 2050 carbon reduction target, gas is the dominant source for electricity generation flexibility. This will be the case from the late 2020s onwards.

Peak demand

Between 2025 and 2045 we see the average annual increase in peak demand, solely from EVs, being about 1.3GW per year. This additional demand plateaus after 2045, as saturation point is reached, with additional peak demand of about 30GW per year. Currently total peak demand is 61GW.

The resultant additional demand required is illustrated in Figure 5.9. **Consumer Power**, the scenario with the highest peak demand, is shown on the same chart.

The extent to which EVs will affect peak demand is predicated on how many units are being charged and the size of the chargers. As in **Consumer Power** we have assumed that consumers are largely unconstrained, that is, they will charge their vehicles when they want. This means about 20 per cent of car owners will charge their vehicles at peak time.

In this sensitivity the rapid uptake of EVs has been explored in relation to the demands that would be required in this world. It is one in which EVs are relatively cheap, vehicle pollution reduction is paramount and carbon reduction targets foregone. Gas sourced generation, which is sited away from urban settings, and imports appear to offer the most flexibility to meet the potential demands. High flexibility of the system will be required to meet peak demand in this high EV, high unconstrained world, much more so than in the *FES* scenarios.

Sensitivity summary

- PHEVs, with their ICEs, will not be sold after 2025.
- All cars sold after 2040 will be PEVs.
- The additional annual demand created by EVs will be around 21TWh in 2030 and 90TWh by 2050.
- After 2025, gas and electricity imports will supply the required flexibility to meet the rising demand from EVs.
- Between 2025 and 2045 peak demand will rise, on average, by 1.3GW year on year.
- By 2050, peak demand from EVs will have risen to over 30GW.

Sensitivities

5.4 Consumer renewables

Much has been discussed in industry about the potential impact of a consumer revolution in energy, with citizens becoming 'prosumers' – producers and consumers at the same time. A number of developments could move us towards a world like this – perhaps cheap and easy to install solar roofs and windows, low cost domestic storage systems or a huge take up of community energy schemes.

What would happen if we saw millions of consumers and businesses installing small-scale renewable generation in their homes and neighbourhoods? Could we see a world where the 2050 carbon reduction target is met with a lot more decentralised rather than transmission connected generation?

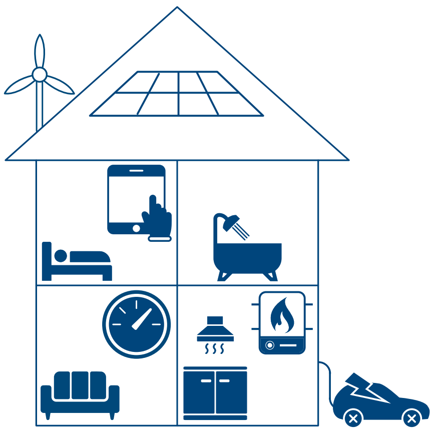
To begin to answer these questions, we start by looking at a world that is similar to the Two Degrees scenario in terms of prosperity, green ambition and broad energy demand assumptions. However, electricity supply looks quite different, with a focus on small-scale renewable generation.

Setting the scene

To find ourselves in a world where almost all consumers and businesses have enthusiastically invested in small-scale electricity generators, certain things would need to happen. We might have seen the development of technologies that dramatically change the cost and convenience of installing small-scale or residential generation systems. We explored some of these in our Emerging Technologies spotlight. Government intervention could further facilitate a shift to small renewables, for example subsidising appropriate technologies, incentivising system installations, or providing specific support such as tax relief for smaller, community-owned energy schemes.

Many buildings in this world would be able to act as mini power stations, with rooftop solar or small wind turbines, a battery and an integrated building control system linked to multiple smart appliances. A number of different commercial models would be operating to facilitate this. These could include: domestic energy systems wholly belonging to homeowners, systems owned and operated by third parties (for example aggregators managing your home's energy or solar rent-a-roof type schemes) or community owned solar and wind farms.

A home in the consumer renewable world.



The journey to 2050

What impact would these assumptions have on how electricity is generated across GB? In the Consumer Renewables sensitivity, wind and solar generation capacity grows rapidly from the mid-2020s, and gas and nuclear capacity reduces. For example, nuclear capacity falls to approximately 5 GW by 2050, significantly lower than the 20 GW of nuclear seen in **Two Degrees**. Meanwhile we see 63 GW of solar and 65 GW of wind on the system by 2050, considerably higher than any of the *FES* scenarios.

A lot of flexibility is needed to smooth output from these high levels of intermittent generation and to provide services such as frequency response to the System Operator. In the Consumer Renewables world, where we are considering community and decentralised energy, this flexibility is provided by small-scale storage. By 2050, 42 GW of storage is installed, roughly four times the amount of storage we see in our highest storage scenario, **Consumer Power**.

This very high amount of storage is crucial to balance supply and demand when such a large proportion of generation is dependent on the weather.

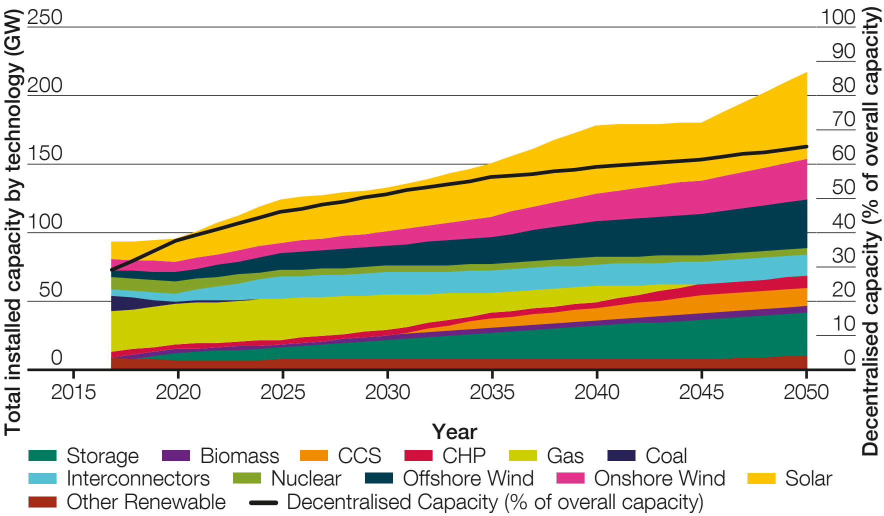
When the supply of electricity is high in GB, for example due to high wind, this large volume of storage means that electricity is more likely to be stored rather than exported. As a result, in this sensitivity both interconnection capacity (16 GW) and the volume of energy traded on interconnectors is lower than in **Two Degrees**.

63GW of solar

42GW of storage

65GW of wind

Figure 5.10
Generation capacity – Consumer renewables



Sensitivities

Transmission connected electricity generation grows slightly from the 2020s onwards, but actually falls as a proportion of overall capacity, as decentralised sources grow much more quickly. By 2050, 65 per cent of generation capacity is located behind the meter or on the distribution network, as can be seen in Figure 5.10. This is higher than our highest decentralised generation scenario, **Consumer Power**, which has only 50 per cent of generation located behind the meter or on the distribution network by 2050.

Impact on carbon emissions

By 2050 in the Consumer Renewables world, GB produces 105 megatons of CO_2 per year. This meets the 2050 carbon reduction target, but represents quite a different route to achieving this goal compared to **Two Degrees**, which has a lot of large transmission connected power plants such as nuclear. Proportionally more emissions reduction is achieved from electricity generation in this sensitivity, due to renewable growth and the reduction in use of gas for electricity generation.

System impacts

With a large growth of intermittent renewables on the distribution network, balancing the system (and associated issues such as managing frequency and voltage) will become more complex. This is because intermittent generation is more closely aligned to weather and therefore is less predictable. It may also be harder to ensure accurate data is consolidated from numerous smaller generators, so it could be more difficult to predict how these will behave. Reverse flows of power from distribution networks onto the transmission system could also become a regular occurrence.

In addition, highest solar generation output typically coincides with periods of low electricity demand during the summer. Conversely, in winter solar generation falls to zero early in the evening during times of peak demand. This sensitivity analysis has not explicitly modelled how winter demand would be met under very low temperatures coinciding with low wind conditions and zero solar output. This requires further investigation to understand whether the high levels of intermittent generation in this sensitivity could meet winter demand in such conditions. Potentially further innovation such as the development of seasonal electricity storage would be required, or there would need to be confidence that sufficient generation or demand side response would be available in these specific weather conditions.

Another way to help balance generation and supply could be the production of hydrogen. In this sensitivity, some hydrogen is produced using electrolysis. This means that excess electricity from, for example, solar generation over the summer could be used to produce hydrogen. This could then be stored and used later to provide heat.

Sensitivity summary

- In the Consumer Renewables world, the 2050 carbon reduction target can be met primarily through the use of small-scale renewable generation.
- By 2050, 65 per cent of generation is located on the distribution network or behind the meter.
- A large proportion of installed generation capacity is intermittent generation, with 63 GW of solar and 65 GW of wind by 2050.
- The resulting increased need for flexibility sees storage playing a crucial role in the Consumer Renewables world, and 42 GW is installed by 2050.
- The large increase in intermittent generation sources will lead to increased complexity in meeting high winter demand.

5.5 **High electrification**

The energy industry is divided about the best way to achieve decarbonisation and our climate change targets. Views of the future have ranged from total electrification to greater use of renewable fuels. In our Two Degrees scenario we show a pathway that meets the targets in a balanced way, making emissions reductions across all sectors. But what would happen if society decided that we should pursue a more electric future, with more renewable electricity, to help us reduce our dependency on fossil fuels?

To investigate this we have created a sensitivity where we have taken a different approach to the three sectors: heating, transport and electricity generation. More electricity is used in heating, transport is decarbonised using electric vehicles (EVs) and hydrogen fuel cell vehicles, and the installation of renewable generation is significantly increased.

This sensitivity shares the green ambition of our **Two Degrees** scenario. Adopting an even more ambitious electrification policy than **Two Degrees** will require considerable government support and intervention.

Setting the scene

In this world removing fossil fuels is both driven by consumer preference but also strongly led by government. The most efficient technology for space heating is the heat pump so it is widely used across all market sectors in this sensitivity. It is difficult to remove gas entirely. Some gas is used in hybrid heat pumps, where the majority of the heat demand is met by an electric heat pump but the peak heat demand is supplemented by output from a gas boiler. Some gas is also used in industrial processes such as steel or glass making where high temperature heat is needed.

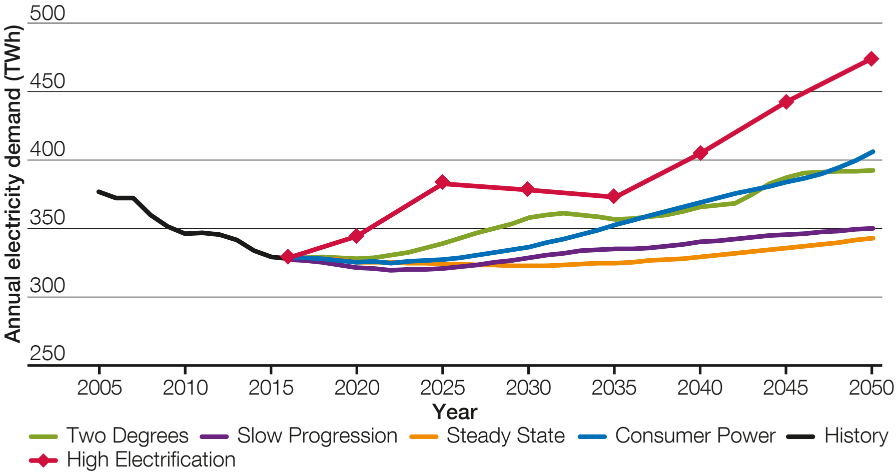
EVs dominate the private car market by 2050, though there is still some fossil fuel use. The majority of HGVs are powered by fuel cells. In keeping with the drive to reduce fossil fuel use, the hydrogen needed for the fuel cells is created by electrolysis rather than from natural gas.

Electricity demand and supply

With ambitious electrification across all sectors the total annual electricity demand rises from around 330 TWh today to 475 TWh by 2050. This is higher than in any of our four scenarios, as shown in Figure 5.11.

Sensitivities

Figure 5.11
Electricity demand in sensitivity and scenarios



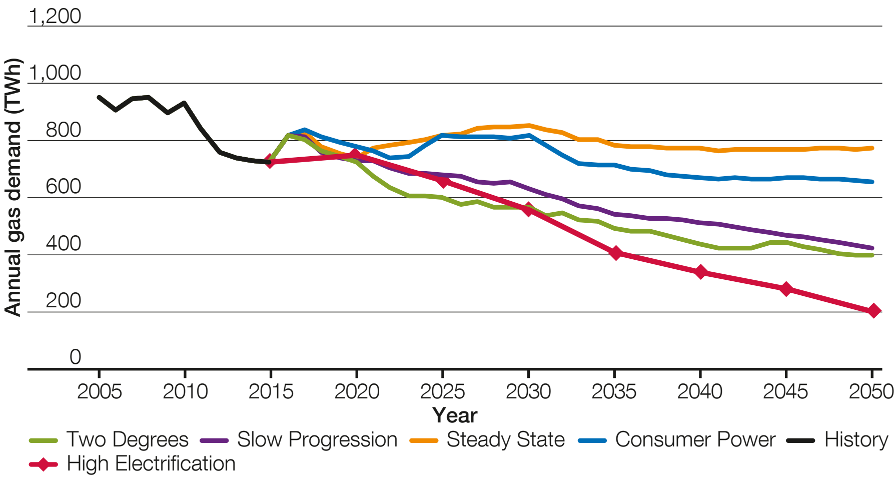
Electricity supply is almost completely decarbonised. There is a modest increase in nuclear capacity, up from today's 9GW to around 13GW. The biggest increase however is in renewable capacity and especially in wind. Total wind capacity reaches 69GW by 2050, far higher than the 51GW in **Two Degrees**, our highest wind scenario. Wind generation is, by nature, intermittent, so we have included 30GW of storage in this sensitivity. As with the wind capacity, this is far more ambitious than in any of our scenarios, although not as high as the Consumer Renewables sensitivity. Flexibility is also helped by 23GW of interconnector capacity. The final part of the flexibility picture is provided by 21GW of gas with carbon capture and storage (CCS). As gas is principally used for supporting intermittent generation it operates at a low load factor.

With the level of new generation capacity expected, there will be a requirement for considerable electricity network development.

Gas demand and supply

As we have seen, gas is largely, though not completely, removed from heating markets and from electricity generation. As a result gas demand falls from around 820 TWh today to around 200 TWh by 2050, as shown in Figure 5.12.

Figure 5.12
Gas demand in sensitivity and scenarios



In this world with very high green ambition there will have been limited investment in fossil fuels, so production from the UK Continental Shelf (UKCS) will have fallen to zero before 2050. In contrast, there will be investment in renewable gases, both biomethane and bio substitute natural gas (bioSNG), and production reaches around 45 TWh (4 bcm)[6] in 2050. The remaining gas could be supplied from Norway, from continental Europe through the interconnectors, or as LNG.

[6] Gas production is usually described in units of volume rather than energy. See the Energy supply chapter for more detail.

Sensitivities

Sensitivity summary

- This 2050 compliant sensitivity is very ambitious on the electrification of heat, decarbonisation of transport with electric vehicles and hydrogen fuel cells, and with a very high rollout of renewable generation.
- Electricity can provide for the heating needs of residential and commercial properties, but there are some high temperature industrial processes where gas will still be required.
- Electricity demand rises from around 330 TWh today to 475 TWh by 2050.
- Wind generation capacity reaches 69 GW by 2050. Connecting this many new windfarms will require significant network development.
- Gas demand is reduced from 820 TWh today to 200 TWh.

Chapter six

Glossary

Word	Acronym	Description
2050 carbon reduction target		UK commitment to reduce carbon emissions by at least 80 per cent from 1990 levels by 2050.
Aggregator		A party who acts on behalf of a number of smaller energy consumers or producers to derive value from their resources. For example, an aggregator could be given control over a number of households' energy appliances, and sell this resource into different flexibility markets where the ability to turn this large number of appliances up and down is valuable from a system operation perspective.
Air source heat pump	ASHP	Air source heat pumps absorb heat from the outside air. This heat can then be used to produce hot water or space heating.
Anaerobic digestion	AD	Bacterial fermentation of organic material in the absence of free oxygen.
Ancillary services		Services procured by a System Operator to balance demand and supply and to ensure the security and quality of electricity supply across the transmission system. These services include reserve, frequency control and voltage control. In GB these are known as Balancing Services and each service has different parameters that a provider must meet.
Autonomous vehicle		A vehicle that is capable of driving without human input.
Balgzand Bacton Line	BBL	A gas pipeline between Balgzand in the Netherlands and Bacton in the UK.
Behind the meter generation		Onsite generation that is connected before a customer's meter and therefore can provide electricity for consumption onsite without this power being metered on the distribution or transmission network.
Billion cubic metres	bcm	Unit of measurement of volume, used in the gas industry. 1 bcm = 1,000,000,000 cubic metres.
Biomethane		A naturally occurring gas that is produced from organic material and has similar characteristics to natural gas.
Biosubstitute natural gas	BioSNG	Pipeline quality gas created from waste.
Capacity Market	CM	The Capacity Market is designed to ensure security of electricity supply. This is achieved by providing a payment for reliable sources of capacity, alongside their electricity revenues, ensuring they deliver energy when needed.
Carbon capture and storage	CCS	A process by which the CO_2 produced in the combustion of fossil fuels is captured, transported to a storage location and isolated from the atmosphere. Capture of CO_2 can be applied to large emission sources like power plants used for electricity generation and industrial processes. The CO_2 is then compressed and transported for long-term storage in geological formations or for use in industrial processes.
Carbon dioxide	CO_2	The main greenhouse gas. The vast majority of CO_2 emissions come from the burning of fossil fuels.
Carbon price floor	CPF	A price paid by UK generators and large carbon intensive industries for CO_2 emissions.
Combined cycle gas turbine	CCGT	A combustion turbine that uses natural gas or liquid fuel to drive a generator to generate electricity. The residual heat from this process is used to produce steam in a heat recovery boiler which, in turn, drives a steam turbine generator to generate more electricity.
Combined heat and power	CHP	A system where both heat and electricity are generated simultaneously as part of one process. Covers a range of technologies that achieve this.
Contract for Difference	CfD	A contract between the Low Carbon Contracts Company (LCCC) and a low carbon electricity generator, designed to reduce its exposure to volatile wholesale prices.
Decentralised generation		Electricity generation that is connected to power networks below the high voltage transmission system. Includes distributed generation and onsite generation.
Demand side response	DSR	A deliberate change to a user's natural pattern of metered electricity or gas consumption, brought about by a signal from another party.

Word	Acronym	Description
Department for Business, Energy and Industrial Strategy	BEIS	UK Government department with responsibilities for business, industrial strategy, science, innovation, energy and climate change.
Dispatch (also economic dispatch)		The selection of generating capacity in order of increasing marginal cost, within the bounds of network and other operational constraints.
Distributed generation		Generation connected to the distribution networks, the size of which is equal or greater than 1 MW and up to the mandatory connection thresholds of the onshore transmission areas. The thresholds are 100 MW in NGET transmission area, 30 MW in Scottish Power (SP) transmission area and 10 MW in Scottish Hydro-Electric Transmission (SHET) transmission area.
Distribution Network Operator	DNO	A company that owns and operates gas or electricity distribution networks.
Electric vehicle	EV	A vehicle powered 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 Ten Year Statement	*ETYS*	A document published by the System Operator which illustrates the potential future development of the National Electricity Transmission System (NETS) over a ten year (minimum) period and is published on an annual basis.
Electricity Transmission Licence	ETL	A permit which allows transmission companies to own and operate electricity transmission assets. Conditions within the licence place rules on how holders can operate within their licence.
European Union	EU	A political and economic union of 28 member states that are located in Europe.
Feed-in tariffs	FiT	A government programme designed to promote the uptake of a range of small-scale renewable and low carbon electricity generation technologies.
Frequency response		An ancillary service procured by National Grid as System Operator to help ensure system frequency is kept as close to 50 Hz as possible. Also known as frequency control or frequency regulation.
Frequently asked questions	FAQ	A list of questions and answers.
Fuel cell		An electrochemical device than converts chemical energy from fuel into electricity.
Fuel cell vehicle	FCV	A vehicle powered by a fuel cell using hyrogen as fuel.
Future Energy Scenarios (publication)	*FES*	*FES* contains a range of credible futures which have been developed in conjunction with the energy industry. They are a set of scenarios covering the period from now to 2050, and are used to frame discussions and perform stress tests. They form the starting point for all transmission network and investment planning, and are used to identify future operability challenges and potential solutions.
Future Energy Scenarios in five minutes	*FES in 5*	A summary version of *FES*.
Gas absorption heat pump	GAHP	A heat pump powered by natural gas rather than electricity.
Gas day		The period from 5:00 to 5:00 UTC the following day for winter time and from 4:00 to 4:00 UTC the following day when daylight saving is applied. Gas flows into and out of the NTS have to balance over a gas day.
Gas Ten Year Statement	*GTYS*	A document published by the System Operator which illustrates the potential future development of the (gas) National Transmission System (NTS) over a ten year period and is published on an annual basis.
Gigawatt	GW	1,000,000,000 watts, a unit of power.
Gigawatt hour	GWh	1,000,000,000 watt hours, a unit of energy.
Gram of carbon dioxide per kilowatt hour	gCO_2/kWh	Measurement of CO_2 equivalent emissions per kWh of energy used or produced.

Glossary

Word	Acronym	Description
Great Britain	GB	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
Green Deal		A scheme that provided financial support to individuals and businesses to make energy efficiency improvements to their buildings. Now discontinued.
Green gas		A term used to describe low carbon gas. In the 2017 FES this category includes biomethane and bioSNG.
Gross domestic product	GDP	The total market value of all goods and services produced in a country in a given year. This is equal to total consumer, investment and government spending, plus the value of exports, minus the value of imports.
Ground source heat pump	GSHP	Heat pumps which absorb heat from the ground. This heat can then be used to produce hot water or space heating.
Heat pump		A device that transfers heat energy from a lower temperature source to a higher temperature destination.
Heavy goods vehicle	HGV	A truck weighing over 3,500 kg.
Industrial and commercial	I&C	A category used for aggregating energy demand, based on the Standard Industrial Classification (SIC (2007)).
Information communication technology	ICT	Includes computing and digital communication.
Interconnector (UK)	IUK	A bi-directional gas pipeline between Bacton in the UK and Zeebrugge Belgium.
Interconnector		Transmission assets that connect the GB market to Europe and allow suppliers to trade electricity or gas between markets.
Internal combustion engine	ICE	An engine powered by petrol, diesel or gas. Used in FES to refer to engines powering vehicles.
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		The average power output divided by the peak power output over a period of time.
Loss of load expectation	LoLE	Used to describe electricity security of supply. It is an approach based on probability and is measured in hours/year. It measures the risk, across the whole winter, of demand exceeding supply under normal operation. This does not mean there will be loss of supply for 3 hours per year. It gives an indication of the amount of time, across the whole winter, which the System Operator (SO) will need to call on balancing tools such as voltage reduction, maximum generation or emergency assistance from interconnectors. In most cases, loss of load would be managed without significant impact on end consumers.
Marine technologies		Tidal streams, tidal lagoons and energy from wave technologies.
Medium range storage	MRS	Gas storage facilities designed to switch rapidly between injection and withdrawal to maximise the value from changes in gas price.
Megawatt (electrical)	MWe	1,000,000 watts, a unit of electrical power.
Megawatt hour	MWh	1,000,000 watts hours, a unit of energy.
Micro-combined heat and power	mCHP	A subset of CHP, designed for domestic use.
Million cubic meters	mcm	A unit or measurement of volume, used in the gas industry. 1 mcm = 1,000,000 cubic metres.
N-1		Condition used in a security of supply test, where total supply minus the largest single loss is assessed against total peak demand.
National Transmission System	NTS	A high-pressure gas transportation system consisting of compressor stations, pipelines, multijunction sites and offtakes. NTS pipelines transport gas from terminals to NTS offtakes and are designed to operate up to pressures of 94 barg.
Natural gas vehicle	NGV	A vehicle which uses compressed or liquefied natural gas as an alternative to petrol or diesel.

Word	Acronym	Description
Office of Gas and Electricity Markets	Ofgem	The independent National Regulatory Authority in GB; a non-ministerial government department. Their principal objective is to protect the interests of existing and future electricity and gas consumers.
Open cycle gas turbine	OCGT	A combustion turbine plant fired by gas or liquid fuel to turn a generator rotor that produces electricity.
Peak demand, electricity		The maximum electricity demand in any one fiscal year. Peak demand typically occurs at around 5:30pm on a week-day between November and February. Different definitions of peak demand are used for different purposes.
Peak demand, gas		The level of demand that, in a long series of winters, with connected load held at levels appropriate to the winter in question, would be exceeded in one out of 20 winters, with each winter counted only once.
Photovoltaic	PV	A method of converting solar energy into direct current electricity using semiconducting materials.
Plug-in hybrid electric vehicle	PHEV	A vehicle which has a battery that can be charged by plugging it in, as well as a combustion engine.
Political, Economic, Social, Technological and Environmental	PESTE	A framework used to analyse and monitor the macro-environmental factors that have an impact on an organisation.
Pure electric vehicle	PEV	A vehicle powered only by a battery.
Renewable Heat Incentive	RHI	A payment incentive administered by Ofgem which pays owners of certain renewable heating technologies per unit of heat produced. There is a domestic and a non-domestic version.
Renewables Obligation	RO	A support mechanism for renewable electricity projects in the UK. It places an obligation on UK electricity suppliers to source an increasing proportion of the electricity they supply from renewable sources.
Repowering		Re-fitting a generation site with new equipment such as new wind turbine blades so that it can continue to generate electricity, usually more efficiently than previously.
Seasonal storage or long range storage	LRS	A gas storage facility which mainly puts gas into storage in the summer and takes gas out of storage in the winter. There was one long-range storage site on the national transmission system: Rough, situated off the Yorkshire coast. Rough was formally closed in June 2017.
Shale gas		A natural gas that is found is 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.
Shared vehicle		A vehicle that fulfils the transportation requirements of more than one person.
Small modular reactor		Nuclear reactors, generally 300MWe 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.
Space heating		Heating an enclosed area.
Steam Methane Reforming	SMR	A method for producing hydrogen, carbon monoxide, or other useful products from hydrocarbon fuels such as natural gas.
System operability		The ability to maintain system stability and all of the asset ratings and operational parameters within pre-defined limits safely, economically and sustainably.

Glossary

Word	Acronym	Description
System Operator	SO	An entity entrusted with transporting energy in the form of natural gas or electricity at a regional or national level, using fixed infrastructure. The SO may not necessarily own the assets concerned. For example, National Grid operates the electricity transmission system in Scotland, which is owned by Scottish Hydro Electricity Transmission and Scottish Power.
Terawatt hour	TWh	1,000,000,000,000 watt hours, a unit of energy.
Time-of-use tariff	TOUT	A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high electricity demand times.
UK Continental Shelf	UKCS	Comprised of those areas of the sea bed and subsoil beyond the territorial sea over which the UK exercises sovereign rights of exploration and exploitation of natural resources.
Unabated coal		Coal fired electricity generation that is not fitted with carbon capture and storage.
United Kingdom of Great Britain and Northern Ireland	UK	A geographical, social and economic grouping of countries that contains England, Scotland, Wales and Northern Ireland.

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Write to us at:
Energy Insights
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

YouTube
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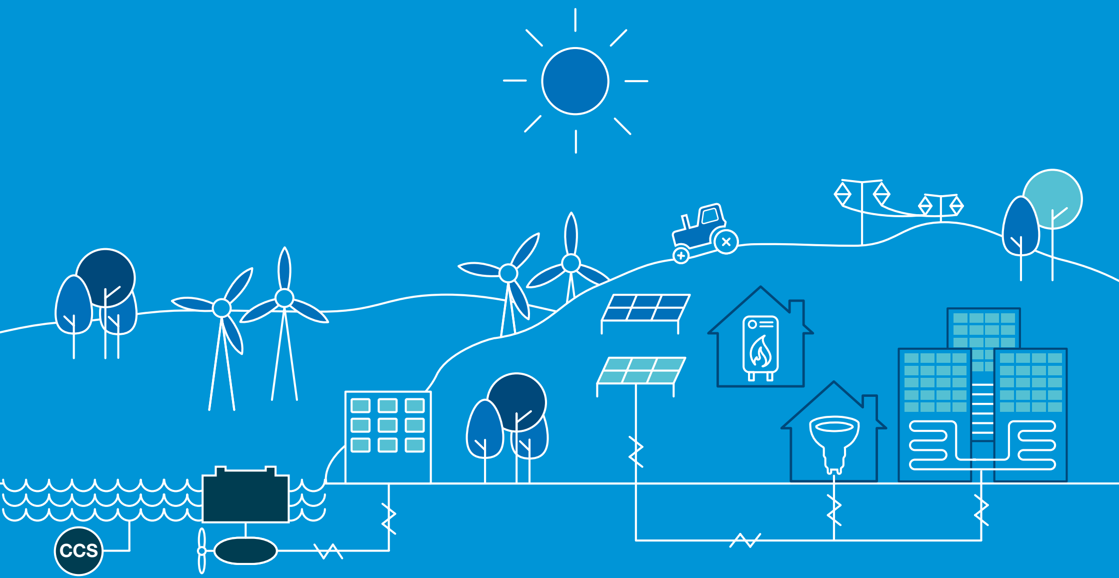

National Grid plc
National Grid House,
Warwick Technology Park,
Gallows Hill, Warwick.
CV34 6DA United Kingdom
Registered in England and Wales
No. 4031152

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