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Briefing: Shale Gas and UK Energy Security

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wbs WARWICK BUSINESS SCHOOL THE UNIVERSITY OF WARWICK
UKERC UK Energy Research Centre
UKSGL Shale Gas Landscape
UKUH Unconventional Hydrocarbons in the UK Energy System
UKRI
UKRI

Summary

This benchmark report considers the relationship between UK Energy Security and the potential development of a domestic shale gas industry. This is done through a threefold analysis: First, the report assesses the current status of the UK's gas security by considering the future of the UK's gas supply chain. Second, it analyses the various assessments of future shale gas production potential by conducting a review of a representative spread of predictions and considers their implications for the UK gas industry. Third, it assesses the future role that domestic shale gas production might play given the UK's need for natural gas in the context of achieving net zero emissions by 2050. The report concludes that a UK shale gas industry is unlikely to do more than partially compensate for the decline of domestic offshore production, although exact resource estimates remain uncertain due to the lack of exploratory drilling. Given the current circumstances surrounding the industry, commercial shale gas production in the UK is far from a certainty. The absence of a domestic shale gas industry will lead to a higher level of imports along with an increased balance of payments deficit, in addition to a higher lifecycle carbon footprint and the offshoring of emissions. This is all within the context of a UK energy system that is currently resilient, but is entering a period of uncertainty brought about by the need to: achieve net zero by 2050 at the latest; and, navigate a new geopolitical path as a result of exiting the European Union.

Introduction

> **Shale gas could be an important new domestic energy source reducing the level of gas imports while delivering broad economic benefits, including through the creation of well-paid, quality jobs. It could also support our transition to net zero emissions by 2050.**
> *BEIS (2019a)*

> **Given shale gas has the potential to provide a new source of domestic energy, the Government has supported the development of the UK shale gas industry. Domestic gas production provides jobs and other economic benefits. The industry is currently in an exploration phase and the Government has always been clear that it will only allow development in a way which is safe and sustainable – both for the environment and local people. We have therefore taken a precautionary, evidence-based approach to exploring this potential, underpinned by world-leading environmental and safety regulations.... On the basis of the current scientific evidence, Government is confirming today that it will take a presumption against issuing any further Hydraulic Fracturing Consents. This position, an effective moratorium, will be maintained until compelling new evidence is provided which addresses the concerns around the prediction and management of induced seismicity.**
> *BEIS et al. (2019)*

The two statements above make clear the recent change in position of the Government since August 2019. While the Government continues to maintain that the exploitation of the UK's shale gas potential could improve energy security and the UK's balance of payments by reducing the volume of gas imported; could attract investment and create jobs; and is compatible with the desire to create a net-zero economy by 2050. The previous consensus was disrupted by events of 29th August 2019 when, following a 2.9ML seismic event at Cuadrilla's Preston New Road well, the Oil & Gas Authority stopped the company's hydraulic fracturing operations. It then commissioned a number of technical reports and published a summary document (OGA 2019) that led the Government to impose another moratorium (BEIS et al. 2019) (there had been a moratorium in 2011-12 following seismic events at Cuadrilla's Preese Hall well).

The Government has made clear that the current moratorium is not a ban, further, it has no plans to impose a ban and still sees a potential role for shale gas in the future. It is in that context that the aim of this review is threefold: 1. to assess the current status of the UK's gas security,[1] 2. To review the various assessments of future shale gas production potential and 3. to analyse the future role that domestic shale gas production might play given the UK's future need for natural gas in the context of achieving net zero emissions by 2050. This report builds on, and updates, our recent work on future UK gas security (see Bradshaw 2018).

The report is structured as follows: after this brief introduction, the first substantive section analyses the situation as

1 The term UK is used in the report to convey the national situation, but the reality is that most gas security assessments consider the GB situation (England, Scotland and Wales) as Northern Ireland is part of a separate all-island gas and electricity network along with the Republic of Ireland.

of the end of 2019 and identifies the UK's gas security challenges. This is then followed by a description of the 'shale gas opportunity' based on the British Geological Survey's resource-assessment. After that the various scenarios for future shale gas development are compared. Next the current status of the shale gas industry is presented. The concluding section brings together these elements to assess the potential for domestic shale gas production to address the UK's future gas security challenges and, by default, the consequences of a 'shale failure'.

As with our other work, the report uses a definition from the former Department of Energy and Climate Change's (DECC) (2012) *Energy Security Strategy* that: 'energy security is about ensuring that we have access to the energy services (physical security of supply) at prices that avoid excessive volatility (price security).' It is also assumed that the future role of gas must be compliant with the Climate Change Act (2008) and its associated carbon budgets, which are now re-calibrated to achieve net-zero emissions by 2050. Thus, to evoke the notion of the energy trilemma, the current and future role of natural gas—and shale gas—in the UK's energy mix must be: 'secure', 'affordable' and 'sustainable.' This report focuses on the potential contribution of shale gas to the UK's physical security of supply. It is widely recognised that the open and liberal nature of the UK's gas market means that the market price—the National Balancing Point (NBP)—is unlikely to be influenced by shale gas development. However, developing a new domestic source of natural gas, in addition to production from the UK continental shelf (UKCS), could bring economic benefit by reducing the level of payments made to purchase gas from abroad. This factor is considered in this report. Finally, this report makes no judgement on whether or not shale gas should be developed in the UK; but it recognises that the ultimate pace and scale of development will be determined by the extent to which the industry can overcome the various challenges that it currently faces.

The UK's Gas Security Challenge

The dynamics of the UK's gas balance over the past decades are well understood. After the discovery of oil and gas resources offshore on the UKCS, the country embarked on a 'dash for gas,' first in households and industry, where it replaced 'town gas' and coal; then in the 1990s gas power generation rapidly replaced coal-fired power stations. However, in 2000 natural gas production peaked and in 2004 the UK became a net importer of natural gas. As Figure 1 charts, since then domestic production has declined at a faster rate than demand, the net result being a growing level of import dependence. In 2018 the UK imported 48.5 per cent of the natural gas that its consumed.

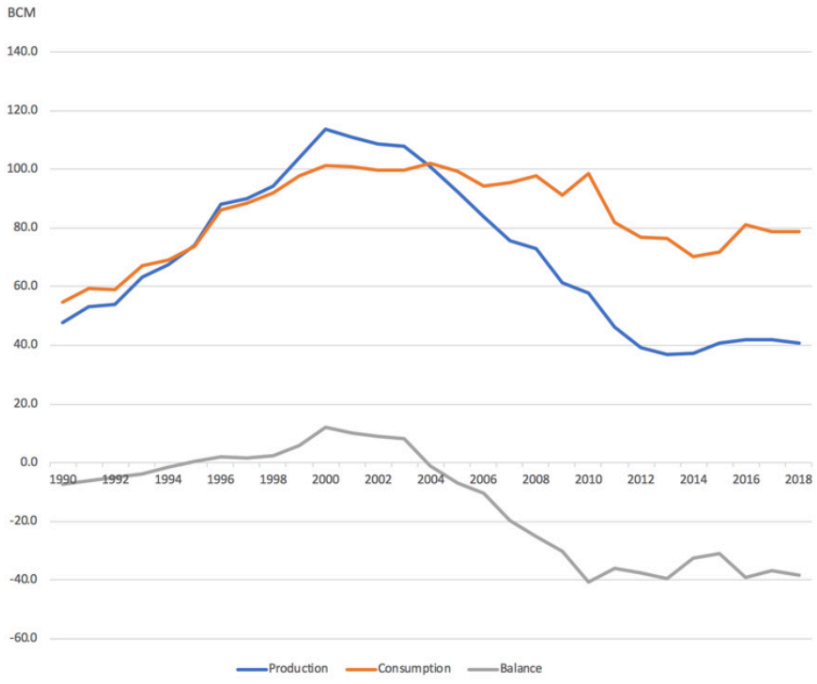

Figure 1: The UK's Gas Balance 2009-2018 (BCM)
Source: calculated from BP (2019)

Growing import dependency is not itself a source of energy insecurity, but it does expose UK consumers to price volatility in the wider European gas market and global LNG markets. It also exposes them to geopolitical events that might

constrain supply—for example, in the past, disputes between Russia and Ukraine have threatened pipeline supplies to Europe, and, more recently, frictions in the Persian Gulf have threatened the transit of Qatari LNG through the Straits of Hormuz. However, recent gas supply emergencies have been the result of technical failure (the Forties pipeline in late 2017) and extreme weather events (the so-called 'Beast from the East' in March 2018) (Bradshaw & Solman 2018). It is also worth noting that Sterling's devaluation as a result of Brexit has increased the cost of importing gas; furthermore, a hard Brexit and departure from the EU's Single Energy Market could potentially increase the cost of imported gas to consumers.

In anticipation of growing import dependence, in the late 1990s and early 2000s the gas industry invested in new pipeline infrastructure to connect Norwegian offshore production to the UK, and to connect the UK's pipeline network to Continental Europe; it also invested in the construction of three LNG import terminals. The net result is that the UK's import infrastructure is more than adequate and connects to a diverse source of supplies. Figure 2 shows the different sources of supply into the UK.

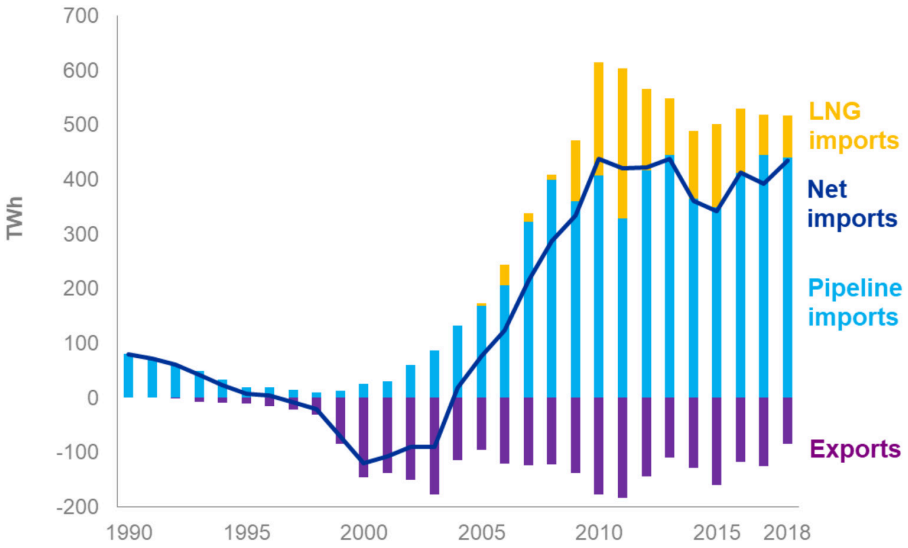

Figure 2: UK Trade in Natural Gas, 1990-2018
Source: BEIS (2019b: 26)

Today, the UK imports gas from three sources: pipeline gas directly from offshore fields on Norway's continental shelf (NCS); from the Continental European gas market via two interconnector pipelines—IUK that connects to Belgium and BBL that connects to the Netherlands; and from the global LNG market via three LNG terminals: Grain, at the Isle of Grain in Kent, and South Hook and Dragon at Milford Haven, in Wales. The balance of supplies varies depending on market conditions, but Norway is the most significant source of supply. Over the last five years (2014-18), on average, 66.6 percent of UK gas imports have come from Norway, 8.2 per cent from the Netherlands via BBL, 3.3 per cent from Belgium via IUK and 21.6 per cent as LNG (BEIS 2019c). The LNG component is the most volatile as it is dependent on the price and availability of supply on a global scale. Traditionally, deliveries of LNG have tended to be counter-cyclical, coming in the summer months when demand was slack in Asia and serving as a form of inter-seasonal storage. However, in 2018-19 there have been more substantial deliveries throughout the winter months, with lower summer deliveries. This may reflect changing global market conditions with LNG supply exceeding demand (National Grid 2019c). Until recently, Qatar has been the dominant source of LNG imports—over 90 percent—but in recent years supplies have been more diverse and now include imports from the Yamal LNG project in Russia's Arctic, as well as LNG from the United States (US). In 2016, Qatar accounted for 99.7 per cent of the UK's LNG imports, in 2018 that share had fallen to 40.5 per cent, with 21.4 per cent coming from Russia and 16.7 per cent from the US. Data up to the end of October 2019 suggest a return of Qatari LNG, reaching 63 per cent across the first three quarters of 2019, but deliveries continued from Algeria, Russia and the US as the level of LNG imports also increased to compensate for interruptions to the delivery of Norwegian pipeline gas (BEIS 2019d).

In recent years a number of studies have assessed the UK's gas security of supply. On an annual basis, BEIS and Ofgem produce a *Statutory Security of Supply Report*. Their 2019 report (BEIS & Ofgem 2019:21) concludes that:

GB's gas system has delivered securely to date and is expected to continue to function well, with a diverse range of supply sources and sufficient delivery capacity to more than meet demand. The UK Continental Shelf (UKCS) remains a major source of gas in the GB market, with the remainder imported from a variety of sources, including pipelines from Norway, interconnection with the Continent through the IUK and BBL pipelines and some of the largest liquified natural gas (LNG) import infrastructure in Europe. There are a range of future supply outlooks, but all show sufficient gas available from the combination of domestic, regional and global markets.

In 2017, Cambridge Economic Policy Associates Ltd. (2017: 3-4) conducted a review of gas security of supply within Great Britain's gas market from the present to 2035. Their main findings were:

- The GB system is resilient to almost all significant individual shocks under normal demand conditions.
- Where there is an extreme shock to global LNG markets, GB demand can be met if GB consumers are willing to pay for it.
- GB demand for gas will be met in circumstances where there is an extreme disruption to Russian gas supplies to Europe if GB customers are willing to pay for it.
- As long as customers are willing to pay sufficiently for scare gas supplies, only in the most extreme (and highly unlikely) scenario...considered...might there be some unmet demand.

They stressed that 'price is the primary determinant of whether sufficient gas is available to meet GB demand.' This highlights the crucial relationship between physical security of supply and price security of supply; UK customers can have secure gas as long as they are willing to pay the price necessary to attract supplies to the GB market.

Naturally, the increasing need to import natural gas has had an impact on the UK's balance of payments as more of the money spent to secure gas supplies goes to foreign suppliers. Figure 3 shows the changing UK balance of payments in relation to natural gas trade. The changing cost of imports is a function of the volume of gas imported, the price of gas in a given year and the exchange rate between the pound and the currency in which the imported gas is purchased, all of which are variable. In 2018 the net cost of gas imports to the UK was nearly £8.9 billion.

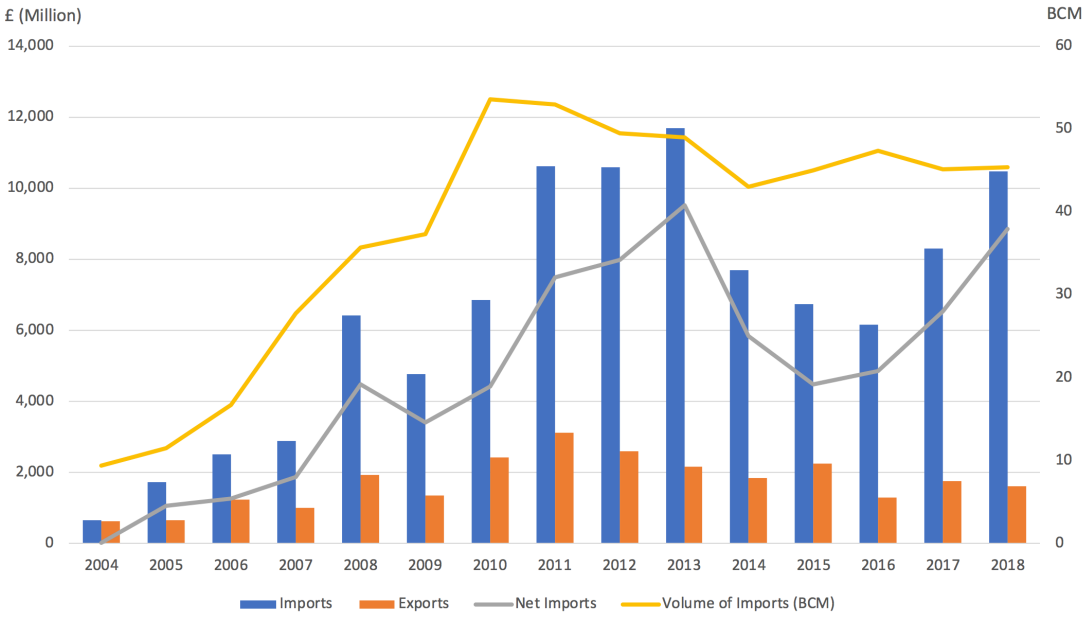

Figure 3: UK Natural Gas Balance of Payments, 2004-18.
Source: National Grid 2019b & HMRC 2019.

The scale of the UK's future gas security of supply challenge is the product of two variables: first, the future role of gas in the UK energy mix (demand); and second, the future of domestic gas production in the UK, both onshore and offshore. Both of these variables are subject to a good deal of uncertainty. The UK Government, through the Oil

& Gas Authority, is seeking to achieve 'maximum economic recovery' from the remaining reserves on the UKCS. Marshall Hall (2019) at the Oxford Institute for Energy Studies has produced a detailed analysis of prospects for gas production from the UKCS. He notes that gas production is sensitive to oil price and prospects for investment in oil as almost all gas production in the UKCS is associated with oil. He expects gas production to continue at about 40 bcm until 2021 and then fall to 33 bcm by 2024. The OGA's current projections for longer term production are presented in Figure 4, alongside the latest gas demand projections from BEIS.

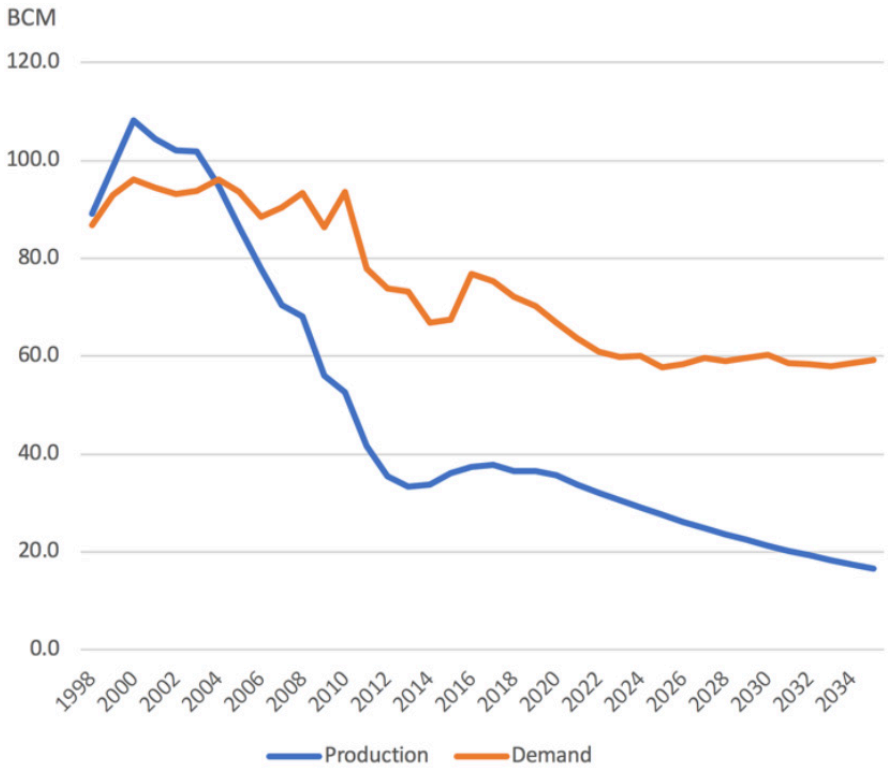

Figure 4: OGA Gas Production Projections and BEIS Gas Demand Projections to 2035
Sources: OGA (2019a) & BEIS (2019e)

Gas demand is projected to plateau, but production will continue to decline. The net result will be growing import dependence, up from around 48 percent at present to 57.6 percent by 2025, reaching 60.2 per cent by 2030. These projections do not allow for future onshore shale gas production. In their 2018 *UK National Risk Assessment on Security of Gas Supply* (BEIS 2018:34), BEIS noted that: "The development of a successful UK shale gas industry has the potential to improve investment prospects for the production sector in the long-term. It could also create whole new British industry, provide more jobs and make us less reliant on imports from abroad." However, as they go on to explain: "...it is not yet known whether it will be possible to commercially or technically extract shale gas in the UK." For that reason, they do not assume any contribution from UK-produced shale gas in their assessment of gas security of supply.

The Shale Gas Opportunity

As is made clear below, based on resource estimates, the UK has the opportunity to create a shale gas industry (BGS 2013), the questions are whether it will, and if so, what type of industry? The possibilities have been described as everything from a cottage industry (Davies in House of Lords 2013:128) to a revolution (Cuadrilla in House of Lords 2013:65). The former would presumably see occasional wells providing a small-scale production source similar to the role currently played by UK onshore oil production – which provides less than two per cent of the crude oil consumed in the UK (BEIS (2019f)). The latter would be akin to the United States' experience, where domestic gas production increased by 58% in the period 2007-2018 with the country becoming a net exporter (EIA 2019).

It is recognised that the largest shale 'play' in the UK, and also the most likely to be commercialised, is the Bowland-Hodder area spanning the north of England. Most of what we know about this shale play comes from the British Geological Survey (BGS) report conducted in 2013 (BGS 2013) for the then Department of Energy & Climate Change (DECC). They split

the area into two sections, the upper unit and the lower unit. They found that the upper unit had been more thoroughly investigated and looked very similar to several of the North American shale fields. The majority of the potential for shale gas in the UK came from the little studied lower unit (roughly 80% of total reserves) (BGS 2013:3). These estimates have not been revised since 2013 as there has been very little activity – exploratory drilling - that would inform such a revision. One of the key observations about shale formations is that they are highly heterogeneous (BGS 2013:6), therefore, a number of test wells will need to be sunk across the region in order to gain a clear picture. At present there is little physical evidence to support or disagree with the estimates produced by the BGS. The BGS has around 15,000 onshore cores within its stores (BGS 2019) – although only 64 of these are to the required depth to feature shale deposits (BGS 2013:11). To date, very little testing of the shale deposits within these cores has been carried out as historically the shale was seen as a barrier layer for trapping hydrocarbon deposits rather than a hydrocarbon bearing resource.

The BGS resource estimates contain three sets of figures. The Central estimate has a 50% chance of being exceeded. This is bounded by high and low estimates with low having a 90% chance of being exceeded and high having a 10% chance of being exceeded. The table below shows the fully modelled range of possibilities.

Table 1: BGS estimate of total gas in place within the Bowland-Hodder Shale play.

	Total gas in-place estimates (tcf)			Total gas in-place estimates (tcm)		
	Low (P90)	**Central (P50)**	**High (P10)**	**Low (P90)**	**Central (P50)**	**High (P10)**
Upper unit	164	264	447	4.6	7.5	12.7
Lower unit	658	1065	1834	18.6	30.2	51.9
Total	822	1329	2281	23.3	37.6	64.6

Source: BGS 2013:3.

The BGS also collate external estimations of economically recoverable resources for the purpose of international comparison. They quote a figure of 538bcm for the UK (BGS 2013:10). Whilst this is a sizeable amount of gas it only equates to around 20 per cent of everything that has, and will, come out of the North Sea (BGS 2013:47). Even at the top end of the BGS estimates total gas in place is 64.6 tcm, which would still be unlikely to see production exceeding domestic demand for any substantial period of time.

This is important because one of the decarbonisation pathways being explored is the production of hydrogen, through the conversion of natural gas using steam methane reformation (SMR) twinned with Carbon Capture Usage and Storage (CCUS). In National Grid's Net Zero sensitivity analysis, UK natural gas consumption would increase compared to present demand out to 2050 (National Grid 2019a). The Committee of Climate Change's (2019: 252) Net Zero report sees a continued, but more modest, role for gas to 2050 and beyond: "Our scenarios that achieve a net-zero target suggest a decline in gas consumption of 32% by 2050 (reaching close to 600 TWh [61.4 bcm]). Significant reductions in natural gas consumption across buildings, industry and power in our net-zero scenarios are somewhat offset by new demand for gas to produce hydrogen." This, therefore, prolongs the relevance of the gas trilemma to UK energy policy out to 2050, if not beyond. This relates to where the money used to pay for UK gas supplies is going to end up – in the UK or abroad – as well as arguments relating to the offshoring of emissions (i.e. life-cycle emissions from LNG and long-distance pipeline supplies being higher than domestic shale gas production (Stamford 2020)). Thus, gas can play a role in the transition to net-zero and it is therefore not a simple argument of green renewable growth versus dirty gas atavism.

Irrespective of how gas is going to be used in the future, international projected demand growth is still strong (IEA 2019). This, twinned with the success of the US shale industry, may help to explain why since 2008 the OGA has seen interest in onshore petroleum exploration and development licenses (PEDLs) increase during their regular licensing rounds. The 13th round in 2008 saw the first interest in the Bowland-Hodder shale play with 93 licenses issued across the UK (National Archives 2019). This interest then increased further during the 14th Round in 2015 when another 93 licences were issued covering 159 blocks (OGA, 2015a). Figure 5 below shows the licenses acquired in these areas during the two rounds.

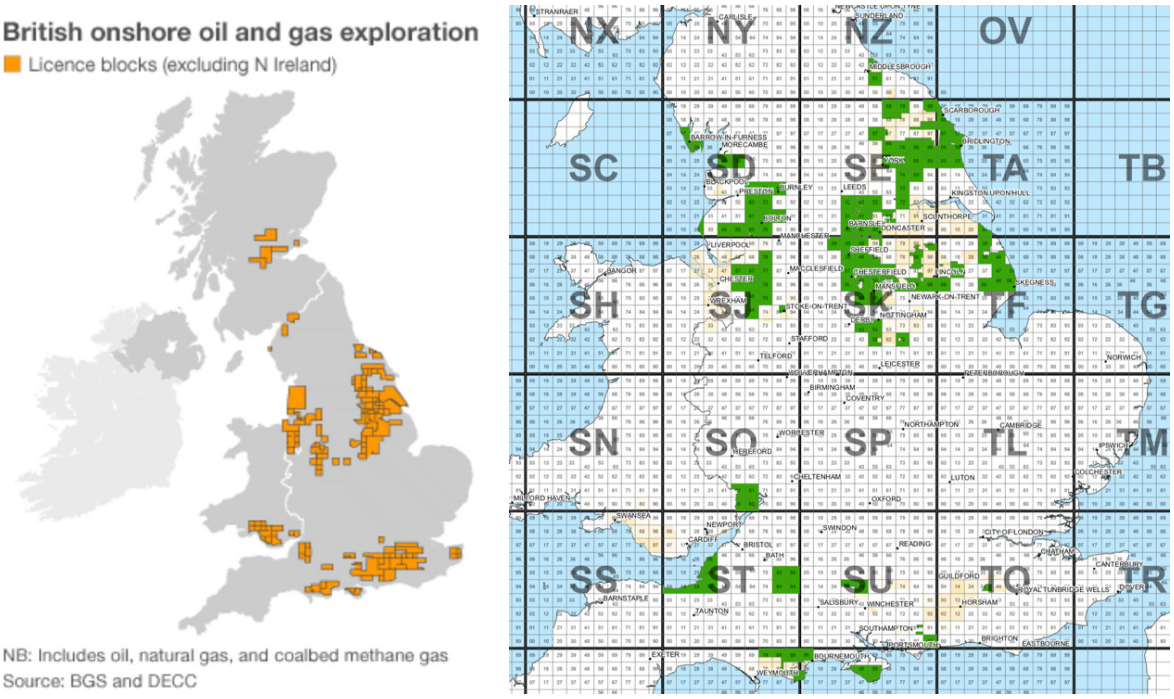

Fig 5: Onshore Licence Blocks released for Exploration & Development (2008 (L) and 2015 (R) – shown in green with previously issued, active licences underlaid in yellow).
Sources: Left – (IGas 2013, B2); Right – (OGA 2015b)

Analysis by the BGS (Figure 6) suggests that the UK is still in the first phase of five when it comes to developing a shale gas industry. Perhaps crucially, establishing whether or not the resources exist is far from the most difficult of the five stages (BGS 2013, 7), meaning that the UK still has a long way to go before commercial production could begin. Because the five stages are not discrete, the UK is already grappling with the difficulties of establishing a regulatory framework to manage the environmental impact of shale gas production. The clearest example is in establishing the Traffic Light System (TLS) used to monitor and manage the impacts of induced seismicity (OGA 2019b). An initial limit of 0.5 on the Richter Scale was set but the industry has argued that this has made it impossible to fracture wells fully, which hinders the commercial extraction of hydrocarbons (UKOOG 2019b). This was observed in the case of both hydraulically fractured wells at Preston New Road. The PNR1-z well saw two of 41 stages fully fractured and propped (Cuadrilla 2019a). The PNR2 well saw six of 45 stages fractured and propped prior to operations being halted (Cuadrilla 2019c).

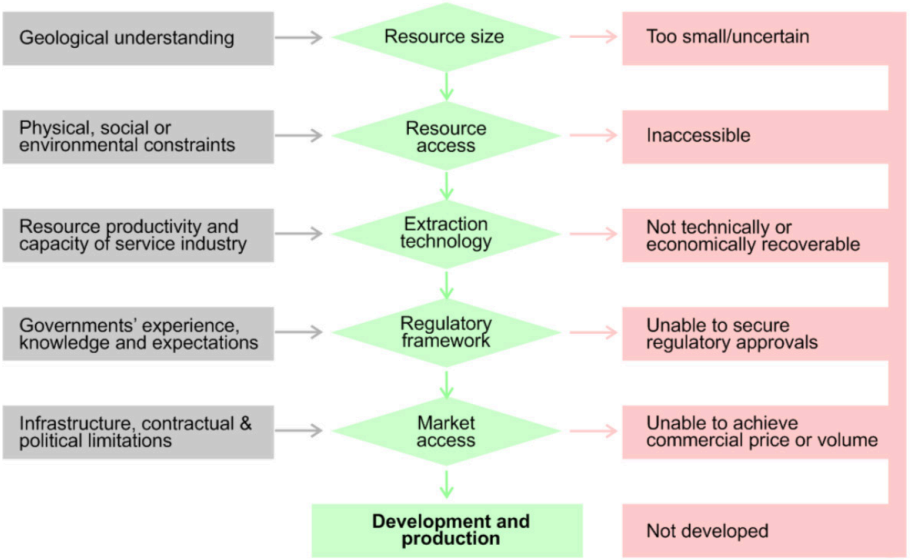

Fig 6: BGS Five Stage Diagram of Shale Gas Industry Development
Source: BGS 2013:7.

Scenarios for Shale Gas Development

Due to the lack of exploration, it is difficult to determine accurately several of the key factors in the latter stages of the BGS analysis (Fig 6). These factors influence the extent to which any future UK shale gas industry will emerge. This uncertainty is demonstrated through analysis of the various reports that have been commissioned looking at the possibilities for a UK Shale Gas industry (Table 2).

As is shown in Table 2, there is a great deal of variation in the estimates of even the most basic figures. There is, however, some consensus. Since the publication of the BGS report (2013) all of the reports have used their estimates of resources. There is also a consensus that wells will produce over a 20-year timeframe (with the exception of Jones, 2018 – which assumes 15 years). It should be noted that Table 2 does not provide an exhaustive list of all reports on this subject since 2014, rather it shows reports by a variety of authors since 2013 in order to illustrate the breadth of predictions.

Using the figures from Table 2, estimates can be produced for a high and low potential UK shale gas industry production range between 2020 and 2050. Most of the reports assume a profitable lifespan of 20 years per well and that they will be sunk over a period of time. If we assume that all wells are sunk between 2020 and 2030 (for the sake of simplicity) this means that the last well will finish producing in 2050.

Table 2: Summary of Reports concerning UK Shale Gas Potential

Report	IoD (2013)	AMEC (2013)		Ricardo AEA (2014)	Jones (2018)	UKOOG (2019a)	Summary of Range
Scenario	**Central**	**High**	**Low**	**Medium**	**Central**	**Central**	
Pads	100 (p.127)	30-120 (p.30)	30-120 (p.30)	310	1020 (p.12)	100 p.11	30 - 1020, with 100-300 being sensible high and low estimates.
Wells/pad	10 (p.127)	12-24 (p.30)	6-12 (p.30)	10 (p.66)	6 (p.10)	10 (p.11)	Ranges from 6-24 with 10 being the median.
Laterals/well	4 (p.127)	1	1	1 (p.61)	1 (p.10)	4 (p.11)	The general consensus is for only 1.
Total production per well	356mcm (p.16)	84mcm (p.x)	84mcm (p.x)	57 mcm (p.62)	57 mcm (p.10)	155mcm per lateral p.3	57-364 mcm with a median in the 80-150 range. If the IoD outlier is removed the average is closer to 100mcm.

Sources: Detailed in Table.

The number of pads required varies widely depending upon the authorship of each report with industry focussed ones—IOD & UKOOG—reporting a lower number of pads for a higher level of production and an NGO backed report (Jones 2018) giving a higher number of pads for a relatively low level of production. This reflects the relative positions of the two interest groups, with industry wanting to suggest that significant production can be achieved with limited impact and the NGO community the reverse! There is little consensus between the reports, but 100 and 300 pads make for sensible high and low estimates. The number of wells per pad follows a similar path but with most reports estimating around 10 wells per pad. With regard to laterals per well, all reports work on the basis of one, with the exception of UKOOG, who estimate four. Given the general consensus we shall assume one.

As regards production per well, it is only recently that a flow-test has taken place, as a result, UK specific data is very thin on the ground. Whilst the UKOOG report (2019a) is the only one to use actual UK flow data, it comes from one well

and relies on scaling-up data from Cuadrilla's Preston New Road site where they report that only two of 41 stages were hydraulically fractured – N.B. the latest data from the PNR2 well-test does support the initial flow-test from PNR1-z (Cuadrilla 2019c). The reasons for this are discussed below. This estimate, therefore, needs to be treated with extreme caution due to possible inaccuracies in the scaling up process and the heterogenous nature of shale plays. It should be noted that UKOOG (2019a:8-9) do try to mitigate against these problems by producing a range of possibilities. On that basis an estimate of 90-110 mcm per well over its lifetime would not seem to be an unrealistic figure to use. Combining these figures would see a high estimate of 330 bcm and a low figure of 90 bcm produced by a UK shale gas industry between 2020 and 2050.

If we combine these figures with those of National Grid's *Future Energy Scenarios* (FES) (2019b), which provide a range of future possibilities for gas consumption, we can build a rudimentary picture of the impact that this type of industry could have on future UK gas production, and therefore imports. National Grid has produced two scenarios that would see the UK reduce its greenhouse gas emissions 80% from 1990 levels by 2050. These see UK gas consumption decline from 80 bcma in 2018 to between 26 bcma (***Community Renewables***) and 63 bcma (***Two Degrees***) by 2050 (National Grid 2019a). Using the higher estimated production of 330 bcm, this would only contribute between 17 per cent of cumulative consumption (using National Grid's ***Two Degrees*** estimate of total consumption over this period of 1.969 tcm) and 22 per cent (using National Grid's ***Consumer Renewables*** Scenario projection of 1.503 tcm) of cumulative gas consumption (National Grid 2019b). Therefore, whilst there is a great deal of uncertainty in terms of the actual figures, the general message seems to be clear: should the UK wish to have a shale gas industry its role will be to mask the declining production of the UKCS and displace a limited quantity of imports. It will not be a UK shale gas revolution, but rather an exercise in slowing the increase in import dependence, thereby improving the UK's Balance of Payments.

Current Status of the Shale Gas Industry in the UK

At present, only the Cuadrilla site at Preston New Road has completed a flow-test, following horizontal drilling and the hydraulic fracturing of two shale gas wells. This is a long way behind what the UK Government had originally foreseen as the likely timescale for progress within the shale gas industry as outlined in a report by the National Audit Office (2019). The report details that as recently as 2016 the Cabinet Office expected to have 5-20 hydraulically fractured wells by the middle of 2020 (Cabinet Office 2016:4) - three have currently been fractured. Whilst the first round of hydraulic fracturing by Cuadrilla - following the lifting of the 2011 moratorium - was completed without any seismic issues that far-exceeded the Traffic Light System (TLS), there was a failure to inject the required amount of proppant as a result of repeatedly having to stop in order to adhere to the TLS. This meant that only 2 of the 41 stages were fully fractured (Cuadrilla 2019a). Conversely, the second round resulted in the largest induced seismic event from hydraulic fracturing in the UK. The magnitude 2.9 tremor was larger than the event which caused a moratorium on hydraulic fracturing in 2011 (BBC 2019). A second moratorium on High Volume Hydraulic Fracturing was therefore announced in November 2019 citing the inability of companies to predict the size of seismic events prior to, or during, fluid injection (BEIS et al. 2019). At this point it is worth noting that this magnitude is below most of the thresholds in countries around the world with mature shale gas industries, with acceptable limits in the USA ranging from 2 - 4.5 and the limit in Canada being 4 (UKOOG 2019b:12). It was also below Cuadrilla's upper limit for seismicity in their fracture plan that was submitted to the Environment Agency where a maximum possible seismic event of 3.1ml was detailed (Cuadrilla 2019b). Nonetheless, drilling activity was suspended by the OGA; Cuadrilla have since demobilised the hydraulic fracturing equipment and will need new planning permissions if they plan to do any further drilling at the site.

Whilst it is possible for exploratory and appraisal work to continue whilst the moratorium is in place it is unlikely that the industry will be looking to invest heavily whilst such uncertainty remains. Therefore, should the moratorium be lifted, the next stage in the development of the UK shale gas industry will be to establish the extent and quality of the resources. Between the two moratoria the rate of progress has been slowed by significant public opposition, particularly in the vicinity of well pads, that has complicated gaining the local planning approvals required to carry out drilling operations (Hawkins 2020). The campaigners, that combine national environmental organisations and local community groups, have been very effective in slowing down the approvals process and testing decisions in the courts. They have also mounted protests at the drilling sites, causing local congestion, attracting media attention and consuming significant policing resources. At the General Election in June 2017, only the Conservative Party supported shale gas development, and had continued to do so in government; the Labour Party promised to ban hydraulic fracturing and the Liberal Democrats opposed it, they have since called for an EU-wide ban. In addition to all three main parties opposing high volume hydraulic fracturing at the 2019 General Election, there are already *de facto* bans in place in Northern Ireland, Scotland and Wales and the current level of central government intervention in England is clearly at odds with the intent of the Localism Act (2011) to give people greater say over what happens locally - although the government did withdraw its proposal to

include shale developments under the Nationally Significant Infrastructure Projects legislation as part of the moratorium (Cotton 2020). Given that the current moratorium only bans high volume hydraulic fracturing and that there is scope for it to return under the current Conservative Government should the geoscience develop sufficiently, there is still a high level of uncertainty that only adds to the precarity of an industry that is struggling to make the case for further investment to support exploration. Below are details of the level of activity in each quadrant of the Bowland-Hodder Shale up to the end of 2019. Given the introduction of the moratorium, the next step for a number of the projects is unclear.

North-West:

- Preston New Road: Cuadrilla have flow-tested two wells. The second caused the UK's largest hydraulic fracturing induced seismic event mid-way through injection (BBC 2019).
- Altcar Moss: Aurora are seeking consent to sink and fracture two exploratory vertical boreholes (Hayhurst, 2019a).

South-West:

- Ellesmere Port: IGas's flow-test application is subject to an appeal that is being presided over directly by the Secretary of State (Hayhurst, 2019b).
- Ince Marshes: IGas has said no further progress will be made with the planning application of this site prior to the conclusion of the Ellesmere port inquiry. (Hayhurst, 2018).

North East:

- Kirby Misperton: Following the sale of Third Energy there are now no plans to hydraulically fracture a well at this site (Hayhurst, 2019c).
- Woodsetts: Presently subject to a public enquiry which is being presided over directly by the Secretary of State (Hayhurst, 2019d).
- West Newton: Rathlin Energy have now drilled a second exploratory well at this site (Hayhurst, 2019e).

South East:

- Misson: IGas have drilled a borehole and announced that the results were "highly encouraging" (Hayhurst, 2019f).
- Tinker Lane: IGas failed to find the Bowland Shale and have abandoned the site with restoration work commencing in July 2019 (Hayhurst, 2019g).
- Biscathorpe: An independent analysis of the core drilled earlier in 2019 has been reported to show potential (Hayhurst, 2019h).

Even if sufficient scientific progress were to be made, in order to allow the moratorium to be lifted, further planning approval is required for production to start. It is therefore highly unlikely that commercial shale gas production will start in the UK during 2020. Even if it does, at the current rate of progress, the chance of a meaningful number of wells being in operation prior to 2025 seems rather limited. With reference to Figure 6, at present, the UK (England) is still in the early stages of confirming its shale gas resources and reserves. In addition to this, the moratorium means that this part of the development process is unlikely to be completed soon. Given the present situation and the slow progress between the two moratoria it is likely to be a very long journey before a shale gas industry reaches maturity, if it ever does.

Conclusions

This review has addressed three issues: the current status of the UK's gas security; the various assessments of future shale gas production potential; and, thirdly, the future role that domestic shale gas production might play given the UK's future need for natural gas in the context of achieving net zero emissions by 2050.

On the first issue, it is clear that if the rate of gas production from the UKCS continues to fall faster than UK gas consumption, more gas will have to be imported. This may raise energy security concerns, though the UK benefits from a more than sufficient import infrastructure and has a diversity of supply options; it will certainty have an impact on the UK's balance of payments going forward. The growing reliance on imported gas—particularly LNG—will also increase the overall carbon intensity of the gas consumed by customers in the UK and could be seen as offshoring emissions.
On the second issue, the BGS survey suggests that there is a significant amount of gas-in-place across the north of England; however, although Cuadrilla is very positive about the findings of its drilling activities at PNR, the very

limited amount of exploration and appraisal activity to date means that there is no comprehensive assessment of the commercial reserve base. This means that any assessment of the scale of future shale gas production in the UK must be treated with extreme caution. The bottom line is that without an extensive programme of exploratory drilling and flow testing it is not possible to reach a reliable assessment of the industry's commercial potential.

On the third issue, recent studies by National Grid (2019b) and the Committee on Climate Change (2019) suggest that natural gas has a role to play in the UK's low carbon transition. Although the future level of consumption is uncertain, what is clear is that the role played by natural gas in the UK's energy system will have to change significantly and the majority of gas consumption will have to be decarbonised via the use of CCUS and the production of hydrogen. In such a scenario, if considered socially and politically acceptable and economically viable, domestic shale gas production could have a role to play and, if carefully regulated, could provide gas with lower life-cycle emissions compared to imported pipeline gas and LNG. Equally, should shale gas not be developed, the implications are clear, the UK will have to pay more to foreign suppliers of natural gas with the attendant geopolitical and environmental concerns.

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Postscript

This postscript presents some early observations on the likely implications of the oil price war and Covid-19 pandemic, for UK energy security and shale gas development. Global gas markets were stressed even before the current crisis. Surging LNG production and weakening demand had resulted in low prices and a surge in supply to the UK and the rest of Europe. In 2019, the UK imported 18.7 bcm of LNG, accounting for 39% of gas imports and 20% of total supply, double the volumes imported in 2019. So far, natural gas has not been as hard hit as oil by the demand crisis, but prices continue to fall, and we can expect Europe's LNG and gas storage capacity to fill up. The UK is in an ambiguous position as it is a producer, exporter and importer. Today oil and gas account for 75% of our energy demand and UKCS production is enough to meet 63% of that. In 2019 the UK imported 49% of its gas needs. A prolonged period of low prices would be good for imports, but very bad for sustaining production from the UKCS. More worrying is whether the UKCS can attract the future investment needed to ensure the maximum economic recovery required by the UK Government, as well as the demands of net-zero. The result could be an even more rapid decline in UKCS production and a greater reliance on imports. Before the crisis, the latest OGA forecasts predicted by 2030 a more than doubling of the UK's oil import dependence to 54% and for gas an increase to 67%. Does this present an opportunity for domestic shale gas? It seems unlikely, most shale companies in the UK are small and may not have the resources to survive a deep economic recession, very low gas prices will also challenge the economics of future shale gas production.

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