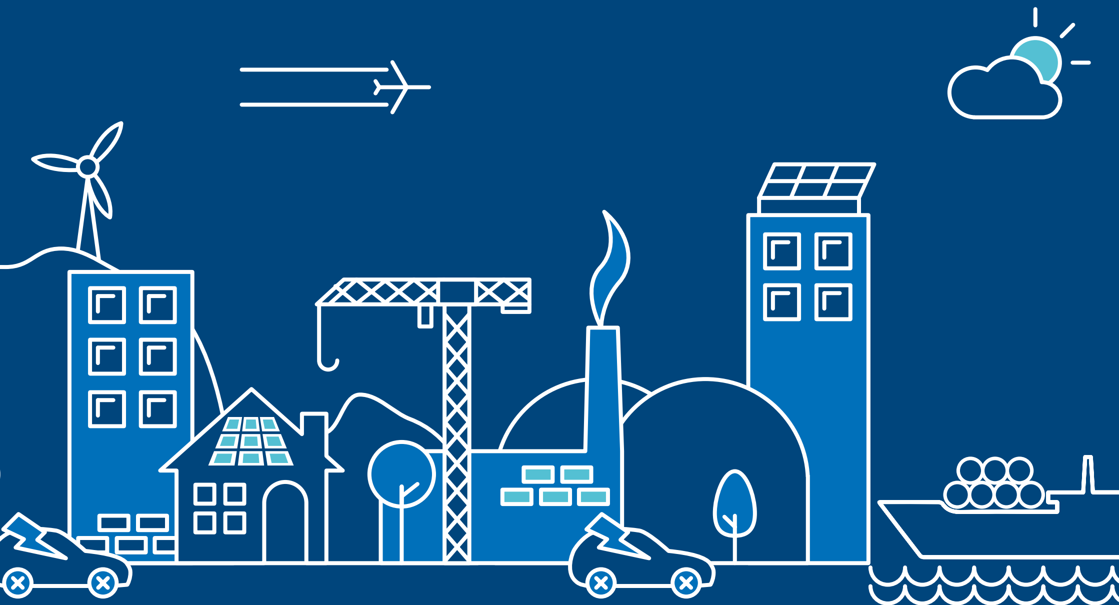
nationalgrid

Future Energy Scenarios

GB gas and electricity transmission



JULY 2016

How to use this 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.

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

Hyperlinks
Hyperlinks are highlighted in bold throughout the report. You can click on them to access further information.

Over the past year, the changing dynamics of energy have become increasingly evident, creating more opportunities than ever across the industry. Our 2016 *Future Energy Scenarios*, along with our other System Operator publications, aims to facilitate debate and lead to changes which ensure a secure, sustainable and affordable energy future.

We are in the midst of an energy revolution. The economic, technological and consumer landscapes are changing at an unprecedented rate. 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*, we can be confident that the reality will be captured somewhere within that range.

I would like to thank you for your engagement with us over the past year. It is your views, knowledge and insight which shape the scenarios and allow us to better understand the uncertainties surrounding the future of energy.

Now we've completed our analysis, we can look holistically at our possible energy futures. In doing so, a number of key themes arise.

Firstly, it is clear that our world is changing and we need to respond. We have seen significant change over the past year: renewable electricity generation growth rates, advancements in alternative sources of gas, innovation of new consumer technologies and more. This transformation is set to continue. Indeed it must, and we cannot afford to delay advancement if we are to progress towards our environmental targets.

Secondly, it is clear that components of our energy world are becoming increasingly interlinked. The role and use of our gas and electricity systems are increasingly connected. These changes demand a new, more flexible way of thinking and create opportunities for innovation across the energy industry.

I hope that you find this document, along with the other publications from the System Operator, useful as a catalyst for wider debate. Please do share your views with us; you can find details of how to engage with us on our website **http://fes.nationalgrid.com**.

Marcus Stewart
Head of Energy Insights,
System Operator

Contents

Chapter one

Executive summary

1.1
The 2016 Future Energy Scenarios – an evolutionary approach

We are only able to produce a credible set of Future Energy Scenarios through the involvement of our stakeholders from across the energy sector and beyond. Our 2016 scenarios have been created following thorough data collection and stakeholder engagement, as shown in Figure 1.1.

We host a suite of engagement activities to allow our stakeholders to get involved in a way that suits them, including workshops and bilateral meetings. We then analyse the feedback we have received to shape the development of our scenarios. Through improvements to our stakeholder engagement activities, we have consulted 362 organisations this year, up by 129 since last year.

In line with our Electricity Transmission Licence Standard Condition C11, we submitted our *Stakeholder Feedback Document* to Ofgem in January 2016. Following its review, Ofgem stated it was provided with sufficient comfort that a wide range of views have been taken into account.

Since January we have been undertaking detailed analysis and modelling to produce the scenarios set out in this document.

Most feedback we received on our 2015 scenarios was highly positive. Overwhelmingly, our stakeholders told us that they want to see consistency year on year in the *FES*. This has reaffirmed our approach to *FES* 2016 and there are no big changes to our scenarios this year.

Consequentially, our 2016 scenarios are once again an evolution from the previous year. We have continued to use the 2×2 matrix approach (with axes of Green ambition and Prosperity) to structure our scenarios. We have also maintained the names **Gone Green**, **Slow Progression**, **No Progression** and **Consumer Power**, as shown in Figure 1.2.

Figure 1.1
The scenario development process

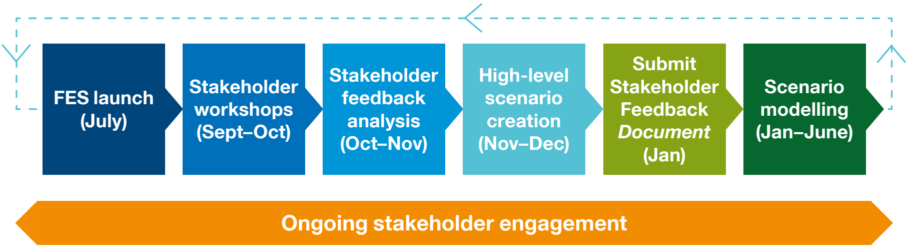


Figure 1.2
The 2016 scenario matrix

Executive summary

1.2
Continuing the conversation

The *FES* is one document within the System Operator (SO) suite of publications on the future of energy for Great Britain. We aim to inform the whole energy debate through addressing specific issues in each document.

FES considers the potential changes to the demand and supply of energy. Our scenarios are not constrained to the capability of the current gas and electricity networks. To explore what network and operability changes would be required to operate the electricity scenarios, please see the *Electricity Ten Year Statement* and the *System Operability Framework*.
For gas, these are explored in the *Gas Ten Year Statement* and the *Future Operability Planning* documents.

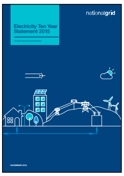
Figure 1.3
The key SO publications in 2016 and 2017

Future Energy Scenarios
July 2016

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

Winter Outlook Report
October 2016

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

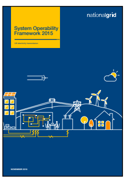


Electricity Ten Year Statement
November 2016

The likely future transmission requirements on the electricity system.

Gas Ten Year Statement
November 2016

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

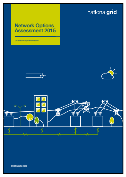


System Operability Framework
November 2016

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

Future Operability Planning
November/December 2016

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



Network Options Assessment
January 2017

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

Summer Outlook Report
April 2017

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

Winter Review
May 2017

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

Winter Consultation
June 2017

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

Executive summary

1.3
Key messages arising from *FES* 2016

The decarbonisation agenda is driving significant changes to the energy supply market. Traditional sources of supply are being replaced with an ever-divergent mix.

- This is a trend we have been anticipating for some years for electricity supply. The scale of change has been faster than many anticipated, for example in the rate of decline of traditional fossil fuel generation, the roll-out of some types of renewable capacity and prominence of small-scale generation.
- Many of these changes reduce generation flexibility. This creates an increasingly important opportunity for consumers to offer demand flexibility services.
  - Through our Power Responsive programme we are collaborating and engaging with potential participants to accelerate the uptake of demand side response opportunities.
  - Electricity storage can support flexibility requirements. Our scenarios show a maximum installed capacity from storage technologies of approximately 18 GW in 2040.
- We are also now anticipating an evolution of gas supplies. New sources of gas are under development to supplement traditional gas supplies. These include shale, biomethane, bio-substitute natural gas, and hydrogen from electricity to gas schemes. **Consumer Power** 2016 sees 54 per cent of gas demand met by alternative sources by 2040.

Over the past year the volume of renewable electricity sources has increased substantially. While the electricity generation sector is on the required trajectory, significant progress is still needed in the heating and transport sectors if the UK is to meet the 2020 renewable target on time.

- **Gone Green** meets the (unofficial) sub-target (34 per cent of electricity being sourced from renewables) on time due to the growth of wind, bioenergy and solar generation.
- The slower progress in the heating and transport sectors means the scenarios reach the overall target (15 per cent of energy being sourced from renewables) after 2020. It is met at dates ranging between 2022 in **Gone Green** and 2029 in **No Progression**.
- The sector requiring most development is heating. To meet the 15 per cent target, renewable heat needs to increase by around 60 TWh from 2016 levels. Over the past four years there was an increase of less than 10 TWh, therefore the pace of change needs to increase significantly.
- Approximately a 25 TWh increase in renewable transport is also required, above the current level of 14.5 TWh.

Action needs to be taken this decade to drive progress towards the 2050 target (an 80 per cent reduction in greenhouse gas emissions from 1990 levels).

- We agree with the Committee on Climate Change that the cost-optimal route is to decarbonise electricity generation, then use low-carbon electricity to support decarbonisation in the heat and transport sectors.
- While other technologies can support the transition, decarbonising the electricity generation sector requires at least two of nuclear, renewable and carbon capture and storage (CCS). The cost-optimal pathway utilises all three of these technologies; using approximately 22 GW of nuclear, 100 GW of renewables and 20 GW of CCS in 2050.
- A clear pathway to decarbonise heat and transport is vital, with heating posing the biggest long-term challenge. To do this in the most cost-effective way, approximately 25 per cent of heat and of transport need to be decarbonised by 2030. Renewable sources of both electricity and gas will be utilised in the transition.

The importance of gas in GB's energy mix has been further emphasised this year. It will play a key role in energy decarbonisation by providing flexible electricity generation and top-up heating over the long term.

- In line with the Secretary of State's energy policy announcement in November 2015 our scenarios have a high level of gas-fired generation.
- While currently used as base load generation, over the scenario period gas will become an increasingly important source of flexible electricity generation. This flexibility will support the growth of renewable sources of electricity generation.
- Gas will be a primary heating fuel until the 2040s and will then support the electrification of the sector by providing the most efficient source for top-up heating.
- These changes to the demand for gas, enabling customers to take the demand they want from the system when they want it, will create new operability challenges, requiring greater system flexibility.

Executive summary

1.4
Key statistics in 2030

Table 1.1
Key statistics in 2030

	2015	Gone Green	Slow Progression	No Progression	Consumer Power
Electricity					
Annual demand (TWh)	334	346	318	322	331
Peak demand (GW)	61	67	59	61	63
Total installed capacity (GW)	97	165	131	114	157
Low carbon capacity (GW)	39	103	78	53	87
Interconnector capacity (GW)	4	23	15	11	23
Total storage capacity (GW)	3	8	4	3	11
Gas					
Annual demand (TWh)	880	603	633	808	746
1-in-20 peak demand (GWh/day)	5,194	4,714	4,906	5,640	5,261
Residential demand (TWh)	326	189	251	299	275
Gas imports (%)	58	72	80	62	25
Shale production (bcm/yr)	0	0	0	15	30
Decarbonisation					
Renewable energy (%)	~8[1]	31	27	21	23
Reduction in carbon emissions (%)	~37[1]	58	53	48	49

All numbers rounded to the nearest whole number.

[1] Actual 2015 data not available at the time of writing. This estimate is based on DECC's 2014 figures.

1.5
Using this document

Stakeholders have asked us to provide more of our insight within the *FES*. In order to do so we have introduced two new features to the document this year: spotlights and road maps. You'll find these throughout chapters three to five.

Road maps, like the one shown in Figure 1.4 below, are used to show one credible pathway to a given outcome, such as installing 11 million low carbon heating technologies, or reaching the 2050 carbon reduction target. While this is our best view, it may not be the only route to the outcome.

Here is an example of a road map to over 7 GW of new gas-fired electricity generation capacity opening by 2022.

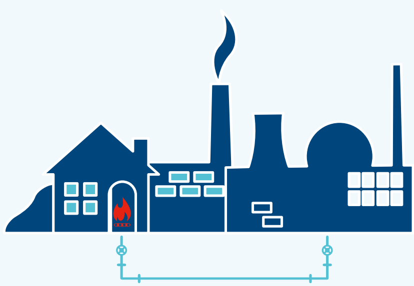
Figure 1.4
Road map to over 7 GW of new gas capacity by 2022

Spotlights are breakout boxes which provide more detail on specific topics. These range from more information on technologies used in the scenarios, to discussions on how new innovation or market change could affect the future of energy. Here is an extract of our spotlight on district heat, which you can see in full on page 50.

Spotlight: District heat

A district heat network constitutes a heat source and a distribution network of thermally insulated pipes.

Heat is transferred from the source into the buildings on the network. The heat enters the internal distribution network of the building, just like a boiler but via a heat exchanger, and puts heat into the radiators of a centrally heated home.



Chapter two

Scenarios

Gone Green is a world where policy interventions and innovation are both ambitious and effective in reducing greenhouse gas emissions. The focus on long-term environmental goals, high levels of prosperity and advanced European harmonisation ensure that the 2050 carbon reduction target is achieved.

Political
In **Gone Green**, policy interventions are a driving force behind realising a renewable, low carbon world. Regulations and incentives are in place to support the green ambition and are effective, resulting in high taxes for carbon-intensive technologies. Funding is available to support innovation in green technologies such as renewable generation and low carbon heating systems. High levels of environmental legislation are in place, for example in the building and transport sectors. There is fast progress towards a more harmonised European energy market, which also favours a high level of green ambition.

Economic
Disposable incomes, and economic growth rates over time, are high. This allows individuals and businesses to invest in new products and solutions, despite high energy prices resulting from subsidies and taxation.

Social
Innovation in demand technologies helps to enable progress towards environmental targets. Society is actively engaged in reducing greenhouse gas emissions, therefore knowledge and adoption rates are high. This results in high installation rates for products such as insulation, home energy management systems and domestic batteries.

Technological
Electricity generation developments are focused on renewable and low carbon technologies. As such we see the highest build rates of nuclear, solar and wind generation in this scenario. Electricity interconnection is high due to a mixture of commercial and regulatory support. As gas plays an important role in the energy mix, investment is also made in new developments. Support is focused on green methods of production, favouring biomethane and other sources of renewable gas, over shale gas.

These demand and supply changes result in progress being made towards the 2020 renewable energy target (15 per cent of energy being met from renewable sources), though only the 34 per cent electricity sub-target is met on time. A combination of carbon capture and storage (CCS), wind and nuclear generation ensures that the 2050 carbon reduction target (80 per cent reduction from 1990 levels) is met on time.

Life in 2040
We follow Oscar and his family in 2040. They have decided it is a priority to install new products to increase the efficiency of their home. Their smart meter is integrated in a whole-house smart energy system, which automatically shifts discretionary energy usage to times of lower cost. This also manages the charging of Oscar's electric car to ensure he always has enough charge for his upcoming journey but at lowest cost. Around half of Oscar's neighbours have replaced their gas boilers with low carbon alternatives. Air source heat pumps are the most popular choice. Oscar's car fits in well with his neighbours' as a third of the town have also bought an electric car. His wife travels to work on a bus that is powered by compressed natural gas.

Oscar's employer also wants to reduce energy usage in the workplace. The building minimises its electricity consumption by utilising highly efficient light emitting diode (LED) light bulbs and heat pumps. The whole site is managed by an integrated energy management system. The company also aims to maximise the energy they produce themselves, so have installed solar panels on the roof and purchased a battery to store excess electricity for use later. They offer demand side services, flexing their electricity demand in return for payment.

15% of energy sourced from renewable sources by 2022.

23.3 GW of electricity import capacity in 2030.

84% of electricity generation is from low carbon sources in 2040.

6 million residential low carbon heating technologies installed by 2040.

Scenarios

Slow Progression is a world where economic conditions limit society's ability to transition as quickly as desired to a renewable, low carbon world. Choices for residential consumers and businesses are restricted, yet a range of new technologies and policies develop. This results in some progress towards decarbonisation but at a slower pace than society would like.

Political
In **Slow Progression**, government intervention is constrained by affordability. Policies balance the objective of moving to a renewable, low carbon world against the constraint of less money being available. There is a focus on low-cost solutions, delivering long-term value for money. Modest developments towards European harmonisation also help facilitate the decarbonisation agenda.

Economic
Economically, Great Britain sees a relatively slow and low growth rate. This results in society having a low disposable income. High taxes and subsidies inflate retail gas prices. Subsidies to support renewable and low carbon generation increase electricity retail prices, but to a lesser extent than in **Gone Green** as support mechanisms are limited.

Social
Despite the lower levels of prosperity, society is actively engaged in reducing greenhouse gas emissions. Individuals and businesses are knowledgeable about their energy use and the technologies available to them. They seek out opportunities to reduce their energy use and emissions, but will only make an investment if a reasonable payback period is achievable. Within homes and businesses the cheapest energy reduction solutions are preferred such as loft and cavity wall insulation. There is significant progress towards the electrification of transport, with much of the rail network electrified by 2050, and a high adoption rate of plug-in hybrid electric vehicles (PHEVs).

Technological
Money available to invest is relatively low and incentive schemes have a reduced potential due to limited budgets. This results in a slower than desired installation rate of low carbon generation technologies such as nuclear, wind and solar. As such, the 2020 renewable target is met in 2024 and the 2050 carbon reduction target beyond the scenario period. Investment in gas production is limited and focused on alternative technologies such as biomethane. Low offshore production and a lack of development in GB shale gas see the import dependency rise significantly.

Life in 2040
Despite her low income, Lily works hard to reduce her greenhouse gas emissions at home and at work. She considers replacing her car with a new electric model, but decides to wait for costs to come down before making such a large purchase. She shares her daily commute with a colleague to save money and reduce her impact on the environment. Lily decides to replace her ageing gas boiler and looks into many options. She chooses to install a hybrid heat pump, as it is a cost-effective step towards reducing emissions. Lily's neighbours have a new-build house which is connected to the new district heating scheme, with biomass supplying their heat.

Lily's business partner has researched a number of investment opportunities for their business. They sign off plans to upgrade the company's vehicle fleet to PHEVs as their low running cost makes the payback period acceptable. Additionally they install both loft and cavity wall insulation to reduce the heat energy escaping from the building.

960,000 homes use district heating to supply their heat demand in 2040.

7.8 million electric vehicles in 2040.

93% of gas is imported in 2040.

Wind provides 34% of electricity in 2030.

Scenarios

No Progression is a world where business as usual activities prevail. Society is focused on the short term, concentrating on affordability above green ambition. Traditional sources of gas and electricity dominate, with little innovation altering how energy is used.

Political
No Progression focuses on the here and now, with little emphasis placed on reducing greenhouse gas emissions. Government intervention aimed at driving change in the energy sector is limited, with a reduction in environmental incentives and no further progress towards European harmonisation. Policies focus on supporting traditional, indigenous energy supplies.

Economic
Economic conditions are restricted, with low growth rates and disposable incomes. Minimal subsidies result in low electricity retail prices. Gas retail prices are neither high or low, as they are influenced by both high gas demand which drives up the price and low taxes which reduce the price.

Social
Energy users focus on reducing their bills and costs. Adoption and replacement rates are low as people prefer to stick with products and services that they know and only replace them when they break. There is little consumer interest in green products and little incentive to encourage replacement. Commercial users are reluctant to commit to long payback periods for investment in new technologies, limiting their uptake. Heating and transport demands are mostly met from traditional sources, with little progress in electrification.

Technological
Technological innovation and developments focus on reducing costs and ensuring security of supply. As such, established electricity generation technologies dominate, such as wind, gas and nuclear. Progress towards the 2020 renewable energy target and the 2050 carbon reduction target is very slow. The 2020 renewable target is met in 2029 and the 2050 carbon reduction target is met beyond the scenario period. In the gas sector, the focus on security of supply drives developments in offshore production and shale extraction. This reduces GB's import dependency and supports a continuing role for gas generation.

Life in 2040
Phoebe is cost conscious and focused on short-term savings. She has a limited disposable income and doesn't want to make any big changes. She embraces new technologies if they can save her money. Phoebe has no intention to change her home's heating system. If it broke she would choose a like-for-like replacement, as the easiest and cheapest option. She picked the cheapest energy supplier and is not interested in green tariffs or products.

The company Phoebe works for runs as usual. It makes investments to drive business growth and maximise profits. Environmental impacts are given very little consideration.

88% of residential heating is met by gas in 2040.

There is 50% less wind generation installed than in **Gone Green** by 2040.

25% of electricity is generated from gas-fired power stations in 2030.

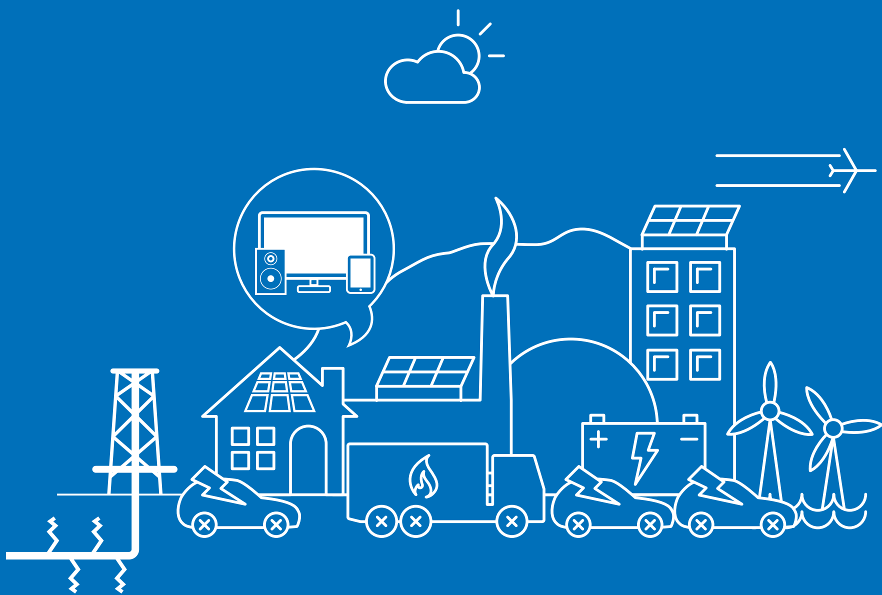
There is the lowest electricity demand of all scenarios by 2050.

Scenarios

Consumer Power is a market-driven world, with limited government intervention. High levels of prosperity allow for high investment and innovation. New technologies are prevalent and focus on the desires of consumers over and above reducing greenhouse gas emissions.

Political
In **Consumer Power**, there is limited government intervention and many decisions and policies are set at local levels. Policies focus on facilitating the free market, with less focus on reducing greenhouse gas emissions.

Economic
Economic conditions are favourable in **Consumer Power**; high growth rates result in money being plentiful for both residential consumers and businesses. Gas retails at a low price due to low taxes on consumers. The high levels of distributed generation, low levels of taxation and subsidies, and high demand for electricity have conflicting impacts on the electricity retail price.



Social
Society is enjoying the benefits brought by high prosperity. Consumers actively look for new products to enhance their lifestyle and comfort or to save money, causing high product replacement rates. Any reductions in emissions are a by-product of new technologies being more efficient, rather than a demand for green products. In some areas energy use rises, for example, air conditioning. Other trends, such as the electrification of heating, result in higher efficiencies and therefore cause a reduction in energy consumption.

Technological
There is a high level of support for local energy production from individuals and communities. As a result, the level of installed capacity from distributed generation and electricity storage technologies is higher than in the other three scenarios. Technologies new to GB, such as liquid air electricity storage, are introduced following high market-driven expenditure on innovation projects. Commercial opportunities drive high levels of electricity interconnection. There is significant investment in the gas sector, targeted at maximising indigenous production rates. This results in high rates of production from both offshore fields and shale gas, and lower requirements for imports. The 2020 renewable target is met in 2026 following further electrification of the heat and transport sectors, and developments in renewable generation. The 2050 carbon reduction target is met beyond the scenario period as electricity demand remains high and decarbonising energy sources is a lower priority.

Life in 2040
Jack likes gadgets and buys products to improve his quality of life. He has a PHEV, air conditioning and appliances connected to the internet. He recently installed solar photovoltaics (PVs) to produce his own electricity. Additionally Jack has installed a micro-CHP unit to heat his home and provide further electricity. He has a home energy management system to ensure it is always at a comfortable temperature when he is at home.

Jack's company has been investing lots of money to drive higher profits. The vehicle fleet has been upgraded to natural gas vehicles. Solar PV, along with a micro-CHP unit, produce electricity on site.

18 GW of electricity storage installed by 2040.

207,000 natural gas vehicles by 2040.

32 bcm of UK shale gas extracted per year in 2040.

49% of electricity generation is from small-scale generation in 2040.

Chapter three

Russell Fowler
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Energy demand

3.1 Energy demand

Energy demand comprises both electricity and gas demand; these are increasingly interlinked. The demand for gas currently makes up about 75 per cent of the total. However, in the future there is the potential for change, for example, through the electrification of heating and transport.

Key insights

- Annual electricity demand in 2015 was 334 TWh; by 2040 it is between 329 and 384 TWh.
- Annual gas demand in 2015 was 880 TWh. By 2040 it is between 589 and 809 TWh.
- Electricity demand in **Gone Green** grows as a result of increased use of electric vehicles and the electrification of heating.
- Gas-fired generation enabled with carbon capture and storage (CCS) helps meet electricity demand in this scenario. This also reverses the decline in gas demand seen before 2030.
- The lower level of innovation in **No Progression** leads to higher gas power station demand.

880 TWh

Annual gas demand in 2015

334 TWh

Annual electricity demand in 2015

3.1.1
Annual demand

Figure 3.1.1
Electricity – Annual demand[1]

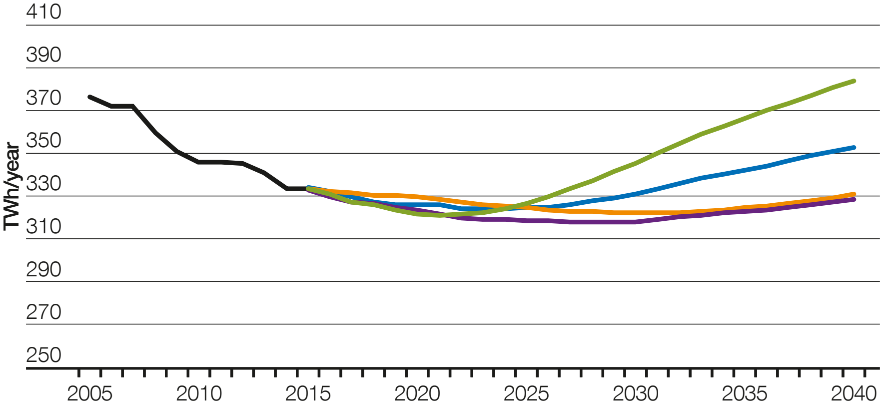
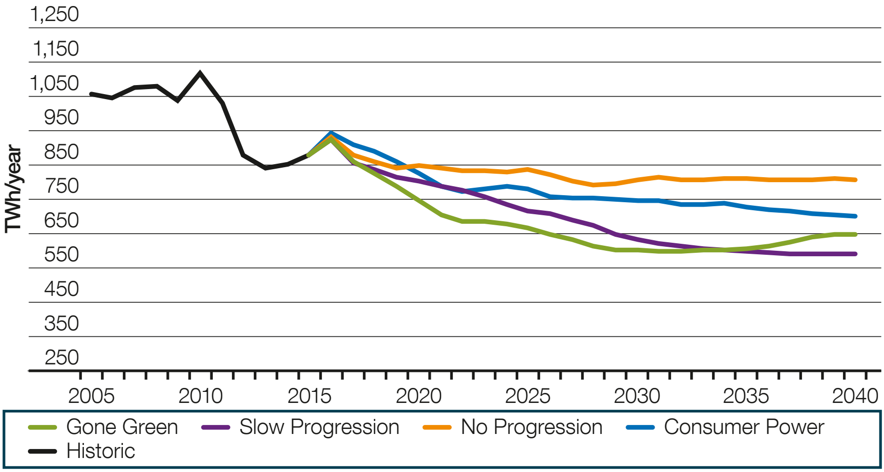


Figure 3.1.2
Gas – Annual demand



[1] Here we consider underlying demand (see Method). Other National Grid reports will use different definitions for demand. Care should be taken over making comparisons between reports.

Energy demand

Annual gas and electricity demand is comprised of residential, commercial, industrial and transport consumption.

In **Slow Progression**, **No Progression** and **Consumer Power** there is a decline in electricity demand from the commercial and industrial sectors from 2016 levels. Only in **Gone Green** do these sectors' demands rise above current levels.

In this section we consider the period from 2016 out to 2040. There is an increase in residential electricity demand above 2016 levels in all of the scenarios by the end of the period. This offsets most, if not all, of the reduction in demand experienced in the industrial and commercial sectors.

Recently, gas demand has stabilised following the reduction experienced between 2010 to 2013. One of the largest drivers for this drop, relatively high gas prices compared to coal, has reversed to the point where gas-fired electricity generation is currently increasing its output. For more information please see section 4.1.

Generally gas demand reduces over the scenario period, as reflected within **Gone Green**, **Slow Progression** and **Consumer Power**. Energy efficiency, new technologies, innovations and incentives broaden consumers' choices and contribute to a reduction in the use of gas. In **No Progression**, where there is less green ambition and less prosperity, there are limited choices and gas remains at the current demand level.

Gone Green

Figure 3.1.3
Electricity – Gone Green's demand components

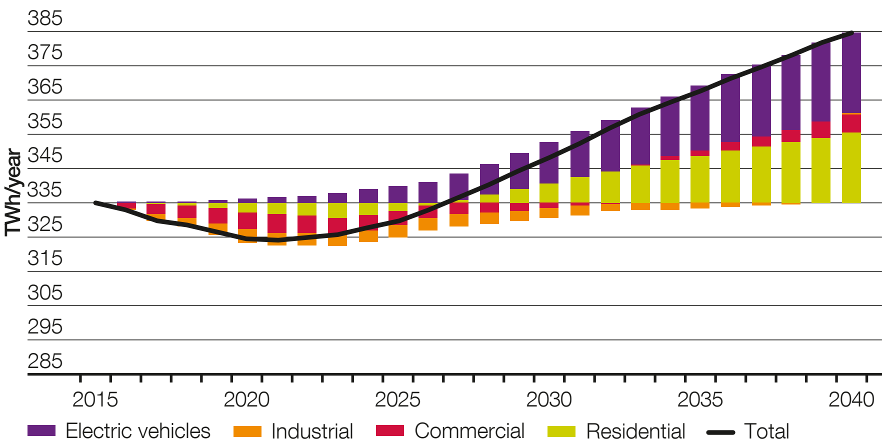
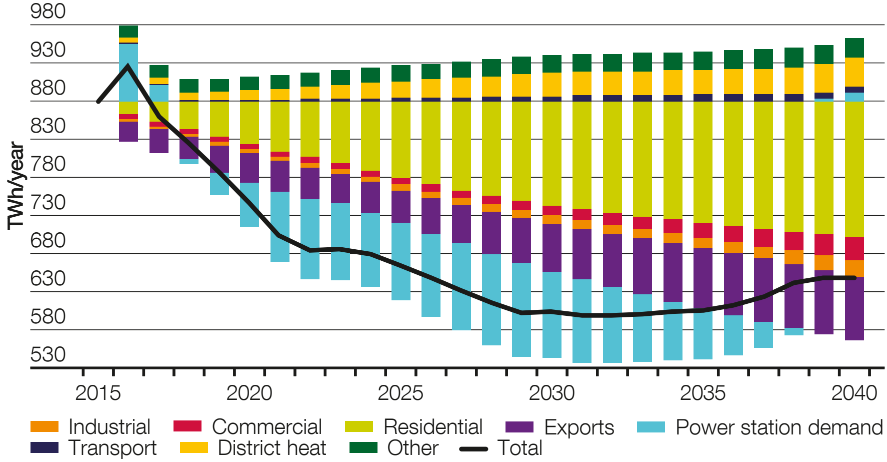


Figure 3.1.4
Gas – Gone Green's demand components



In **Gone Green**, from 2020, carbon reduction policy becomes focused on the electrification of heating across the industrial, commercial and residential sectors. The residential sector has a significant capacity to contribute to this aim because of its high energy demand. This is achieved by a high uptake of heat pumps, which increases electricity demand.

Policies such as the European Commission's 2030 climate and energy framework[2] are adopted. Their ambitious energy reduction targets for residential appliances, such as televisions and refrigerators, are met. This, with a continued move to efficient lighting, creates significant savings in the short term. These electricity savings are more than offset from the early 2020s by increased demand from heat pumps and an increasingly high uptake of electric vehicles (EV) throughout the period.

The electrification of heating, that increases electricity demand, conversely reduces gas demand. This is coupled with: more efficient boilers; the use of new technology to control our heating; supplemented heating with biomass; and more insulation installed in our buildings. These factors combine to further reduce gas demand. Electricity generation relies less upon gas in the short term as more renewable and lower carbon generation technologies connect. The introduction of carbon capture and storage (CCS) to the remaining gas generation fleet in the early 2030s reverses the trend. Industrial gas demand continues to decline due to the electrification of low-grade heat, and due to a general reduction in GB industry over time.

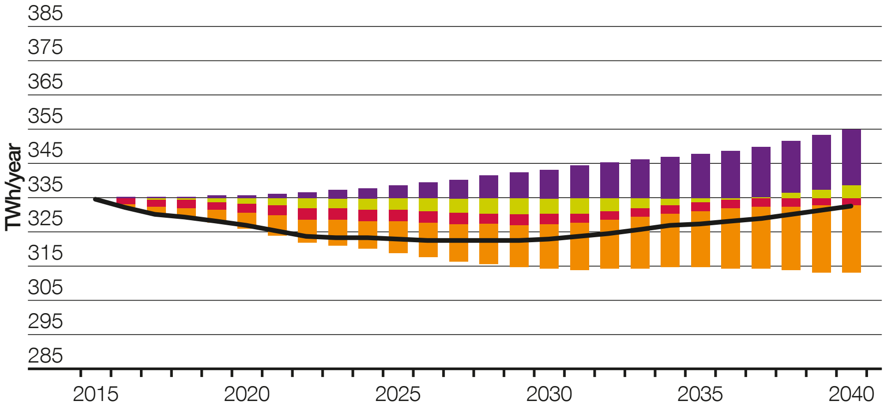
[2] European Commission, 2030 climate & energy framework, April 2016, http://ec.europa.eu/clima/policies/strategies/2030/index_en.htm

Chapter three

Energy demand

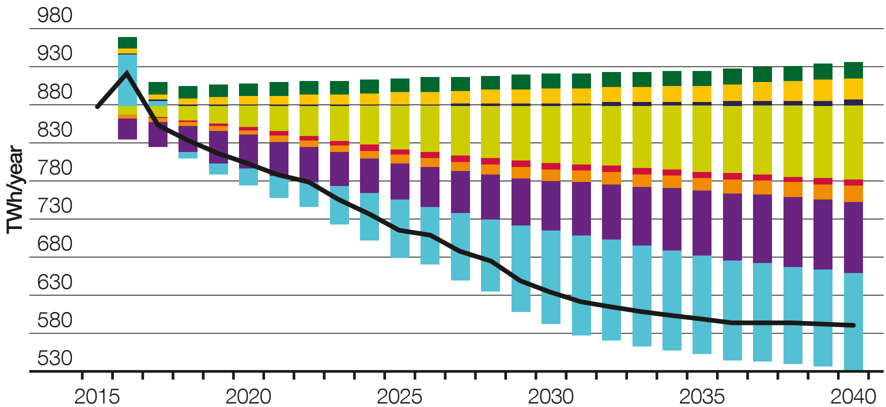
Slow Progression

Figure 3.1.5
Electricity – Slow Progression's demand components



Electric vehicles · Industrial · Commercial · Residential · Total

Figure 3.1.6
Gas – Slow Progression's demand components



Industrial · Commercial · Residential · Exports · Power station demand · Transport · District heat · Other · Total

Although there is green ambition in **Slow Progression**, there is less money in the economy to realise it. Green policies may be adopted, but there are fewer opportunities for incentives to drive the required behaviours. Subsidies are lower than in **Gone Green** for items such as EVs and heat pumps. Focus on achieving green targets is high, but they are achieved later than anticipated.

There is an increase in demand from heat pumps and EVs, but to a lesser extent than in **Gone Green**. At the same time, appliance efficiency savings dampen the level of gas and electricity demand.

In this less prosperous world, industrial and commercial energy demand reduces. The impact of efficiencies is immediately evident, with the initial drop brought about, for instance, by the introduction of more efficient lighting.

Gas demand for heating declines as the efficiency of boilers increases and residential insulation measures are widely implemented. However, unlike in **Gone Green**, the uptake of low carbon heating such as heat pumps is low. This results directly from reduced money available in the economy to invest in low carbon heating. Where low carbon technologies are deployed, many of these take the form of hybrid heat pumps that have a gas boiler to top up heating during cold spells. In **Slow Progression**, due to cost, CCS is not developed. Consequentially gas generation declines out to 2040.

Energy demand

No Progression

Figure 3.1.7
Electricity – No Progression's demand components

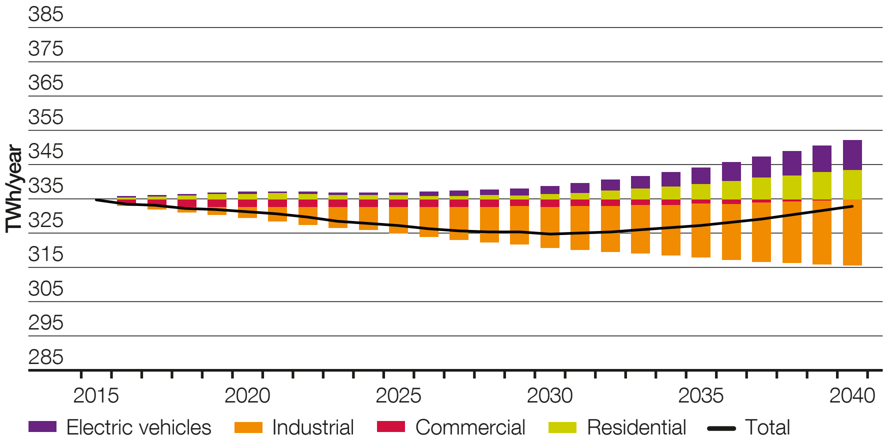
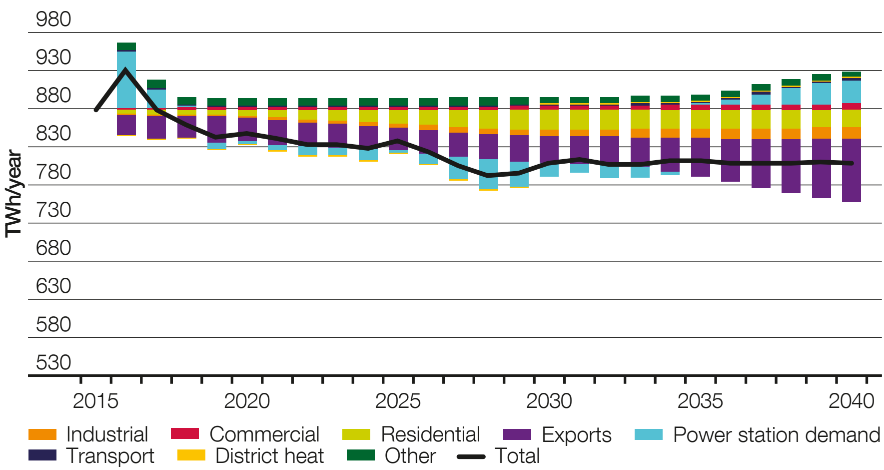


Figure 3.1.8
Gas – No Progression's demand components



In the **No Progression** world of low prosperity and low green ambition there is a lower uptake of energy saving appliances. Incentives and subsidies are very limited and targeted at only the most essential schemes. Consequently items such as EVs and heat pumps are not subsidised.

In the growing residential sector there is little appetite for EVs. Gas is relatively cheap and, with a lack of subsidies, heating by electricity remains limited.

The decline of the industrial sector's electricity demand is most acute in this scenario and demand drops by almost 20 TWh per year by 2040 (see section 3.2.2).

The commercial sector prefers to use cheaper gas for its heating requirements. It makes some headway in energy efficiency savings, but these are muted compared to the greener scenarios.

Gas demand fluctuates around current levels of approximately 850 TWh per year. Population growth and the resulting increase in the housing stock increases the number of boiler connections. This is more than offset by changes such as energy efficiency of boilers, smart controls and improved thermal efficiencies. In this world there is a less pronounced fall in the industrial gas demand than in the greener scenarios. There is an increased demand for gas to be exported to Ireland and the Continent.

Energy demand

Consumer Power

Figure 3.1.9
Electricity – Consumer Power's demand components

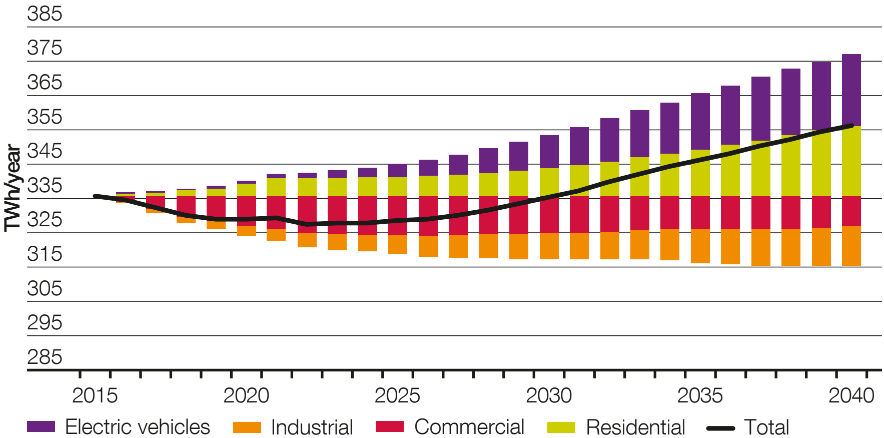
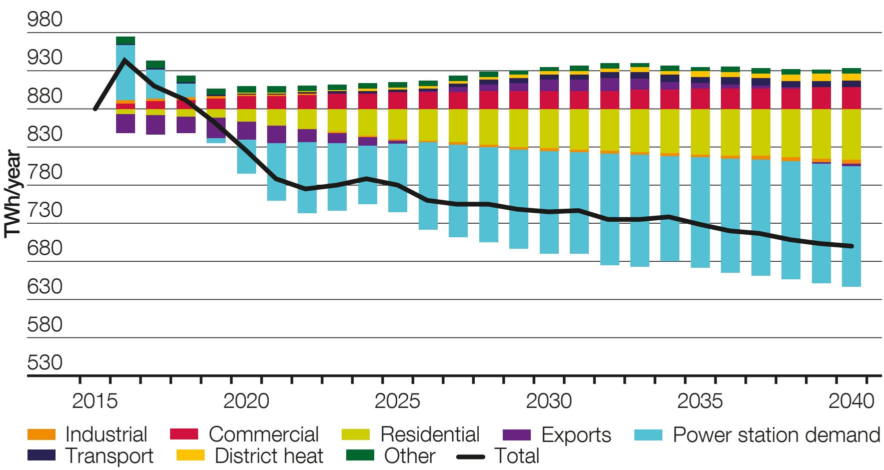


Figure 3.1.10
Gas – Consumer Power's demand components



In **Consumer Power** there is high prosperity and low green ambition. Retail electricity prices are moderate but gas is cheap, so gas is the fuel of choice. There is little desire to move towards greater efficiency, but there is a desire for newer, superior appliances.

In the residential sectors, both appliance numbers and demand increase steadily. Must-have items such as EVs and the latest gadgets proliferate. At the same time there is a deeper penetration of conventional items, such as dishwashers. This, combined with the increase in household numbers, produces a steep rise in residential demand.

Within residential heating there is a drive for new technologies from prosperous consumers. In this scenario we see micro-combined heat and power (mCHP) and fuel cell technology develop, both of which use gas to provide heat and electricity. These allow homes to produce their own electricity from cheaper gas.

The industrial sector's decline is less marked than in the low prosperity scenarios of **No Progression** and **Slow Progression** due to stronger economic growth, but it does decline and as such so does its demand.

Consumer Power sees the biggest decrease in commercial electricity demand. This is primarily caused by the low cost of gas. The commercial and transport sectors also see an increase in gas demand due to the adoption of new gas technologies such as CHP and natural gas vehicles (NGVs). This is again driven by the cheaper gas price.

Within the electricity generation sector, new interconnection, nuclear, small-scale and renewable generation reduce the need for large-scale gas generation compared to other scenarios. This cuts gas demand for electricity generation from 170 to 23 TWh per year by 2040.

Energy demand

3.1.2
Peak demand

Figure 3.1.11
Electricity – Average cold spell peak demand

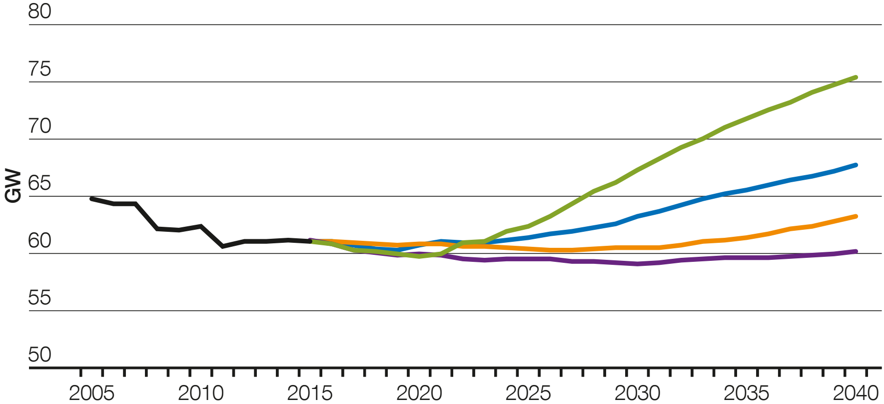
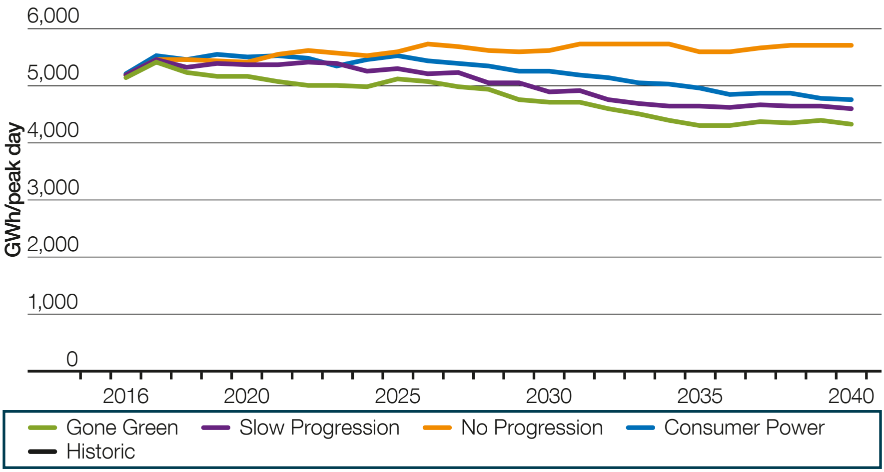


Figure 3.1.12
Gas – Demand for 1-in-20 peak day



Electricity peak demand typically occurs between 5:30pm and 6:00pm on a weekday during the winter months. This is when it is dark and cold, hence electricity is required to heat and illuminate houses, offices and factories. The combined effect of fast-rising residential demand and slow-falling commercial and industrial demand produce a system peak.

Electricity peak demand follows similar trajectories to the annual demand (see Figure 3.1.1) and for similar reasons. Industrial and commercial demand side response (DSR, excluded from the *FES* definition of peak demand) and residential time-of-use tariffs (TOUTs) have more of an effect on **Gone Green's** and **Slow Progression's** within-day profiles. The effect on **Gone Green** is offset by the increased use of heat pumps at peak time.

For more detail on DSR and TOUTs see section 3.5 on flexible demand.

Peak gas demand is based on a historical relationship between daily gas demand and weather, combined with the amount of gas-fired power station demand expected on a peak day.

Peak gas-fired electricity generation is less related to weather than residential gas demand. It is more dependent on generation availability and the position of gas-fired electricity generation within the merit order. During the next decade peaks remain broadly in line with recent history. This is because the increasing requirement for gas-fired electricity generation to act as a back-up for renewable generation counters the decreasing residential peak demand. From 2026, the peak demand in **Gone Green**, **Slow Progression** and **No Progression** then decreases as a consequence of further reductions in residential demand.

Figure 3.1.12 shows the peak gas demand for the 1-in-20 peak day, for all four scenarios. The difference in peaks reflects the differing assumptions in residential and commercial annual demand and level of dependence on gas-fired generation.

Energy demand

Method

Electricity

In *FES* we consider underlying demand. That is end consumer demand, regardless of where (transmission, distribution or on site) that electricity is generated, plus network losses. Demand is weather-corrected to seasonal normal for annual and average cold spell (ACS) for peak. For clarity it does not include exports, station demand, pumping station demand or other forms of storage demand.

When we illustrate residential, industrial and commercial components we have not assigned the distribution or transmission losses. We estimate these losses at the system level to average around eight per cent.

Peak demand is the maximum demand on the system in any given financial year. In order to make long-term ACS peak projections from annual demand we apply a recent historical relationship of annual to peak demand. For the residential sector there is a further adjustment using background data from the household electricity survey[3]. This creates an initial peak demand, to which we add components that history cannot predict, such as EVs, heat pumps and TOUTs.

[3] Cambridge Architectural Research, HES 24-Hour Chooser, 28 April, 2016, https://www.hightail.com/download/ZUczYkJrQXA1R01pR01UQw

Method

Gas

The annual gas demand is defined as the total Local Distribution Zone (LDZ) consumption, plus the consumption of sites that are directly connected to the National Transmission System (NTS). This includes gas for Ireland exported via Moffat and the exports to the continent via Interconnector UK. Shrinkage is included at the total system level but not assigned to demand sectors. All values are weather-corrected where appropriate. Peak gas demand is calculated as 1-in-20 demand, as per our Gas Demand Forecasting Methodology[4].

[4] National Grid, Gas Demand Forecasting Methodology, February 2012, http://www2.nationalgrid.com/uk/industry-information/gas-transmission-operational-data/supporting-information/

Industrial and commercial demand

3.2
Industrial and commercial demand

Industrial and commercial demand is influenced by the rate of economic growth, fuel prices, and the type of industry making up the mix. Across our scenarios there is a decline in industrial demand due to a switch from heavy to lighter industry.

In the commercial sectors there are disruptive technologies which impact demand to varying degrees. Gas CHP use boosts demand in Consumer Power due to cheaper gas prices. Air source heat pumps (ASHP) impact both electricity and gas demand in Gone Green due to the focus on achieving environmental targets.

Slow Progression moves towards the 2050 carbon reduction target with renewable biomass heating and No Progression sees little change to energy demand.

Key insights

- In **Gone Green** heat pumps provide 3.6 GW of heat capacity by 2040, using an extra 11 TWh per year of electricity.
- Industrial and commercial gas demand moves from 219 TWh per year in 2015 to between 168 and 243 TWh per year in 2040, partly due to the range of heat pump uptake across the scenarios.
- Industrial and commercial electricity demand changes from 197 TWh per year in 2015 to between 178 and 203 TWh per year in 2040.

Maximum of
243 TWh
gas demand per year in 2040

3.2.1
Economic and energy price impacts

There are two economic growth forecasts used within our scenarios: a higher one for **Gone Green** and **Consumer Power**, and a lower one for **No Progression** and **Slow Progression**. Both forecasts have some economic growth in the industrial sector and higher growth within the commercial sector.

Historically, there has been a strong link between economic growth and energy demand but over recent years we have seen this relationship start to decouple. This is due to two factors: firstly, the sub-sectors which make up industrial demand are changing from higher energy intensity industries to lower intensity ones. For example, paper production (which is in decline in GB) is very energy intensive whereas car assembly (which is growing in GB) uses much less energy per unit of output. This means that economic output from the industrial sector can continue to grow while energy use declines.

Secondly, gross domestic product growth in GB continues to be fuelled by expansion in the financial and service sectors. Creating more value in these sectors generally requires people and computers working more efficiently, using similar amounts of energy. Moreover, companies are using denser workspaces, with approaches like desk sharing, which saves heating and cooling partly empty buildings. This saves energy for the same output. Additionally, laptops are replacing desktop computers at work, contributing further to electricity savings.

As this decoupling effect becomes more pronounced, changing energy prices become more important to the energy demand of the market. In **Consumer Power**, gas retail prices remain low while electricity prices grow by more than 60 per cent. This widening gap is what makes gas CHP and the prospect of fuel switching, from more expensive electric heating to gas, attractive.

No Progression has the opposite effect with gas prices growing at a faster rate, keeping electricity demand higher than in **Slow Progression** and **Consumer Power**. Despite this, **No Progression** sees the lowest retail energy prices. This keeps energy use high despite the less prosperous economic situation.

In **Gone Green**, low carbon technologies are the main reason for changing demand. Their economics are helped out by high retail gas prices brought on from strong government intervention. However, **Gone Green** also has the highest total energy costs, which encourages energy efficiencies such as more efficient lighting, better controls and insulation.

Slow Progression has the same high gas prices as in **Gone Green** but cheaper electricity prices caused by lower penetration of renewable generation. It still has the second most costly energy of our four scenarios which, like **Gone Green**, causes economically prudent investment in energy efficiencies. Biomass boilers, encouraged by government incentives, displace some of the more expensive and carbon-intensive technologies, helping both environmental ambitions and companies' bottom lines.

Industrial and commercial demand

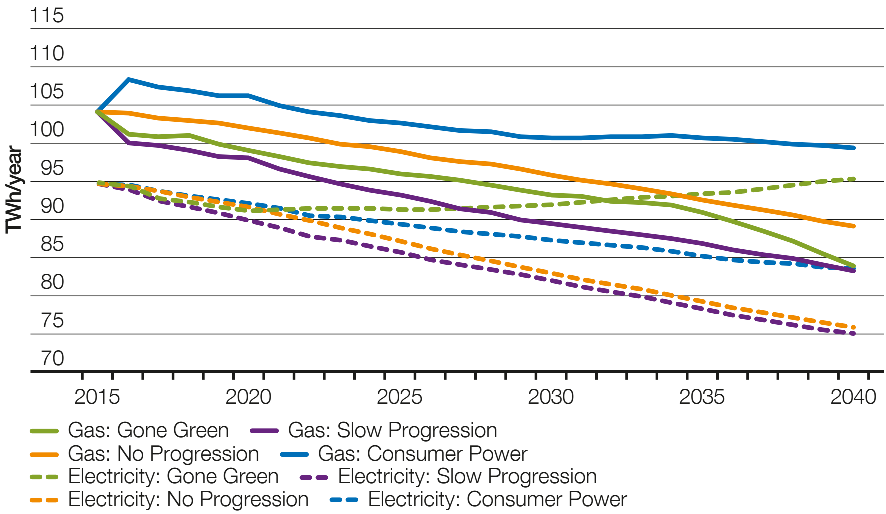
3.2.2
Industrial demand

Industrial energy demand continues its recent decline in GB in most of the scenarios. In the long term, **Gone Green** moves towards renewable heat in the form of ASHPs along with some biomass. These satisfy space heating demand and accelerate the reduction in overall energy demand (due to high efficiency of ASHPs) while reversing the declining trend in electricity demand.

Consumer Power enjoys the benefits of relatively cheap gas and thus sees high installations of gas CHP units adding 3.5 TWh per year of gas demand by 2030; see section 4.1 for more information. As such, gas demand remains higher in the short term but still declines over the longer period.

Slow Progression has the starkest decline in gas due to the conversion to biomass boilers, lower economic growth and higher gas prices. The 1.7 TWh per year of gas demand reduction caused by the switch to biomass is partially offset by the use of gas CHP, which adds an additional 1.1 TWh per year to demand by 2030.

Figure 3.2.1
Gas and electricity – Industrial annual demand

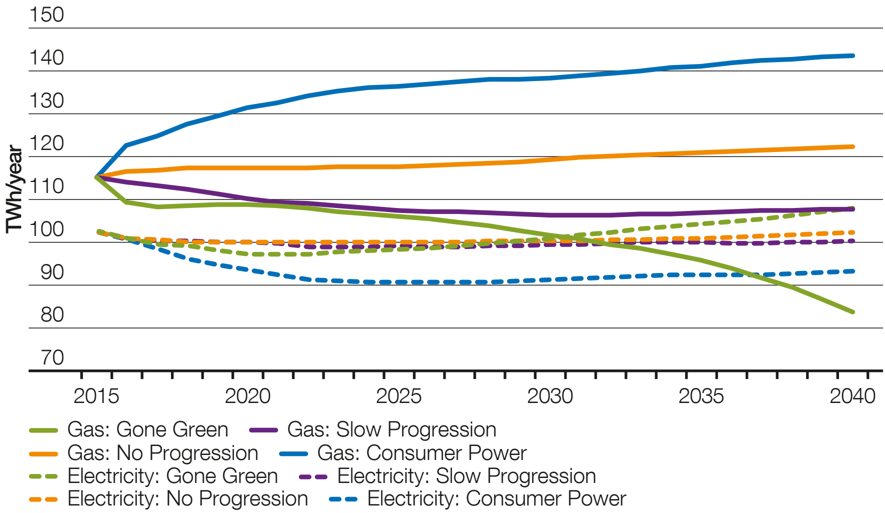


3.2.3
Commercial demand

Commercial electricity demand declines slowly away from 2016 levels. This reduction comes in spite of growing economic activities and is due to energy efficiencies such as better computing power or more efficient lighting.

In **Consumer Power**, cheaper gas leads to fuel switching, where gas heating replaces electric heating systems. This has the effect of reducing electricity demand, replacing it with gas. Gas CHP is also built. These units are of a smaller size (less than 1 MW of electrical output) and can be part of a heating control room, providing base load heat alongside regular gas boilers. An additional 8.7 TWh per year of gas demand comes from CHP alone by 2030.

Figure 3.2.2
Gas and electricity – Commercial demand



Industrial and commercial demand

Following stakeholder feedback, we have reduced and delayed the anticipated deployment of heat pumps in our scenarios. **Gone Green** still achieves the 2050 carbon reduction target; the reduced progress in the residential sector is offset by progress in the industrial and commercial sectors. By 2030 nearly 1 GW of ASHPs are installed; by 2040 this is doubled to 2.1 GW.

Biomass boilers have been popular on the non-domestic Renewable Heat Incentive (RHI) scheme to date and are included over the long term in our greener scenarios. **Slow Progression** replaces some of its gas demand with biomass as an alternative source of renewable energy; by 2030 nearly 9 TWh per year of gas demand is offset. ASHPs have a higher penetration in **Gone Green** (which is more focused on the electrification route) leading to a lower uptake of biomass boilers; about 3 TWh per year of gas is displaced in 2030.

3.2.4
Other heating technologies

As the need to decarbonise intensifies, alternative technologies need to be introduced to meet heating requirements within the industrial and commercial sectors. In **Gone Green** the green ambition is high and ASHPs are adopted in both sectors to meet low-grade heat demand such as for space heating or hot water. However, high temperature process heat still requires fossil fuels.

ASHPs are more efficient than gas boilers and therefore less energy is required for the same heat demand. This ensures that running costs can be similar or lower than alternative gas appliances. By 2040, 3.6 GW of heat pumps are installed, requiring 11 TWh per year of electricity demand but offsetting 50 TWh per year of gas demand. This is due in part to reduced capital costs and government incentives to keep ASHPs economical. The RHI is funded by the Treasury which has committed to increasing funding to £1.15 billion in 2021[5].

Another potential technology is CHP, which has the biggest uptake in **Consumer Power**. CHP uses energy to produce both electrical and heat output, for example, using a Stirling engine. This makes them a more efficient electricity source because heat that would otherwise be wasted is instead used, for example for space heating. As a result it may be more efficient both to use CHP rather than two separate and conventional gas heating and electricity generation systems. Economically, gas CHP could provide lower cost electricity supplies if electricity becomes relatively more expensive than gas.

However, gas CHP can become detrimental to environmental targets in the long term as transmission-level electricity continues to move to lower carbon sources. Commercial CHP units are generally installed as small-scale units with a capacity of less than 1 MW of electrical output. Industrial installations tend to be much larger and are included in section 4.1.

[5] Department of Energy and Climate Change, Evaluation of Renewable Heat Incentive (RHI), February 2016, https://www.gov.uk/government/news/evaluation-of-renewable-heat-incentive-rhi

Method

Economic data from Oxford Economics was used to create a high and low case for GB economic growth. Retail energy prices are generated from our wholesale energy prices and then benchmarked against the Department of Energy and Climate Change's (DECC) scenarios.

The model examines 24 sub-sectors and their individual energy demands, giving a detailed view of GB demand, and uses an error-correcting model to produce projections for each sub-sector individually. The model then has two further modules to investigate the economics of increasing energy efficiency (e.g. heat recovery) and new technologies such as onsite generation (e.g. CHP) or different heating solutions (e.g. biomass boilers).

These modules consider the economics of installing particular technologies from the capital costs, ongoing maintenance costs, fuel costs and incentives. These are used along with macro-financial indicators such as gearing ratios and internal rate of return (IRR) for each sub-sector to consider if the investment is economical and the likely uptake rates of any particular technology or initiative. This allows us to adjust the relative cost benefits to see what is required to encourage uptake of alternative heating solutions and understand the impact of prices on onsite generation which give our scenarios a wider range.

Residential demand

3.3
Residential demand

Residential demand is a significant part of energy use within GB. It represents the largest single portion of our gas consumption and about a third of the electricity demand. New low carbon heating technologies and a focus on household efficiencies could change the balance between electricity and gas demand. However, there remains a unique set of challenges ahead for households to use energy more efficiently.

Key insights

- In **Gone Green** there are over 10 million low carbon heating systems in 2040.
- In **Consumer Power**, opportunistic fuel pricing means mCHP units and fuel cells make up over a third of low carbon heating systems.
- **No Progression** is largely similar to today, however the boiler population rises in line with housing growth.

10 million+

Gone Green low carbon heating systems in 2040

Figure 3.3.1
Electricity – Annual residential demand

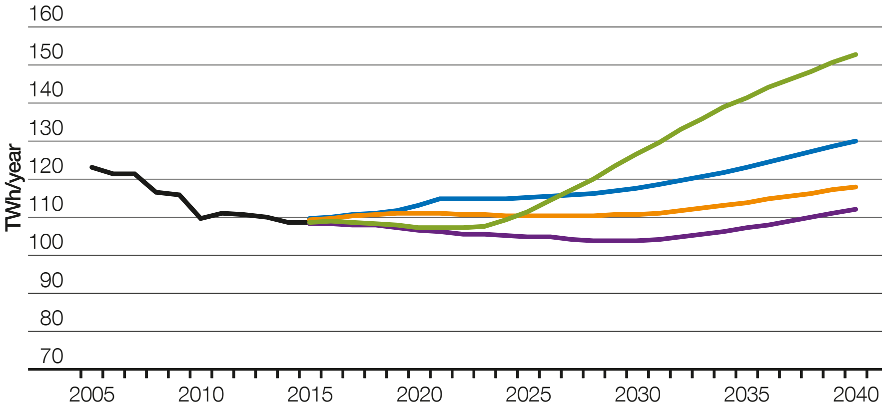
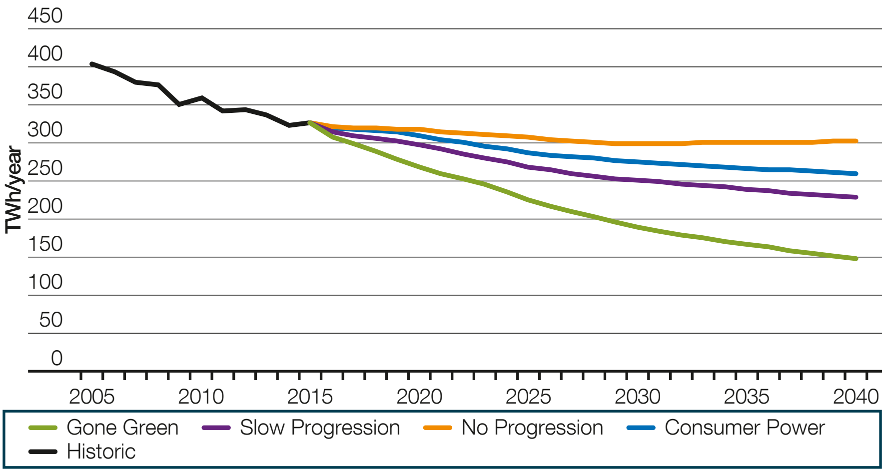


Figure 3.3.2
Gas – Annual residential demand

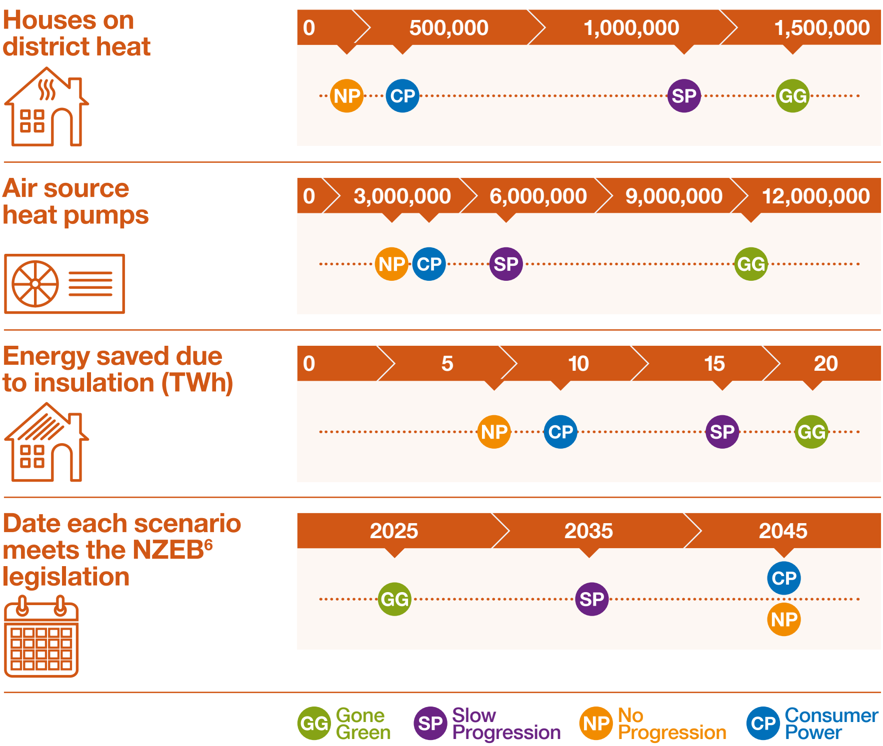


Residential demand

3.3.1
Heating

Heating our homes currently accounts for approximately 40 per cent of gas use and eight per cent of electricity use. Gas boilers are installed in around 90 per cent of British homes. However, innovation in this area could open new avenues of heat supply.

Figure 3.3.3
Scenario ranges in 2040 for residential heating



[6] Nearly-Zero-Energy Buildings

Figure 3.3.3 shows how this landscape will change in our scenarios. **Gone Green** is the most ambitious scenario with regards to heat. In this world there is a recognition that residential heating and insulation requires government support in order to reach the 2050 carbon reduction target. This manifests itself in new and existing incentive schemes such as the RHI and Energy Company Obligation (ECO) stimulating growth in the low carbon heating industry and encouraging overall costs to come down.

Insulation

GB has benefited from a series of energy efficiency schemes designed to reduce energy consumption in homes. From the Energy Efficiency Commitment in 2002 through to the current ECO scheme, these have been successful at increasing the levels of both loft and cavity wall insulation across the country. The ECO scheme was extended to 2017 and a less extensive replacement has been announced.

It is estimated[7] that GB has nearly eight million houses with solid walls and yet only 300,000 are insulated, less than five per cent. Currently, solid wall insulation provides the greatest potential energy saving for the housing stock (due to the saturation of loft and cavity wall insulation) but is the most expensive.

> To upgrade the insulation in the remaining housing stock to solid wall insulation would cost between £50–70 billion and save around 40 TWh of energy per year.

Gone Green sees the highest uptake in all three types of insulation with approximately 3 million solid wall measures installed. This is driven by a more robust extension beyond 2017 of government insulation schemes designed to hit the decarbonisation target. The energy-conscious society take advantage of these schemes and low energy consumption is commonplace.

The less prosperous **Slow Progression** follows the energy-conscious trend with high uptake of loft and cavity wall insulation but sees solid wall insulation as a lower priority and so uptake is lower. **No Progression** has the lowest insulation uptake in all areas due to the lower green ambition and consumer engagement. Solid wall insulation has a low uptake in **Consumer Power** as homeowners are less willing to invest in the more expensive measures. However, they do use their higher disposable income to install loft and cavity wall insulation.

New builds

New houses represent a sizeable portion of energy usage in 2040 with over five million more homes than in 2016. GB homes will align with the European Directive of Nearly-Zero-Energy Buildings (NZEB). This requires all new homes built to be “a building that has a very high energy performance”[8]. While the exact make-up of energy performance can be decided by each EU member state, we have used an estimated performance as the standard to work to of 44 kWh/m^2 of primary energy use.

In **Gone Green**, progress is made and new homes meet the target in 2025 as low energy requirements are seen as attractive when buying a new home. **Slow Progression** sees a ten-year delay due to financial constraints; as such the new standard is introduced in 2035. Both **Consumer Power** and **No Progression**, with lower green ambition, take even longer to achieve this standard. Households have a greater focus on the immediate increased cost of a house than the long-term view on the energy costs.

[7] DECC, Green Deal and Energy Company Obligation (ECO) Statistics, November 2015, https://www.gov.uk/government/collections/green-deal-and-energy-company-obligation-eco-statistics

[8] European Parliament, Directive 2010/31/EU of the European parliament and of the council, May 2010, http://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=FZMjThLLzfxmmMCQGp2Y1s2d3TjwtD8QS3pqdkhXZbwqGwlgY9KN!2064651424?uri=CELEX:32010L0031

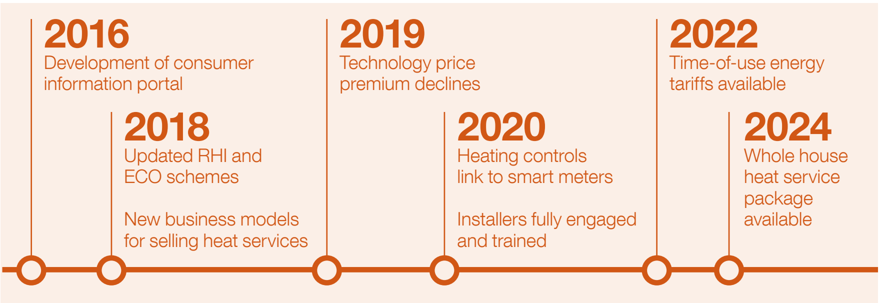
Residential demand

Heating technologies

The current home heating market is dominated by gas, which is supplied to over 24 million houses. Houses that have no gas connection tend towards using types of electric heating or oil-fuelled boilers, accounting for about 10 per cent of the market.

Emerging and established alternative technologies have the potential to change this landscape if economic and environmental factors can drive public behaviour. Government desire to achieve environmental targets, paired with a strong green agenda and public lobbying, could be a huge catalyst for change.

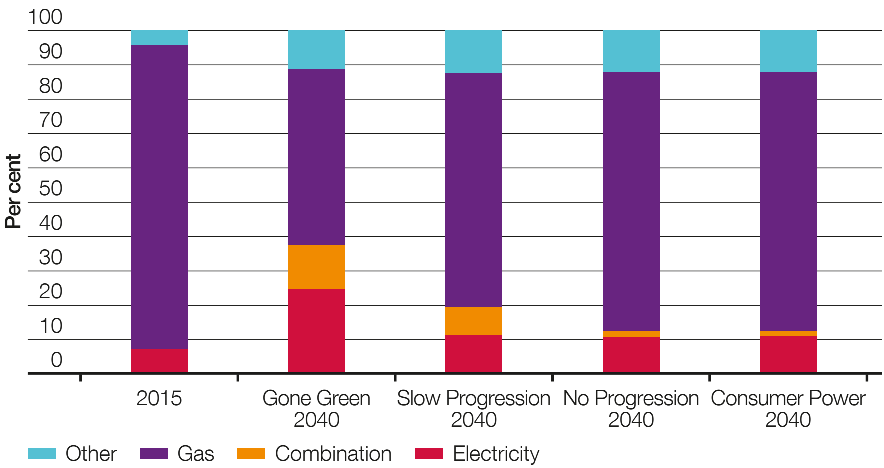
Figure 3.3.4
Road map to 3.5 million low carbon heating technologies by 2025



Altering the public perception and engagement with low carbon technologies could be a large task. There is currently little consumer knowledge of alternatives, with technologies such as ASHPs and district heating widely unknown. Because of this, it may be difficult to encourage people to commit to a long-term domestic heating appliance without prior knowledge. This is compounded by new technologies having relatively high upfront costs compared to established technologies. Therefore, establishing a public knowledge base around low carbon heating technologies and their advantages is required to support a high proliferation scenario.

If additional money to support the low carbon heating industry were provided, this would drive innovation and bring the upfront costs of emerging technologies down. This would almost certainly mean an expansion of support mechanisms to incentivise the use of a range of low carbon heating technologies.

Figure 3.3.5
Distribution of demand met by various heating technologies across the scenarios



Residential demand

In **Gone Green**, the main alternative technology used is heat pumps, with additional government incentives in place to try to meet the decarbonisation target. This reduces gas demand and increases electricity demand. **Gone Green** also features a revival in electric storage heating as TOUTs mean that smaller properties can benefit economically.

Slow Progression attempts to follow the same path as **Gone Green**. Although consumer engagement is high, the financial constraints result in a lower penetration of heat pumps.

In **Consumer Power**, although heat pumps are seen as a desirable product to have in your house, their initial sharp rise in sales is curtailed in the 2020s when other heating sources gain traction. This takes the form of mCHP units as well as fuel cells to take advantage of the relatively low gas costs.

No Progression represents business as usual with new houses opting to install gas boilers as a familiar, cheap technology. There is little consumer engagement resulting in poor sales of alternative heating and so innovation is stifled. By 2040, there are just over 1.1 million low carbon heating technologies in homes, approximately a tenth of those installed in **Gone Green**.

Spotlight: District heat

A district heat network constitutes a heat source and a distribution network of thermally insulated pipes.

Heat is transferred from the source into the buildings on the network. The heat enters the internal distribution network of the building, just like a boiler but via a heat exchanger, and puts heat into the radiators of a centrally heated home.

There can be significant losses within the network while transporting the heat, but gains are accumulated through the scale of the heat source, better controls, and the ability to use multiple sources together to generate the heat. District heat networks can support decarbonisation efforts only if a low carbon source is used.

For *FES* 2016 we have worked with Buro Happold to study the role district heat can play in GB. Specifically, we investigated

where there are reasonable locations for district heat. This is based on the thermal density of a group of properties (i.e. the density of the properties and their related demands for thermal energy) and the suitability of nearby heat sources such as power stations. High thermal densities and local sources minimise heat losses through the transportation of heat. These locations were then analysed for the economics of different sources for a heat network against the alternatives.

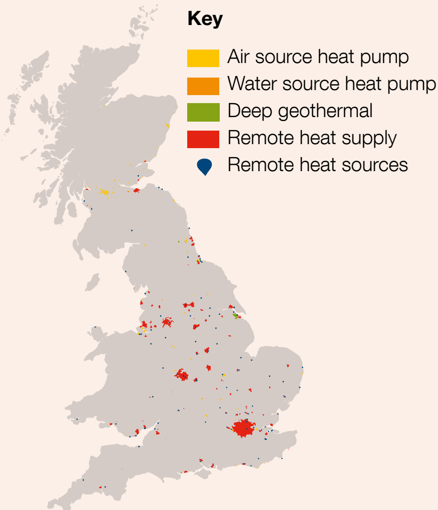
Urban areas are the obvious location for effective district heat networks. The high population density, and therefore thermal density, minimises the amount of pipe required and the thermal losses. It is unsurprising that the majority of the networks are located in cities such as London or Birmingham. New builds, with low thermal demand, are often a poor fit for district heating as the losses account for a much higher proportion of the heat consumed, thus making the system uneconomic.

Using remote heat sources is very expensive and has several challenges. Firstly, waste heat is not a free resource; for the heat to be at the required temperature the power station often needs to work at a lower efficiency.[9] Secondly, the heat needs moving via a transmission network before it can be distributed. Finally, the heat output from these remote sources also needs a top-up heating system. This means that the peak demand from the network doesn't need to match the peak output from the remote source. When demand exceeds the remote source's supply, additional top-up heat can be used. This makes the system more economic as it can utilise more of the heat from the remote source.

Strong centralised planning with a focus on sustainability is required to be able to utilise heat networks with remote sources. As such we have included them only in our **Gone Green** and **Slow Progression** scenarios. Without incentives for using waste heat, appropriate regulation and sources of funding for the assets required, it is unlikely that developers would take on the risk of building a network which requires high upfront costs to be spread over a high uptake rate of homes on the network route.

Local sources, in particular in our **Consumer Power** and **No Progression** scenarios, are focused on gas CHP installations which can take advantage of feed-in tariffs. This fits especially well in **Consumer Power**, which has cheaper gas prices and less focus on environmental sustainability. These struggle to compete economically against incumbent gas boilers and therefore the scenarios have a much lower range of district heat networks.

Figure 3.3.6
District heat systems in 2050 Gone Green



[9] Note this is accounted for in our modelling.

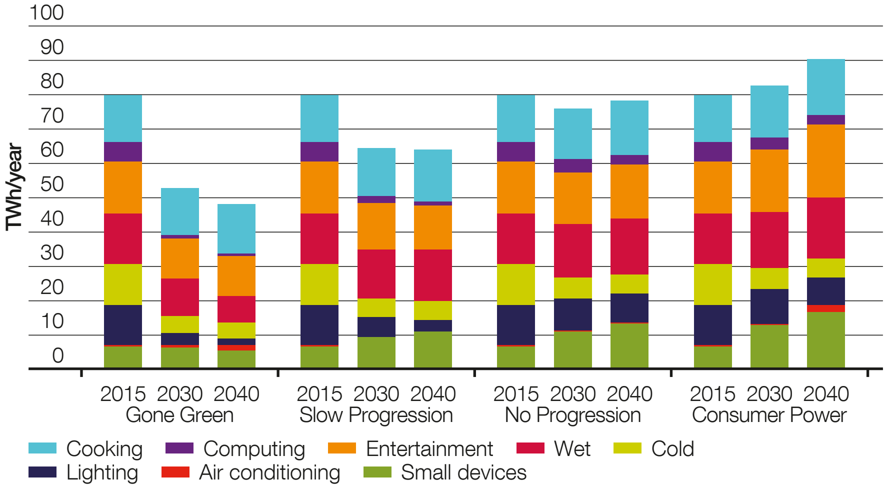
Residential demand

3.3.2
Appliances and lighting

Each appliance category has its own growth profile (see Figure 3.3.7) but in general terms their future trajectories are governed by six interplaying factors which are:

1. The increase in the number of households; this is the same across all the scenarios.
2. The number of appliances per household; this tends to increase with the more prosperous scenarios of **Gone Green** and **Consumer Power**.
3. Energy efficiency, which, in order of most to least savings, is **Gone Green**, **Slow Progression**, **Consumer Power** and **No Progression**.
4. The growth in the size and power of individual units (e.g. US style refrigerators), with larger units having greater prevalence in the more affluent scenarios.
5. The turnover and penetration levels of products, which is greater in the more prosperous scenarios.
6. Product life cycle, e.g. desktop computers are in their declining phase.

Figure 3.3.7
Electricity – Annual demand for appliances, lights and air conditioners



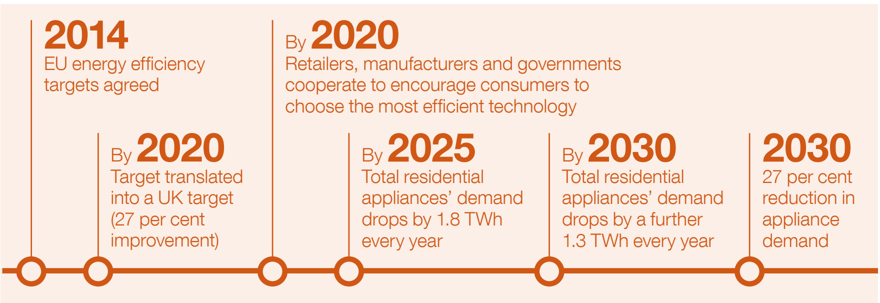
Gone Green

Gone Green has a prosperous society and as such more appliances are purchased. However, demand still falls from 79 to almost 48 TWh per year. This is mainly due to improvements in energy efficiency, as the energy efficiency target from the European Commission's non-binding 2030 climate and energy framework is adopted.

All but two of the appliance categories see a drop in demand over the period. Some of these drops are quite significant. Lighting converts exclusively to light emitting diodes (LEDs) and so brings the demand down by 80 per cent to 2 TWh per year. Cold appliances, such as freezers and refrigerators, increase in number from 43 million to 52 million, but their demand drops from 12 to 4 TWh per year due to efficiency savings. Similarly computers increase from 96 million units, demanding 6 TWh per year, to 112 million units demanding 1 TWh per year.

Both cooking and air conditioning run contrary to this reduced demand trend. Cooking experiences a modest gain in efficiency but it is not enough to offset the increasing demand required for the expanding household sector. Air conditioning, a relatively unusual appliance in GB homes in 2016, becomes more commonplace in this prosperous world with almost four million units by 2040.

Figure 3.3.8
Road map to meeting the EU energy efficiency target in Gone Green



Residential demand

Slow Progression

Being less prosperous than **Gone Green**, there are some efficiency gains, but society has limited money to buy more appliances. The EU efficiency gains are achieved, but they are realised over a decade later. The result is a drop in overall demand from 79 to 63 TWh per year by 2040. This is a smaller reduction than in **Gone Green** and there are fewer appliances which, again, demonstrates how successful the efficiency gains are in **Gone Green**.

Demand reduces up to 2031, by approximately 1 TWh every year, due to the decline in demand from lighting, cold appliances and home computers, after which it plateaus.

In this less affluent world air conditioners do not penetrate the market to a significant extent. Compared to **Gone Green** there are fewer smaller devices (such as tablets, smartphones and routers). However, they do not achieve the same efficiency savings, thereby producing an overall growth in demand of 4 TWh per year.

No Progression

This scenario has neither a drive for efficiency nor the prosperity to buy more items. This results in a broadly flat demand profile. There are only three appliance types that see demand reductions which are not offset by higher demand: lighting, cold appliances, and computing.

By 2040, lighting is dominated by LEDs but there are also compact fluorescent lights (CFLs) and halogen bulbs. The ratio of this mix is 6:3:1, thus contributing to a modest drop in demand of 3 TWh per year.

For cold appliances there are an extra 8.5 million units. There are efficiency improvements of 50 per cent, despite the low green ambition. The result is a final demand reduction of 6 TWh per year.

Consumer Power

In this scenario there is additional money available to buy extra goods which are often more energy intensive as they increase in both size and power. In this scenario, less attention is paid to energy efficiency and electricity retail prices are moderate. Consequently, throughout the period there is a steady rise in demand which by the end of 2040 reaches 91 TWh per year, a rise of 11 TWh, or 14 per cent.

Table 3.3.1
Comparison of the number of household electrical items

	2015	2040 High prosperity scenarios	2040 Low prosperity scenarios
Appliances (millions of units)	648	892	713

Only lighting and cold appliances make any efficiency gains which counteract their increasing numbers and sizes. Lighting sees more LEDs than in **No Progression**. This reflects a move away from CFLs and their lighting characteristics and more towards the style and convenience of LEDs.

Cold appliances, as in all the scenarios, experience a drop in demand. Even in this prosperous world, cold appliances achieve energy savings of about 40 per cent per unit. There is also a 20 per cent increase in the number of units.

There is a decline in the number of home computer units and a switch to mobile technology, which is a sub-set of small devices. These appliances' demand grows consistently throughout the period.

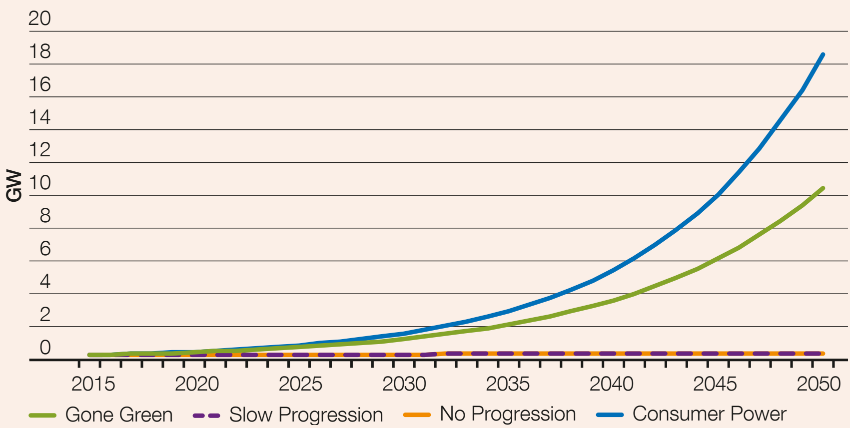
In this prosperous economy, consumer electronics flourish as do wet appliances such as dishwashers and tumble dryers.

This is an affluent society which can indulge in luxuries such as air conditioning. By the end of the period there are over five million units installed.

The dramatic potential rise in residential air conditioning after 2040

- There could be a steep rise in the adoption of air conditioners beyond 2040.
- The maximum potential by 2050 is over 18 GW of demand.
- This could have a significant impact on summer demand.

Figure 3.3.9
Electricity – Air-conditioners' maximum demand out to 2050



Residential demand

Spotlight:
Regional electricity demand split

The key driver for electricity demand is demographics.

For electricity demand **Gone Green** has the higher deployment of both heat pumps and EVs. It is unlikely they will be spread evenly across the country and instead they will cluster in certain areas.

This will lead to an asymmetric increase in electricity demand across the regions in **Gone Green**. For other scenarios this regionalisation effect still exists but its impact will be dependent upon the number of units.

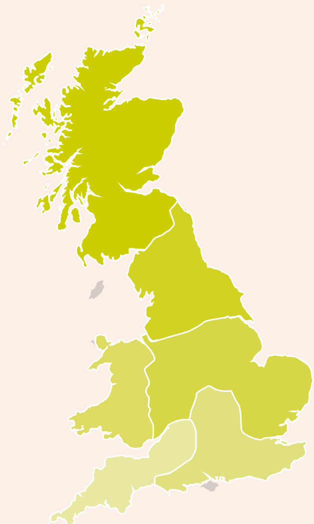


Table 3.3.2
Gone Green's 2040 regional split of heat pumps and electric vehicles

Region	Heat pumps (millions)	Electric vehicles (millions)
England – south east	2.5	3.1
England – south west	0.7	1.0
England – midlands	2.2	2.3
England – north	2.4	2.2
Scotland	0.8	0.8
Wales	0.5	0.4

Method

Our base housing and population assumptions, based on analysis from Experian, are consistent across our modelling scenarios. We assume that the population of GB reaches 72.1 million and that the number of homes grows to 32.8 million by 2040 in all of our scenarios. These compare with a population of 63.2 million and 27.7 million homes today.

We create residential demand using a bottom-up method. For each component part we use historical data, where available, as our starting point. The main source is DECC's Energy Consumption in the UK[10].

From this point, we create projections using a selection of historic assessments; household projection data provided by external consultants; outcomes from reported external projects; regression analysis; deterministic and econometric methods. We benchmark these against stakeholder feedback and trial outcomes. We adjust each projection with our scenarios' assumptions to create the final results for each component. The component parts we use are: appliances, lighting, heating technologies, insulation and home energy management systems.

[10] DECC, Energy Consumption in the UK, April 2016, https://www.gov.uk/government/collections/energy-consumption-in-the-uk

Transport demand

3.4
Transport demand

Transport contributes just under a quarter of GB's greenhouse gas emissions. As the sales of EVs and natural gas vehicles (NGVs) continue to increase, the carbon intensity of the transport sector will fall. In scenarios where there is more disposable income, there is a higher uptake of both NGVs and EVs.

Key insights

- There are estimated to be an additional 20,000 to 135,000 NGVs on the road by 2030 from a starting position of near zero in 2013.
- This represents a gas demand growth of between 3.5 and 24 TWh per year.
- There could be up to 9.7 million EVs on the road by 2040, as seen in **Gone Green**, requiring 24 TWh of electricity per year.

20k to 135k

Estimated additional NGVs on the road by 2030

3.4.1
Electric vehicles

In all but one of the scenarios, the number of hybrid vehicles exceeds the number of pure EVs. Only in **Consumer Power**, between 2032 and 2040, do pure EV sales exceed hybrids as they are perceived as more desirable.

Table 3.4.1
Electric vehicle numbers

’000 vehicles	2016	2030	2040
Gone Green	50	5,814	9,742
Slow Progression	50	4,757	7,787
No Progression	50	1,163	3,861
Consumer Power	50	4,163	7,937

In the scenarios with higher green ambition there is government support and incentives for the electrification of transport. The decarbonisation of road transport is one of the few remaining ‘less hard wins’ which are required if the government is to achieve its carbon reduction target by 2050. In **Gone Green** there are incentives available and the prosperity to enable the vehicle market to grow. In this scenario there are almost 10 million vehicles on the road by 2040, requiring 24 TWh per year of electricity.

With less money available to purchase vehicles and to incentivise their purchasing and running costs, **Slow Progression** follows a similar but reduced trajectory.

No Progression sees a slow uptake of EVs and by 2040 there are only four million, 66 per cent of which are hybrids. 8.6 TWh per year of demand is required to drive this fleet, a third of that required in **Gone Green**.

Consumer Power may not have the incentives to support EV purchases but the economy supports high spending and investment. Consumers find these cars more desirable and relatively cheap to run.

To reflect the changes across the period we assume that the average power of EV chargers increases from 3.3 kW in 2016 to 7 kW by 2040. In the greener scenarios, where there is a high uptake of smart meters and TOUTs, there is a shift away from charging vehicles at peak time (see section 3.5.2). Consequently **Consumer Power**, despite having fewer EVs than **Gone Green**, requires more energy at peak times (see Figure 3.4.1), reaching almost 7 GW by 2040.

Transport demand

Figure 3.4.1
EVs' peak demand

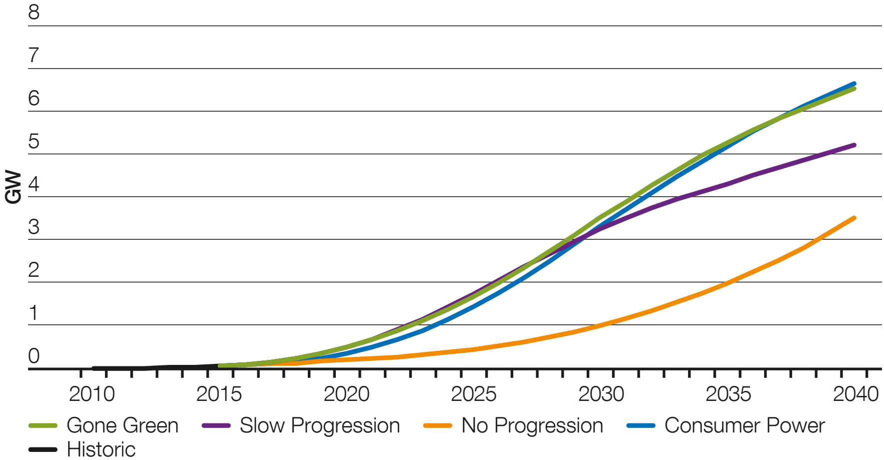
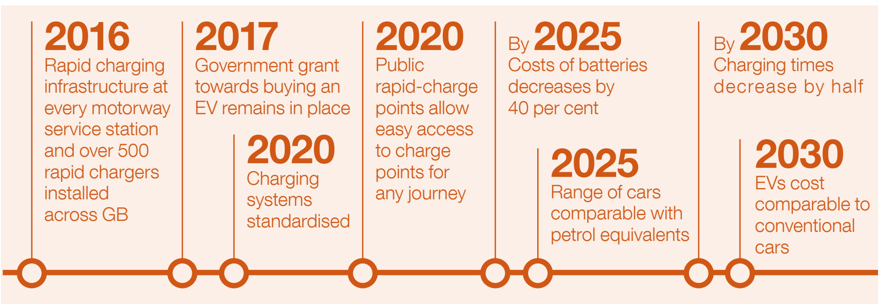


Figure 3.4.2
Road map to Gone Green's EV scenario



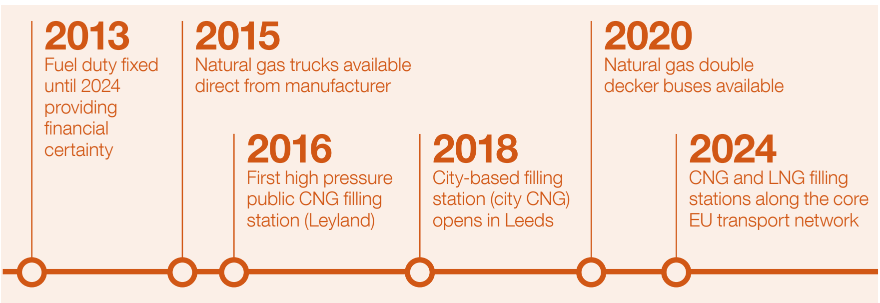
3.4.2
Natural gas vehicles

NGVs have a number of benefits. Fuel costs for NGVs are lower than diesel and petrol vehicles and the engines are quieter which could allow for earlier deliveries in residential areas. Vehicle emissions (such as carbon dioxide, nitrous oxide and particulate emissions) are also reduced. On the downside, ranges are typically shorter and GB currently lacks an extensive refuelling network.

Gas is stored for use in the vehicle in two types: liquefied natural gas (LNG) or compressed natural gas (CNG). LNG is either taken by tanker to the pump or liquefied onsite, while CNG is gas stored at high pressure and compressed at the fuelling station. Typically, CNG vehicles are attractive for back-to-depot applications (logistics, public transport) where they can be refuelled regularly. LNG is more costly but has a higher energy density so can be cost-effective for long-distance haulage.

While hybrid options, running with diesel and gas, are currently available, stakeholders tell us that by 2017 all CNG NGVs will be dedicated gas.

Figure 3.4.3
Road map to Gone Green's 50,000 NGVs by 2025



The most extensive use of NGVs occurs in **Gone Green** and **Consumer Power**. The need for decarbonisation in **Gone Green** drives the conversion of the fleets, while in **Consumer Power** the motive is to take advantage of the lower gas prices. **Slow Progression** has a more gradual rate of uptake due to lower availability of investment capital, but with the same drivers as **Gone Green**. **No Progression** has the lowest uptake, with less intervention and less capital available for investment. The infrastructure is not built, preventing NGVs being a viable option other than within private refuelling infrastructure.

Transport demand

3.4.3
Rail demand

Our stakeholder engagement suggests that there will continue to be a growth in electricity demand from trains, but there are two potential trajectories. In **Gone Green** and **Slow Progression** the growth rate exceeds the historical average and is at 2.5 per cent per year. This increases today's annual demand of 4.3 TWh per year to 8 TWh per year in 2040. This is driven by the policy decisions to invest more in the electrification of the network. In **No Progression** and **Consumer Power**, growth remains at the historical average of 1.5 per cent per year which results in a demand of 6.2 TWh per year in 2040.

Flexible demand

3.5
Flexible demand

Flexible demand is provided by processes that permit the consumer to make active management decisions on their consumption of energy, particularly during peak times. The introduction of new control technologies will enable more consumers to make better-informed decisions.

Key insights

- Small and medium businesses' electricity use will be charged on a half-hourly basis by 2017.
- The smart meter roll-out programme has commenced and will peak at over 7 million installations per year in 2018.
- Smart thermostats have the potential to reduce household gas consumption by 10 per cent.

7 million+

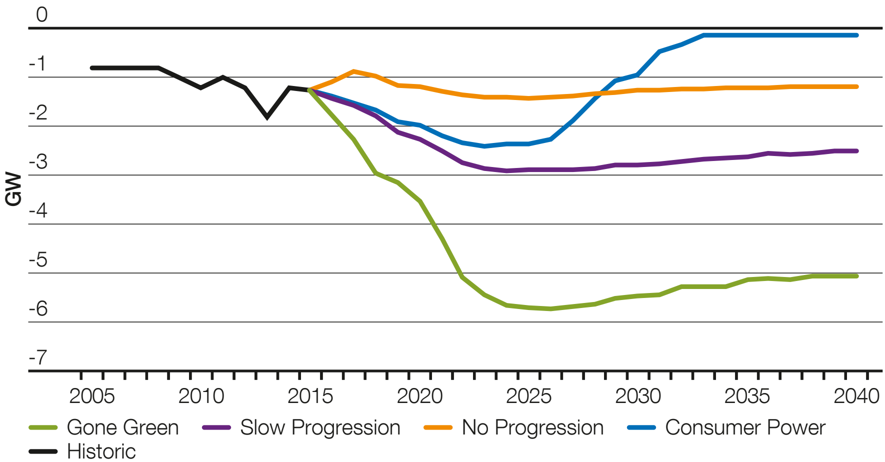
peak installations of smart meters per year in 2018

Flexible demand

3.5.1
Industrial and commercial demand side response

In *FES* we examine the underlying demand. Therefore we view demand side response (DSR) as a shifting of this demand. We do not consider using an alternative source of electricity, such as a back-up generator, as DSR. This is treated as small-scale generation and considered within section 4.1.

Figure 3.5.1
Electricity – Industrial and commercial DSR peak reduction



Traditional Triad[11] avoidance has been the main driver for DSR. The nature of Triads is that they are variable, as illustrated by the historic data shown in Figure 3.5.1. We have assumed that the maximum Triad DSR is 1.8 GW, which occurs in **Gone Green**. The minimum will be 0.8 GW, seen in **No Progression**.

Stakeholders have told us that the present system for DSR within the market place is complicated. Power Responsive[12] has been established to address this and other concerns. The programme, involving stakeholders from across the industry, has been set up to provide a platform for raising awareness, providing understanding and ensuring commercial signals are clear. The goal is to create equitable access to the markets for all flexibility technologies, including DSR.

[11] The Triad refers to the three half-hour settlement periods with highest system demand between November and February, separated by at least ten clear days. National Grid uses the Triad to determine charges for demand customers with half-hourly metering.

[12] Power Responsive, http://www.powerresponsive.com/

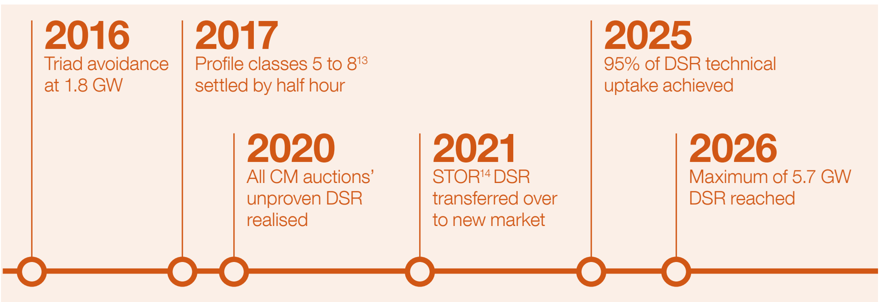
By 2040, **Gone Green** develops a further 3.4 GW of DSR and **No Progression** only 0.3 GW.

The combined effect of these DSR sources is reflected in the increase in DSR that is evident in all but **No Progression's** peak demand reduction profile.

Battery storage and onsite generation negates the need for businesses to reduce their demand. They just change their supply source. Our analysis of battery storage is explored further in section 4.3. As a result, **Consumer Power** sees a drop in its requirement for DSR as these alternative sources develop from the mid-2020s onwards. To a lesser extent, **Gone Green** and **Slow Progression** are also affected by battery storage.

Combining the above factors gives the profiles presented in Figure 3.5.1. **Gone Green** has a significant increase of new DSR, mainly brought about by the Capacity Market (CM). **Slow Progression** produces a moderate increase in the untapped potential and CM potential. **Consumer Power** is similar to **Slow Progression** but its reliance upon onsite generation and batteries quickly reduces the requirement for DSR. **No Progression** drops back to the historical levels of Triad avoidance, in the short term, and then relies only on the proven DSR sources from the CM to make a partial recovery thereafter.

Figure 3.5.2
Road map to 5.7 GW of industrial and commercial electricity DSR



[13] Small to medium consumers who are non-residential, e.g. shops, commercial premises, small manufacturers.
[14] Short-term operating reserve.

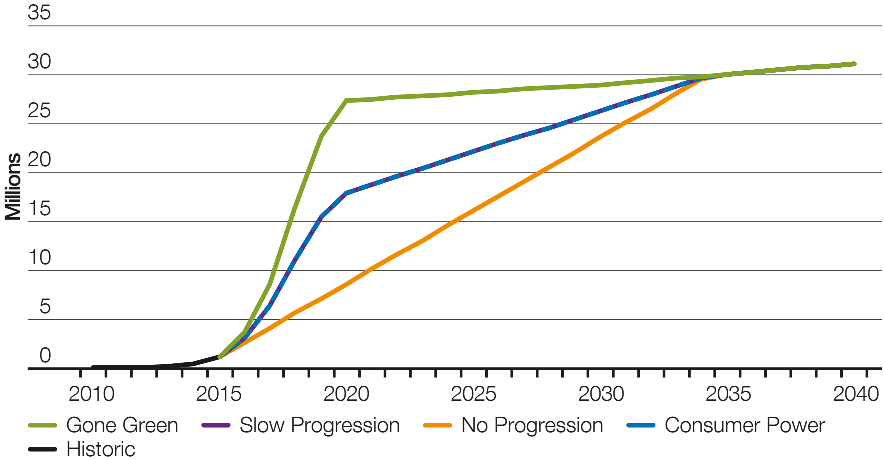
Flexible demand

3.5.2
Smart meters and TOUTs

We have used three potential roll-out programmes for electricity smart meters (see Figure 3.5.3). In **Gone Green** we have adopted DECC's profile which peaks at approximately seven million units installed in a year, or 22,000 every day of the year. This is a significant number of installations which, if combined with the additional gas smart meters, seems challenging.

For **No Progression** we assume an electricity smart meter replacement rate of 1.5 million units per year. For **Slow Progression** and **Consumer Power** a mid-course between **Gone Green** and **No Progression** is taken.

Figure 3.5.3
Electricity – Cumulative smart meter roll-out programmes

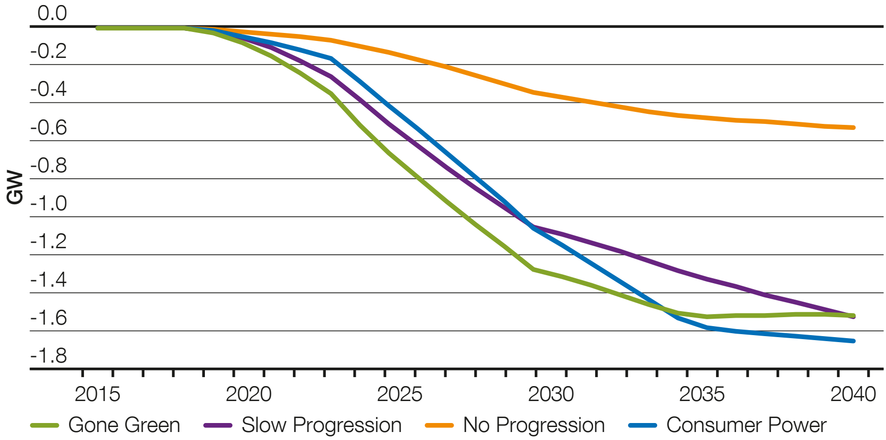


The engagement levels with TOUTs, once the smart meters have been installed, are differentiated by scenario. This is based upon Ofgem's categories of consumers' switching behaviour (Permanently Disengaged, Disengaged, Reactive, Proactive and Passive Switchers)[15] and the outcomes of a number of low carbon innovation funded projects[16].

The introduction of TOUTs allows for smart appliances to contribute towards peak shifting (see Figure 3.5.4). **Consumer Power**, which has more smart appliances (which have greater consumption rates), achieves the largest savings. The two greener scenarios reach the same end point, which is similar to **Consumer Power**, but **Gone Green** achieves it faster with its quicker roll-out programme along with more enthusiastic engagement.

Only **No Progression** lags behind in the potential savings to be made. This is because there is a slow roll-out of smart meters, a minimal engagement with TOUTs, and few smart appliances to facilitate the required responses.

Figure 3.5.4
Electricity – Residential peak reduction due to TOUTs and smart appliances



[15] Ofgem, The Retail Market Review – Findings and initial proposals, April 2016, https://www.ofgem.gov.uk/ofgem-publications/39708/rmrfinal.pdf

[16] Ofgem, Low Carbon Networks Fund, April 2016, https://www.ofgem.gov.uk/electricity/distribution-networks/network-innovation/low-carbon-networks-fund?

Flexible demand

3.5.3 Smart thermostats

Smart thermostats are relatively low-cost energy saving devices. They allow consumers to remotely control their home's heating schedule from a smartphone, tablet or computer. Some devices are able to automatically adjust the heating according to the consumer's location, the weather conditions and the characteristics of the boiler and property.

By efficiently heating the home and reducing occurrences where an empty home is heated, energy demand can be lowered without impacting comfort. Following stakeholder feedback, we have revised down our view of potential savings to a 10 per cent reduction in **Gone Green** and **Slow Progression**, and a five per cent reduction in the other two scenarios. The lower potential savings in **Consumer Power** and **No Progression** are a result of simpler smart thermostats being provided with fewer features.

When combined with sales forecasts, our analysis shows that through installing smart thermostats there is a potential to reduce current heat demand in 2040 by 10 TWh per year in **No Progression** to 20 TWh per year in **Gone Green**.

Method

TOUTs

To model the effects of residential TOUTs we have made a number of assumptions on the time extent of the tariffs and the percentage of people who are engaged in changing their electricity consumption pattern. These assumptions are supported by the outcomes of related projects, in particular those from Ofgem's Low Carbon Network Fund, the Customer-Led Network Revolution and Low Carbon London.

However there still remain a number of uncertainties, which could significantly change how the consumer could react to TOUTs. For example: profile of the smart meter roll-out, timing of the introduction of TOUTs, and the structure and mechanics of the TOUTs.

Industrial and commercial DSR

We have made an assessment of what the potential for future DSR could be in the sector. This assessment was derived from a literature review of DSR potentials. However there is a scarcity of data and what is available is broad in its conclusion. We have used this range to inform our scenario ranges. We anticipate that there are a number of DSR activities which act as precursors to our modelling assumptions. These include:

- STOR
- Electricity Market Reform mechanism
- Triad avoidance actions
- Turn-down contracts with suppliers
- TOUTs.

The true scale of Triad avoidance is difficult to gauge as it is generally done on a business-by-business basis. The type of avoidance adopted can either be a speculative reduction on potential Triad days, or it can be a guaranteed systemic reduction on all the days during the Triad period. There are two ways to achieve these reductions: either reducing demand or using a back-up generator. We consider only the former which we estimate to be 63 per cent[17] of the observed Triad avoidance. Additional DSR has emerged as a result of the CM auctions. These are either defined as proven or unproven. For our greener scenarios we have assumed more of the unproven DSR becomes a reality.

[17] The energyst , Demand Side Response – Bringing businesses into balancing, April 2015, http://www.openenergi.com/wp-content/uploads/2016/01/Demand-Side-Response-report-2015.pdf

Chapter four

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Electricity supply

4.1
Electricity supply

Electricity supply in GB is transforming at an unprecedented rate. Our scenarios show a credible range of possible future electricity supply sources including scenarios high in low carbon, gas-fired and distribution-connected generation.

Key insights

- As a result of environmental pressure and legislation there is no unabated coal-fired generation after 2025 in any scenario.
- By 2040 in **No Progression**, unabated gas capacity exceeds 38 GW and output is more than 112 GWh (32 per cent of all electricity output).
- In **Gone Green**, the high green ambition sees low carbon technologies contributing 56 per cent of total output in 2020, rising to 84 per cent in 2040.
- By 2040 in **Consumer Power**, the emphasis on local energy projects means these represent 49 per cent of total installed capacity, and provide 40 per cent of electricity generation.

Over the next 10 years there will be an increase in the number of closures of traditional large-scale power stations, due to a combination of environmental and economic factors. To meet forecast demand in all scenarios requires significant new build programmes. Our scenarios consider which types of generation may connect, where, in what timescales, and how much capacity and output they could provide.

This section considers the scenario period out to 2040. In each of our scenarios, all coal-fired power stations will have closed by 2025 at the latest, in line with recent government announcements. The existing nuclear power stations begin to reach the end of their life during the next decade and start decommissioning. By 2030 an excess of 7.7 GW of generation is retired from the system. The first new nuclear power station is not expected until the mid-2020s at the earliest, causing a dip in nuclear generation (capacity and output) during the early to mid-2020s.

Security of supply is maintained through an increasingly diverse combination of technologies: more small-scale thermal generation, access to additional capacity through greater interconnection, and the continued growth of thermal low carbon technologies.

Gas remains the backbone of the electricity supply mix. Capacity Market (CM) contracts encourage investment in new plant, particularly small-scale thermal, and incentivise existing generators to remain operational. This helps to ensure that periods of peak demand can be met.

No Progression, which is the highest case for new build gas, requires approximately 7 GW[1] of new large-scale combined cycle gas turbines (CCGTs) by 2022 to maintain security of supply to compensate for coal plant closures. For this to be achieved the milestones in Figure 4.1.1 need to be met.

Figure 4.1.1
Road map to over 7 GW of new gas capacity by 2022

[1] Our scenarios assume a phased build programme for new build gas across the generation backgrounds. While this road map looks at the 7 GW requirement in No Progression by 2022 this does not mean that no new gas build is required before this point. For more detail on new gas build requirements across the scenarios please refer to the *FES* supporting data worksheet.

Electricity supply

Table 4.1.1
Transmission-connected gas capacity currently contracted with National Grid

Future gas plant connections (with a completion date before 2022)	**Future gas connections with planning consent**	**Future gas projects with a CM contract**
12 GW	**11.5 GW**	**1.5 GW** (1 project)

The required levels of new CCGTs will mean the network should be prepared for a potential dash for gas.

Delivery of 7 GW of new build gas capacity will require an increased level of certainty for investors to make FID. This certainty can be delivered by clear articulation and a reduction in ambiguity around the CM.

In 2020, gas capacity is broadly similar in all four scenarios at between 25 GW and 30 GW of installed capacity. In **No Progression** unabated gas-fired generation increases and by 2040 provides 38 GW of installed capacity and accounts for over a third of total generation capacity (35 per cent) and output (32 per cent). In the other three scenarios gas-fired generation capacity reduces by 2040.

4.1.1
The energy landscape

4.1.1.1
Shift from transmission to distribution connections

Current environmental legislation, energy policy and economic conditions have created a challenging environment for traditional large-scale thermal plant to operate in. This has resulted in many plant closures, with coal, oil and gas-fired generation being affected. In particular, coal-fired generation capacity has reduced by 25 per cent since 2012 and all oil-fired generation is now closed.

Compounding this issue, the current nuclear fleet is nearing the end of its operational life. Decommissioning is due to commence at the beginning of the next decade in **No Progression**, and by 2023 in **Gone Green** and **Consumer Power**.

The closure of nuclear power stations is not immediately compensated for by the commissioning of new nuclear plant. The first new addition to the nuclear fleet is not expected to be operational until the second half of the next decade at the earliest. This situation occurs in our **Gone Green** scenario.

The closure of these very large, transmission-connected power stations contrasts with the deployment of numerous small-scale generation throughout GB. **Consumer Power** has by far the most dispersed generation profile with almost 89 GW connected at the local level by 2040, making up 49 per cent of total generation capacity and providing 40 per cent of generation output. This is largely due to having significant levels of solar generation and storage, accompanied by an offshore wind generation fleet. There is also a tendency for certain technologies to be grouped in particular regional areas. For example, there is a large amount of solar photovoltaic (PV) installed in the south west of England, while Scotland has considerably more onshore wind and hydro generation.

This downward shift in the size of generation and the tendency to decentralise are important characteristics of all four of our scenarios, albeit to differing extents and timescales. This trend represents a change in the way the National Electricity Transmission System (NETS) is designed, built and operated. The implications of this are considered in more detail in the *Electricity Ten Year Statement*[2] and *System Operability Framework* (SOF)[3], also published by National Grid as the System Operator.

[2] National Grid, Electricity Ten Year Statement, November 2015, http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-Ten-Year-Statement/

[3] National Grid, System Operability Framework, November 2015, http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/

Electricity supply

Spotlight: Changing faces of electricity supply

Electricity supply is going through a period of unparalleled transformation in GB. New technologies emerging in the supply market have coincided with increased social awareness of how and where our electricity comes from.

At the beginning of this century our electricity was mainly sourced from traditional large-scale generation with nuclear, coal- and gas-fired generation providing over 90 per cent of electricity. Renewable generation represented just three per cent of installed capacity and nearly two thirds of this was hydroelectricity. The vast majority of this generation was connected to the high-voltage network.

Since then the electricity supply landscape has gone through a period of significant transformation. Changes to environmental legislation and other government policies have resulted in greater diversity regarding generation technologies, their sizes and locations.

In 2015, 30 different technologies help meet our electricity needs. Large-scale nuclear, coal- and gas-fired generation still provide nearly two-thirds of our electricity requirements. Renewable generation represents 30 per cent of installed capacity and meets 24 per cent of demand. Onshore wind capacity has increased from 0.2 GW in 2000 to 8.2 GW. Solar PV has seen an even higher increase over the same period, from 0.02 GW to 9.6 GW by the end of 2015. The emergence of renewable generation has been underpinned by the Government's 2020 target of sourcing 15 per cent of our energy from renewable sources.

This transformation has also extended to the location of generation. 23 per cent of installed capacity is not directly connected to the high-voltage network. Instead it is connected to either the lower-voltage distribution networks or to domestic, commercial and industrial buildings.

This trend towards smaller, more distributed, technologies has been exaggerated for certain technologies, with all of the 9.6 GW solar PV connected to either domestic dwellings, industrial buildings or the lower-voltage networks. Two fifths of renewable generation is connected to the high-voltage network. This has resulted in the network extending further into new parts of the country e.g. new areas of the highlands and borders of Scotland and offshore waters surrounding GB.

Whether this pace of change will continue will depend on energy policy, the economy, environmental legislation and technology life cycles. If the rate of change continues, potentially half of all generation will be connected directly to our homes, local businesses or the lower-voltage networks. New electricity storage technologies may emerge and work with other (low carbon) technologies to provide a more constant and flexible generation output.

Other technologies may continue to connect and use the NETS, in particular, larger-scale low carbon, offshore renewable and thermal technologies, along with additional interconnector capacity.

Regional variations may emerge over time. By 2040 the south west of England may be dominated by locally connected renewable generation (solar PV and marine), with no reliance on traditional large-scale generation. This trend may spread across the south and south east of England along with new interconnectors connecting in this part of the country.

Wales could have significant volumes of low carbon technology as the next generation of nuclear connects and large-scale marine projects begin operation. This bias towards low carbon technologies is inclusive of renewable generation with hydro and wind projects maximising the natural resources of the landscape.

In the north of the country, Scotland's generation could potentially come from 100 per cent low carbon sources. This could occur as older conventional plant is replaced with increasing volumes of renewable generation (wind, hydro and marine) and CCS replaces other forms of low carbon technology. The north of England and the central regions may be dominated by thermal technologies and low carbon technologies with renewable generation entering the generation mix at a slightly slower pace compared to other parts of the country.

Whatever happens to the sources of our generation over the next 25 years, it is important to recognise that change will continue and it is only the pace which is unknown. Given the potential rate of change, the electricity system, network and markets must be able to continually adapt to the energy landscape.

Electricity supply

4.1.1.2 Interconnection

Another important feature of all of the scenarios is the significant increase in interconnection, both in terms of capacity and contribution to security of supply. We see an increase from approximately 4 GW of capacity at present, to between 11 GW in **No Progression** and 23 GW in **Gone Green** and **Consumer Power** by 2030.

The ability to access additional capacity contributes to security of supply. This additional contribution from interconnectors may reduce the requirement for domestic generation as generation from other countries, which may be cheaper, will have access to the GB market.

Refer to section 4.2 for more information regarding electricity interconnection.

4.1.1.3 Diversification of technology

The closure of large-scale and conventional plant creates opportunities for new technologies to establish themselves in the market, resulting in a generation mix that continues to diversify out to 2040 in all scenarios. Where this is combined with energy policies focused on low carbon and renewable generation, it provides a favourable environment in which various sources of low carbon and thermal generation are encouraged and supported.

CCS only appears in our **Gone Green** scenario (before 2040), and its presence here demonstrates how political and social commitment to the green agenda needs to be accompanied by the prosperity afforded by a strong economy to encourage new forms of low carbon generation to enter the market place.

As the amount of renewable capacity connected to the system increases, more flexibility is required from other technologies. This is due to the variable nature of some renewable generation and the challenges in accurately controlling output.

Levers used in the past to encourage or discourage plants from running are not as effective in scenarios with high levels of renewables, as these technologies have no fuel cost savings when they curtail their generation. It is therefore essential that there is adequate flexible generation that can be called upon by the System Operator to accommodate the peaks and troughs in demand. More information regarding future challenges for electricity system operation can be found in our *System Operability Framework*[4].

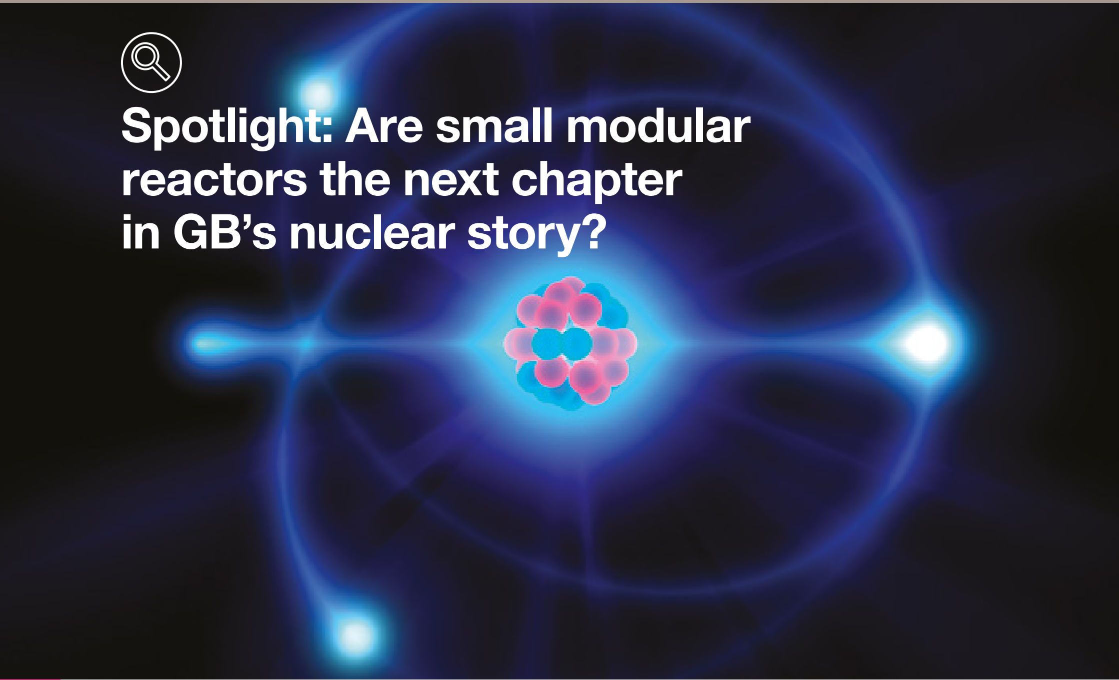
[4] National Grid, System Operability Framework, November 2015, http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework

Small-scale gas and diesel reciprocating engines are currently the preferred technologies for investors. They have advantages over large-scale conventional plant both in terms of reduced capital costs, avoidance of Transmission Network Use of System costs, and the ability to access multiple markets within the energy sector. This unlocks potential revenues that are not necessarily available to transmission-connected generators.

There is a considerable amount of growth in these technologies up to the mid-2020s, with small-scale thermal plant providing between 2.7 GW to 4.5 GW of generation capacity in **No Progression** and **Gone Green** respectively.

This year we have included a wider range of electricity storage technologies in all of the scenarios. By 2040 in **Consumer Power**, the high deployment case, over 18 GW of storage capacity is installed. This contrasts with the low case, **No Progression**, where only 3.6 GW is installed. This illustrates the uncertainty of how much and when these emerging storage technologies will break into the market on a commercial scale, and make a significant contribution to the energy landscape.

Although both the timeline and best utilisation are unclear for large-scale storage deployment, it is likely that it will play a part in the future of energy. See section 4.3 for more information about electricity storage.



Spotlight: Are small modular reactors the next chapter in GB's nuclear story?

Nuclear power, CCS and renewables are likely to be fundamental technologies in the transition to a low carbon future.

The role of nuclear generation, particularly the potential role of small modular reactors (SMRs) as part of GB's future energy landscape has recently been given impetus with the government's announcement of a £250 million research and development programme[5]. The centrepiece of the initiative is a competition, the first phase of which was launched in March 2016, to identify the best value SMR design, enabling the country to be a global leader in innovative nuclear technologies.

Phase one of the competition will last until autumn 2016 and will gauge market interest in developing, commercialising and financing SMRs. In parallel, DECC intends to develop an SMR road map. The road map will include details of the process that government will use to identify suitable sites and any work that the government will undertake with the Office for Nuclear Regulation to ensure that appropriate provisions are made for regulatory approval, including the generic design assessment[6]. Wales, the north of England and existing or previous nuclear sites are being cited as possible locations for the technology.

[5] Department of Energy and Climate Change, Small Modular Reactors, March 2016, https://www.gov.uk/government/collections/small-modular-reactors

[6] Office of Nuclear Regulation, Generic Design Assessment (GDA) of new nuclear power stations, February 2016, http://www.onr.org.uk/new-reactors/

SMRs have been in operation for more than 50 years, particularly on military submarines and ships. They are smaller than conventional nuclear reactors, with power outputs ranging between 50–225 MW. It is a relatively new technology for electricity generation.

SMRs could complement the country's large-scale nuclear reactor programme[7, 8]. As the technology comes in modular components, much of the design and plant can be fabricated in a factory environment and transported to site. Their size makes them quicker and easier to build and they offer the ability to bring capacity online gradually.

Potential advantages of SMR technology may include the ability to vary output quicker than their larger-scale counterparts. It is important to note that the detailed technical characteristics of SMRs are not yet available and the potential technical functionality will have to be proven in an operational setting.

SMRs aim to capture the advantages of traditional nuclear power: predictable, low carbon energy, while avoiding the significant capital expenditure and time required for their larger-scale equivalents. The emergence of SMRs as part of the GB energy landscape will require political support, stringent environmental safeguards, rigorous safety procedures, proof of concept, and social acceptance of the technology.

The relevant industrial codes and standards will also have to be updated to connect and accommodate their operation. Challenges in system operability relating to nuclear technologies were discussed in our 2015 *System Operability Framework*, and similar issues are expected to affect SMR technology.

Given the myriad of factors that need to be considered, worked through and agreed upon, it is likely that the earliest possible operational date for SMR will be around 2030[9]. The uncertainty surrounding the introduction of SMRs means that the next few years are important if the technology is to play a role in the transition to a low carbon energy system. SMRs may be the next chapter in GB's long association with nuclear power[10], the beginning of which has just started.

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[7] Energy Trade Association, Small Modular Reactors In A UK Low Carbon Energy System, April 2016 http://www.eti.co.uk/wp-content/uploads/2016/04/2016-04-15-Small-Modular-Reactors-In-UK-Low-Carbon-Energy-System-WIDESCREEN-Final.pdf

[8] National Nuclear Laboratory, Small Modular Reactors (SMR) Feasibility Study, December 2014, http://www.nnl.co.uk/media/1627/smr-feasibility-study-december-2014.pdf

[9] Energy Technologies Institute, Nuclear – The role for nuclear within a low carbon energy system, September 2015, http://www.eti.co.uk/wp-content/uploads/2015/09/3511-ETI-Nuclear-Insights-Lores-AW.pdf

[10] Calder Hall, UK's first nuclear power station – 1956 to 2003

Electricity supply

4.1.1.4
Route to 2020

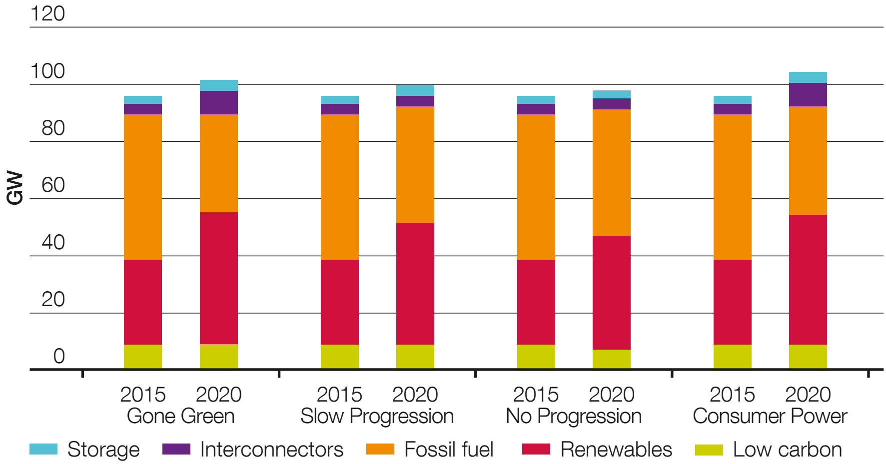
Between now and 2020, the major changes to electricity supply are centred on the decline of traditional large-scale generation and the continued development of renewable and small-scale technologies. The combined effect of which is a shift from new generation connecting to the NETS, towards more locally connected generation at the distribution network level.

Security of supply is maintained through the award of CM contracts, ensuring that there is enough available generation to meet peak demand. However, the prevailing trend from 2016 to 2020 is for coal plant, and some old gas-fired power stations, to close due to difficult market conditions and environmental legislation.

New generation is led by renewables, with a strong deployment of offshore wind. In addition, new small-scale generation, with particular emphasis on solar, further increases the total amount of generation capacity connected to the distribution networks.

Electricity storage technology is evolving rapidly. By 2020, commercial opportunities for large-scale deployment of storage will become clearer. Emerging contracts for new services could lead to a considerable ramp-up over the following decade of electricity storage based solutions. The breakdown of installed generation is shown in Figure 4.1.2.

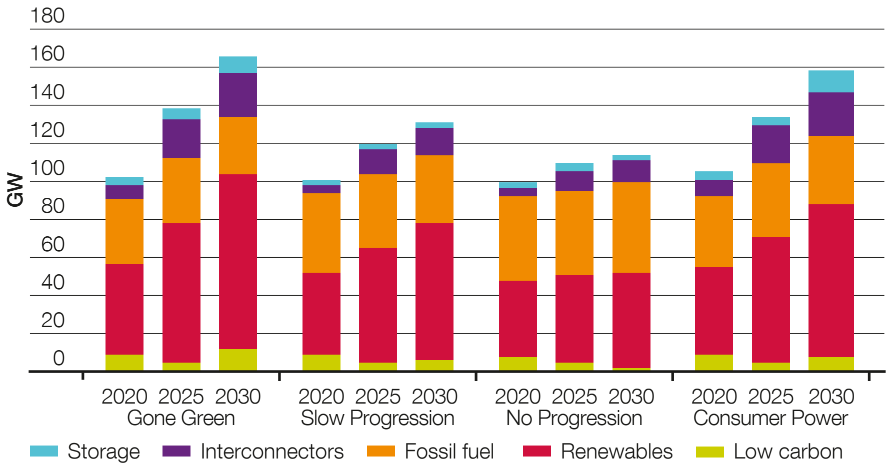
Figure 4.1.2
Amount of installed generation by type 2015–2020



4.1.1.5
2020–2030

This decade sees the closure of the last coal-fired power station. By 2025, there is no unabated coal-fired generation in any of the scenarios. The breakdown of installed generation is shown in Figure 4.1.3 below.

Figure 4.1.3
Amount of installed generation by type 2020–2030



Nuclear decommissioning picks up pace throughout the period with all but one of the existing fleet closing over the course of the decade. New build nuclear programmes vary widely over the scenarios during this period. This ranges from no new stations commissioning in **No Progression** to the first new nuclear plant to open in over 30 years, and a total of nearly 9 GW of new capacity, in **Gone Green** by 2030.

During the 2020s a considerable number of new gas plants become available in all scenarios, helping to maintain security of supply following the closure of conventional plant. Deployment differs across the scenarios depending on what other technologies are connecting. More gas capacity is commissioned in scenarios where investment in renewable and low carbon technologies is subdued. **No Progression** adds

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Electricity supply

the most new gas plant with over 19 GW coming online. However, even in **Gone Green**, where renewables and low carbon technologies are the favoured sources of generation, an additional 8.7 GW of new gas capacity is required.

This emphasises the ongoing role that gas plays in the electricity supply mix over the medium to long term. Not only is it the favoured fuel when prosperity and green ambition are low, but it is needed to provide important grid and market services in high-renewable scenarios. As a flexible source of generation, gas can assist system operation and offset some of the variable output associated with renewable generation. For both of these reasons, gas makes a valuable contribution to security of supply.

With interconnectors, we see a rapid increase in new capacity in all scenarios; overall, the range is between 7.2 GW in **No Progression** and 18.1 GW in **Gone Green** over the course of the decade.

The largest increase in capacity is found in the offshore wind sector, with between 10 GW in **No Progression** and 19 GW in **Gone Green** of new capacity being installed. This is largely due to increasing certainty and visibility of how and when the large Round 3[11] projects will connect over this period.

Storage capacity increases considerably in both scenarios where prosperity is high. **Consumer Power** sees the highest deployment of storage technologies, with overall capacity increasing from 3.7 GW in 2020 to 10.7 GW by 2030. For further details on electricity storage, see section 4.3.

CCS features only in our **Gone Green** scenario (before 2040), and begins to appear in 2029. This is because, for CCS to become commercially viable, high levels of investment are required, accompanied by a green agenda and government support.

4.1.1.6
2030–2040

During the 2030s, the nuclear build programme continues to grow, with between 1.7 GW in **No Progression** and 8.4 GW in **Gone Green** of new capacity being installed. By 2030, only one plant of the existing nuclear fleet is still operational and it stays open throughout this decade.

Assuming a life span of approximately 25 years, a considerable amount of wind generation will reach the end of service life by 2040. The majority of this, approximately 7 GW, will be onshore and what happens to it at this point will be determined by several key factors.

The duration of the original subsidies contracts for onshore wind projects: renewables obligation[12] (RO), contracts for difference (CfD) and the feed-in tariff will have come to an end, so the availability of further financial support will be an important factor in the decision to either repower projects or decommission them. This is considered in more detail in the onshore wind repowering spotlight on page 86.

Similar factors will impact the repowering of solar generation as they come to end of service life, over the same period.

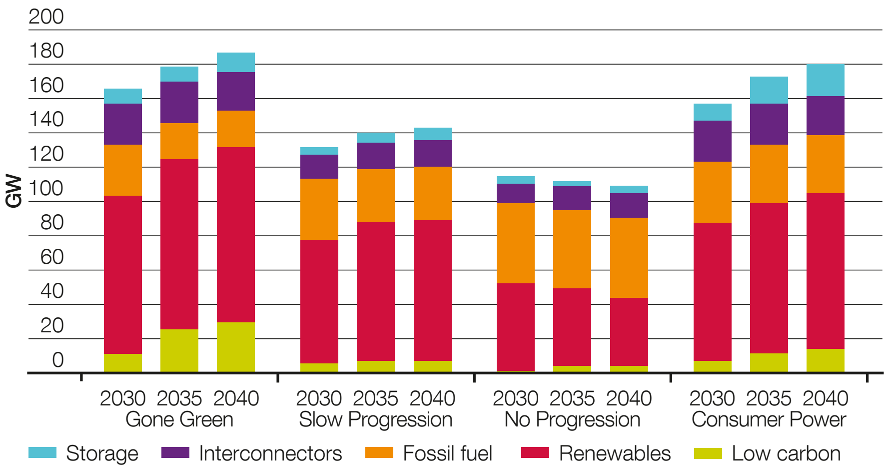
[11] The Crown Estate, Round 3 Offshore Wind, March 2016, http://www.thecrownestate.co.uk/media/5699/ei-round-3-offshore-wind-a4.pdf

[12] Ofgem, Closure of Renewables Obligation, accessed March 2016, https://www.ofgem.gov.uk/environmental-programmes/renewables-obligation-ro/information-generators/closure-renewables-obligation-ro

As in previous decades, gas continues to play an important role in all four of our scenarios. In **No Progression**, in 2040, there is more gas-fired generation connected than at any other time, in excess of 38 GW. In comparison, **Gone Green** has 14.7 GW. This highlights how established technology is favoured in **No Progression**, but also how gas-fired generation remains a fundamental part of the supply mix in all of our scenarios, where it offers valuable services for system operation alongside high levels of renewables.

In **Gone Green**, deployment of new, low carbon generation such as nuclear and CCS projects is high, with 8.4 GW and 9.4 GW respectively of additional capacity being installed. This is possible due to the investment being available along with the ambition to meet the 2050 carbon reduction target. The breakdown of installed generation is shown in Figure 4.1.4.

Figure 4.1.4
Amount of installed generation by type 2030–2040

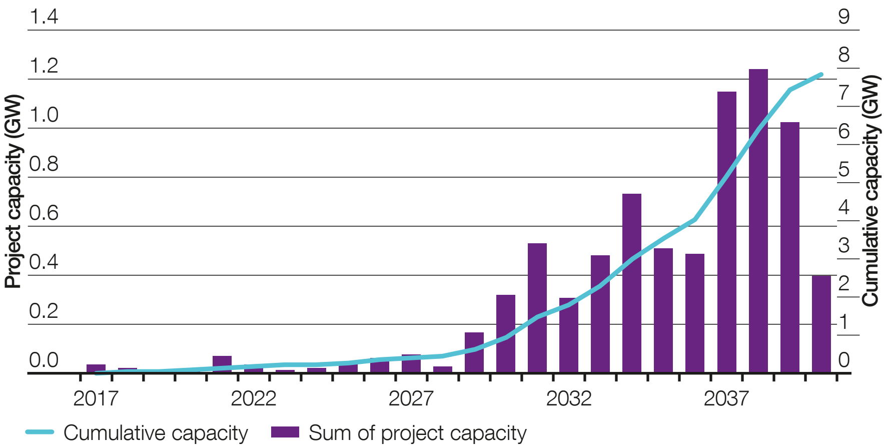


Spotlight: Onshore wind repowering

Commercial onshore wind farms emerged in GB in the early 1990s as a low carbon alternative to traditional electricity generation.

Over the past 25 years, onshore wind has proven to be a credible technology and is currently one of the cheapest sources of low carbon renewable energy. It now constitutes approximately 8 GW of total installed capacity in GB. Between now and 2020, less than 100 MW of installed capacity is due to reach end of life, rising to about 1 GW by 2030. The majority of projects will come to end of life from 2030 onwards, based on original deployment rates (see Figure 4.1.5).

Figure 4.1.5
Onshore wind end of service life profile



There are three main options available to wind farm operators when the turbines reach the end of their lives. Firstly, they could choose to decommission the turbines and cease generation. Secondly, they could invest in new turbines and continue to generate (full repowering). Thirdly, they could extend the life of the existing turbines by replacing some of the components where necessary (partial repowering). The market and economics will dictate which of these options is most attractive. Other influencing factors are likely to be: electricity prices, the availability of financial support from subsidies, renewable energy policy, planning regulations and opportunities to invest elsewhere.

In the event that repowering is not a viable option and wind farms decommission after 25 years, between 2016 and 2030 only an estimated 1 GW will come off the system. However, in the following decade 7 GW of capacity will be lost. This would increase the dependency on alternative new low carbon projects to achieve the 2050 carbon reduction target.

To date, few wind farms have repowered in GB, but those that have have increased their capacity significantly, while at the same time reducing the number of turbines installed. This trend has also been evident in other countries where repowering has taken place, most notably in Denmark and Germany. Repowering in this way exploits the benefits of the much larger capacity that current turbines have compared to those of the 1990s. This level of increased productivity can be expected to continue until the mid-2020s. At this point, due to a marked increase in the capacity of turbines deployed post-2000, the benefits are not expected to be quite as significant (assuming no major step change in onshore wind turbine capacity). Provided that two thirds or more of existing onshore wind farms repower, and at the same time increase their capacity by at least 50 per cent, the current 8 GW of onshore wind capacity currently on the system will still be available in 2040.

While full repowering provides opportunities to benefit from the latest, most efficient units available, there are some circumstances where a partial repower may be a better option. If a wind farm is operating at or near its maximum output for the electrical infrastructure in place, or planning for larger turbines is rejected, then it may be preferable to extend the life of the existing assets by only replacing essential components. Life extensions typically add up to 10 years to the operational life of a project, although this is reflected accordingly in the associated cost.

Decommissioning may be considered to be the least likely of the three options when a wind farm reaches the end of its life. This is mainly because the early wind projects selected the best sites, so putting more efficient turbines in makes economic sense. In addition, although the consenting process will have to be reiterated, the previous existence of wind turbines at a site may be a positive factor in gaining permission for a new development. Also, repowering typically results in fewer turbines onsite and, with new models tending to operate at slower wind speeds and fewer revolutions per minute, they are quieter, so there are a number of benefits to the local environment.

The decisions on repowering will be made based on the economic viability of the project for the generators and investors. Historically, the onshore wind industry in GB has been supported by government incentives. However, since the premature closure of the RO scheme was announced in 2015, doubt has subsequently been cast over the availability of CfD for future projects.

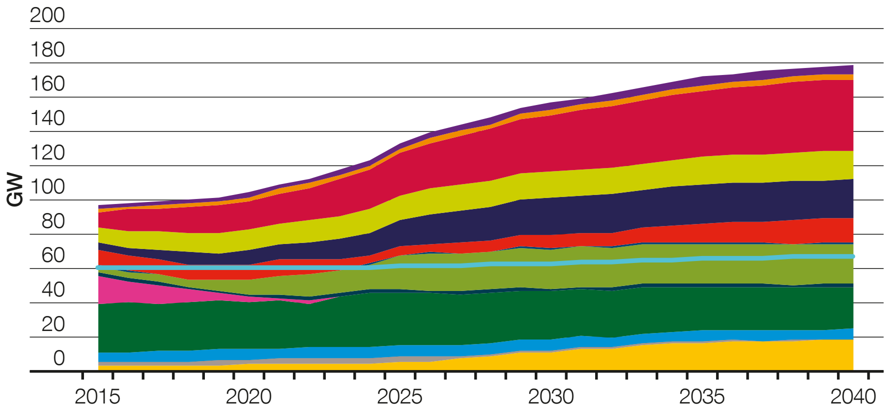
Denmark and Germany, who both have mature wind industries, have incentivised their countries' repowering projects with subsidies. This leads to the more pertinent question: will onshore wind farms in GB repower without financial support?

Electricity supply

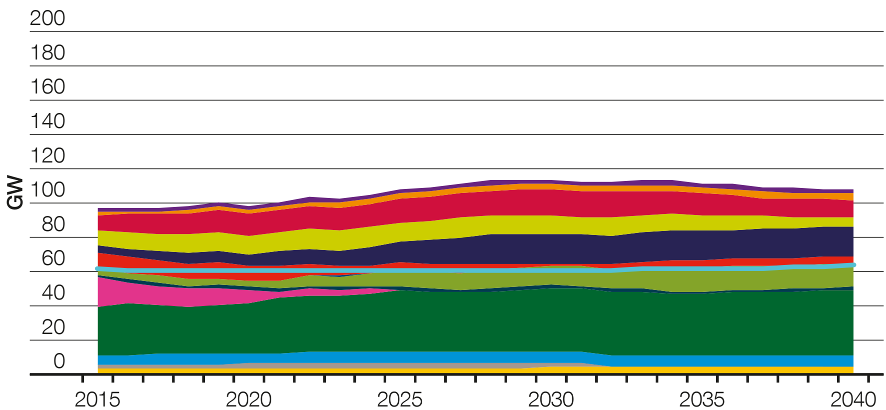
4.1.2
How the scenarios compare

Figures 4.1.6 and 4.1.7 show the installed capacity, output and carbon intensity for all of our scenarios out to 2040. They illustrate how the generation mix adjusts in the future due to changes in political, environmental, technology and social landscape.

Figure 4.1.6
Installed generation by type – Consumer Power

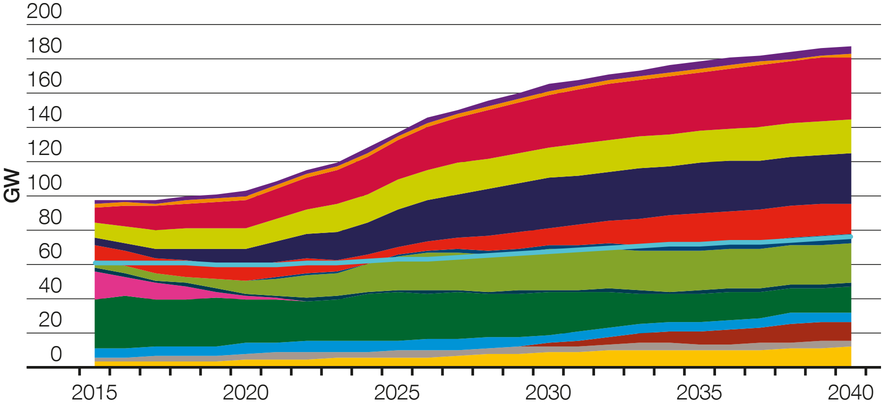


Installed generation by type – No Progression

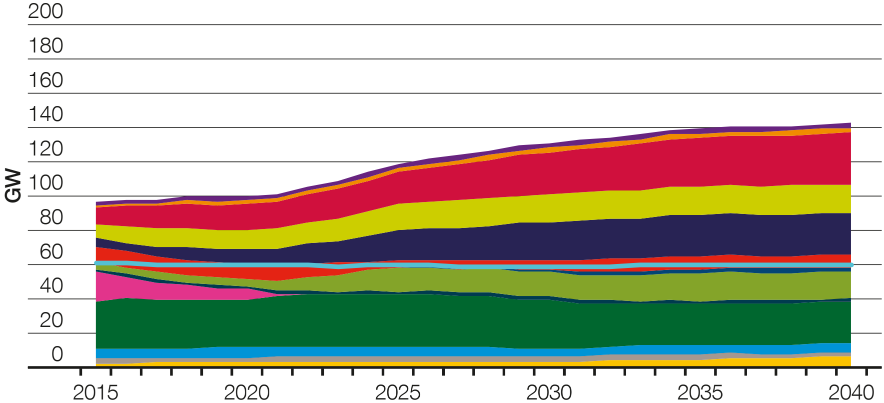


Other renewable | Other thermal | Solar | Onshore wind | Offshore wind | Nuclear | Marine | Interconnectors | Hydro | Coal | Gas | CHP | CCS | Biomass | Storage | ACS peak demand

Installed generation by type – Gone Green

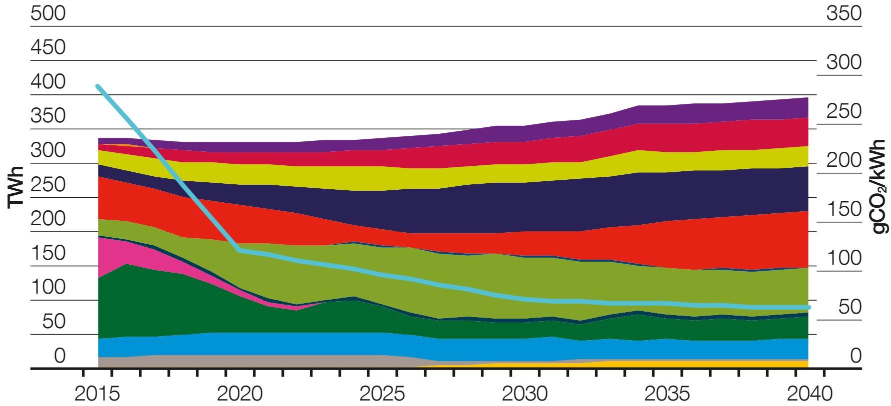


Installed generation by type – Slow Progression

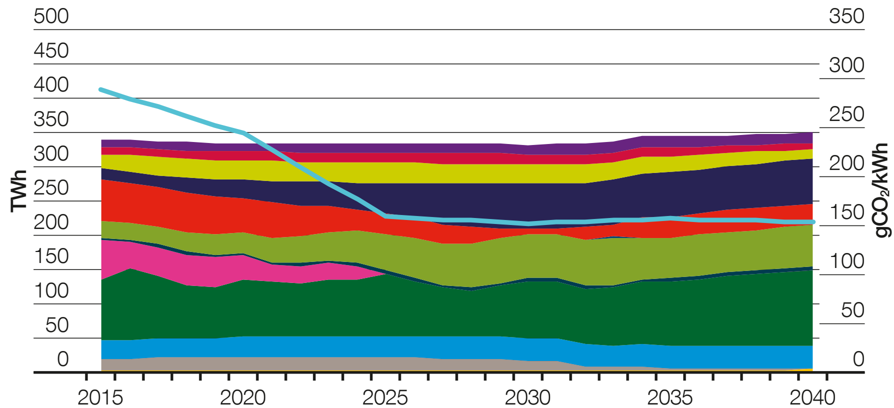


Electricity supply

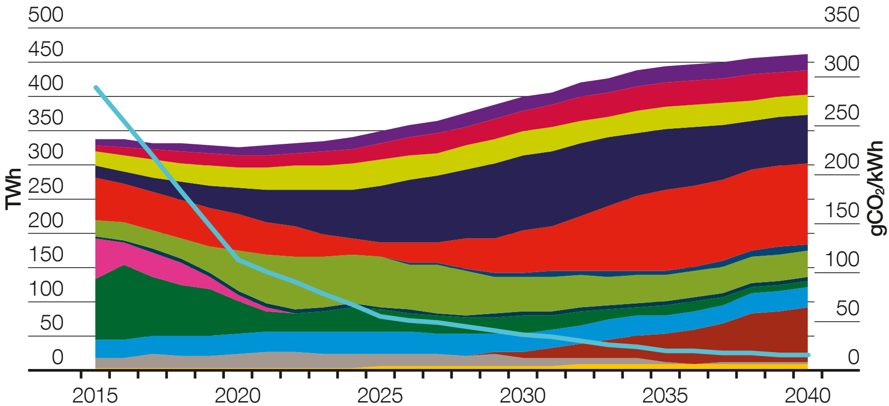
Figure 4.1.7
Output and carbon intensity – Consumer Power



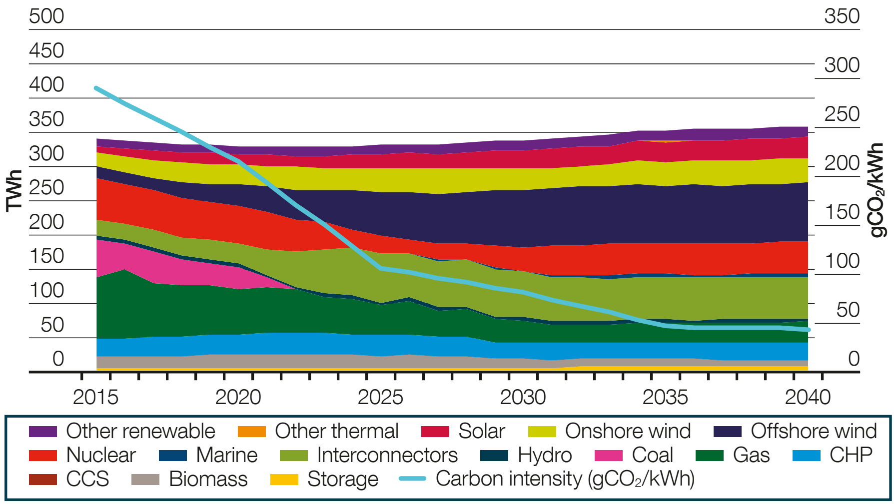
Output and carbon intensity – No Progression



Output and carbon intensity – Gone Green



Output and carbon intensity – Slow Progression



Electricity supply

Method

Scope

Our scenarios consider all sources and sizes of generation, irrespective of where and how they are connected; from large generators connected to the NETS, medium-size industrial and commercial generation connected at the distribution level, through to small-scale, sub-1 MW generation connected directly to commercial premises or domestic residences throughout GB.

Out to 2020, our analysis is largely driven by market intelligence. Between 2020 and 2030, there is a mixture of market intelligence and assumptions, with assumptions playing an increasing part towards the end of the decade. After 2030, there is very little market intelligence available so we rely more on our assumptions. These can be accessed in the Scenario Framework document available at **http://fes.nationalgrid.com**.

Generation backgrounds

The scenario narrative and assumptions provide the uncertainty envelope of generation technologies. The emphasis placed on a particular technology is determined by a number of factors such as market intelligence, government policy and legislation, project status and power station economics. The generation backgrounds are then developed to meet the security of supply standard for each of our electricity demand scenarios.

Electricity generation output

A generation dispatch model provides the output for each of the power stations connected to the NETS.

In each half hour of the year, the model calculates the running costs of each power station considering their fuel costs, carbon emissions, any additional costs and estimating the financial support that the station receives for its output. These running costs are condensed in a single metric, the short-run marginal cost (SRMC).

Depending on the technology of a power station, their SRMC can range from virtually zero to tens of pounds per MWh. The technologies with the lowest SRMC include renewable technologies such as wind, solar and marine. They are assumed to operate whenever they are able to: when the wind is blowing or water is flowing. Each technology has an assumed availability figure as shown in Table 4.1.2.

The next group of technologies have low but not negligible SRMC; they include CHP and low carbon power stations such as nuclear, biomass and CCS. Each technology has an assumed availability figure which represents the percentage of time the power station could run if required. These are shown in Table 4.1.3.

The last group of technologies, with high SRMC, include conventional fossil fuel power stations that run on coal, gas and fuel oil. Based on their SRMC, the individual power stations are ordered from the least to the most expensive to run in a merit order, and dispatched in the most cost-effective way. When a power station is dispatched, the output is determined by its position in the merit order, its capacity and availability. The dispatching algorithm ensures that the aggregated output of all of these power stations meets the demand level in that half hour.

Table 4.1.2
Renewable technology average availabilities (transmission-connected)

Technology	Average availability
Onshore wind	29 per cent (2016) to 32 per cent (2040)
Offshore wind	39 per cent (2016) to 46 per cent (2040)
Marine	22 per cent
Solar PV	11 per cent
Hydro	33 per cent

Table 4.1.3
Low carbon technology average availabilities (transmission-connected)

Technology	Average availability
Biomass	77 per cent
CHP	60 per cent
CCS	85 per cent
Nuclear	77 per cent

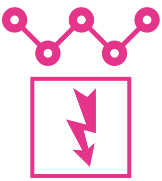
Electricity interconnectors

4.2
Electricity interconnectors

The introduction of Ofgem's cap and floor regime has led to an increase in investment certainty in the electricity interconnector market. This has contributed to increased interconnector capacity, in all scenarios, compared to FES 2015. GB remains a net annual importer of electricity in most scenarios apart from Gone Green after 2031 due to increased renewable generation. In all scenarios GB experiences imports at peak times.

Key insights

- GB's current electricity interconnector capacity is 3.8 GW.
- Capacity in 2040 ranges from 13.6 GW in **No Progression** to 23.3 GW in **Gone Green** and **Consumer Power.**
- In 2020 the net import annual flows range from 28.5 TWh in **Slow Progression** to 63.9 TWh in **Consumer Power.**
- **Gone Green** and **Consumer Power** meet the EU 2030 interconnection capacity target of 15 per cent of installed generation capacity.
- **Gone Green** from 2031 onwards is the only net export scenario, reaching exports of 33 TWh by 2035.



23.3 GW

GB's current electricity interconnector capacity is 3.8 GW. This could increase to 23.3 GW in 2040.

4.2.1
Capacity levels

In May 2014 Ofgem rolled out the cap and floor regulatory regime for electricity interconnectors. This resulted in increased regulatory certainty and reduced investment risk. This policy change may be one of the reasons why there is an increase in the number of potential electricity interconnector projects seeking to connect to GB.

The highest electricity interconnector capacities are in the high prosperity scenarios of **Gone Green** and **Consumer Power**, as seen in Table 4.2.1 and Figure 4.2.1. The greater regulatory certainty and EU harmonisation within **Slow Progression** results in more electricity interconnector capacity being built than under **No Progression**.

The current GB electricity interconnection capacity is 3.8 GW. To reach the 2025 levels in **Gone Green** a further 15.6 GW of additional capacity would be required to be commissioned. Although this is a high delivery profile, it is both consistent with external benchmarking[13, 14], and within the supply chain capacity for high-voltage direct current (HVDC) projects[15]. This growth is due to the progression of the current cap and floor projects, and the increased certainty for further projects under the second cap and floor window in 2016.

[13] Department of Energy and Climate Change, More interconnection: improving energy security and lowering bills, December 2013, https://www.gov.uk/government/publications/more-interconnection-improving-energy-security-and-lowering-bills

[14] Aurora Energy Research, Dash for Interconnection, October 2015, https://auroraer.com/files/reports/Dash%20for%20interconnection%20-%20Aurora%20Energy%20Research%20-%20February%202016.pdf

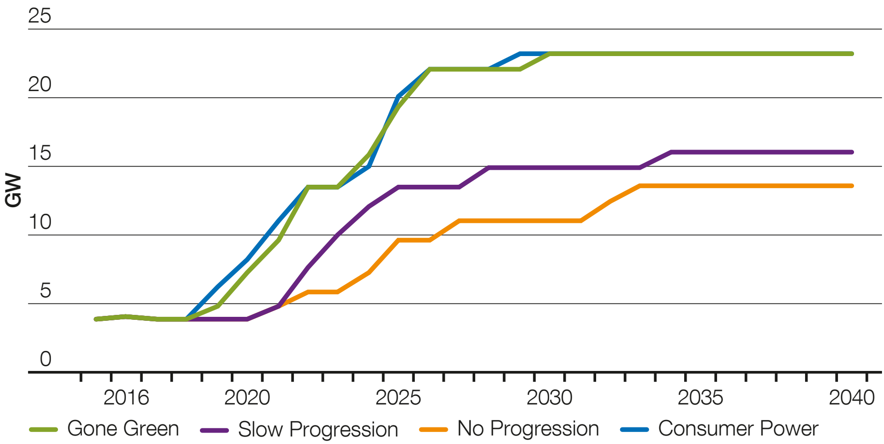
[15] ABB, ABB to invest $400 million on expansion of cable production capacity in Sweden, December 2011, http://www.abb.com/cawp/seitp202/47b4bc352349fd3dc125796000480a21.aspx

Electricity interconnectors

Table 4.2.1
Capacity levels[16] in each scenario (GW)

Year	Gone Green	Slow Progression	No Progression	Consumer Power
2015	3.8	3.8	3.8	3.8
2020	7.2	3.8	3.8	8.2
2025	19.4	13.5	9.6	20.1
2030	23.3	14.9	11.0	23.3
2035	23.3	16.1	13.6	23.3
2040	23.3	16.1	13.6	23.3

Figure 4.2.1
Capacity levels by scenario and year (GW)



[16] Based upon import where import and export capacities are not equal.

4.2.2
EU capacity targets

The EU has non-binding targets for electricity interconnector capacity. The targets are based upon a percentage of installed electricity production capacity in each country[17].

For GB the targets are: electricity interconnector capacity of at least 10 per cent of installed electricity production by 2020, and 15 per cent by 2030.

Both **Gone Green** and **Consumer Power** meet the 2030 targets[18]. A more aggressive build programme than envisaged in the scenarios would be required to reach the 2020 target.

In **Gone Green**, high levels of variable renewable generation encourage market coupling through electricity interconnection. However, the more regulated approach in this scenario leads to small development delays. **Consumer Power** sees fewer delays as it is market driven with little regulation in place. The main driver in **Consumer Power** is to gain competitive advantage through the lower costs available in new markets.

The drivers in **Consumer Power** are seen in both **Slow Progression** and **No Progression**, although they are limited by the low level of prosperity. Under lower prosperity conditions the certainty of a regulated approach means there is more capacity in **Slow Progression** than in the more risk-averse **No Progression**.

Consumer Power has the highest interconnector capacity in 2025, and to achieve this the milestones in Figure 4.2.2 will need to be met.

Chapter **four**

Figure 4.2.2
Road map for delivering a new interconnector of up to 750 km[19] by 2025

[17] European Commission, Connecting power markets to deliver security of supply, market integration and the large-scale uptake of renewables, February 2015, http://europa.eu/rapid/press-release_MEMO-15-4486_en.htm

[18] For the EU target installed electricity production is calculated as the sum of transmission, distribution and sub-1 MW generation capacity, excluding storage and interconnection.

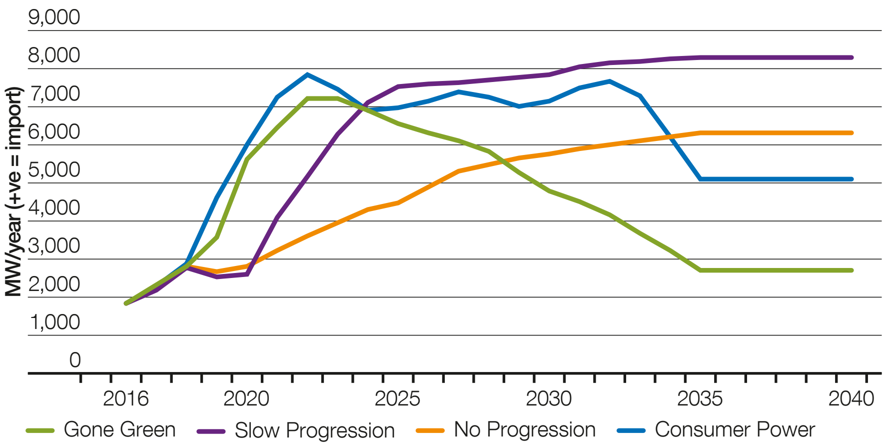
[19] 750km of cable is the upper limit where the construction of the converter station takes longer than laying the cable.

Electricity interconnectors

4.2.3
Peak flows

In comparison to *FES* 2015, the increased capacity in our scenarios enables much higher imports from the continent in peak conditions under 1-in-10 winter stress conditions. This can be seen in Figure 4.2.3. However, actual flows at times of ACS peak demand could differ significantly from these figures due to the impact of other factors such as wind generation.

Figure 4.2.3
Aggregate peak flows (MW/year)

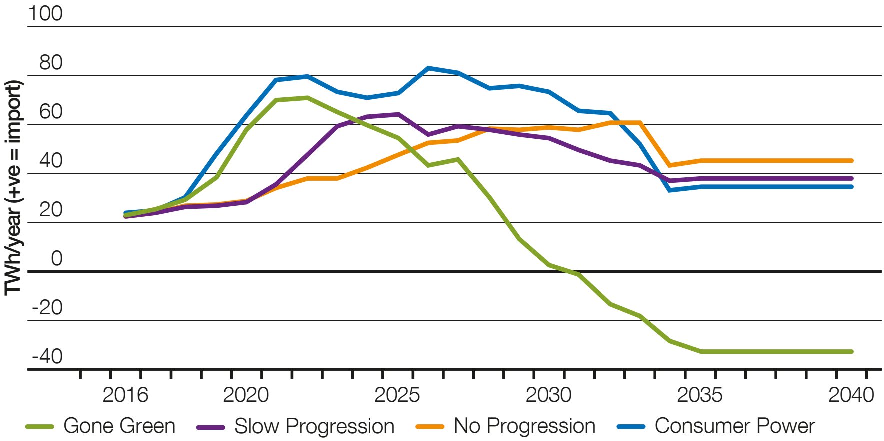


4.2.4 Net annual flows

As with all interconnector flows, annual flows are driven by prices. Until the mid-2020s the carbon price floor encourages cheaper continental generation to be imported into GB across all of the scenarios. Later in the period the increasing proportions of renewable generation and the price coupling effects of electricity interconnection bring the market prices closer together. While this reduces the net annual flows, GB retains a net import position.

The exception to this is **Gone Green**, shown in Figure 4.2.4, which has an increasing proportion of renewable generation. This helps bring the price of GB generation below that of continental countries for large periods of the year. This results in a net annual export of energy from 2031 onwards.

Figure 4.2.4
Net annual flows (TWh)



Electricity interconnectors

Method

Capacities

We have further developed our analysis methods over the past year based on stakeholder feedback.

We identify potential projects and their expected commissioning dates to connect to GB. This information is from a range of sources including the electricity European Network of Transmission System Operators (ENTSO-e) ten-year network development plan[20], 4C Offshore[21] and the European Commission[22]. Where only a commissioning year is given we assume the date to be 1 October of that year.

We assess each project individually against political, economic, social, technological and environmental factors to determine which interconnector projects would be built under each scenario. If it does not meet the minimum criteria we assume it will not be delivered in the given scenario, or that it will be subject to a commissioning delay. We calculate this delay using a generic accelerated HVDC project timeline. All projects which have reached final sanction are delivered, though they may be subject to delays in some scenarios.

In all scenarios we assume that the supply chain has enough capacity to deliver all interconnector projects. We have assumed that the cap and floor regime is required for all scenarios other than **Consumer Power** which is market driven. Additionally, we assume that only one project between GB and another market can be delivered at any one time under **No Progression**. While we analyse individual projects,

we anonymise the data by showing only the total capacity per year, due to commercial sensitivities.

[20] ENTSO-e, Ten-Year Network Development Plan 2016, https://www.entsoe.eu/major-projects/ten-year-network-development-plan/ten%20year%20network%20development%20plan%202016/Pages/default.aspx

[21] 4C Offshore, Offshore Interconnectors, http://www.4coffshore.com/windfarms/interconnectors.aspx

[22] European Commission, Projects of Common Interest candidates for electricity, https://ec.europa.eu/energy/sites/ener/files/documents/pci_candidates_for_electricity.pdf

Method

Annual and peak flows
We commissioned external consultants to assess the flows between GB and connected countries for each scenario using a pan-European market model. Annual flows were modelled deterministically for each scenario based on *FES* 2015 demand and generation data, *FES* 2016 electricity interconnector capacity, and the consultancy's own dataset for non-GB countries.

In *FES* 2016, we define peak flows as the flows which could be relied on to supply winter peak demand under 1-in-10 stress conditions. Using 1-in-10 conditions provides a better indication of the imports that can be relied upon than using average cold spell (ACS) conditions. This is because, in the ACS measure, stress events in connected countries may not occur at the same time.

The system operability of having significant interconnector capacity will be considered in the *System Operability Framework* document which will be available online in November 2016 at **http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/**.

Electricity storage

4.3
Electricity storage

There is heightened industry interest in electricity storage due to the falling cost of new storage technologies and increased system flexibility needs arising from greater levels of renewable generation. Storage has the potential to be a significant contributor to meeting system flexibility needs. The extent to which it penetrates the market will be based on the value of revenue streams. Commercial and regulatory changes which are expected in the next 12 months will be key to the successful large-scale deployment of new storage technologies.

Key insights

- New electricity storage technologies have been included in this year's scenarios.
- **Consumer Power** has 18.3 GW of storage in 2040, the majority of this (13.2 GW) being connected to the distribution network due to the high level of support for local energy.
- **Gone Green** has 11.4 GW of storage in 2040 and contains the highest level of transmission-connected storage due to the high central intervention, with 5.9 GW in 2040.
- Despite some developments in distribution-connected storage, **Slow Progression** only reaches a total of 6.4 GW of storage in 2040.
- There are minimal developments in **No Progression**, with only 3.6 GW of storage in 2040.

18.3GW

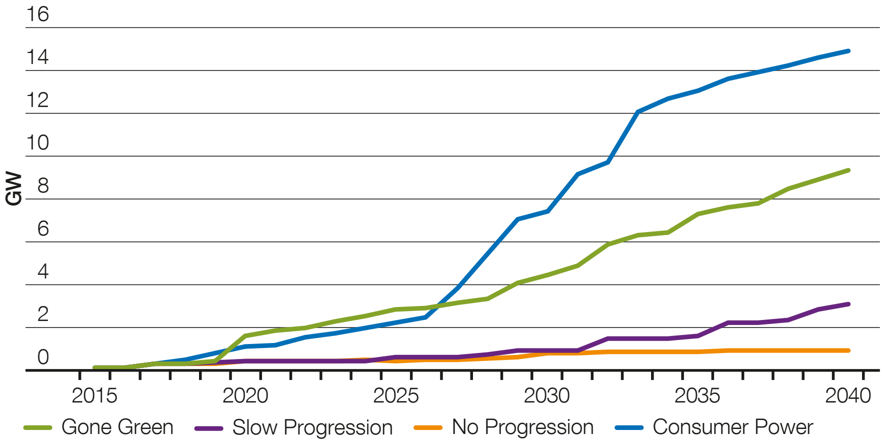
Storage in 2040 for
Consumer Power

4.3.1 Capacities

GB currently has 2.7 GW of storage, mainly pumped hydro storage (PHS), accounting for three per cent of total installed generation capacity. Batteries account for approximately 30 MW[23]; until recently the largest site was UK Power Network's 6 MW (10 MWh) pilot at Leighton Buzzard. However, this year has seen an increase in new (non-PHS) storage facilities.

As shown in Figure 4.3.1, the penetration of new storage technologies is significant in both **Gone Green** and **Consumer Power**. Technology cost reductions and increased system flexibility requirements allow storage to compete with other flexibility sources.

Figure 4.3.1
New installed storage capacity (excluding pumped storage) (GW)



[23] Eunomia, Investing in UK Electricity Energy Storage, January 2016, http://www.eunomia.co.uk/investing-in-uk-electricity-storage/

Electricity storage

Storage is connected at all network levels. Pumped storage and batteries, such as lithium ion, are connected to both the transmission and distribution networks as well as consumer premises. Compressed air electricity storage is assumed to be connected to the transmission network as the technology is also suited to taking advantage of arbitrage opportunities. Liquid air electricity storage is connected to the distribution network as an ongoing trial is currently situated at this level.

As shown in Table 4.3.1, **Consumer Power** has the highest uptake of distribution-connected storage with 13.2 GW by 2040. This is predominantly battery storage. **Gone Green** has the highest level of transmission-connected storage and PHS with 5.9 GW in 2040, in the form of compressed air storage and transmission-connected batteries. Additionally, **Gone Green** sees the highest deployment of small-scale storage with 0.6 GW by 2030 and 1.7 GW by 2040. **Slow Progression** and **No Progression** have very little additional storage penetration as the technology costs do not make storage competitive.

Table 4.3.1
Levels of storage connected in 2040 (GW)

	Transmission-connected	Distribution-connected	Sub-1 MW	Total electricity storage
Gone Green	5.9	3.8	1.7	11.4
Slow Progression	3.9	2.3	0.2	6.4
No Progression	3.0	0.5	0.1	3.6
Consumer Power	4.1	13.2	1.0	18.3

Globally, a similar trajectory is expected: electricity storage is forecast to grow from 2.5 GW in 2016[24] to approximately 9 GW by 2020, with batteries making up the vast majority[25]. Growth will then accelerate and by 2030 battery capacity is forecast at 150–240 GW[26].

[24] California Energy Storage Alliance, http://www.storagealliance.org/

[25] IHS Technology, Energy Storage Market Trends presentation, January 2016

[26] IRENA, Renewables and Electricity Storage, June 2015, http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_Electricity_Storage_2015.pdf ; Citigroup, September 2014

4.3.2 Applications

Storage has a wide variety of applications which could deliver value to consumers. They cover three categories:

- balancing and ancillary services provided to the System Operator
- asset services for Distribution Network Operators (DNOs) and Transmission Owners (TOs)
- wholesale and arbitrage opportunities whereby storage would help market participants (e.g. suppliers) to balance their positions.

Storage is extremely versatile and can be used for a wide range of applications.

Many of the 18 applications outlined in Figure 4.3.2 can be provided by other flexibility tools such as interconnectors, flexible generation and demand side response (DSR), but none cover as wide a range as storage.

The greatest economic value for storage is created when multiple applications are stacked together. Stacking unlocks the value from applications which are high value when utilised, but not required all year round. For example, transmission and distribution asset deferral is required for only approximately 5–10 per cent of the year, but frequency response may be provided throughout the year.

Electricity storage

Figure 4.3.2
Potential applications of electricity storage

	GB consumer benefit and system challenges…	…create storage opportunity and applications	Connection	Length	Customer
Balancing and ancillary services	1. Maintain grid frequency 2. Minimise reserve costs 3. Minimise foot room costs 4. Ensure black start capability	1. Enhanced frequency response	Generation, Transmission, Distribution, End-users	Short	System Operator
		2. Firm frequency response	Generation, Transmission, Distribution, End-users	Short	System Operator
		3. Reserves: STOR	Generation, Transmission, Distribution, End-users	Long	System Operator
		4. Reserves: fast reserve	Generation, Transmission, Distribution, End-users	Short	System Operator
		5. Demand turn-up	Generation, Transmission, Distribution, End-users	Long	System Operator
		6. Black start	Generation, Transmission, Distribution, End-users	Long	System Operator
Asset services Storage needs to be in correct location to deliver service	5. Minimise TO/DNO reinforcement costs 6. Reduce congestion management 7. Keep voltages in limits 8. Provide backup power	7. Transmission deferral	Transmission	Long	Transmission and/ or distribution
		8. Distribution deferral	Distribution	Long	System Operator
		9. Constraint management	Generation, Transmission, Distribution, End-users	Varies	System Operator
		10. Triad and Distribution Use of System cost reduction	End-users	Long	Industrial and commercial consumers
		11. Voltage (asset-based) 12. Voltage (commercial)	Generation, Transmission, Distribution, End-users	Any	Transmission and distribution asset-based, System Operator (commercial)
		13. Backup power	End-users	Any	Industrial and commercial consumers
Wholesale and arbitrage	9. Lower wholesale costs 10. Optimise self-consumption 11. Optimise imbalances 12. Reduce capacity costs	14. Arbitrage (wholesale only)	Generation, Transmission, Distribution, End-users	Long	Wholesale agents
		15. Self-consumption (residential)	End-users	Long	Residential consumers
		16. Self-consumption (industrial and commercial)	End-users	Long	Industrial and commercial consumers
		17. Imbalance; cash-out	Generation, Transmission, Distribution, End-users	Long	Wholesale agents
		18. Capacity Market	Generation, Transmission, Distribution, End-users	Long	Wholesale agents

Key

- Generation
- Transmission
- Distribution
- End-users
- Long – Typically >1 hour
- Short – Typically <1 hour

4.3.3
Deployment

The first wave of new storage deployment is likely to deliver ancillary and balancing services.

One of the most popular balancing and ancillary services is likely to be frequency response, as fast-response storage devices are technically well suited to the provision of frequency services.

Transmission and distribution asset services, including congestion management, are likely to form the second wave of deployment. Application stacking will make such network services economic. For example, asset deferral services can be stacked with STOR, or voltage with frequency.

In the medium to long term, arbitrage and imbalance opportunities will likely arise, enabling end-user and generator deployments. End-user deployments are especially likely if costs decrease.

Our scenarios assume that transmission-connected storage is primarily used for arbitrage, congestion management, and balancing and ancillary services. Distribution-connected storage is assumed to be paired with new solar PV to maximise solar output while also delivering balancing and ancillary services, and asset deferral. End-user storage is assumed to be paired with residential solar and used for self-consumption.

Our scenarios provide a wide range of outcomes and opportunities for storage. Successful storage deployment is dependent on positive developments in the following areas:

- policy and regulatory developments
- commercial developments
- technological developments
- system needs.

We have assessed the progress made in these areas since *FES* 2015 and outline in the following sections how this has impacted the indicator score of green, amber or red.

Significant market, commercial and regulatory changes are needed for new storage technologies to become reality.

Electricity storage

4.3.3.1
Policy and regulatory developments

The policy and regulatory landscape for storage is rapidly evolving.

Storage faces competition from other flexibility tools, including DSR, interconnection and flexible generation. At the time of writing Ofgem and DECC are considering policy changes to facilitate greater use of flexibility, and are due to publish a Call for Evidence in summer 2016. This follows the National Infrastructure Commission's Smart Power report[27] which identified a potential £8 billion of annual benefits from flexibility by 2030, and recommended creating a level playing field for storage. The EU is also considering the issue, including whether it should introduce a specific definition of energy storage.

In *FES* 2015, we rated the policy and regulatory landscape for storage as red and requiring significant change. With progress underway and commitments from the government and regulator to unlocking the barriers to wider storage deployment, we have now moved to amber.

There are a number of key issues which still need to be resolved to move the policy and regulatory landscape to green. These include:

- Clarity on the role and definition of storage, including the potential for a new licence definition.
- Ensuring charges and levies are cost-reflective.
- Rolling out half-hourly settlement to more customers to increase the number of parties who can benefit from arbitrage opportunities.
- The removal of end-user levies. Storage is defined as an end-user, so the Levy Control Framework and Climate Change Levy are charged twice. There has been a call by stakeholders throughout the industry for this end-user classification to be removed.

Policy and regulatory

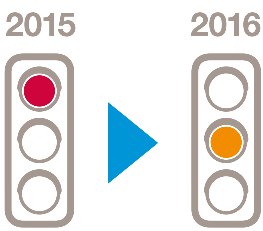


Figure 4.3.3
Road map to deploying 1 GW of non-pumped storage by 2020

[27] National Infrastructure Commission, Smart Power, March 2016, https://www.gov.uk/government/publications/smart-power-a-national-infrastructure-commission-report

4.3.3.2
Commercial developments

The System Operator is committed to shaping a market framework which is accessible to all flexibility providers including storage.

In *FES* 2015 we identified a number of commercial developments (e.g. stacking of applications) which would help to bring storage to market. This year, we review the issues, identify progress and provide a set of measures which will contribute to making the commercial landscape more attractive.

Stacking and bundling

Progress is underway to understand how storage could provide services to multiple parties. Our demand turn-up service which will run throughout summer 2016 will allow both the System Operator and Western Power Distribution to make use of DSR in the south west. We intend to use the results of this service to design a shared services framework from late 2016 onwards, to allow both synergies and conflicts to be managed when flexibility providers offer multiple services to multiple parties.

In addition, the System Operator intends to review its current set of products to allow parties to offer bundled services where appropriate. This is planned to commence in autumn 2016.

Information provision and commercial signals

Market information is a significant enabler to new players and technologies. This is particularly true when those players are reliant on ancillary service revenues. The System Operator intends to improve on the effectiveness of the information provided to the market by:

- improving the historical information available to market participants
- simplifying the information on various products and services available, where possible
- providing the market with forward visibility of how products are likely to change over time
- providing forward projections of commercial requirements (future ancillary services requirements).

In addition, the System Operator intends to enhance the effectiveness of its commercial strategy. This will be done by improving the identification and communication of the System Operator's commercial requirements and deploying a better process to create external market signals ahead of need.

Cost-reflective signals

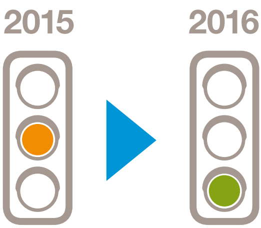
Efficient pricing signals are needed to allow storage to capture multiple revenue streams. This is particularly true for revenue streams relating to asset deferral, as they are locational. The System Operator will be considering such issues as part of a broader charging review in summer 2016.

Electricity storage

Progress in all of the above is expected in the next 12 months. This will represent a significant improvement in the commercial framework for new storage providers.

In addition, the System Operator is considering the effectiveness of the overall market framework. Access to as many markets as possible is a significant prerequisite for the development of new storage technologies, considering their versatility and their requirement to stack revenue streams.

Commercial landscape



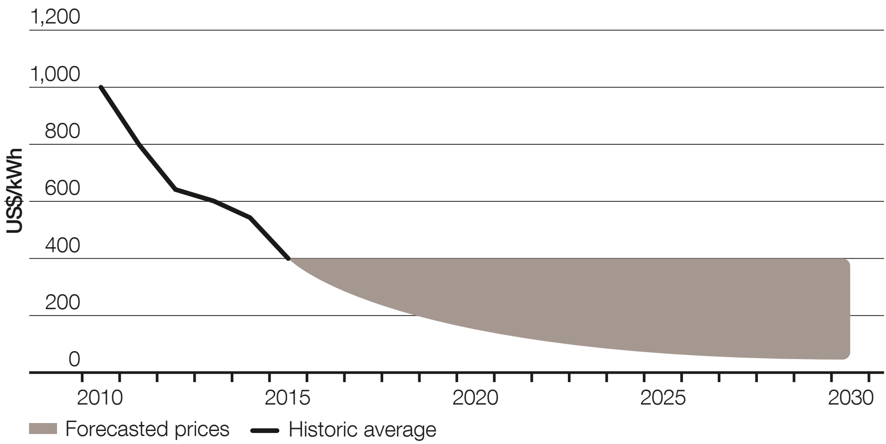
We believe that the resolution of any two of the commercial development issues would move the landscape to green.

4.3.3.3
Technological developments

Technology costs are rapidly falling, contributing to the future cost competitiveness of storage as a flexibility provider.

The cost of storage technologies has fallen considerably over the past few years. We expect prices to fall within the range shown in Figure 4.3.4. Costs are expected to continue falling in response to the wider deployment of new storage technologies globally, and the continuous improvement in technology efficiency.

Figure 4.3.4
Lithium-ion battery cell costs



Electricity storage

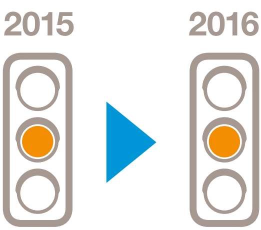
Other technologies which have been considered in our scenarios are compressed and liquid air storage. We assume that the costs of these technologies are also likely to fall further. We recognise that there are other technologies such as power to gas, super capacitors and flow batteries which have not been included in the scenarios. These technologies are still in their infancy and there is not yet sufficient data to incorporate them within our scenarios.

The *FES* 2015 case study highlighted that a green technological developments indicator would require storage to be competitive with other technologies such as interconnectors, DSR and thermal generation.

At present, new storage technologies are still not able to directly compete with the other more established flexibility providers. However, the forecasted rapid fall in costs means that this is likely to become reality in the short to medium term. The speed of the storage deployment also depends on changes to the commercial and regulatory landscape.

While significant progress has been made in the last 12 months, we will maintain technological developments at amber until the new storage technologies can compete on an equal footing with other providers.

Technology developments



4.3.3.4
System needs

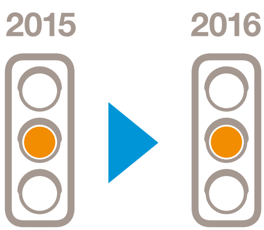
The *FES* 2015 case study identified storage as a part of the system needs solution, alongside other flexibility technologies such as DSR, interconnection and flexible generation. The ability of storage technologies to meet the system needs is heavily dependent on their ability to provide a cost-effective solution to the System Operator.

The system is already facing flexibility challenges. The increased need for faster frequency containment services led us to seek expressions of interest which will be followed by the launch of the Enhanced Frequency Response tender in July 2016. There was a large response at the expression of interest stage. 68 submissions were received which totalled 1,370 MW of capacity, at new and existing sites and connected to both transmission and distribution networks. Of this capacity approximately two thirds was from batteries, with the rest being from a variety of technology types.

The tender outcome (due 26 August 2016) will provide a view of the cost-effectiveness of storage compared to other flexibility technologies. This is partly dependent on the extent to which the policy and regulatory challenges are resolved, the cost of the technologies, as well as the commercial frameworks being in place.

In light of the current uncertainty, and until the tender results are known, we are maintaining the current status for system needs at amber.

System needs



Electricity storage

Storage has the potential to be a significant contributor to the future flexibility requirements of the system. As storage becomes more cost-competitive and the identified barriers are removed, we anticipate a significant rise in new storage deployment.

Some of the more significant changes include the need for efficient and cost-reflective pricing signals to allow storage to capture multiple revenue streams. In addition, it will be important for the System Operator, the DNOs and the TOs to work together to ensure that synergies in the use of storage by various market participants are maximised and conflicts minimised.

The progress in the next 12 to 18 months in the regulatory, policy and commercial landscape, as well as in clarifying the roles and responsibilities of various parties, will be key determinants of future storage deployment.

Method

New electricity storage technologies have been included in our scenarios this year, in response to stakeholder feedback and heightened industry interest.

As some electricity storage technologies, such as lithium-ion batteries, are new, there is limited data available for modelling and analysis. We have examined the storage trials currently under development to gather data on the potential of storage. Additionally we have benchmarked and considered other external projections, such as those by Poyry and Imperial College London. To create a range of credible outcomes we have also determined what the potential revenue streams are for storage. These include balancing and ancillary services, asset deferral (at both transmission and distribution network levels) and pairing storage with solar PV. We have considered which streams would be available in each of the scenarios to create the range in transmission and distribution-connected technologies.

Gas supply

4.4
Gas supply

Our scenarios present a range of possible gas supply patterns. Production from the UK Continental Shelf (UKCS) declines in all scenarios and the reduced output means that a number of gas terminals will close. Shale gas is included in Consumer Power and No Progression, but not in the two greener scenarios due to public perceptions of its greenness. In Consumer Power consistent levels of production across the year from UKCS and shale means that other sources will supply the seasonal variation. Imports from Norway, continental Europe, and via liquefied natural gas (LNG) remain significant.

Key insights

- UKCS production rises from 33 bcm in 2015 to peak at 36 bcm in 2017 in **Consumer Power**. Production falls to under 2 bcm by 2040 in **Slow Progression**.
- Shale gas production rises to 32 bcm by 2032 in **Consumer Power** in response to high levels of support.
- A combination of higher demand and low production from the UKCS means that the volume of gas imported is highest in **No Progression**: 54 bcm in 2040.
- The volume imported in **Slow Progression** is less, but the lower demand means that the import dependency reaches a maximum of 93 per cent by 2040.
- In response to successful pilot demonstrations we have included bio-substitute natural gas (bioSNG) in our scenarios for the first time, contributing to 4 bcm of green gas in 2040.

Gas supply

4.4.1
Gas supply in each scenario

Gone Green

This section considers the scenario period out to 2040. In **Gone Green** gas demand is lower than all other scenarios until the mid-2030s. After this date demand increases as gas-fired power stations with carbon capture and storage (CCS) are built. Support for production from the UKCS remains at a similar level to 2016 as gas is still required in the energy mix, but nevertheless volumes decline steadily from around 2018 as existing fields deplete. UKCS production in **Gone Green** falls between the two extremes of our range.

There is no shale gas development in either of the two green scenarios. Stakeholders have told us that they do not think that shale development will be publicly acceptable in a world with high green ambition. DECC published a paper[28] suggesting that the carbon footprint of shale gas extraction and use is lower than the carbon footprint of LNG. However, the exclusion of shale gas in these two scenarios is based on current public perception[29].

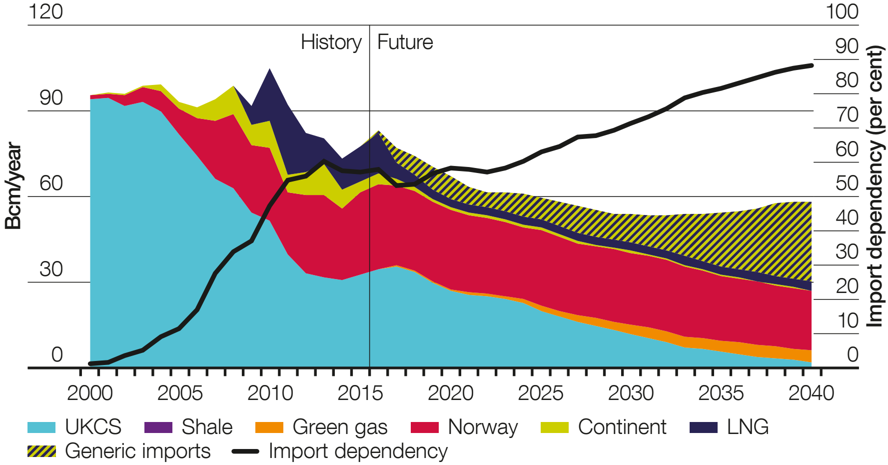
Injection of biomethane into gas networks is currently supported under the renewable heat incentive (RHI). In **Gone Green**, with its high green ambition, support for biomethane continues into the future. To help meet the 2050 carbon reduction target there is a high requirement for renewable gas in 2040. This is higher than the level that we expect to be available from anaerobic digestion (AD). We have therefore additionally included a level of bioSNG. This is grouped with the biomethane from AD to create the 'green gas' category. For more information on progress towards the carbon reduction target, please see section 5.2.

With low indigenous production, there is a requirement for substantial imports, both from Norway and generic imports. Import dependency reaches nearly 90 per cent by 2040.

[28] Department of Energy and Climate Change, Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use, September 2013, https://www.gov.uk/government/publications/potential-greenhouse-gas-emissions-associated-with-shale-gas-production-and-use

[29] The University of Nottingham, Support for fracking continues to drop, October 2015, https://www.nottingham.ac.uk/news/pressreleases/2015/october/support-for-fracking-continues-to-drop-.aspx

Figure 4.4.1
Annual supply pattern in Gone Green



Gas supply

Slow Progression

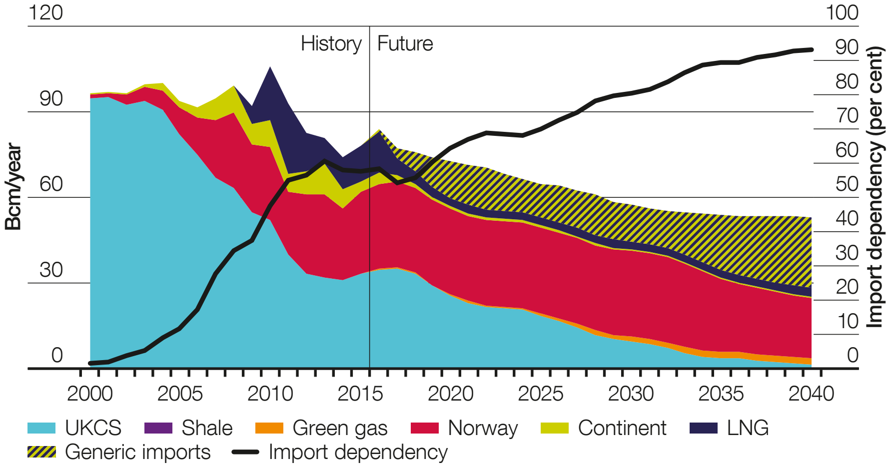
Demand in **Slow Progression** falls throughout the period and, from the mid-2030s onwards, is the lowest of all the scenarios. In this world of low prosperity and high green ambition there is less money available for supporting UKCS development. Current fiscal support is reduced as the government prioritises low carbon and renewable projects. As a result UKCS production is at the bottom end of our range. There is still some production in 2040 but the volumes are very low.

As discussed in the **Gone Green** section, there is no shale gas production in **Slow Progression** due to the public perception that it does not align with their green ambition.

There is still some support for biomethane projects, at a similar level to 2016, but monetary constraints mean that support cannot be extended above this level. As a result production is lower than in **Gone Green**.

The very low indigenous supply leads to an import dependency of 93 per cent by 2040, the highest level in any of the scenarios. However, low demand means that the volume of gas imported is not as high as in **No Progression** or **Gone Green**.

Figure 4.4.2
Annual supply pattern in Slow Progression



Chapter four

No Progression

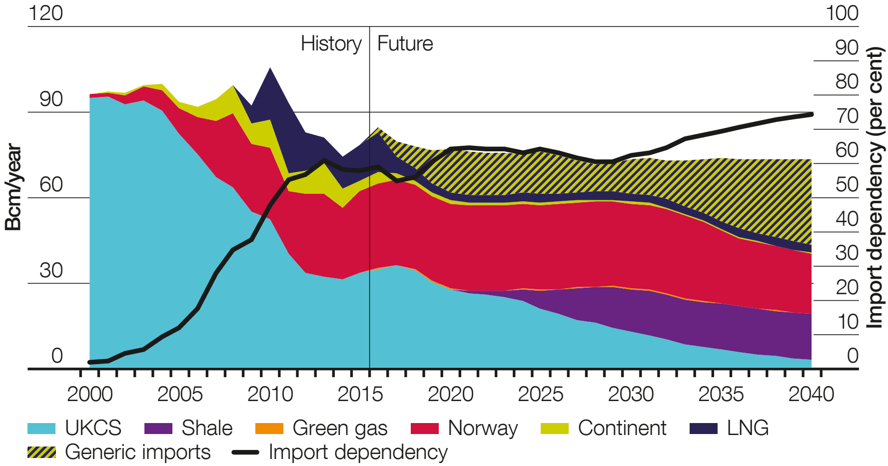
In **No Progression** gas demand is higher than in the other scenarios from 2020 onwards. Like **Slow Progression** this is a world of low prosperity. However, in the absence of high green ambition there is no requirement to divert available funds to support green technologies. Support for the UKCS continues at a similar level to today as gas is more important in the energy mix. Production lies between our two extreme cases: **Gone Green** and **Slow Progression**.

The high gas demand means that there is also support for shale gas development. Commercial production starts in 2021, but progress in developing the technology is hampered by lack of money and the total annual production levels off at 16 bcm by 2031.

There is limited support for biomethane. The money that is available is spent on technologies offering higher production instead. Production increases slightly from 2016 to 2020 and then levels off at just over 0.2 bcm per year.

The import dependency reaches almost 75 per cent by 2040. This is less than in **Slow Progression**, but because demand is higher, the volume of imported gas is higher than in any of the other scenarios.

Figure 4.4.3
Annual supply pattern in No Progression



Gas supply

Consumer Power
Gas demand in **Consumer Power** is in the middle of the range of our scenarios from 2020 onwards. Government policies focus on indigenous supplies so support is available for UKCS development. There is also a high level of investment in research and development which helps with the development of technically challenging gas fields that would otherwise be unattractive. Our projection for UKCS production in **Consumer Power** is at the top of our range, peaking at 36 bcm in 2018.

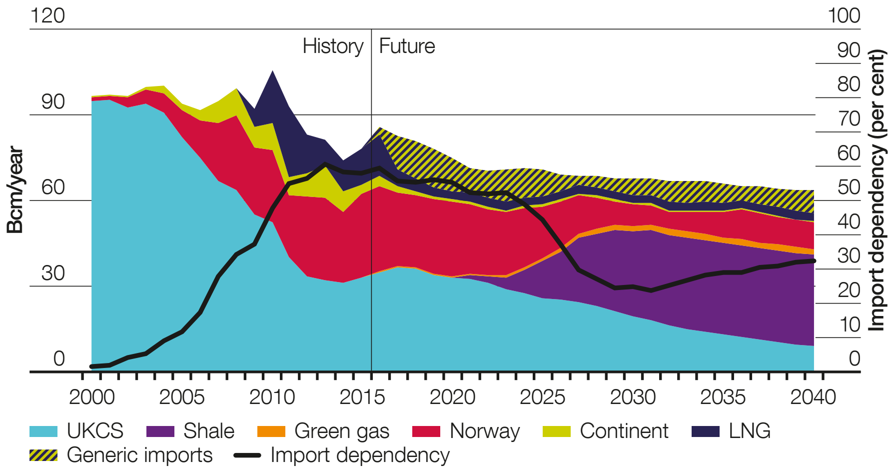
The same drivers that make UKCS development attractive apply to shale gas as well. As a result, **Consumer Power** has our highest level of shale gas development. Production starts in 2021 and reaches a level of 32 bcm per year by 2031.

Support for biomethane continues, and the level of prosperity in **Consumer Power** means that there is some investment and consequent improvement in efficiency. Annual production reaches 2 bcm per year by 2033.

With high indigenous production and only moderate demand there is much less requirement for imported gas in **Consumer Power**. As such the import dependency falls to around 25 per cent in 2030, before rising again to just over 30 per cent by 2040 as UKCS production falls. Both Norwegian flows and generic imports are sharply reduced from the mid-2020s.

By the late-2020s, production from the UKCS and shale account for over 70 per cent of the total supply. The 'swing' fields on the UKCS (capable of ramping up production to meet seasonal demand) have largely declined, with the remaining fields producing at a flat rate throughout the year. Shale gas is also produced at a fairly constant rate through the year. There are exports from GB to the continent in the summer as production exceeds summer demand, while in the winter additional seasonal supply is needed. Much of this is provided by imported gas, but this is a scenario where additional long-range storage could also make a useful contribution.

Figure 4.4.4
Annual supply pattern in Consumer Power



4.4.2
Gas supply by type

UK Continental Shelf
Our UKCS projections continue to be based on information provided by producers through an annual process which is run in conjunction with Oil & Gas UK, combined with market intelligence and our own analysis. Following many years of decline, production in 2015 increased over the previous years. This is a trend which is set to continue for a few years in all four scenarios, before production begins to decline again.

Differences between the four scenarios are inevitably quite small in the first few years as our projections are based on fields that are already in, or close to, production. In later years, the decline in production is least in **Consumer Power**, though even in this scenario production falls to 9 bcm per year by 2040. In this scenario, the growing economy and a high level of technical innovation support the development of fields that are too difficult or too expensive for the other scenarios. Without this additional support, our projections for the other three scenarios are quite similar, though they are lowest of all in **Slow Progression**, falling to less than 2 bcm by 2040. In all four scenarios production in some areas will decline to the point where receiving terminals are no longer financially viable and will close.

UKCS volumes can be seen in the context of the annual supply patterns for each scenario: Figure 4.4.1 to Figure 4.4.4 which are shown in section 4.4.1.

Shale gas
There has been some progress with shale gas applications recently. At the time of writing, two applications to drill and hydraulically fracture (frack) were rejected by local planning authorities in the north-west of England, but subsequently appealed. Elsewhere, planning applications to frack have currently been submitted in Nottinghamshire, and an application has been approved in North Yorkshire.

The Government has continued to support shale gas development with a number of changes to acts and regulations. A new planning process was announced that is designed to speed up shale gas planning applications. The Infrastructure Act 2015[30] simplified the process for drilling, boring or fracking underground land.

The Onshore Hydraulic Fracturing (Protected Areas) Regulations 2016[31] came into force in April 2016. This was to ensure that fracking only takes place below a certain depth in specified groundwater areas, national parks, areas of outstanding natural beauty and World Heritage Sites.

The final results of the 14th onshore oil and gas licensing round are expected in the second half of 2016. Although progress has been made in a number of areas, the industry is still waiting for the results of the test wells to understand the potential for shale gas development.

[30] The Infrastructure Act 2015: http://www.legislation.gov.uk/ukpga/2015/7/part/6/crossheading/petroleum-and-geothermal-energy-in-deeplevel-land/enacted

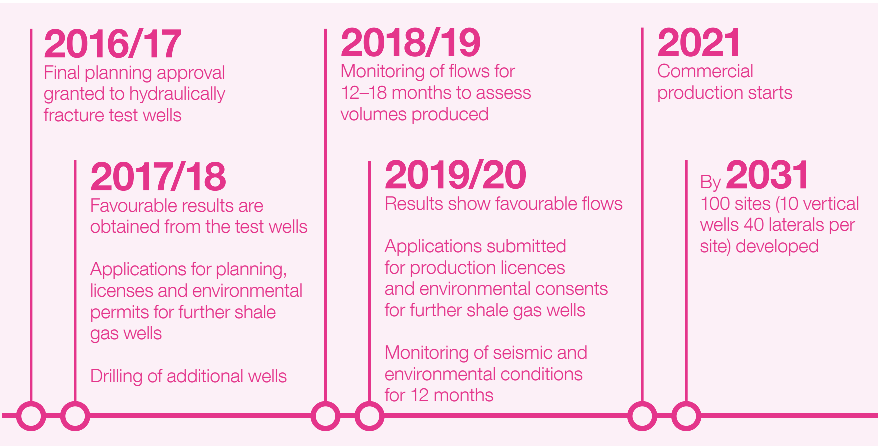
[31] The Onshore Hydraulic Fracturing (Protected Areas) Regulations 2016: http://www.legislation.gov.uk/uksi/2016/384/regulation/3/made

Gas supply

There is uncertainty within the industry regarding shale gas projections. In the absence of any new data on possible production we have based our 2016 projections on last year's analysis, but have delayed commercial start up until 2021 due to the delays in the planning approval process. We have continued to use a broad spread for shale gas production ranging from no development in **Gone Green** and **Slow Progression** to a peak of 32 bcm per year in **Consumer Power**.

The high shale case represents a significant part of the total gas supply in **Consumer Power**, as shown in the annual supply pattern in Figure 4.4.4. To achieve this level of production by 2031 we have outlined some indicative milestones that will be needed.

Figure 4.4.5
Road map to achieving 32 bcm of shale production by 2031



Green gas

The injection of biomethane into a gas network is supported under the non-domestic RHI and will contribute to the 2020 renewable energy target. There is continuing interest in this area. Both the number of biomethane projects and the volume of gas entering the network increased substantially in 2015, though the volume provided is still low, at less than 100 mcm per year.

Our projections for biomethane from AD are based on the latest information available to us on the number of biomethane connections and the flow rates. For our short-term projections, we show an increase of around 10 per cent from our 2015 scenarios as a result of the increased number of connections seen in the last 12 months. From 2020, our flow projections are slightly lower than our 2015 scenarios as the rate of production that we have seen from sites is lower than we had anticipated. Based on feedback from our stakeholders, we have flattened our biomethane projections from the early 2030s to reflect the shortage of feedstock[32] for further development.

Current biomethane plants are all connected to the lower-pressure distribution networks rather than the higher-pressure transmission network.

For our 2016 scenarios, we have included bioSNG in our green gas projections for the first time. This technology is in its early stages in GB, but has demonstrated its success in an early pilot project and has subsequently received funding to build a bigger demonstration plant in 2018.

The volume of green gas can be seen in the context of the annual supply patterns for each scenario: Figure 4.4.1 to Figure 4.4.4 as shown in section 4.4.1.

[32] Feedstock is defined here as any organic material that can be used in the digestion process to produce biomethane

Gas supply

Spotlight: New sources of gas

In order to meet the 2020 renewable energy target, the focus has historically been on the decarbonisation of electricity supplies. More recently there has been a growing interest in AD that can produce biomethane for injection directly into a gas network. However, issues such as feedstock limitations and reducing financial incentives are likely to limit the amount of biomethane that can be provided in the longer term. In order to increase the potential volumes of green gas, a number of projects have started recently to look at alternative technologies.

BioSNG

Using household waste to produce renewable gas overcomes the problem of shortage of feedstock. A project to build a demonstration bioSNG plant has been awarded funding by Ofgem as part of the Network Innovation Competition (NIC). The demonstration plant is planned to be operational in 2018 producing up to 2 mcm per year of bioSNG. This will either be used as compressed natural gas (CNG) for road transport or injected into the gas network. If the technology can be developed successfully the developers anticipate that there could be production of around 3 bcm by 2030, rising to 9 bcm by 2050.

Hydrogen injection

Hydrogen produced by reforming natural gas or other fossil fuels has been available for a number of years. However, a cleaner, lower carbon product could be achieved by using excess electricity produced from wind farms or solar generation. This would produce hydrogen from water using an electrolysis process. The renewable hydrogen could then be injected directly into a gas network and blended with the natural gas.

One of the current limitations the technology faces in GB is that the gas must be compliant with the Gas Safety (Management) Regulations (GS(M)R) to ensure the gas burns safely. This currently limits the hydrogen content of natural gas to 0.1 per cent. The Health and Safety Executive produced a report in 2015 concluding that natural gas with a hydrogen content of 20 per cent or less is unlikely to have an adverse effect on the gas network and most appliances, but further work would be necessary to investigate the longer-term effects.

National Grid has applied for NIC funding for two hydrogen projects. One project[33] looks at developing a standardised approach for the injection of hydrogen which could be generated from surplus renewable power, into the natural gas network. The second project[34] aims to demonstrate that natural gas containing levels of hydrogen beyond those currently in the GS(M)R specification can be distributed and utilised safely and efficiently in a representative section of the GB distribution network.

A third project[35], run by Northern Gas Networks, is studying the possibility of supplying the city of Leeds with pure hydrogen, rather than a mixture of hydrogen and natural gas. Results are expected in 2017.

[33] National Grid, Gas Network Innovation Competition Screening Submission Pro-forma – Haven Bridge, April 2016, https://www.ofgem.gov.uk/system/files/docs/2016/04/nic_proforma_-_nggt_haven_energy_bridge_2016.pdf

[34] National Grid, Gas Network Innovation Competition Screening Submission Pro-forma – HyDeploy, April 2016, https://www.ofgem.gov.uk/system/files/docs/2016/04/ng_ngn_hydeploy_isp.pdf

[35] Energy Networks Association, H21 Leeds Citygate, accessed April 2016, http://www.smarternetworks.org/Project.aspx?ProjectID=1630

Norway

In making our projections of supplies of Norwegian gas to GB we consider two different aspects: total production of Norwegian gas and the proportion of the total that comes to GB. Our projections of production are based on reserve data for the North Sea, Norwegian Sea and Barents Sea. We use external forecasts for some key individual fields. A range of possible production is created by assuming different success rates for developing new fields. In 2015, GB received approximately 30 bcm of Norwegian exports.

Supplies of Norwegian gas to GB in our scenarios are not pre-determined, but are derived as part of the process of matching supplies to demand. The difference in Norwegian flows between scenarios is not as marked as for other imported gas. This is based on stakeholder feedback and also reflects the fact that there are fewer opportunities for Norwegian gas to find alternative markets than for other import supplies. Norwegian supply volumes can be seen in the context of the annual supply patterns for each scenario, Figure 4.4.1 to Figure 4.4.4.

Imported gas: LNG and continental gas

In all scenarios we assume that there will be at least a minimum flow from both LNG imports and continental gas. In the short term, the minimum levels for LNG are defined by the global LNG availability and the recent history for GB LNG deliveries. Indications are that LNG availability is likely to be high, at least until the early 2020s. New liquefaction projects have come on line this year, including four in Australia and the first US export terminal, Sabine Pass.

In the longer term, the minimum LNG supply is the amount of gas that boils off from the LNG terminals as part of their normal operation.

There is much speculation as to how much LNG will flow from the US to European markets where it will compete with LNG from Qatar, as well as gas from Norway and Russia. The first US cargoes were sent to South America, though one cargo was delivered to Europe in April 2016.

For continental imports, through the IUK and BBL interconnectors, the minimum supply has been defined by contractual volumes and our assessment of any additional flows which could be expected under the conditions in the scenarios.

The remainder is assigned to generic imports which could be made up of either continental imports or LNG. In all scenarios there is enough infrastructure capacity for the generic import to be all LNG or all continental gas without the need for any new capacity to be built.

The nature of the generic import depends on the world gas market and can be influenced by a wide range of factors. For example:

- The expected restarting of nuclear power stations in Japan reduces the Japanese demand for LNG imports which releases more LNG into the market.
- Heavy rain in Chile in November 2015, attributed to the El Niño weather phenomenon, increased hydroelectric generation and consequently reduced gas-fired generation by 59 per cent, releasing LNG into the market.

Storage

Gas storage plays an important role in supporting security of supply and providing flexibility in the operation of the gas network. There has been some development of mid-range storage sites in the last two years but the economics, and in particular the price spread between winter and summer, have limited activity in the development of new seasonal storage.

Storage has a role to play throughout the year. During the winter, seasonal storage sites can provide base load supplies. All sites can also provide cover at periods of high demand. The sites are active throughout the year, optimising injection and withdrawal patterns to help balance supply and demand. Supporting the seasonal demand patterns may be particularly important when the majority of supply has a flat profile through the year as is the case in **Consumer Power**.

Gas supply

Spotlight: North-West European supply potential

We have analysed the key uncertainties in the north-west European gas markets of France, Germany, the Netherlands and Belgium. We have looked at the potential range of both supply and demand in these countries.

In the scenarios we define an area of generic imports which could be met by either LNG or continental imports. For 2035 these imports range between 7–23 bcm, up to 35 per cent of total supply. The supply and demand dynamics of these gas markets are one of the key factors which impact the amount of gas imported to GB from the continent.

Demand in the region is expected to follow a similar trend to GB, with the potential to slightly decline or remain at similar levels to today. The factors driving demand are also similar to those in GB. These are expected to be:

- economic growth
- electricity generation strategy
- energy efficiency in homes
- how homes are heated.

Our assessment is that these factors lead to a range of 133–170 bcm for gas demand in the region by 2035.

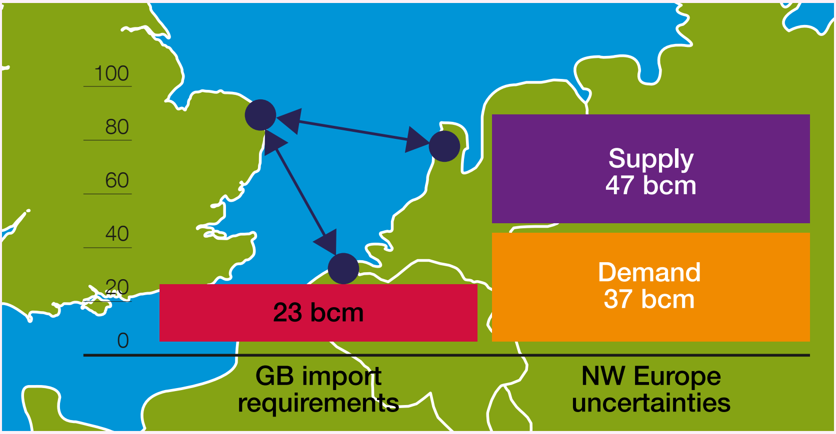
Imports of Norwegian gas and LNG play a significant role in supply to north-west Europe. However, since these can be imported directly to GB we do not expect them to have a significant impact on interconnector imports from the continent on an annual basis. They could play a more significant role, along with European storage, on a seasonal basis as has been the case in the past.

We believe that the biggest influence on future imports from the continent to GB will be Russian gas. Russia currently has significant potential to increase exports to Europe. There is additional production which could be made available to the market if required and sufficient capacity is available in existing infrastructure to deliver this. Our assessment is that this potential for increasing exports of Russian gas continues out to 2050. Our analysis suggests that in 2035 there is the potential for 47 bcm of additional exports to north-west Europe.

Given the potential range of supply and demand in north-west Europe, GB could receive significant imports from the continent. The potential for lower demand or increased exports of Russian gas are both sufficient to meet the range defined in our generic imports.

For GB this leads to significant uncertainty over how the import requirements will be met going forward. It is for this reason we continue to assess the implications for our network if this gas is supplied by imports from the continent or shipments of LNG.

Figure 4.4.6
North-west European supply/demand dynamics in 2035



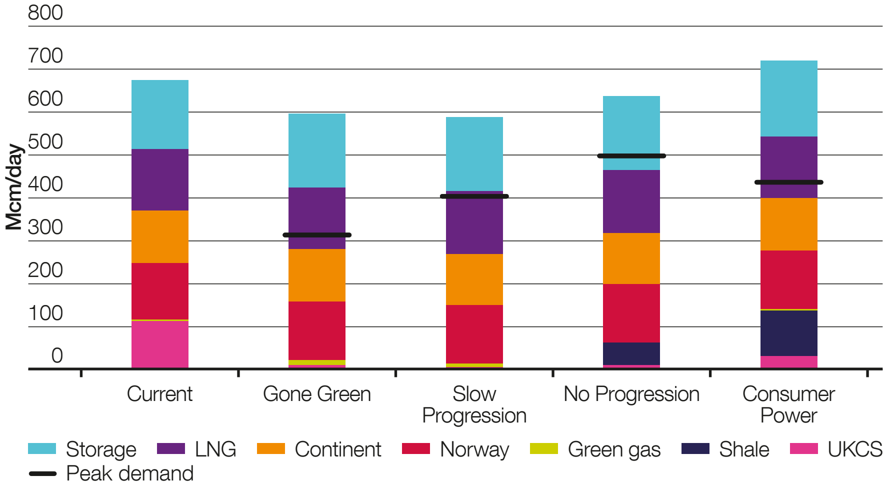
4.4.3
Peak gas supply

In the assessment of peak gas supply, we compare peak demand with the maximum supply potential from all sources. For GB production (UKCS, green gas and shale gas) we apply a swing factor of 20 per cent to assess the peak supply potential. For imports and storage this is defined by the maximum technical capacity of all existing sites and those who have taken a final investment decision.

In both **Gone Green** and **Slow Progression** the potential peak supply falls relevant to the current level throughout the period, as shown in Figure 4.4.7. This is caused by the decline in the UKCS production. Peak capability in **No Progression** also falls as the limited shale development does not replace the fall in UKCS. **Consumer Power** is the only scenario where peak capability increases over the period. These increases are driven by the significant volumes of shale gas in this scenario.

Gas supply

Figure 4.4.7
Peak supply potential in 2040



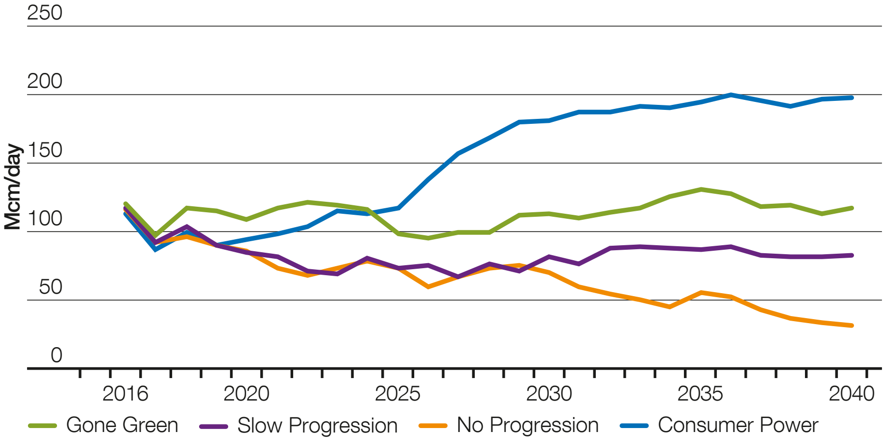
To ensure there is sufficient peak supply to meet demand we carry out the N-1 test. This assesses whether there is sufficient supply to meet demand when the largest single piece of supply infrastructure is removed. For all scenarios this represents losing supply from both LNG terminals at Milford Haven, a loss of 86 mcm per day. At the start of the scenarios this results in a margin of approximately 115 mcm per day.

Figure 4.4.8 highlights the margin by which supply exceeds demand, with the N-1 condition applied, and shows that all of our scenarios pass this test. Increasing peak demands see all margins fall in 2017 for all scenarios. In **Consumer Power** the margins grow significantly from 2016 levels to almost 200 mcm per day by 2040. Despite the falling supply potential in **Gone Green**, margins at the end of the period are at about the same level as in 2016. This is because the peak demand reductions are about the same as the decline in UK gas production.

The margins in the **Slow Progression** scenario fall until the mid-2020s reaching a low of 66 mcm per day. They then increase slightly as peak demands fall faster than supply. The combination of falling peak supplies and increasing peak demands result in **No Progression** having the lowest margins. These fall steadily throughout the period reaching a low of 31 mcm per day by 2040.

As all scenarios maintain a margin under the N-1 test, no additional capacity has been added in any of the scenarios. This is consistent with the gas rule described in the Method in Chapter 6.

Figure 4.4.8
Peak day N-1 margins



Method

Annual supply match

Indigenous gas production (UKCS, shale and biomethane) is driven by our primary assumptions and is allocated first. The minimum levels of LNG and continental gas are then applied along with Norwegian imports, which are determined by the conditions of the scenario. A match is then achieved by applying generic imports.

Locational supplies

The calculations behind our four scenarios include details of all points where gas enters or leaves the National Transmission System. This forms the basis of the network analysis that is described in more detail in our *Gas Ten Year Statement*.

Peak gas supply

For indigenous gas production (UKCS, shale and green gas) a 20 per cent swing factor is applied. This is based on observed values from UKCS production. For green gas and shale there is insufficient data to derive a likely swing factor. As these sources are likely to be base load, but with outages for maintenance, the UKCS swing profile was seen as the most appropriate.

For imports and storage the design capability is used to determine the capacity. This may differ from shorter-term documents, such as the *Winter Outlook*, which are based on near-term operational expectations. All existing sites are assumed to remain operational throughout the period; unless a closure date has been announced. New sites are only included if a final investment decision has been taken.

Chapter five

Duncan Sluce

Environmental targets

5.1
2020 Renewable Energy Directive target

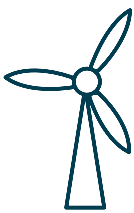
The UK has a target to produce at least 15 per cent of its energy consumption from renewable sources by 2020. Over the past year the volume of renewable electricity sources has increased substantially. While the electricity sources generation sector is on the required trajectory to meet its unofficial sub-target, significant progress is still needed in the heating and transport sectors if the UK is to meet the target on time. The biggest challenge is decarbonising the heating sector.

Key insights

- The UK generated 7 per cent of energy from renewable sources in 2014.
- In **Gone Green** there is the most progress towards the Renewable Energy Directive (RED) target, with 12 per cent of energy coming from renewable sources in 2020.
- The scenarios meet the target at dates ranging between 2022 in **Gone Green** and 2029 in **No Progression**.

12%

of energy coming from renewable sources in 2020 in **Gone Green**



5.1.1
Background

The 2009 RED set a legally binding EU target to produce 20 per cent of final energy consumption from renewable sources by 2020. EU countries have committed to reaching their own national renewable targets ranging from 10 per cent in Malta to 49 per cent in Sweden. The UK target is 15 per cent. Although *FES* is GB focused, as the 2020 target is UK based, this chapter will reference the UK throughout.

The European Commission has the power to take legal action if the obligations of EU law are not fulfilled. Although the Directive did not include a standalone penalty mechanism, if the target is missed, the UK may face significant financial sanctions.

While the 10 per cent transport target is legislated, there is no specific target legislated for the electricity generation and heating sectors. Table 5.1.1 shows how our analysis translates the 15 per cent overall target to sector-specific targets.

Table 5.1.1
Our breakdown of sector-specific targets to meet the RED target

Electricity generation	34%
Heating	10%
Transport	10%
Overall energy	15%

EU countries have also agreed to a new, non-legally binding, renewable energy target for 2030 of at least 27 per cent of final energy consumption from renewable sources.

None of our scenarios specifically aim to achieve the renewable energy target within the 2030 climate and energy framework, because it is not known how this target translates to the UK.

The elements that still need clarification are:
- what the UK target will be
- whether it will become legally binding
- whether the 2030 target will change to 30 per cent (as discussed in the 2015 United Nations climate change conference).[1]

[1] United Nations, Framework Convention on Climate Change, November 2015, http://unfccc.int/meetings/paris_nov_2015/meeting/8926.php

Environmental targets

5.1.2
Progress

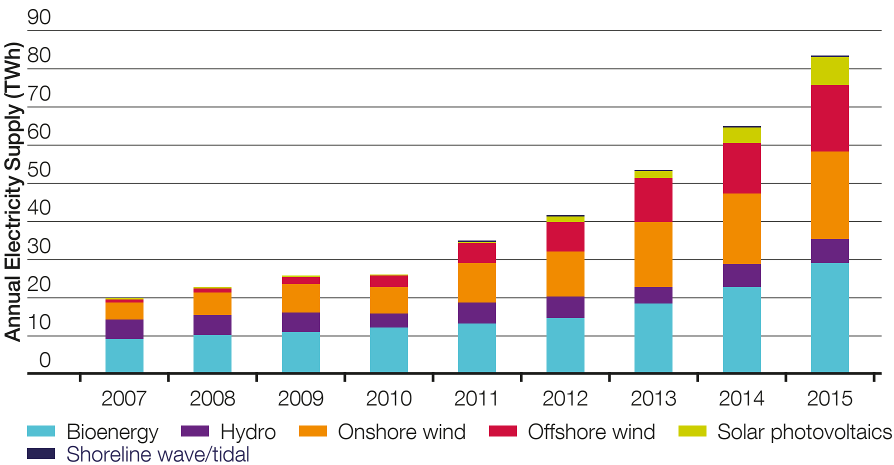
There has been good progress with renewable energy growth in the UK. This has grown from 3.8 per cent of all energy being sourced from renewable sources in 2010 to 7 per cent in 2014.

The greatest contribution to renewable energy is in the electricity sector. This has increased substantially in 2015, growing from 19 per cent of total generation capacity in 2014 to 25 per cent. As shown in Figure 5.1.1, the most significant contribution to renewable electricity generation is from biomass, followed by onshore and offshore wind. Solar, hydro and wave generation contribute the least.

Our analysis suggests electricity generation can meet the required contribution to the renewable target on time. We assess this to be around 34 per cent of electricity being from renewable sources in 2020.

For renewable heat to achieve its contribution to the target, it needs to increase by 60 TWh from today's level of 35 TWh. The technologies are available to reach this level, but to achieve the target within four years the pace of change would need to increase significantly. Over the past four years there was an increase equivalent to 2.5 TWh per year. To reach the target this needs to increase to an average of 12.5 TWh per year.

Figure 5.1.1
UK renewable electricity generation history



Chapter five

There is currently approximately 14.5 TWh of renewable transport. Our analysis suggests that a 24 TWh increase is required by 2020 to meet the target. Over the last four years the increase averaged at 1 TWh per year. With an average increase of 6 TWh required per year, it is less challenging than the increase required in renewable heating.

While we believe the electricity sector can achieve its contribution to the 2020 renewable target, we believe the progress required in the heat and transport sector is beyond what can be achieved on time. As a result, none of our scenarios achieve the 15 per cent level by the 2020 date. Our **Gone Green** scenario is the earliest to reach this, meeting the target by 2022.

60 TWh

increase in renewable heat needed

Environmental targets

5.2
2050 carbon reduction target

The UK has committed to the legally binding target of reducing carbon emissions by at least 80 per cent from 1990 levels by 2050. Meeting this target requires decarbonisation of the electricity generation, heating and transport sectors. Good progress is being made to decarbonise electricity generation. Three key technologies enabling this are nuclear, renewable and carbon capture and storage (CCS) enabled generation. However, further progress is required to decarbonise the heating and transport sectors.

Key insights

- To meet the 2050 target, emissions need to reduce from 2015 levels by:
  – 100 per cent in the electricity sector
  – 65 per cent in the heat sector
  – 70 per cent in the transport sector.
- Only **Gone Green** meets the target on time. Other scenarios show carbon reductions between 50 and 70 per cent below 1990 levels.
- In **Gone Green** in 2050 there is:
  – 22 GW of nuclear capacity
  – 20 GW of CCS-enabled generation
  – 12 million heat pumps
  – 35 million electric vehicles, including plug-in hybrids.

5.2.1
Background

The Climate Change Act 2008 established a target for the UK to reduce its carbon emissions by at least 80 per cent from 1990 levels by 2050. This target represents the UK's contribution to global efforts to limit the temperature rise to 2°C from 1990 levels.

To ensure that regular progress is made towards this long-term target, the act also established a system of legally binding five-yearly carbon budgets, as shown in Table 5.2.1.

The Committee on Climate Change (CCC) advises the Government on setting the level of carbon emissions for these budgets. If the carbon budgets and target are not met the UK may be subject to significant financial penalties and sanctions, although it is not yet clear what these are.

Table 5.2.1
Details of the UK carbon budgets

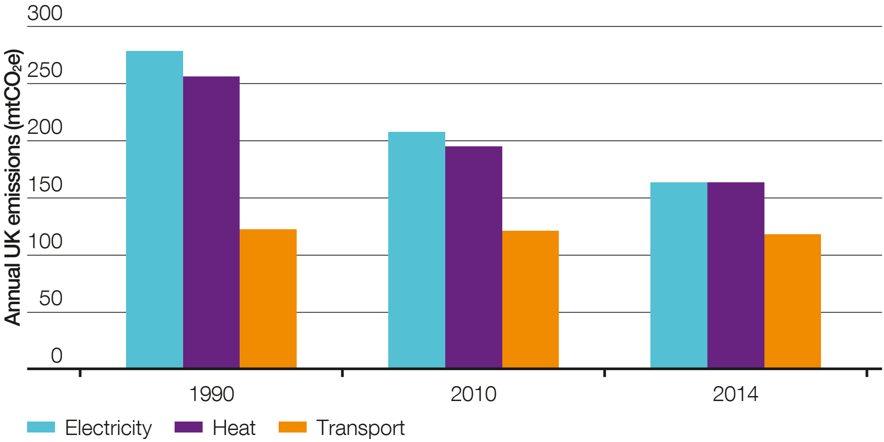
Budget	Period	Five-year carbon budget/final target ($MtCO_2e$)	% reduction below base year
First carbon budget	2008–2012	3,018	23
Second carbon budget	2013–2017	2,782	29
Third carbon budget	2018–2022	2,544	35
Fourth carbon budget	2023–2027	1,950	50
Fifth carbon budget recommendation	2028–2032	1,765	57
2050 target	2050	160	80

Environmental targets

There has been significant progress in reducing carbon emissions. The first carbon budget (2008–12) was achieved on time. The last official UK Government statistics show a decrease of 35 per cent in total greenhouse gas emissions between 1990 and 2014. This suggests that the second carbon budget (2013–17) will also be met.

Figure 5.2.1 shows the emissions from the energy sector since 1990. Most progress has occurred in the electricity and heat sectors. Most heat progress has been achieved by a combination of better insulated buildings and more efficient boilers.

Figure 5.2.1
UK emissions history



The electricity sector has provided the largest contribution to reductions in emissions. This has been predominately through the decline in coal-fired electricity generation; this has been driven by the Large Combustion Plant Directive and the Emissions Performance Standard[2], reducing by 52 per cent between 1990 and 2014. Further progress towards decarbonising the electricity system was made in 2015, mainly due to the accelerated decline in coal-fired generation combined with increased wind generation. The legislated phasing-out of coal-fired generation by 2025, and support for low carbon technologies, signal that progress towards decarbonisation will continue.

The UK is currently on track to outperform the third carbon budget (2018–22). However, further measures to encourage progress will be required to meet the fourth budget (2023–27) and the 2050 target.

The CCC's advice for the fifth carbon budget (2028–32) recommends that emissions should reduce to 57 per cent below 1990 levels. Our 2016 **Gone Green** scenario was prepared before the Government published their proposals for legislation on the fifth carbon budget in June, but it is consistent with the CCC's advice.

[2] DECC, Emissions Performance Standard Regulations, September 2015, http://www.legislation.gov.uk/uksi/2015/933/pdfs/uksiem_20150933_en.pdf

5.2.2
Changing energy landscape

Since *FES* 2015 there have been a number of developments and announcements impacting progress towards the 2050 carbon reduction target. These have generally reduced financial support available for prospective carbon reduction initiatives. In some cases this has been reflected in reduced low carbon generation growth. We have taken these announcements into account in the development of our scenarios.

The Chancellor of the Exchequer announced the budget in July 2015. Firstly, the Zero Carbon Homes and Buildings obligation was withdrawn. This obligation would have required all new dwellings, built from 2016, to generate as much renewable energy as they consume either onsite or through offset schemes. Secondly, the Government's flagship energy efficiency scheme, the Green Deal, was cancelled. Thirdly, the abolition of the CRC Energy Efficiency Scheme[3] from 2019 was announced, and the Climate Change Levy (CCL) raised to compensate. Finally, the CCL exemption for renewable electricity producers was closed for renewables from 1st August 2015. This increases the cost of future renewable energy generation. It is as yet unclear what the impact will be on existing and planned renewable energy projects, especially biomass.

In November 2015 the Secretary of State for Energy and Climate Change announced a new direction for energy policy. One announcement within this was that unabated coal-fired electricity generation would be restricted from 2023 and cease by 2025. Additionally the government recognised that gas-fired electricity generation will play an important role in facilitating decarbonisation as it can support low carbon electricity generation. The Secretary of State also reiterated support for nuclear generation as a low carbon source of electricity.

The announcement also stated that offshore wind support will continue via contracts for difference (CfD) auctions, provided cost-reduction targets can be met. The next relevant auction for offshore wind projects is anticipated later in 2016, continuing to 2019 when an evaluation of cost-effectiveness will be undertaken. The Government is consulting on whether onshore wind will be eligible for future CfD auctions. Planning decisions for onshore wind have also been moved to local authorities in England and Wales.

The annual Autumn Statement was announced in November 2015. The decision was made not to support phase two of the CCS pilot project scheme. Both proposed projects have now halted. For more information about CCS, and its potential role in decarbonising the energy sector, please see the spotlight on page 140.

Another significant change has been reductions in solar photovoltaic (PV) panel costs over the last few years. Costs have reduced by around two thirds since 2010, to close to £1,000 per kW for a domestic installation. Solar subsidies from February 2016 have been reduced from 12.47 to 4.39 pence per kWh to reflect lower installation costs.

[3] DECC, CRC Energy Efficiency Scheme: qualification and registration, April 2014, https://www.gov.uk/guidance/crc-energy-efficiency-scheme-qualification-and-registration

Environmental targets

Spotlight: What is CCS?

CCS has three main elements.

- Capturing carbon dioxide emissions from a process, most commonly via combustion.
- Transporting the captured carbon dioxide to a storage facility. This is normally through pipelines, although shipping can also be used.
- Storage of the carbon dioxide in offshore storage facilities such as gas and oil fields and large-scale aquifers.

Benefits of CCS

CCS has many potential applications. Without CCS the 2050 target can be met but costs are estimated to increase by between 50 and 100 per cent[4]. The main benefits are:

- **Electricity generation sector:** Having an amount of controllable, flexible electricity supply is important when the majority of supply is inflexible. CCS-enabled gas, coal and biomass-fired generation can all satisfy this requirement and provide low carbon baseload supply. Increased flexibility reduces costs as generation capacity can be lower, and networks can be smaller.
- **Heat sector:** CCS may facilitate the decarbonisation of high temperature industrial demand.
- **Hydrogen:** CCS can create low carbon energy storage in the form of hydrogen. Hydrogen produced from gas can provide a zero carbon energy source. Hydrogen produced from biomass can be a negative emissions source.
- **Transport sector:** Heavy goods vehicles (HGVs) can be decarbonised using hydrogen that has been created from processes using CCS.
- **Atmosphere:** Using sustainable biomass in CCS-enabled processes can indirectly remove carbon dioxide emissions from the atmosphere. This reduces the magnitude of the most expensive, residual decarbonisation requirements, such as aviation.

Challenges

Although CCS is expected to be economic in the long term, upfront costs are high (see Figure 5.2.2). Additionally, while nothing in the constituent parts of CCS is a new technology, its application at scale is new and the technology is not commercially developed in the UK. To best facilitate future cost reductions it is essential that new CCS-enabled facilities are co-located to make use of shared infrastructure and storage sites. This limits the number of possible locations.

Developments

Two pilot projects were supported by a government-backed CCS competition which would have provided £1 billion of capital support and access to a CfD. In November 2015 the decision was made not to support stage two of this competition. This is expected to delay CCS development in the UK.

The Government's view is "that CCS has a potential role in the long-term decarbonisation of the UK" although "the detailed design and implementation of CCS policy changes have yet to be developed"[5].

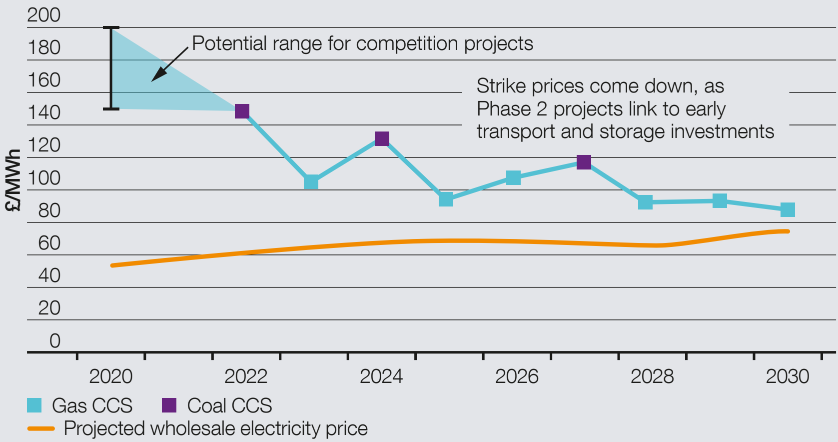
[4] Energy Technology Institute, Helping to accelerate the implementation of CCS in the UK, March 2014, http://www.eti.co.uk/wp-content/uploads/2014/03/3427-CCS-Brochure-Lores-AW----------Amended.pdf

[5] Amber Rudd, Carbon Capture and Storage letter to Angus MacNeil, January 2016, http://www.parliament.uk/documents/commons-committees/energy-and-climate-change/DECC-CCS-announcement-SOS-TO-CHAIR.pdf

In early 2016 there were 15 large-scale CCS projects in operation outside the UK, with a further seven under construction[6]. The driver for these developments is mainly enhanced oil recovery (pumping carbon dioxide into oil fields to help extract oil). Only one of the projects is for electricity generation (Boundary Dam, Canada). The majority of projects are in the USA or Canada, however there are two projects operational in Norway. One route to develop efficient and affordable UK CCS technology could be via initial development overseas. As projects progress, it is important that the opportunity is taken to develop large-scale shared transportation networks. Future projects can then connect to the existing pipeline and realise significant cost savings.

The anticipated reduction in costs from second and third phases of these projects from the CCS Association is shown in Figure 5.2.2[7].

Figure 5.2.2
Forecasted CCS strike prices



[6] Global CCS Institute, Large scale CCS projects, accessed April 2016, https://www.globalccsinstitute.com/projects/large-scale-ccs-projects

[7] CCS Association, Delivery CCS – Essential infrastructure for a competitive, low-carbon economy, June 2015, http://www.ccsassociation.org/press-centre/reports-and-publications/delivering-ccs/

Environmental targets

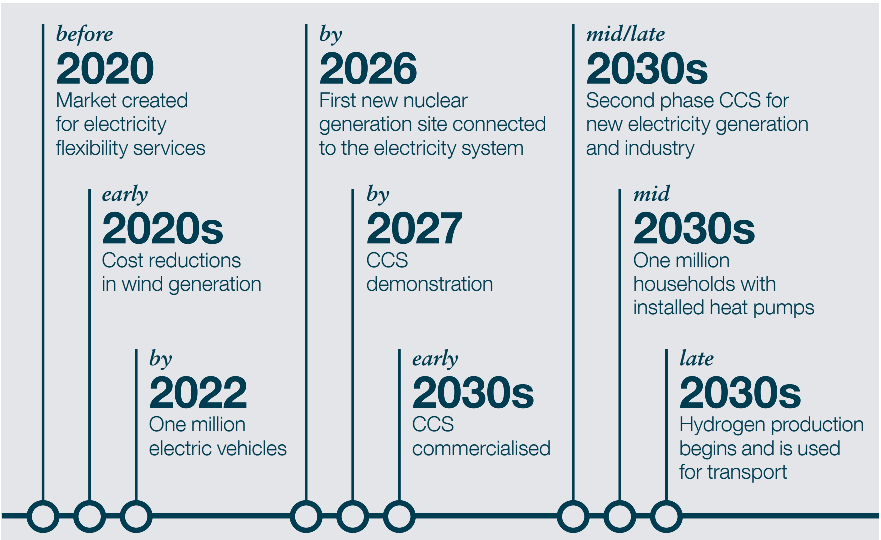
5.2.3
Extending the scenarios to 2050

Results
In this section when we refer to the scenario period this is 2016–2050. Our 2050 analysis is based on whole energy system modelling, calculated on a cost-optimised basis. This means the energy demand for transport, heat and electricity sectors is met as efficiently as possible by the available technologies and natural resources, with least cost to consumers. The model uses costs of fuels, technologies and networks, and is constrained by technology growth rates. For more information, please see the Method on page 175.

The scenarios are aligned to the pre-2040 FES outputs as outlined in chapters three and four. These use detailed modelling based on market intelligence and stakeholder engagement. The whole energy system modelling comes into effect in 2040, as it is not possible to do bottom-up intelligence-driven modelling this far into the future. However, the 2030 to 2040 time period is informed by the 2050 analysis to ensure there is a smooth transition.

This section focuses mainly on **Gone Green** as this is the only scenario to meet the 2050 target on time. We do however, in section 5.4, explain how the other scenarios could be adjusted to reach the 2050 target.

Figure 5.2.3
Road map showing the cost-optimal route to the 2050 target

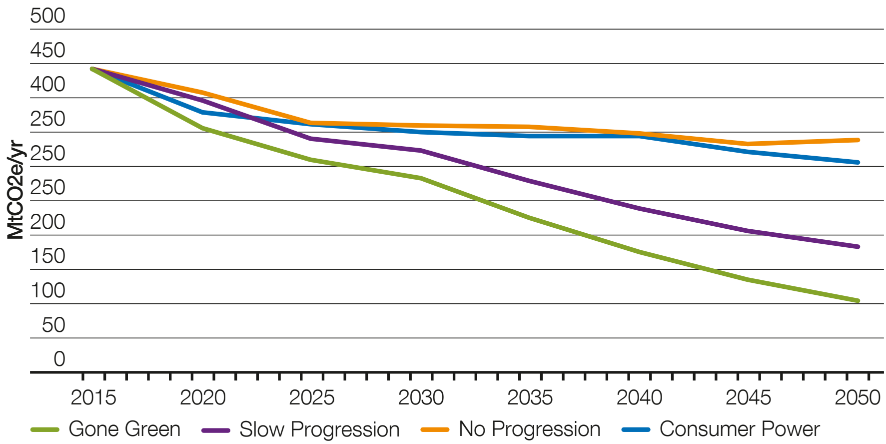


Emissions

Carbon emissions from energy reduce considerably in all scenarios; by 2050 they are 23–76 per cent lower than 2015 levels (48 and 84 per cent below 1990 levels). Figure 5.2.4 illustrates how the largest emissions reduction occurs in the next decade, in all scenarios.

In the short term, the largest decline in emissions occurs in the electricity sector. This is a substantial decline in all scenarios. The cessation of coal-fired generation and increases in renewable generation are the main reasons for this. This represents positive progress towards the UK carbon budgets.

Figure 5.2.4
Total UK carbon emissions from energy



Gone Green achieves the 2050 target by fully decarbonising the electricity generation sector by 2045. There are three key technologies required to achieve this. These are nuclear, renewable and CCS-enabled generation. Low carbon electricity is then used to electrify large parts of the heat and transport sectors, reducing emissions by 65 per cent and 70 per cent respectively.

A report by the UK Energy Research Centre[8] specifies that the lead time between innovation and commercial roll-out of a new technology takes, on average, 38 years. Energy generation technologies are typically above this average. This means that energy generation technologies not already in development are unlikely to materialise in time to support the 2050 carbon reduction target. It also highlights that pre-commercialised technologies need support and development in this decade to be able to contribute to the carbon reduction target.

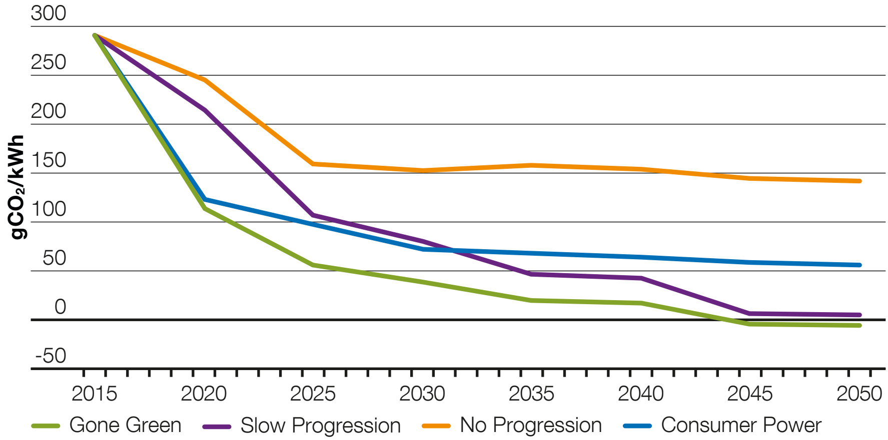
Chapter five

[8] UK Energy Research Council, Innovation timelines from invention to maturity, December 2015, http://www.ukerc.ac.uk/asset/ADA12E92-C1DC-4033-8CFA63AC9EA9FE59/

Environmental targets

Electricity supply
As shown in Figure 5.2.5, all of the scenarios show a considerable decline in emissions from electricity generation over the next decade. This is driven mainly by the cessation of coal-fired generation by 2025, and an increase in renewable generation (mainly wind). Renewable generation increases most in **Gone Green** and least in **No Progression**.

Figure 5.2.5
Carbon intensity of electricity generation



All scenarios assume considerable imports from Europe, particularly earlier in the scenario period. As seen in section 4.2, in **Gone Green** GB becomes a net exporter after 2030. As seen in Table 5.2.2, GB also becomes a net exporter in **Slow Progression**, after 2040. This is due to increasing capacities and high baseload generation. **Consumer Power** also has a high capacity but a lower baseload. As such annual imports and exports balance in 2050. **No Progression** has the lowest capacity, resulting in net imports throughout the period.

In **Gone Green**, nuclear, CCS and renewable generation (mostly wind) account for over 99 per cent of total net electricity supplied in 2050.

Gone Green requires 17 GW of new nuclear by 2040 and 22 GW by 2050. While there is political support for new nuclear developments, a significant change in build rates is required to reach these levels. In addition, uncertainty remains within the industry regarding the successful commissioning of the next generation of nuclear power stations.

Wind accounts for around two thirds of renewable electricity generated. It is currently on the required trajectory to meet the target. To ensure sustainable long-term growth, clarity is needed on post-2020 support mechanisms. This will provide a strong investment environment.

Table 5.2.2
Import/export position of the four scenarios

Consumer Power	Gone Green	No Progression	Slow Progression
Imports and exports balance in 2050	Net exporter from 2030	Remains net importer	Net exporter from 2040

In **Gone Green** the increasing levels of nuclear and wind generation create an increasingly important role for flexibility, to manage supply and demand variability, both seasonally and over short timescales. This can be provided by services on both the demand and supply sides. Possible sources include storage, demand side response (DSR), interconnection, thermal and non-thermal generation.

One thermal generation option is CCS-enabled generation. To meet demand, **Gone Green** requires 2 GW of CCS by 2030 and 20 GW by 2050, supplying approximately a quarter of demand. Our stakeholders have estimated that without CCS the cost of meeting the 2050 target increases by between 50 and 100 per cent[9]. This is because CCS could be a relatively cheap electricity flexibility tool and can additionally enable decarbonisation in other areas such as heavy industry. Of the three key technologies, CCS has seen the least progress to date and the recent government decision to withdraw the CCS competition will delay progress in this sector. For further information on CCS, see the CCS spotlight on page 140.

CCS is mainly linked with gas-fired generation. In **Gone Green** some CCS is produced with biomass generation. This provides negative emissions[10], and reduces the decarbonisation requirement from other sectors.

As **Gone Green** requires the highest level of electricity demand, due to the electrification of heat and transport, it has the highest overall electricity supply.

Slow Progression has similar sources of supply to **Gone Green** yet the quantities are lower. CCS is available from 2040 to facilitate its progress towards the carbon reduction target.

Consumer Power has high growth in renewable and nuclear generation. Interconnection imports support the electricity system as gas generation declines in the 2030s. By 2050, growth in nuclear and renewable generation results in zero net imports.

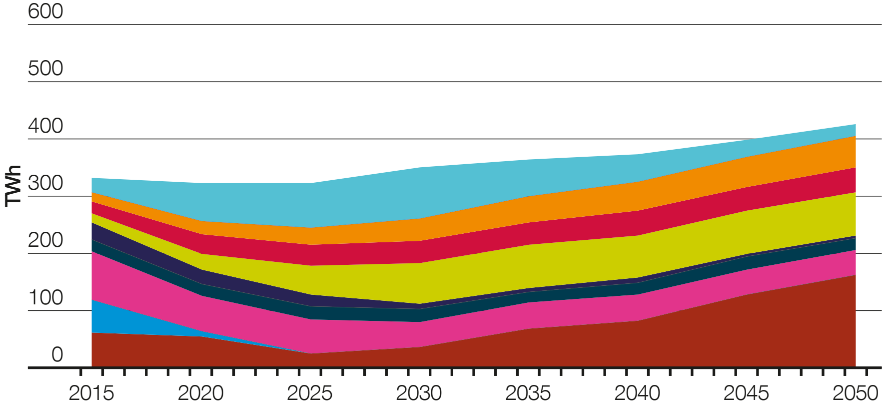
No Progression results in the least growth in renewable generation and nuclear remains below 2015 levels. As a result gas supplies the largest proportion of electricity demand, supported by imports. A comparison between the scenarios is shown in Figure 5.2.6.

[9] Energy Technology Institute, Helping to accelerate the implementation of CCS in the UK, March 2014, http://www.eti.co.uk/wp-content/uploads/2014/03/3427-CCS-Brochure-Lores-AW----------Amended.pdf

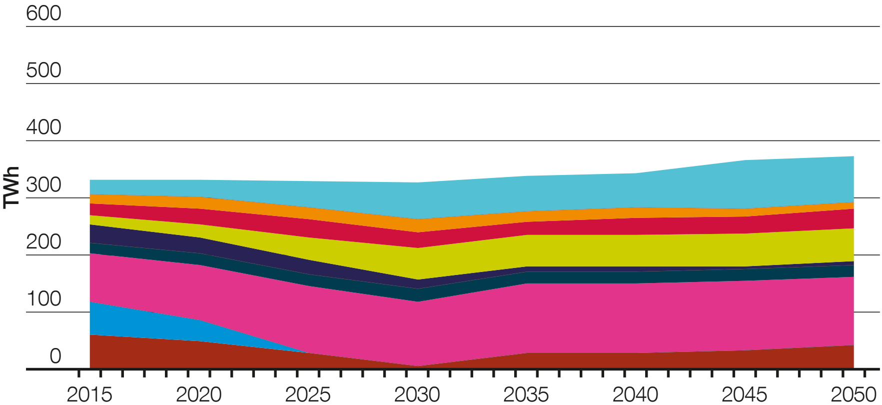
[10] Sustainably sourced biomass is emissions neutral, as trees grown to replace those felled take carbon from the atmosphere when growing. If the emissions from burning a sustainably sourced tree are captured the whole cycle has the net effect of reducing atmospheric carbon dioxide.

Environmental targets

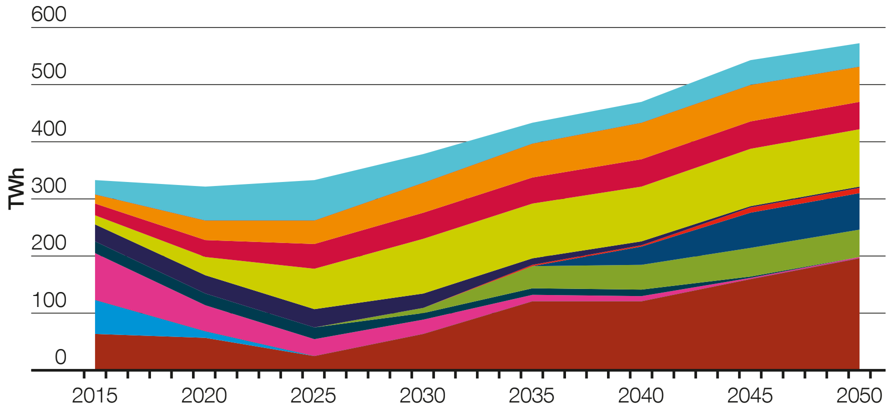
Figure 5.2.6
Electricity supply – Consumer Power



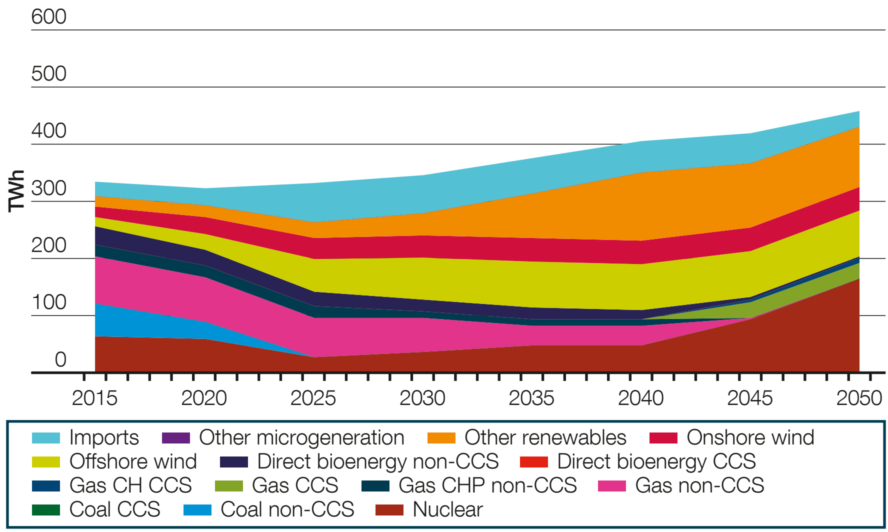
Electricity supply – No Progression



Electricity supply – Gone Green



Electricity supply – Slow Progression



Environmental targets

Heat

We believe, as do our stakeholders, that heating is the most difficult sector to decarbonise. This is mainly due to the need for over 80 per cent of UK homes to change their heating technology by 2050.

Gas is a relatively low cost, reliable and established fuel, currently used to heat 90 per cent of UK houses. Significant behavioural change is required for consumers to move away from this. Low carbon heating options currently have higher capital costs, are often disruptive to install, and are operated differently to what people are familiar with. However, they can offer long-term cost savings. Although the RHI pays for a heat pump in around seven years, there has been a low uptake of this technology. This suggests that further action is required, be it legislative or other, to incentivise progress in the residential sector. Our **Gone Green** scenario has less electrification of heating than in *FES* 2015, as a result of recent data and stakeholder feedback. While we still include a high level of heating electrification, alternative technologies are also required to meet the 2050 carbon reduction target.

Options include low carbon heating from anaerobic digestion and bio-substitute natural gas (bioSNG) (creating gas from non-digestible waste). Low carbon gas accounts for around a tenth of gas supply in 2050 in **Gone Green**. Anaerobic digestion is an established technology, and bioSNG is being developed under its second Ofgem-funded Network Innovation Programme[11].

Focusing on low carbon gas or hybrid gas and electric heating systems may be an alternative way to drive the uptake of low carbon heating systems. Many of our stakeholders believe that having gas available for top-up heating could alleviate consumer concerns of switching to electric heating. The smaller heat pump capacity could also reduce capital costs and minimise the extra space requirements of a heat pump. Low carbon gas accounts for around a tenth of gas supply in 2050 in **Gone Green**.

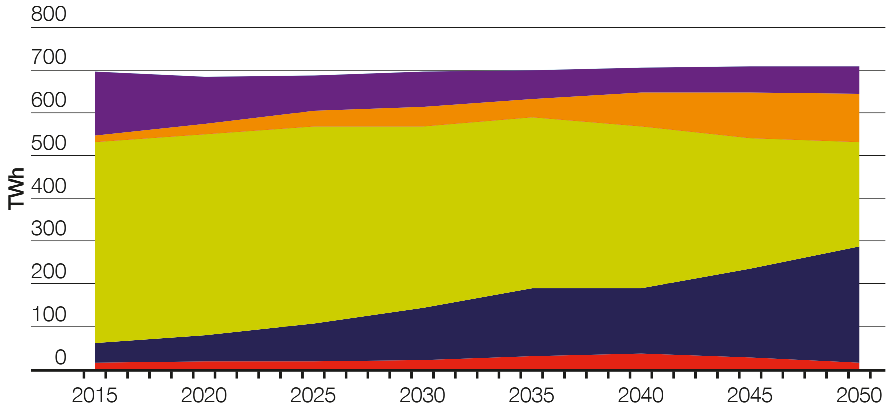
Utilising hybrid heating would also reduce the peak generation and flexibility requirements from the electricity system, allowing some of the flexibility requirements to be addressed by the gas system. This is particularly relevant to additional heating requirements in cold months.

District heating schemes are another technology used to decarbonise heat in our scenarios. There is a lack of agreement across the industry on what level of potential will be realised. Some analysts believe it will supply up to half of residential heating, while others think its contribution will be 10 per cent. Our scenarios have a range of 5–20 per cent of residential heating demand met by district heating in 2050, with **Gone Green** having the highest. District heating is higher in all scenarios compared to last year's scenarios. This is informed by the study we have been doing in conjunction with Buro Happold (see spotlight on district heat on page 50 for more information).

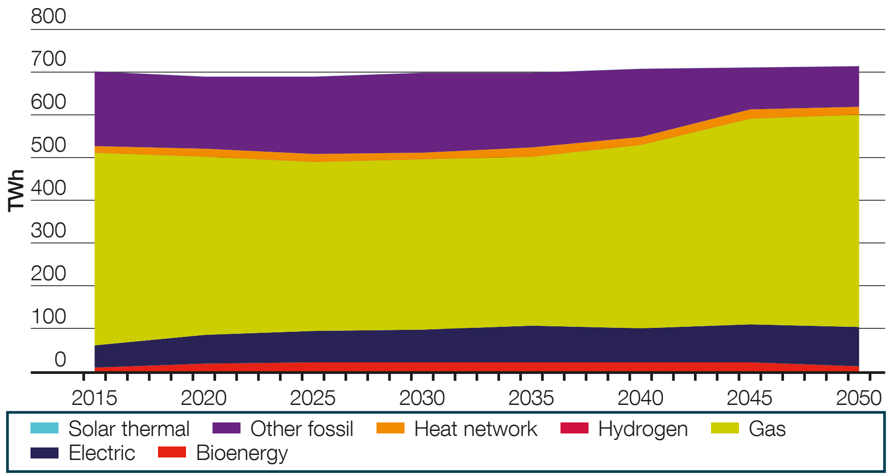
Varying efficiencies of heating technologies result in different energy supply requirements between the scenarios, but there is relatively little difference in total heat demand between the four scenarios. This is because the assumed population size is the same across the scenarios. However, the sources meeting this demand vary considerably, as seen in Figure 5.2.7. **Gone Green** has the highest electrification of heating via heat pumps, followed by **Slow Progression**. **No Progression** sees very limited increase in electrification.

[11] Ofgem, 2015 Innovation Competitions Brochure, December 2015, https://www.ofgem.gov.uk/publications-and-updates/2015-innovation-competitions-brochure

Figure 5.2.7
Heat demand – Gone Green



Heat demand – No Progression



Environmental targets

Transport

The transport sector can have a large contribution to decarbonisation, but it experiences lower emissions reductions than the electricity generation and heating sectors. This is due to the scale of the challenge to decarbonise shipping and aviation.

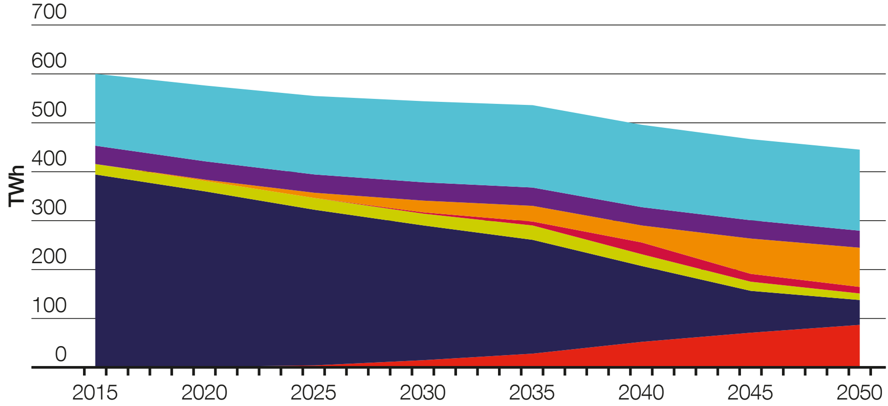
Both cars and vans can be electrified at relatively low cost. While still in its infancy, the electrification of light vehicles is on the required trajectory to meet the target. Good progress in this sector, driven by legislation and incentives, has resulted in higher projected rates of vehicle electrification in all scenarios compared to FES 2015. **Gone Green** has the highest electrification of vehicles, but all scenarios show electrification to varying degrees, using pure electric vehicles (EVs) and plug-in hybrids. As EVs are around three times more efficient than traditional petrol or diesel vehicles, this trend reduces overall road transport energy demand in all scenarios, as seen in Figure 5.2.8.

HGVs are more difficult to decarbonise. All scenarios assume reduced carbon emissions in the HGV sector by fully converting the fleet to run on natural gas by 2050. This can reduce emissions by 20–30 per cent per HGV[12]. **Gone Green** achieves further progress by additionally converting around a fifth of HGVs to hydrogen. This hydrogen is created from electrolysis using excess low carbon generation (e.g. at times of low demand and high wind generation output). **Slow Progression** also utilises hydrogen, but in a more limited number of vehicles.

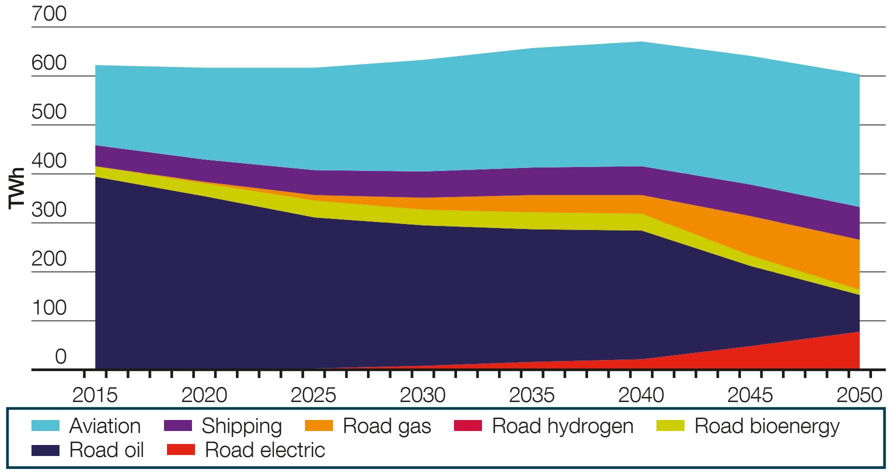
The most difficult sectors to decarbonise are aviation and shipping. Efficiency gains are generally more than offset by higher demands for aviation and shipping as populations increase. **Gone Green** has the lowest demand from these sectors because green ambition limits demand growth and drives successful investment in efficiency improvements. **Consumer Power** has the highest demand in this sector due to high prosperity and limited green ambition. **No Progression** and **Slow Progression** see some growth but at a slower rate than in **Consumer Power**.

[12] Gasrec, A cleaner solution – cutting harmful emissions with natural gas, May 2015, http://gasrec.co.uk/a-cleaner-solution-cutting-harmful-emissions-with-natural-gas/

Figure 5.2.8
Transport demand – Gone Green



Transport demand – Consumer Power



Environmental targets

Electricity demand

The majority of electricity is consumed in the traditional demand sector. This category includes appliances and lighting in domestic, commercial and industrial sectors. There are relatively small differences between scenarios in the level of traditional demand as population size is assumed to be equal.

The main differences between the electricity demand in the scenarios are in the heat and transport sectors. There is higher electrification of transport compared to last year in all scenarios.

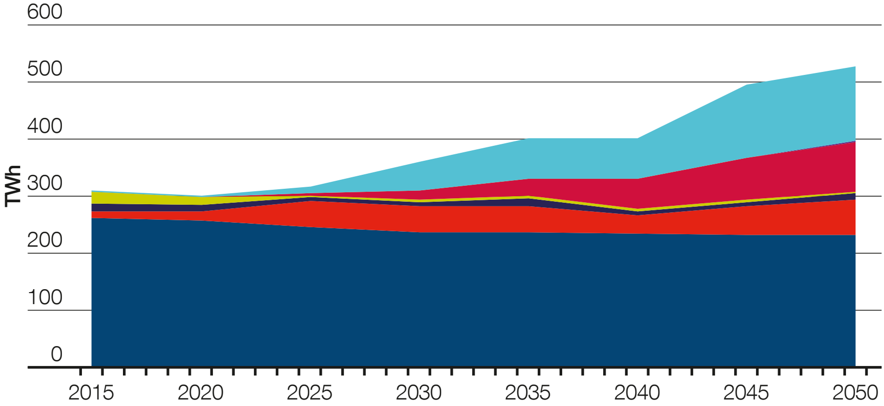
As seen in Figure 5.2.9, **Gone Green** has the highest electricity demand as a result of the electrification of heat and transport. Exports are also highest in **Gone Green** due to the high levels of low carbon generation. Interconnection is utilised (among other options) to balance the system at times of excess generation.

While there is also high electrification of the heating and transport sectors in **Slow Progression**, this is to a smaller extent than in **Gone Green**. Similarly, there are lower levels of exports in **Slow Progressio**n. This results in **Slow Progression** having the second highest electricity demand of the four scenarios.

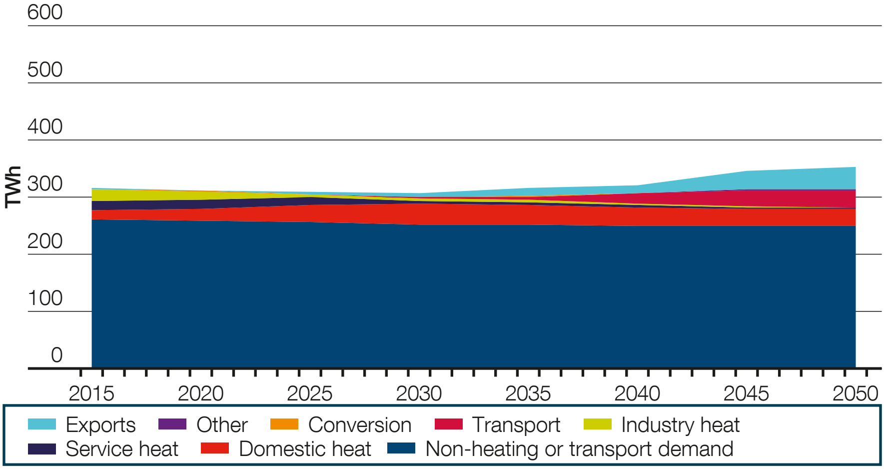
Consumer Power has the highest level of traditional demand due to high prosperity and low green ambition. There are high levels of transport electrification but limited electrification of heating. Exports are also lower than the greener scenarios. These factors result in total electricity demand being marginally lower than **Slow Progression**.

No Progression experiences the lowest demand across all electricity demand sectors. This is due to the low demand from traditional sectors and minimal electrification of heat and transport.

Figure 5.2.9
Electricity demand – Gone Green



Electricity demand – No Progression



Environmental targets

Gas demand

Gone Green has the lowest gas demand in 2050 while **No Progression** has the highest, as seen in Figure 5.2.10. The difference between the scenarios is around a third. Demand for CCS-enabled gas generation in **Gone Green** increases overall gas demand in the 2030s. This reduces in the 2040s as the electrification of heating increases.

In **No Progression**, higher total gas demand is maintained. This is a result of increasing unabated gas-fired electricity generation and little change in domestic gas demand. The minimal change to industrial gas demand, and an increase in gas for commercial vehicles, increases demand to levels above 2015 demand.

Consumer Power has the second highest gas demand, as gas dominates the heating market, despite the lower levels of gas-fired generation. Overall, gas demand in **Slow Progression** is only marginally higher than in **Gone Green**; it has less demand for electricity generation but higher demands for heating.

Hydrogen

Hydrogen features in **Gone Green** and **Slow Progression**. It is essentially a storage mechanism. Hydrogen provides many options for storing and transporting energy to be used in various applications, many of these are low carbon options.

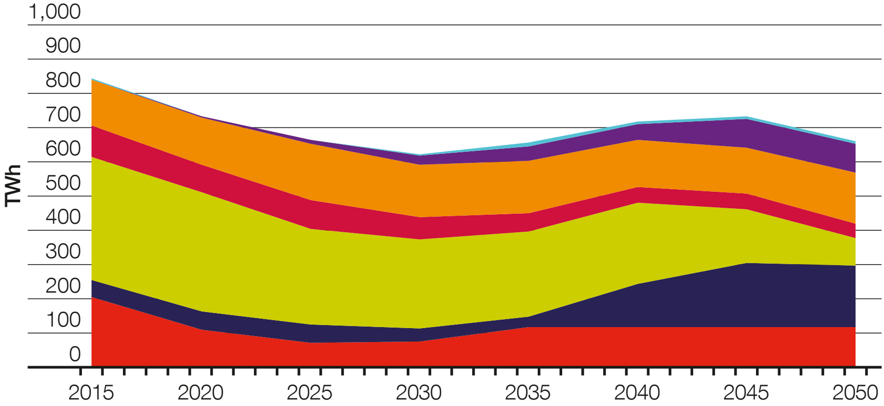
The importance of hydrogen increases as other easier decarbonisation options become exhausted. As such it is used only in the later years (from 2030 onwards) and helps to decarbonise the most challenging elements of energy.

As hydrogen technology is in its infancy there remains uncertainty regarding how it is best created and used. Possible applications include heat, transport and electricity balancing. It is clear that hydrogen is an important part of a low carbon economy, though this may be at relatively low levels. This is consistent with market analysis and stakeholder feedback. Hydrogen accounts for just over one per cent of the total UK energy delivered in 2050 in **Gone Green**, and around half a per cent in **Slow Progression**.

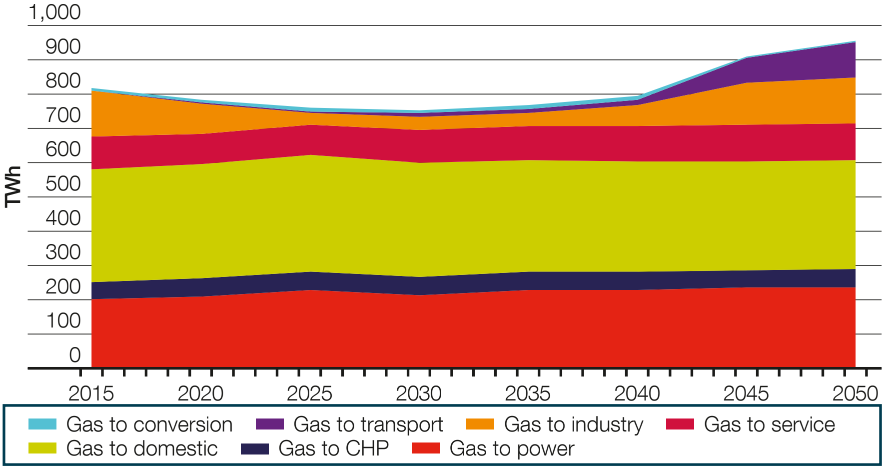
We have reduced our hydrogen projections from the 2015 scenarios as increased levels of low carbon gas have reduced the requirement for hydrogen. In *FES* 2015, we assumed that 60 TWh of hydrogen would be used in **Gone Green**, while in *FES* 2016 it is around 15 TWh. Additionally, last year we assumed most hydrogen was created from CCS-enabled processes. This year we assume CCS is used primarily for electricity generation. As a result our **Gone Green** scenario creates hydrogen from electrolysis at times of excess generation. This hydrogen is used to fuel some of the HGV fleet.

Slow Progression has around half the CCS-enabled generation capacity of **Gone Green**. This leaves CCS capacity available for other processes. In this scenario biomass is used in a CCS-enabled process to create hydrogen which is also used to fuel part of the HGV fleet.

Figure 5.2.10
Gas demand – Gone Green



Gas demand – No Progression



Environmental targets

5.2.4
A comparison between Gone Green and the CCC's fifth carbon budget recommendation

The CCC released their fifth carbon budget advice to Government in November 2015. At the time of writing the government has not announced the legislated carbon budget level (due June 2016). We have compared **Gone Green**'s pathway to the 2050 target to the CCC's advice to show where there are similarities and where there are differences.

Electricity

The CCC believes that the electricity generation sector has the greatest potential to be fully decarbonised. Like our **Gone Green** scenario, the CCC central case shows electricity generation being decarbonised first, to enable decarbonisation of heat and transport.

The CCC states that, while good progress has been made, incentives are required to ensure low cost and low carbon electricity is maximised in the 2020s. They also highlight the importance of developing key emerging technologies to ensure a cost-optimal pathway to the carbon reduction target and budgets.

As a consequence of the growth in nuclear and renewable generation, the CCC concludes, as do we, that there will be an increasingly important role for flexibility. This can be met from both the demand and supply sides.

A summary comparison between our **Gone Green** scenario and the 2015 CCC central case is shown in Table 5.2.3.

Table 5.2.3
A comparison of the key electricity components to deliver the carbon budgets

	Gone Green	CCC central scenario
Period from which there is no further unabated coal-fired generation	By 2025	During 2020s
Three key electricity generation technologies in 2050 are nuclear, renewable and CCS	Yes	Yes
Increased flexibility requirements managed via a range of options including DSR	Yes	Yes
Energy efficiency improvements continue in the demand sector, mainly via appliances and lighting	Yes	Yes
Increased infrastructure requirements to deliver electricity	Yes	Yes
Carbon intensity (g/kWh)	<100 by 2030 ~0 by 2050	<100 by 2030 ~0 by 2050

Environmental targets

Heat

Due to the magnitude of the behavioural change required, the CCC advice is aligned with our view that heating is the most difficult sector to decarbonise.

As in our **Gone Green** scenario, one of the components of the CCC advice is hybrid heating. This may require less change for consumers, and reduces the peak generation and flexibility requirements.

Bioenergy is another area where the CCC central case aligns with **Gone Green**. We both agree it is predominantly used for industrial heating, particularly increasing through the 2030s. Its use declines subsequently, as the availability of imported sustainable bioenergy reduces through the 2030s with increases in world demand. This reduces bioenergy used in both **Gone Green** and the CCC central case.

Both scenarios show some potential for hydrogen, from the 2030s. The CCC see it as an option to be used for transport and heating in industrial processes and buildings. We assume, in **Gone Green**, that it is used for transport. We both recognise that there is currently considerable uncertainty over how hydrogen is best used.

A summary comparison between our **Gone Green** scenario and the 2015 CCC central case is shown in Table 5.2.4.

Table 5.2.4
A comparison of the key heat components to deliver the carbon budgets

	Gone Green	CCC central scenario
Total number of houses with heat pumps installed (electric and hybrid)	2m in 2030 22m in 2050	2.3m in 2030
Amount of bioenergy used in industry	30 TWh in 2035 14 TWh in 2050	Yes – not specified, reducing from 2030s
Is hydrogen used for heating?	No	Yes – as a potential option

Transport

Gone Green and the CCC central transport scenarios are well aligned. To meet decarbonisation targets both **Gone Green** and the CCC central case require continuing efficiency improvements. This leads to a shift towards ultra-low emission vehicles including EVs, plug-in hybrids and fuel cell vehicles.

As stated above, the main difference between our scenarios and the CCC central case is that hydrogen is used to fuel transport in **Gone Green**, while the CCC believes it could be an option to use in either the heating or transport sector.

5.3
Sensitivities from the Gone Green scenario

There is more than one pathway to achieving the carbon budgets and 2050 carbon reduction target. Our sensitivity analysis shows that it is always essential to decarbonise the electricity generation, heat and transport sectors, starting with the electricity generation sector. While energy efficiency and behavioural changes can support progress, technology changes are essential. The sensitivities all show that nuclear, renewable and CCS-enabled generation are the three key technologies for a cost-optimal pathway. The target can be met with any two of the three, but costs rise considerably. The sensitivities all show that flexibility and balancing requirements on the gas and electricity systems will increase from today's level.

Key insights

- In a cost-optimal sensitivity, heat would be decarbonised earlier than in **Gone Green**, with a mass electrification of heating in the 2030s.
- Maximising all forms of renewable generation would cause electricity capacity to be 10 per cent higher than **Gone Green**, while maximising solar generation specifically would cause it to be 20 per cent higher.
- Biomass can supply approximately 15 per cent of heat demand by 2050.
- Demand-side changes alone, without any changes in technologies, can reduce demand by a maximum of 20 per cent compared to 2015. Therefore, technology changes are still essential to meet the carbon reduction target.

20%
higher electricity capacity by maximising solar generation

Environmental targets

Introduction

Gone Green shows one pathway to reaching the 2050 carbon reduction target. However, this is not the only way. To respond to interest and questions on how the UK can reach the 2050 target we have performed extra analysis.

The following seven sensitivities consider how variations of our **Gone Green** scenario can also meet the target on time and what the impact of these differences would be.

5.3.1 The cost-optimal sensitivity

This sensitivity is similar to **Gone Green**. The main differences are higher levels of both heat electrification and nuclear generation. This results in a lower total electricity capacity than **Gone Green**.

This sensitivity aims to verify what the cost-optimal pathway to meet the 2050 carbon reduction target would be if **Gone Green** was not linked to the pre-2040 analysis. It looks at a whole energy system modelling approach from 2020 to 2050.

As shown in Figure 5.3.1, this sensitivity is relatively similar to the **Gone Green** scenario, with three main differences:

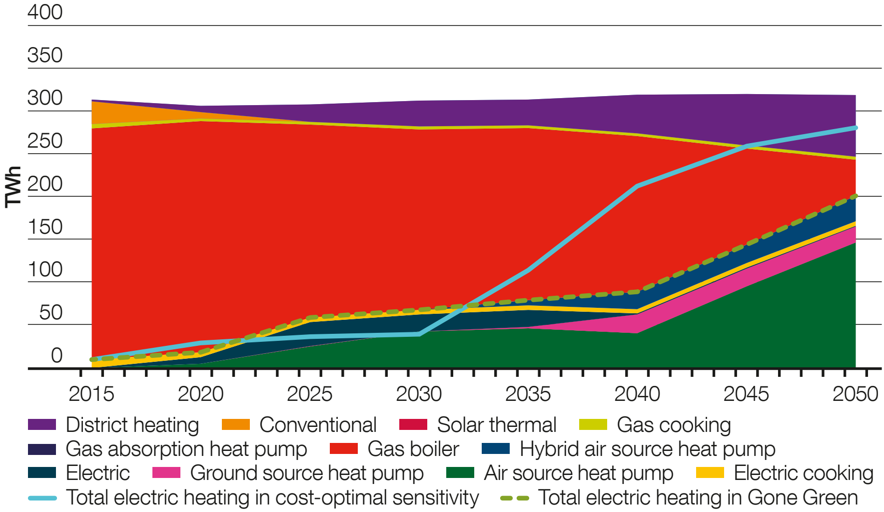
- the roll-out of heat pumps is earlier and faster
- CCS is commercialised earlier
- nuclear generation reaches higher levels.

In this sensitivity CCS develops much earlier than in **Gone Green**, with commercialisation reached in the mid-2020s rather than the 2030s. Nuclear is built earlier and to a higher capacity than **Gone Green**.

There is 10 GW less overall generation capacity in 2050 than in **Gone Green**, due to less non-wind renewables. This results in a lower requirement for network growth. The lower capacity of solar generation, which is replaced by wind generation when it reaches end of life, causes a smaller flexibility requirement than in **Gone Green**.

This sensitivity favours heat pumps. It assumes they are adopted earlier and to a greater extent than in **Gone Green**. The lower level assumed in **Gone Green** is because our stakeholders told us that heat pump uptake will not get to the necessary rate in the required timescales. This is due to the difficulty in influencing people to move away from gas boilers. While **Gone Green** differs from the cost-optimal scenario for electrification of heating, it utilises other options to meet the carbon budgets and target. These include district heating schemes and sources of low carbon gas such as bioSNG and biogas.

Figure 5.3.1
A comparison of domestic heating by source between Gone Green and the cost-optimal sensitivity



Environmental targets

5.3.2
Maximum renewable generation sensitivity

Renewable generation can theoretically deliver around 90 per cent of total electricity supply in 2050. However, major technological flexibility and operability improvements would be required to operate the system.

This sensitivity examines whether the electricity system could be completely powered by renewable generation. In reality this scenario is unlikely to be operable without additional tools. Significant increases in flexibility and operability tools would be required to run this system. These challenges are explored further in the *System Operability Framework*.

Our analysis shows that a system supplied by 90 per cent renewable generation is theoretically feasible. However, a high backup generation capacity would be required, mainly from gas-fired generation, to balance the system. In practice, these plants would be unlikely to be commercially viable unless balancing and/or capacity payments were considerable. The system would also be heavily import dependent for both total energy and balancing requirements.

The overall energy demand is very similar to **Gone Green**. Gas demand is approximately halved as wind generation replaces some gas-fired CCS generation. The technologies meeting heating and transport demand are very similar to those in **Gone Green** by 2050.

Overall, electricity capacity is 10 per cent higher than in **Gone Green** and 15 per cent higher than the cost-optimal sensitivity. This sensitivity is highly reliant on interconnectors and gas-fired generation for balancing services. Without these technologies capacity would increase disproportionately.

The operability of the gas and electricity networks is much more challenging than in **Gone Green**, due to the lower level of controllable thermal generation and greater reliance on imports.

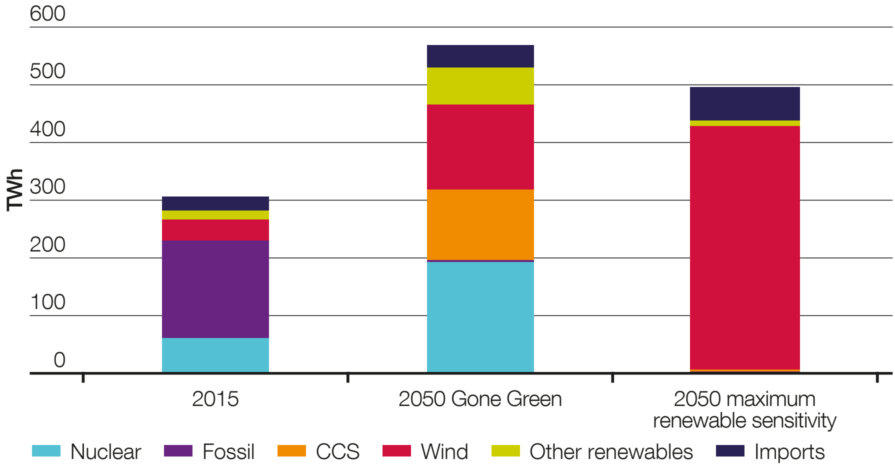
Because the system is considerably harder to balance, this sensitivity reduces indigenous electricity supply, to manage the system. This leads to higher imports and lower demand (less electrification of heat and transport). Lower UK supply results in this sensitivity being import dependent in 2050.

In comparison, in **Gone Green** GB is a considerable net exporter, due to its higher indigenous generation supply, most notably the high nuclear baseload.

The lower electrification of the heat and transport sectors means that other options are needed to hit the 2050 carbon reduction target. This sensitivity quadruples the level of hydrogen production in **Gone Green** to achieve the 2050 target. Unlike **Gone Green**, it is created from CCS-enabled biomass processes to generate 60 TWh of hydrogen.

Figure 5.3.2 shows a comparison of the electricity generation sources between **Gone Green** and the maximum renewable generation sensitivity.

Figure 5.3.2
A comparison of annual electricity supply by type between Gone Green and the maximum renewable generation sensitivity



Environmental targets

5.3.3
Maximum solar generation sensitivity

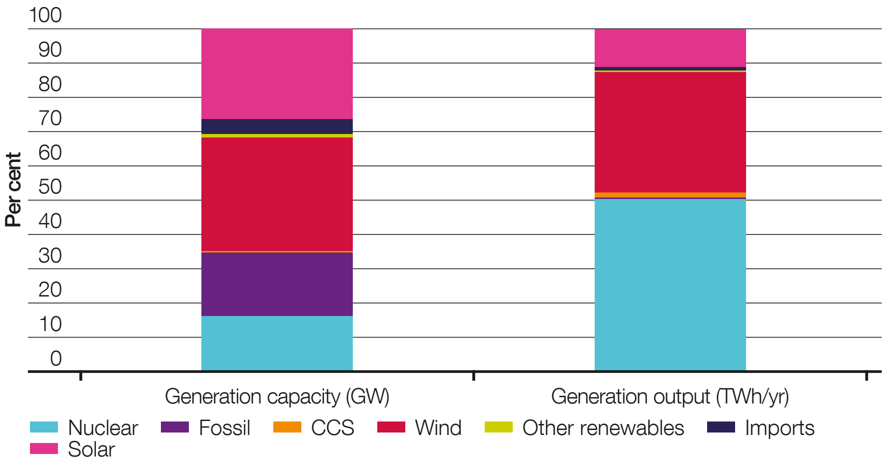
In this sensitivity, solar accounts for around a quarter of UK capacity in 2050 and delivers around 10 per cent of total UK electricity supply. Total UK capacity would be 20 per cent higher than **Gone Green**. There would be significant operational challenges associated with this sensitivity as solar generation is typically low at times of high demand.

This sensitivity investigates the maximum potential of solar generation. This would include high solar farm growth, plus an average-sized domestic system on every appropriately orientated domestic rooftop in the UK.

In this sensitivity, in 2050, solar capacity is approximately 60 GW. This provides 10 per cent of annual electricity demand, as shown in Figure 5.3.3. Total annual electricity generation remains the same as in **Gone Green** but overall capacity is 20 per cent higher and is 33 per cent higher than the cost-optimal sensitivity. This is because solar generation has lower load factors than the wind generation it replaces.

This sensitivity creates challenging operability requirements for the electricity network, as solar generally generates most when demand is at its lowest. It generates very little during peak winter demand periods.

Figure 5.3.3
Generation capacity and output in a maximum solar scenario



Chapter five

5.3.4
No new nuclear generation sensitivity

The carbon reduction target could still be met if no new nuclear generation was built, but a major roll-out of CCS-enabled electricity generation would be required to limit costs.

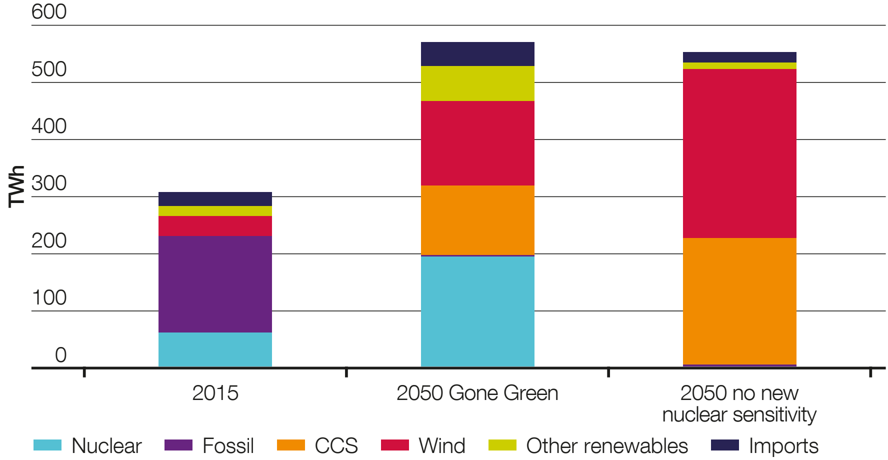
This scenario investigates how the target could be met if no new nuclear was built.

In this scenario the nuclear capacity seen in **Gone Green** is replaced by low carbon generation, mostly CCS. CCS is considered most efficient due to its ability to provide baseload generation and flexibility. The differences between this sensitivity and **Gone Green** are shown in Figure 5.3.4.

Due to the higher levels of gas-fired CCS generation, gas demand in this sensitivity is higher than in **Gone Green**. This results in overall gas demand in 2050 being similar to today's level. In **Gone Green**, gas demand reduces by 20 per cent over this period. All other demands and technologies for heating, electricity generation and transport are very similar to **Gone Green**.

The flexibility requirements, although more demanding than today, are less onerous than in **Gone Green**. This is because of the flexibility of thermal generation and associated inertia.

Figure 5.3.4
A comparison of annual electricity supply by type between Gone Green and the no new nuclear generation sensitivity



Chapter five

Environmental targets

5.3.5
Maximum biomass sensitivity

High biomass imports make achieving the 2050 carbon reduction target easier, but significant electrification of heat is still required to achieve the target.

This sensitivity explores how much impact biomass could have on the overall energy landscape. We have maximised the amount of biomass available to the UK to the highest level we believe is credible.

Biomass can be used as a fuel for electricity generation and heating, and for hydrogen production. It assists decarbonisation, but has a relatively small overall impact. Even in a high case, there is not enough biomass available to the UK to offset the requirement for large-scale electrification of heating.

Biomass can supply up to 100 TWh, or 15 per cent, of total heat demand by 2050. In the 2030s this is mainly used to meet industrial demand. By 2050, it fuels domestic and commercial buildings via district heating schemes. This reduces the need for electrification, resulting in 15 per cent lower electricity capacity than in **Gone Green**.

5.3.6
Low energy demand sensitivity

Significant reductions in energy demand can help facilitate achieving the carbon reduction target, but fundamental changes to technologies are still required.

Our main analysis focuses on the impact of technology changes. This sensitivity investigates the impact reducing overall energy demand could have on meeting the 2050 carbon reduction target. This sensitivity assumes the maximum realistic reductions in underlying demand from energy efficiency in products, and behaviour change from residential, commercial and industrial users.

As expected, energy demand decreases in this sensitivity. Total energy demand falls by approximately 20 per cent between 2016 and 2050. Demand from the heating and transport sectors falls by 40 per cent. While there are the same number of heat pumps and EVs as in **Gone Green**, there are lower energy demands from these products as they are used less frequently.

In 2050 the demand reduction results in 20 per cent less renewable generation than in **Gone Green**. Additionally it reduces the requirement for CCS by over 90 per cent, as the lower electric heating demand creates a lesser requirement for CCS as a flexibility tool. Approximately 80 per cent less hydrogen is used in this sensitivity as there is not enough demand to necessitate the more challenging and costly residual carbon reductions. The small amount of hydrogen on the system is used for electricity balancing using a similar process to gas-fired generation.

5.3.7
No heat pumps sensitivity

The 2050 carbon reduction target cannot be achieved without a significant shift from gas boilers to heat pumps.

Many people have questioned what impact heat pumps have on the 2050 target. This sensitivity investigates if the target could still be achieved without a mass move away from gas boilers to heat pumps.

Our analysis shows that without significant heat pumps, the 2050 target would not be met. Without heat pumps there is insufficient low carbon heating to decarbonise the heating sector. Neither the transport nor electricity generation sectors can offset the reduced progress of carbon reduction in the heating sector. Aviation and shipping pose too large a challenge, and electricity generation is already zero carbon in 2050 so cannot contribute any more.

Environmental targets

5.4
How the other scenarios can achieve the 2050 target

While Gone Green utilises the most efficient route, all of the other scenarios have the potential to change their trajectories to meet the 2050 target. However, this becomes increasingly difficult over time. Progress is needed now to provide enough lead time for the required technologies to roll-out.

Key insights

- In **No Progression**, due to the reduced environmental focus, the latest date the scenario can change to a trajectory which achieves the 2050 target is 2025.
- In **Consumer Power** this date is 2035 as there is more natural progress towards efficiencies and new technologies.
- In **Slow Progression** this date is 2045 due to the high green ambition.

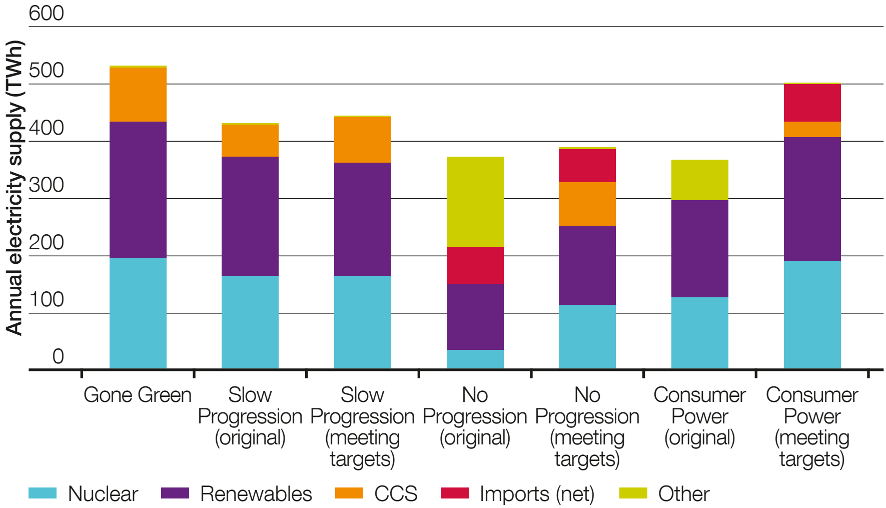
5.4.1
What needs to happen in our other three scenarios to achieve the 2050 carbon reduction target?

As seen in section 5.2.1, all scenarios make good progress in reducing carbon emissions in the next decade. After this date the scenarios diverge and only **Gone Green** continues the decarbonisation required to achieve the 2050 target on time. However, all of the scenarios can achieve the target if work occurs now to change their trajectory. This section provides an overview of our preliminary analysis, with further work planned for the coming year. It uses the highest realistic uptakes of all relevant technologies to establish the last realistic date each scenario can change to achieve the 2050 carbon reduction target.

Slow Progression, **No Progression** and **Consumer Power** can change trajectory to achieve the 2050 target by adopting more of the technologies in **Gone Green**, including:
- renewables
- nuclear generation
- CCS
- electricity interconnectors
- heat pumps
- hydrogen.

Figure 5.4.1 shows the mix of technologies supplying electricity in 2050 in the scenarios, before and after they are adjusted to meet the 2050 carbon reduction target. This adjustment leads to higher levels of nuclear, renewable and CCS-enabled generation to achieve a carbon intensity that is almost zero carbon.

Figure 5.4.1
Electricity supply by technology type



Environmental targets

As the scenarios experience delays relative to **Gone Green**, the total capacity is lower. Consequently, the UK relies upon higher imports in **No Progression** and **Consumer Power** to access the low carbon generation required. In **Slow Progression** there are minimal delays and additional CCS, and as such the UK remains a net exporter in 2050.

As the non-**Gone Green** scenarios experience delays relative to **Gone Green**, they require higher uptake rate of the more expensive technologies to meet the 2050 target. For example, as the heat pump roll-out begins later (as seen in Figure 5.4.2), it achieves a lower capacity, resulting in hydrogen being required (see Figure 5.4.3) to meet heating (and transport) demand.

As there is less generation capacity than **Gone Green**, there is less excess generation to create hydrogen from electrolysis. As a result, more expensive options are used to generate the hydrogen, such as biomass. This requires CCS deployment and large quantities of imported biomass.

Figure 5.4.2
Proportion of heat demand met by heat pumps in 2050

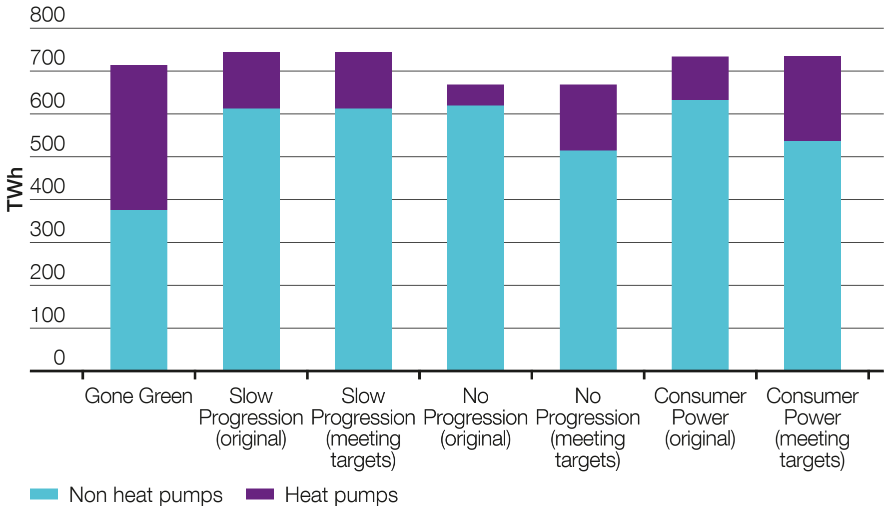
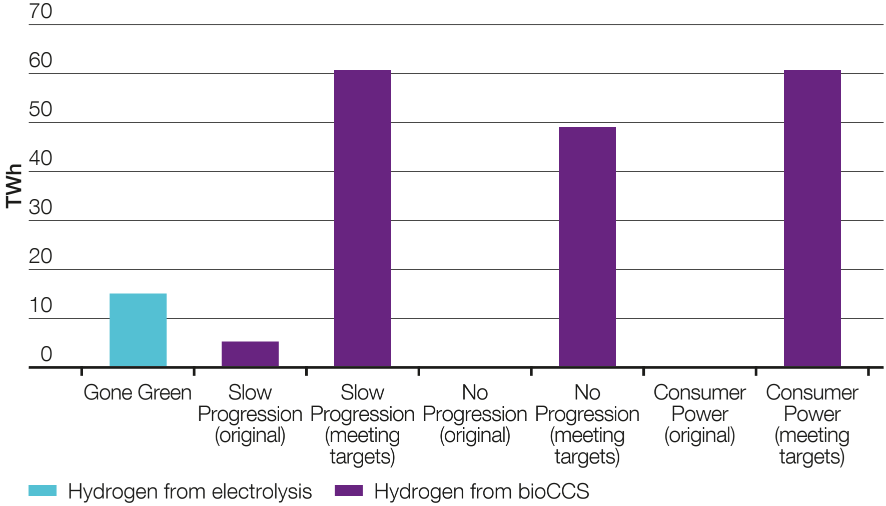


Figure 5.4.3
Hydrogen supply in 2050



Environmental targets

5.4.2
What are the critical dates for the scenarios to change their trajectory to achieve the 2050 carbon reduction target?

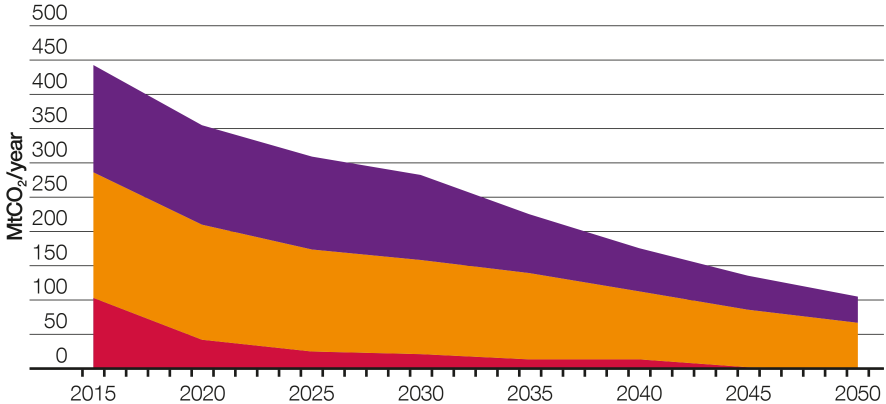
To meet the 2050 target, the scenarios need to be on the required trajectory by a set date. This varies for each of the scenarios and is dependent on the lead times required to invest in new technologies. This includes both demand and supply technologies. In **Slow Progression** some of this decarbonisation progress is assumed in the non-adjusted scenario, but less is assumed in **Consumer Power**. In **No Progression** no further progress is assumed beyond that of existing policies and technology roll-out rates.

As **No Progression** has the least progress assumed, the critical date to change trajectory is earliest. The last date at which it is possible to move on to a trajectory that achieves the target is 2025. However, in order to be on the trajectory by that date, progress needs to start now.

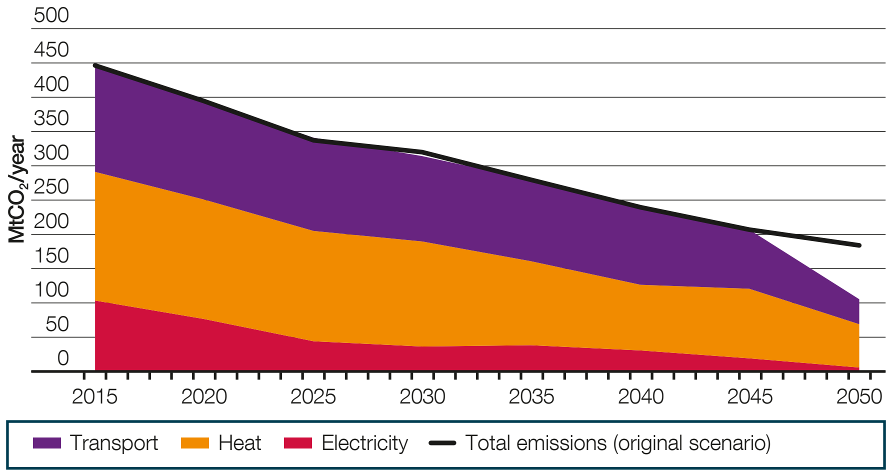
In **Consumer Power** the last credible time the trajectory can be changed is 2035 and in **Slow Progression** it is 2045. This is because these scenarios already assume a high level of decarbonisation progress. However, further actions will be required before 2035 and 2040 respectively to achieve the target.

Carbon emissions from all of the adjusted scenarios are shown in Figure 5.4.4. Their original carbon emissions and the emissions in **Gone Green** are shown for comparison.

Figure 5.4.4
Carbon emissions from all scenarios – Gone Green

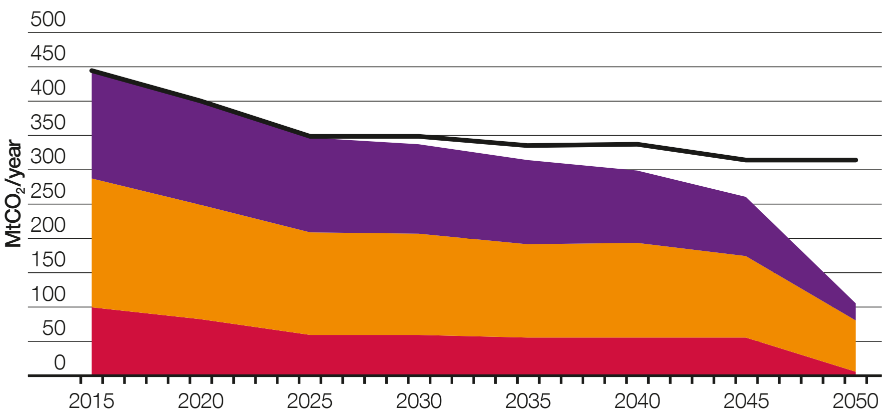


Carbon emissions from all scenarios – Slow Progression

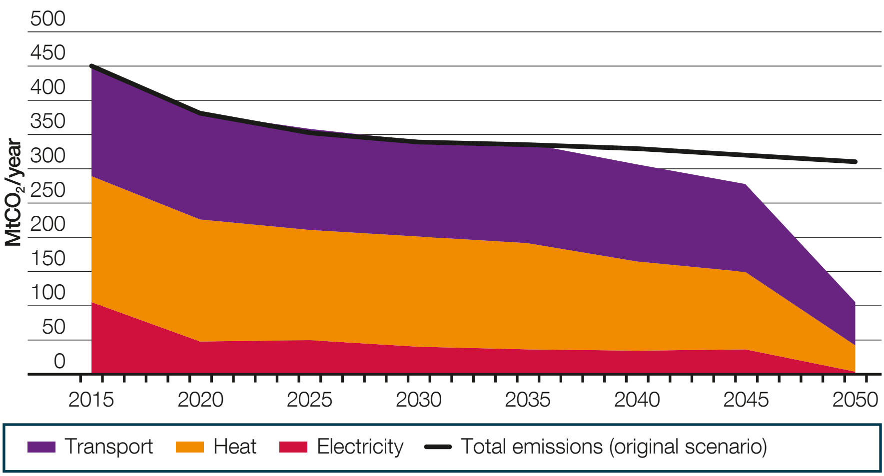


Environmental targets

Figure 5.4.4 (cont.)
Carbon emissions from all scenarios – No Progression



Carbon emissions from all scenarios – Consumer Power

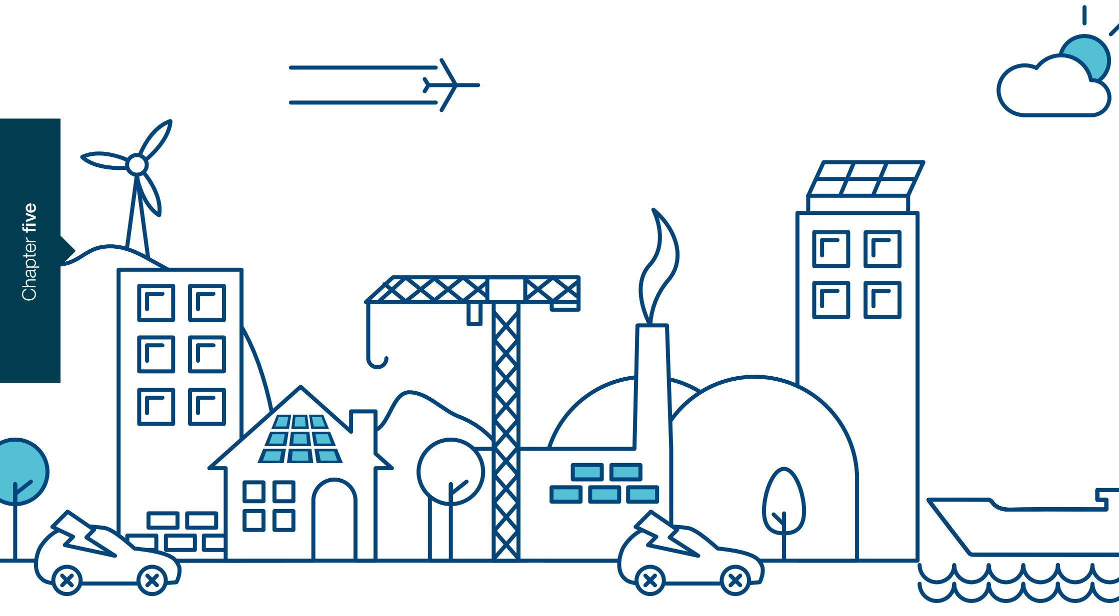


Method

We use a cost-optimisation model for our 2050 and target analysis which was developed by Baringa. This model is known as RESOM (Redpoint Energy Systems Optimisation Model). RESOM is a whole-energy model which selects the least-cost solution that balances on a seasonal, annual and peak basis. It considers the electricity generation, heat and transport sectors separately and assesses the availability of energy products. From this it generates a lowest-cost solution which supplies and balances the energy requirements of the UK. Approximately 5,000 constraints (e.g. maximum capacities and growth rates of technologies) are used for each model run to produce a set of 2050 scenarios which align to our pre-2040 analysis.

We align the pre- and post-2040 scenarios as well as possible. We ensure that over 98 per cent of the main metrics are within 2 per cent variance to be as accurate as possible.

The model inputs and constraints are evaluated against external benchmarks from UK experts in 2050 energy modelling. These include University College London, the CCC, the Energy Technologies Institute and the Energy Research Partnership.



Chapter six

Method

6.1
Scenario development

The *FES* is published every summer, following an annual development cycle. Stakeholders are fundamental to this process, inputting views, knowledge and insight which drive the development of the scenarios.

The production of the scenarios is the start of a development cycle covering stakeholder engagement, feedback analysis, scenario creation and modelling activities.

The *FES* is used by a broad range of stakeholders, from the energy industry through to end consumers. Our process begins by gathering views from across the spectrum of our stakeholders through a number of channels and events. These events include workshops, bilateral meetings and webinars. We seek to improve our engagement activities every year and this year we increased the number of organisations we engaged with by 129 to 362.

Following the main engagement period, we create the assumptions and high-level scenarios for the following year. In January, we share the details of our high-level scenarios and engagement activities with Ofgem (in line with our Electricity Transmission Licence Standard Condition C11).[1]

Over the following months, our analyst teams gather and verify the input data and undergo detailed modelling processes to produce the scenario outputs. The inputs, models and outputs are all subject to quality checks including internal challenge and reviews, peer reviews and quality assurance.

The outputs are then translated into the *FES* publication and are shared with our stakeholders at our annual launch event.

Overwhelmingly, our stakeholders told us through our feedback channels that they want to see a consistent approach year on year in the *FES*. For more information on how our stakeholder engagement influenced the development of our 2016 scenarios please see our *FES Stakeholder Feedback Document* which is available on our website: **http://fes.nationalgrid.com**.

[1] Ofgem Transmission Licence Standard Conditions, March 2016, https://www.ofgem.gov.uk/licences-codes-and-standards/licences/licence-conditions

6.2
Scenario framework

Our readers have told us that they would like us to clearly demonstrate how we build our scenarios and in particular understand more about our assumptions. We have created a new framework approach for 2016, detailing what assumptions we have made in the four scenarios across the political, economic, social and technological themes. Environmental assumptions are integrated across the four themes.

Scenario world

The first layer of our scenario framework is the scenario world. This contains the building blocks and inputs which are consistent across all of the scenarios: the axes on which they are placed and the fixed rules regarding security of supply. The two axes are, as last year, 'Prosperity' and 'Green ambition'. The four scenario names are also the same as last year: **Gone Green**, **Slow Progression**, **No Progression** and **Consumer Power**. In 2015 there were three fixed rules across the four scenarios. The majority of stakeholders told us that the Levy Control Framework did not fit as a rule as it is short term and can be changed. As such for 2016 the Levy Control Framework is an assumption. This leaves two rules for 2016: security of supply for gas and for electricity.

Electricity security of supply: In all scenarios, and across the whole study period, there will be sufficient electricity generation to meet the security of supply reliability standard. The Government sets a reliability standard for the GB market at a level which balances the impact of failure to deliver sufficient energy with the cost of the capacity required to provide that energy. This standard is three hours per year loss of load expectation (LOLE). LOLE measures the risk across the whole winter of demand exceeding supply under normal operation. It does not mean that there will be a loss of supply for three hours per year. It gives an indication of the amount of time the System Operator will need to use balancing tools across the winter period. These tools include voltage reduction (reducing voltage to reduce demand), maximum generation (accessing capacity which is outside of the generator's usual operating range) and interconnector assistance (calling upon extra electricity flows from the continent). In most cases, loss of load would be managed without significant impact on end consumers. The electricity generation backgrounds used in all of the FES scenarios have been developed to ensure that this standard is always met.

Gas security of supply: In all scenarios, and across the whole study period, there will be sufficient capacity to ensure that the gas N-1 security of supply test will be satisfied. The N-1 test assesses whether peak demand could still be met in the situation where the largest single piece of infrastructure was lost. This rule is used by the European Commission and in the UK the assessment is published by the Department of Energy and Climate Change (DECC) in the UK *Risk Assessment on Security of Gas Supply*[2]. This rule is applied to ensure a consistent method is used across all of our scenarios and to allow comparison with other countries. If there is insufficient existing gas supply capacity to pass the N-1 test then additional capacity will be added to the scenario. To ensure the required level of new capacity can be delivered it will be based on the current view of import and storage projects. This is both in terms of the overall levels of capacity and the expected start dates. However, no single project will be selected to provide this capacity, instead it will be a generic scheme based on a number of projects which could meet this need.

[2] DECC, UK Risk Assessment on Security of Gas Supply, June 2014, https://www.gov.uk/government/publications/uk-risk-assessment-on-security-of-gas-supply

Chapter six

Method

Assumptions

The second layer of the scenario framework is the assumptions; these are the variables which are flexed at high, medium or low in each scenario. They name specific policies, technologies or behaviours. The assumptions are grouped into political, economic, social and technological themes. For the full list of assumptions, and to see which level they have been set at in each scenario, please see the scenario framework Excel workbook which is available on our website: **http://fes.nationalgrid.com**.

Glossary

Word	Acronym	Description
1-in-10 stress conditions		For electricity interconnector modelling we define a stress event as times when net interconnector imports are required to ensure electricity supply and demand balances. The 1-in-10 event is the 90th percentile of all modelled stress events, not an event which occurs every 10 years.
Advanced conversion technology	ACT	Gasification, pyrolysis or anaerobic digestion, or any combination of those.
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.
Amsterdam Rotterdam and Antwerp (Coal Price)	ARA	The cost of coal in the major north-western Europe coal importing ports of Amsterdam/Rotterdam/Antwerp (ARA).
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.
Annual electricity demand		The electricity demand in any one fiscal year. Different definitions of annual demand are used for different purposes.
Average cold spell	ACS	Defined as a particular combination of weather elements which gives rise to a level of winter peak demand which has a 50% chance of being exceeded as a result of weather variation alone. There are different definitions of ACS peak demand for different purposes.
Balgzand Bacton Line	BBL	A gas pipeline between Balgzand in the Netherlands and Bacton in the UK.
Baseload electricity price		The costs of electricity purchased to meet minimum demand at a constant rate.
Billion cubic metres	bcm	Unit or measurement of volume, used in the gas industry. 1 bcm = 1,000,000,000 cubic metres.
Bio-substitute natural gas	BioSNG	Methane created from waste.
Biomethane		Biomethane is a naturally occurring gas that is produced from organic material and has similar characteristics to natural gas.
Boil-off		A small amount of gas which continually boils off from LNG storage tanks. This helps to keep the tanks cold.
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 (coal, natural gas and oil).
Carbon price floor	CPF	A price paid by UK generators and large carbon intensive industries for CO_2 emissions.
Carbon price support	CPS	A price paid by UK generators and large carbon intensive industries in addition to the EU ETS to guarantee a minimum floor price for CO_2 emissions.

Glossary

Word	Acronym	Description
CRC Energy Efficiency Scheme	CRC Energy Efficiency Scheme	A mandatory scheme aimed at improving energy efficiency and cutting emissions in large public sector and large private sector organisations.
Cash out		The prices used to settle the difference between contracted generation (or consumption) and the amount that was actually generated (or consumed) in each half hour trading period.
Climate Change Levy	CCL	A UK energy tax introduced to provide an incentive to reduce emissions. It only applies to energy delivery to non-residential users.
Climate change targets		Targets for share of energy use sourced from renewable sources. The 2020 UK targets are defined in the Directive 2009/28/EC of the European Parliament and of the Council of the European Union.
Coal bed methane	CBM	Methane that is extracted from un-mined coal seams by drilling wells directly into the seams to release the gas.
Coefficient of performance	COP	The ratio of heating (or cooling) provided per unit of electrical energy consumed.
Combined cycle gas turbine	CCGT	A gas turbine that uses the combustion of natural gas or liquid fuel to drive a gas turbine 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 whereby both heat and electricity are generated simultaneously as part of one process. Covers a range of technologies that achieve this.
Committee on Climate Change	CCC	An independent body established under the Climate Change Act to advise the Government regarding greenhouse gas emissions.
Compact fluorescent light	CFL	A lighting technology introduced to replace traditional incandescent bulbs. Commonly referred to as energy-saving bulbs.
Composite weather variable	CWV	A measure of weather incorporating the effects of both temperature and wind speed. We have adopted the new industry wide CWV equations that took effect on 1 October 2015.
Compressed natural gas	CNG	A gas made by compressing natural gas to less than 1 per cent of the volume it occupies at standard atmospheric pressure.
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.
Demand Side Balancing Reserve	DBSR	A balancing service that has been developed to support National Grid in balancing the system during the mid-decade period. DSBR is targeted at large energy users who volunteer to reduce their demand during winter weekday evenings between 4 and 8 pm in return for a payment. Along with Supplemental Balancing Reserve (SBR), this service will act as a safety net to protect consumers, only to be deployed in the event of there being insufficient capacity available in the market to meet demand.
Demand side response	DSR	A deliberate change to an industrial and commercial user's natural pattern of metered electricity or gas consumption, brought about by a signal from another party.
Department of Energy and Climate Change	DECC	A UK government department which works to make sure the UK has secure, clean, affordable energy supplies and promote international action to mitigate climate change.
Deterministic		A modelling approach that produces a single view or outcome. This approach has no random elements as all outcomes and inputs are completely determined.
Digest of UK Energy Statistics	DUKES	A DECC publication which contains historic information on energy in the UK.

Word	Acronym	Description
Dispatch (aka economic dispatch)		The operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognising any operational limits of generation and transmission facilities.
Distributed generation		Generation connected to the distributed networks which is equal or greater than 1 MW in size, up to onshore transmission areas; mandatory connection thresholds. 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 losses		Losses that are caused by the electrical resistance of the distribution system.
Distribution Network Operator	DNO	Companies which own and operate gas or electricity distribution networks.
Electric vehicle	EV	A vehicle driven by an electric motor. It can either be driven solely off a battery, as part of a hybrid system or have a generator that can recharge the battery but does not drive the wheels. We only consider EVs that can be plugged in to charge in this report.
Electricity Market Reform	EMR	A government policy to incentivise investment in secure, low-carbon electricity, improve the security of Great Britain's electricity supply, and improve affordability for consumers.
Electricity storage technologies		Mechanical (for example, pumped hydro and compressed air), thermal (for example, molten salt), electrical (for example, supercapacitors), electrochemical (various battery types), chemical (for example, hydrogen). Each technology has different characteristics, such as speed and duration of response, scale and maturity status.
Electricity supply background (Generation background)		The sources of generation across Great Britain to meet the power demand.
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.
Emissions Performance Standard		An annual limit on carbon emissions from new fossil-fuel plant, as set by the Government.
Energy Company Obligation	ECO	A government scheme which places a legal obligation on energy suppliers to help households meet energy efficiency and fuel savings targets.
Energy consumption in the UK	ECUK	A UK government publication which reviews historic energy consumption and changes in efficiency, intensity and output since the 1970s.
Energy Efficiency Commitment	EEC	A Government scheme which set energy suppliers an energy saving target based on the number of domestic customers they supplied. This scheme ran between 2002 and 2005.
Energy Networks Association	ENA	An industry association representing gas and electricity transmission and distribution licence holders.
Energy Savings Opportunity Scheme	ESOS	A mandatory energy assessment scheme for qualifiying organisations in the UK.

Glossary

Word	Acronym	Description
Error correcting model		A model with the characteristics that the deviation of the current state from its long-run relationship will be fed into its short-run dynamics.
EU Emissions Trading Scheme	EU ETS	A European Union trading scheme that allows participants to buy and sell carbon emissions allowances.
European Network of Transmission System Operators - Electricity	ENTSO-e	An association of European electricity TSOs. ENTSO-E was established and given legal mandates by the EU's Third Legislative Package for the Internal Energy Market in 2009, which aims at further liberalising electricity markets in the EU.
European Union	EU	A political and economic union of 28 member states 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.
Firm frequency response	FFR	The firm provision of dynamic or non-dynamic response to changes in frequency.
Foot room		The ability for generation plant to allow output to decrease without going below its minimum output level and disconnecting from the system.
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.
Fuel cell		A device which generates electricity via a chemical reaction, using gas and oxygen as an input.
Future Energy Scenarios	FES	The FES is a range of credible futures which has 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.
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.
Gearing ratio		A financial leverage ratio; comparing equity to debt.
Gigawatt	GW	1,000,000,000 watts, a measure 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.
Great Britain	GB	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
Green Deal		A scheme that allows individuals and businesses to make energy efficiency improvements to their buildings.
Green gas		A term used to describe low carbon gas. In the 2016 *FES* this category includes biomethane and bioSNG.
Greenhouse gases	GHG	A gas in the atmosphere that absorbs and emits radiation within the thermal infrared range.

Word	Acronym	Description
Gross domestic product	GDP	An aggregate measure of production equal to the sum of the gross values added of all resident, institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs).
Gross value added	GVA	The value of goods and services produced in a sector of the economy.
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.
Gas Safety (Management) Regulations	GS(M)R	Regulations issued by the Health & Safety Executive that place certain requirements on gas transporters, shippers, terminal operators and other parties on the conveyance of natural gas.
Heat pump		A device that provides heat energy from a source of heat to a destination called a 'heat sink'.
Heavy goods vehicle	HGV	A truck weighing over 3,500 kg.
High voltage direct current	HVDC	The use of direct current for the transmission of electrical power, in contrast with the more common alternating current (AC) systems.
Household disposable income	HHDI	Household income minus tax.
Industrial Emissions Directive	IED	A European Union directive which commits member states to control and reduce the impact of industrial emissions on the environment.
Integrated Transmission Planning and Regulation	ITPR	An Ofgem project which examined the arrangements for planning and delivering the onshore, offshore and cross-border electricity transmission networks. Ofgem published the final conclusions in March 2015.
Interconnector (UK)	IUK	A bi-directional gas pipeline between Bacton in the UK and Zeebrugge, Belgium.
Interconnector, electricity		Transmission assets that connect the GB market to Europe and allow suppliers to trade electricity between markets.
Interconnector, gas		Interconnectors which connect gas transmission systems from other countries to the National Transmission System (NTS) in England, Scotland and Wales. There are currently three gas interconnectors which connect to the NTS. These are: ■ IUK interconnector to Belgium ■ BBL to the Netherlands ■ Moffat to the Republic of Ireland, Northern Ireland and the Isle of Man.
Internal rate of return	IRR	The annualised rate of return, independent of inflation, for the net present value of an investment of zero in a given time frame.
International Energy Agency	IEA	The International Energy Agency is an intergovernmental organisation that acts as an energy policy adviser to member states.
Large Combustion Plant Directive	LCPD	A European Union Directive which introduced measures to control the emissions of sulphur dioxide, oxides of nitrogen and dust from large combustion plant.
Levy Control Framework	LCF	Caps the annual amount of money that can be levied on bills to support UK low carbon generation each year, rising to £7.9bn in 2020/21.
Light emitting diode	LED	An energy efficiency electronic lighting technology which is increasingly being adopted in UK homes and businesses.
Liquefied natural gas	LNG	Formed by chilling gas to -161˚C so that it occupies 600 times less space than in its gaseous form.
Load factor		The average power output divided by the peak power output over a period of time.

Glossary

Word	Acronym	Description
Local Distribution Zone	LDZ	A gas distribution zone connecting end users to the (gas) National Transmission System.
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.
Low Carbon Contracts Company	LCCC	A private company owned by the Department of Energy and Climate Change (DECC) that manages the Contracts for Difference (CfD) scheme introduced by Government as part of the EMR programme.
Low carbon heating technology	LCHT	A heating technology that has a lower carbon intensity for heating homes than an A-rated condensing gas boiler.
Low Carbon Networks Fund	LCNF	A fund established by Ofgem to support projects sponsored by the electricity Distribution Network Operators (DNOs) to try out new technology, operating and commercial arrangements. This has now been replaced by the Network Innovation Competition and Network Innovation Allowance.
Marine technologies		Tidal streams, tidal lagoons and energy from wave technologies.
Market coupling		The integration of electricity markets to create a European internal electricity market.
Medium-range storage (gas)		These commercially operated sites have shorter injection/withdrawal times so can react more quickly to demand, injecting when demand or prices are lower and withdrawing when they are higher.
Megawatt (electrical)	MWe	1,000,000 watts, a measure of power.
Megawatt hour	MWh	1,000,000 watts hours, a unit of energy.
Merit Order		An ordered list of generators, sorted by the marginal cost of generation.
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.
Million tonnes of CO_2 equivalent	Mte CO_2	A quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years).
N-1		Refers to the European Commission security of supply gas test, where total supply minus the largest single loss is assessed against total peak demand.
National balancing point	NBP	The wholesale gas market price in Britain. There is one single price for gas irrespective of where the gas comes from which is usually quoted in pence per therm of gas.
National balancing point (NBP) gas price		Derived from the buying and selling of natural gas in Britain after it has arrived from offshore production facilities.

Word	Acronym	Description
National Electricity Transmission System	NETS	The system which transmits high-voltage electricity from where it is produced to where it is needed throughout the country. It is made up of high voltage electricity wires that extend across Britain and nearby offshore waters. It is owned and maintained by regional transmission companies, while the system as a whole is operated by a single System Operator (SO).
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.
Nearly-Zero-Energy Building	NZEB	One requirement of the EU's Energy Performance of Buildings Directive; legislation aimed at improving the energy efficiency of buildings. It is defined as "a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."
Network Innovation Competition	NIC	A competition introduced by Ofgem for electricity and gas network companies to compete for funding for the development and demonstration of new technologies, operating and commercial arrangements.
Nitrous oxide	NOx	A group of chemical compounds, some of which are contributors to pollution, acid rain or are classified as greenhouse gases.
Office of Gas and Electricity Markets	OFGEM	The UK's independent National Regulatory Authority, a non-ministerial government department. Their principal objective is to protect the interests of existing and future electricity and gas consumers.
Oil & Gas UK		Oil & Gas UK is a representative, not-for-profit, body for the UK offshore oil and gas industry.
Open cycle gas turbine	OCGT	Gas turbines in which air is first compressed in the compressor element before fuel is injected and burned in the combustor.
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 that has a battery which can be charged by plugging it in, as well as a combustion engine.
Pumping demand		The electricity required by hydro-electric units to pump water into the reservoirs.
Pure electric vehicle	PEV	A vehicle which only has a battery for energy storage.
Renewable Energy Directive	RED	An EU directive that establishes a policy related to energy from renewable sources. It requires the EU to fulfil at least 20 per cent of its total energy needs from renewable sources by 2020. It is to be achieved through the attainment of individual national targets.
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.

Glossary

Word	Acronym	Description
Seasonal storage or long-range storage		A gas storage facility which mainly puts gas into storage (called 'injection') in the summer and takes gas out of storage in the winter. There is one long-range storage site on the national transmission system: Rough, situated off the Yorkshire coast.
Self-consumption		Where an end user consumes the electricity they generate, commonly from solar generation. This reduces the need to import electricity from grid but does not necessarily mean an end user is self-sufficient.
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.
Short-run marginal cost	SRMC	The instantaneous variable cost for a power plant to provide an additional unit of electricity. It is derived from the cost of fuel, the cost of CO_2 emissions, the share of operating and maintenance (O&M) costs that varies with the plant electricity output and any income from incentives and the provision of heat associated to the plant electricity output.
Short-term operating reserve	STOR	A service for the provision of additional active power from generation and/or demand reduction.
Shrinkage		Gas used by the transmission and distribution system operators to operate the networks, and gas lost to theft and leakage.
Small modular reactors	SMRs	Compact nuclear fission power plants of less than 300 MW generation capacity.
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 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.
Station demand		The onsite electricity generation station requirement, for example for systems or start-up.
Summer minimum		The minimum electricity demand on the transmission network in any one fiscal year. Minimum demand typically occurs at around 6am on a Sunday between May and September.
Supplemental Balancing Reserve	SBR	A balancing service that has been developed to support National Grid in balancing the system during the mid-decade period. SBR is targeted at keeping power stations in reserve that would otherwise be closed or mothballed. Along with Demand Side Balancing Reserve (DSBR), this service will act as a safety net to protect consumers, only to be deployed in the event of there being insufficient capacity available in the market to meet demand.
System operability		The ability to maintain system stability and all of the asset ratings and operational parameters within pre-defined limits safely, economically and sustainably.
System Operator	SO	An entity entrusted with transporting energy in the form of natural gas or power on a regional or national level, using fixed infrastructure. Unlike a TSO, 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.
Tonne of carbon dioxide	tCO_2	A fixed unit of measurement commonly used when discussing carbon dioxide emissions.

Word	Acronym	Description
Transmission entry capacity	TEC	The maximum amount of active power deliverable by an electricity generator at its grid entry point (which can be either onshore or offshore). This will be the maximum power deliverable by all of the generating units within the power station, minus any auxiliary loads.
Transmission losses		Losses that are caused by the electrical resistance of the transmission system.
Transmission System Operator	TSO	An entity entrusted with transporting energy in the form of natural gas or electricity on a regional or national level, using fixed infrastructure.
Triad		Demand measured as the average demand on the system over three half hours between November and February (inclusive) in a financial year. These three half hours comprise the half hour of system demand peak and the two other half hours of highest system demand which are separated from system demand peak and each other by at least ten days.
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.
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.
Weather-corrected demand		The actual demand figure that has been adjusted to take account of the difference between the actual weather and the seasonal normal weather.

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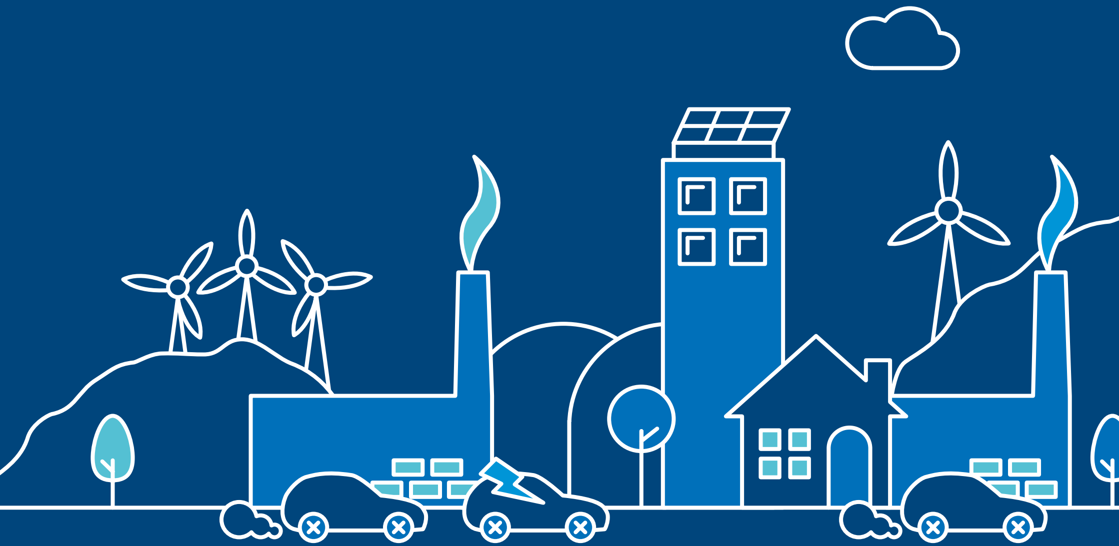

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