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PROOF OF EVIDENCE

of

Professor Kevin Anderson (PhD, CEng, FIMechE)

Chair of Energy and Climate Change,School of Mechanical, Aerospace and Civil Engineering

University of Manchester

Deputy Director of the Tyndall Centre for climate change research

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For a public inquiry into appeals by Cuadrilla Elswick Limited and Cuadrilla Bowland Limited concerning Exploration Works at:

1) Roseacre Wood: APP/Q2371/W/15/3134385; LCC/2014/0101

2) Preston New Road: APP/Q2371/W/15/3134386; LCC/2014/0096

On behalf of

Friends of the Earth

Contents

1. Introduction

1.1 My name is Professor Kevin Anderson. I have examined issues around energy and climate change within the Tyndall Centre (the UK's leading interdisciplinary and academic climate change research centre) since 2001. Prior to moving to academia in the mid-1990s I worked for a decade as an engineer in the petrochemical industry.

1.2 I am the co-author on a range of reports appraising the climate change and environmental impacts of shale gas, and have undertaken a quantitative assessment of the 'exported' emissions embodied in coal displaced, in part, by shale gas in the USA. I was commissioned by the European Parliament Petitions Committee to review the 'low carbon' credentials of unconventional natural gas and have acted as a peer reviewer for the Department of Energy and Climate Change report on the same topic. I am regularly asked to present on the implications of shale gas for climate change targets and obligations, most recently at an international Chatham House conference and in the House of Commons at an 'All-party parliamentary group on unconventional oil and gas' seminar.

1.3 As a commissioner on the Welsh Government's 'climate change commission' (CCCW) I provide scientific guidance to the commission directly, advice that is subsequently used to inform the commission's guidance to the Welsh Government. In addition to this formal role, I periodically give written and oral evidence to the Environmental Audit Committee and the Energy and Climate Change Committee, and provide *ad hoc* advice to DECC, DEFFRA, the UK Committee on Climate Change (CCC), and the EU Commission and Parliament. I regularly am asked to present at the annual Party conferences, give seminars to “All-Party Groups” and engage across a breadth of industry stakeholders, NGOs and wider civil society groups.

1.4 I attended both weeks of the Paris COP21 event as a scientific ‘observer’, presenting at a range of formal side events and engaging widely with other scientists, policy makers and media. Several scientific colleagues and I carefully scrutinised the evolving drafts of the Paris text, making clear and public assessments during packed press conferences. I was commissioned by Nature to provide a personal evaluation of the final text of the Paris Agreement.

1.5 I am providing evidence at the behest of Friends of the Earth. In so doing I am acting as an independent expert offering my (pro-bono) services based on my academic and industrial experience.

1.6 All views contained within this statement are attributable to the author and do not necessarily reflect those of researchers within the wider Tyndall Centre or the University of Manchester.

2. Three Headline Conclusions

2.1 The UK government's current choice of carbon budgets is open to criticism, as it arguably falls far short of what is necessary to deliver on its 2°C obligations. Nevertheless, taking the current carbon budgets as setting the requirements within which the government must act, the basic maths of the situation make clear there can be no significant and long-term role for shale gas either in electricity generation or heat production. Based on relatively conservative assumptions, no more than 4% of the BGS central "gas-in-place" estimate for the Bowland Shale can be combusted between 2025 and 2050 if the emissions from this source alone are not to exceed the UK government's existing carbon budget **[CD 41.31,** page 13] .

2.2 In relation to electricity generation, the Committee on Climate Change (CCC) has demonstrated how the average emissions of all of the UK electricity generation need to be in the region of 50gCO2/kWh by 2030 [**CD 41.13,** pages 38 and 39]. Put simply, the 50gCO2/kWh limit relates to the total of all emissions released in a particular year, divided by the total quantity of electricity generated by all power stations in that same year; this provides a clear average level of emissions for all power stations. It is this average that the CCC conclude is necessary by 2030 if the UK is to be on the right track to the deliver on its carbon budgets.

2.3 Emissions from gas-fired power generation are typically nine fold higher than this, at around 450gCO2/kWh. With highly optimistic assumptions, it may be possible to reduce this to nearer 350gCO2/kWh; still seven times higher than the mean carbon intensity required of a 2030 grid.

2.4 In terms of supplying domestic, commercial and industrial heat, both DECC and the CCC (and their appointed consultants, AEA) have been unable to develop low-carbon (~2°C) post-2030 scenarios that maintain a significant role for gas [**CD 41.14** and **CD 41.15**]. Gas emits approximately 200gCO2/kWh of heat produced, a level that, at scale, cannot be reconciled with even the UK's existing carbon budget.

2.5 **First Headline Conclusion:** Consequently, under the UK existing carbon budget, gas can only have a marginal and rapidly declining role in generating electricity post-2030.

2.6 This stark conclusion is still more challenging when assessing the proposed developments against a carbon budget adjusted to take into account the IPCC carbon budgets and the UK's commitments under the Paris Agreement.

2.7 Assessing the proposal as two exploratory-only projects, unrelated to the development of a UK shale gas industry, and considering the six year period over which Cuadrilla anticipate emissions arising:

2.7.1 then their own estimate of emissions represents between **5% and 9%** of Fylde's prorated proportion of the UK's carbon budget, adjusted to be consistent with the UK's commitment under the international treaty signed on 12 December 2015 by all 197 parties to the UN Framework Convention on Climate Change and known as the Paris Agreement;

2.7.2 relative to all of the UK, and again consistent with the Paris Agreement, the emissions are in the region of **0.007% to 0.01%** of total UK emissions for the six years Cuadrilla claim their two projects will be emitting gas.

2.8 Whether considered regionally or nationally, the emissions from this solely 'exploratory' project remain very high (it is worth noting that the concentration of carbon dioxide [CO_2] in the atmosphere is only around 0.04% of the total atmosphere – yet without it the global average temperature would be -18°C rather than the +15°C we actually measure). Furthermore, given the enormous challenge facing the UK's energy system in delivering mitigation consistent with the Paris Agreement, it is hugely disproportionate to allocate approximately 120 thousand tonnes of highly constrained emissions to a single non-productive project.

2.9 Only if the proposal was part of a larger shale gas programme could such a level of exploratory emissions be justified, and only then if the emissions of such a programme were consistent with the relevant five-year carbon budget (and, arguably, the UK's carbon budget constraints of the Paris Agreement).

2.10 **Second Headline Conclusion:** Taking the Preston New Road and Roseacre Wood exploration works together as one "project", the emissions from Cuadrilla's proposal as a stand-alone and non-productive project are very high. It is my judgement that these emissions, both at a UK and regional level are hugely disproportionate and cannot be justified within the tight UK carbon budget constraints consistent with the Paris Agreement.

2.11 Cuadrilla's proposal is self-evidently not a stand-alone project, but instead is an important and provisional phase of the UK's fledgling shale gas industry. Cuadrilla itself justifies the proposed exploration works using arguments about natural gas supply, energy security, government support for the shale industry, the economic impact of the production phase and national economic impact, all of which relate to production at scale and the creation of a UK shale gas industry. I address a number of these arguments below [Planning

Statements **CD 12.6,** pages 47-57; **CD 28.6,** pages 52-62]. Any reasoned analysis of the appropriateness or otherwise of the project's emissions must therefore consider it in relation to the anticipated role of the emissions from the UK shale gas industry in meeting the UK's commitments under the Paris Agreement. In this regard, the analysis is very clear.

2.12 **Third Headline Conclusion:** If the UK is to abide by the explicit commitment of the Paris Agreement to hold "t*he increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C*" [**CD 41.2**, Article 2 page 22; also pages 2 and 3] then there is no viable emission space within the UK's carbon budget for shale gas to fulfil even a transition role. This stark conclusion holds for shale gas in relation to electricity generation, as a source of energy for heating fuel or indeed as a transport fuel.

2.13 The method and quantitative analysis underpinning these three headline conclusions are presented in sections 4 and 5 below.

3. General Issues

Shale gas is a high-carbon energy source

3.1 It is often reported that natural gas has lower emissions per unit of energy than coal. Although the carbon content varies between them, and between production methods, it would be erroneous to regard any fossil fuel as "low carbon". Fossil fuels are by their nature high carbon energy sources with natural gas (almost identical to shale gas) comprising 75% carbon by mass, and consequently emitting large quantities of carbon dioxide once combusted[1].

Shale gas with CCS emissions still too high for "well below 2°C"

3.2 For the UK to deliver on its Paris commitments, there is a need to almost completely decarbonise the UK's energy system within the next two decades. Even a gas plus carbon capture and storage (CCS) energy pathway is unlikely to realise very low or zero carbon emissions and so will be severely restricted in the potential scale of deployment. For instance, gas plus CCS could not form the majority of an electricity grid with an emissions intensity of 50g/kWh(e),[2] as is UK's electricity generation decarbonisation target (a target that is anyway too high to be compatible with the newer Paris Agreement). Although not a dominant component of the emissions footprint of unabated gas, emissions from production may add a significant penalty of up to 20%, dependent upon the source and transport of the gas. This has particular implications for CCS where the capture process itself imposes an energy penalty, requiring more fuel and hence realising greater upstream emissions

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1 This is just a simple molecular weight calculation for CH4 , C=12, H4=4; so 8 out of 12 = 75%. And when combustion occurs the C reacts with O2 to become CO2. This calculation does ignore the very small % of VOCs etc.

2 The recommended average emissions intensity of the national grid by 2030 as proposed by the Climate Change Committee; see paras 2.2-2.3 above.

outside of the capture mechanism. As a result, Hammond et al (2013) estimate the final emissions intensity of electricity from gas CCS to be approximately 80g CO2e/kWh(e), approximately four to five times more than nuclear or renewable power per kWh of electricity generated [**CD 41.21**].

The EU ETS is a pre-Paris mechanism

3.3 The EU's emission trading scheme (ETS) is a mechanism intended to help efficiently reduce emissions from large point sources (powerstations, factories, etc.). As a mechanism it has it strengths and weaknesses, but whatever the different interpretations of these, the mechanism was not designed to meet the stringent carbon budgets accompanying the latest IPCC analysis. Specifically, the EU ETS is not intended to deliver mitigation in line with "well below 2°C", let alone the budgets associated with 1.5°C. Consequently. Whilst Cuadrilla's recourse to EU ETS to cover the emissions from flaring may satisfy procedural requirements, it is without scientific merit in relation to 2°C.

Disaggregating emissions to regions and even sectors

3.4 Whilst carbon budgets are typically considered at a global or national level, there are increasing examples of methods and analyses that disaggregate these emissions to devolved administrations, regions and even sectors, including by the UK Government [**CD 41.22**] DECC has produced a nationally consistent set of carbon dioxide emissions estimates at Local Authority level, in recognition of the "increasing emphasis" being placed on "the role of regional bodies and local government in contributing to energy efficiency improvements, and hence reductions in carbon dioxide emissions" [**CD 41.22**, page 5]. Clearly, DECC considers that estimates at Local Authority level are an appropriate metric to use to allow Local Authorities to track their

GHG emissions trends over time and to measure progress against any targets they have [**CD 41.22**, page 6]

3.5 There are a number of other examples. The Welsh government and Manchester City Council have commissioned two projects each to estimate the carbon budget and mitigation rates within their respective geographical boundaries [**CD 41.29**]. More widely, many European and some US cities have used the GRIP methodology to understand the options available to reduce their emissions in line with national headline commitments disaggregated to the city level [**CD 41.23**].

3.6 Whilst no formal protocol yet exists for disaggregating emissions, within national boundaries population is commonly used as at least one of the principal criteria; it is this approach that was used to derive the figures for Fylde presented within this this analysis[3].

Coal and/or gas – substitution or addition?

3.7 The most relevant metric in considering climate change is the cumulative amount of greenhouse gases released during the next century, particularly in the next thirty-five years where we have the most immediate influence over emissions. Not only is the carbon intensity of a fuel important but also the quantity of it being combusted and, therefore, the cumulative amount of CO_2 it contributes to the atmosphere.

3.8 A comparative per unit footprint is relevant only if the coal displaced by gas remains in the ground and is not combusted elsewhere. In practice, the net effect of displacing coal with gas depends upon the subsequent impact on

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3 National Indicator 186 was the previous assessment of local authority level data – see **CD 41.30**.

energy commodity markets and whether appropriate carbon constraints are in place. In the case of the USA, evidence suggests that during the rapid expansion of shale gas production, and corresponding price reduction locally within the USA, there was some displacement of coal use in electricity generation. Between 2005 and 2012 carbon emissions from energy use in the USA fell by 12%, in part due to a reduction in coal consumption of 25% in the same period [**CD 41.24**]. However, during the same time frame, much of the displaced coal production was sold on global markets, exported and burnt elsewhere. The 32% drop in EU coal import prices between 2005 and 2011 and an increase of US coal exports to the EU of 187% have been attributed to the reduction in the USA's indigenous demand for coal [**CD 41.25**]. Broderick and Anderson (2012) found that more than half of the emissions avoided in the US power sector may have been exported as coal [**CD 41.26**].

3.9 If monitored and policed effectively, the GHG emissions from shale gas operations within the UK could be captured and reported in respective national emissions inventories. If carbon budgets are adhered to, then no increase in national emissions should arise within their scope. However, this is unlikley to be the case for net global emissions. As DECC's then Chief Scientific Advisor concluded "*If a country brings any additional fossil fuel reserve into production, then in the absence of strong climate policies, we believe it is likely that this production would increase cumulative emissions in the long run. This increase would work against global efforts on climate change.*" [**CD 41.25**, page 33].

3.10 For a similar reason, the IEA reported in their World Energy Outlook 2011 supplement, "Are We Entering a Golden Age of Gas?", that a high-gas-use scenario would probably result in 3.5 °C warming, well beyond what is generally regarded as dangerous climate change [**CD 41.27**]. Their Chief

Economist, Fatih Birol, commented, *"We are not saying that it will be a golden age for humanity – we are saying it will be a golden age for gas, but only if problems with fracking are overcome"* [**CD 41.32**]

3.11 The science of global warming, the maths of our emissions to date and our Paris obligations to limit temperature increases to "well below a 2°C" rise, all lead to the clear conclusion that shale gas must remain in the ground if we are not to renege on the commitments to "secure radical reductions in greenhouse gas emissions" [CD48.1 paragraph 93]. The argument equally applies to all novel and additional sources of fossil fuels. Committing to any new high carbon infrastructure runs the risk of it not being used for its full design life and thereby becoming a 'stranded asset'.[4] Or worse, it locks the UK into extended dependency on fossil fuels, creating higher cost barriers for alternative energy sources to compete with and ultimately undermining the UK's long standing and high profile commitment to making its fair contribution to mitigate emissions in line with the 2°C threshold.

Energy security – 'supply' or 'services'?

3.12 The issue of energy security is open to considerable interpretation and ultimately not amenable to simple quantitative conclusions.

3.13 In practice, virtually all users of electricity are uninterested in the security of energy supply – the typical default framing of energy security. In contrast, what users desire is security of the services afforded them by energy; it is the services that matter directly and energy supply indirectly. This apparently

[4] A situation where "*environmentally unsustainable assets suffer from unanticipated or premature write-offs, downward revaluations or are converted to liabilities*" [**CD 41.28**, page 2].

nuanced distinction opens up a much wider framing of "energy security" and what constitutes appropriate approaches for addressing it.

3.14 Most energy services in the UK, whether it is travelling from A to B (or even specifically car travel), having a comfortable home temperature and humidity, enjoying a televisions programme, or chilling a beer – all are typically done using highly inefficient means. The mean car on the UK street has emissions of over 160gCO2/km, yet across all categories (excluding high power SUVs) there are over 200 model variants of standard-engine cars (i.e. not electric or hybrid) with emissions of under 100gCO2/km being sold at little to no price premium. The UK housing stock has a typical Energy Performance Certificate rating of D or below – yet retrofitting could see this rise to at least a B rating - with new passive house designs being zero energy. Televisions and IT equipment have huge variations in energy consumption for essentially the same level of service, - a situation that holds for refrigerators where an A rated design of the same size consumes in the region of 80% more energy than an A+++ alternative; again at very little price penalty.

3.15 If energy 'service' security is seen as a pivotal issue, then the most cost effective and long lasting means of improving it is to reduce the energy required to provide the service. There are many analyses that demonstrate factors of 4 or more improvements in mean efficiency levels at often zero or negative cost. However, what is often missing from such analyses is "Jevons' paradox" – or as it more commonly referred to in the energy realm – rebound. This is where money 'saved' through energy efficiency is then spent on further energy services. Amongst those living in fuel poverty this is a progressive response that is, at least in the short-term, to be welcomed. But amongst those already energy-rich this increases energy demand and undermines some of the security benefits of energy efficiency. Consequently, if energy service security is a genuine concern, a suite of carefully designed polices are required to ensure the gains intended are realized and that perverse outcomes are avoided, or at least mitigated.

3.16 Despite rebound issues, the potential for improving energy service security through efficiency improvements combined with sophisticated umbrella policies is very significant – and far more cost effective than simply increasing energy supply.

Shale gas and medium to long term [in]security

3.17 Shale gas development in the UK is probably the most publically contested source of energy – certainly it is on a par with nuclear, at least in terms of local opposition. This itself only adds to 'insecurity' of supply. Will it proceed or will it not; will it proceed here but not there; will it face ongoing public opposition. In a highly populated nation (England has a population density over three times that of China), extracting gas via a process that requires an enormous patchwork of industrial infrastructure (in contrast to say Wytch Farm in Dorset) will inevitably face opposition. Regardless of the cogency and legitimacy of such opposition, it will always play against issues of security of energy supply.

3.18 Shale gas emissions cannot be reconciled with the UK Governments existing and relatively weak carbon budgets and are still further incompatible with the Paris Agreement. This is another and potential devastating source of energy insecurity. Either, it will need to be abandoned soon after 2030, having not become well established until post-2025 (in terms of major production); or it will help catalyse a collapse of any international efforts to curb climate change. If the UK, one of the world wealthiest nations, with a highly educated workforce and a world leading renewable energy resource base, chooses to pursue another fossil fuel at the same time as it continuities to support its North Seas oil and gas industry – then it flagrantly is violating any of its climate change obligations. Such an evident dismissal of the fundamental issues of climate change can only serve to weaken international resolve – with the potential for higher temperatures, greater levels of global impacts and hence increased insecurity; including in terms of energy services.

4. Overview of Carbon Commitments

Analysis Based on the UK's Existing (pre-Paris) Framing of Climate Change

4.1 Prior to the fifth and latest report from the Intergovernmental Panel on Climate Change and the subsequent Paris Agreement, the UK Government's position on national levels and rates of mitigation was premised on the Committee of Climate Change's recommendations.

4.2 The Committee on Climate Change (CCC) built its case on the IPCC's fourth assessment report (2007) and the range of academic literatures that fed into that report. Moreover, their recommendations and the Climate Change Act 2008 were informed by the various European positions on climate change, for example, that *"[t]he EU must adopt the necessary domestic measures and take the lead internationally to ensure that global average temperature increases do not exceed pre-industrial levels by more than 2°C* [**CD 41.16**].

4.3 Despite the EU's clear position that it should *"ensure"* temperatures do not exceed 2°C, the CCC concluded, in light of the economic and political constraints under which it operated that it was not possible, as that time *"to ensure with high likelihood that a temperature rise of more than 2°C is avoided"*. More specifically, it noted that *"to limit our central expectation of temperature rise to 2°C, or as close as possible. In addition we propose an additional rule which is to reduce the risk of extremely dangerous climate change to very low levels (e.g. less than 1%). We have made the judgement that 4ºC this century would be this 'extreme danger' threshold"* [**CD 41.17**].

4.4 Clearly the CCC's starting position was not in line with the EU's *"ensure"* framing of 2°C, nor of the numerous international agreements to which the UK is a signatory; for example the Copenhagen Accord's clear objective *"to* *hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity".*

4.5 The CCC chose to offer the UK government two national and century-wide carbon budgets, along with a mid-century obligation of an 80% reduction in emissions by 2050. The two carbon budgets were related to a 56% and a 63% chance of exceeding 2°C and were subsequently divided into sequential five year budgets. The UK government opted for the less demanding budget of a 63% of exceeding 2°C. It should also be noted here that in deciding on the share of the global budget that should be apportioned to the UK, the CCC made virtually no quantitative allowance for those issues of equity repeatedly held by the UK government to be a key consideration.

4.6 To achieve even the UK's lax carbon budget (relative to the UK's repeated headline commitments) the CCC and DECC draw attention to two very important criteria.

4.6.1 First, that by 2030 the mean carbon intensity of electricity generation should be 50gCO2/kWh; the CCC has maintained this conclusion through various iterations of its analysis, including in the "Fourth Carbon Budget Review – technical report."

4.6.2 Second, as DECC notes in its "Strategic framework for low carbon heat in the UK" (2012) the role of gas in the provision of domestic, commercial and industrial heating is expected to have reduced significantly by 2030 [**CD 41.14**]. Moreover, all three of the post-2030 heating scenarios developed in the AEA report for the CCC, "Decarbonising heat in buildings 2030-2050", see a rapid phase out of gas [**CD 41.15**].

4.7 The implications of these two criteria for deciding on an evidence-based post-2030 cannot be overplayed.

4.8 Gas-fired electricity (combine cycle gas turbines, CCGT) typically emit around 450gCO2/kWh generated. This figure could be lower or higher by around 50gCO2/kWh depending on the efficiency of the particular plant and on whether life-cycle emissions are taken into account. To provide some perspective, the life-cycle emissions for mature renewables and nuclear are typically in the region of 5 to 15gCO2/kWh.

4.9 Set against a 2030 objective of grid emissions of 50gCO2/kWh, those from a typical CCGT are nine fold higher. Therefore, however viewed significant gas-fired electricity beyond 2030 cannot be reconciled with the Government's carbon budgets under the climate change act (still less the much more stringent budgets clearly implied in the Paris Agreement).

4.10 Turning to the post-2030 role for shale gas in relation to domestic, commercial and industrial heating, the situation is similar to that for electricity. Even for the UK's existing (and weak relative to 2°C) carbon budgets, there is a rapidly declining role for gas.

4.11 The broad thrust of both of the above positions holds should carbon capture and storage be considered. Lifecycle emissions from 'gas with CCS' will almost certainly be in excess of 80gCO2/kWh, with some estimating it could be significantly higher. Added to this, the UK government's more recent decision to renege on its manifesto commitment to support CCS, at the same time as supporting the Paris Agreement, further undermines what could only ever be a very marginal the role of CCS within the UK.

IPCC carbon budgets

4.12 In November 2014 the Intergovernmental Panel on Climate Change (IPCC) published their Climate Change 2014 Synthesis Report [**CD 41.3**]. Bringing together expertise from across the IPCC's working groups, the Synthesis Report provided a clear suite of "cumulative CO2 emissions" (carbon budgets) for a range of different probabilities of "limiting warming" to below a rise of 1.5°C, 2°C and 3°C (relative to an 1861 to 1880 baseline).

4.13 These carbon budgets remain the most authoritative source and should provide the foundation for any evidence-based policies around energy issues related to climate change (see Table 2.2 of the IPCC Synthesis Report [**CD 41.3** page 64]; copied below with the block arrows marking the most relevant rows to this proof of evidence).

Table 2.2 | Cumulative carbon dioxide (CO_2) emission consistent with limiting warming to less than stated temperature limits at different levels of probability, based on different lines of evidence. *{WGI 12.5.4, WGIII 6}*

Cumulative CO_2 emissions from 1870 in $GtCO_2$									
Net anthropogenic warming [a]	<1.5°C			<2°C			<3°C		
Fraction of simulations meeting goal [b]	66%	50%	33%	66%	50%	33%	66%	50%	33%
Complex models, RCP scenarios only [c]	2250	2250	2550	2900	3000	3300	4200	4500	4850
Simple model, WGIII scenarios [d]	No data	2300 to 2350	2400 to 2950	2550 to 3150	2900 to 3200	2950 to 3800	n.a. [e]	4150 to 5750	5250 to 6000
Cumulative CO_2 emissions from 2011 in $GtCO_2$									
Complex models, RCP scenarios only [c]	400	550	850	1000	1300	1500	2400	2800	3250
Simple model, WGIII scenarios [d]	No data	550 to 600	600 to 1150	750 to 1400	1150 to 1400	1150 to 2050	n.a. [e]	2350 to 4000	3500 to 4250
Total fossil carbon available in 2011 [f]: 3670 to 7100 $GtCO_2$ (reserves) and 31300 to 50050 $GtCO_2$ (resources)									

4.14 The headline carbon budgets for the temperature ranges of below 1.5°C and 2°C (<1.5°C & <2°C in the row with the blue arrow) are the focus of this analysis. The row signalled with the purple arrow provides the probabilities of staying below that temperature (for a more precise explanation of these probabilities see Notes b to e accompanying the Table 2.2 in the full IPCC report [**CD 41.3**]. The headline carbon budgets for each of these probabilities for 1.5°C and 2°C are provided in the row signalled with the orange arrow.

4.15 The carbon budgets are given in GtCO2, i.e. billion (Giga) tonnes of carbon dioxide. It is important to note the budget is for the period of 2011-2100; this is adjusted to allow for emissions between 2011 and 2016 in Section 4.

The Paris Agreement

4.16 In December 2015 all 195 member states (including the EU) of the United Nations Framework on Conference on Climate Change (UNFCCC) adopted the final text of the Paris Agreement [**CD 41.2**]. One of the principal aims of the agreement is to hold *"the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change"* [**CD 41.2,** Article 2(1)(a)].

4.17 The UK signatory to the Paris Agreement was under the auspices of the EU in full consultation with the UK delegation that also participated in the Paris "conference of the parties" (COP21). Moreover, early in the negotiations, when the leaders of the participating countries addressed the conference, the UK Prime Minister gave what was typically described as an impassioned speech outlining the importance of *"sticking to 2 degrees above industrial levels"* and the need for a *"binding legal mechanism"* to ensure the necessary action is delivered [**CD 41.7**].

4.18 Another important commitment within the Paris Agreement and of particular relevance to this proof of evidence is that *"Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties"* [**CD 41.2,** Article 4]. This explicit distinction between industrial and poorer and industrialising nations is important in determining how to apportion the global carbon budget between different nations.

Converting qualitative obligations into quantitative objectives

4.19 The language of various international agreements on climate change is typically framed in qualitative terms in relation to quantitative temperatures. The Copenhagen Accord is *"hold … below 2°C"* [**CD 41.5**]; the Camp David Declaration to *"limit… the increase … below 2°C"* [**CD 41.6**]; and now the Paris Agreement to stay *"well below 2°C"* – and importantly to *"pursue efforts to limit the temperature increase to 1.5 °C"* [**CD 41.2**]. In relation to all of these it would be disingenuous to suggest anything other than they require mitigation in line with at least a *likely* chance of remaining below 2°C. With its additional reference to pursuing efforts for 1.5°C, the Paris Agreement clearly implies a still more stringent likelihood, so at least a very likely chance of 2°C.

4.20 Within the IPCC's Guidance Notes to the authors of their latest report [**CD 41.10**], they provided a taxonomy of likelihoods that facilitate a translation of qualitative chances into quantitative probabilities. Based on Table 1 of the Guidance Notes [[**CD 41.10,** page 3] the language of the major international agreements on climate change, from Copenhagen onwards, clearly relates to a 66-100% probability of not exceeding 2°C. The Paris Agreement, with its reference to pursing 1.5°C as well as 2°C, suggests a still higher chance of the latter – more in line with a 90-100% probability of 2°C.

Table 1. Likelihood Scale	
Term*	**Likelihood of the Outcome**
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

4.21 Consequently, the sequential logic of the Paris Agreement leads to a carbon budget from IPCC's Synthesis Report of somewhere between 850 and 1000 GtCO2.[5] The lower end of this range equates to an "unlikely" chance of staying below 1.5°C (i.e. a probability of 0 to 33% of <1.5°C) with the upper end relating to a "likely" chance of staying below 2°C (i.e. a probability of 66-100% of <2°C).

Estimating the global energy-only CO2 budget for 2016-2100

4.22 The 850 to 1000 GtCO2 range is for all carbon dioxide emissions from all sectors for the period 2011 to 2100. Therefore in order to understand what emissions are available from 2016, it is necessary to subtract those emissions released between 2011 and 2016. Based on CDIAC data [**CD41.34**]. extrapolated out to include 2015, at least 150GtCO2 have been emitted since 2011; leaving a range of 700 to 850GtCO2 for the period 2016 to 2100.

4.23 Given this analysis relates specifically to the energy sector, it is necessary to remove projected deforestation and industrial process emissions for the period 2016 to 2100; the latter of which relates primarily to cement

5 This is a conservative range, as it does not truly represent the very clear language of the agreement – where the "well below 2°C" certainly implies much better than a one in three chance of exceeding 2°C, on which the upper end of this range is premised (i.e. 1000GtCO2).

production. It could be argued that these should both be considered at a national level, however, given the very clear equity steers within all agreements since the Copenhagen Accord, such emissions are more rightly considered as a global overhead. Wealthy industrial nations already have highly developed and cement-rich infrastructures – from the domestic and commercial built environments, to transport and energy networks, power stations and industrial facilities. Poorer and less-industrialised nations still have to construct their modern societies. Penalising them for their later development is inconsistent with the equity dimension of their various agreements. Similar arguments prevail for deforestation emissions, where most industrial nations have already benefitted from the land released through deforestation. Considering these emissions as a global overhead does not absolve those nations using cement and deforesting from responsibility. It does however reduce the burden and provide an incentive for all nations to encourage a global reduction in deforestation and the development of low-carbon cements (or alternatives).

4.24 Based on research recently published in Nature Geoscience an optimistic[6] interpretation of deforestation and cement process emissions for 2016 to 2100 are, respectively, in the region of 60GtCO2 and 150GtCO2 [**CD 41.62**]. Both of these figures are dependent on efforts to reduce emissions broadly in line with that required across the energy sector.

4.25 Combining recent emissions with those from deforestation and cement (process only) leaves an energy-only global CO2 budget of 490 to 640GtCO2 (i.e. rounded up to 500 to 650GtCO2) for 2016 to 2100.

6 Optimistic in assuming that a lot is achieved in curtailing deforestation and cement emissions, thereby giving a larger remaining budget for energy.

Apportioning the global budget to *Industrial* nations

4.26 This is undoubtedly an area where different interpretations of fairness and equity can give potentially very different results in terms of national carbon budgets. However, the Paris Agreement (and its international forebears) all draw attention to the importance of issues of equity and how poorer and less industrialised nations (hereafter referred to as industrialising nations) will need some significant period of grace in terms of decarbonising their energy systems. Specifically, they acknowledge that the peak in emissions from these poorer nations will be later than that within the wealthier industrial nations (hereafter referred to as industrial nations). Combine this equity criterion with the small and rapidly dwindling global carbon budget for 2°C (i.e. 500 to 650GtCO2) and the range of potential national budgets is very significantly constrained.

4.27 The approach adopted here builds on the pragmatic and open process of apportionment used in a range of analyses and high-level reports since 2011 [**CD 41.11 pages 20-44]**. Put simply, the approach recognises the highly constrained nature of the 2°C carbon budget and then asks, within such a constraint, what is the most ambitious peak date industrialising nations could achieve and what could they subsequently deliver in terms of mitigation rates. This permits a mitigation pathway to be plotted for these nations. It is worth noting here, that the emission profile of China dominates those of the industrialising nations. Furthermore, even at a per-capita level, China is undoubtedly wealthier than many of the so-called 'developing' nations. Consequently, an emission profile for industrialising nations will mask the fact that many poorer nations will have a peak in their emissions up to a decade after that of China.

4.28 Assuming an aggregate peak in emissions by industrialising nations of 2025, followed by a programme of rapidly ramping up mitigation rates to deliver around 10% p.a. by 2035, then the total emissions for 2016 -2100 would be at least 550 to 600GtCO2. Put simply, a mitigation agenda across the industrialising nations at a level of ambition far beyond anything discussed in Paris would nevertheless exceed the global (energy-only) carbon budget for a "very likely" chance of 2°C. That is to say, the political framing of the Paris ambition in terms of "well below 2°C" is no longer a viable goal. Even for the more lax carbon budget accompanying a "likely" chance of 2°C, the enormous scale of ambition assumed here for industrialising nations would still consume at least 85% of the global budget.

4.29 Based on the most optimistic estimate from above, industrialised nations have between 50 and 100GtCO2 to emit across the remainder of the century if they are to play their fair part in a "likely" chance of staying below 2°C.

What mitigation rates are required by the UK?

4.30 There are various approaches to apportioning the emissions budget for industrialised nations to the individual countries, ranging from relative population to grandfathering on the basis of current emissions. For the purpose of this analysis, a simple grandfathering approach is adopted and based on the latest emission values from the global carbon atlas website [**CD 41.34**] as part of the peer-reviewed Global Carbon Project's analysis. Industrialised nations are assumed here to be those captured under the umbrella label of Annex B.

4.31 Taking this approach, the UK's share of the 50 and 100GtCO2 budgets equate to 1.6 to 3.3GtCO2 for energy-only and for the period 2016 to 2100.

4.32 Taking at face value the Paris Agreement and the UK's recognition of it as the new framework for considering issues of climate change and mitigation, it is possible to calculate the rate of emission reduction required to meet the "well below 2°C" objective.

4.33 If the UK were to begin a programme of deep mitigation now, it would need to deliver over 13% reduction in emissions year on year – and potentially in excess of 20%. Even under the lower rate, by 2025 emissions of energy-only CO2 would have reduced by over 70% (c.f. 2016) reaching a reduction of almost 95% by 2035.

5. Assessment of the Projects' Carbon Emissions

Conservative emission assumptions

5.1 The analyses underpinning the headline conclusions set out in Section 1 above are premised on the emissions data provided by Cuadrilla, this despite important reservations across a range of areas as to the appropriateness of some of their assumptions. Typically, these concerns would likely see an increase in the estimate of their emissions. Nevertheless, given that categorical quantitative conclusions can be drawn from Cuadrilla's own submitted data, unpicking the detail of their assumptions risks being an unnecessary distraction, with one significant caveat. It is important to recognise that, in relation to methane emissions, there is a significant likelihood that the emissions during exploratory phase (and any subsequent production) could be substantially higher than Cuadrilla's own estimate (see 5. 2 below).

Low-end methane estimates

5.2 Recent atmospheric research, in multiple locations, suggests that leakage from natural gas production may be up to five times higher than that included within current emissions inventories [**CD 41.18**, 40(16), 4393-4397]. This therefore questions the accuracy of current bottom up estimates of emissions intensity. Such discrepancies indicate the need for greater attention to be paid to the monitoring of emissions, the process of developing inventories and of obtaining background measurement prior to development; all this needs to be undertaken at the appropriate field scale and sensitivity [**CD 41.20**].. As it stands today, Ekins et al capture the plethora of uncertainties around methane leakage from shale gas when they note *"the literature on this issue is not yet at a mature enough stage to have any confidence on what a reasonable range for fugitive emissions may be"* [**CD 41.33**]. It is also important to note that the latest scientific assessment (IPCC AR5) of methane's global warming potential (a GWP of 34) is some 36% higher than that used in Cuadrilla's analysis (25 and based on the 2007 value from IPCC AR4).

Assessment of Cuadrilla's Emissions

5.3 In considering how significant Cuadrilla's emissions are in relation to climate change it important to define clear boundaries of analysis. For the analysis to be more than a Machiavellian ruse, the boundaries need to be developed on the basis of cogent and sensible reasoning. For the purpose of this report, two sets of boundaries are considered.

5.4 The first set of boundaries takes the developments as simply a stand-alone exploratory project unrelated in any way to the findings of the exploration. This disassociated the project from its results, which will clearly inform the development or otherwise of any future decisions on UK shale gas. If this is considered an appropriate framing of the proposed project, then the boundaries of analysis relate solely to the emissions released during its construction, operation and decommissioning.

5.5 Given Cuadrilla are a commercial company it is only reasonable to view their proposal as an integral part of their broader intention of becoming a major UK producer of shale gas. This view is borne out by the fact that Cuadrilla seeks to justify the proposed exploration works using arguments about natural gas supply, energy security, government support for the shale industry, the economic impact of the production phase and national economic impact, all of which relate to production at scale and the creation of a UK shale gas industry [Planning Statements [**CD 12.6** pages 47-57; **CD 28.6** pages 52-62]. I have already addressed these arguments

5.6 Consequently, it is appropriate and sensible to set the boundaries in relation to a shale gas industry contributing to the mix of the UK's energy supply. Logically, if the emissions of such an industry were incompatible with the UK's Paris commitments, then, from an emissions perspective, it would be unwise to proceed with the exploratory proposal as its emissions would reduce still further the small 2°C carbon budget available to the remainder of the UK generally or Fylde more specifically.

<u>Emissions Cause by Exploration Phase</u>

5.7 Cuadrilla predict emissions during the six year exploratory phase of the development as 118418 to 124397 tonnes of greenhouse gases (tCO2e).

5.8 Assuming the project begins in 2017 and completes at the end of 2022 (i.e. six years) then based on the mitigation accompanying, as near as possible, the UK's "well below 2°C" commitment's it is possible to estimate the proportion of the six year UK budget taken up by Cuadrilla's proposal.

5.9 Based on the analysis within paragraphs 4.19-4.22 and assuming the UK begins its mitigation programme to deliver on its Paris commitments as a matter of urgency (as Article 4(1) of the Agreement suggests it should), then the UK emissions for 2017 to 2022 are between 986 and 1516MtCO2.

5.10 Assuming 90% of Cuadrilla's emissions relate to CO2 (simplifying assumption based on Cuadrilla table 8.3) then for the period 2017 to 2022 the Cuadrillaproject alone represents between 0.007% and 0.01% of the UK's total budget.

5.11 However, comparing two 'exploratory-only' projects with the carbon budget for all of the UK raises serious issues of inappropriate centralisation at a time when responsibility is increasingly being distributed to the regions. Consequently, a more apposite assessment would be to consider the emissions from Cuadrilla's Fylde-based proposal with Fylde's per capita proportion of the UK's carbon budget.

5.12 Building on the 2011 Census, Fylde's 2017-2022 carbon budget is in the region of 0.12% of the UK's 2°C (Paris-based) budget range of 986 to 1516MtCO2; that is, a budget for Fylde of between 1.183 and 1.819MtCO2.

5.13 Consequently and based on UK emissions consistent with the Paris commitments and prorated to Fylde, the two Cuadrilla's 'exploratory-only' proposals represent between 5% and 9% of the region's total emission budget.

Emissions Caused by Commercial Shale Gas Production

5.14 Cuadrilla have previously acknowledged that a full production UK shale gas industry would not be on stream before 2025. However, by then and assuming the UK was not to renege on its clear Paris commitments, there would be only a very short window during which shale gas could provide any meaningful proportion of UK energy supply. This holds for both electricity generation and domestic heat, with DECC envisioning a significant proportion of the latter being electrified by 2030. Moreover, it remains the case even if shale gas can be combined with carbon capture and storage (CCS) technologies. The CO2 emissions from gas-CCS are anticipated to be five to fifteen times greater per kWh of electricity generated than are the emissions from either renewables or nuclear. Add to this the timeframe for developing a mature UK shale gas industry and, even with CCS, shale gas can have no appreciable role in the UK's energy mix.

5.15 The degree to which the development of a UK shale gas industry is incompatible with its climate change commitments was made very clear in DECC's own report on climate change. Here the authors David MacKay (DECC's chief scientific advisor) and Tim Stone concluded [**CD 41.25**]:

> *"If a country brings any additional fossil fuel reserve into production, then in the absence of strong climate policies, we believe it is likely that this production would increase cumulative emissions in the long run. This increase would work against global efforts on climate change."*

5.16 In relation to the IPCC carbon budgets for a *"likely"* chance of 2°C, it is abundantly clear that there is a complete *"absence of strong climate policies"*. Consequently, over and above all the detailed discussion in the increasing number of technical reports on shale gas (e.g. the RAE and RS review of hydraulic fracturing) their statement can only be interpreted as concluding that a significant UK shale gas industry is incompatible with the UK's commitment to maintaining temperatures "well below 2°C".

5.17 Consequently, regardless of the success of otherwise of technologies and protocols for minimizing operational emissions, the addition of shale gas to the UK's energy mix is simply incompatible with the UK's commitments under even a conservative reading of the Paris Agreement.

Kevin Anderson

Tyndall Centre (HQ)
Zuckerman Institute for Connective Environmental Research
School of Environmental Sciences
University of East Anglia
Norwich, NR4 7TJ, UK
Phone: +44 (0)1603 593900
Fax: +44 (0)1603 593901
Email: tyndall@uea.ac.uk