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Brexit, Net-Zero and the Future Role of Gas in the UK Energy System

July 2021

Nicholas Solman & Michael Bradshaw – Warwick Business School.

Executive Summary

- ▶ Gas consumption is widespread in the UK economy being a key fuel in domestic space and water heating, electricity generation, and industry. In total supplying 39% of the UK's primary fuel.
- ▶ By virtue of its extensive use and physical characteristics, gas provides a large degree of short-term flexibility within the UK energy system at very low cost to consumers.
- ▶ To meet Net Zero the UK will have to abandon the use of unabated natural gas consumption. This means that the two pathways to decarbonisation are electrification or the use of hydrogen (possibly converted from Natural Gas). Without the availability of CCUS the UK will have to pursue a policy of electrification by default.
- ▶ As the UK navigates its way through Brexit, recovers from the pandemic and transitions to a Net Zero country winners and losers will be created. Lessons from the failure of the shale industry need to be taken on board if the UK is going to deliver the extensive quantity of infrastructure that is required to reach Net Zero by 2050.

Introduction

Briefing 1 in this series (Solman & Bradshaw 2020) considered the UK shale gas question – what role might shale gas have to play within the UK gas landscape. This briefing considers the more fundamental gas question – what role does gas, and more specifically natural gas, have to play within the UK's Net Zero decarbonisation pathway between now and 2050 (NZ50)? The debate about the future role of natural gas is taking place within a country where there is notable opposition to fossil fuel development both in theory (Ryder et al. 2021) and on the ground (Short et al. 2021). With the removal of coal from the UK's electricity generation mix by 2025, natural gas, along with oil, are now the most carbon-intensive fuels widely used in the UK's energy mix and are therefore the next targets for decarbonisation. In the electricity generation sector there have been obvious and easy to implement pathways to reducing carbon intensity – coal reduction twinned with increased renewable generation. Given the extent to which gas is used in the UK energy system – it represents the most widely used primary fuel in the UK's energy mix at 39% in 2019 (BEIS 2020a:25) – the future role of gas is of vital importance. To understand the complexities of decarbonising the UK's energy mix – and the role of gas within that – three areas need to be considered:

1. What is the current role of gas in the UK's energy mix – and how this has changed in recent years (since 2000).
2. What role does gas play in the wider UK energy system, specifically, how do its fundamental qualities deliver particular energy services, i.e., heating, storage, flexibility.
3. Within NZ50 Pathways and Scenarios what are the possible roles for gas and what are the wider implications of these routes.

Table 1 provides an overview of some of the key terms and issues that are central to understanding the future of UK energy policy.

Table 1. Definitions and Net Zero Considerations

Term	Definition	Net Zero Considerations
Net Zero	Balancing emissions of Greenhouse Gases (GHGs) with the ability to sequester them either in natural carbon sinks or using technology. (see CCC 2019)	Changing the goal to Net Zero means that the most difficult to decarbonise sectors of the economy must be fully decarbonised – thereby ruling out certain easy fixes that were available at 80% reduction.
Sustainability	The need to use resources in a way that they are not depleted for future generations. Spending today without borrowing from the future. (UN 2020).	The solutions to decarbonisation must aim to have minimal impact upon the earth's resources. For example, questions are raised concerning whether or not batteries can be produced over generations at the rate required.
Bridge Fuel	Gas was seen as a fuel that would allow the decarbonisation of energy generation by removing dirtier fuels more quickly than if renewables were used in isolation (McGlade et al. 2018)	With 30 years until Net Zero must be achieved there is now no incentive to build new gas-fired power stations as they may not have paid for themselves before, they need to be decommissioned – Especially with the decreasing load factors presently witnessed. For a limited number of plants there may be an option for retro-fitting CCS within the UK's carbon budget.
Trilemma	The need to address security of supply, sustainability & affordability. It highlights the need for governments to balance these conflicting goals within their energy policies (WEC 2019).	The conflicting goals of the trilemma must be met whilst phasing out an energy system with a distinct set of characteristics and replacing it with a system that possesses different strengths and weaknesses.
Energy Security	This includes both physical security (can consumers get the energy services they require without supply chain disruption) and price security (can they afford the fuel on offer) (DECC 2012). Here the term energy security is used interchangeably with gas security.	As new fuel sources and energy carriers start to enter the market governments have to ensure that there are appropriate quantities at appropriate prices of both the outgoing and incoming fuel sources. This will likely involve a managed decline of the outgoing fuel sources.
Gas Supply Chain	The gas supply chain consists of three stages, Upstream (extraction), Midstream (transport) and Downstream (consumption) (Bradshaw 2018)	During the energy transition each stage of the gas supply chain will experience unique challenges that could affect both the availability and affordability of gas. Monitoring and addressing this will be essential (Bradshaw 2018; Bradshaw & Solman 2018).
CCUS	Carbon Capture, Utilisation and Sequestration. This is a process that can be added to either industrial processes (post-process) or fossil fuel burners/transformers (pre-process) in order to prevent carbon dioxide entering the atmosphere (CCC 2018:40)	It is generally only around 90% efficient with the process itself drawing power as well. As yet, there is no business model for the deployment of CCUS, therefore posing questions surrounding whether it can ever be deployed at scale. Questions also persist concerning the long-term sustainability of CCUS.
Decarbonised/ Low-Carbon Gases	Refers to a range of gases that have either had carbon extracted, use renewable electricity to produce them (hydrogen) or are produced using waste products and where burning them reduces the carbon intensity of emissions (BioGas, SNG etc.) (National Grid 2017:94).	Given the need to reduce waste, it raises questions regarding feedstock availability. Similarly, how easy will it be to either fuel switch (repurpose) the gas network or create a new, parallel, one.

Sources: Detailed in Table.

As can be seen from Table 1, there are a wide range of issues for policy makers to consider concerning the continued use of natural gas. These are issues that the UK Government is starting to grapple with in a holistic fashion following the publication of a series of recent documents (CCC 2020; UK Government 2020a; UK Government 2020b). Whilst climate change is the global incentive to act, individual countries want to decarbonise in a way that does not negatively impact upon the living standards of their citizens or disadvantage particular regions and stakeholders in the short term – before the longer-term benefits of cleaner air and averted climate change impacts have materialised. It is within this context of a 'just transition' (Smith 2017) that we must consider the current role of gas and how the UK should move to a position of decarbonisation that leaves the country in a better position – whilst also renegotiating trading relationships with Europe and the wider world following the UK's decision to leave the EU.

The future of gas in the UK was, until the Coronavirus outbreak, largely being seen as one of incremental change (CCC 2019; National Grid 2019). The coronavirus pandemic could have introduced an element of paradigmatic shift in relation to the pace of the energy transition (at the time of writing the effects were unclear) (Kuzemko et al. 2020). A number of effects have already been noted, such as the continued suppression of fossil fuel consumption (IEA 2020) and economic activity (Economist 2020) and changing patterns of gas consumption in the UK (Wilson 2020). These considerations are having to be incorporated into an energy system that was already changing rapidly. So, how did we get here and where could we be going?

The Current Role of Gas in the UK's Energy Mix: How do we use Gas? Its Role and Economy-wide Usage – how has this changed?

Natural gas (Methane) has been used in the UK to provide lighting on a commercial basis since 1812 and heat since 1855 (National Grid 2020a). Originally known as town gas – produced via coal gasification – it was used to illuminate streetlights. It was only after the discovery of gas under the North Sea in the 1960s that gas began to play a larger role in the UK with a national rollout of natural gas into homes, commercial and industrial properties during the 1960's and 1970's to be used for space heating (via central heating systems) and hot-water, cooking and industrial processes (National Grid 2020a). However, it was from the late 1980s that the consumption of natural gas began to increase markedly as the ban on using it for electricity generation was lifted (see Fig. 1). Through the 1990s both gas consumption and production in the UK began to peak as gas was consumed more efficiently (consumption) and as North Sea output began to decline (production). Since the early 2000s gas production and consumption have seen a pattern of continual decline with domestic production now accounting for around half of domestic consumption from 100% at the turn of the millennium.

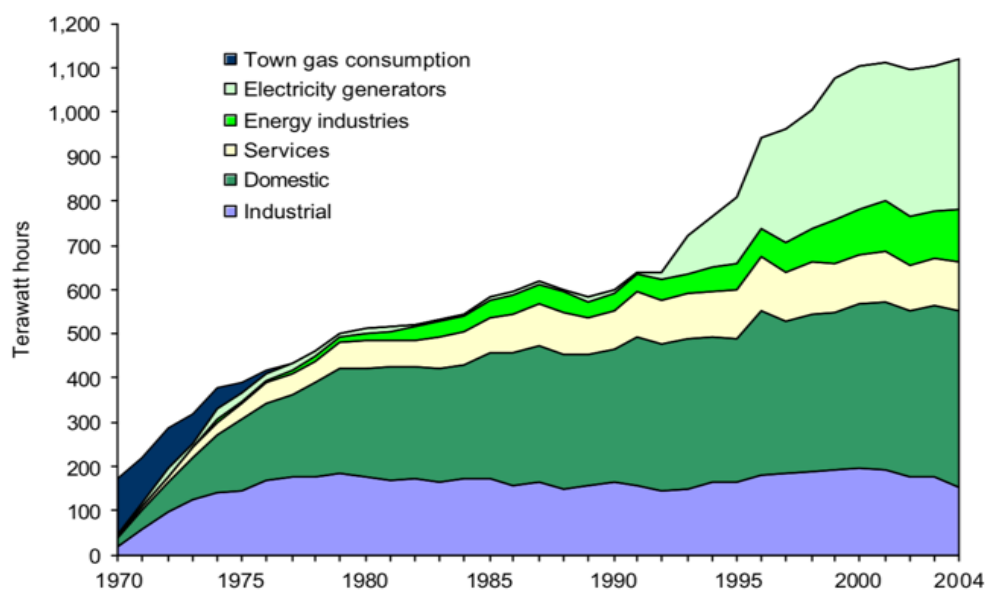


Figure 1: UK Gas consumption by Sector 1970-2004

Source: National Archives, Digest of UK Energy Statistics, 2005

With the declining availability of domestically produced gas and the increasing prominence of policies aimed at mitigating climate change, how the UK uses gas has changed markedly. Figures 2 and 3 show how inputs and outputs of natural gas in the UK have changed between 2007 and 2019. These energy flow diagrams show that reduction in gas consumption is not limited to a single sector but is divided between power generation, domestic consumption and industrial use.

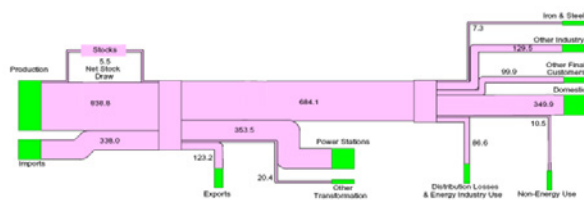


Figure 2: Gas Flow Chart 2007 (TWh)
Source: National Archives – DUKES (2008)

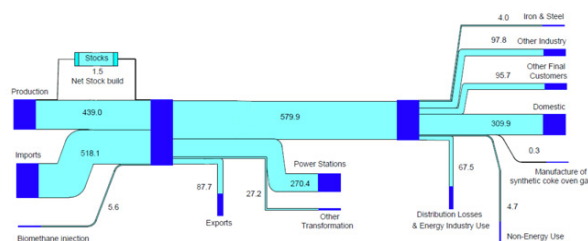


Figure 3: Gas Flow Chart 2019 (TWh)
Source: BEIS 2020a:65

The UK was also at the forefront of creating a liberalised market for energy. This resulted in the UK's gas market changing from a state-controlled and heavily regulated system to one that involves a number of freely acting parties, with Ofgem regulating the industry to avoid abuses of market power. By 1999 the basic market structure had been completed and is shown in Figure 4. The public gas transporters (at this time Transco – later National Grid) have since been privatised and separated out into separate entities as the controller of the operator of the National Transmission System (National Grid) and the operators of the Local Distribution Zones (LDZs) – Cadent, SGN, Northern Gas Networks and Wales and West Utilities.

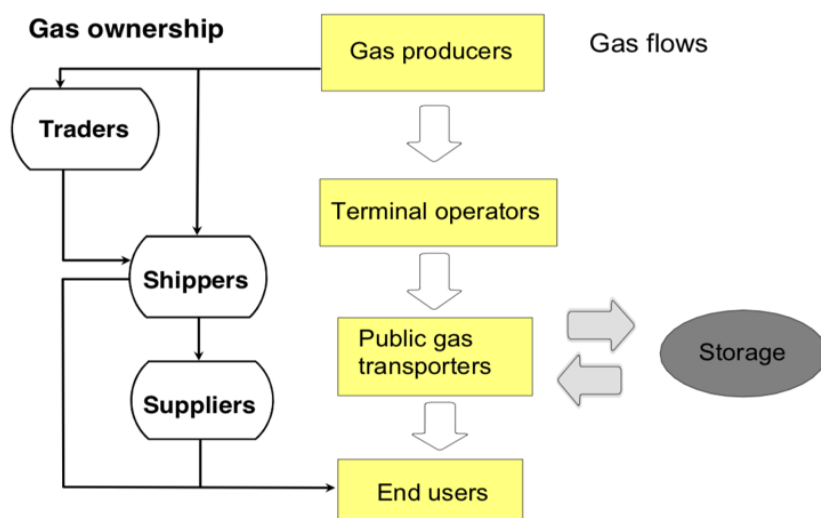


Figure 4: GB Market Structure
Source: National Archives – DUKES (2000:105)

As gas became more widely used around the world, as well as throughout the UK economy, the supply-chain became more complex. Figure 5 highlights the nature of the market's supply chain and also details some of the issues that actors at each level of the supply chain were already encountering prior to Brexit and NZ50. It is worth noting that, however it is measured, the UK has a resilient energy system (WEC 2019; BEIS & Ofgem 2020 CEPA 2017; USCoC 2020). Likewise, whilst the international gas market is described as liberalised – and this is broadly a fair assessment – it is comprised of a combination of private companies and state owned/ supported enterprises operating within a variety of national, regional and international legislative regimes. Consequently, there is the potential for freedom to be curtailed during times of shortage. There are also concerns surrounding how the infrastructure responsible for gas distribution will respond, in the long term, if demand falls steeply (See Bradshaw 2018 for a full discussion of these issues). In sum, the consumption of gas through the liberalised, international, largely free market is deeply embedded in the UK energy system as a guarantor of energy security.

What Roles Does Gas Play in the UK Energy System?

From an understanding of how the UK's usage of gas has developed in a broad context it is important to understand how gas is used in individual sectors. This is because gas performs different functions within different sectors of the economy. These differing uses all have their own unique challenges when it comes to decarbonisation. To make matters more complicated, consumers within different sectors will not be decarbonising in isolation but will be competing with consumers in other sectors for the low-carbon energy sources that are available.

Domestic Heat

At present 85% of the 23.9 million homes in the UK are connected to the gas network and able to use it for domestic heat (space heating, hot-water and cooking). The remainder use a wide variety of heating solutions including: LPG, solid-fuel, heat pumps and fuel-oil. To date, this sector has proved difficult to decarbonise with emissions for 2019 being 83% of what they were in 1990 – although the number of houses connected to the grid has grown from 17.3 million in 1990 (BEIS 2020b) to 24.1 million in 2019 (BEIS 2020c) meaning that each household in 2019 used on average 59% of the gas that it did in 1990. This is in contrast to the emissions from electricity generation that in 2019 were only 28% of their 1990 level (BEIS 2020d:7-9). The UK Government is now focusing on how to decarbonise heat, but the fear is that it will find it much harder than decarbonising electricity.

There are two – complementary – means of decarbonising domestic heat. The first is to improve efficiency through measures such as: increased insulation of floors walls and roofs; improved heating appliances; smarter heating and better consumer understanding. The second is to switch from a high-carbon heating source (e.g. coal, oil, gas etc.) to a low-carbon heating source (renewable electricity, green hydrogen, geothermal etc.). Greater efficiency in UK homes is described by the CCC as a low-regret option (CCC 2019:141) as it will be beneficial to achieving decarbonisation under all scenarios. This is because it can be potentially rolled out more rapidly than larger infrastructure changes and will begin reducing energy consumption immediately. These measures would also continue to restrain consumption for decades to come, both in terms of total energy consumed and the size of peaks during periods of high demand (although an increased amount of working from home during lockdown has shown how this type of behavioural change can flatten energy demand without the need for spending on efficiency measures (Wilson 2020 & National Grid 2020c)).

However, whilst the UK has plenty of housing that would benefit from improved energy efficiency (see figure 6) it would not be cost-effective – or indeed physically possible – for these homes to decarbonise using energy efficiency measures alone (Howard & Bengherbi 2016). Estimates vary concerning how much improved efficiency could feasibly reduce domestic heat demand by. To provide an estimate for context, a report by the think-tank, Policy Exchange, estimates that from 2015 – 2050 improved efficiency could reduce domestic heat demand by 20% even with the addition of new homes (Howard & Bengherbi 2016).

Figure 2. The Natural Gas Supply Chain

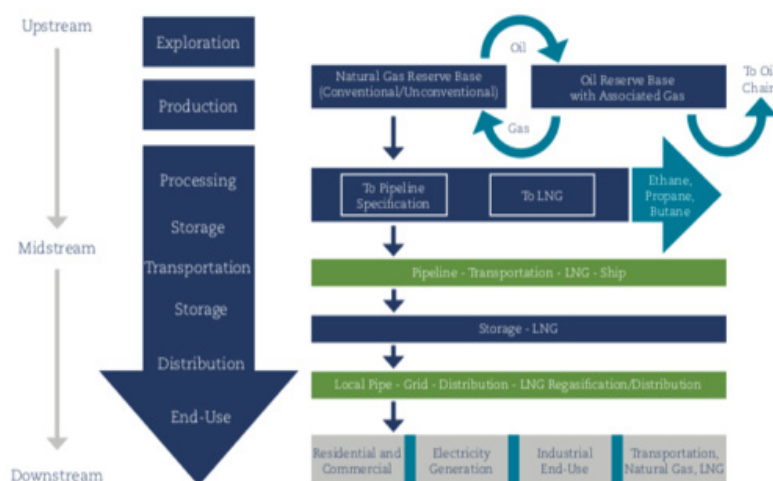


Table 2. A Supply Chain Approach to Gas Security

	Energy Security	Dimensions	Issues
Upstream	Security of Supply	<ul style="list-style-type: none"> Resource Base Technology Investment 	<ul style="list-style-type: none"> Extent of proven reserves Access to reserves for investors Access to investment to develop proven reserves Availability with existing technology and prevailing price
Midstream	Security of Transport (Transit)	<ul style="list-style-type: none"> Processing Transportation Storage 	<ul style="list-style-type: none"> Processing of associated gases Pipeline network Compressor stations Liquefaction facilities LNG Shipping Regasification facilities Storage Interconnectors
Downstream	Security of Demand	<ul style="list-style-type: none"> Power generation Industrial use Domestic use Transport 	<ul style="list-style-type: none"> Role of gas in the energy mix Price formation Price competitiveness Contract structure Energy policy Carbon tax/Cap & Trade Carbon Capture & Storage

Figure 5: UK Gas Supply Chain Analysis

Source: Bradshaw et al. 2014:17

The energy efficiency of the English housing stock has increased over the last decade.

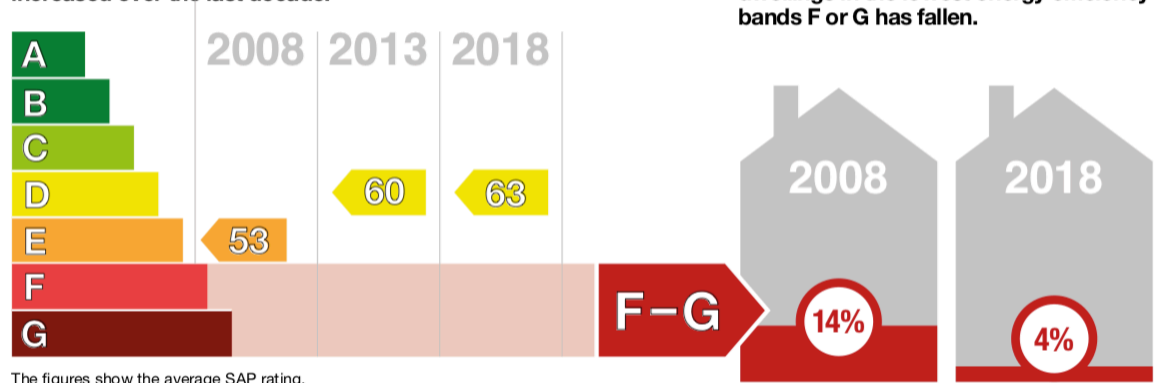


Figure 6: The improvement in the average energy efficiency of English Homes between 2008 & 2018.

Source: Ministry of Housing, Communities & Local Government's English Housing Survey 2018-19 (2018).

This means that the remaining 80 per cent of domestic heating emissions will need to be removed by 2050 using fuel-switching – this will be difficult as boilers are only usually replaced when the previous one has failed – often referred to as a distressed purchase – and the average boiler last 10-15 years. This is an area that the UK Government is now starting to turn its attention to.

In its 2016 report on UK heat policy (CCC 2016a) the CCC said that there are three broad approaches to decarbonising heat and that the UK government must have a clear idea of the direction of its gas and heat policies by 2025. This has been echoed in much of the literature since (see CCC 2018, CCC 2019, National Grid's Future Energy Scenarios). These are; a heat-pump led electrification policy; a hydrogen approach; and, a regionally differentiated approach (Howard and Bengherbi 2016 offers a useful overview of the technologies discussed below). The CCC have recently updated these recommendations in their 6th Carbon Budget Report (2020: 112) which gives a far more prescriptive list of the measures required in buildings between 2025 and 2033 if the UK is to meet Net Zero.

A heat-pump led electrification policy is one where gases of all kinds are largely removed from the domestic heating market and are replaced with a mixture of heat pumps and district heating systems. Hydrogen focussed heat supply will see the natural gas grid repurposed to transport hydrogen to boilers in homes – much like the present system. A regionally differentiated system sees the two previous options being used where they are most appropriate. For example, if the hydrogen is produced from natural gas it may need to be near disused gas fields where the carbon can be sequestered (blue hydrogen) – areas further away from these disused fields would need a longer hydrogen infrastructure to reach them, making this option less financially competitive. Whilst the hydrogen scenario could see continued widespread use of natural gas as a feedstock for hydrogen, an electrification scenario could see its near or total removal from the domestic heating sector. If natural gas is used for hydrogen production, it is important to note that this is still unsustainable, regardless of its carbon emissions, and therefore would have to be replaced by green hydrogen over time.

Figure 7 suggests that between 2025 and 2030 the Government sets a clear pathway for the future of domestic heat. Failure to see large-scale CCUS test projects in operation by 2030 are likely to lead to the removal of all gases from the UK domestic heating sector by default rather than by design. The only other avenue open to gas would be if hydrogen electrolysis technology advances faster than is expected by 2030, allowing the use of SMR+CCUS to be superseded. This scenario would only happen if government were to create markets to incentivise electrolysed hydrogen, as this is not likely to happen under current market conditions alone.

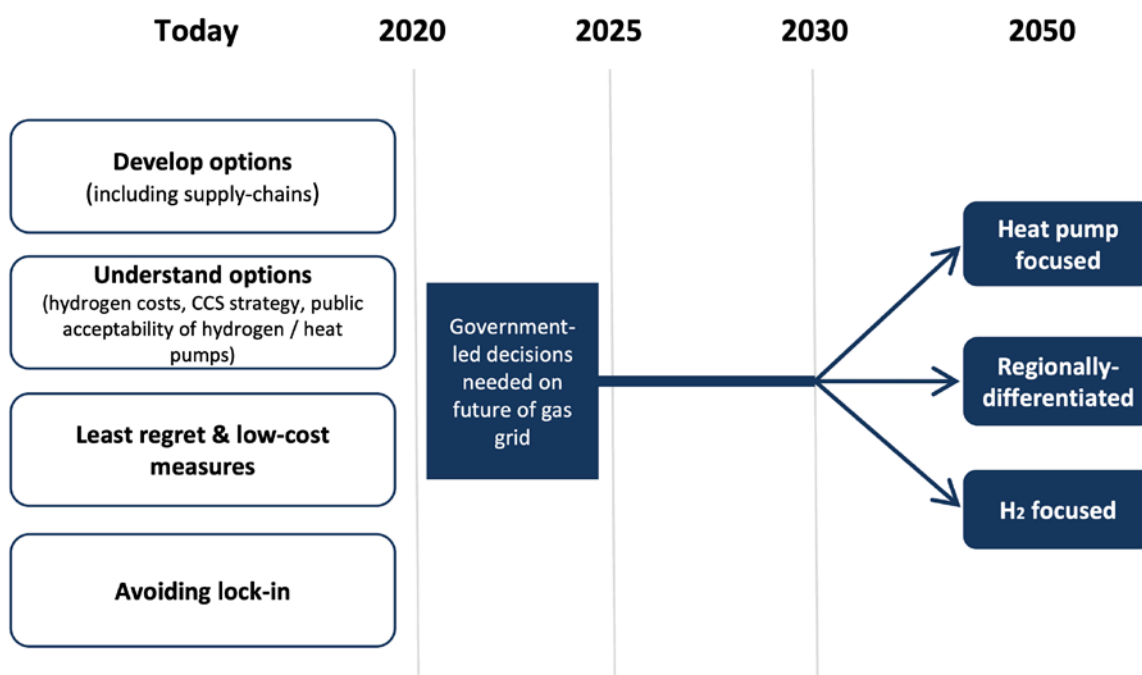


Figure 7: Timeline for the future of the gas grid.
Source: CCC (2016a) Next steps for UK heat policy: p.29.

Power Generation

Natural Gas is still the largest source of electricity generation in the UK. It first became so in 1999 and vied with coal until 2016 when gas became the undisputed leader (BEIS 2020e: Dataset 5.3). This generation is delivered through two main types of power station (gas combustion engines are also used to a far lesser degree for peaking capabilities). Open cycle gas turbines (OCGTs) are cheaper to build and faster to deploy but offer lower efficiency. They are therefore well-suited to supporting variable renewables. Combined Cycle Gas Turbines (CCGTs) are more expensive to build and slower to deploy but offer higher efficiency as they recover energy from the exhaust gases of the initial turbine (see University of Calgary 2020 for a full explanation of the differences between these types of power station). At present the UK has 34.7 GW of gas generating capacity of which 32.6 GW is CCGT with 2.1 GW OCGT (BEIS 2020e: Dataset 5.12).

In the introduction Figure 1 showed that in the 1990's there was a 'dash for gas' in UK power generation that allowed the decarbonisation of electricity generation by replacing coal with gas. When the Government announced in 2015 that it would ban the use of unabated coal by 2025 it was assumed that there was sufficient room for a second 'dash for gas' because gas could be used as a bridge fuel to help manage the intermittency of renewables. There was, however, already scepticism regarding this role for gas (McGlade et al. 2014). Figure 8 shows what percentage of the time during each calendar year that CCGTs were operating – this is referred to as the load factor. The graph shows that this has steadily been declining over the past 20 years (with notable lows between 2012 and 2015 during the last hurrah of coal). Whilst there is talk of gas being used as a supplementary technology for renewables, most of the UK's gas generation capacity is made up of CCGTs [and less than 10% of generation capacity is the OCGTs designed to fulfil this role. This would appear to be supported by the fact that in the last 5 years only one new gas plant has been commissioned – although the conversion of the two remaining boilers at Drax to gas is still planned. Therefore, if gas is going to be a bridge to decarbonisation it could be a very small and short bridge. Indeed, McGlade et al. (2014) concluded that the main problem would be how to maintain and pay for the level of gas power generation required to balance the grid and provide security of supply with such low load factors – making gas a bridge to nowhere. This raised the question of who would pay to cover the gaps in renewable production? Recent analysis suggests that battery storage is likely to provide a more cost-effective solution than new gas-fired generation (CTI 2021).

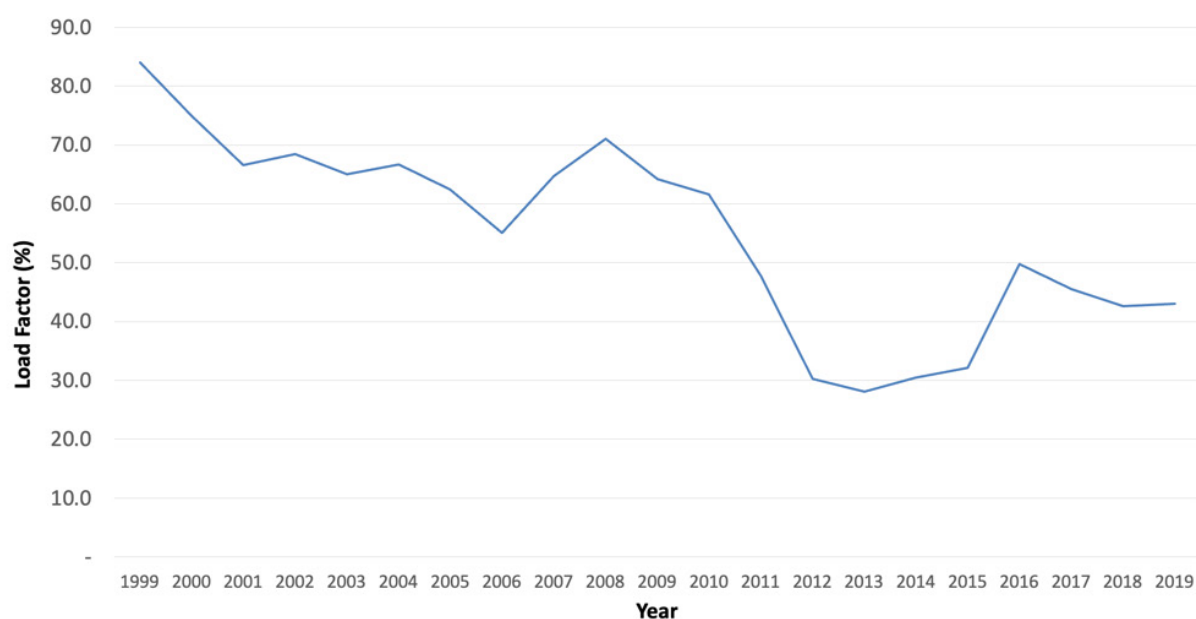


Figure 8: Load Factor of Combined-Cycle Gas Turbines 1999-2019.

Source: BEIS (2020e) – DUKES Dataset 5.10.

It is unlikely that battery storage developments will signal the end of gas generation (as it only reduces the need for gas in daily demand swings as opposed to seasonal ones), however, it could continue the erosion of gas in the electricity generation mix. With respect to longer-term, seasonal storage a number of possibilities are emerging. One school of thought is that the use of natural gas could gradually be replaced by green hydrogen, which is easier to store in large quantities than electricity in batteries – this will require prices to fall significantly though.

A possible route to extending the life of gas generation is through the use of CCUS. Should this become available at scale within the near future it may allow low-carbon gas to be used more extensively for generation (Stamford 2020). However, given the precipitous falls in the cost of renewable generation (BEIS 2020f) and electricity storage, there is uncertainty surrounding the cost competitiveness of a gas plus CCUS solution. The problem of cost-competitiveness was the central focus of the UK CCUS Cost Challenge Taskforce (Morgan 2018). However, the fact remains that life-cycle emissions of gas + CCUS will still be higher than all other types of generation (Stamford 2020). It is clear to see that a failure to make meaningful progress of CCUS by 2030 will lead to the eventual abandonment of natural gas as a source of electricity generation in any form.

Industry

The term 'industry' does not refer to a homogeneous group of businesses. There is great variance within the term in relation to the quantity and purpose of natural gas consumption. This impacts on how easy it is to replace gas with low carbon alternatives. The majority of gas usage within the UK industrial sector is used by a small number of industries referred to as the Energy Intensive Industries (EIs) (Parliamentary Office of Science & Technology 2012). Given their specific problems and needs, this group has set up an industry body called the Energy Intensive Users Group (EIUG) with its own manifesto (EIUG 2017). This group accounted for over 60 per cent of all industrial natural gas used in the UK in 2017 (BEIS 2020f: Dataset 4.2). The intensive industries are defined as; iron, steel, aluminium and non-ferrous metal production; cement; ceramics; chemicals; food & drink; foundries; lime production; glass; paper; industrial gases (Parliamentary Office of Science & Technology 2012).

The UK's record of decarbonising industry is complex. This is because most international measures look at the total industrial output of a country and its total industrial emissions. This can allow countries to reduce their emissions by moving to lighter industry as opposed to making EIs more energy efficient, thereby sacrificing jobs in heavy industry. The UK is seen, in some quarters, as a world-leading success story when it comes to decarbonising industry because the UK has managed to increase industrial output whilst also decreasing emissions (UK Government 2017:5). However, this assumes uniformity of emissions across the industrial sector. The counter argument is that the UK has achieved this reduction by shipping its most energy intensive industries

abroad (Lodge 2020) – a process known as offshoring emissions or carbon leakage. It should be noted though that this is part of a far wider discussion about deindustrialisation and the many possible causes of it.

Looking at the UK's trade data for the last decade and comparing EIs – based on the definition provided by the Parliamentary Office of Science & Technology (2012:1) – with non-EIs suggests that in terms of economic output there has been no shift away from EIs whilst emissions have fallen. This would support the view that there is genuine decarbonisation going on in UK industry as opposed to an offshoring of industry. However, this picture can sometimes be blurred by anecdotal evidence, for example, the closure of a large steel plant. Instead, the evidence suggests that these high-profile closures are being cancelled out by other EIs expanding (see figure 9).

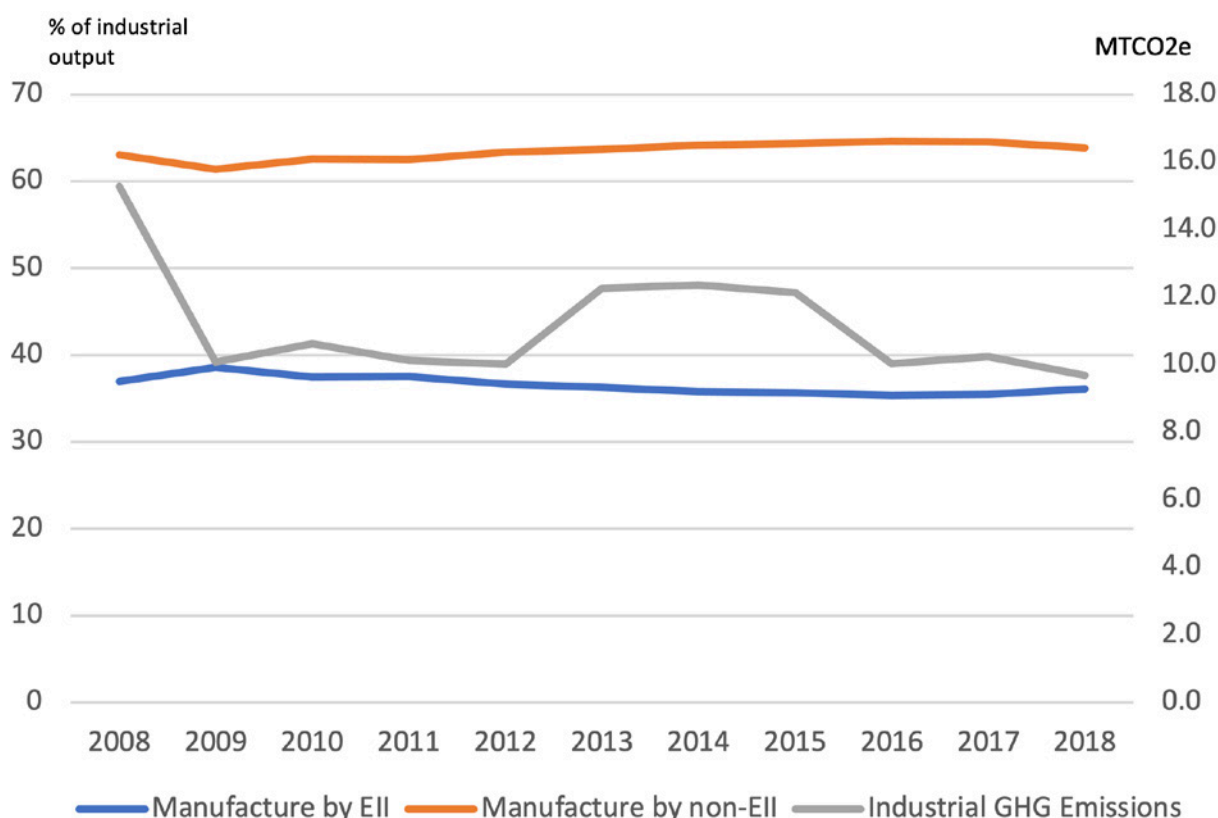


Figure 9: Percentage of Industrial Output (EIs v. non-EIs) versus UK Industrial Emissions

Sources: BEIS 2020g: 2019 UK Greenhouse Gas Emissions Provisional Figures Data Tables & ONS 2019 UK Manufacturers' Sales by Product Survey

Figure 10 shows that this is not due to a decline in manufacturing either as since 2008 both EIs and non-EIs have been growing in terms of economic output. This implies that UK industry has become more carbon efficient over the past decade through its use of innovation, investment in research and development, creation of policy frameworks and public subsidies (UK Government 2017: 5-7). This raises the question of how long industry-led efficiency gains and minor government interventions can continue to produce these reductions in GHG output? Studies by both Gerres (2019) and Lehne & Preston (2018) imply that the easy wins presented by improving efficiency of existing processes are now coming to an end and further gains require more fundamental change, such as, post-process CCUS or fuel switching. Given the large amount of capital expenditure required to implement these projects and the present lack of any competitive advantage to companies who pursue them, questions remain concerning how this will be achieved.

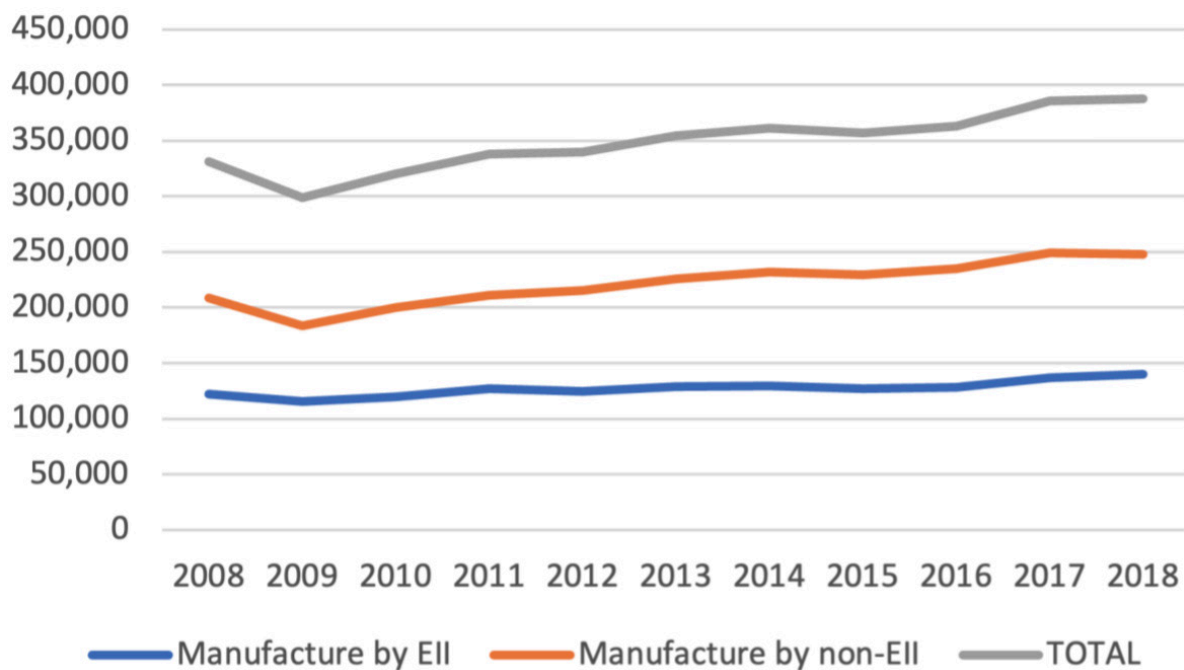


Figure 10: UK Manufacturing output – EIs versus non-EIs (£m)
Source: ONS (2019)

Given that electrification is ill-suited to providing high-level heat for industrial processes (Policy Connect 2018a:6), there are four possible routes when it comes to fuel switching in industry. **Pre-process CCUS** would see natural gas converted to hydrogen at large centralised facilities, this would then be piped to end users following conversion of the natural gas grid. The changes involved are relatively simple, but this would not allow for the capture of greenhouse gases produced during the production process. Conversely, **Post-process CCUS** would see natural gas continue to be pumped to end-users where emissions from burning the gas *and* process emissions would be captured and transported back to central carbon capture facilities. This would involve the creation of a carbon capture network that mirrored the gas network – a sizeable undertaking. Alternatively, **green hydrogen** could be produced using electrolysis with the power being supplied by renewable energy. This would again involve the conversion of the gas grid but without the sustainability issues surrounding CCUS. At present this is a more expensive means of hydrogen production than SMR+CCUS. There is the possibility of introducing this or pre-process CCUS by blending them into the natural gas grid at up to 20% (Hynet 2020; Hydeploy 2020). The final alternative is to use **biogas**. This does not require the conversion of the gas network or a CCUS process. However, it is dependent upon the availability of feedstock. There are presently concerns regarding the amount of feedstock available, whether it could satisfy industrial demand, and, whether this is where it is best deployed – twinned with CCUS, biogas offers a rare opportunity for negative emissions (Policy Connect 2018a:6 & 2018b:8). In terms of natural gas demand, pre or post-process CCUS would be the only options that could retain present demand. The questions are how would these conversions be funded, are they suitably sustainable, and, will there be enough other gas consumers to continue financing the existence of a gas grid.

Transport

Transport is now the largest GHG emitting sector in the UK economy (BEIS 2020d). Much like domestic heating, it has proved – and will probably continue to prove – difficult to decarbonise (CCC 2019). This is because the only route to Net Zero is fuel substitution across all transport types with each fuel type requiring a unique supply chain to be created. At this point it is important to note that whilst treated as a single sector, transportation refers to several modes of transport, all with their own specific requirements in terms of propulsion system and possible routes to decarbonisation. On this basis, the sector can be separated into road, rail, shipping and aviation. Further sub-categories relevant to types of propulsion system depend on whether travel needs are for short/long-haul, occasional/frequent use, and large/small payload. Because of this variety it is likely that a number of different decarbonised or low-carbon propulsion systems will be required to meet the needs of the transportation sector (CCC 2018:53). Figure 11 offers a comparison of how different

fuels and energy carriers relate to each other in terms of energy density (weight and volume). Batteries are the only item capable of increasing their energy density – without changes in storage temperature or pressure, both of which require additional energy. It should also be noted that the energy density of the fuel carrier is not the only consideration – batteries do not require an additional storage tank, they can also allow for a smaller and lower weight drivetrain – whilst this does not mitigate the disparities shown in the table, it is worth noting that the full picture (especially in terms of batteries) is not quite as bad as it seems.

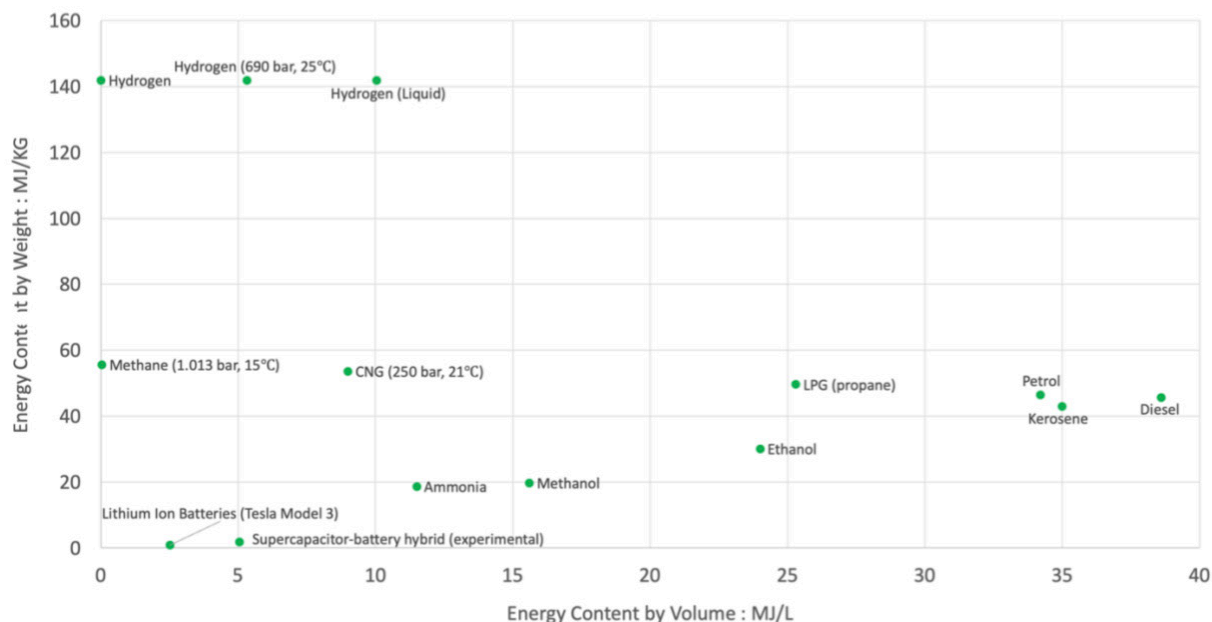


Figure 11: Comparative Energy Density of Fuels and Energy Carriers

Figure 11 is useful at illustrating how different types of transport gravitate towards different solutions depending on the relative importance the volume or weight of a fuel has upon the propulsion of the vehicle. There are already patterns starting to emerge regarding the future of propulsion in different sectors. **Road transport** is moving towards Battery Electric Vehicles (BEVs) for personal transport with Fuel Cell Electric Vehicles (FCEVs) being considered more appropriate for haulage (DfT 2018 & CCC 2018). **Aviation** is beginning to experiment with biofuels and hydrogen for long-haul and batteries for short-haul (CCC 2018; Airbus 2020). **Shipping** is seeing the use of LNG as an intermediate step with the possibility of ammonia or possibly hydrogen being used in the longer term (Royal Society 2020; Wärtsilä 2020). **Rail** is continuing to see the expansion of electrification where possible with the use of hydrogen being trialled as a replacement for diesel on the difficult to electrify lines (CCC 2018). Some of the key obstacles to change are proving to be: cost – who pays for these expensive and non-competitive changes; international agreement – especially for vehicles that operate in multiple jurisdictions such as aviation & shipping; Inertia – many of these vehicles have long operating lives during which the drivetrain would not, normally, be replaced. In terms of what this means for natural gas in the long-term, at present it is very much a niche fuel within transportation and is likely to remain so unless the use of SMR + CCUS allows it to be used as a feedstock for either hydrogen or ammonia. If this is the case, transport could well become a growth sector for natural gas.

Whole-System Constraints

Whilst the decarbonisation options available within each sector seem wide and varied, considering available pathways from a whole-system perspective begins to limit these. The type of constraints imposed by a whole-system creates priorities between different sectors. The UK increasing its goal from 80% to Net Zero by 2050 also restricts choice as it now almost entirely removes continued use of unabated fossil fuels as an option and reduces the number of reduced-carbon fossil fuel options that can remain in the energy mix – comparing National Grid's Two Degrees Scenario (2019) and its Net Zero compliant scenarios (2020b) offers an illustration of the reductions required. When further physical constraints are included from the sectoral analyses above, then a clearer picture starts to emerge regarding which fuels, and at what quantities, can be used in each sector. There are also international considerations. At present there are regional markets for electricity and international markets for oil and gas – these help to smooth supply and therefore prices around the world.

As different nations prioritise different decarbonisation solutions there is the potential that price and supply volatility will increase – this is because when a fuel is widely used, large and unexpected swings in supply and demand are uncommon – leading to a relatively stable price. When supply and demand are small, the relative market share of individual nations or companies is larger in comparison – meaning that a smaller number of unexpected supply or demand changes are required to disrupt the market equilibrium. It is important to understand the role that gas plays and the network services that it provides by allowing large swings in energy demand to be met far more easily than through the use of other fuels. The three sections below look at different types of demand swing and explain gas's role in managing them:

Daily Swing

Both the natural gas and electricity grids move between periods of low demand and high demand throughout the day. Figure 12 shows how this happened over a period of days in February & March 2018. The key points to note from the graph are that due to natural gas providing space and water heating, which is greater than electrical demand, the swings are far more pronounced for natural gas than electricity. Due to winter demand for heating, the peak energy demand provided by the natural gas network was approximately four times higher than that provided by the electricity grid.

The natural gas network provides capacity for, and manages, large overnight and within-day swings in energy consumption by the use of linepack, the natural gas stored in the pipeline network. This involves increasing the pressure at night when demand is low and then reducing it during peak times to satisfy demand without the need to match supply and demand in real-time as is the case for the electricity grid. A move to electrification removes this arguably free service that the natural gas network provides, meaning that managing flexibility between supply and demand will need to be provided and paid for in another way in a net-zero energy system. The following options presently exist; the peak can be reduced either by reducing demand – improved insulation, heat pumps, more efficient appliances etc.; the peak can be moved – hot water and heat storage, time-of-use tariffs (TOUTs), home batteries etc.; or, the services can be provided by the electricity grid using grid-level storage, hydrogen peaking plants and interconnectors (Wilson & Rowley 2019; National Grid 2020b). All of these are likely to be useful means to help provide energy system flexibility over a sub-daily and overnight timeframe. However, due to the daily rhythms of energy demand, they are of less benefit the longer the timeframe required to match supply and demand.

Figure 12 also shows the level of capacity increase that could potentially be needed for the electricity grid to cater for heat demand (the blue line shows the amount of gas used for domestic and commercial space heating, cooking and small-scale commercial operations – it excludes larger industrial operations, meaning that much of the demand shown relates to space heating). However, if those homes presently on the gas grid in the UK converted to heat pumps this would reduce the level of energy demand and also flatten the peaks. This is because heat pumps are at least two and a half times more efficient than a gas condensing boiler and operate over longer periods (Howard & Bengherbi 2016:44). This type of scenario sees electrical heat demand peak at a much lower level than under a gas heating scenario (Watson et al. 2019).

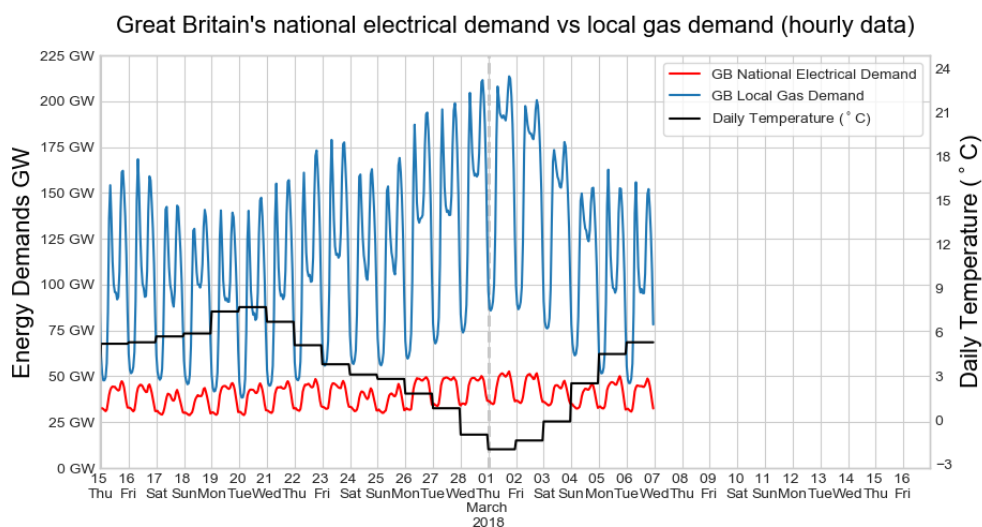


Figure 12: Energy Demand Profile – Electricity versus Gas.

Source: Wilson (2019)

Seasonal Swing

How the UK delivers seasonal storage has changed in recent years. After the discovery of gas in the North Sea it was possible to peak production in the winter months to more closely match demand. Once the reserves began to deplete it was more difficult to do this, as a result British Gas (and later Centrica) used the Rough Storage facility, up until 2018 this provided 73% of the UK's gas storage capacity (Bradshaw 2018:20). As the international gas market developed the winter-summer price spread in the UK gas market decreased, this meant that the business case for a large long-term gas storage facility in the UK had been eroded (Redpoint 2013). As a result, the UK now relies on winter demand being met through the gas stored in the remaining medium-range storage (MRS) facilities, LNG terminals and the Belgian (IUK) and Dutch (BBL) interconnectors with limited surge production from Norway (Bradshaw 2018:15–25).

In a report commissioned by BEIS and produced by CEPA in 2017 (CEPA 2017) it was noted that the UK has a secure gas supply on the basis that the UK is prepared to pay a higher price than competing markets. This includes an assumption that this status quo will remain. It also ignores the lag time of 7–10 days for securing non-contracted LNG cargoes. Should the UK not have the ability to pay more than our competitors for a scarce natural gas resource (possible in the winter months) then the final tool at the disposal of National Grid in the management of the UK's gas network is demand-side reduction – this is where large volume consumers reduce their demand at peak times or during emergencies in order to ensure that demand does not exceed supply – although the system did not work during the Beast from the East. The Standard conditions of gas supply licence have now been updated by Ofgem to clarify when and how firms can have their supply forcibly curtailed during a Gas Deficit Emergency if required (Ofgem 2020).

'Event' Swings

In addition to the relatively predictable daily and seasonal swings there are also what we shall call the less predictable 'event' swings. This is where a single or combination of events cause a sudden change in the natural gas market equilibrium. These swings are characterised by periods where demand is extremely high, usually as the result of a weather event (extreme cold – 'The Beast from the East') or when supply is unusually low (the Baumgarten facility explosion in Austria at the same time that the Forties pipeline closure) (see Bradshaw & Solman 2018 for a case study of these events). At relatively short notice, these types of event can push demand above or reduce supply below seasonal norms with little time to prepare. Moving forward, the question will be whether or not the UK's energy system can continue to cope with these sudden and unexpected changes in supply and demand. At present, linepack plays a role because it can – in the short term – balance supply and demand. This is a service that is not presently available on the electricity grid, as was demonstrated during the large-scale outage on 9th August 2019. One of the key observations was that as the UK's electricity generation starts to change there are likely to be unexpected events (Ofgem 2020b) as all parties concerned learn how to adapt to the UK's changing energy system.

The discussions above show that natural gas presently plays a key role in some of the UK's most energy intensive and hard to decarbonise sectors. In addition, there are also 'system services' the UK energy system receives by virtue of having natural gas involved in the UK's energy mix. Therefore, the challenge when replacing gas within the UK's energy mix is two-fold. Firstly, it must be decarbonised or replaced by lower carbon fuels if the UK is to meet NZ50. Secondly, if the UK wishes to retain a reliable energy supply a solution needs to be found whereby the 'system services' of natural gas can be delivered by other means at a reasonable cost.

Pathways & Scenarios

Central to the UK's ability to successfully decarbonise are the pathways and scenarios that help us to consider the advantages and disadvantages of possible futures. In reality this is a dynamic problem where changes will inevitably lead to unforeseen consequences. Therefore, scenarios and pathways – whilst being useful tools – should not be seen as predictions. Scenarios and pathways published prior to the UK government's decision to amend the Climate Change Act 2008 only considered 80% reductions (National Grid 2011 – 2019; McGlade 2016). Since the amendment to the legislation the focus has been on how to achieve net zero emissions by 2050 (National Grid 2019 & 2020b). As noted above, but worth repeating, removing this final 20% means having to make the most difficult and expensive changes. This takes the form of removing any remaining high carbon activities, replacing low carbon options with zero/near zero carbon options and increasing measures that improve efficiency, reduce emissions or absorb carbon from the atmosphere – as is shown below.

80% Decarbonisation Pathways

National Grid

The Future Energy Scenarios (National Grid 2011-2019) are treated with great importance within the sector and are used by BEIS & Ofgem in their statutory security of supply report (BEIS & Ofgem 2019:22). These documents have consistently contained a scenario that was compliant with the Climate Change Act 2008 in its original form. This scenario was originally named *Gone Green* (GG15 & 16) and was then renamed *Two Degrees* (2D17, 18 & 19). From 2018 National Grid included a second scenario that was 80% compliant called *Community Renewables* (CR18 & 19). This scenario was designed to show what a more decentralised approach to decarbonisation might look like. In these scenarios generation is generally smaller scale and more diffuse than in the *Two Degrees* scenario from the same year. Figure 13 shows the effect that the various scenarios have upon the consumption of natural gas within the UK from 2015-2050.

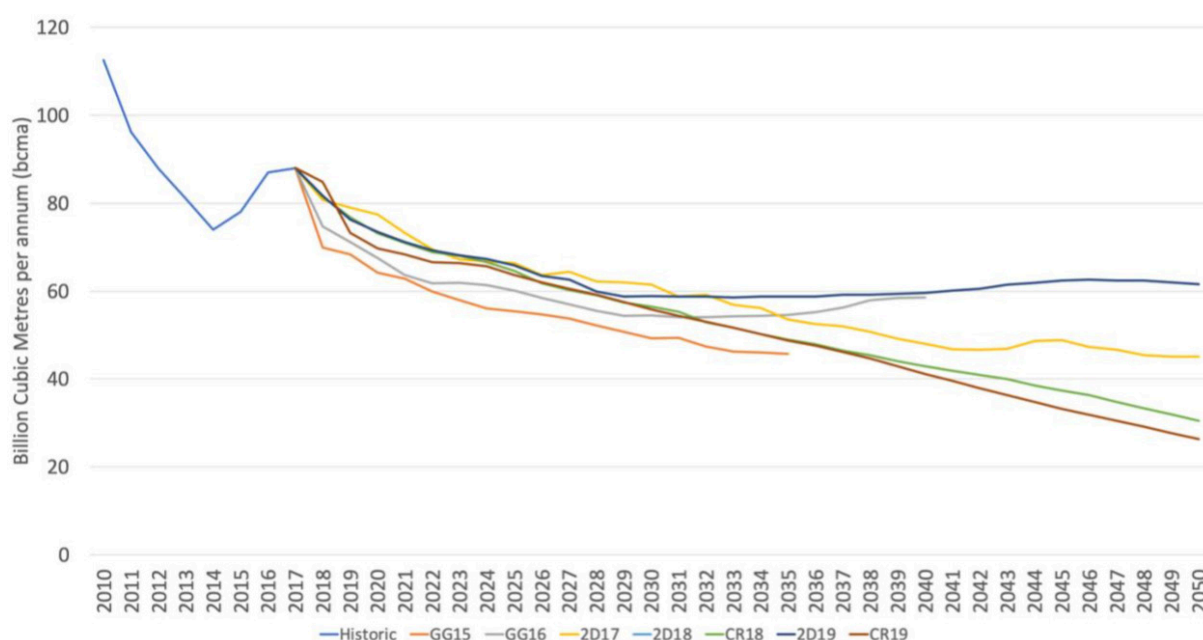


Figure 13: A comparison of the gas supply volumes (bcma) associated with all Gone Green/Two Degrees/Community Renewables Scenarios

Source: National Grid (2015-2019) Future Energy Scenarios

For the *Two Degrees* scenarios emissions are reduced in the **Generation** sector through a mixture of nuclear, renewables and CCUS fitted to coal and gas plants as a means of dealing with intermittency in renewables. This CCUS facility at 2050 ranges between 12 GW (2D17) and 20 GW (2D18) which is equivalent to between three to five Drax-sized power stations being fitted with CCUS. These power stations will still be the dirtiest form of electricity generation even with CCUS (see Stamford 2020). In addition to these wide-spread measures, there would also be a suite of balancing and storage technologies such as battery storage, interconnection and vehicle-to-grid (V2G) to balance power usage over shorter timeframes e.g., overnight, within-day, up to a week. In CR18 & 19 the focus is on local energy schemes and an early growth in electricity storage capacity. This sees a decrease in nuclear generation (with retired plants not being fully replaced) as well as an increase in offshore wind-capacity compared to 2D19.

Heat would be decarbonised through varying means. The GG15, 16 & CR18 scenarios see the wide-spread use of heat pumps (HPs), 2D17 sees hybrid heat pumps (HHPs) preferred and 2D18 sees the widespread use of hydrogen. All three options will see wide-scale and disruptive changes required to homes within the UK – in a variety of different ways. Meanwhile CR19 sees a larger role for district heating systems in addition to hybrid heat pumps. **Hydrogen** forms an increasingly significant role in the 2017 & 2018 reports as it begins to be used in commercial **Transport** after 2035 as well as **Industry**. Generally, **Industry** is seen to adopt the most cost-effective measures. New passenger cars are all EVs between 2050 (2015 & 2016) and 2040 (2017, 2018 & 2019).

Efficiency and Technology play a significant role in these scenarios as demand reduction is a cheap means of decarbonisation. **Housing** sees the wide scale adoption of zero-carbon new-builds with 70% of the UK's housing stock upgraded to Grade C or above. In addition, there are wide-spread complementary measures such as smart meters, LED lighting, increased appliance efficiency, time-of-use-tariffs and energy storage.

UKERC

In comparison, **UKERC** (McGlade et al. 2016) produced a range of scenarios in 2016 that also dealt with a wide range of possible energy futures. The scenarios of interest with relation to decarbonisation are named **Maintain** and **Maintain (techfail)** – the difference is that **(techfail)** sees a failure to commercialise CCUS technologies. These can be compared to a third scenario named **Abandon** which represents abandonment of the GHG reduction principles enshrined in the Climate Change Act 2008. The following two figures illustrate the difference that occurs when the new technologies are not available:

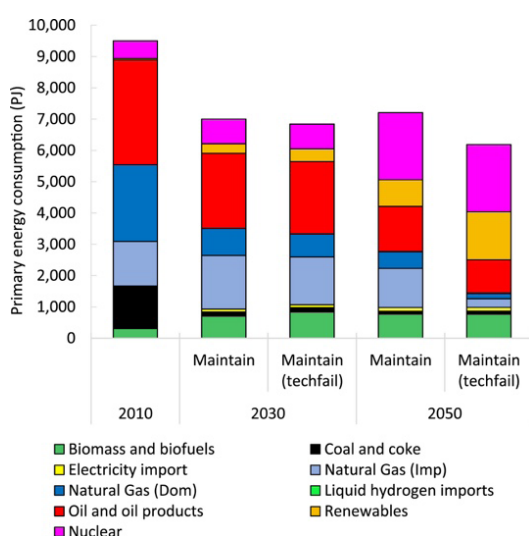


Figure 14: Primary energy consumption (PJ) in UKTM scenarios that meet the 2050 carbon targets
Source: McGlade et al. 2018

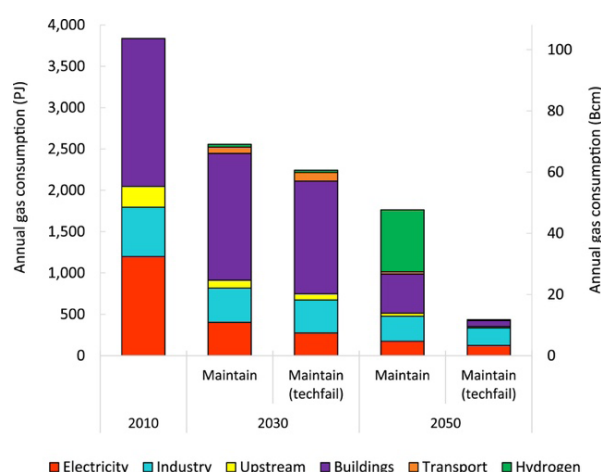


Figure 15: Sectoral gas use in UKTM scenarios that meet the UK's 2050 targets

The two scenarios show the vast difference that could possibly occur in 2050 by virtue of having CCUS technologies available. The lack of CCUS shows a far diminished role for gas in the UK's energy mix. The difference in pathways offers an important insight into the divergence in UK energy policy that could occur as a result of the fortunes of CCUS. Across both scenarios there is also a small fall in gas demand between 2020 and 2030 which follows a steeper decline from 2010 to 2020; 60% of this overall reduction comes from the generation sector with 20% from residential and 15% from industrial uses. This is countered by a small increase in the transport sector.

In the **Maintain** scenario CCUS begins to be used from 2025 and it is after 2030 that the divergence becomes starker. The small amount of gas that remains at 2050 in the **Maintain (techfail)** scenario is largely for petrochemical feedstock and non-energy uses in industry or marginal load factor back up generation – a generator of last resort. As a result, gas consumption at 2050 in this scenario is approximately 10% of the 2010 level at 12 bcm. In contrast **Maintain** sees a significant reduction in gas demand due to the electrification of domestic heat. However, this reduction is largely replaced by the increased non-combustible use of gas as a feedstock for the production of hydrogen using SMR+CCS. This hydrogen then goes on to be used in transport and industry. Natural gas continues to be used in the electricity generation sector both as a back-up for intermittency and as CCS enabled power plants.

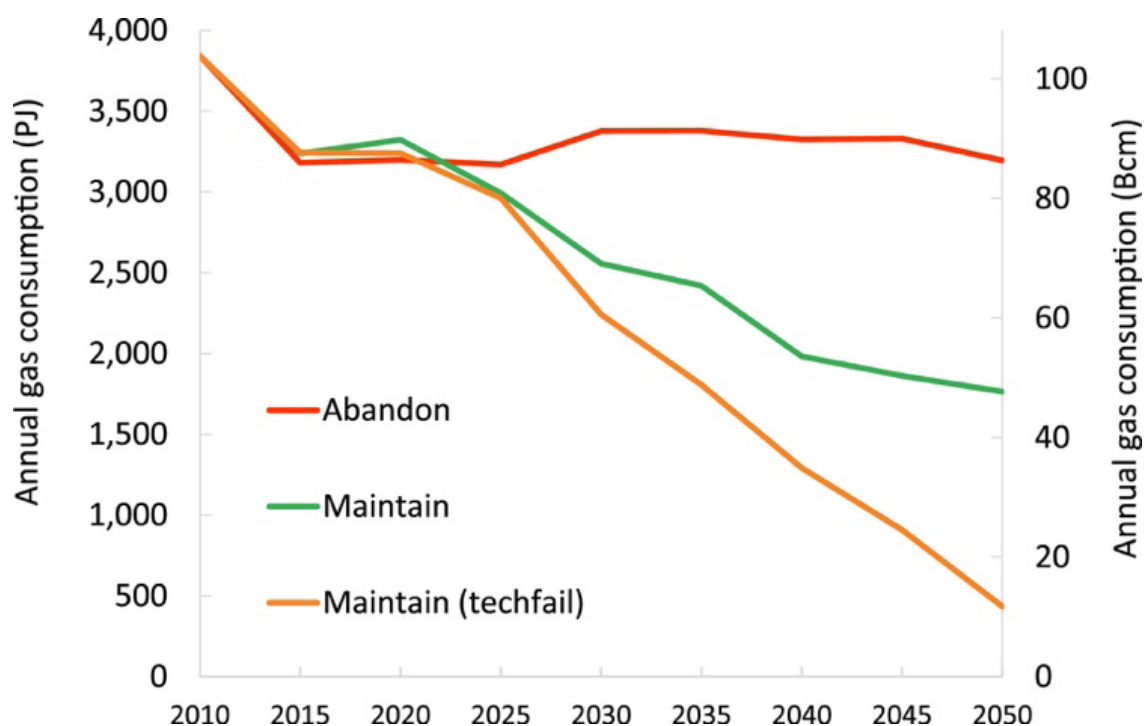


Figure 16: Gas consumption over time in Abandon, Maintain and Maintain (techfail)

Source: McGlade et al. (2016) *The future role of gas in the UK*, p. 32

When these three scenarios are plotted on a graph (Figure 16) it results in three very distinct scenarios.

Maintain shows a pathway that is very similar to National Grid's Gone Green/Two Degrees scenarios. This highlights the assumption made by National Grid that technology will allow for the continued use of gas in the UK's Energy mix. **Maintain (techfail)**, however, raises a number of questions concerning the feasibility of continued gas consumption in the UK. Given such a low level of utilisation would it be feasible to continue operating a National Transmission System for natural gas?

Climate Change Committee

The **CCC** produces analysis across the whole economy, here the emphasis is upon its power sector scenarios. In 2015 the CCC published a report on power sector scenarios for the fifth carbon budget (CCC 2015). In that report, it presented three scenarios that it did not consider prescriptive, rather they tested 'low-carbon sources of energy that are low cost, secure, acceptable to the public and attractive for investors (CCC 2015; 11). The scenarios were designed to minimise cost whilst maintaining security of supply and ensuring that statutory 2050 targets were met.

The three scenarios were:

- ▶ **High Renewables:** that assumed more acceptable sites are available for onshore wind and solar and that offshore wind could be deployed at low cost at 2GW a year in the second half of the decade (the 2020s).
- ▶ **High Nuclear:** that included three new nuclear power stations by 2030, rather than the two included in the other scenarios.
- ▶ **High CCS:** that assumed CCS progressed relatively smoothly during the 2020s and that 7GW of CCS power (at that time just specified as fossil fuels plus CCS) was available by 2030.

In addition to these three main scenarios, a further four were also considered: **No CCS, No Nuclear, Low Demand** (due to slow economic growth), and **High Low Carbon** (a faster rate of growth than the High Renewables Scenario). A number of key uncertainties were identified: the level of energy demand, fossil fuel prices, variations in output from renewable technologies due to weather variations, and the possibility of nuclear outages from the existing fleet of power stations.

In 2016, as a result of the Infrastructure Act (2015), the CCC was asked to consider the compatibility of the development of UK onshore petroleum (shale gas) with meeting the UK's carbon budgets (CCC 2016b).

Although the focus was on the possible impact of shale gas, the analysis is useful as it makes clear, over a longer-term, the consequences of the availability of CCS to future demand for natural gas. Using the fifth carbon budget scenarios, the analysis presents two outcomes for total natural gas consumption (not just gas in power): one where CCS is widely available and provides a way to consume fossil fuels in a low carbon way; and second where it is not available, which would require the elimination of almost all fossil fuels from power generation, transport and buildings.

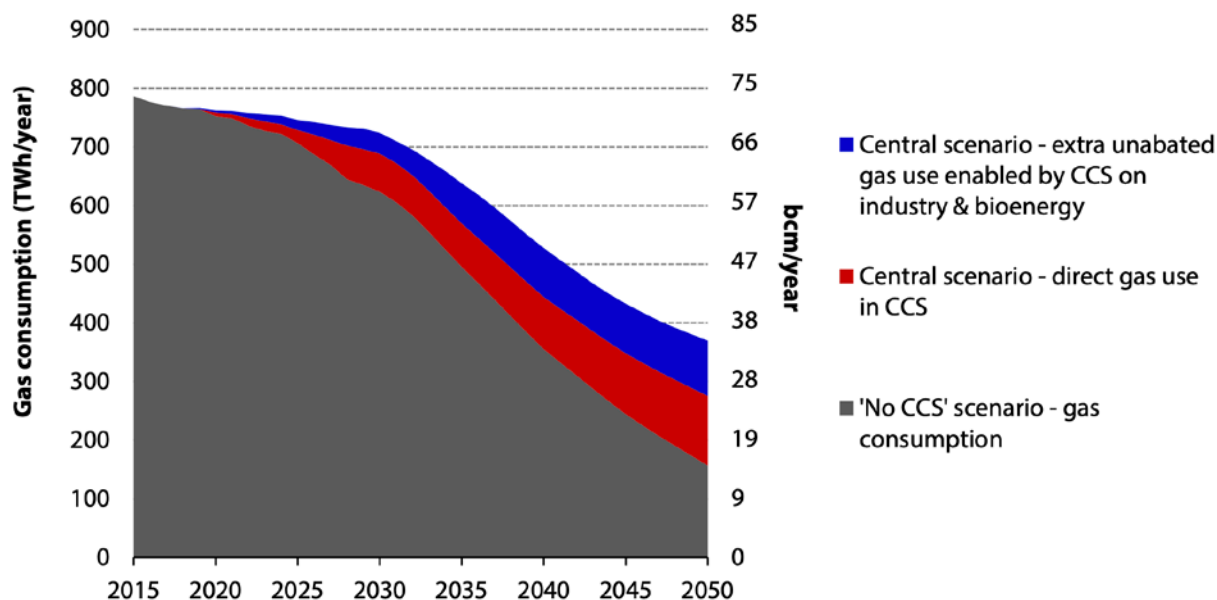


Figure 17: Direct and indirect impacts of CCS availability on gas consumption to 2050

Source: CCC (2016b) Onshore Petroleum: The compatibility of UK onshore petroleum with meeting the UK's carbon budgets, p. 10.

Figure 17 shows that in the central scenario with CCS additional unabated gas can still be used because CCS is being used in industry and bioenergy to create room in the overall carbon budget. Both scenarios see a significant fall in the level of gas consumption by 2050: the 'CCS widely adopted' scenario would see a reduction in gas consumption to around 50% of the level in 2015. The 'No CCS' scenario would result in a reduction of around 80% of 2015 levels.

The report makes clear that there is still a role for natural gas in the power mix in the 2020s, but the level of generation is determined by what happens with new nuclear builds and the growth of renewable generation. The availability of CCS provides a modest additional opportunity, but it is likely that the true value of CCS will not become apparent until the 2030s and beyond.

It is clear to see from the reports produced by the four authors that reaching an 80% reduction in GHGs by 2050 can be achieved in the UK by deploying a range of solutions and technologies. In these scenarios there are multiple possibilities for natural gas remaining as a key fuel or its almost total removal from the UK's energy mix. For natural gas to be the former, the use of CCUS is vital, as is the ability to extend into hydrogen consumption. There does remain room for unabated gas in certain sectors though. Below we show how the options for gas in the UK's energy mix are limited further by changing to a Net Zero target.

Net Zero Pathways

National Grid produced its first Net Zero compliant sensitivity in the 2019 Future Energy Scenarios document. Given that the announcement of the amendment for the Climate Change Act 2008 (2019) was made after the scenarios had been produced it did not form a full scenario. Key figures were noted for the year 2050 (Figure 18 therefore shows gas consumption declining in a linear fashion as these were the only datapoints available for the scenario). Given the increasingly strong focus both within government and society on climate change, National Grid produced three Net Zero compliant scenarios in its 2020 Future Energy Scenarios – each with a slightly different focus. **Leading the Way** (LTW20) focuses on reaching net

zero as quickly as possible. It is important to note that this is with a number of key variables remaining static – afforestation remains static across all scenarios. In reality these could be affected by government policy, thereby achieving net zero faster. This scenario achieves net zero by 2048 (National Grid 2020b). The other two scenarios consider how net zero could be achieved by 2050 using the opposing methods of; **Consumer Transformation** (CT20) where the consumer is keen to amend their behaviour in order to help achieve NZ50; and **System Transformation** (ST20) where consumers want to achieve net zero but want the system to deliver this rather than having to change their behaviour. Domestic heating is good example of the difference between the two approaches: CT20 sees extensive use of heat pumps (where consumers install new technologies and accept greater domestic disruption) whilst ST20 (with a presumption of less disruption) sees the use of hydrogen boilers (where the fuel changes but the method of usage remains the same as the gas boilers that presently dominate the market) (National Grid 2020b).

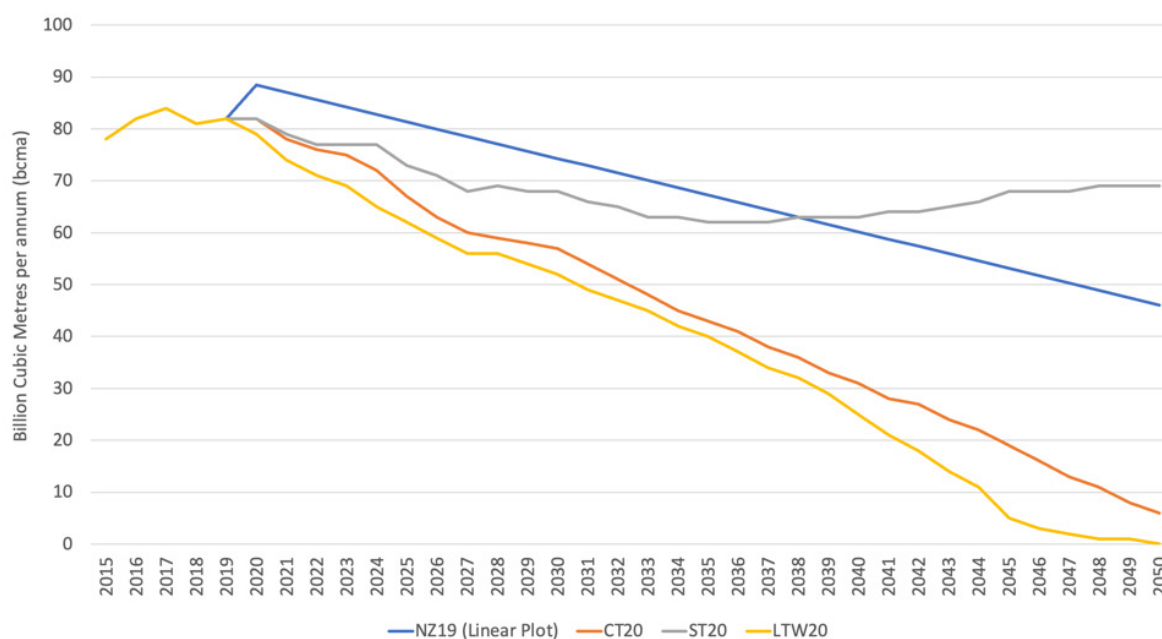


Figure 18: National Grid's NZ50 compliant scenarios (bcma)
Source: National Grid's Future Energy Scenarios 2019 & 2020b.

In contrast to the 80% scenarios, National Grid's Net Zero compliant scenarios follow two clear pathways where gas consumption is concerned (Figure 18). One set sees the heavy use of CCS to allow the widescale production of hydrogen using SMR (NZ19 & ST20). The second is almost a natural gas free pathway where the hydrogen that is required is produced via electrolysis and natural gas can only be used for very limited purposes by 2050 due to its carbon footprint (CT20 & LTW20). None of the scenarios allow widespread unabated gas usage continue. This is because other sectors are harder to decarbonise and as a result they retain the right to create the limited carbon emissions that are allowed. In reality, the choice is not binary. It would be entirely feasible for different parts of the UK to run differing strategies depending on the cost of accessing a CCS network. This type of hybrid arrangement would therefore allow natural gas consumption at 2050 to be between a high of 70 bcma (with CCS) and a low of 0 bcma (without CCS). Legitimate questions do remain concerning the long-term sustainability of SMR+CCS, but, if natural gas is to be a bridge to decarbonisation this is the likely form that it will take, when and how the end of the bridge will be reached is a question that few have grappled with as it depends on either expansion of green hydrogen or the ability to transfer to electrification. The key point to note is that in a net zero UK natural gas will not be used by consumers as natural gas – only as a feedstock for other energy carriers.

Conclusions

This briefing started by showing the extent of gas usage within the UK energy system and its increasing importance over recent decades. The second section showed how gas is deeply embedded in a number of key sectors within the economy to the extent that it is providing the near-free service of short-term demand management through the ability to flex linepack pressure. Thus, not only does unabated gas need to be replaced but the 'system services' that it provides also need to be replaced. The third section showed that to reach net zero all unabated burning of gas must cease and the commercialisation of CCS within the next decade is of paramount importance to the future of natural gas within the UK's energy system.

Therefore, where the future role of natural gas in the UK energy system is concerned it would appear that the only certainty is uncertainty. Natural gas is presently a critical fuel in all sectors of the UK economy, except transport, and has an extensive infrastructure to match this role. This extensive infrastructure provides positive neighbourhood effects through the use of linepack that improve the UK's energy security. However, reaching net zero greenhouse gas emissions by 2050 will require a major reconfiguration of the UK's energy system – that will leave no sector of the economy untouched. There is however a range of options available concerning which options will deliver the best outcome for the UK in terms of the energy trilemma.

What is clear from the scenario analysis is that there are two differing and highly divergent core options concerning the future of natural gas. The first scenario sees a hydrogen economy that initially uses natural gas as a feedstock. Under this scenario natural gas consumption could remain similar to current levels. The second scenario sees the UK move towards electrification with only marginal uses for natural gas in the energy system. Under this scenario the energy system services – flexibility and inter-seasonal storage – provided by natural gas will need to be replaced by other means. Evidence suggests that if the UK is to reach net zero by 2050 then the viability of the relevant technologies will have to be confirmed by 2025 with large-scale demonstrations operational by 2030. Consequently, for natural gas to play a role in this net zero world, CCS is the critical technology that has to be available at a commercial scale by 2030. What does this mean for potential shale gas production in the UK? If shale gas extraction in the UK is to have any future the argument needs to be won that SMR+CCUS will form part of the UK's net zero energy system and that—with UKCS production falling (Solman and Bradshaw 2020)—shale gas is integral to ensuring UK energy security. This does not account for the fact that domestic shale gas would itself be a source of GHG emissions.

Further complicating this process is Brexit, which can be seen as a potential threat multiplier. Over the next decade there will be a period of adjustment for the UK as it finds its own way in the world, at the same time it is having to navigate the longer-term choices surrounding deep decarbonisation. It should not be forgotten that the scenarios where Britain decarbonises most quickly rely upon consistent and strong economic growth of over 2% between 2020 and 2050. This difficulty has now been further added to by the global pandemic, which promises a global recession that will compound the impact of what seem likely to be long-running post-Brexit trade negotiations.

The understandable lack of certainty concerning the optimal pathway is resulting in a period of rapid technological developments, government consultations and industrial re-alignment. After this current period of contemplation – and as the effects of climate change become ever more apparent – there is the possibility that things will begin to move quickly, as they did once it was decided to remove coal from the electricity mix. Whatever pathway the UK adopts, it is likely to have winners and losers. As the outcome becomes clear, the decarbonisation conversation might more closely start to mirror the recent debate about shale gas as a significant amount of new infrastructure will need to be built and, potentially, a significant new role for the subsurface accepted. Understanding this may help the UK to avoid making the same mistakes a second time round ensuring the rapid deployment of new energy infrastructures that are needed to achieve a net-zero energy system by 2050.

About the Authors

Professor Michael Bradshaw

Is Professor of Global Energy at Warwick Business School and works within the Strategy and International Business Group. His academic background is in human geography. He completed his undergraduate training at the University of Birmingham (BSc) and he has an MA from the University of Calgary (Alberta) and he gained his PhD at the University of British Columbia. He works at the interface between economic and political geography, energy studies and international relations. He is a Fellow of the Royal Geographical Society (and past Vice President) and an Academician of the Academy of Social Sciences. Mike is also a Researcher for the UK Energy Research Centre (UKERC) where he has published a number of briefings and position papers concerning the UK energy landscape.

Nicholas Solman

Is a Researcher at Warwick Business School working within the Strategy and International Business Group. He received an MA(Hons) in Economics from Heriot-Watt University before going on to complete an MA in Political Theory at the University of Birmingham. His research has focused on the future of gas within the UK, specifically with regard to energy security and decarbonisation pathways. Outside of academia Nick has undertaken several roles in front-line politics.

Acknowledgments

The research underpinning this review is part of the NERC-ESRC Funded project: *Assessing and Monitoring the UK Shale Gas Landscape* [NERC REF: NE/R017492/1]. For further information see: <http://www.ukuh.org/theukshalegaslandscapeuksgl/> or email: UKUH@newcastle.ac.uk. We would like to thank Dr Grant Wilson for his review of this document and note that any errors are the sole responsibility of the authors.

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FOR FURTHER INFORMATION
nicholas.solman@wbs.ac.uk