Shale Gas: Risk and Benefit to Health

Notes from the literature

Produced by Medact, September 2016

Contents

A. Introduction

1. In April 2015, Medact published an assessment of the potential health threats associated with shale gas production (SGP), including the process of high volume, hydraulic fracturing (‘fracking’) and reported that:
   - significant hazards are unavoidably associated with fracking and could impact negatively on the health and wellbeing of local communities;
   - the regulatory framework for fracking in the UK was unclear, incomplete and inadequate, and compromised further by budget and staff cuts to regulatory agencies; and
   - shale gas is not necessarily a ‘clean’ source of energy and may hinder our transition towards a decarbonised energy system.

2. Medact concluded that the risks and threats associated with SGP outweighed its potential benefits, and recommended that it should not be encouraged in the UK.

3. Since publishing that report, Medact has continued to monitor the scientific literature and policy debates concerning SGP. In addition, Medact staff have participated in publication of a systematic review of the scientific research on the health effects of SGP.

4. *This document* consists of a set of semi-structured notes that have been used to inform a new publication that sets out Medact’s position on SGP. This new publication (*Shale Gas Production in England: An Updated Public Health Assessment*) is freely available from the Medact website.[1]

5. The purpose of these notes is to present some of the wide-ranging issues, data and analysis that are needed for a well-informed, holistic and nuanced understanding of SGP. We hope the notes will provide a useful resource for others working on this issue and for interested members of the general public.

6. This document is a work in progress, and will be updated on an ongoing basis.

7. Having reviewed at the literature on SGP and at arguments put forward by proponents of shale gas who argue that SGP can be conducted safely, and that shale gas is a relatively clean, beneficial and strategically-important source of energy, we continue to advise against the development of a shale gas industry in the UK on the grounds that it represents a significant threat to human health and wellbeing that may be avoidable.

8. Many of the concerns about the potential risks associated with SGP relate to natural gas and fossil fuels more generally. However, this document is focused specifically on the policy to encourage SGP in the UK.

---

[1] http://www.medact.org/wp/wp-content/uploads/2016/07/medact_shale-gas_WEB.pdf

B. Fracking and Unconventional Shale Gas Production

9. The term 'fracking' is commonly used to describe a process of shale gas extraction that uses a technique known as 'high-volume, hydraulic fracturing' (HVHF) in which high volumes of fluid are injected underground under high pressure. This is designed to fracture gas-bearing shale formations that lie underground, allowing gas to be released and to flow up to the surface where it can be captured for use.

10. Fracking is also associated with the term 'unconventional natural gas' (UNG) which is loosely defined to mean gas that is captured from unconventional reservoirs and includes shale gas and coalbed methane.

11. Shale gas is a form of UNG because it is trapped or locked within the fine-grained sedimentary rocks of shale formations that lie underground, and can only be released once the shale is artificially fractured. Although hydraulic fracturing has been used to stimulate oil and gas wells for many decades, the high volumes and high pressures of fluid required to fracture shale rock are relatively new developments.

12. Shale gas production (SGP) is also characterised by improvements in horizontal drilling techniques which allow horizontal boreholes to be drilled for up to 10km at depths of more than 1.5km. These developments in engineering have allowed the oil and gas industry to fracture greater amounts of shale rock that were previously considered inaccessible or uneconomic.[2]

13. This report is not limited to an assessment of the potential health effects of HVHF, but covers *the entire process* of SGP including the construction of wellpads; the drilling of boreholes; the extraction and use of water; the storage, transportation of waste products; *and* the processing, storage and transportation of natural gas to end users.

C. Assessing potential harms and benefits

10. An assessment of the potential health impact of SGP has to be balanced, and must consider both the potential harms and benefits of SGP.

11. We have used a framework that incorporates two sets of benefits (Figure 1). First, those related to energy itself, which has been a crucial ingredient to the remarkable improvements in human health witnessed over the past 250 years. Second, the potential economic benefits in terms of revenue, job creation and local investment.

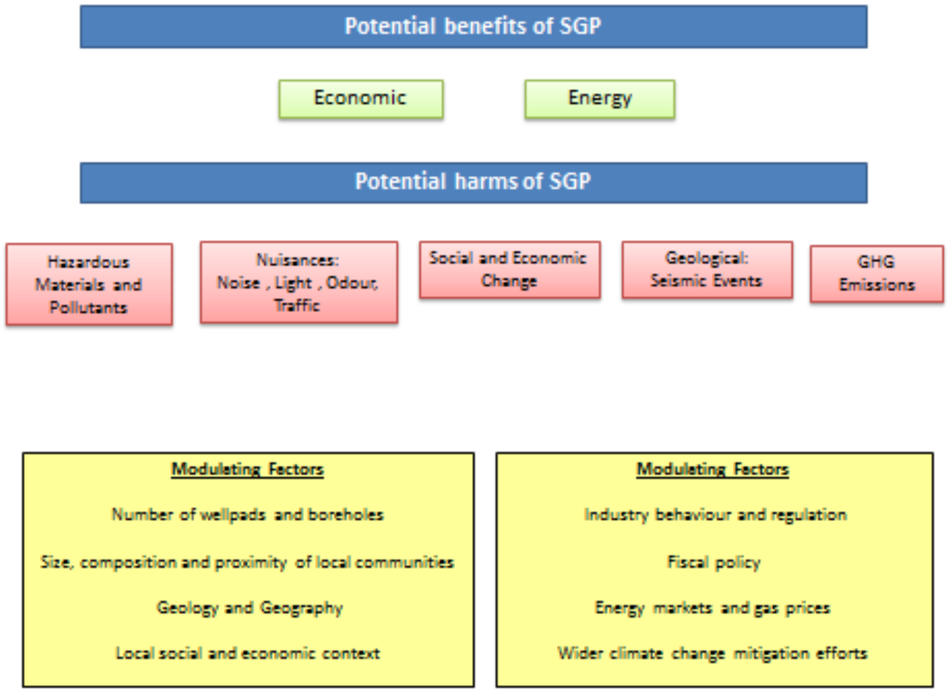
12. The framework also describes five sets of potential harms: 1) exposure to hazardous materials and pollutants; 2) exposure to so-called 'nuisances' such as noise, light pollution, odour and traffic congestion; 3) social and economic effects that may have an adverse impact on health and

---

[2] Adgate et al (2014) has noted that the rapid increase in the technology's development in the US has brought wells and related infrastructure closer to population centres

wellbeing; 4) seismic (earthquake) activity; and 5) the release of greenhouse gases (GHGs) and the effects of global warming and climate change.

Figure 1: A framework describing the potential benefits and harms of SGP



13. The *type* of negative health effects that may arise from these five sets of potential harms are many, and consist of both acute and chronic diseases and illnesses, including those mediated by psychological and emotional pathways. Negative health effects may arise from perceptions of risk which can result in anxiety, stress and fear.[3] Some effects may be experienced immediately, whilst others (such as exposure to carcinogenic toxins) may take many years.

14. The framework above excludes occupational health risks related to accidents or equipment malfunctions on and around the wellpad. Although there are few data specific to SGP, oil and gas production is relatively dangerous compared to many other forms of industrial activity.[4] [5]

15. Blowouts can cause drill pipe, mud, cement, fracking fluids, and flowback to be ejected from the bore and expelled at high pressure; and can set off an explosion. Fires can involve other equipment on the well pad. Historical data from the oil and gas industry indicate that blowout

---

[3] Luria, Parkins and Lyons (2009) 'Health Risk Perception and Environmental Problems: Findings from ten case studies in the North West of England'. Liverpool JMU Centre for Public

[4] Adgate JL, Goldstein BD and McKenzie LM, 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol 48 (15), pp 8307–8320

[5] Witter R Z, Tenney L, Clark S and Newman L. Occupational exposures in the oil and gas extraction industry: state of the science and research recommendations. Am. J. Ind. Med. 2014, in press.

frequency is approximately 1 per 10,000 wells.[6] Published data from the Marcellus Shale indicates a blowout risk of 0.17% for the years 2005 – 2013.[7]

16. The potential harms associated with climate change relate to the fact that natural gas is both a fossil fuel and a greenhouse gas in its own right. Because of its potential to contribute to global warming, a health impact assessment of SGP in the UK needs to consider the potential impacts of climate change on global health more generally.

17. In assessing the potential harms and benefits of SGP, it has to be recognised that the effects and outcomes of SGP are dependent on a range of modulating factors that are context-specific (as illustrated in Figure 1).

18. Clearly, the scale and intensity of SGP, and the size, composition and proximity of local communities, will have a considerable bearing on the level of risk and impact on health. Similarly, local demographic features and the nature of pre-existing economic activities will influence the extent to which any social, cultural and economic disruption caused by SGP impacts negatively on local communities.

19. The specific geological features of the shale formations and their overlying strata, geographic variables such as the local climate and topography, and the nature of the local ecosystem and road network, are also important variables that influence the type and degree of risk associated with SGP.

20. The adequacy and effectiveness of regulation and the ethical standards and operating practices of shale gas operators (including the adoption of new engineering technologies and safety improvements) are similarly important in determining levels of safety.

21. The economic benefits of SGP and their distribution across society are dependent on various factors including future gas prices; the tax and subsidy regime applied to the shale gas industry; the employment practices of shale gas operators; and the adequacy and effectiveness of a sanctions regime in the event of accidents, malpractice or negligence.

22. For these reasons, there is no such thing as a standard fracking operation and one cannot derive a generalisable measure of the harms and benefits associated with SGP. While it is important to learn from experiences of SGP in other settings, especially the United States, lessons must be applied carefully to the UK. Differences in the geology, geography, regulatory environment and energy economy of the US and UK can be considerable.

23. Even within the USA, conditions and practices differ from state to state. According to the California Council on Science and Technology, "*hydraulic fracturing practice and geologic conditions in California differ from those in other states, and as such, recent experiences with*

---

[6] International Association of Oil & Gas Producers, 2010. Blowout frequencies. http://www.ogp.org.uk/pubs/434-02.pdf

[7] Considine TJ, Watson RW, Considine NB, Martin JP, 2013. Environmental regulation and compliance of Marcellus shale gas drilling. Environ. Geosci. 20,1e16.

hydraulic fracturing in other states do not necessarily apply to current hydraulic fracturing in California"[8]

24. Another general point is that there is a distributional dimension to consider. Both the negative and positive effects of SGP will be unevenly distributed across populations along geographic, temporal and social dimensions. The balance of benefit and harm will vary within and between local communities directly affected by SGP, as well as across national and global populations. Even the impact of exposure to chemical hazards will vary within a community due to the uneven distribution of risk factors such as deprivation, poor diet and pre-existing health conditions that influence vulnerability to the effects of potential hazards.

25. The unequal distribution of harms and benefits across society (including between current and future generations), as well as the need to consider the trade-off between harms and benefits, involves ethical considerations and the accommodation of different social values and preferences.[9]

26. The approach taken in this report to assess the health effects of SGP is therefore broad and involves a wide range of factors. It stands in contrast to the 2014 Public Health England (PHE) report on shale gas which only addressed the risks associated with chemical and radioactive pollutants, and excluded *"other considerations, such as water sustainability, noise, traffic (apart from vehicle exhaust emissions), odour, visual impact, occupational exposure and wider public health issues, have not been addressed",* as well as the impacts of on climate change.

27. In terms of the scientific literature, SGP is a relatively new and evolving activity. Research examining the relationship between SGP and health is limited both in terms of the quantity and quality of studies. Although the scientific literature is expanding, a summation made by Adgate et al in 2014 still holds true: *"To date observational studies exploring the association between human health and UNG development have had a number of scientific limitations, including self-selected populations, small sample sizes, relatively short follow-up times and unclear loss to follow-up rates, limited exposure measurements and/or lack of access to relevant exposure data, and lack of consistently collected health data, particularly for non-cancer health effects".*[10]

28. Additionally, because rigorous and independent exposure and health impact studies may be expensive, a tendency to rely on data collected by the industry itself, results in bias within the existing scientific literature.[11] Incomplete regulation and the application of non-disclosure

---

[8] California Council on Science and Technology, 2015. An Independent Scientific Assessment of Well Stimulation in California: Summary Report. An Examination of Hydraulic Fracturing and Acid Stimulations in the Oil and Gas Industry.

[9] See Evensen, D. (2016), Ethics and 'fracking': a review of (the limited) moral thought on shale gas development. WIREs Water, 3: 575–586. doi:10.1002/wat2.1152

[10] Adgate JL, Goldstein BD and McKenzie LM, 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol 48 (15), pp 8307–8320.

[11] Watterson and Dinan, 2015. Health Impact Assessments, Regulation, and the Unconventional Gas Industry in the UK: Exploiting Resources, Ideology, and Expertise. Journal of Environmental and Occupational Health Policy 0(0) 1–33.

agreements have also hindered data collection and public interest monitoring and evaluation of the gas industry in the US.[12] [13] [14]

29. A number of authors have noted the common methodological challenges involved in conducting risk assessments associated with engineering and industrial processes such as SGP, including: a) inherent uncertainties in assigning probabilities and appropriate values for estimations; b) the difficulty in distinguishing between objective knowledge and subjective judgments; c) the challenges of working with intangibles and temporal data; d) the frequent use of non-disclosure agreements that allow companies to hold back data required for making risk assessments; and e) the fact that psychological, social, institutional and cultural factors affect perceptions of risks and influence risk behaviours.[15]

30. Because a degree of judgement is inevitable in the formation of any position on SGP, it is important that conflicts of interest (financial and otherwise) are declared.

31. It is worth noting that in the US, there have been a number of controversies associated with research and commentary pieces about shale gas that have been produced by university scientists sponsored by the oil and gas industry.[16] Here in the UK, there has been little independent shale gas-related research, research. A review of shale gas extraction conducted by the Royal Society and the Royal Academy of Engineering in 2012 recommended that a cross-council research programme be established in the UK, but this has not happened.[17]

D. Hazards, Risks and Harms

Hazardous Materials and Pollutants

32. SGP is an inherently risky activity. According to a United National Environmental Programme (UNEP) briefing note, "hydrologic fracking may result in unavoidable environmental impacts even if unconventional gas is extracted properly, and more so if done inadequately".[18] Furthermore, even if risk can be reduced theoretically, "in practice many accidents from leaky or malfunctioning equipment, as well as from poor practices, regularly occur".

---

[12] Maule A, Makey C, Benson E, Burrows I and Scammel M, 2013. Disclosure of hydraulic fracturing fluid chemical additives: analysis of regulations. *New Solut.* 23(1): 167–87. PM. 23552653.

[13] https://www.guernicamag.com/daily/naveena-sadasivam-in-fracking-fight-a-worry-about-how-best-to-measure-health-threats/

[14] http://www.businessweek.com/news/2013-06-06/drillers-silence-u-dot-s-dot-water-complaints-with-sealed-settlements

[15] See: Renn et al., 1992). Aven (2012), Aven and Kristensen (2005) Pidgeon (1998)

[16] Nelson C. Fracking research: playing with fire. Times Higher Education Supplement, https://www.timeshighereducation.co.uk/features/fracking-research-playing-withfire/2007351.article

[17] The Royal Society and The Royal Academy of Engineering, 2012. Shale gas extraction in the UK: a review of hydraulic fracturing. https://royalsociety.org/~/media/policy/projects/shale-gas-extraction/2012-06-28-shale-gas.pdf

[18] UNEP. Gas fracking: can we safely squeeze the rocks? UNEP Global Environmental Alert Service, http://www.unep.org/pdf/UNEP-GEAS_NOV_2012.pdf (accessed 23 May 2013).

33. Even the industry-funded Task Force on Shale Gas notes that "clearly there is a range of hazards potentially associated with shale gas operations".[19]

34. Among the health risks is exposure to hazardous pollutants, which are typically either airborne or waterborne; and which can affect humans either directly or indirectly.

35. Pollutants, with subsequent risks to both the environment and people, are produced across all stages of SGP including wellpad construction; drilling; hydraulic fracturing; gas extraction, treatment, storage and transportation; the management of waste products; and even after wells have been sealed and abandoned.

36. Among the potentially hazardous chemicals and compounds are: particulate matter (PM); oxides of nitrogen (NOx); volatile organic compounds (VOCs), including formaldehyde, benzene, toluene, ethylbenzene, xylene and poly-aromatic hydrocarbons (PAHs); hydrogen sulphide; ozone[20]; silica; heavy metals such as lead, selenium, chromium and cadmium; and normally-occurring radioactive material (NORM).

37. Elliott[21] systematically reviewed the potential reproductive and developmental toxicity of over 1000 chemicals identified in fracturing fluids and/or wastewater. Data were available for only 24% of these chemicals; 65% of which suggested potential toxicity. Webb et al's 2014 literature review also concluded that chemicals used and produced in unconventional oil and gas operations were known developmental and reproductive toxins.[22]

38. Colborn[23] reviewed the toxicity of 352 chemicals used in US natural gas operations including UNG development and found that 25% were potentially mutagenic or carcinogenic. In addition, over 75% had the potential to cause effects on the skin, eyes, respiratory and gastro-intestinal (GI) systems; 40-50% on the nervous, immune, cardiovascular and renal systems; and 37% on endocrine system. Inevitably, this is not a comprehensive review. Information on the full composition of the products used in the US is limited, partly by commercial confidentiality, and some of the chemicals disclosed have not been subjected to a full toxicological assessment.

39. When it comes to NORM, a study published in June 2014 by Durham University on the likely radioactivity of flowback fluid, concluded that "levels of NORM measured in flowback water are many times higher than found in groundwater, but a long way below the permitted UK exposure

---

[19] Task Force on Shale Gas. First report: Planning, Regulation and Local Engagement.

[20] Tropospheric ozone is a secondary air pollutant produced photochemically through complex reactions involving volatile organic compounds (VOCs) and nitrogen oxides

[21] Elliott, EG, Ettinger, AS, Leaderer, BP, Bracken, MB, Deziel, NC (2016) A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity, Journal of Exposure Science and Environmental Epidemiology advance online publication, 6 January 2016; doi:10.1038/jes.2015.81.

[22] Webb et al, 2014. Developmental and reproductive effects of chemicals associated with unconventional oil and natural gas operations. Rev Environ Health. 29(4):307-18. doi: 10.1515/reveh-2014-0057.

[23] Colborn T , Kwiatkowski C, Schultz K, Bachran M (2011) Natural Gas Operations from a Public Health Perspective, Human and Ecological Risk Assessment: An International Journal, Vol. 17, Iss. 5

limits. Their radioactivity is also lower than that of fluids produced by conventional oil or gas production, or nuclear power. In terms of flux per unit of energy produced, shale gas flowback fluids are also much less radioactive than the burn products of coal-fired power stations". The study concludes that although SGP will bring NORM to the surface and that flowback fluids must be treated, their radioactivity remains low and unlikely to pose a threat to human health.[24]

40. The health risk posed by the different potential hazards varies. Some such as benzene are known carcinogens; some increase the risk of birth defects; while others cause respiratory and cardiovascular disease. The inhalation of benzenes and xylenes can irritate eyes and the respiratory system and cause difficulty in breathing and impaired lung function. Inhalation of xylenes, benzene, and aliphatic hydrocarbons can adversely affect the nervous system with effects ranging mild and temporary dizziness, headaches, fatigue, and numbness to serious effects if there is acute and severe poisoning.

41. It is worth noting that there is incomplete scientific knowledge about the risk of exposure to many chemical and radioactive hazards. Many of the potential hazards associated with HVHF lack a full toxicity characterization, and there is even less knowledge about the potential risks associated with the 'cocktail' effects of being exposed to multiple hazards simultaneously.[25]

42. Anxiety and fear about exposure can also result in harms to stress, anxiety and other impacts on emotional wellbeing.

43. In terms of the overall toxic potential of SGP for electricity generation in the UK, Stamford et al estimated it to be 3-4 times worse than conventional gas, although an order of magnitude better than nuclear, solar or coal power.[26]

Risk of pollution and exposure to hazardous pollutants

44. The risk of pollution depends on many variables including: a) the type and composition of the shale formations; b) the nearby presence of aquifers; c) the number of wells and boreholes; d) the operating practices of fracking companies, including the type of equipment and technology used and the specific constituents of the drilling and hydraulic fracturing fluids; e) the system of regulation in place to ensure safety, including the monitoring and surveillance of pollution; f) leakage rates and the frequency of venting and flaring; and g) the adequacy of facilities for the treatment and management of flowback fluid and other waste materials.

---

[24] The flux of radionuclides in flowback fluid from shale gas exploration, Durham University, Environmental Science & Pollution Research, June 2014

[25] According to the California Council on Science and Technology (2015), a study of a list of chemicals that were disclosed by industry revealed that knowledge of the hazards and risks was incomplete for almost two-thirds of the chemicals. The Council noted that the toxicity and biodegradability of more than half the chemicals used in hydraulic fracturing were un-investigated, unmeasured and unknown. Additionally, basic information about how these chemicals would move through the environment was said to not exist.

[26] Stamford L and Azapagic A (2014) Life cycle environmental impacts of UK shale gas, Applied Energy Vol 134, 1 December 2014, Pages 506–518

45. Health risks only arise if there is human exposure to pollutants. The magnitude of risk also depends on many variables including: (1) the type of pollutant that humans are exposed to; (2) the amount of pollution and length of time of exposure; (3) the age and health profile of exposed persons; (4) topographical features and meteorological conditions that influence the dispersion of pollutants; and (5) the extent to which households source their drinking water directly from groundwater sources (negligible in the UK).

E. Water pollution

46. SGP can cause both ground and surface water pollution. The source of pollutants include: a) hydraulic fracturing fluid; b) run off from cuttings and other process residues generated by the drilling of wells; c) 'flowback fluid', including formation and production waters; and d) natural gas itself.

47. Water pollution may manifest in different ways: stray gas contamination of aquifers; surface water contamination from spills, leaks, and/or the disposal of inadequately treated wastewater; and the accumulation of toxic and radioactive elements in soil or stream sediments near disposal sites.[27]

48. According to one review, accidents and malfunctions, such as well blowouts, leaking casings, and spills of drilling fluids or wastewater, are more likely to contaminate surface and groundwater supplies than the process of HVHF itself.[28]

49. Another review noted that evidence from the US points to the failure of well cement and casing barriers being the most common cause of water pollution; followed by surface spills (due to leaks, overflowing pits and failures of pit linings) and the accidental release of fracking fluid or flowback.[29]

50. Rahm and Riha's (2014) review reported that spills at the surface were the cause of most incidents of environmental concern including some events with confirmed and significant impacts on local water resources.[30] They also concluded that while good policy and practices can reduce some risks substantially, significant uncertainty remains and that there is a need for more and longer term water quality monitoring.

---

[27] Vengosh et al, 2014. A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States. Environ. Sci. Technol. 2014, 48, 8334−8348

[28] Adgate JL, Goldstein BD and McKenzie LM, 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol 48 (15), pp 8307–8320.

[29] Massachusetts Institute of Technology, 2011. Study on the Future of Natural Gas. MIT Energy Initiative. Available at: http://mitei.mit.edu/system/files/NaturalGas_Report.pdf

[30] Rahm B and Riha S, 2014. Evolving shale gas management: water resource risks, impacts, and lessons learned. Environ. Sci.: Processes Impacts, 2014, 16, 1400

51. Following concerns about contamination of groundwater in NE Pennsylvania, Reilly et al (2015) analysed samples from 21 drinking water wells suspected of having been contaminated.[31] Samples were taken in 2012 and 2013 and compared against data on groundwater well chemistry from the Pennsylvania Geological Survey and the US Geological Survey reports for 1979–2006. The results revealed evidence of contamination by animal waste, septic effluent or road salt, but no indication of contamination by Marcellus shale flowback.

52. Vidic et al (2013) described the potential for leakages, blowouts and spills to affect water quality and reported only a single case of fracking fluid directly contaminating groundwater, but referred to problems with commercial confidentiality and a lack of baseline data and research.[32]

53. Vengosh et al's review of published data (through January 2014) found that while direct contamination of water resources by fracturing fluids or the fracturing process was uncertain, there was some evidence for stray gas contamination of shallow aquifers and surface waters in areas of intensive shale gas development, and the accumulation of radium isotopes in some disposal and spill sites.[33] The paper described various interventions that could mitigate these risks including enforcing safe zones (1 km) between shale gas sites and drinking water wells, mandatory baseline monitoring, transparency and data sharing, a zero discharge policy for untreated wastewater, establishing effective remediation technologies for adequate treatment and safe disposal of wastewater, and limiting the use of fresh water resources for shale gas development through substitution or alternative fluids for hydraulic fracturing.

54. Gross et al (2013) used industry-reported data to assess the potential impact of 77 reported surface spills on groundwater contamination over a year in Weld County, Colorado.[34] Analyses for benzene, toluene, ethylbenzene and xylene showed an exceedance of the Maximum Contaminant Level (MCL) in 90% of cases for benzene, 30% for toluene, 12% for ethylbenzene and 8% for xylene. Given the delay between notification of the spill and the taking of samples, the authors postulate that some levels may have been higher at the time of the incident. The overall number of incidents is small in comparison to the 18,000 active wells, although the self-reported nature of the data indicates a potential for under-reporting.

55. Lauer et al's study (2016) of surface waters (n = 29) in areas impacted by oil and gas wastewater spills in the Bakken region of North Dakota identified elevated concentrations of dissolved salts (Na, Cl, Br) and other contaminants (Se, V, Pb, NH4) relative to background levels.[35] They also

---

[31] Reilly D, Singer D, Jefferson A, Eckstein Y. 2015. Identification of local groundwater pollution in northeastern Pennsylvania: Marcellus flowback or not? Environ. Earth Sci. 73 (12): 8097–8109

[32] Vidic RD, Brantley SL, Vandenbossche JM, Yoxtheimer D, Abad JD (2013) Impact of shale gas development on regional water quality. Science 340(6134):1235009.

[33] Vengosh et al, 2014. A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States. Environ. Sci. Technol. 2014, 48, 8334−8348

[34] Gross SA, Avens HJ, Banducci AM, Sahmel J, Panko JM, Tvermoes BE. 2013. Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. RJ Air Waste Manage Assoc 63(4): 424-432, doi: 10.1080/10962247.2012.759166.

[35] Lauer et al, 2016. Brine Spills Associated with Unconventional Oil Development in North Dakota. Environ. Sci. Technol

observed that inorganic contamination associated with brine spills were persistent, with elevated levels of contaminants observed in spills sites up to 4 years following the spill events.

56. Olmstead et al (2013) assessed the impact of discharged wastewater on surface water in Pennsylvania.[36] This study developed a Geographic Information Systems (GIS) database from several publicly available sources including the results of over 20,000 water quality samples (2000–2011), UNG locations, consignments of waste to treatment plants, and data on the quality of the receiving water bodies. These data were used to model average impact of UNG development, controlling for other factors. Relationships between increasing upstream density of wastewater treatment plants releasing treated waste to surface water and increased downstream chloride concentrations were identified. Relationships between the upstream density of wellpads and increased downstream total suspended solid concentrations were also identified. However, there was no significant relationship between wells and downstream chloride concentrations or between waste treatment and downstream TSS concentrations. The results suggest that upstream shale gas wells do not increase chloride concentrations but the treatment and release of wastewater does, and that increases in TSS associated with UNG development may be due to land clearance for infrastructure development.

57. Warner et al (2013b) examined the impact on surface water quality following discharge of treated Marcellus liquid wastes (including UNG-derived) during 2010-2012.[37] Samples were taken from the treatment plant effluent and downstream and upstream water and sediments. The latter, together with data from other streams, were used as comparators. Samples were analysed for a range of parameters including Cl, Br, Ca, Na, Sr, alkalinity, and NORMs. Levels varied during the sampling period with some concentrations up to 6,700 times higher than the concentrations measured in the upstream river sites. The total radium (Ra) activity in the effluent was well below the industrial discharge limit although sediment levels adjacent to the treatment discharge site were over 200 times greater than background sediment samples. Chloride concentrations around a mile downstream were 2-10 times higher than background. The authors concluded that while treatment reduces the levels of contaminants, wastewater effluent discharge to surface water has a ‘discernible impact’.

58. Nelson et al’s (2015) small study found no evidence of elevated levels of natural uranium, lead-210 and polonium-210 in private drinking wells within 2km of a large hydraulic fracturing operation in Colorado before and approximately one year after the start of drilling.[38] Groundwater samples from three residences and single samples from surface water and a municipal water supply were analysed.

---

[36] Olmstead SM, Muehlenbachs LA, Shih J-S, Chu Z, Krupnick AJ. 2013**.** Shale gas development impacts on surface water quality in Pennsylvania. PNAS 110(13): 4962-4967, doi: 10.1073/pnas.1213871110.

[37] Warner NR, Christie CA, Jackson RB, Vengosh A. 2013. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environ Sci Technol 47(20): 11849-11857, doi: 10.1021/es402165b.

[38] Nelson et al, 2015. Monitoring radionuclides in subsurface drinking water sources near unconventional drilling operations: A pilot study Journal of Environmental Radioactivity DOI: 10.1016/j.jenvrad.2015.01.004

59. Drollette et al (2015) examined health and safety contravention reports and sampled private residential groundwater wells in NE Pennsylvania (n=62) and southern New York (n=2) between 2012 and 2014.[39] Fifty-nine samples were analysed for VOCs and gasoline range hydrocarbons, and 41 samples were analysed for diesel range hydrocarbons. Organic and inorganic geochemical fingerprinting, groundwater residence times and dissolved methane concentrations were used to identify potential sources of any contamination. They found trace levels of hydrocarbon contamination in up to a quarter of groundwater samples with significantly higher levels invariably in samples from within 1 km of active UNG operations. Trace levels of VOCs including BTEX compounds, well below MCLs, were also detected in 10% of samples. Analysis of regulatory data revealed that almost 5,800 contraventions had been reported at 1,729 sites in Pennsylvania between 2007 and June 2014. However, geochemical fingerprinting data found no evidence of upward migration and were consistent with contamination from a surface source.

60. Alawattegama et al (2015) assessed the impact of UNG activity on well water serving a small Pennsylvania community of 190 households by analysing the chemical and microbiological quality of water and community perceptions.[40] The study was conducted following a major increase in shale gas activity in 2011. 143 households were questioned and 57 samples from 33 wells were analysed for a range of inorganic chemicals, 18 wells were tested for six light hydrocarbons, and bacteria tested for in 26 wells. 35% of the surveyed households reported perceived changes in the quality, taste and/or smell of water. Elevated levels of chloride, iron and manganese (with the latter exceeding the MCL in 25 households) were found. Additionally. methane (of likely thermogenic origin) was identified in 78% of samples although the levels were low in the majority of analyses. The findings are highly suggestive of contamination from shale gas activity, and the study also identified several contraventions including compromised well casings and inadequate plugging. However, the lack of pre-drilling baseline data prevents a definitive conclusion.

61. Heilweil et al (2015) sampled and analysed 15 streams in the Marcellus shale play for the presence of hydrocarbons and noble-gas. High concentrations of methane consistent with a non-atmospheric source were found in four of the 15 streams. The isotopic characteristics of dissolved gas in one stream were also suggestive of a local shale source. Modelling indicated a thermogenic methane flux discharging into this stream which was consistent with a reported stray gas migration from a nearby well.[41]

---

[39] Drollette BD, Hoelzer K, Warner NR, Darrah TH, et al. 2015. Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities. Proc Natl Acad Sci, doi: 10.1073/pnas.1511474112.

[40] Alawattegama SK, Kondratyuk T, Krynock R, Bricker M, Rutter JK, Bain DJ, Stolz JF. 2015. Well water contamination in a rural community in southwestern Pennsylvania near unconventional shale gas extraction. Journal of environmental science and health Part A, Toxic/hazardous substances & environmental engineering 50(5):516-528, doi: 10.1080/10934529.2015.992684.

[41] Victor M. Heilweil, Paul L. Grieve, Scott A. Hynek, Susan L. Brantley, D. Kip Solomon, Dennis W. Risser. Stream Measurements Locate Thermogenic Methane Fluxes in Groundwater Discharge in an Area of Shale-Gas Development**.** *Environmental Science & Technology*, 2015; 150330072215005 DOI: 10.1021/es503882b

62. Sharma et al (2015) monitored the geochemistry of gas samples from seven vertical Upper Devonian/Lower Mississippian gas wells, two vertical Marcellus Shale gas wells and six horizontal Marcellus Shale wells two months before, during and 14 months after the fracturing of the latter.[42] The results were used to assess gas migration pathways between the hydraulically fractured formation and protected shallow underground sources of drinking water. The analysis indicated that no detectable gas migration had occurred although the authors were cautious, given the limited size of the study, about generalising these findings.

63. Pelak and Sharma (2014) sampled 50 streams in a river basin in West Virginia where there had been past coal mining and current UNG development.[43] Geochemical and isotopic parameters and sampling zones based on the intensity of shale production were used to identify sources of salinity and the effects of the mining and UNG development. The study found no evidence of significant contamination from deep formation brines through natural faults/fractures, conventional oil and gas wells, nor any pathways created by shale gas drilling in the region. As the study was a 'one-time snapshot' of water quality, the authors recommended routine monitoring to more effectively assess any impact of shale gas drilling on water quality.

64. Darrah et al (2014) used noble gas and hydrocarbon tracers to distinguish between natural and anthropogenic sources of methane in an analysis of water samples from 113 wells in the Marcellus Shale and 20 wells in the Barnett Shale during 2012/13.[44] Eight clusters of fugitive gas contamination were identified with a chemical signature that suggested the cause to be failures of well integrity.

65. Warner (2013a) sampled 127 drinking water wells and compared them against the composition of flowback samples from Fayetteville Shale gas wells to assess potential contamination by stray gas or fluid migration.[45] Methane was detected in 63% of the drinking-water wells but isotopic characterisation found no spatial relationship with salinity occurrences and proximity to shale-gas drilling sites.

66. Fontenot et al (2013) analysed water samples from 100 private drinking water wells (95 in areas of active gas extraction in the Barnett Shale and five from areas with no wells within 60 km).[46] Levels of several inorganic substances were higher in samples taken within 3km of active gas wells compared to those more distant from wells and the reference samples. A number of the

---

[42] Sharma S et al, 2015. Assessing changes in gas migration pathways at a hydraulic fracturing site: Example from Greene County, Pennsylvania, USA. Applied Geochemistry Volume 60: 51–58

[43] Pelak and Sharma, 2014. Surface water geochemical and isotopic variations in an area of accelerating Marcellus Shale gas development. Environmental Pollution Volume 195: 91–100

[44] Darrah TH, Vengosh A, Jackson RB, Warner NR, Poreda RJ. 2014. Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales. PNAS 111(39): 14076-14081, doi: 10.1073/pnas.1322107111.

[45] Warner NR, Christie CA, Jackson RB, Vengosh A. 2013. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environ Sci Technol 47(20): 11849-11857, doi: 10.1021/es402165b.

[46] Fontenot BE, Hunt LR, Hildebrand ZL, Carlton DD, Oka H, Walton JL, Hopkins D, Osorio A, Bjorndal B, Hu QH, Schug KA. 2013. An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale formation. Environ Sci Technol: doi: 10.1021/es4011724.

elevated results exceeded the EPA Drinking Water MCL including arsenic in 32% of samples. These MCL breaches were randomly distributed within the active gas extraction zone suggesting a variety of contributory factors including changes in the water table, activation of natural sources, and industrial accidents. Comparing the results with historical data prior to gas activities showed significant increases in the mean concentration and maximum detected concentration for arsenic, selenium and strontium.

67. Kassotis et al (2013) reported that most water samples from sites with confirmed drilling-related incidents exhibited more oestrogenic, antioestrogenic, and/or antiandrogenic activity than reference samples.[47] Thirty-nine water samples from five sites with a reported spill or incident in the previous six years together with five surface water samples from the Colorado River were taken. Groundwater reference samples were collected from an area with no drilling activity and from two zones with low activity (≤2 wells within 1 mile). Surface water references were taken from two locations with no activity. They found that oestrogen or androgen receptor activity increased from very low in drilling sparse reference water samples, to moderate in samples from the Colorado River, to moderate to high in samples from spill sites. The authors recognised that such effects could be due to sources other than drilling (e.g. agriculture, animal care and wastewater contamination) but considered these to be extremely unlikely. The authors concluded that the results supported an association between gas drilling and endocrine disrupting chemical (EDC) activity in surface and ground waters.

68. An industry-supported study by Molofsky et al (2013) assessed the isotopic and molecular characteristics of hydrocarbons in wells in NE Pennsylvania and concluded that the methane concentrations were not necessarily due to migration of Marcellus shale gas through fractures.[48] Siegel et al (2015) also showed no association between groundwater pollution and shale gas activities after analysing groundwater samples from locations near gas wells and finding no evidence of systematic increased methane concentration.[49]

69. The California Council on Science and Technology (CCST) also found no recorded incidents of groundwater contamination due to stimulation, nor releases of hazardous hydraulic fracturing chemicals to surface waters in California. But the CCST also noted that there have been few attempts to detect such contamination with targeted monitoring, nor studies to determine the extent of compromised wellbore integrity, and that well stimulation chemicals *may* potentially contaminate groundwater through a variety of mechanisms.

70. Li and Carlson (2014) also used isotopic characterisation of produced gas and dissolved methane to examine groundwater wells in the North Colorado Wattenberg Oil and Gasfield and found little relationship. 95% of the methane was of microbial origin and there was no association

---

[47] Kassotis et al, 2013. Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region.

[48] Molofsky et al, 2013. Evaluation of Methane Sources in Groundwater in Northeastern Pennsylvania. Ground Water. 2013 May; 51(3): 333–349.

[49] Siegel et al, 2015. Methane Concentrations in Water Wells Unrelated to Proximity to Existing Oil and Gas Wells in Northeastern Pennsylvania. Environ. Sci. Technol. 2015, 49, 4106−4112.

between methane concentrations and the proximity of oil/gas wells.[50] Thermogenic methane was detected in two aquifer wells indicating a potential contamination pathway from the producing formation, but microbial-origin gas was by far the predominant source of dissolved methane.

71. Jackson et al (2013) found that 82% of 141 drinking well water samples from sites in NE Pennsylvania contained methane of thermogenic origin. Levels of methane were strongly correlated with distance to gas wells (average methane concentrations six times higher for homes <1 km from natural gas wells).[51] They suggest that the methane reaches shallow well water through casing failures or imperfections in cement annulus of the gas wells.

72. Hildebrand et al (2015) assessed whether Unconventional Oil and Gas (UOG) activity had an impact on groundwater quality by measuring the level of natural constituents and contaminants from a 550 groundwater samples overlying the Barnett shale and adjacent areas of north-central Texas.[52] Collectively, these data constitute one of the largest studies of groundwater quality in a shale formation associated with UOG activities. The study found elevated levels of 10 different metals and the presence of 19 different chemical compounds, including benzene, toluene, ethylbenzene, and xylene (BTEX) in a number of samples. Although the findings do not prove unconventional UOG extraction as the source of contamination, they demonstrate the need for further monitoring and analysis of groundwater quality.

73. In 2007, a well that had been drilled almost 1200m into a tight sand formation in Bainbridge, Ohio was not properly sealed with cement, allowing gas from a shale layer above the target tight sand formation to travel through the annulus into an underground source of drinking water. The methane eventually built up until an explosion in a resident‘s basement alerted state officials to the problem.[53]

74. Osborn et al (2011), found evidence of methane contamination of drinking water associated with shale gas extraction in north-eastern Pennsylvania. The average and maximum methane concentrations increased with proximity to the nearest gas well and were high enough to be a potential explosion hazard.[54] Chemical analysis confirmed the methane as being thermogenic

---

[50] Li H, Carlson KH. 2014. Distribution and origin of groundwater methane in the Wattenberg oil and gas field in northern Colorado. Environ Sci Technol 48(3): 1484-1491, doi: 10.1021/es404668b.

[51] Jackson RB et al, 2013. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction

[52] Hildebrand ZL, et al, 2015. A Comprehensive Analysis of Groundwater Quality in The Barnett Shale Region. Environ. Sci. Technol. 2015, 49, 8254–8262

[53] Ohio Dept of Natural Resources 2008. Report on the investigation of the natural gas invasion of aquifers in Bainbridge Township of Geauga County, Ohio.

[54] Osborn SG, Vengosh A, Warner NR and Jackson RB, 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. PNAS, 8172–8176, doi: 10.1073/pnas.1100682108

and coming from the shale extraction sites. The study found no evidence of contamination with deep saline brines or fracturing fluids.

75. Siegel el (2015) responded to the Osborn et al's results with an analysis of a dataset of 11,300 pre-drilling samples of domestic wellwater in the vicinity of 661 oil and gas wells (92% unconventionally drilled) taken between 2009 and 2011.[55] They found no statistically significant association between methane levels in wellwater and proximity to pre-existing oil or gas wells.

76. Kohl et al (2014) assessed samples of produced waters from six wells in the Marcellus Shale play and a nearby spring over a period four months prior to, and 14 months after, hydraulic fracturing and found no evidence of migration of produced waters or contamination of groundwater.[56]

Groundwater contamination

77. The fear of groundwater pollution is a prominent feature of public concerns over fracking. In the UK, the spatial correspondence between potential shale reservoirs and productive aquifers has heightened such concern.

78. The industry-funded Task Force on Shale Gas also recognises that there is a risk of aquifer contamination and recommends that risk assessments of aquifer contamination are carried out whenever appropriate, and that the detail of this assessment increases as the separation distance between the frack zone and the aquifer decreases. It also recommends that operators be "required to monitor the size of fractures in UK wells so that over time a more complete statistical picture is built up, to assist the ongoing assessment of aquifer contamination".[57]

79. Understanding the scientific literature on the risks of groundwater contamination is helped by making a few clear distinctions. First, the potential sources of contamination include different processes: a) hydraulic fracturing which takes place more than a thousand metres below the ground; b) drilling and injecting fluid down the well; and c) producing gas (accompanied by production and formation waters) up the well. Second, groundwater may be polluted by both gas (e.g. methane) and liquid (i.e. fracking fluid, and production or formation waters). Finally, the pathway for the pollution of shallow groundwater may include: a) direct pathways from the target formation (via fractures or faults); b) pathways from the well caused by a failure of well integrity; and c) spills and leakages of wastewater at the surface which seep into the ground.

---

[55] Siegel et al, 2015. Methane Concentrations in Water Wells Unrelated to Proximity to Existing Oil and Gas Wells in Northeastern Pennsylvania. *Environ. Sci. Technol.*, 2015, 49 (7), pp 4106–4112

[56] Kohl et al, 2014, Strontium Isotope Test Long Term Zonal Isolation of Injected and Marcellus Formation Water after Hydraulic Fracturing, *Environ Sci Technol* 2014, 48: 9867-9873

[57] Task Force on Shale Gas. Second report: Assessing the impact of shale gas on the local environment and health.

80. According to Adgate et al (2014), "the evidence for contamination of groundwater wells with methane, fracturing chemicals, or other process wastes is mixed".[58] Where associations have been found between UNG and drinking water contamination, a lack of baseline data on water quality prior to UNG development have prevented firm conclusions from being drawn.

81. There is however some evidence that shale gas extraction resulting in groundwater pollution, including sources used to supply drinking water. In particular, there is strong evidence of cases where both fluid and gas have leaked as a result of failure of well integrity and permeable pathways between the well and aquifers allowing for the contamination of groundwater.

82. Osborn et al (2011) discuss three possible mechanisms for fluid migration into the shallow drinking-water aquifers: a) upward migration from the target formation; b) leaky gas-well casings, with methane passing laterally and vertically through fracture systems; and c) the process of hydraulic fracturing itself generating new fractures or enlarging existing ones above the target formation, increasing the connectivity of the fracture system and allowing methane to potentially migrate upward through the fracture system.[59] The authors think the first is unlikely, but that the other two pathways are possible. They also note that several models have been developed to explain how gas can be rapidly transport vertically from depth to the surface, including pressure-driven continuous gas-phase flow through dry or water-saturated fractures and density-driven buoyancy of gas microbubbles in aquifers and water-filled fractures, but that more research is needed to determine the mechanism(s) underlying the higher methane concentrations observed.

83. In general, the risk of contaminants *from the fracking zone* directly reaching aquifers is considered by geoscientists to be remote because of the depth at which fracking occurs, the distance between the shale gas production zone and drinking water sources, the presence of impermeable layers of rock between the shale gas production zone and drinking water sources and because fracture propagation caused by HVHF rarely extends beyond 600m (and often much less[60]) above well perforations.[61] [62] [63] [64] [65]

---

[58] Adgate JL, Goldstein BD and McKenzie LM, 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol 48 (15), pp 8307–8320

[59] Osborn, Vengosh, Warner and Jackson, 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. PNAS 108 (20): 8172–8176

[60] Verdon (in Solid Earth Discussions debate): hydraulic fractures rarely extend more than about 50m above the injection zones, and in the most extreme cases have only propagated a few hundred metres above the injection zone, even where they have intersected pre-existing faults.

[61] AEA Technology, Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. Report for the European Commission DG Environment 2012.

[62] Davies et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology 56 (2014) 239e254

[63] Vengosh et al, 2014. A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States. Environ. Sci. Technol. 2014, 48, 8334−8348

[64] Flewelling S A; Tymchak MP; Warpinski N. Hydraulic fracture height limits and fault interactions in tight oil and gas formations. Geophys. Res. Lett. 2013, 40 (14), 3602−3606.

84. *Even if* a pathway exists, subsurface driving forces are likely to be insufficient to direct the flow of gas and fluids upwards and contaminate aquifers. Flewelling and Sharma (2014) note that having both strong upward gradients and significantly permeable pathways to drive upward migration is unlikely.[66] Engelder et al (2014) also describe that various geo-physical forces (e.g. capillary and osmotic forces) are more likely to result in fracturing fluid and formation water being sequestered in the shale formation rather than being transported upward.[67]

85. However, some scientists remain concerned about the possibility of contamination via permeable pathways between the fracking zone and aquifers.[68] Such pathways may be natural (permeable fractures or faults) or artificial (abandoned, degraded, poorly constructed, or failing wells).[69]

86. Smythe (2016) has argued in the online journal Solid Earth Discussions that the presence of natural faults (as opposed to the artificial fractures caused by fracking) and the possibility of upward flow from the target zone make the contamination of groundwater a greater risk than is commonly accepted.[70]

87. According to Smythe, modelling studies confirm that fluid from the fracked shale may use faults as an upward migration route to aquifers. The estimated transit times for reaching the near-surface vary considerably, ranging from ten to a thousand years in the case of liquid; but in the order of hours to hundreds of days in the case of gas. Smythe quotes literature that he claims helps to substantiate his argument.[71] [72] [73] [74] [75]

---

[65] Warner NR, Jackson RB, Darrah TH, Osborn SG, et al. Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. Proc. Natl. Acad. Sci. U. S. A. 2012, 109 (30), 11961−11966.

[66] Flewelling SA and Sharma M. Constraints on upward migration of hydraulic fracturing fluid and brine. Ground Water 2013, 52 (1), 9-19.

[67] Engelder et al, 2014. The fate of residual treatment water in gas shale. Journal of Unconventional Oil and Gas Resources 7 (2014) 33–48

[68] See Rozell and Reaven quoting references 44,45, 46,47,48,49 and 50.

[69] Reagan, Moridis, Keen and Johnson (2015), Numerical simulation of the environmental impact of hydraulic fracturing of tight/ shale gas reservoirs on near-surface groundwater: Background, base cases, shallow reservoirs, short-term gas, and water transport, Water Resour. Res., 51, doi:10.1002/2014WR016086.

[70] Smythe D, 2016. Hydraulic fracturing in thick shale basins: problems in identifying faults in the Bowland and Weald Basins, UK. Solid Earth Discuss., doi:10.5194/se-2015-134, Manuscript under review for journal Solid Earth

[71] Myers T. Potential contaminant pathways from hydraulically fractured shales to aquifers. Ground Water 50, no. 6: 872–882. DOI: 10.1111/j.1745-6584.2012.00933.x, 2012.

[72] Northrup J L. Potential leaks from high pressure hydrofracking of shale, September 8, 2010

[73] Bicalho C C, Batiot-Guilhe C, Seidel J L, Van Exter S, and Jourde H. Geochemical evidence of water source characterization and hydrodynamic responses in a karst aquifer, http://www.sciencedirect.com/science/article/pii/S0022169412003733, 2012

[74] Gassiat, C., Gleeson, T., Lefebvre, R., and McKenzie, J.: Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential long term contamination of shallow aquifers, Water Resour. Res., 49(12), 8310-8327, doi:10.1002/2013WR014287, 2013.

88. In his paper, Smythe argues that a case of groundwater contamination in Bradford County, Pennsylvania supports his concern that faults are an important risk factor. He argues that the contamination of drinking water was caused by passage of frack fluid and/or produced water in part through the geology.

89. The case concerns the drilling of five wells in Bradford County in 2009 and 2010 by Chesapeake Energy. Contamination of private water wells with stray gas in the vicinity (1200m away) started almost immediately, and was followed by the Pennsylvania Department of Environmental Protection fining the company $900,000. The company drilled three new water wells to replace three existing wells, but the contamination continued, which included white foam in the water wells, vapour intrusion in the basement of a house, and bubbling of gas in the Susquehanna River. In June 2012 the homeowners won a civil case against the company, which had to buy the properties and compensate the owners.

90. Smythe also argues that English shale basins are considerably thicker than their US counterparts, and characterised by pervasive and complex faults, some of which extend upwards from the shale to outcrop. According to Smythe, UK shale basins are characterised by having major 'through-penetrating faults' and that the presence of permeable cover rocks in some areas mean that there is an inadequate seal for prevention of upward migration of wastewaters and gas from any future unconventional shale gas site.[76] In contrast, he argues that it is extremely rare for faults to extend up to outcrop in US shale basins. He also criticises the joint review of fracking for shale gas by the Royal Society and Royal Academy of Engineering (2012) for not addressing the potential problem of through-penetrating faults in UK shale basins.

91. The views of Smythe have been challenged by many experts including authors of papers that he has used to support his case, leading to a lively and heated online debate in Solid Earth Discussions.

92. According to Younger, faults are 'hydro-geologically ambiguous' and while some may present permeable zones (most notably where they cut relatively hard rocks such as sandstone, limestone or igneous / metamorphic lithologies); many serve as barriers to flow. Furthermore, even where optimum conditions exist for faults to display permeability, it is rare for this to be continuous over large vertical intervals.

93. Younger argues that even if one were to believe that faults cutting thick shale sequences (contrary to common experience) are permeable throughout the vertical extent, the risk of actual groundwater contamination is low because a hydraulic gradient that favours the upflow

---

[75] Lefebvre, R., Gleeson, T., McKenzie,, J. M., and Gassiat, C.: Reply to comment by Flewelling and Sharma on ''Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential contamination of shallow aquifers over long time scales,'' Water Resour. Res. 51, 1877– 1882, doi:10.1002/2014WR016698.

[76] Verdon and an anonymous reviewer in Solid Earth Discussions argue that Smythe's claims about complex and pervasive faulting in the UK relative to the US is not substantiated.

of water (and any pollutants) to shallow aquifers in the context of fracking is unlikely. If anything, the depressurisation of wells to allow gas to enter them during the production phase results in downward gradients over periods of years to decades. Even after the cessation of production (when active depressurisation has been suspended), the re-establishment of an upward gradient is unlikely to result in significant upflow over anything less than geological time. And even if faults are permeable throughout their vertical extent *and* subjected to sustained upward hydraulic gradients, Younger argues that the loading of pollutants would be insufficient to make a detectable difference to the overlying aquifer groundwater.

94. Llewellyn et al's study of the Bradford Country case concluded that the most likely cause source of the contamination of drinking wells was stray natural gas and drilling or HVHF compounds being driven 1–3 km along *shallow to intermediate depth* fractures to the aquifer.[77] They noted that contamination due to fluids returning upward from *deep* strata would be surprising given that the time required to travel 2km up from the shale would likely be thousands to millions of years, and because the chemical composition of the drinking waters showed an absence of salts that would be diagnostic of fluids coming from the shale. The data implicate fluids flowing vertically along gas well boreholes and then through intersecting shallow to intermediate flow paths via bedrock fractures. Such flow is likely when fluids are driven by high annular gas pressure or possibly by high pressures during HVHF injection.

95. Verdon also argues that if fluids have propagated upwards from depth, the migration pathway would be the poorly-cemented wellbore, and that faults and/or fractures only provide a pathway for fluid migration in the upper 300m or so of the subsurface where compressive stresses are low. Verdon also states while it is possible (even common) that a hydraulic fracture will intersect a fault, if and when it does so, the easiest flow pathway in terms of permeability will be along the propped fractures and into the production well.

96. Another study which consisted of an experiment where a faulted section of Marcellus Shale was fracked using fluids containing chemical tracers (which allowed the tracking of subsurface fluid movement), found no evidence of upward fluid migration or hydraulic connection from the shale to overlying layers, despite the interaction between hydraulic fractures and faults.[78] However, Smythe argues that the study did not examine a geological situation with 'through-penetrating faults' and therefore has no direct relevance to his argument.

97. A further point of debate raised by Smythe concerns the importance of identifying faults before and during drilling. He argues that before any fracking takes place, faults should be thoroughly mapped and a 'setback' distance be established between the frack zone and the nearest faults.

---

[77] Llewellyn GT et al, 2015. Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development PNAS | May 19, 2015 | vol. 112 | no. 20 | 6325–6330

[78] Hammack R, Harbert W, Sharma S et al, 2014. *An Evaluation of Fracture Growth and Gas/Fluid Migration as Horizontal Marcellus Shale Gas Wells are Hydraulically Fractured in Greene County, Pennsylvania*; NETL-TRS-3-2014; EPAct Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory.

However, according to him, identification of faults within a thick shale sequence such as the Bowland-Hodder Unit is difficult, and cannot always be guaranteed.

98. The issue of faults in the UK is underlined by the experience of the only shale well to have been fracked in the UK: Preese Hall in Lancashire which was fracked in 2011 by Cuadrilla to test the shale and which triggered earthquakes. According to Smythe, analyses of two independent datasets – a 3D seismic survey and wellbore deformation – demonstrate that the fault on which the earthquakes were triggered, was transected by the wellbore. Furthermore, he points out that these data contradict the initial conclusion of the operator which claimed that the triggered fault lay hundreds of metres away from the wellbore.

99. Smythe also describes how in 2014 in the Weald Basin in Sussex (Balcombe-2), Cuadrilla drilled a horizontal well along a 40m thick limestone sandwiched between two oil-prone shale layers and intersected two normal faults which had not been foreseen by the operator.

100. Smythe argues that it is unacceptable that current UK regulations permit the drilling of faults (if they are identified) either vertically or horizontally because cement bonding of the casing, either in the deviation zone or in the horizontal section of the well, would be difficult to achieve.[79] As shown at Preese Hall, a well that penetrates a fault can be deformed by seismic activity triggered by HVHF and increase the chance of the integrity of the well bore being degraded.

101. Haszeldine concludes that faults (and fractures) may act as a conduit for both fluids and gas to aquifers at *higher subsurface levels* from the wellbore in the case of concurrent well integrity failure and agrees that the potential for faults to act as leakage conduits is more likely in intensely faulted basins. He also states that geoscientific investigations may have failed to recognise these potential hazards ahead of drilling and after fracking and that there are legitimate questions to be asked about subsurface evaluation competence and the ability to recognise faults before or after drilling; the adequacy of current legacy information to position fracking boreholes; and the state of knowledge of fluid and gas flow along faults penetrating towards the land surface.

102. He agrees that regulatory oversight of drilling applications and industrial activity appears to be inadequate and that some of information and insights contained in Smythe's case studies are "remarkable and even shocking as examples of how current practice has not produced anything like technically adequate assurance of high quality for UK citizens". In his view, "the observations made, of pressure leakage at Preese Hall, and of basic subsurface ignorance and technically bad seismic processing at Fernhurst and Wisborough Green are shocking, and could be investigated for mandatory cleanup".

---

[79] The eccentricity of the drill casing with respect to the borehole means that it is hard to flush out drilling mud, and a subsequent cement job may then fail because the resulting cement-mud slurry does not make not a sound bond.

103. Westaway, one of Smythe's strongest critics, argues that what happened at Preese Hall would not be permitted in the UK in the future as all 'stakeholders' accept the need to do things differently.[80] However, he agrees that the actions of Cuadrilla at Preese Hall were far from ideal,[81] and that there were also problems about the release of data about the incident. According to him, 'something is clearly fundamentally wrong with the present arrangements for implementing the UK government's publically stated commitment to open disclosure and discussion of data pertaining to shale gas development'.

104. Although Haszeldine does not think that there is a compelling case for deep waters being brought up to the surface along steeply dipping faults, he agrees that this is worthy of greater investigation, especially as the consequences may be serious for drinking water supplies. He also states that while the upward migration of fluids from the fracking zone to aquifers is unlikely, *gas* ascent through pathways along or parallel to fault planes is possible. In short, faults could act as conduits for fugitive gas emissions from fracked basins.

I. Well integrity

105. As noted above, pollution can occur through leaky wells, during drilling and casing, and even after wells have been sealed and abandoned.[82] [83] The loss of well integrity can potentially lead to direct emissions of gas to the atmosphere and/or subsurface migration of gas and/or liquid to groundwater, surface waters or the atmosphere.[84] [85] Under certain conditions, leaks that continue undetected or are inadequately remedied may also lead to the accumulation of explosive gases.

106. Drillers use steel casing (pipes), cement between nested casings and between the outside casing and rock wall, as well as mechanical devices to keep fluids and gas inside the well.

107. The causes of loss of well integrity include failure of the cement or casing surrounding the wellbore and an improperly sealed annulus. Cement barriers may fail at any time over the life of

---

[80] Westaway 2016a. Interactive comment on: Hydraulic fracturing in thick shale basins: problems in identifying faults in the Bowland and Weald Basins, UK" by Smythe DK. Solid Earth Discussions, se-2015-134, SC2

[81] For example, Westaway states that the induced seismicity should have been detected earlier (by applying a series of standard tests) so that fracking could have been stopped rather than continuing for almost two months until being 'voluntarily' terminated just before the UK government imposed a moratorium. In addition, the in-situ stress dataset collected *during* drilling should have been analysed before the fracking began, rather than afterwards, as this would have shown that faults in the vicinity were already stressed and that fracking might induce seismicity.

[82] Kissinger A, Helmig R, Ebigbo A, Class H, et al. Hydraulic fracturing in unconventional gas reservoirs: risks in the geological system, part 2. Environ. Earth Sci. 2013, 70, 3855–3873

[83] Vengosh et al, 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environmental science & technology* 48.15: 8334-48.

[84] Ingraffea et al 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. PNAS 111(30): 10955–10960

[85] Stuart ME, 2011. Potential groundwater impact from exploitation of shale gas in the UK. *British Geological Survey Open Report*, OR/12/001.

a well for various reasons including inappropriate cement density, inadequately cleaned bore holes, premature gelation of the cement, excessive fluid loss in the cement, high permeability in the cement slurry, cement shrinkage, radial cracking due to pressure fluctuations in the casings, poor interfacial bonding, and normal deterioration with age.[86] Casing may fail due to failed casing joints, casing collapse and corrosion.[87]

108. The risk of loss of well integrity increases with age as steel corrodes, and as cement shrinks, cracks or disbonds from the casing and rock. Factors that increase the risk of loss of well integrity include: unconventional and horizontal wells; wells being longer and curving laterally; wells being exposed to more intense hydraulic pressures and larger water volumes; the adoption of poor practices by companies (wells being drilled during boom periods in the US have led to operators cutting corners in an attempt to maximise the number of wells drilled).[88] [89] Drilling through strata with pervasive and complex faults also increases the risk of well damage and integrity failure.

109. The structural integrity failure rate of oil and gas well barriers is a subject of debate.

110. According to Davies et al, data from around the world indicate that more than four million onshore hydrocarbon wells have been drilled globally. In their assessment of all reliable datasets on well barrier and integrity failure (including production, injection, idle and abandoned wells, as well as both onshore and offshore wells, exploiting both conventional and unconventional reservoirs), they found datasets that varied considerably in terms of the number of wells examined, their age and their designs. They found that the percentage of wells with some form of well barrier or integrity failure was highly variable, ranging from 1.9% to 75%.[90]

111. In the US, because of the lack of publicly available structural integrity monitoring records for onshore wells *from industry*, studies have relied on data from state well inspection records to estimate the proportion of unconventional wells that develop cement and/or casing structural integrity issues.

112. Davies' own assessment of unconventional wells in Pennsylvania indicated that 6.26% had well barrier or integrity failure, and 1.27% leaked to the surface.

113. Ingraffea et al's analysis of 75,505 compliance reports for 41,381 conventional and unconventional oil and gas (O&G) wells in Pennsylvania drilled from January 2000 and December 2012 found a sixfold higher incidence of cement and/or casing issues for shale gas wells relative

---

[86] Bonnett A, Pafitis D (1996) Getting to the root of gas migration. Oilfield Review 8(1): 36–49.

[87] Ingraffea et al 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. PNAS 111(30): 10955–10960

[88] Davies et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology 56 (2014) 239e254

[89] Jackson 2014. The integrity of oil and gas wells. PNAS 111(30): 10902–10903

[90] Davies RJ, Almond S, Ward RS, Jackson RB et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology 56 (2014) 239e254

to conventional wells.[91] Overall, between 0.7% and 9.1% of the O&G wells developed since 2000 showed a loss of well integrity. The well-barrier or integrity failure rate for unconventional wells was 6.2%. The most common causes were "defective, insufficient or improperly installed" cement or casing.

114. The same study also identified temporal and geographic differences in risk. Temporal differences may reflect more thorough inspections and greater emphasis on finding well leaks, more detailed note taking in the available inspection reports, or real changes in rates of structural integrity loss due to rushed development or other unknown factors. The predicted cumulative risk for all wells in the NE region of Pennsylvania was 8.5-fold greater than wells drilled in the rest of the state.

115. In Considine et al's analysis of records from the Pennsylvania Department of Environmental Protection from 2008 to 2011, between 1% and 2% of wells had one or more potential structural integrity issues reported during that time period.[92] Another study using data from 2008 to 2013 found that 3.4% of all monitored unconventional wells drilled in Pennsylvania might have structural integrity failures related to cement/casing integrity.[93] However, both these studies are limited by the inadequacy of the frequency and completeness of state inspections as a basis for accounting for all incidences of cement/casing failure.

116. Few data exist in the public domain for the failure rates of onshore wells in Europe. It is also unclear which of the available datasets would provide the most appropriate analogues for well barrier and integrity failure rates at shale gas production sites in the UK and Europe.[94]

117. In the UK, the integrity failure rates of onshore (conventional) oil and gas wells are largely unknown. Davies et al (2011) note a small number of reported pollution incidents associated with the few existing active onshore (conventional) wells and none with inactive abandoned wells. They state that this could indicate that pollution is not a common event, but warn that monitoring of abandoned wells does not take place in the UK and that less visible pollutants such as methane are unlikely to be reported. Thus "well integrity failure may be more widespread than the presently limited data show".

118. They call for more research (e.g. a survey of the soils above abandoned well sites to establishing whether there is a loss of integrity and fluid / gas migration following well

---

[91] Ingraffea AR, Wells MT, Santoro RL, Shonkoff SBC, 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. Proc Natl Acad Sci USA 111:10955–10960.

[92] Considine T, Watson R, Considine N, Martin J (2012) Environmental Impacts During Marcellus Shale Gas Drilling: Causes, Impacts, and Remedies. Report 2012-1 Shale Resources and Society Institute (State University of New York, Buffalo, NY)

[93] Vidic RD, Brantley SL, Vandenbossche JM, Yoxtheimer D, Abad JD (2013) Impact of shale gas development on regional water quality. Science 340(6134):1235009.

[94] Davies et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation

abandonment), a mechanism for funding repairs on orphaned wells, and an ownership or liability survey of existing wells.

F. Wastewater management

119. As noted earlier, one of the hazards associated with SGP is the volume and level of toxicity of fluid that is brought to the surface.

120. Options for managing large volumes[95] of hazardous flowback fluid and wastewater on the surface include the reuse of flowback fluid for further hydraulic fracturing; on-site or off-site wastewater treatment followed by discharge; and deep well injection.

121. Initially flowback fluid returns to the surface in large volumes and closely reflects the composition of fracking fluid. Later, when the well is producing gas, formation and produced waters are returned in lower volumes, but with higher concentrations of heavy metals, NORM and other contaminants from the shale. This may continue for months after HVHF. In this report, both the initial flowback fluid and the subsequent produced or formation water are considered together as wastewater.

122. High levels of contamination and pollutants in wastewater, and particularly radioactive NORM, require specialised treatment facilities before they can be safely disposed. The actual composition of wastewater fluid is an important factor. For example, high levels of dissolved salts require distillation (which is generally expensive because of the high energy inputs) or reverse osmosis before the wastewater can be safely disposed of.

123. In the US, the management of wastewater includes storage in open pits; deep well injection (reinjecting wastewater into the ground); transportation to treatment facilities followed by disposal; and on-site treatment with some re-use of water and disposal of remaining liquids and solids. Although some well operators recycle and reuse flowback fluid for hydraulic fracturing, many operators do not due to the cost of separation and filtration.[96] Deep well injection and storage in open pits is presently not an option in the UK. Neither is.

124. Difficulties with wastewater treatment that have been reported in the US include the lack of treatment plant capacity or technology[97] and the difficulty in predicting the content and

---

[95] The Institution of Civil Engineers estimate that a single well could produce between 7,500 to 18,750 m3 of flowback annually. See written submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA070), para 2.1.

[96] Rozell DJ and Reaven SJ (2012). Water pollution risk associated with natural gas extraction from the Marcellus Shale. *Risk Anal* **32**(8): 1382–93.

[97] J.M. Wilson, J.M. VanBriesen, 2012. Oil and gas produced water management and surface drinking water sources in Pennsylvania Environ. Pract., 14 (2012), pp. 288–300

composition of fluid brought up to the surface.[98] Some US municipal wastewater treatment facilities have struggled to handle wastewater containing high concentrations of salts or radioactivity.[99] The pollution of some rivers has also been associated with municipal wastewater treatment facilities not being able to handle wastewater with high concentrations of salts or radioactivity.[100]

125. In the UK, issues about wastewater management became apparent during the Public Inquiry into Cuadrilla's appeal against Lancashire's decision to reject planning applications for two exploratory shale gas wells (in Roseacre Wood and Preston New Road).[101]

126. One of the issues was the limited capacity and availability of treatment facilities in the UK. Constraints on treatment capacity became greater when a change in law designated wastewater as a low level radioactive substance which excludes ordinary sewage treatment works as a viable option.

127. In Watson's evidence to the Lancashire Public Inquiry, he notes that the Government has been unable to confirm the existence of adequate treatment capacity in the event of shale production at scale and that a likely increase in NORM generation from iron, steel and titanium dioxide production, as well as the decommissioning of offshore oil and gas infrastructure from the North Sea and the anticipated growth in provision of O&G decommissioning services to other countries, are likely to place even more pressure on limited capacity.

128. The problem of limited treatment capacity is illustrated by the considerable volume of wastewater expected from the two exploratory fracking sites that Cuadrilla sought to develop in Lancashire: a DECC Strategic Environmental Assessment reported that a 'high activity scenario' would result in an annual production of 108 million m^3 of wastewater from the two sites which on their own would represent as much as 3% of UK total annual wastewater.[102]

129. Another issue is the transportation of wastewater to treatment facilities. According to Watson, Cuadrilla's two exploratory sites in Lancashire would involve transporting at least 50 million litres, an amount that equates to 1,440 tankers with a capacity of 35,000 litres (360 tanker loads per well). In order to transport this volume of fluid to a treatment facility, a

---

[98] E. Barbot, N.S. Vidic, K.B. Gregory, R.D. Vidic, 2013. Spatial and temporal correlation of water quality parameters of produced waters from Devonian-age shale following hydraulic fracturing. Environ. Sci. Technol., 47 (2013), pp. 2562–2569

[99] See Rozell and Reaven refs 42 and 56

[100] Pennsylvania DEP investigates elevated TDS in Monongahela River. Water and Wastes Digest. October 27, 2008. Available at: http://www.wwdmag.com/Pennsylvania- DEP-Investigates-Elevated-TDS-in-Monongahela-RivernewsPiece16950,

[101] Cuadrilla's applications include provisions for an extended flow testing period of 18-24 months after an initial 90 day flow testing. It was anticipated that produced fluids would be generated throughout that extended period.

[102] According to Watson, the impact of such a sudden and significant surge in demand, even if only for a relatively short-term, in terms of the opportunity costs to other major users and the consequences of any accidents or disruption at the treatment sites was not considered in Cuadrilla's planning applications.

potential total tanker mileage of 470,000 miles (approximately 19 times around the earth) would be required, and result in emissions of around 2,000 tonnes of carbon dioxide.[103]

130. Although on-site treatment and re-use of flowback could reduce the volumes of wastewater generated and lessen any effects on offsite treatment infrastructure capacity, this would require more sophisticated equipment. There is also significant uncertainty as to the quantity of flowback fluid which may be suitable for re-use.

G. Air pollution

131. Air pollutants include: (1) unintended or irregular (fugitive) emissions of gas from the ground, well and associated infrastructure (e.g. pumps, flanges, valves, pipe connectors, and collection and processing facilities); (2) diesel fumes from engines used to power equipment, trucks and generators; (3) emissions from drilling muds[104], fracturing fluids[105] and flowback water; (4) silica dust (silica is used to prop open the shale fractures); (5) venting or the deliberate release of gas into the atmosphere (when there is a safety risk); and (6) the flaring of gas (limited in the UK to exploratory fracking due to the expected requirement for green or reduced emissions 'completions' during the production phase).

132. Moore et al (2014) conducted a critical review of the air impacts of all five stages of the natural gas life cycle (pre-production; production; transmission, storage, and distribution; end use; and well production end-of-life).[106] Each stage has a potential to produce hazardous air pollutants which may include particulate matter from diesel powered equipment and truck traffic, VOCs, respirable silica, H_2S, NOx and SO_2. Photochemical reactions involving nitrogen oxides (NO_x and VOCs can also produce ground-level ozone, sometime many miles away from the actual sites of fracking.

133. Air pollution may also arise from the sub-surface. According to Macey et al, "we do not understand the extent of drilling-related air emissions as pockets of methane, propane, and other constituents in the subsurface are disturbed and released to the atmosphere".[107] The potential for gas to be released from the sub-surface directly into the atmosphere has been

---

[103] These figures are conservative, and based on the assumption that the flowback rate would only be 19% of the total water injection during the initial flow testing/exploration period (although confusingly, a figure of 40% was reported elsewhere). The flowback rate over the three months testing at Preese Hall was 70%.

[104] During the drilling stage a water-based fluid known as "drilling mud" is circulated through the borehole to lubricate and cool the drill bit and to loosen and collect fragments of rock caused by the drilling ('cuttings').

[105] Fracking fluid may include biocides to prevent bacterial growth; surfactants to reduce surface tension to aid fluid recovery; gels and polymers to increase viscosity and reduce friction; acids; and chemicals to inhibit corrosion of metal pipes. The exact composition will vary from operator to operator, and from site to site depending on factors such as the depth of the operation, the length of the well and the nature of the shale.

[106] Moore C et al, 2014. Air Impacts of Increased Natural Gas Acquisition, Processing, and Use: A Critical Review Environ. Sci. Technol. 2014, 48, 8349−8359

[107] Macey et al, 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 2014, 13:82 doi:10.1186/1476-069X-13-82

poorly studied, and echoes some of the issues discussed earlier about the potential for faults and fractures to act as conduits for the migration of gas and fluid below the surface.

134. Multiple factors (described earlier) are involved in determining the actual level of air pollution. These include variable operating practices as well as geological and meteorological variables. This explains why air quality studies carried out in regions with high levels of unconventional O&G production have yielded variable and conflicting results. The variability in findings across the scientific literature is also a function of the scientific methods used to measure air pollution.

135. Colborn et al (2013) demonstrate this variability in a study which gathered weekly, 24-hour air samples 0.7 miles from a well pad in Garfield County which showed a "great deal of variability across sampling dates in the numbers and concentrations of chemicals detected".[108]

136. Eapi et al (2014) also found substantial variation in fenceline concentrations of methane and hydrogen sulphide, which could not be explained by production volume, number of wells, or condensate volume at natural gas development sites.[109] Two sets of drive-by measurements were taken (the researchers did not have access to the sites) and the study defined 'high' levels as > 3 ppm for methane and > 4.7 ppb (the odour threshold) for H_2S. Elevated levels of methane and/or H_2S were found at 21% of sites (high methane levels at 16.5% of sites and high H_2S at 8% of sites). While mean methane concentrations at dry (where the produced gas is overwhelmingly methane) sites were significantly higher than those at wet sites (where produced gas is comprised of methane and other volatiles such as ethane and butane), no relationship with the size of the site or production volume was found.

137. Some studies have shown little in the way of significant air pollution caused by SGP. Other studies show that some pollutants are emitted at levels that can breach air quality and safety standards.

138. Goetz et al (2015) assessed the composition of air samples using a mobile laboratory at sites with high levels of shale gas activity in the summer of 2012 in NE and SW Pennsylvania, including over 50 compressor stations and 4200 wells.[110] They found no elevation of sub-micrometer particles, nor of light aromatic compounds such as benzene and toluene. Nearly all VOCs detected were attributed to on-road engine exhaust. According to the authors, the absence of light aromatics was not surprising because the Marcellus shale does not have associated oil deposits.

---

[108] Colborn T, Schultz K, Herrick L, Kwiatkowski C. An exploratory study of air quality near natural gas operations. Hum Ecol Risk Assess 2013. http://dx.doi.org/10.1080/10807039.2012.749447

[109] Eapi GR, Sabnis MS, Sattler ML, 2014. *Mobile measurement of methane and hydrogen sulfide at natural gas production site fence lines in the Texas Barnett Shale.* J Air Waste Manag Assoc.64(8): 927-44.

[110] Goetz J, Floerchinger C, Fortner E et al, 2015..Atmospheric emission characterization of Marcellus Shale Natural Gas Development Sites.

139. Bunch et al (2014) analysed data on VOC levels collected by the Texas Commission on Environmental Quality using 7 monitors at 6 sites from 2000-2011.[111] They found almost zero exceedance of health-based comparison values. The study, supported by an industry funded Energy Education Council, also ran risk assessment studies based on these data and concluded that shale gas production activities had not led to VOC exposures of public health concern.

140. Paulik et al (2015) used passive air samplers to assess levels of 62 PAHs at 23 residential properties in Carroll County Ohio located between 0.04 and 3.2 miles of an active wellpad in early 2014.[112] Sampling sites excluded other sources of PAHs such as urban areas and proximity to airports, and samplers were deployed as far as possible from obvious potential confounding sources. Levels of PAHs were an order of magnitude higher than results previously published for rural areas with a clear pattern of increasing PAH levels with closer proximity to wellpads.

141. Macey et al (2014) assessed concentrations of VOCs in 35 air samples around UNG sites that were collected by trained members of the community in five US states.[113] Residents used an assessment of local conditions to determine the sites of 35 grab samples and supplemented these with 41 formaldehyde badges at production facilities and compressor stations. 46% of the former and 34% of the latter exceeded established air safety standards. High concentrations of benzene, formaldehyde, hexane and H_2S were identified. In some cases, benzene levels exceeded standards by several orders of magnitude.

142. A study in six counties of the Dallas/Fort Worth areas by Rich et al (2016) assessed chemicals in ambient air samples in residential areas near shale gas wells.[114] Samples were collected using 24-hour passive samplers at 39 locations within 61m of a UNG site from 2008-2010. Approximately 20% of the 101 chemicals identified were designated HAPs, including 1,3-butadiene, tetrachloroethane and benzene (with the latter identified at 76% of sites). Virtually all the analyses detected high methane levels, with the mean level being six times higher than background concentrations. Principal component analysis identified compressors as the dominant source of many of the chemicals, although further studies with larger sample sizes are required to confirm these findings.

143. Ethridge et al (2015) reported on extensive monitoring of airborne VOCs in the Barnett Shale region by the Texas Commission on Environmental Quality (TCEQ). TCEQ developed an extensive inventory of emission sources including information on location, type and number of emission sources; equipment and activities conducted; releases to air; and proximity of receptors. A range of monitoring techniques was used to estimate long and short-term exposures in areas with and without UNG during 2009 and 2010. While several short-term samples exceeded odour-based

---

[111] Bunch AG, Perry CS, et al, 2014. Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Sci Total Environ 468–469: 832–42.

[112] Paulik et al, 2015. Impact of Natural Gas Extraction on PAH Levels in Ambient Air. Environ. Sci. Technol. 2015, 49, 5203−5210

[113] Macey et al, 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 2014, 13:82

[114] Rich and Orimoloye. Elevated Atmospheric Levels of Benzene and Benzene-Related Compounds from Unconventional Shale Extraction and Processing: Human Health Concern for Residential Communities. *Environmental Health Insights* 2016:10 75–82 doi: 10.4137/EHI.S33314.

air monitoring comparison values and detected levels above typical background norms downwind of UNG, only three samples exceeded health-based AMCVs. Short-term sampling found elevated levels of VOCs, most notably benzene, being emitted from a small percentage of those facilities.

144. In a study of air quality before, during and after the development and operation of a fracked gas well pad, Colborn et al (2014) measured levels of VOCs and carbonyls using a monitoring station 1.1 km from a site in Western Colorado over the course of a year.[115] Various chemicals were monitored, and methane, ethane, propane, toluene, formaldehyde and acetaldehyde were detected in every sample. Chemicals associated with urban traffic emissions as opposed to gas operations (e.g. ethane) were found at low levels. There was considerable temporal variability in the number and concentrations of chemicals detected although levels of NMHCs were highest during the initial drilling phase prior to fracturing. The authors also noted that exposure to some NMHCs at even very low concentrations (and below government safety standards) could have health effects. They highlighted that certain PAHs "were at concentrations greater than those at which prenatally exposed children in urban studies had lower developmental and IQ scores" and that "the human and environmental health impacts of the NMHCs, which are ozone precursors, should be examined further given that the natural gas industry is now operating in close proximity to human residences and public lands".

145. Litovitz 2013 estimated levels of VOC, NOx, PM_{10}, $PM_{2.5}$ and SO_2 emissions and the cost of the environmental and health damages associated with shale gas extraction in Pennsylvania.[116] While emissions were a small proportion of total statewide emissions, NOx emissions were up to 40 times higher in areas with concentrated shale gas activities than permitted for a single minor source. They estimated the environmental and health costs for 2011 to range from $7.2 to $32 million with over 50% due to compressor stations. However, they emphasise that a substantial proportion of these damages cannot be specifically attributed to shale gas and are less than those estimated for any of the state's large coal power plants. Despite the uncertainties associated with the estimates, they consider the pollution emissions to be non-trivial.

139. Swarthout et al (2015) analysed air samples from across a region surrounding Pittsburgh and compared data from two sites: one with nearly 300 unconventional natural gas (UNG) wells within 10 km and the other a remote location with a single well within 10 km.[117] They found elevated mixing ratios of methane and C2−C8 alkanes in areas with the highest density of UNG wells. The finding that alkane mixing ratios were not elevated near conventional wells supports the conclusion that UNG wells may leak at a higher rate than conventional wells. Source apportionment methods indicated that UNG emissions were responsible for the majority of mixing ratios of C2−C8 alkanes, but accounted for a small proportion of alkene and aromatic

---

[115] Colborn T, Schultz K, Herrick L, Kwiatkowski C. An exploratory study of air quality near natural gas operations. Hum Ecol Risk Assess 2014;20(1):86–105.

[116] Litovitz A, Curtright A, et al (2013). Estimation of regional air-quality damages from Marcellus Shale natural gas extraction in Pennsylvania. *Environ Res Lett* **8**(1), 014017 doi: 10.1088/1748-9326/8/1/014017.

[117] Swarthout R, et al, 2015. Impact of Marcellus Shale Natural Gas Development in Southwest Pennsylvania on Volatile Organic Compound Emissions and Regional Air Quality Environ. Sci. Technol. 2015, 49, 3175−3184

compounds. The VOC emissions from UNG operations were also associated with levels of ozone formation that compromised federal air quality standards, but were deemed not to be high enough to raise concern about cancer and non-cancer risks.

140. Vinciguerra et al (2015) used ambient levels of ethane, a marker for fugitive natural gas emissions, and reported that daytime ethane concentrations had increased from about 7% of total measured non-methane organic carbon to about 15% from 2010 to 2013 in areas overlying the Marcellus Shale.[118] This trend was not observed in a control area with similar urban sources of pollution but no extensive natural gas production. They conclude that a substantial fraction of natural gas is escaping uncombusted, and the signal is detectable hundreds of kilometers downwind. They conclude that this could cause ozone and PM levels to rise and breach air quality standards in major urban centers downwind.

141. Kemball-Cook et al (2010) developed projections of future UNG production in the Haynesville shale under three different intensity conditions based on the number of new wells drilled and production estimates for each new active well.[119] These estimates were used to develop emission inventories for each scenario using data from a development in a similar nearby formation. Estimated emissions of NOx, VOCs and CO were large enough to threaten the achievement of proposed ozone standards even in the model assuming limited UNG development. Drill rigs, compressor stations and gas plants were identified as the principal sources of NOx and the authors suggested additional controls on these elements of the process.

142. The authors of a study of the traffic-related environmental impacts of fracking operations (Goodman et al, 2016), concluded that “the local impacts of a single well pad may be short duration but large magnitude”, and that while single digit percentile increases in emissions of CO_2, NOx and PM were estimated over the period from start of construction to pad completion (potentially several months or years), excess emissions of traffic-related NOx on individual days of peak activity could reach 30% over baseline.[120]

143. The West Virginia Natural Gas Horizontal Well Control Act of 2011 requires determination of the effectiveness of a 625 foot set-back from the center of the pad of a horizontal well drilling site. An investigation which collected data on dust, hydrocarbon compounds and radiation to characterize levels that might be found at 625 feet from the well pad center of unconventional gas drilling sites found detectable levels of dust and VOCs with some benzene concentrations above what the CDC calls the “the minimum risk level for no health effects.” But there were no concerns found related ionizing radiation levels from airborne particulate matter.[121]

---

[118] Vinciguerra T et al (2015) Regional air quality impacts of hydraulic fracturing and shale natural gas activity: Evidence from ambient VOC observations. Atmospheric Environment 110 (2015) 144e150

[119] Kemball-Cook S, Bar-Ilan A, et al (2010). Ozone impacts of natural gas development in the Haynesville Shale. *Environ Sci Technol* **44**(24): 9357–63.

[120] Goodman et al, 2016 Investigating the traffic-related environmental impacts of hydraulic-fracturing (fracking) operations, Environment International 89–90 (2016) 248–260

[121] McCawley M, 2013. Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project. http://wvwri.org/wp-content/uploads/2013/10/a-n-l-final-report-for-web.pdf

144. Gilman 2013 compared VOC concentrations measured at an atmospheric research facility located in the Colorado Wattenberg field with ambient levels monitored in two other NE Colorado sites.[122] VOCs related to oil and natural gas were identified at all three sites and considered to represent a significant source of ozone precursors.

145. Several other papers note that O&G operations contribute to the formation of ozone. Field et al 2015 reported numerous localised ozone episodes during the winter of 2011 associated with fugitive emissions of natural gas (as well as other sources such as traffic, condensate and water treatment facilities).[123] Edwards et al (2014) described that O&G activities contributed to the formation of ozone during the winter of 2012-13 in the Uintah basin.[124]

146. Helmig et al's (2014) examination of the high ozone levels in the Uintah basin in the winter of 2012/13 noted that the Uintah Basin Winter Ozone Studies had previously identified highly elevated levels of atmospheric alkane hydrocarbons with enhanced rates of C2−C5 non-methane hydrocarbon (NMHC) mole fractions. The total annual mass flux of C2−C7 VOC was estimated to be equivalent to the annual VOC emissions of a fleet of ~100 million automobiles, "reaching or exceeding levels reported from the most heavily polluted inner cities". Total annual fugitive emission of benzene and toluene were also estimated (1.6 ± 0.4 × 106 and 2.0 ± 0.5 × 106 kg yr−1 respectively). Their findings reveal "a strong causal link between oil and gas emissions, accumulation of air toxics, and significant production of ozone in the atmospheric surface layer". They also estimated that fugitive methane and NMHC emissions amounted to a total hydrocarbon/natural gas production loss rate of 8.4−15.9%.

147. Roy et al (2014) developed an emission inventory to estimate emissions of NOx, VOCs, and $PM_{2.5}$ in Pennsylvania, New York, and West Virginia for 2009 and 2020.[125] The analysis suggested that Marcellus shale development would be an important source of regional NOx and VOCs potentially contributing 12% (6–18%) of emissions in the region in 2020. This level of release was considered large enough to offset projected emissions reductions in other sectors and challenge ozone management in rural areas. While the Marcellus shale was not predicted to contribute significantly to regional $PM_{2.5}$ levels, it could account for 14% (2-36%) of elemental carbon.

148. Ahmadi and John 2015 conducted a comprehensive analysis of historical ozone data and developed a time series analysis to evaluate the long term relationship between shale gas development and ozone pollution in the Dallas-Fort Worth region of Texas. They also conducted a comparative assessment with an adjacent non-shale gas region. Regional air quality had been extensively monitored for over 30 years and provided an exceptionally comprehensive and extensive dataset. The analysis considered trends during the periods 2000 to 2006 and from

---

[122] Gilman JB, Lerner BM, Kuster WC, de Gouw JA. Source signature of volatile organic compounds from oil and natural gas operations in Northeastern Colorado. Environ Sci Technol 2013;47(3):1297–305

[123] Field et al 2015. Influence of oil and gas field operations on spatial and temporal distributions of atmospheric non-methane hydrocarbons and their effect on ozone formation in winter. Atmos. Chem. Phys., 15, 3527–3542,

[124] Edwards PM, Brown SS, Roberts JM et al, 2014. High winter ozone pollution from carbonyl photolysis in an oil and gas basin. *Nature,* 2014, **514**, 351-354.

[125] Roy et al, 2014. Air pollutant emissions from the development, production, and processing of Marcellus Shale natural gas. J Air Waste Manag Assoc. 2014 Jan;64(1):19-37.

2007 to 2013 and showed that ozone levels decreased in the non-shale gas region compared to the shale gas region. The average long-term component of meteorologically adjusted ozone was 2% higher in the shale gas area from 2008 and the mean short-term meteorologically adjusted ozone was almost 10% higher.

149. UNG's photochemical oxidant formation potential has been estimated to be about nine times higher for UK shale gas compared to North Sea gas when used for electricity generation and 60% worse than coal power (Stamford et al 2014).

H. Health impacts of pollution

150. Potential hazards become risks to health when there is exposure to those hazards at levels that might harm health. Some pollutants are acutely detrimental (i.e. toxic) whilst others may cause long term health effects due to chronic exposure at even relatively low levels.

151. The number of risk studies is limited and more research is needed to address public concerns about the risks of SGP on human and ecosystem health.[126] [127] A cumulative risk assessment approach would incorporate chemical, physical, and psychosocial stressors that contribute to stress-related health effects in populations living near UNG development sites.[128]

152. Some studies which have measured levels of pollution have been able to model or estimate the potential impact on health. These include studies mentioned earlier. However, few studies have actually assessed or measured states of health and looked for any associations with O&G activities.

153. A study by Zielinska et al (2014) of the impact of SGP on population exposure to air pollutants in the Barnett Shale region used a combination of active well VOC emission characterisation, pollutant monitoring in a local residential community of 250-300 households in an area of high well density and adjacent to a compressor station, and measurement of the pollutant gradient downwind of a gas well.[129] Monitoring included NOx, NO_2, SO_2, C5– C9 hydrocarbons, carbon disulphide and carbonyl compounds, $PM_{2.5}$ and PAHs. Samples from wellhead condensate tank venting emissions were used to establish a source profile. The average VOC and $PM_{2.5}$ concentrations in the residential area were found to be generally low, and "not likely to be discernible beyond a distance of approximately 100m in the downwind direction". However, the results also indicated a significant contribution to regional VOCs from gas production sources.

---

[126] Sexton, K.; Linder, S. H.Cumulative Risk Assessment for Combined Health Effects From Chemical and Nonchemical Stressors Am. J. Public Health 2011, 101 (S1) S81– S88, DOI: 10.2105/ajph.2011.300118

[127] Brittingham, M. Ecological Risks of Shale Gas Development. Risks of Unconventional Shale Gas Development; Washington DC, 2013; http://sites.nationalacademies.org/DBASSE/BECS/DBASSE_083187.

[128] Adgate 2013

[129] Zielinska et al, 2014. Impact of emissions from natural gas production facilities on ambient air quality in the Barnett Shale area: a pilot study. J Air Waste Manag Assoc. 2014 Dec;64(12):1369-83.

154. Brown et al (2015) conducted a modelling study to determine the health impact of exposure to VOC and PM2.5 in a hypothetical town in proximity to a shale gas development site.[130] They combined data on weather patterns with known and estimated measures of emissions from shale gas operations to assess potential health impact. They found that residents would be exposed to different intensities of pollutants at different times, and that these differences are related to the type of activity at the well pad in conjunction with other conditions for the specified time period. Drilling, flaring, finishing and gas production stages produced higher exposure levels than the hydraulic fracturing stage. The study demonstrated the importance of air stability and wind direction in exposure at the residential level which would "provide a possible explanation for the episodic nature of health complaints and symptoms in gas drilling and processing areas". The authors make 3 recommendations: 1) more research is needed to measure emissions in very short time intervals while also measuring over a long period of time; 2) the health care community should consider the possibility of patients suffering from intermittent industrial exposures if they live or work near UNG development sites; and 3) individuals living in shale gas areas should monitor weather conditions to understand when the air is likely to be particularly polluted and when it is likely to be less polluted.

155. McKenzie et al's (2012) assessment of the risk of exposure to air pollution involved calculating hazard indices (HIs) for residents living <1/2 mile and >1/2 mile from wells.[131] The study used routine ambient air monitoring data from 187 fracking sites from January 2008 to November 2010 and assumed a cumulative effect from multiple chemicals. It found that residents living within 0.5 mile of wells were at greater risk than those living > 0.5 mile away. For sub-chronic non-cancer conditions this was principally due to exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons. Cumulative cancer risks were 10 in a million for the proximal zone and six in a million in the distal zone, with benzene and ethylbenzene as the major contributor to risk. The largest HI was attributed to the relatively short-term effects of high emissions during the well development and completion period, driven principally by exposure to trimethylbenzenes, aliphatic hydrocarbons and xylenes which have neurological and/or respiratory effects (haematological and developmental effects also contributed to the combined HI). According to PHE, "the paper suggests that the potential risks from sub-chronic exposure are of most concern, especially among residents closest to the well pad".

156. However, in Swarthout et al's (2015) study of air samples in a region surrounding Pittsburgh, which found that local people are exposed to higher levels of hazardous air pollutants compared to populations living more remotely from gas operations, the actual concentrations of VOCs

---

[130] Brown DR, Lewis C, and Weinberger BI, 2015. Human exposure to unconventional natural gas development: A public health demonstration of periodic high exposure to chemical mixtures in ambient air. J. Environ. Sci Heal. A, 50, 460–472, doi:10.1080/10934529.2015.992663.

[131] McKenzie et al, 2012. Human health risk assessment of air emissions from development of unconventional natural gas resources. Science of the Total Environment 424 (2012) 79–87.

resulted in a relatively low HI for both cancer and non-cancer risks (using a modified version of the method used by McKenzie in 2012).[132]

157. A risk assessment of the potential public health implications resulting from the inhalation of VOCs in Garfield County indicated slightly elevated excess lifetime cancer risks driven mainly by benzene but which were within the EPA's acceptable range of risk. It also found some elevation of acute or subchronic non-cancer risks for those living closest to well sites, but little indication of chronic non-cancer risks.[133] [134]

158. A population-based study of the association between ozone levels and health effects in a UNG development region in Wyoming between 2008 and 2011 observed a 3% increase in the number of clinic visits for adverse respiratory-related effects for every 10 ppb increase in the 8 h ozone concentration the previous day.[135]

159. Community-based surveys have documented various symptoms, as well as instances of sleep loss, stress and odour complaints in association with shale gas developments. Though these studies lack scientific rigor because they are small, and use self-selecting or convenience samples of the local population, many of the findings are consistent with the known health effects of exposure to petroleum hydrocarbons.

160. A self-reporting survey of 108 individuals from 55 households in 14 counties in Pennsylvania between August 2011 and July 2012 found over 50% of participants reporting various respiratory, behavioural, neurological, muscular, digestive, skin and vision symptoms; some of which were associated with proximity to fracking and experience of odours. The same study conducted 34 air tests and 9 water tests in a subset of 35 households. 19 air samples recorded a variety of VOCs and BTEX levels higher than those previously reported by the local Department for Environmental Protection; and 26 chemicals detected in 11 well water samples which exceeded the MCL for manganese, iron, arsenic, or lead. There was some congruence between

---

[132] Swarthout R et al, 2015. Impact of Marcellus Shale Natural Gas Development in Southwest Pennsylvania on Volatile Organic Compound Emissions and Regional Air Quality. Environ Sci Technol, 49: 3175−3184

[133] Health Consultation: Public Health Implications of Ambient Air Exposures to Volatile Organic Compounds as Measured in Rural, Urban, and Oil & Gas Development Areas Garfield County, Colorado, Agency for Toxic Substances and Disease Registry; U.S Department of Health and Human Services Agency; Atlanta, GA, 2008; http://www.atsdr.cdc.gov/HAC/pha/Garfield_County_HC_3-13-08/Garfield_County_HC_3-13-08.pdf.

[134] Garfield County Air Toxics Inhalation Screening Level Human Health Risk Assessment: Inhalation of Volatile Organic Compounds Measured In 2008 Air Quality Monitoring Study. Colorado Department of Public Health and Environment: Disease Control and Environmental Epidemiology Division; Rifle, CO, 2010. http://www.garfield-county.com/public-health/documents/6%2030%2010%20%20RisK%20Assessment%20for%20Garfield%20County%20based%20on%202008%20air%20monitoring.pdf

[135] Associations of Short-Term Exposure to Ozone and Respiratory Outpatient Clinic Visits - Sublette County, Wyoming, 2008–2011; Pride, K.; Peel, J.; Robinson, B.; Busacker, A.; Grandpre, J.; Yip, F.; Murphy, T.; State of Wyoming Department of Health: Cheyenne, WY, 2013;

symptoms and chemicals identified by environmental testing, but the study was small and did not involve a random sample of participants.[136]

161. A cross sectional study of patients presenting to a primary care centre in Pennsylvania by Saberi (2014) used a self-administered questionnaire to explore attribution of health perceptions and 29 symptoms to environmental causes including UNG over one week in 2012.[137] Of the 72 participants, 42% attributed at least one symptom to an environmental cause with 22% identifying UNG development. 22% of respondents linked a health problem to natural gas (16 of 72), however some of these symptoms are of dubious plausibility. Nine of the 16 linked natural gas to a 'medical symptom', a reduced list of 15 drawn from the 29 in the questionnaire. Case reviews were conducted on six participants linking 'medical symptoms' to natural gas and only one had a record of both the symptom and the concern and in three cases there was no record of either. There was no measure of potential exposure and while mapping of 74% of respondents showed residence within two miles of a well, it also demonstrated no evidence of clustering. The potential for bias is reflected in the high levels of symptom linkage to other environmental issues such as antibiotics in food (22%) and ageing due to free radicals (11%).

162. Steinzor et al (2013) reported a questionnaire based community health survey supplemented with environmental data (VOCs in air and heavy metals in well water) from sites close to participants' homes.[138] This study involved 108 individuals including people recruited at public events from 14 Pennsylvania counties. All interviewees reported symptoms (range 2-111) with over 50% reporting more than 20. A variety of symptoms was identified including respiratory, behavioural, neurological, muscular, digestive, skin and vision symptoms. Throat and sinus issues increased with residential proximity to UNG sites and an association between odours and some symptoms was also identified. There is likely bias in the selection of study subjects and while some environmental data were collected, this study used distance as a proxy for exposure. 34 air and nine water samples were taken at 35 households; locations were selected based on household interest, severity of reported symptoms, and proximity to gas facilities. 19 air samples recorded a variety of VOCs and while BTEX levels were higher than those previously reported in samples taken by the local Department for Environmental Protection and used as controls, no comparisons with regulatory or advisory standards were made. 26 chemicals were detected in well water with 11 samples exceeding the MCL for manganese, iron, arsenic, or lead. While the study reports some congruence between symptoms and chemicals identified by environmental testing all the symptoms were self-reported, mostly highly non-specific and cannot be confidently linked to emissions from UNG sites.

163. A retrospective study of 124,862 births in rural Colorado showed an association between maternal proximity to natural gas well sites and birth prevalence of congenital heart defects and

---

[136] Ferrar KJ, Kriesky J, Christen CL, Marshall LP, Malone SL, et al. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region Int. J. Occup. Environ. Health 2013, 19 (2) 104– 12, DOI: 10.1179/2049396713y.0000000024

[137] Saberi P.Navigating Medical Issues in Shale Territory New Solutions 2013, 23 (1) 209– 221.

[138] Steinzor N, Subra W and Sumi L (2013). Investigating links between shale gas development and health impacts through community survey project in Pennsylvania. *New Solut* **23:** 55–83.

neural tube defects, but no association with oral clefts, term low birth weight or preterm birth.[139] Exposure was imputed by calculating tertiles of inverse distance weighted natural gas well counts within a 10-mile radius of maternal residence (range 1 to 1400 wells per mile) and a reference population with no wells within 10 miles. Associations were examined using logistic regression and multiple linear regressions. The number of births was approximately equal in exposed/non-exposed groups. Prevalence of CHDs increased with exposure tertile with an OR in highest tertile of 1.3 (CI 1.2, 1.5). NTD prevalence was also associated with the highest tertile (OR 2.0; CI 1.0, 3.9), compared with the non-exposed group. Exposure was negatively associated with prematurity and low birthweight and there was a modest positive association with foetal growth. No association was reported for oral clefts. This well conducted analysis of a large population suggests a positive association between proximity and density of gas wells in relation to mothers' residence and an increased prevalence of CHDs and possibly NTDs. This type of study has several recognised limitations, which the authors acknowledge, including incomplete data, undercounting, the effect of folic acid supplements, residual confounding and lack of exposure measures. Again the authors call for further research addressing these issues.

164. A working paper exploring 1,069,699 births in Pennsylvania reported increased prevalence of low birthweight and small for gestational age births, as well as reduced appearance, pulse, grimace, activity, respiration (APGAR) scores in infants born to mothers living within 2.5 km of a natural gas well compared to infants born to mothers living further than 2.5 km from a well.[140]

165. An industry-funded study (Fryzek at al, 2013) of childhood cancers before and after fracking in Pennsylvania found no difference in the incidence rate, except for CNS tumours although no relationship was apparent with the number of wells drilled. The study found a higher incidence of total cancers for counties with 500 wells or fewer compared to counties with more than 500 wells. The period of data analysis after drilling was generally too short for an adequate assessment of cancer risks, given latency in cancer development.[141] The authors recognise that SIRs should not be directly compared but actually do so to make reassuring conclusions. This has been challenged on other key methodological issues by others.[142]

166. Few studies have attempted to use biomonitoring to explore risks from shale gas-related pollutants. Blood and urine samples collected from 28 adults living in Dish, Texas, a town with large numbers of gas wells, storage tanks, and compressor stations near residences, found no indication of community wide-exposure to VOCs.[143] These results likely reflect the multiple potential sources and the short half-lives of most VOCs in urine and blood, especially since the

---

[139] McKenzie L.M, Guo R, Witter RZ, et al, 2014. Maternal residential proximity to natural gas development and adverse birth outcomes in rural Colorado Environ. Health Perspect. DOI: 10.1289/ehp.1306722

[140] Hill, E. Unconventional Natural Gas Development and Infant Health: Evidence from Pennsylvania. Cornell University: Working Paper, Charles Dyson School of Applied Economics and Management, 2012

[141] Fryzek J, Pastula S, Jiang X, Garabrant DH. Childhood cancer incidence in Pennsylvania counties in relation to living in counties with hydraulic fracturing sites J. Occup. Environ. Med. 2013, 55 (7) 796– 801

[142] Goldstein D, Malone, S. Obfuscation Does Not Provide Comfort: Journal of Occupational and Environmental Medicine. 2013. 55(11); 1376–1378).

[143] DISH, Texas Exposure Investigation; Texas Department of State Health Services: Dish, Denton County, TX, 2010; www.dshs.state.tx.us/epitox/consults/dish_ei_2010.pdf.

sampling did not coincide with known or perceived exposures, and concurrent air samples were not collected for study subjects.

167. Rich et al (2016) found elevated atmospheric levels of carbon disulphide (CS_2) and 12 associated sulphide compounds present in the atmosphere in residential areas where UOG extraction and processing operations were occurring. Atmospheric chemical concentrations were compared to the US Environmental Protection Agency's Urban Air Toxics Monitoring Programme and indicated that atmospheric CS_2 concentrations in the study areas exceeded the national maximum average by 61% (2007), 94% (2008–2009), 53,268% (2010), 351% (2011), and 535% (2012)" above national background levels. The literature regarding the health effects of CS_2 was also reviewed and found to be consistent with complaints of adverse health effects. However, because air monitoring analysis also found multiple VOCs present simultaneously with CS and sulphide chemicals, it was difficult to determine which chemical or chemicals may have been responsible for the health complaints'[144].

168. Jemielita et al (2015) examined the relationship between inpatient rates and well numbers and density (wells per km^2) in three Pennsylvania counties for 2007-2011.[145] Two of the counties had experienced a large increase in UNG activities during this period while the third hadn't. The study found that cardiology inpatient prevalence rates were significantly associated with well numbers (p<0.00096) and well density (p<0.001) and neurology inpatient prevalence rates were also significantly associated with density (p<0.001). According to the authors, other evidence "also supported an association between well density and inpatient prevalence rates for the medical categories of dermatology, neurology, oncology, and urology". However, rates for gynaecology and orthopaedics were found to have decreased. While this study involved a large resident population, there are several recognised limitations. While population demographics were similar by county there was no analysis by zip code and no control for smoking, a key confounder for cardiology inpatient prevalence. Most wells appear to have been established in last year of study which covered a relatively short period and there was considerable variation in the number of wells by zip code adding to the potential for exposure misclassification.

169. Casey et al (2016) conducted a retrospective cohort study of more than 9,000 mothers linked to almost 11,000 neonates over four years to examine the relationship between proximity to UNG and level of drilling activity and four adverse reproductive outcomes: birthweight, preterm birth, 5-minute Apgar scores, and small for gestational age (SGA).[146] Multilevel linear and logistic regression models found a strong association between UNG activity and preterm birth, but not with the other outcomes. A post hoc analysis also identified an association with

---

[144] Rich et al, 2016, Carbon Disulfide (CS2) Interference in Glucose Metabolism from Unconventional Oil and Gas Extraction and Processing Emissions, *Environmental Health Insights* 2016:10 51–57 doi: 10.4137/EHI.S31906.

[145] Jemielita T, Gerton GL, Neidell M, Chillrud S, Yan B, Stute M, et al. (2015) Unconventional Gas and Oil Drilling Is Associated with Increased Hospital Utilization Rates. PLoS ONE 10(7): e0131093. doi:10.1371/journal.pone.0131093

[146] Casey JA, et al, 2016. Unconventional natural gas development and birth outcomes in Pennsylvania, USA. *Epidemiology*. 2016 March ; 27(2): 163–17

physician recorded high-risk pregnancy (OR 1.3 95% CI 1.1, 1.7). The authors concluded that prenatal residential exposure to UNG development activity was associated with two pregnancy outcomes, "adding to evidence that UNG development may impact health". While this study controlled for a number of confounding factors, there is potential for residual confounding and the lack of exposure measures inevitably increases the risk of exposure misclassification.

170. Stacy et al (2015) conducted a retrospective cohort study of over 15,000 live births to examine the association between proximity to UNG with birthweight, SGA and prematurity in SW Pennsylvania for the period 2007-2010.[147] Multivariate linear (birthweight) or logistical (SGA and prematurity) regression analyses found no significant association between proximity and density of UGD with prematurity. However, there was an association between lower birth weight and SGA, and being in the 'most exposed' quartile compared with the 'least exposed' quartile.

171. Rabinowitz (2015) conducted a household survey of residents' self-reported symptoms and views on environmental quality in Washington County Pennsylvania in 2012 during a period in which there were 624 active wells (95% first drilled between 2008-12). Homes were visited to establish access to ground-fed water wells and households classified according to distance from the nearest well: < 1 km, 1–2 km, or > 2 km.[148] After adjustment for age, sex, household education level, smokers in household, job type, animals in household, and awareness of environmental risk, household proximity to wells remained associated with the number of symptoms reported per person < 1 km ($p = 0.002$) and 1–2 km ($p = 0.05$) compared with > 2 km from gas wells respectively. Living in a household < 1 km from the nearest well remained associated with increased reporting of skin conditions (OR= 4.13; 95% CI: 1.38, 12.3) and upper respiratory symptoms (OR = 3.10; 95% CI: 1.45, 6.65) when compared to households > 2 km from the nearest gas well. Environmental risk awareness was also significantly associated with reports of all groups of symptoms. The sample size is relatively small in epidemiological terms and is also limited by the self reported nature of the symptoms, potential bias and lack of direct exposure measures and the issue of multiple testing. However, the authors also out forward a number of plausible explanations for the findings.

172. Bamberger and Oswald (2012) used an ecological study with interviews of farmers and families from six US states together with limited exposure, diagnostic and toxicological data.[149] The families were referred by environmental groups or activists and associated with seven conventional well sites and 18 HVHF sites. The researchers also conducted two opportunistic natural experiments where livestock had been exposed and non-exposed on the same farms. Exposures were alleged to have occurred through contamination of water. Virtually all health

---

[147] Stacy SL, Brink LL, Larkin JC, Sadovsky Y, Goldstein BD, Pitt BR, et al. (2015) Perinatal Outcomes and Unconventional Natural Gas Operations in Southwest Pennsylvania. PLoS ONE 10(6): e0126425. doi:10.1371/journal.pone.0126425

[148] Rabinowitz et al, 2015. Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. Environmental Health Perspectives volume 123 (1):

[149] Bamberger and Oswald (2012) Impacts of gas drilling on animal and human health. NEW SOLUTIONS, Vol. 22(1) 51-77, 2012

data were self-reported and included a wide range of symptoms for humans (neurological, GI, dermatological, headaches, nosebleeds, fatigue and backache) and animals (mortality, reproductive, neurological, GI, and dermatological symptoms). Outcomes reported for the two natural experiments included 21/60 cattle exposed to fracking fluid having died and 16 having failed to calve versus zero deaths and one failure to calve in the 36 non-exposed cattle (no significance levels reported). Twenty-one of the interviewees were followed up 15-34 months after the initial interview and questioned about subsequent exposures and health effects. There were no significant health changes reported by those living in areas where industry activity had either increased or remained constant. Where industry activity had decreased the total number of reported symptoms in humans and animals also decreased.

173. A follow up study by Bamberger and Oswald (2015) set out to follow-up on several case studies reported in their 2012 publication to see if health impacts had changed over time and whether that correlated with an increase, decrease, or no change in oil and gas industrial activity.[150] Overall, they found that symptoms improved for families moving out of affected areas and those living in areas where O&G activity had decreased. In the cases of families that remained in the same area and for which drilling activity either remained the same or increased, no change in health impacts was observed. The distribution of symptoms was unchanged for humans and companion animals, but was significantly changed for food animals. Reports of reproductive failure fell, while respiratory issues and stunted growth were reported more often.

174. A Health Impact Assessment conducted by Witter (2013) following concerns reported by communities in Battlement Mesa estimated an increased risk of non-cancer health effects from subchronic VOC exposures during the well completion period and a small increased lifetime excess cancer risk (10 x 10−6) for those living close to wells compared to those living farther from wells (6 x10−6).[151] Self-reported short term symptoms such as headaches, nausea, upper respiratory irritation and nosebleeds in residents living within a half mile of well development were considered plausibly associated with odour events.

175. Having determined that households in proximity to gas wells in Ohio were exposed to higher levels of PAHs, Paulik et al (2015) used quantitative risk assessment to estimate the excess lifetime cancer risks for residents and workers associated with the recorded levels of PAHs.). Using an assumed exposure duration of 225 days per year for a period of 25 years with daily exposure durations of 8 hours, they estimated an excess lifetime cancer risk for outdoor workers ranging from 40 to 59 in a million (depending on whether they worked closer or further from the closest active well pad). They also concluded that the risk in the proximal residential exposure

---

[150] Bamberger and Oswald (2015) Long-term impacts of unconventional drilling operations on human and animal health. Journal of Environmental Science and Health, Part A (2015) 50, 447–459

[151] Witter RZ, McKenzie L, et al (2013). The use of health impact assessment for a community undergoing natural gas development. *Am J Pub Health* 103(6): 1002–10.

group exceeded the EPA acceptable range and was 30% higher compared to the distal population.[152]

I. Hazards and risks associated with traffic, noise, light and odour

176. SGP involves continuous activity conducted over the entire course of a day, seven days a week, for a sustained period of time.[153] The noise of compressors, generators and drilling; extensive truck movements; intrusive un-natural lighting overnight; and the release of bad smelling chemicals, can have significant negative health and wellbeing impacts on nearby communities, especially in the context of quiet rural and semi-rural areas.

177. SGP in the UK is expected to be sited close enough to a mains water supply and gas distribution network which will considerably reduce the number of truck movements compared to many operations in the US. Nonetheless, truck-heavy traffic is still required to construct wellpads (including ancillary infrastructure such as offices, generators, compressors and tanks), drill the boreholes, and transport fracking fluid, silica and wastewater.

178. The amount of traffic affecting any given area involved will depend on the number of wellpads and boreholes in that area, and the volume of wastewater needing to be transported away. The Institution of Civil Engineers estimated that a single well might require between 500 and 1,250 HGV lorry movements.[154] The Royal Society for the Protection of Birds give a figure of between 4,300 and 6,600 truck trips per well pad.[155] As noted earlier, Watson estimated that the volume of fluid needing treatment from two exploratory fracking sites in Lancashire would involve about 1,440 tankers with a capacity of 35,000 litres (360 tanker loads per well) and a total tanker mileage of 470,000 miles.

179. Potential adverse impacts from truck traffic include congestion; road traffic accidents (with potential spills of hazardous materials); as well as damage to roads, bridges and other infrastructure. One study from the US reported that automobile and truck accident rates were between 15% and 65% higher in counties with shale gas drilling compared to those without, including an associated increase in traffic fatalities.[156]

180. In the Bakken shale region, there was an increase of 68% of crashes involving trucks from 2006 to 2010.[157] In the Eagle Ford region, the Texas Department of Transportation reported a

---

[152] Paulik et al, 2015 Impact of Natural Gas Extraction on PAH Levels in Ambient Air. Environ. Sci. Technol. 2015, 49, 5203–5210

[153] The typical lifetime for a well is variable and not well established; but it seems to range from about two to five years depending on how much the shale is re-worked and the well re-fracked.

[154] Institution of Civil Engineers. Written Submission, Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA070), para 2.1

[155] Royal Society for the Protection of Birds. Written Submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA015), para 3.6

[156] Graham J, Irving J, Tang X, Sellers S, et al. (2015). Increased Traffic Accident Rates Associated with Shale Gas Drilling in Pennsylvania. *Accident Analysis and Prevention*, 74:203–209.

[157] Ridlington E and Rumpler J, 2013. Fracking by the Numbers. Environment America Research & Policy Center. http://www.environmentamerica.org/reports/ame/fracking-numbers

40% increase in fatal motor vehicle accidents from 2008 to 2011.[158] Likewise, the Crash Reporting System from the Pennsylvania Department of Transportation reported an increase in accidents involving heavy trucks between 1997 and 2011.[159] Some data from Pennsylvania indicate that between 1997 and 2011, counties with a relatively large degree of shale gas development experienced a significant increase in the number of total accidents and accidents involving heavy trucks compared to counties with no shale gas development.[160]

181. Noise, smells and intrusive lighting are also potential hazards associated with SGP.

182. Such nuisances are well recognised as health hazards and potentially serious interferences to normal day-to-day living.[161] [162] [163] The stress and loss of sleep that may be caused by nuisances such as traffic congestion, noise and light pollution are forms of ill health in their own right, but are also factors in the genesis of a range of other diseases and illnesses.[164] [165]

183. The Health Impact Assessment conducted by Witter (2013) following concerns reported by communities in Battlement Mesa found that increased traffic would increase the risk of accidents and reduce levels of walking and cycling. Recorded noise levels and complaint data suggested that noise levels related to the site could be in the range associated with health impacts.[166] The paper also reported a 15% reduction in property values in the vicinity of the site and postulated that anxiety and stress levels would be increased as a result of community concerns.

184. The effects of a nuisance are source dependent, meaning that objective measures of nuisance are not sufficient to gauge its potential effect. The source and underlying cause of the nuisance is an important influence on the type and degree of impact of that nuisance.

---

[158] Increased Traffic, Crashes Prompt New Campaign to Promote Safe Driving on Roadways Near Oil, Gas Work Areas; Texas Department of Transportation: Austin, TX, 2013; http://www.txdot.gov/driver/share-road/be-safe-drive-smart.html.

[159] Adgate JL, Goldstein BD and McKenzie LM, 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol 48 (15), pp 8307–8320

[160] Muehlenbachs, L.; Krupnick, A. J. Shale gas development linked to traffic accidents in Pennsylvania. Common Resources. 2013; http://common-resources.org/2013/shale-gas-development-linked-to-trafficaccidents-in-pennsylvania/

[161] https://www.gov.uk/statutory-nuisance

[162] WHO/European Commission. Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. The WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe . ISBN: 978 92 890 0229 5 2011

[163] http://ec.europa.eu/health/scientific_committees/opinions_layman/artificial-light/en/l-2/4-effects-health.htm#1

[164] Battlement Mesa Health Impacts Assessment (Colorado, USA). Available at http://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-ehms.aspx

[165] Gee GC, Payne-Sturges DC, 2004. Environmental Health Disparities: A Framework Integrating Psychosocial and Environmental Concepts. Environ Health Perspect. 112(17): 1645–1653

[166] Witter RZ, McKenzie L, et al (2013). The use of health impact assessment for a community undergoing natural gas development. *Am J Pub Health* 103(6): 1002–10.

185. The level of stress that will be experienced by individuals and communities affected by SGP cannot be predicted with precision, but will clearly depend on the scale of SGP and the size and proximity of surrounding communities.

186. When considering the health impacts of noise from a given source, the volume and intensity of the noise, whether it is prolonged and continuous, how it contrasts with the ambient noise levels, and the time of day must be taken into account. Noise levels depend not only on the source, but also on other factors such as distance from the source, air temperature, humidity, wind gradient, and the topography.

187. Both the sound level of the noise (objective noise exposure) and its subjective perception can influence the impact of noise on neuroendocrine homeostasis.[167] In other words, noise exposure can lead to adverse health outcomes through direct and indirect pathways. Non-physical effects of noise are mediated by psychological and psycho-physiological processes.[168] Noise annoyance may produce a host of negative responses, such as feeling angry, displeasure, anxious, helpless, distracted and tired.[169] [170]

188. Sleep disturbance is another common response among populations exposed to environmental noise, and is associated with negative impacts on both health and quality of life.[171] Meaningful levels of sleep fragmentation and deprivation can adversely affect both physical and mental health, and are often considered the most severe non-auditory effect of environmental noise exposure.[172]

189. According to Goodman et al (2016), the local impacts of a single well pad on traffic may be of short duration but large in magnitude.[173] They also note that the effects of SGP on surrounding communities will vary over time. While excess noise emissions may appear negligible (b1 dBA) when normalised or averaged across the whole period from construction to completion, they “may be considerable (+3.4 dBA) in particular hours, especially at night”.

190. An investigation which collected data on noise levels at 625 feet away from the well pad center of unconventional gas drilling sites in West Virginia found that average noise levels for the duration of work at each site were not above the recommended 70dBA level recommended

---

[167] Munzel, T., T. Gori, W. Babisch, and M. Basner (2014), Cardiovascular Effects of Environmental Noise Exposure. Eur Heart J., 35, 829–836; doi:10.1093/eurheartj/ehu030.

[168] Shepherd, D., D. Welch, K.N. Dirks, and R. Mathews (2010), Exploring the Relationship between Noise Sensitivity, Annoyance and Health-Related Quality of Life in a Sample of Adults Exposed to Environmental Noise. Int J. Environ Res Public Health, 7, 3579–3594; doi:10.3390/ijerph7103580

[169] Babisch, W. (2002), The Noise/Stress Concept, Risk Assessment and Research Needs. Noise Health, 4, 1–11.

[170] Babisch, W., G. Pershagen, J. Selander, D. Houthuijs, O. Breugelmans, E. Cadum, et al. (2013), Noise Annoyance — A Modifier of the Association between Noise Level and Cardiovascular Health? Science of The Total Environment, 452–453, 50–57; doi:10.1016/j.scitotenv.2013.02.034.

[171] Muzet, A. (2007), Environmental Noise,Sleep and Health. Sleep Medicine Reviews, 11, 135–142; doi:10.1016/j. smrv.2006.09.001

[172] Hume, K.I., M. Brink, and M. Basner (2012), Effects of Environmental Noise on Sleep. Noise Health, 14, 297–302; doi:10.4103/1463-1741.104897.

[173] Goodman et al, 2016 Investigating the traffic-related environmental impacts of hydraulic-fracturing (fracking) operations, Environment International 89–90 (2016) 248–260

by the EPA for noise exposure, but that noise at some locations was above the local limits set by some counties and cities.[174]

K. Social, economic and local environmental effects

191. Shale gas production can produce positive health effects in local communities through social and economic pathways by generating new investment, profits and employment. Evidence from the US shows various forms of economic benefit associated with the shale gas boom.

192. It is less commonly understood that SGP also produces social and economic dis-benefits and can impact negatively on health by disrupting the social fabric of local communities, harming *other* economic activity, and damaging public infrastructure.

193. The scale and nature of the social and economic effects of SGP will be context specific and distributed unevenly within particular localities. For some members of a community, SGP may improve social and economic wellbeing, while for others it may do the opposite.

194. A comprehensive assessment of the economic effects of shale gas development involves looking at who will benefit from the economic benefits and new jobs; who will suffer the costs associated with shale gas development, and who will pay for the different costs associated with shale gas production. The latter includes the tax payer who has to foot the bill for a large amount of the required infrastructure and the necessary levels of effective regulation.

195. Government policy is important in shaping the economic effects of SGP. In the UK, the government has agreed that local communities will receive £100,000 per well site during the exploration or appraisal stage as well as 1% of revenues during the production stage. Finally, local councils will also be allowed to keep 100% of the business rates they collect from shale gas operators (double the current 50% figure).

196. A health impact assessment of proposed shale gas development in Garfield Country, conducted by the Colorado School of Public Health noted that the proposal itself had already caused “additional stress” associated with: the likely social effects of industrial activity in a non-industrial area; perceived loss of shared community ideals and cohesion; declining property values; and worries about possible impacts on the education system, population numbers and local customs.[175] It also noted that the impacts of a gas industry boom in 2003-2008 and its subsequent decline in 2009 elsewhere in the state had included “increased crime and sexually transmitted diseases, declining property values and impacts on the educational environment”.

---

[174] McCawley M, 2013. Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project. http://wvwri.org/wp-content/uploads/2013/10/a-n-l-final-report-for-web.pdf

[175] Battlement Mesa Health Impacts Assessment (Colorado, USA). Available at http://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-ehms.aspx

197. As part of a health impact assessment in Lancashire related to two exploratory faking applications, the Director of Public Health noted that the main risks of the proposed projects were “a lack of public trust and confidence, stress and anxiety from uncertainty that could lead to poor mental well-being, noise-related health effects due to continuous drilling and issues related to capacity for flow-back wastewater treatment and disposal”.[176]

198. This includes the contentious and divisive nature of SGP within the community causing stress, anxiety and illness already being experienced by local communities. In the Health Impact Assessment, the Director of Public Health reported that: *“The over-riding responses about the two proposed exploration sites voiced by members of the local communities who attended the workshops were those of fear, anxiety and stress, which are affecting their mental wellbeing, with some people experiencing sleep disturbance and depression”.*[177]

199. Importantly, levels of stress and community division (and consequent negative mental health effects) are amplified when levels of trust and transparency concerning industry and government action are low.[178]

200. A review of risks to communities from shale energy development by Jacquet (2014) notes that the introduction of temporary but intensive extractive industries into an area can produce benefits in the form of new jobs and increased local revenue, but also bring a variety of harms. Among the effects with negative impacts is an influx of temporary workers (often predominantly composed of young men) undermining community cohesion, increasing the cost of living, and raising levels of alcohol and drug use, mental illness and violence.[179]

201. Other studies have also noted that the extraction of non-renewable natural resources such as gas is typically characterized by a “boom-bust” cycle, and that after the initial period of construction and drilling, there is a decline in well-paying, stable jobs during the production phase.[180] [181] [182]

---

[176] Lancashire County Council, 2014. Potential health impacts of the proposed shale gas exploration sites in Lancashire. Minutes, http://council.lancashire.gov.uk/ieIssueDetails.aspx?IId¼29552&PlanId¼0&Opt¼3#AI22656

[177] Ben Cave Associates. Overview report on HIA work concerning planning applications for temporary shale gas exploration: health impact assessment support, shale gas exploration. Lancashire County Council, 2 September. Leeds: Ben Cave Associates Ltd., 2014, http://bit.ly/1BsZ3Au

[178] Ferrar K, Kriesky, Christen C, Marshall L et al, 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. Int. *J. Occup. Environ. Health 2013*. 19 (2): 104–12. Doi: 10.1179/2049396713y.0000000024.

[179] Jacquet J, 2009. Energy boomtowns and natural gas: Implications for Marcellus Shale local governments and rural communities. The Northeast Regional Center for Rural Development: University Park, PA,. Available from: http://aese.psu.edu/nercrd/publications/rdp/rdp43/view.

[180] Adgate J, Goldstein B, McKenzie L, 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol. 48 (15): 8307-8320. Doi: 10;1021/es404621d.

[181] House of Representatives Standing Committee on Regional Australia. 2013. Cancer of the bush or salvation for our cities? Fly-in, fly-out and drive-in, drive-out workforce practices in regional Australia. Canberra: Commonwealth of Australia. http://www.aph.gov.au/parliamentary_business/committees/house_of_representatives_committees?url=ra/fifodido/report.htm

202. Concerns about boom-bust cycles were also described by Haefele and Morton (2009) in their assessment of the large increase in natural gas wells in the Rocky Mountain region from 1998-2008. A review of specific case studies which highlighted the spectre of a subsequent local economy 'bust' precipitated by a drop in natural gas prices.[183] They concluded that the same natural gas industry 'boom' that brings some benefits for rural communities also brings an influx of non-local workers; increased crime, housing costs and demand for public services; and additional burdens on local infrastructure.

203. Increased pressure on local public services can also precipitate negative knock-on effects. Anecdotal evidence from the US notes that the shale gas industry has subjected local municipalities to a range of demands for additional or new services, and that the administrative capacity, staffing, equipment, and expertise needed to meet those demands can overwhelm available public budgets.[184] Likewise, health services and Public Health departments must be prepared to receive and respond to incident reports and citizen concerns about environmental health issues.

204. One area of impact has been on local roads and bridges which are damaged and worn down by the heavy traffic associated with shale gas. In the Barnett Shale region of Texas, it has been reported that early deterioration of city streets has increased the burden on taxpayers because, even though access roads to the well sites are built and maintained by the operators, many of the journeys made by the trucks were on public roads that were not designed to withstand the volume or weight of this level of truck traffic.[185] Abramzon et al (2014) estimated that Marcellus UNG-related heavy truck traffic caused between $13-23,000 of damage per well to state maintained roads in 2011.[186]

205. SGP is a spatially intense activity that can alter the character and aesthetic of the surrounding landscape, affect wildlife and biodiversity, and cause habitat fragmentation. The economic development of gas and oil from shale formations can result in high well densities of at least one well per 80 surface acres, over large continuous areas of a play.[187]

---

[182] Hossain D, Gorman D, Chapelle B, et al. Impact of the mining industry on the mental health of landholders and rural communities in southwest Queensland. *Australas Psychiatry* 2013; 21: 32-37.

[183] Haefele, M. and P. Morton. 2009. The influence of the pace and scale of energy development on communities: Lessons from the natural gas drilling boom in the Rocky Mountains. *Western Economics Forum* 8(2): 1-13.

[184] Christopherson and Rightor, 2011. How Should We Think About the Economic Consequences of Shale Gas Drilling? Cornell University

[185] Christopherson and Rightor, 2011. How Should We Think About the Economic Consequences of Shale Gas Drilling? Cornell University

[186] Abramzon et al 2014 Estimating The Consumptive Use Costs of Shale Natural Gas Extraction on Pennsylvania Roadways. Journal of Infrastructure Systems10.1061/(ASCE)IS.1943-555X.0000203, 06014001.

[187] Ingraffea et al, 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. www.pnas.org/cgi/doi/10.1073/pnas.1323422111

206. Lave and Lutz (2014) considered that while the landscape disturbance of UNG sites may be small compared to some other land use activities, fragmentation of ecosystems was extensive and requires further research.[188]

207. The social, health and economic impact of damaging green space and 'ecosystem services', undermining leisure and tourism, and eroding the intrinsic value of the natural integrity and beauty of the environment may also be notable (although these considerations apply to all types of energy development). The health benefit of the availability and access to green spaces has been documented.[189] [190]

208. The importance of social, psychological and emotional attachments to people's environments is recognised as an important determinant of health.[191] Large scale developments may bring loss of amenity, including impact on landscapes and visual impact. The health impact of unwelcome environmental change depends on the nature of the amenity lost, but is exacerbated by the perception of powerlessness over the change and in cases where communities strongly identity with their sense of place.[192] [193]

209. There is also a growing literature describing the pathways by which psycho-social factors, influenced by the wider social and physical environment, impact on both physical health and mental wellbeing.[194] [195][196] It is also recognised that levels of trust, community cohesion, social capital and agency can influence psychological and emotional states that influence health and wellbeing.[197] [198] [199]

---

[188] Lave and Lutz, 2014. Hydraulic Fracturing: A Critical Physical Geography Review. Geography Compass 8/10: 739–754, 10.1111/gec3.12162

[189] Mitchell R, Popham F, 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *The Lancet*. 372: 1655-1660. Doi: 10.10166/50140-6736(08)61689-x.

[190] CABE, 2010. Community green: using local spaces to tackle inequality and improve health. London. Available from: http://www.openspace.eca.ed.ac.uk/pdf/appendixf/OPENspacewebsite_APPENDIX_F_resource_1.pdf.

[191] Baldwin C, 2014. Assessing impacts on people's relationships to place and community in health impact assessment: an anthropological approach. Impact Assessment and Project Appraisal, 2014 http://dx.doi.org/10.1080/14615517.2014.983725

[192] Warsini S, Mills J, Usher K. Solastalgia: living with the environmental damage caused by natural disasters. Prehosp Disaster Med. 2014:29(1);87-90.

[193] Albrecht et al, 2007. Solastalgia: the distress caused by environmental change. Australasian Psychiatry

[194] Siegrist and Marmot, 2004. Health inequalities and the psychosocial environment—two scientific challenges. Social Science & Medicine 58 (2004) 1463–1473

[195] Whitehead M, et al, 2016. How could differences in 'control over destiny' lead to socio-economic inequalities in health? A synthesis of theories and pathways in the living environment. Health &Place39(2016)51–61

[196] Lynne Friedli, 2009. Mental health, resilience and inequalities. World Health Organisation.

[197] Kawachi I and Berkman L, 2001. Social ties and mental health. J Urban Health. 2001 Sep; 78(3): 458–467.

[198] Muruyama et al, 2012. Social Capital and Health: A Review of Prospective Multilevel Studies. J Epidemiol. 2012; 22(3): 179–187.

[199] Giordano and Lindström, 2016.Trust and health: testing the reverse causality hypothesis. *J Epidemiol Community Health 2016;70:10-16*

210. There is some, but limited, literature assessing the ecological impacts of shale gas development in the US.[200] [201] [202] [203] [204] [205] [206] [207] [208] Some adverse effects on agro-ecosystems and animal husbandry have also been identified.[209]

211. Following a study[210] that reported a decline in cow numbers and milk production in drilled areas, Finkel et al (2013) compared the effect of UNG activities on milk production in five Pennsylvania counties with the most unconventional drilling activity were six neighbouring counties with much fewer wells.[211] They found that the number of cows and total volume of milk production declined more in the most fracked counties compared to the six comparison counties. The authors recognised the weaknesses of their study but recommended further research given the importance of the milk production industry in Pennsylvania.

212. Another concern is the use of considerable quantities of water posing localised risks to water supplies.[212] There are many figures used to describe the amount of water required for SGP. The average estimated water usage for drilling and hydraulic fracturing a well in the Marcellus Shale is said to range from 13,000 m3 to 21,000 m3 with limits of 9,000 m3 to 30,000 m3 for a typical 1,200m horizontal well.[213] According to the UK Task Force on Shale Gas, a well needs between 10,000 and 30,000 m3 (two to six million gallons). The Institution of Civil Engineers, in a written

---

[200] Jones NF and Pejchar L, 2013. Comparing the ecological impacts of wind and oil & gas development: a landscape scale assessment. PLoS ONE 8 (11), e81391.

[201] Jones I, Bull J, Milner-Gulland E, Esipov A, Suttle K, 2014. Quantifying habitat impacts of natural gas infrastructure to facilitate biodiversity offsetting. *Ecol. Evol*. 4 (1): 79–90. Doi: 10.1002.ece3.884.

[202] Souther S, Tingley M, Popescu V, Hayman et al, 2014. Biotic impacts of energy development from shale: research priorities and knowledge gaps. *Front. Ecol. Environ*. 12 (6): 330–338. Doi: 10.1890/130324.

[203] Hamilton L, Dale B, Paszkowski C, 2011. Effects of disturbance associated with natural gas extraction on the occurrence of three grassland songbirds. *Avian Conserv.Ecol*. 6 (1): 7. Doi: 10.5751:ACE-00458-060107.

[204] Papoulias D, Velasco A, 2013. Histopathological analysis of fish from Acorn Fork Creek, Kentucky, exposed to hydraulic fracturing fluid releases. *Southeast. Nat*. 12 (sp4): 92–111.Doi: 10.1656/0(!.012s413.

[205] Weltman-Fahs M, Taylor J, 2013. Hydraulic fracturing and brook trout habitat in the Marcellus Shale region: potential impacts and research needs. *Fisheries*. 38 (1): 4–15. Doi: 10.1080/03632415.2013.750112.

[206] Brittingham M, Maloney K, Farag A, Harper D, Bowen Z, 2014. Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. *Environ. Sci. Technol.* 48 (19):11034–11047.

[207] Racicot A, Babin-Roussel V, Dauphinais J, Joly J-S et al, 2014. A framework to predict the impacts of shale gas infrastructures on the forest fragmentation of an agroforest region. *Environ. Manag*. 53 (5): 1023–1033. Doi: 10.1007/s00267-014-0250-x.

[208] Kiviat E, 2013. Risks to biodiversity from hydraulic fracturing for natural gas in the Marcellus and Utica shales. *Ann N Y Acad Sci*. 1286: 1–14. Doi: 10.1111/nyas.12146.

[209] Bamberger M, Oswald RE, 2012. Impacts of Gas Drilling on Human and Animal Health. New Solutions 22, 51–77.

[210] Adams and T. W. Kelsey, *Pennsylvania Dairy Farms and Marcellus Shale, 2007-2010*, 2012, Penn State Cooperative Extension, College of Agricultural Sciences; Marcellus Education Fact Sheet, http://pubs.cas.psu.edu/freepubs/pdfs/ ee0020.pdf (accessed June 15, 2012)

[211] Finkel et al, 2013. MARCELLUS SHALE DRILLING'S IMPACT ON THE DAIRY INDUSTRY IN PENNSYLVANIA: A DESCRIPTIVE REPORT. NEW SOLUTIONS, Vol. 23(1) 189-201, 2013

[212] Chartered Institute of Environmental Health (CIEH) and Scientists for Global Responsibility (SGR) 21/7/2014 'Shale Gas and fracking - examining the evidence'

[213] New York State Dept. of Environmental Conservation. Preliminary Revised Draft Supplemental Generic Environmental Impact Statement of the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs. October 5, 2009. Revised July 2011.

submission to Environmental Audit Committee, gave a figure of 10,000 to 25,000 m^3. The CCC gives figures of between 1,200 and 45,000 m3 per well, quoting King.[214]

213. The amount of water used per well varies depending on geological characteristics, well construction (depth and length) and fracturing operations (chemicals used and fracture stimulation design).[215] [216] Of the total water, 10% is used for drilling, 89% for fracking, and the rest is consumed by infrastructure. In regions where local, natural water sources are scarce or dedicated to other uses, the limited availability of water may be a significant impediment to gas resource development.[217] [218]

214. Broderick et al (2011) estimate that a multi-stage fracturing operation for a single well requires around 9,000-29,000 m3.[219] They also estimate that in order to provide 9bcm/year of shale gas for 20 years in the UK, an estimated 1.25 to 1.65 million m3 of water is needed annually, which would add a relatively small amount to the 905 million m3 of water abstracted annually by industry as a whole. Thus, although the volumes of water that would be used sounds large, when set in the context of overall water use in other industries, it is not.[220]

215. Nonetheless, a large number of active wells may have the potential to create localised and occasional periods of water stress.

216. Both the economic and commercial viability and benefits of shale gas production are dependent on a range of variables including the actual productivity of the wells, future energy market conditions, and the policy / regulatory environment within which natural gas is extracted. Production in shale plays is unpredictable and only a small number of wells may be able to produce commercial volumes of gas over time without re-fracking, which is very costly.

217. The claims of economic development and public benefit need to be looked at carefully because they are often produced by those with a vested interest and are based on optimistic assumptions. Several papers have noted that claims about employment generation associated

---

[214] King (2012) *Hydraulic Fracturing 101*, http://www.kgs.ku.edu/PRS/Fracturing/Frac_Paper_SPE_152596.pdf

[215] Freyman, M., 2014 Hydraulic fracturing & water stress: water demand by the numbers (2014) http://www.ceres.org/issues/water/shale-energy/shale-and-water-maps/hydraulic-fracturing-water-stress-water-demand-by-the-numbers (accessed 10.20.14)

[216] Torres Yadav and Khan 2016. A review on risk assessment techniques for hydraulic fracturing water and produced water management implemented in onshore unconventional oil and gas production. Science of the Total Environment 539 (2016) 478–493

[217] Stuart ME, 2011. Potential groundwater impact from exploitation of shale gas in the UK. *British Geological Survey Open Report*, OR/12/001.

[218] Nicot JP, Scanlon BR, 2012. Water use for shale-gas production in Texas, U.S. Environ. Sci. Technol. 2012, 46 (6), 3580–3586.

[219] Broderick et al, 2011.Shale gas: an updated assessment of environmental and climate change impacts. Tyndall Centre University of Manchester

[220] Chartered Institution of Water and Environmental Management, 2015. Written Submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA006), para 4

with shale gas in the US have usually been over-stated,[221] [222] [223] and that initial economic booms often transform into long-term social and economic declines.[224] [225]

218. Kinnaman's analysis[226] of six industry-sponsored reports (three of which had an academic affiliation) that highlighted the economic benefits of UNG identified several shortcomings including: a) assumptions that all the lease and royalty payments and the great majority of industry expenditure is spent locally; b) that the level of well activity is a function solely of the current gas price; c) erroneous interpretation of data; d) disregard of the impact on other users of the resource; and e) failure to assess whether the overall benefits of gas extraction exceed the costs. Kinnaman considered the consistent use of the term 'conservative estimates' in industry-sponsored reportage to be misleading and that estimates were more likely to be 'overstated'.

219. Lave and Lutz (2014) noted that where research on the social effects of UNG is available, it is not necessarily of adequate quality and that most of the economic analysis is speculative and not subject to academic peer-review.[227] The lack of funding for independent research has left a knowledge vacuum which has been largely filled by industry funded or produced literature. However, they also claim that the limited research on the social and cultural impacts of UNG to be overwhelmingly negative, and note that government agencies often behave more like advocates for the industry than mediators in the debate**.**

220. Hughes (2013) also concluded that industry and government projections are 'wildly optimistic'.[228] His analysis, based on data for 65,000 shale wells from an industry and government production database, showed well and field productivity declining rapidly, production costs in many cases exceeding current gas prices, and production requiring increased drilling and major capital input to maintain production. He identifies a familiar pattern of an

---

[221] Weber J, 2012. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. *Energy Econ*. 34 (5), 1580–1588 (Sep). Doi: 10.1016/j.eneco.2011.11.013.

[222] Patridge M, Weinstein A, 2013. Economic implications of unconventional fossil fuel production. National Agricultural & Rural Development Policy Center. Available from: http://www.nardep.info/uploads/Brief15_EconomicsFossilFuel.pdf.

[223] Mauro F, Wood M, Mattingly M, Price M, Herzenberg S and Ward S, 2013. Exaggerating the Employment Impacts of Shale Drilling: How and Why. Multi-State Shale Research Collaborative. Available from https://pennbpc.org/sites/pennbpc.org/files/MSSRC-Employment-Impact-11-21-2013.pdf

[224] Jacquet J, 2009. Energy Boomtowns & Natural Gas: Implications for Marcellus Shale Local Governments & Rural Communities. NERCRD Rural Development Paper N° 43. Available from: http://aese.psu.edu/nercrd/publications/rdp/rdp43.

[225] Christopherson S, Rightor N, 2011. How should we think about the economic consequences of shale gas drilling? A Comprehensive Economic Impact Analysis of Natural Gas Extraction in the Marcellus Shale. Working Paper, City and Regional Planning, Cornell University. Available from: http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/PDFs/Comprehensive%20Economic%20Analysis%20project.pdf.

[226] Kinnaman T, 2011. The economic impact of shale gas extraction: A review of existing studies. Ecological Economics 70 (2011) 1243–1249

[227] Lave and Lutz, 2014. Hydraulic Fracturing: A Critical Physical Geography Review. Geography Compass 8/10 (2014): 739–754, 10.1111/gec3.12162

[228] Hughes DJ, 2013. A reality check on the shale revolution. Nature 494, 307–308

initial drilling boom, exploitation of 'sweet spots' (small, highly productive areas) followed by the drilling of more marginal areas, and then rapid decline within a few years. The investment required for new wells to maintain supply often exceeds sales income, which in turn necessitates higher gas prices.

221. Paredes et al (2015) used two econometric methods to isolate and quantify the effect of UNG on local income and employment.[229] They found that the direct income effects of Marcellus shale UNG development had a negligible income impact on the general population. While local employment effects were more substantial, many of the new jobs were low paid and taken up by outsiders who would tend to spend/send much of their income home.

222. Sovacool (2014), on the other hand, described several economic benefits of a number of shale booms. These included about 29,000 new jobs and $238m in tax revenues in Pennsylvania in 2008; a contribution of $4.8 billion to gross regional product, 57,000 new jobs and $1.7 billion in tax revenue across West Virginia and Pennsylvania in 2009; and $11.1 billion in annual output representing 8.1% of the region's economy and 100,000 jobs in the Barnett Shale in Texas in 2011.[230] However, the review also identified the complexities of assessing economic impact and the expense of cost overruns, accidents and leakages, and concluded that the benefits of SGP are uncertain and conditional on the "right" mix of technological systems; operating procedures, government regulations, and corporate values at each locality.

223. Wren et al (2015) noted that the varied findings in the literature about employment effects was related in part to difficulties in capturing accurate data about workers' place of residence and found that increases in employment may have little benefit to those localities directly faced with the costs of UNG activity. Their analysis of local employment in Pennsylvania found that while UNG activity had had a positive effect on employment, it was only statistically significant for counties in which 90 or more wells were drilled in a given year.

224. Hardy and Kelsey (2014) found modest employment increases in counties with drilling activity in Marcellus shale development in Pennsylvania, and that many of the new jobs were going to non-residents, leaving minimal employment impact on residents.[231]

225. Munasib and Rickman (2014) wider economic effects of unconventional shale oil and gas exploration in Arkansas, North Dakota and Pennsylvania on employment, income and poverty rates,[232] using a synthetic control method was used to assess economic activity in the absence of increased unconventional energy development. They found significant positive effects for all oil and gas counties in North Dakota across all regional labour market metrics, but that positive

---

[229] Paredes et al 2013. Income and employment effects of shale gas extraction windfalls: Evidence from the Marcellus region. Energy Economics 47 (2015) 112–120

[230] Sovacool 2014. Cornucopia orcurse?Reviewingthecostsandbenefits ofshale gas hydraulicfracturing(fracking) RenewableandSustainableEnergyReviews37(2014)249–264

[231] Hardy and Kelsey 2014. Local and non-local employment associated with Marcellus Shale Development in Pennsylvania. Policy Brief published by National Agricultural & Rural Development Policy Center

[232] Munasib and Rickman, 2014 Regional Economic Impacts of the Shale Gas and Tight Oil Boom: A Synthetic Control Analysis

effects in Arkansas were only identified in counties with the most intensive shale gas production. They felt that the positive impacts on employment were generally smaller than those estimated in other analyses and that local inflation and other effects had a negative impact on the local quality of life. In addition, they found no significant positive effects in Pennsylvania. The study also highlighted that areas with significant levels of economic activity such as agriculture and tourism, may be more likely to experience adverse economic effects.

226. Weber's (2012) study of counties in Colorado, Texas and Wyoming with increased UNG found modest increases in employment and income.[233] Analysis of gas deposit and production data with economic data for 1998/99 to 2007/08 suggested the creation of fewer than 2.5 jobs per million dollars of gas production, an annual employment increase of 1.5% on pre-boom levels.

227. A subsequent study by Weber et al (2014) assessed the benefits of the oil and UNG boom in rural North Dakota in the 2010s which was estimated to have contributed over a billion dollars to the State's finances and created 65,000 new jobs.[234] This region had seen previous oil related booms in the 1950s and late 1970s which had led to housing shortages, more expensive public services, and a legacy of costs for obsolete infrastructure. Their study of the associated social effects of the boom, through interviews with social workers and Directors of Social Care, found housing to be a recurrent theme, especially inadequate supply and high housing costs. Social Services Directors also reported an increase in child protection issues, increasing day care shortage and a diminishing supply of foster homes, while data from the police suggested 'troubling increases in domestic violence issues disproportionate to population'. Reported benefits included economic development, partnerships with the industry, and decreases in benefit support. However, these were regarded as 'mixed blessings'. The authors noted the limitations inherent in the design of their small cross-sectional study.

228. Muehlenbachs et al (2015) used a methodology to quantify the real or perceived effects of shale gas development on property prices in Pennsylvania.[235] They had access to a substantial property sales dataset and used both a technique to control for potential confounders. They found that the prices of homes dependent on groundwater were negatively affected by proximity to shale gas developments (up to -16.5% for those within 1 km), while the value of homes on a mains supply showed a small increase. However, the latter was only applicable to homes proximal to *producing* wells which received homeowner royalty payments, and if the wells were not visible from the property.

229. Jones et al (2014) reviewed the potential implications for UK property and investment in a professional briefing note based on internet resources, peer reviewed papers and government

---

[233] Weber J, 2012. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. Energy Economics 34 (2012) 1580–1588

[234] Weber et al, 2014. Shale gas development and housing values over a decade: Evidence from the Barnett Shale.

[235] MuehlenbachsL, Spiller E and Timmins C, 2015. The Housing Market Impacts of Shale Gas Development *American Economic Review 2015, 105(12): 3633–3659*

agency research.[236] They noted reasons for concern about adequate and affordable insurance cover and problems with obtaining mortgages for homes in close proximity to shale gas operations. The UK Government's own investigation into the impact of SGP on rural communities was only released under a legal challenge, but when it was released it was in a heavily redacted form.[237]

230. Barth (2013) noted that UNG activities in the Marcellus Shale area could increase demand and costs for rental properties as well as a reduction in house prices, difficulties in obtaining property insurance and a negative impact on future construction and economic development.[238] While Barth recognised that shale gas will generate some local and regional jobs and revenues, the levels of both have probably been exaggerated in the industry-funded literature. He notes that some studies have used inappropriate economic modelling assumptions such as using costs from Texas which has a long established extractive industry infrastructure and applying them to areas without infrastructure. In addition, costs from such areas like Texas which is predominantly non-urban with smaller populations and with lower economic diversity would be different from areas dependent on agriculture, tourism, organic farming, hunting, fishing, outdoor recreation, and wine and brewing.

231. The social desirability of different forms of energy has also been studied through various economic choice studies, and there is some literature suggesting that households are willing to pay a premium for electricity from renewable energy sources such as wind, solar and biomass. [239] [240] [241]

232. Popkin et al (2013) explored the likely welfare impacts of using UNG extracted by hydraulic fracturing for household electricity in an economic choice experiment involving 515 households from nine New York counties in the Marcellus Shale region and 18 outside the shale region.[242] The analysis controlled for age, gender, education, place of residence and proximity to UNG sites. They found respondents being willing to accept UNG derived electricity provided their monthly bills were reduced by between $22-$48 (mean bill $124) with the required discounting increasing with increased proximity to UNG sites. Respondents also generally expressed a preference to continue with the status quo (out of state fossil fuel and nuclear energy).

---

[236] Jones P, Comfort D and Hillier D, 2014. Fracking for shale gas in the UK: property and investment issues'. Journal of Property Investment & Finance, 32,5: 505–517

[237] Rural Community Policy Unit, 2014. Shale Gas Rural Economy Impacts. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408977/RFI6751_Draft_Shale_Gas_Rural_economy_impact_paper.pdf

[238] Barth J, 2013. The economic impact of shale gas development on state and local economies: Benefits, costs and uncertainties. New Solutions, Vol. 23(1) 85-101, 2013

[239] Susaeta A, et al, 2011. Random preferences towards bioenergy environmental externalities: A case study of woody biomass based electricity in the Southern United States. Energy Economics 32, 1111-1118.

[240] Borchers AM, et al, 2007. Does willingness to pay for green energy differ by source? Energy Policy 35(6), 3327-3334.

[241] Scarpa and Willis, 2010. Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies. Energy Economics 32 (2010) 129–136

[242] Popkin et al, 2013. Social costs from proximity to hydraulic fracturing in New York State. Energy Policy 62: 62–69

233. This negative local perception of UNG is also reflected in Bernstein et al's (2013) contingent valuation study of a random sample of Susquehanna Valley Pennsylvania residents' (n=186) WTP for eliminating the risks of water pollution due to hydraulic fracking.[243] This found that residents were willing to pay up to $10.50 a month for additional safety measures to protect local watersheds from shale gas extraction.

L. Fugitive emissions

234. Fugitive emissions are gases (mainly methane, but also other hydrocarbons such as ethane) that are unintentionally lost to the atmosphere during the process of gas extraction, collection, processing and transportation. They can emanate from above or below the ground.

235. Above the ground, leaks may arise from any of the 55 to 150 connections between pieces of equipment such as pipes, heaters, meters, dehydrators, compressors and vapour-recovery apparatus of a typical well.[244] Pressure relief valves are also designed to purposefully vent gas.

236. Leaks and emissions also occur in the distribution system used to supply gas to end consumers. Large emissions of VOCs have been observed on oil and gas (O&G) well pads because of leaks from dehydrators, storage tanks, compressor stations, and pneumatic devices and pumps, as well as evaporation and flow back pond water.[245] The EPA report that pneumatic devices contribute to 14% of gas supply-chain emissions in the US, while compressors are used to boost the gas pressure and are estimated to be responsible for 20% of emissions.[246]

237. Heath el al's (2015) review of the US GHGI concluded that approximately 43% of total methane emissions across the natural gas industry ere from compressors and compressor stations.[247]

238. Small volumes of gas may also be generated during the development of the well, most of which is likely to be burned in a flare. Generally speaking, there is little information about emissions associated with exploration, and most studies ignore the GHG emissions associated with this phase of SGP. [248] [249] However, it should not be assumed that emissions from exploration will be low, especially for any extended well tests.[250]

---

[243] Bernstein P, Kinnaman TC & Wu M (2013). Estimating willingness to pay for river amenities and safety measures associated with shale gas extraction. *Eastern Economic Journal*, 39(1), 28-44.

[244] Howarth and Ingraffea 2011. Methane and the greenhouse-gas footprint of natural gas from shale formations**.** Climatic Change (2011) 106:679–690

[245] Warneke C, Geiger F, Edwards PM, Dube W, et al, 2014. Volatile organic compound emissions from the oil and natural gas industry in the Uintah Basin, Utah: oil and gas well pad emissions compared to ambient air composition. Atmos. Chem. Phys. 14, 10977e10988. http://dx.doi.org/10.5194/acp-14-10977-2014.

[246] SGI (2015), *Methane and CO_2 emissions from the natural gas supply chain*, http://www.sustainablegasinstitute.org/publications/white-paper-1/

[247] Heath, Warner, Steinberg and Brandt, 2015. *Estimating US Methane Emissions from the Natural Gas Supply Chain*, http://www.nrel.gov/docs/fy16osti/62820.pdf

[248] DJ MacKay & TJ Stone Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use (DECC, 2013)

239. Key emission sources in the gas production process are from well completions (when methane is released as fracking fluid returns to the surface prior to gas flowing at a high production rate), workovers (periods of time when the well undergoes maintenance, cleaning and re-fracturing) and liquids unloading (the removal of any build-up of liquids that accumulates at the bottom of the well and impedes the flow of gas).

240. In the US, the gas mixed in the flowback fluid has historically been predominantly vented to the atmosphere. The volume of gas produced during completion is linked to the pressure of the well and the initial flow rate.

241. Emission rates will vary from one area to another because gas reservoirs vary by age and geologic properties, and operating practices. Emissions from well completions and liquid unloadings are also highly variable.[251] [252]

242. Current understanding of the distribution of emissions across the global well population is extremely poor within the literature and further research is required to detail and quantify the factors affecting unloading emissions such as well age, reservoir properties, equipment used and operational strategies.[253]

243. According to the Sustainable Gas Institute (SGI), there is incomplete and unrepresentative data for a number of emission sources. Specifically, more data are required for liquids unloading, well completions with RECs, and transmission and distribution pipelines.[254] SGI also note a lack of transparency in data and accounting for methane emissions across all of the LNG stages.

244. Fugitive emissions are a major health hazard because methane is a potent greenhouse gas (GHG). If the amount of fugitive emissions exceeds a certain threshold, the argument that shale gas is a ‘clean energy source’ relative to coal or oil falls apart. Accurate measures of fugitive emissions produced by the O&G industry are therefore important.

245. Methods to quantify fugitive emissions are typically divided into two groups: bottom up methods and top down methods.

---

[249] SGI (2015), *Methane and CO_2 emissions from the natural gas supply chain*, http://www.sustainablegasinstitute.org/publications/white-paper-1/

[250] Committee on Climate Change, 2016. The compatibility of UK onshore petroleum with meeting the UK’s carbon budgets.

[251] Zavala-Aaraiza et al (2015) Reconciling divergent estimates of oil and gas methane emissions PNAS | December 22, 2015 | vol. 112 | no. 51 | 15597–15602

[252] Balcombe, Anderson, Speirs, Brandon and Hawkes, 2015. Methane and CO2 emissions from the natural gas supply chain. London: Sustainable Gas Institute

[253] Balcombe, Anderson, Speirs, Brandon and Hawkes, 2015. Methane and CO2 emissions from the natural gas supply chain. London: Sustainable Gas Institute

[254] Balcombe, Anderson, Speirs, Brandon and Hawkes, 2015. Methane and CO2 emissions from the natural gas supply chain. London: Sustainable Gas Institute

246. Bottom up methods use direct measurements of leakage rates from empirical studies to calculate emission factors (EFs) for different sources of leakage. These EFs are then applied to the number of such sources and their activity levels, from which a total emissions estimate is calculated.

247. This is the basis for the EPA's Inventory of Greenhouse Gas Emissions and Sinks which provides an overall national emission estimate by sector for the US. The EPA also has a Greenhouse Gas Reporting Program (GHGRP) which involves mandatory reporting by O&G operators of GHG emissions from all sources that emit more than 25 000t of CO_2e per year.

248. However, attempts to establish accurate emissions inventories in the US have been hindered by data gaps, a reliance of self-reported data collection, and the use of outmoded emissions factors.[255] Macey et al (2014) also note how the direct measurement of air pollutants from onshore gas operations has been limited by inadequate access to well pads and other infrastructure; the unavailability of a power source for monitoring equipment; and a failure to capture unscheduled episodes of flaring, fugitive releases and movements of truck traffic.[256]

249. Top down methods measure methane concentrations directly in the atmosphere, and then apportion a percentage of the total emissions to different sources of methane in the given source area.

250. Bottom-up estimations of fugitive emissions used in the official US inventories are generally accepted as being too low. Independent top-down investigations suggest that the GHGRP may underestimate the real emission rate by up to a factor of 3.8.[257] Brandt et al's review of 20 years of technical literature on natural gas emissions in the US and Canada found that official inventories consistently underestimate actual CH_4 emissions.[258]

251. Actions which would help converge top-down and bottom-up estimates include ensuring that top-down studies report on fossil methane only; having accurate facility counts in bottom-up analysis; and characterising the contribution of super-emitters accurately.[259]

252. In general, methane emissions in the US have been under-estimated. One recent quantitative estimate of the spatial distribution of anthropogenic methane sources showed that EPA inventories and the Emissions Database for Global Atmospheric Research (EDGAR) have

---

[255] Field RA, Soltis J, Murphy S: Air quality concerns of unconventional oil and natural gas production. Environ Sci Process Impacts 2014, 16:954–969.

[256] Macey et al, 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 2014, 13:82 doi:10.1186/1476-069X-13-82

[257] Lavoie 2015 *Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin*, Lavoie et al., Environmental Science and Technology, vol.49 no.13 pp.7904-7913, http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b00410

[258] Brandt et al, 2014. *Methane Leaks from North American Natural Gas Systems*, Science, vol.343 pp.733-735, http://psb.vermont.gov/sites/psb/files/CLF-SC-2%20Science-Methane%20Leaks.pdf

[259] Heath, Warner, Steinberg and Brandt, 2015. *Estimating US Methane Emissions from the Natural Gas Supply Chain*, http://www.nrel.gov/docs/fy16osti/62820.pdf

underestimated methane emissions by a factor of ~1.5 and ~1.7, respectively.[260] The discrepancy in estimates was particularly pronounced in south-central US where fossil fuel extraction and refining are prominent.[261] According to this paper, regional methane emissions due to fossil fuel extraction and processing could be 4.9 ± 2.6 times larger than in EDGAR.

253. The reasons for this include the use of outdated EFs;[262] inadequate sampling and the failure to account for 'super-emitters' (emissions from individual wells and gas processing facilities do not exhibit a normal distribution, but tend to display a skewed distribution with a 'fat-tail' of super-emitters[263]); assumptions that operators are applying best practice; inaccurate counts of sites, facilities, and equipment; non-reporting by O&G operators;[264] and the false assumption that EFs are consistent across the industry and different regions.[265] [266]

254. According to Brandt et al, because measurements for generating EFs are expensive, sample sizes are usually small and affected by sampling bias due to reliance upon self-selected cooperating facilities. In addition, because emissions distributions have 'fat tails', small sample sizes are likely to underrepresent high-consequence emissions sources.[267]

255. The methodological challenges in accounting for fugitive emissions are demonstrated by large year-to-year revisions of the reported emissions by the EPA.[268] For example, the estimated national average production-sector leak rate for 2008 increased from approximately 0.16% (of total gas produced) in its 2010 report, to 1.42% in the 2011 and 2012 reports, before being

---

[260] Miller 2013 *Anthropogenic emissions of methane in the United States*, PNAS, vol.110 no.50 pp.20018-20022, 10th December 2013 http://www.pnas.org/content/110/50/20018.full.pdf?with-ds=yes

[261] Emissions due to ruminants and manure are were also up to twice the magnitude of existing inventories.

[262] Karion et al, 2013 *Methane emissions estimate from airborne measurements over a western United States natural gas field*, Geophysical Research Letters, vol.40 no.16, http://onlinelibrary.wiley.com/doi/10.1002/grl.50811/pdf

[263] Fat-tail sites do not necessarily have persistently high emissions but may represent short-term emission events caused by maintenance activities or malfunctions.

[264] Lavoie 2015 *Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin*, Lavoie et al., Environmental Science and Technology, vol.49 no.13 pp.7904-7913, http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b00410

[265] Karion et al, 2013 *Methane emissions estimate from airborne measurements over a western United States natural gas field*, Geophysical Research Letters, vol.40 no.16, http://onlinelibrary.wiley.com/doi/10.1002/grl.50811/pdf

[266] Zavala-Aaraiza et al (2015) Reconciling divergent estimates of oil and gas methane emissions PNAS | December 22, 2015 | vol. 112 | no. 51 | 15597–15602

[267] Brandt et al, 2014. *Methane Leaks from North American Natural Gas Systems*, Science, vol.343 pp.733-735, http://psb.vermont.gov/sites/psb/files/CLF-SC-2%20Science-Methane%20Leaks.pdf

[268] Karion et al, 2013 *Methane emissions estimate from airborne measurements over a western United States natural gas field*, Geophysical Research Letters, vol.40 no.16, http://onlinelibrary.wiley.com/doi/10.1002/grl.50811/pdf

revised down to 0.88% in the 2013 report.[269] These changes led the EPA's Office of Inspector General calling for improved emissions data for the natural gas production sector.[270]

256. According to Howarth and Ingraffea, 1.9% of the total production of gas from an unconventional shale-gas well is emitted as methane during well completion [made up of losses from flowback fluids (1.6%) and drill out (0.33%)].[271] Additional fugitive emissions (0.3 – 3.5%) continue at the well after well completion (from leakage at connections, pressure relief valves, pneumatic pumps, dehydrators and gas processing equipment), while emissions during transport, storage and distribution are estimated to be an additional 1.4% to 3.6%.

257. Altogether, Howarth and Ingraffea estimate that 3.6% to 7.9% of methane from shale gas production escapes to the atmosphere. They estimate that emissions are *at least* 30% and possibly twice as great as those from conventional gas.

258. Caulton et al's assessment of the literature on emission rates from unconventional gas production since 2010 is that it ranges from 0.6 to 7.7% at the well site and during processing over the lifetime production of a well; and from 0.07 to 10% during transmission, storage and distribution to consumers. The highest published estimates for combined methane emissions (2.3–11.7%) are based on actual top-down measurements in specific regions.[272] [273]

259. Petron et al's (2014) top down measurement of methane emissions in the Denver-Julesburg Basin in northeastern Colorado over 2 days in May 2012 was used to estimate the emissions from oil and gas operations and other sources of methane (livestock farming, landfills, wastewater treatment and natural micro-seepage).[274] The estimated contribution from O&G operations was on average 19.3 ± 6.9 t/h, or 75% of the total measure. The measurement was almost 3 times higher than an hourly emission estimate based on the EPA's GHGRP. The level of fugitive emissions as a fraction of total gas production was 4.1 ± 1.5%; similar to findings reported from a study in 2008 of the same region.[275]

---

[269] These changes were caused by different EFs for calculating emissions from liquid unloading, unconventional completions with hydraulic fracturing, and the refracturing of natural gas wells. The main driver for the 2013 reduction was a report prepared by the oil and gas industry, which contended that the estimated emissions from liquid unloading and refracturing of wells in tight sands or shale formations should be lower.

[270] U.S. Environmental Protection Agency Office of Inspector General (2013), EPA Needs to Improve Air Emissions Data for the Oil and Natural Gas Production Sector, EPA OIG, Washington, D. C.

[271] Howarth and Ingraffea, 2011. *Methane And The Greenhouse-Gas Footprint Of Natural Gas From Shale Formations – A Letter*, Climatic Change, vol.106 no.4 pp.679-690. http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0061-5.pdf

[272] Pétron G, et al. (2012) Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study. J Geophys Res, 10.1029/2011JD016360.

[273] Karion A, et al. (2013) Methane emissions estimate from airborne measurements over a western United States natural gas field. Geophys Res Lett, 10.1002/grl.50811.

[274] Pétron et al 2014 *A new look at methane and nonmethane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver-Julesburg Basin*, Journal of Geophysical Research: Atmospheres, vol.119 no.11 pp.6836-6852, http://onlinelibrary.wiley.com/doi/10.1002/2013JD021272/pdf

[275] Pétron et al 2012 *Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study*, Journal Of Geophysical Research, vol.117 no.D4, http://www.fraw.org.uk/library/extreme/petron_2012.pdf

260. Peischl et al's (2013) study of methane, carbon dioxide, carbon monoxide and C2–C5 alkane levels across the Los Angeles basin in 2010, found that methane emissions were greater than that which would be expected from bottom-up state inventories. More than half the emissions came from fugitive losses from pipelines and urban distribution systems and geologic seeps.[276]

261. Karion et al's (2013) study of atmospheric measurements of CH_4 from a natural gas and oil production field in Utah in 2012 found an emission rate that corresponded to 6.2% - 11.7% of average hourly natural gas production.[277] The high rates are explained by the fact that the region produces more oil than gas (because gas is not the primary product, more methane is flared or vented due to the absence of gas infrastructure).

262. Peischl et al's (2015) top-down measurement of methane over several regions (representing over half of US shale gas production), found emission rates varying from one region to the next, and being generally lower than those reported in earlier studies.[278] Methane emissions as a percentage of total gas extracted was 1.0–2.1% in the Haynesville region, 1.0–2.8% in the Fayetteville region, and 0.18–0.41% in northeast Pennsylvania. The relatively low rates were thought to be due in part to the composition of the fossil fuel extracted and the use of more efficient technology. It should be noted that these figures do not include an estimate of emissions during the transmission and end-use stages of the gas system. The authors note that repeated measurements would be necessary to determine the extent to which their one day measures of CH_4 are representative of emission rates over the full lifecycle, and why twenty-fold differences in loss rates across different oil and gas-producing regions have been reported.

263. Karion et al's (2015) estimates of regional methane emissions from O&G operations (including production, processing and distribution) in the Barnett Shale (Texas), using airborne atmospheric measurements, found measures that agreed with the EPA estimate for nationwide CH_4 emissions from the natural gas sector, but higher than those reported by the EDGAR inventory or the EPA's GHGRP.[279] The emissions rate amounted to 1.3−1.9% of total CH_4 production, which is lower than rates ranging from 4 to 17% found in other studies.[280] [281] [282]

---

[276] Peischl et al 2013. *Quantifying sources of methane using light alkanes in the Los Angeles basin, California*, Journal of Geophysical Research: Atmospheres, vol.118 no.10 pp.4974-4990, 27th http://www.fraw.org.uk/library/extreme/peischl_2013.pdf

[277] Karion A, et al. (2013) Methane emissions estimate from airborne measurements over a western United States natural gas field. Geophys Res Lett, 10.1002/grl.50811.

[278] Peischl et al, 2015. *Quantifying atmospheric methane emissions from the Haynesville, Fayetteville, and northeastern Marcellus shale gas production regions*, Journal of Geophysical Research: Atmospheres, vol.120 pp.2119-2139, http://onlinelibrary.wiley.com/doi/10.1002/2014JD022697/pdf7

[279] Karion et al, 2015. *Aircraft-Based Estimate of Total Methane Emissions from the Barnett Shale Region*, Environmental Science and Technology, vol.49 no.13 pp.8124-8131. http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b00217

[280] Karion et al 2013. Methane emissions estimate from airborne measurements over a western United States natural gas field. Geophys. Res. Lett. 40 (16), 4393−4397

[281] Peischl, J; et al. Quantifying sources of methane using light alkanes in the Los Angeles basin, California. J. Geophys. Res.: Atmos. 2013, 118 (10), 4974−4990.

[282] Wennberg, P. O et al. On the sources of methane to the Los Angeles atmosphere. Environ. Sci. Technol. 2012, 46 (17), 9282−9289.

264. Lan et al (2015) quantified fugitive CH_4 emissions from more than 152 facilities, including wellpads, compressor stations, gas processing plants and landfills from ONG operations in the Barnett Shale.[283] They estimated a total wellpad emission rate of 1.5 × 105 kg/h in the area, with rates between individual wellpads ranging from 0.009 to 58 kg/h and being linearly correlated with gas production. Methane emissions from compressor stations and gas processing plants were substantially higher, with some "super emitters" having emission rates of 3447 kg/h, more then 36,000-fold higher than reported by the EPA's GHGRP. The emission rate as a proportion of total gas production varied from 0.01% to 47.8% with a median and average value of 2.1% and 7.9%, respectively.

265. Measurements of methane emissions by Lavoie et al (2015) at eight different high-emitting point sources in October 2013 in the Barnett Shale, Texas (four gas processing plants, one compressor station and three landfills) were compared to other aircraft- and surface-based measurements of the same facilities, and to estimates reported to the EPA's GHGRP.[284] For the eight sources, CH_4 emission measurements were a factor of 3.2−5.8 greater than the GHGRP-based estimates. Summed emissions totalled 7022 ± 2000 kg hr−1, roughly 9% of the entire basin-wide CH_4 emissions estimated from regional mass balance flights during the campaign.

266. Allen et al's (2013) study which consisted of direct measurements of methane emissions at 190 onshore natural gas sites in the US (150 production sites, 27 well completion flowbacks, 9 well unloadings, and 4 workovers) also found emissions measurements that varied by orders of magnitude.[285] However, their overall estimate of emissions for completion flowbacks, pneumatics, and equipment leaks amounted to 0.42% of gross gas production which is considerably lower than other findings from other studies and even lower than the EPA's inventory-based rates. However, two papers published in 2015 have indicated that the data in Allen et al's paper may have been flawed.[286]

267. Goetz et al's (2015) study of the composition of air samples using a mobile laboratory from sites in NE and SW Pennsylvania, including over 50 compressor stations and 4,200 wells found methane emissions to be between 4 and 23 times greater than the upper range of well pad

---

[283] Lan et al, 2015 *Characterizing Fugitive Methane Emissions in the Barnett Shale Area Using a Mobile Laboratory*, Environmental Science and Technology, vol.49 no.13 pp.8139-8146

[284] Lavoie et al 2015 *Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin*, Environmental Science and Technology, vol.49 no.13 pp.7904-7913, http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b00410

[285] Allen DT, et al. (2013) Measurements of methane emissions at natural gas production sites in the United States. Proc Natl Acad Sci USA 110(44):17768–17773.

[286] See: a) Howard T, Ferrarab TW, Townsend-Small A. Sensor transition failure in the high flow sampler: implications for methane emission inventories of natural gas infrastructure. *J Air Waste Manag Assoc*. 2015;65: 856–862; and b) 39. Howard T. University of Texas study underestimates national methane emissions inventory at natural gas production sites due to instrument sensor failure. *Energy Sci Eng*. 2015; DOI:10.1002/ese3.81.

equipment leak estimates in Allen et al (2013).[287] The authors argued that the large disparity between the two studies "suggests that there are other factors such as operating practices, production volume decline, location of leaks, scheduled versus unscheduled monitoring, as well as the number and representativeness of sites sampled that may be important considerations when compiling a bottom-up inventory".

268. Zavala-Aaraiza et al's (2015) study constructed a customised bottom-up CH_4 inventory in the Barnett region that was based on extensive local measurements of facility-wide emissions from production sites, compressor stations, and processing plants; updated facility counts; and an explicit account of the contribution of high-emitters (the estimated emission distributions imply that, at any one time, 2% of facilities are responsible for half the emissions).[288] High-emitters were divided roughly equally among production sites, compressors, and processing plants. They estimated that CH_4 emissions for the Barnett region to be 59 Mg CH4/h (48–73 Mg CH4/h; 95% CI), with the three main sources being production sites (53%), compressor stations (31%), and processing plants (13%). This equates to a loss of 1.5% (1.2–1.9%) of total Barnett production. Their measure of emissions was 1.9 times the estimated emissions based on the EPA's Greenhouse Gas Inventory and 3.5 times that of the GHGRP.

269. The leakage rate is low enough for gas-fired electricity *in this region* to be less climate forcing than coal-fired electricity. However, long-distance transmission and storage of natural gas results in a substantial increment of CH_4 emissions that would need to be considered when analysing the climate implications of natural gas consumption in regions that are not proximate to a production area.[289]

270. Zavala-Aaraiza et al note that more work is needed to understand the characteristics that cause an individual site to be a high-emitter. They also note that the challenge facing operators is that high-emitters are always present (at the basin scale) but occur at only a subset of sites at any one time, and move from place to place over time.

271. Lyon et al (2016) used a spatially resolved emission inventory, to measure methane emissions from the O&G industry and other sources in the Barnett Shale region in October 2013.[290] They were estimated to be 72,300 (63,400−82,400) kg/hr of which 46,200 (40,000−54,100) kg/hr were O&G emissions (64% of the total). About 19% of emissions came from fat-tail sites representing less than 2% of all sites. The measured estimate was higher than the EPA Greenhouse Gas Inventory, the EPA's GHGRP, and the Emissions Database for Global

---

[287] Goetz J, Floerchinger C, Fortner E et al, 2015..Atmospheric emission characterization of Marcellus Shale Natural Gas Development Sites.

[288] Zavala-Aaraiza et al (2015) Reconciling divergent estimates of oil and gas methane emissions PNAS | December 22, 2015 | vol. 112 | no. 51 | 15597–15602

[289] Zavala-Aaraiza et al (2015) Reconciling divergent estimates of oil and gas methane emissions PNAS | December 22, 2015 | vol. 112 | no. 51 | 15597–15602

[290] Lyon et al, 2015. *Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region*, Environmental Science and Technology, vol.49 no.13 pp.8147-8157, http://pubs.acs.org/doi/pdf/10.1021/es506359c

Atmospheric Research (EDGAR) by factors of 1.5, 2.7, and 4.3, respectively. Their estimated emission rate was equivalent to 1.2% (1.0−1.4%) of gas production.

272. A study of global and regional trends in atmospheric methane between 2003 and 2012 by Schneising et al (2014) found that methane concentrations had risen dramatically in the northern hemisphere.[291] By evaluating trends in drilling and hydraulic fracturing activity in two large shale regions in the US (the Eagle Ford in Texas and the Bakken in North Dakota), the authors estimated methane emission rates of 9.5% (±7%) in terms of energy content during the 2009–2011 period.

273. Fugitive emissions from abandoned wells have also become a growing concern. In a study which involved direct measurements of methane fluxes from abandoned O&G wells in Pennsylvania, much higher methane flow rates were found when compared to control locations.[292] Three out of 19 measured wells were high emitters and had methane flow rates three orders of magnitude larger than the median flow rate. Given that there are millions of abandoned wells across the US, this may mean that there are tens or hundreds of thousands of high emitting wells. The authors recommend that measurements of methane emissions from abandoned wells be included in greenhouse gas inventories.

274. A study of fugitive emissions of methane from former onshore (conventional) O&G exploration and production in the UK selected 66% (n= 102) of all wells which appeared to have been decommissioned (abandoned) from 4 different basins and analysed the soil gas above each well relative to a nearby control site of similar land use and soil type.[293] Of these wells, 30% had CH4 levels at the soil surface that was significantly greater than their respective control. Conversely, 39% of well sites had significantly lower surface soil gas CH4 concentrations than their respective control. The authors interpret the elevated soil gas CH4 concentrations to be the result of well integrity failure. The data suggest a mean fugitive emission of 364 ± 677 kg CO2eq/well/year. In this study, all the study sites had been decommissioned in line with best practice recommendations. The authors note that wells which have not been appropriately decommissioned are likely to emit greater levels of methane. The potential for diffuse leakage into the surrounding groundwater and over a broader area might mean that the real level of methane leakage is greater.

---

[291] Schneising O, Burrows JP, Dickerson RR, Buchwitz M, Reuters M, Bovensmann H. Remote sensing of fugitive emissions from oil and gas production in North American tight geological formations. Earths Future, 2014;2: 548–558

[292] Kang et al, 2014 *Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania.* ,PNAS, vol.111 no. 51 pp.18173-18177, http://www.pnas.org/content/111/51/18173.full.pdf?with-ds=yes

[293] Boothroyd et al 2016 *Fugitive emissions of methane from abandoned, decommissioned oil and gas wells*, Science of The Total Environment, vol.547 pp.461-469, http://www.sciencedirect.com/science/article/pii/S0048969715312535/pdfft?md5=28d125f6f39d20a2e7783d9dd6443062& pid=1-s2.0-S0048969715312535-main.pdf

275. The observed increase in atmospheric methane concentrations over the US parallels global trends. The global burden of atmospheric methane rose by 1–2% in the 1970s and 1980s, stabilized in the 1990s, but has been rising again since the mid-2000s.[294] [295]

276. The increase of US methane emissions by more than 30% over the past decade is a major contribution to this trend. According to Turner et al (2016), US anthropogenic methane emissions could account for up to 30–60% of the global increase.[296]Caulton et al also agree that increase in anthropogenic CH_4 emission in the US, caused primarily by natural gas systems and enteric fermentation, play a significant part in these global trends.[297]

277. The 20% increase in O&G production (including a nine fold increase in shale gas production) from 2002 to 2014 is a likely cause for the rise in methane emissions seen in the US, although a better understanding of US anthropogenic methane emissions, particularly those from the livestock and O&G sectors, is needed before any definitive conclusions can be made.

278. Atmospheric methane mostly arises from three sources: biogenic methane produced by microbes from organic matter under anaerobic conditions (e.g. in wetlands, ruminants, and waste deposits), thermogenic methane formed in geological processes and released by oil and gas production, and pyrogenic methane produced by incomplete combustion processes such as in biomass burning. The rise in methane concentrations at the global level is believed to be driven by a combination of increased biogenic methane emissions from the tropical wetlands and growing oil and natural gas production. The contribution made by oil and gas operations to the overall increase in methane concentrations is unclear. Hausmann et al have suggested that around 40% of the recent rise in atmospheric methane between 2007 and 2014 can be attributed to oil and gas activities.[298]

279. It is argued that technology can avoid or reduce the amount of fugitive emissions. Methane emissions during the flowback period can potentially be reduced by up to 90% through Reduced Emission Completions (REC) technologies, although such technologies are not always economically viable or practicable. For example, REC technologies require that pipelines to the well are in place *prior* to completion which may not always be possible. The use of better storage tanks and compressors and improved monitoring for leaks may also reduce emissions. RECs technologies are now compulsory in the US, and would expect to be so in the UK.

---

[294] Turner et al, 2016. *A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations*, Turner et al., Geophysical Research Letters (preprint), 2016 – http://onlinelibrary.wiley.com/doi/10.1002/2016GL067987/pdf

[295] Frankenberg C, et al. (2011) Global column-averaged methane mixing ratios from 2003 to 2009 as derived from SCIAMACHY: Trends and variability. J Geophys Res 116(D4):D04302.

[296] Turner et al, 2016. *A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations*, Turner et al., Geophysical Research Letters (preprint), http://onlinelibrary.wiley.com/doi/10.1002/2016GL067987/pdf

[297] Caulton 2013. Toward a better understanding and quantification of methane emissions from shale gas development www.pnas.org/cgi/doi/10.1073/pnas.1316546111

[298] Hausmann P et al, 2016. Contribution of oil and natural gas production to renewed methane increase. Atmos. Chem. Phys., 16: 3227–3244.

280. The UK CCC also notes that techniques and technologies to mitigate fugitive methane exist and include: reduced emissions completions (REC); and the use of a plunger lift system during liquid unloadings, improved pneumatic devices, dry seal compressors, electrified compressors and vapour recovery units; and the adoption of an effective leakage detection and repair (LDAR) programme. The CCC claims that although a complete avoidance of super-emitters may be unachievable, operational and maintenance procedures could largely eliminate these high emitters.

M. Regulation and Risk Management

Introduction

281. Regulation is one way that society expresses its preferences for distributing the potential risks and benefits associated with any industrial or economic activity (including between current and future generations). It expresses the way in which we apply the precautionary principle[299] and how we value nature and other dimensions of the world that have no market value.

282. Given the requirement of commercial companies to maximise profit as a primary goal (and therefore seek to externalise social and environmental costs as much as possible),[300] regulation is important to protect the public interest and ensure that commercial operators behave ethically and safely. Many well-documented case studies from a variety of sectors describe how the imperative to maximise profit results in companies ignoring warning signals about potential harms and dangers, and concealing risk information prior to the emergence of industrial catastrophes.[301] [302] Oil and gas corporations are believed to be especially hostile to regulation and reluctant to acknowledge risk.[303]

283. Companies that face difficulties in securing a profit will be placed under pressure to compromise on safety in order to minimise costs. This is why the economic viability of shale gas production is an important factor to consider from a health protection perspective.

284. Regulatory mechanisms include legal constraints that limit or prohibit certain activities; laws that prescribe mandatory safety standards; and liability and tax systems that are designed to align the economic interests of companies with the interests of society. For regulation to work,

---

[299] The Precautionary Principle is recognised as guidance to 'err on the side of caution' when an activity is believed to threaten human health or the environment, even if there is some scientific uncertainty. See Tickner and Raffensperger (1998),The Precautionary Principle: A Framework for Sustainable Business Decision-Making, *Environmental Policy,* (5/4) 75–82.

[300] Le Menestrel, M., 2002, 'Economic Rationality and Ethical Behavior. Ethical Business between Venality and Sacrifice', *Business Ethics: A European Review*, (11/2) 157–166.

[301] Chernov and Sornette, 2016. Man-made Catastrophes and Risk Information Concealment. Switzerland: Springer Internaitonal Publichsing

[302] EEA, 2001, *Late lessons from early warnings: the precautionary principle 1896–2000*, Environmental issue report No 22, European Environment Agency.

[303] Konschnik KE and Boling MK. Shale gas development: a smart regulation framework. Environ Sci Technol 2014; 48: 8404–8416.

there must also be mechanisms for monitoring the activities of commercial companies and assessing their impact on people and the environment, and the enforcement of appropriate sanctions in the event of negligence or non-compliance with regulation.

Regulation and SGP

285. In line with many other industrial processes and human activities, SGP cannot be considered to risk-free. SGP *will* lead to *some* pollution, and it will have some negative social and economic impacts. The key question is whether the risks and harms are deemed acceptable – both in absolute terms, but also in relation to the potential benefits of SGP.

286. SGP is a particularly difficult industry to regulate for several reasons. Much activity takes place underground and out of sight. There are many sources and types of hazard and pollutants may be geographically dispersed. The leakage of methane into the atmosphere is especially hard to detect. In addition, shale gas operations may involve multiple contractors (comprising drilling companies, hydraulic fracturing service companies, chemical suppliers, waste haulers and cement contractors) which makes compliance determination difficult.

287. Proponents of SGP claim that it is safe if regulated properly. According to PHE, the potential risks from exposure to the emissions associated with shale gas extraction will be low *"if the operations are properly run and regulated".*[304]

288. There is also a view that regulation in the UK is better than in the USA. The industry-funded Task Force on Shale Gas is satisfied that "current regulations in the UK are adequate and on the whole are more rigorous and robust than those in operation in the US". Similarly, PHE stated that concerns and problems associated with SGP in the US *"are typically a result of operational failure and a poor regulatory environment"* and that shale gas developers and operators in the UK can be relied upon *"to satisfy the relevant regulators that their proposals and operations will minimise the potential for pollution and risks to public health*".[305]

289. However, a thorough and independent assessment of the adequacy of the regulatory system (including the capacity of regulatory agencies) for shale gas in the UK has not been conducted.

---

[304] Kibble A, Cabianca T, Daraktchieva Z, Gooding T et al, 2014. Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction. Centre for Radiation, Chemical and Environmental Hazards, Public Health England. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332837/PHE-CRCE-009_3-7-14.pdf

[305] Kibble A, Cabianca T, Daraktchieva Z, Gooding T et al, 2014. Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction. Centre for Radiation, Chemical and Environmental Hazards, Public Health England. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332837/PHE-CRCE-009_3-7-14.pdf

An overview of the regulatory system for SGP in England[306]

288. The regulatory system for SGP in England is spread across a number of national and local government agencies. Responsibility for overall coordination of policy on unconventional oil and gas lies with the Department of Energy and Climate Change (DECC), within which the Office of Unconventional Gas and Oil (OUGO) exists to encourage unconventional oil and gas exploration and production. In 2015, the government established a new executive agency called the Oil and Gas Authority to take responsibility for regulating offshore and onshore oil and gas operations in the UK, including oil and gas licensing. Its purpose is "to work with government and industry to make sure that the UK gets the maximum economic benefit from its oil and gas reserves".

289. The Department for Environment, Food and Rural Affairs (DEFRA) has lead responsibility for the environmental aspects of shale gas policy, while the Department for Communities and Local Government (DCLG) is responsible for the local planning system. Overall responsibility for climate change and seismicity lies with DECC. The Health and Safety Executive (HSE) which reports to the Department for Work and Pensions is responsible for ensuring safe working practices at and around the wellpad, including safe and proper well construction.

290. Once Petroleum Exploration Development Licences have been granted by DECC to operators, giving them rights to drill for shale gas,[307] operators must obtain planning permission from the local Minerals Planning Authority (MPA), usually located in the planning departments of county councils.

291. The operator must also consult the Environment Agency (EA), an executive non-departmental public body sponsored by DEFRA, which is responsible for regulation of air emissions and the protection of water resources (including groundwater aquifers and surface water), and obtain the required permits related to, among other things, water abstraction; wastewater discharge; management and disposal of mining wastes, including radioactive material; and flaring and venting.

292. The focus of the local planning system is on whether the development is an acceptable use of the land and the impacts of those uses, rather than on any control processes, health and safety issues or emissions that are subject to approval under other regimes which local authorities should assume are operating effectively.

293. The UK has a 'goal-setting approach to regulation' in which operators are required to demonstrate that risks relating to oil and gas operations are reduced to 'as low as reasonably practicable', such that they move beyond minimum standards in a continuous effort for improvement.

---

[306] There are some differences in the regulatory systems and approaches across the four home nations of the UK. The focus of this section is on the English system.

[307] The licences also cover conventional exploration and production of hydrocarbons.

294. In terms of standards and best practice guidelines, the United Kingdom Onshore Operators Group (UKOOG), the representative body for UK onshore oil and gas companies, published updated guidelines in January 2015, but only for the exploration and appraisal phase of shale gas exploitation.[308]

295. A 'regulatory roadmap' published by DECC in December 2015 provides an overview of regulation and best practice related to the licensing, permitting and permissions process for onshore oil and gas *exploration and appraisal*, but not for development and production, nor for decommissioning, restoration and aftercare. [309]

296. Draft technical guidance published by the EA to clarify which environmental regulations apply to onshore oil and gas exploration and what operators need to do to comply with those regulations was put out to public consultation in 2013.[310] The results of the consultation were only made publicly available in July 2016.[311]

297. Current regulations state that an environmental risk assessment (ERA) is required for all shale gas operations as a matter of good practice, and that this should involve the participation of stakeholders including local communities and address issues such as noise, ecology, archaeology, site access and visual impact, as well as the disposal of wastes, well abandonment and risks of induced seismicity. An environmental impact assessment (EIA) is only mandatory "if the project is likely to have significant environmental effects".

298. Operators are then required to present an environmental statement (ES) to the local planning authority. This would describe the design and size of the development, incorporate findings from the ERA and EIA and outline the measures envisaged for avoiding, reducing and, if possible, remedying any significant adverse effects. It should also include the data required to identify and assess the main effects that the development is likely to have on the environment and outline the plans for mitigating such effects and the suggested environmental management and monitoring scheme to be followed.

299. If planning permission is granted, the HSE must be notified at least 21 days prior to any drilling commencing so that it can assess the design and construction of the well(s) and the

---

[308] UKOOG, 2015. Guidelines for UK Well Operators on Onshore Shale Gas Wells. http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelinesIssue3.pdf

[309] DECC, 2015. Onshore Oil and gas Exploration in the UK: Regulation and Best Practice. Available at https://www.gov.uk/government/publications/regulatory-roadmap-onshore-oil-and-gas-exploration-in-the-uk-regulation-and-best-practice

[310] Environment Agency, 2013. Draft Technical Guidance for Onshore Oil and Gas Exploratory Operations. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297024/LIT_7983_3b53c2.pdf

[311] Environment Agency, 2016. Onshore Oil and Gas Exploratory Operations: Technical Guidance. A summary of consultation responses. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/538472/Onshore_oil_and_gas_technical_guidance_summary_of_consultation_responses.pdf

proposed measures for controlling major hazards. It is also expected to continue monitoring operations by reviewing weekly reports submitted by the well operator.

300. Health and safety legislation requires a well to be designed and constructed such that, so far as reasonably practicable, there is no unplanned escape of fluids from it. The operator must arrange an examination of the well design by an independent, competent well examiner.

301. The Infrastructure Act requires a period of groundwater monitoring prior to the commencement of fracking. The non-binding UKOOG Code of Practice also commits companies to some baseline monitoring, while the Shale Gas Task Force recommends that "baseline monitoring – for ground, air and water – should begin when a site has been identified, before the environmental permitting and planning have been obtained" They also recommend that "monitoring of gas, casing pressure and soil should take place for the duration of operations on a well".

302. Operators are required to describe the control and mitigation measures for fracture containment and for any potential induced seismicity. This includes the proposed design of the fracture geometry should be included in the HFP, including (fracturing) target zones, sealing mechanism(s) and aquifers (fresh and saline), so as not to allow fracturing fluids to migrate from the designed fracture zone(s). During drilling, a traffic light system for monitoring induced seismicity is required to mitigate induced seismicity.

303. In addition to statutory reporting, operators are expected to keep records of:

- Geological information, including the proposed depth(s) of the top and the bottom of the formation into which well fracturing fluids are to be injected
- Information concerning water supply, usage, recycling and reuse
- A detailed description of the well fracturing design and operations
- A detailed post-fracture job report

301. The composition and potential toxicity of fracking fluid has received much public attention. DECC guidance states that "operators will disclose the chemical additives of fracturing fluids on a well-by-well basis".

302. When it comes to wastewater management, the EA states that operators should aim to: a) reduce the amount of waste generated; b) encourage the reuse of waste fluids wherever possible; and c) reduce the need for freshwater and water treatment facilities. For contaminated flowback fluids, EA guidance states that re-use is the preferred option, but if cannot be re-used, it must be sent to an appropriate permitted waste facility for treatment and disposal.

303. Although the EA has previously stated that disposal of flowback fluid by re-injecting it into the shale strata would be prohibited, it now states that it may be permissible "where, for

example, it is injected back into formations from which hydrocarbons have been extracted and will have no impact on the status of water bodies or pose any risk to groundwater."[312]

304. Guidance published by the EA makes the use of 'reduced emission completions' technology a recommended practice. The Task Force on Shale Gas notes that the US has recently mandated the use of green completions, and recommends that the same policy be adopted in the UK for 'production wells' (as green completions are not feasible for 'exploratory wells' that will require some flaring of gas).

305. On completion of drilling operations, a well may be suspended to allow for future testing or abandoned. If abandoned, the site must be restored and a period of aftercare conducted to ensure the land returns to a state that is the same or better than it was prior to operations commencing.

306. Before wells can be abandoned, they must be securely sealed to prevent leakage from within the well bore. Cement is pumped into the production casing and a steel cap is fitted to the top of the well to seal it off. There is a requirement that the HSE is notified when wells are abandoned and that the process complies with Oil and Gas UK guidelines.

307. Operators are also required to have a closure and rehabilitation plan (to restore the site to a state similar to that before drilling) which must be agreed by the EA before decommissioning begins. Operators will not be allowed to surrender their permit until the EA is satisfied that there is no ongoing risk to the environment. The MPA is responsible for ensuring the wells are abandoned and the site is restored. In the case of an operator defaulting, planning guidance states that the landowner will then be responsible for restoration.[313]

Concerns about the regulatory system

The general approach to regulation

305. Because SGP is a new and generally untested activity in the UK, it is reasonable for regulation to evolve with experience. However, it is notable that in seeking to encourage SGP in the UK, the government has sought to remove or reduce regulatory barriers facing O&G investors and operators.

308. For example, new text written in the UK Infrastructure Act, 2015 (under Section 4A) has changed the definition of fracking so that the controls contained in the Act and associated secondary legislation will only apply to wells that meet this criteria. Fracking is now defined as

---

[312] http://energyandcarbon.com/uk-failing-lessons-fracking-waste-water/#_ftn24

[313] Department for Communities and Local Government, Planning Practice Guidance for Onshore Oil and Gas (July 2013) pg 17. para. 76 and in the 2014 guidance available at http://planningguidance.communities.gov.uk/blog/guidance/minerals/restoration-and-aftercare-of-minerals-sites/

the hydraulic fracturing of shale which involves, or is expected to involve, the injection of 'more than 1,000 m^3 of fluid at each stage, or expected stage, or more than 10,000 m^3 in total.[314]

309. According to Gillfillam and Haszeldine, there is no explanation as to how or why these numbers were chosen, or why volumes of fluid are chosen at all as the basis for defining fracking. By this definition, almost half the gas wells that have been hydraulically fractured in the US over this decade would *not* be classified as having been fracked.[315]

310. The government has also decreed that applications for planning permission must now be determined within 16 weeks and that if a planning authority fails to meet this deadline or rejects an application on grounds that are inconsistent with the local plan or national guidance, applicants may appeal and be awarded costs. The EA also has to now submit reports about environmental risk to councils within sixteen-weeks.

311. At the same time, the powers of the Secretary of State to call in applications and decide on all appeals relating to onshore oil and gas, potentially over-riding any local concerns, have been increased. The 2015 Infrastructure Act has also relaxed the requirement for shale companies to seek permission of home owners to drill under their land.

312. The implications of Brexit are also relevant. The UK will need to consider whether it wants to repeal (totally or partially) or change any laws or regulation that stem from the EU. This includes a number of detailed environmental standards that set out best available techniques for protecting the environment when conducting a variety of activities or operations.

313. The extent to which the UK can amend or repeal environmental law will depend on the type of trade relationship that is established with the EU. If the UK adopts a Norway style model, EU regulatory regimes for water, air, chemicals, waste, noise, climate change, energy efficiency, and technical regulations and standards (including REACH) would continue to apply. But if it left without a trade deal and operates like China and the US, the UK would not be directly bound by EU rules on environmental regulation.

314. However, it is of note that the UK has been subject to numerous criticisms for its non-compliance with EU environmental standards. Recently there have been legal challenges over the UKs failure to meet air quality standards. Furthermore, EU environmental standards have been subjected to much criticism from UK businesses.

Risk assessments

---

[314] Hydraulic fracturing at a well pad for horizontal shale gas wells is not a "one shot" process, but is performed in stages, as the length of the boreholes usually exceeds several kilometres. Sections of 20-40 metres are blocked off along the horizontal well (packed) and then fracked in stages.

[315] http://energyandcarbon.com/whats-in-a-name-the-risks-of-re-defining-fracking/

315. The framework for risk and impact assessments is not comprehensive. For example, it excludes the need for comprehensive social and economic assessments, including an assessment of the impact of SGP on other economic activities such as tourism and agriculture, as well as the opportunity costs incurred by encouraging an onshore shale gas industry. In addition, planning applications and risk assessments are conducted in a piecemeal way, focusing on individual sites one at a time. This avoids any cumulative, holistic and comprehensive assessment of the impact of SGP.

Regulatory capture

316. The UK systems for both regulating *and* encouraging the development of a shale gas industry appear to be heavily intertwined. Much of the regulatory apparatus appears to be tied to processes designed to facilitate the emergence of a shale gas industry in the UK, raising questions about the extent to which regulation is independent of the industry and adequately focused on public and environmental protection.

317. Generally speaking, the approach to regulation is also heavily reliant on self-monitoring by the industry. For example, although an ‘independent and competent person’ is responsible for examining the integrity and quality of well design and construction, the robustness of this system is questionable by because this independent person may be paid or employed by the operator, and because the review and examination of well specifications and design is conducted as a paper exercise and based on information supplied by the operator. As such, there is no mandatory and independent oversight of the *actual construction* of wells, nor provision for unannounced spot checks of well integrity across the lifecycle of a well, including after abandonment.

318. Independent inspection for well integrity was recommended by the Royal Society and Academy of Engineering, and the industry-funded Shale Gas Task Force noted that it is important not to rely solely on self-monitoring and self-reporting by the operator, and that “regular (and sometimes random) visits and inspections by the regulators” is advisable. However, mandatory and independent inspection of wells was rejected during the passage of the Infrastructure Act.

319. As far as local government’s responsibility for deciding whether or not a particular proposed drilling and fracking application should go ahead, reasonable concerns exist around county councils lacking in-house geological expertise or the time and money to seek independent advice. All too often they are reliant on the information provided by the applicant.

Drilling

320. When it comes to drilling, the current regulations may not be stringent enough given the faulted nature of the UK geology and the experience of fracking in Preese Hall. Although the problems at Preese Hall have been partly mitigated by the introduction of a 'traffic light' system of seismic monitoring during fracking, it is not clear if this on its own is sufficient to ensure safe drilling.

321. More detailed and stringent operating requirements (e.g more detailed geophysical surveys using new techniques for imaging faults, and closer monitoring of seismic data during drilling) may need to be specified. It may also be prudent to prohibit fracking altogether in areas where faults penetrate the full thickness of the overburden. In terms of protecting groundwater from contamination, while current laws and regulations prohibit any drilling in 'source protection zones', it may be necessary to specify minimum stand-off distances.

Chemical composition of fracking fluids

318. While there are reassuring requirements for the disclosure of chemical additives to fracking fluid, it is unclear if operators will publicly disclose the exact composition and quantity of racking fluid and individual additives.

Management of wastewater and reinjection

319. The potential seismic hazard posed by new proposals to allow the disposal of wastewater by injection into the ground is a concern. In the US, re-injection is the most common and economically viable solution to deal with flowback waste waters but, in addition to induced earthquakes, the practice has also resulted in environmental contamination through surface spills and leaky wells. [316]

320. A review by Ellsworth (2013) of injection-induced earthquakes associated with SGP concludes that earthquakes can be induced by both hydraulic fracturing and the sub-surface disposal of wastewater.[317] Within the central and eastern United States, the earthquake count has increased dramatically over the past few years. Several cases of earthquakes (associated directly with fracking) were large enough to be felt but too small to cause structural damage have been reported. However, most of the concern centers on the injection of wastewater, and not fracking itself. He argues that better knowledge of the stress and pressure conditions at depth; the hydrogeologic framework, including the presence and geometry of faults; and the location and mechanisms of natural seismicity are needed to develop a predictive understanding of the hazard posed by induced earthquakes.

321. The potential permitting of injection for flowback fluids is also worrying because of the lack of research on the compositions of the waste water and potential chemical reactions in the subsurface.

322. Should high volume re-injection activity of flowback fluid be carried out in the UK, it would need to be carefully monitored. An article written by academics from Edinburgh University strongly recommend that a research-based code of best practice be established to reduce the

---

[316] http://energyandcarbon.com/uk-failing-lessons-fracking-waste-water/#_ftn24

[317] Ellsworth W, 2013. Injection-induced earthquakes, *Science* 341 (6142), doi: 10.1126/science.1225942.

risk of environmental contamination be established before any flowback fluid re-injection permits are granted.[318]

Baseline monitoring

323. Although the importance of environmental benchmarking is well recognised in the UK and some emphasis has been placed on baseline monitoring, there is still a lack of clarity and specification over the scope, quality, frequency and standards of mandatory monitoring. Worries about the lack of mandatory minimum standards for the monitoring of air pollutants, including fugitive methane emissions, is understandable given the fact that there is currently no data regarding the amount of gas vented by existing oil and gas operations in the UK.[319]

Abandoned wells

324. At present it is not clear who will monitor wells for leakage after they have been abandoned. The Shale Gas Task Force notes that the Government needs to "clarify where responsibility for the continued monitoring and documentation of sealed-off sites should lie". They also state that "it is not clear who is responsible for any issues around an abandoned well if the operator has gone out of business at the time when a leak or contamination has been identified", and that even currently, "there is little monitoring of abandoned wells" in the UK.

325. Given that wells may leak (gas and liquid) for up to thirty years after they have been plugged and abandoned,[320] the longterm monitoring of abandoned wells is also an issue. The Task Force on Shale Gas has proposed that wells be inspected two to three months after the concrete plugs have been inserted into the well, and that further inspections focus on soil monitoring and groundwater monitoring "at a suitable recommended interval" and "if there is any reason to believe that well integrity might be compromised".

Sanctions regime

326. The proposal to require companies to secure a bond to insure them against the cost of any potential liability has not been adopted as policy. There are inadequate safeguards to prevent fracking operators from passing the ownership and liability of commercially non-viable wells onto subsidiary companies that subsequently go into administration shortly after.

327. Although the industry has stated that it will develop an insurance mechanism to cover full liability in the event of a pollution incident, this is a non-binding promise and would, in any case, offer weaker protection than a legally-mandated bond agreement that would cover the costs of

---

[318] Haszeldine S, Gilfillan S and O'Donnell M, 2016. UK Failing to Learn US Lessons on Fracking Wastewater. http://www.talkfracking.org/news/uk-failing-to-learn-u-s-lessons-on-fracking-waste-water/

[319] Stamford and Azpagic, 2014. Life cycle environmental impacts of UK shale gas. Applied Energy 134 (2014) 506–518

[320] Kang M, Kanno CM, Reid MC, Zhang X et al, 2014. Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania. PNAS vol. 111 no. 51: 18173–18177, doi:10.1073/pnas.1408315111

decommissioning, faulty well remediation, and compensation for possible pollution of water resources, depreciation of land and house prices, and earthquake damage.

Capacity of regulatory bodies

328. It is frequently stated that regulation of the oil and gas industry in the UK is of a high standard and better than in the US. In reality, the regulatory system in the US varies considerably from state to state, and in some instances, regulatory standards may be more stringent than in the UK. It is worth noting that New York State has actually banned SGP on the grounds that it would be harmful to health.

329. The last few years, however, have seen deep cuts to the budgets, staffing and expertise of a range of regulatory agencies.

330. Local government budgets and capacity have been particularly hard hit, including those related to public health. According to the National Audit Office, there has been a 37% estimated real-terms reduction in government funding to local authorities 2010-11 to 2015-16.[321] Once changes to council tax income are factored in, there has been an estimated 25% real-terms reduction in local authorities' income from 2010-11 to 2015-16. There has also been a 46% budgeted real-terms reduction in spending on planning and development services between 2010-11 and 2014-15.

331. Net spending by local authorities on public services (excluding spending on police, fire and rescue, education, public health and a small component of social care) in England was cut by 20.4% in real terms between 2009-10 and 2014-15. Service areas with the largest cuts included planning and development (cut to less than half its original level), regulation and safety, housing, and transport (all of which were cut by at least 30%). Local authorities are expected to face further cuts to revenues in 2015-16.[322]

332. Budget cuts to the EA have also been severe. According to UNISON, there has been a 16% cut in the total grants made in 2009-10 compared to 2013-14.[323] Taking into account an inflation rate of 11%; this is equivalent to a cut of nearly 25% in real terms. Thousands have jobs have been lost in this period.[324]

333. The HSE budget was cut by 13% from £228 million in 2009–2010 to £199 million in 2011–2012. Its staff numbers were reduced by 22% from 3,702 in 2010 to 2,889 up to 2012.[325]

---

[321] From National Audit Office report, The impact of funding reductions on local authorities, November 2014. https://www.nao.org.uk/wp-content/uploads/2014/11/Impact-of-funding-reductions-on-local-authorities.pdf

[322] David Innes and Gemma Tetlow, 2015. Central Cuts, Local Decision-Making: Changes in Local Government Spending and Revenues in England, 2009/10 to 2014/15

[323] https://www.unison.org.uk/at-work/water-environment-and-transport/key-issues/cuts-at-the-environment-agency/

[324] http://www.endsreport.com/article/41653/environment-agency-cuts-surviving-the-surgeons-knife

[325] Watterson and Dinan, 2015. Health Impact Assessments, Regulation, and the Unconventional

According to HSE chief executive Geoffrey Podger in 2010, 'the number of staff has fallen drastically, from over 4,200 a decade ago to around 2,200'. The HSE's Annual Report & Accounts for 2014/15 furthermore states how it has delivered a 40% real term budget reduction from 2011/12 to 2014/15. According to its Business Plan for 2015/16, grants provided by government to fund certain activities are planned to reduce by over £82m in 2015/16 compared to 2011/12. The extent to which drilling will be properly scrutinised by specialist wells inspectors from the HSE (or any new bespoke regulator) is therefore a contentious point.

334. The figures above relate to funding cuts in general, and it would be necessary to assess the specific budgets and staffing of those departments dealing with onshore oil and gas in order to assess the adequacy of regulatory capacity in more precise terms.

N. Economic and Commercial Viability

322. The likely economic and commercial viability of a shale gas industry is an important consideration in shaping views about its the potential risks and benefits, and whether the industry should be actively encouraged.

323. The speed at which a shale gas industry might develop is uncertain, depending significantly on economic factors affecting its profitability, the time required for planning and approval, and the extent to which public opposition is a constraint. Profitability will depend on the underlying costs of production, costs imposed by regulation, the composition of the gas produced, the productivity of the wells, prevailing wholesale prices and the taxation regime. Because a large proportion of production costs are fixed, the unit costs of production are highly dependent on the quantity of output.

324. The development of the shale gas industry in the US took place under favourable conditions including: a) strong government investment in R&D and a favourable tax regime; b) a high natural gas price; c) favourable geology; d) good knowledge of geology; e) a 'light touch' regulatory regime; f) an already well-developed onshore oil and gas sector; g) private mineral ownership; and h) a public accustomed to the sight of drilling rigs. The industry was also allowed to develop in a way where wells were drilled like a factory production line.[326] These conditions are not all present in the UK.[327] According to the CCC, the costs of environmental, planning and safety regulation are likely to be higher than in the US.

Gas Industry in the UK: Exploiting Resources, Ideology, and Expertise. Journal of Environmental and Occupational Health Policy 0(0) 1–33.

[326] The 'factory production line' style of shale gas wells in the US enabled a large number of wells to be drilled quickly at a reduced cost. Multilateral shale wells add complexity to well design and construction and is still at a relatively early stage of development, according to the CCC who suggest that it is reasonable to assume shale wells in the UK will not utilise this technology, at least in the early stages of a domestic industry developing.

[327] Stevens P, 2013. Shale Gas in the United Kingdom. London: Chatham House. https://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy,%20Environment%20and%20Development/131213shalegas.pdf

325. It is also worth noting that In spite of favourable geology in the US, thousands of 'trial and error' exploration wells were drilled in the US before the 'sweet spots' of high productivity were identified and the industry took off. The CCC estimates that it would take at least two years of exploration to ascertain the commercial viability of shale gas, and possibly as long as 10 years.[328]

326. The productivity of a well depends on its geological characteristics, length of the lateral(s) drilled and the completion design. Productivity can vary across a shale formation by a factor of up to ten.[329] Because the UK has no exploration flow data, let alone production data, it is not possible to even speculate on the likely productivity of UK wells.

327. Similarly, the future price of gas is difficult to predict with confidence. The gas price in DECC's fossil fuel price scenarios ranges from 36 to 95 p/therm for 2025. For these reasons, it is difficult to state with any certainty whether SGP will be economic in the 2020s.

328. In the US, SGP rose to around 50% of overall gas production in 2014. With little connectivity to international markets this added to supply for US consumption, and put downward pressure on prices. The UK, however, is part of a highly connected gas network across Europe, which is the world's largest importing market. Even UK shale gas production at the upper end of our scenarios for 2030 would be less than 10% of this demand, and would do little to reduce energy bills. The weaker downward pressure on wholesale prices does, however, mean that profitability of production is less likely to be undermined. This is in sharp contrast to the US experience, where the fall in gas prices acted to limit the profitability of further production.

329. In spite of the inherent uncertainty, various production scenarios for the UK have been developed. The Institute of Directors (IoD, 2013), funded by Cuadrilla, built bottom-up production scenarios based on an assumed number of wells, productivity assumptions of 0.62, 0.83 and 1.0 TWh per lateral, and the drilling of four laterals per well.[330] This provided a range for production of 250-410 TWh per year by 2030. The National Grid's Future Energy Scenarios assumed the same number of wells as the IoD report but produced a lower range of 180-360 TWh per year in 2030.[331] A study by Pöyry (2011) which accounted for the impact of economic factors (e.g. production costs and wholesale gas prices) on productivity yielded a range for

---

[328] IDDRI (2014) *Unconventional Wisdom*, http://www.iddri.org/Publications/Collections/Analyses/Study0214_TS%20et%20al._shale%20gas.pdf
9 Gény (2010) *Can Unconventional Gas be a Game Changer in European Gas Markets?*, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2011/01/NG46-CanUnconventionalGasbeaGameChangerinEuropeanGasMarkets-FlorenceGeny-2010.pdf

[329] IDDRI (2014) *Unconventional Wisdom*, http://www.iddri.org/Publications/Collections/Analyses/Study0214_TS%20et%20al._shale%20gas.pdf
Browning et al (2013), *Barnett study determines full-field reserves, production forecast*, Oil & Gas Journal, http://www.beg.utexas.edu/info/docs/OGJ_SFSGAS_pt2.pdf

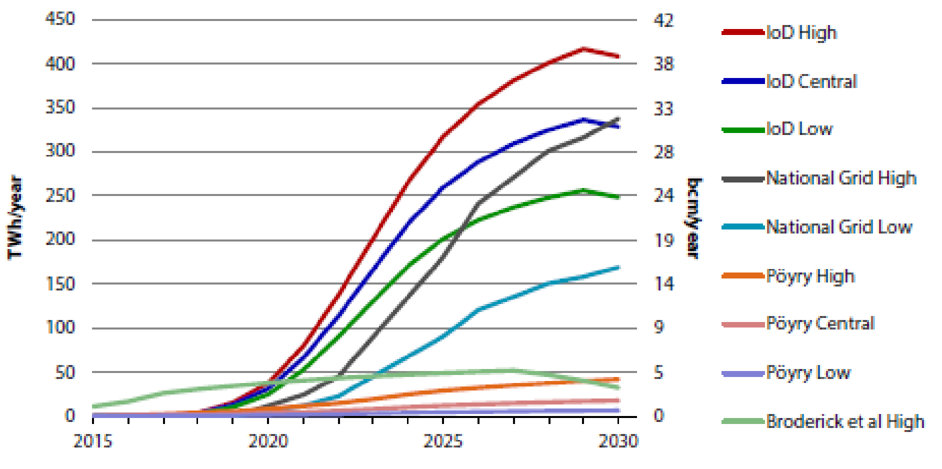
[330] IOD (2013) *Getting Shale Gas Working* http://www.iod.com/~/media/Documents/PDFs/Influencing/Infrastructure/IoD_Getting_shale_gas_working_MAIN_REPORT.pdf

[331] National Grid (2015) *Future Energy Scenarios*, http://fes.nationalgrid.com/

production of 15-50 TWh per year in 2030.[332] Finally, Broderick et al (2011) produced production scenarios in which the highest scenario for production was around 30 TWh per year in 2030, implying a well productivity of 1.1 TWh.[333]

330. These studies provide a wide range of projections of production extending from 15 to 410 TWh per year in 2030. This reflects not just the degree of uncertainty about the productivity of a shale gas industry in the UK, but also methodological differences (e.g. while the Pöyry study incorporated the impact of economics on the rate of production, the others assumed a favourable economic context).

Figure 2.3: Shale gas production scenarios from IoD, National Grid, Pöyry and Broderick et al studies



Sources: Institute of Directors, National Grid, Pöyry, Broderick et al.
Notes: Scenarios presented as published, without any adjustment of timing.

331. The CCC use 0.52 TWh/well as the level of productivity below which production may be uneconomic.

332. Using information from the US Energy Information Association, Dalzell estimates that initial production rates from shale gas wells appear to range between 1 and 11 million cubic feet per day and 125–1370 million cubic feet in total.[334] This would equate to a value of $430,000 - $4,800,000 at current wholesale prices of $3.5 per thousand cubic feet. These figures overlap estimates produced by the Institute of Directors' study of UK shale gas potential (initial production rates of about 2.5 million cubic feet per day and recoverable resources of around 310 million cubic feet per well).

---

[332] Pöyry (2013) *Macroeconomic Effects of European Shale Gas Production*, http://www.poyry.co.uk/sites/poyry.co.uk/files/public_report_ogp__v5_0.pdf

[333] Broderick et al. (2011), *Shale gas: an updated assessment of environmental and climate change impacts*, http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf

[334] Dalzell C, 2016. The economics of shale gas extraction. Glasgow: CommonWeal.

333. Dalzell also estimates that, based on studies that have calculated the lifetime costs of an individual well to range between $3-8 million, to break even at the lower bound of $3 million per well, gas prices would need to be around $10 per thousand cubic feet. At the higher bound of $8 million per well, it would need to be $26 per thousand cubic feet which is twice the all-time gas price high of about $13 per thousand cubic feet seen in 2008. Thus, he concludes that shale gas is unlikely to be economically viable in the current low hydrocarbon price environment and would require significant subsidy or significant efficiency progression before it could be so.

334. Assuming a methane leakage rate of 4%, the IOD's estimate of gas production from a typical UK well and a study which calculated the economic cost of CO2 emissions at $220 per short ton of CO2, Dalzell estimated that the externalised economic costs of shale gas production would be a little under $1.5 million.

N. Climate change and health

Global Warming and climate change

335. The production and consumption of energy has been an important ingredient for the remarkable improvements in human health witnessed over the past two centuries. However, because of global warming, fossil fuel now presents a major threat to human health.[335]

336. The average global land and sea surface temperature has risen by about 1°C since pre-industrial times.[336] Lags in the response of the climate system to historical emissions mean that the world is already committed to further warming over the coming decades.

337. The primary cause for this increase in temperature is the release of GHG emissions. About 70% of all GHG emissions can be linked to the burning of fossil fuel for the production of energy services, goods or energy extraction.[337] Agriculture, deforestation and cement use are also important causes of global warming.

338. The metric commonly used to quantify the total amount of GHGs in the atmosphere is 'giga tonnes of CO_2 equivalent' ($GtCO_2e$). This converts quantities of methane and other GHGs into a measure that is equivalent to the dominant GHG which is carbon dioxide.

---

[335] Global warming caused by human activity is an incontrovertible fact, backed by empirical evidence and sound scientific theories. It is driven by GHGs trapping heat within the earth-atmosphere system.

[336] http://www.metoffice.gov.uk/research/news/2015/global-average-temperature-2015

[337] Victor, D, Zhou, D, Ahmed, E et al. Introductory Chapter. in: O Edenhofer, R Pichs-Madruga, Y Sokona, (Eds.) Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY; 2014

339. About 1600 $GtCO_2e$ has been emitted into the atmosphere since 1870. In 2010, annual global GHG emissions were estimated at 49 $GtCO_2e$.[338]

340. Global GHG emissions from heat and electricity production and transport have tripled and doubled respectively since 1970, whereas the contribution from agriculture and land-use change has slightly reduced from 1990 levels.[339]

341. The rise in temperature increases the amount of energy in the earth-atmosphere system as well as the amount of water in the atmosphere, both of which lead to changes in the weather.[340]

342. CO_2 (and some other pollutants) also causes ocean acidification which damages marine organisms and threatens freshwater supplies across the world. The effect of ice melting and water expansion (caused by temperature rise) and subsequent sea level rise is another important dimension of global warming.

Impacts on global health

343. The impacts of global warming on health can be direct (eg, heatwaves; extreme weather events such as a storm, forest fire, flood, or drought; and sea level rise), or indirect, mediated through the effects of climate change on, amongst other things, food production systems, economies, forced migration and increasing levels of conflict and violence.

344. There are already observed impacts of climate change on health. There is a well-established relationship between extreme high temperatures and human morbidity and mortality[341] and strong evidence that heat-related mortality is rising across a range of localities.[342]

345. Heatwaves and increases in the incidence of extreme heat are projected under all future scenarios of climate change.[343] Heat poses significant risks to occupational health and labour

---

[338] Summary for policymakers. in: O Edenhofer, R Pichs-Madruga, Y Sokona, (Eds.) Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY; 2014

[339] Bruckner, T, Bashmakov, I, Mulugetta, Y et al. Energy Systems. in: O Edenhofer, R Pichs-Madruga, Y Sokona, (Eds.) Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY; 2014

[340] McCoy D and Hoskins B, 2014. The science of anthropogenic climate change: what every doctor should know. BMJ 2014*;* 349 doi: http://dx.doi.org/10.1136/bmj.g5178

[341] Aström, C, Orru, H, Rocklöv, J, Strandberg, G, Ebi, KL, and Forsberg, B. Heat-related respiratory hospital admissions in Europe in a changing climate: a health impact assessment. BMJ Open. 2013; 3: e001842

[342] Smith, KR, Woodward, A, Campbell-Lendrum, D et al. Human health—impacts adaptation and co-benefits. Climate change 2014: impacts, adaptation, and vulnerability Working Group II contribution to the IPCC 5th Assessment Report. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014

[343] Patz, JA, Campbell-Lendrum, D, Holloway, T, and Foley, JA. Impact of regional climate change on human health. Nature. 2005; 438: 310–317

productivity in areas where people work outdoors for long hours in hot regions.[344] Loss of agricultural productivity through impaired labour will amplify direct climate change by impacting negatively on food production.[345]

346. One study estimates that the effects of heat could cost China and India by as much as US$450 billion in 2030.[346] Although there may be modest reductions in cold-related deaths in some parts of the world; at the global scale, these benefits will be outweighed by heat-related mortality.[347]

347. Heatwaves also carry risks for the wider environment. For example, the summer 2010 heatwave in Russia[348] was accompanied by more than 25,000 fires over an area of 1·1 million hectares[349] and raised concentrations of carbon monoxide, nitrogen oxides, aerosols, and particulates (PM_{10}) across European Russia.

348. Changing weather patterns will affect the incidence of certain vector-borne diseases. For example, rising temperatures and changes in precipitation pattern will alter the distribution of disease vectors such as mosquitoes carrying dengue or malaria. Dengue fever for example has 390 million recorded infections each year, and the number is rising. Changing weather patterns will also increase waterborne diseases such as cholera in the coming decades. [350]

349. Airborne particulate matter (PM) produced from the combustion of coal and oil also impinges negatively upon health by causing respiratory and cardiovascular disease. Household and ambient air pollution is estimated to have been responsible for 7 million additional deaths globally in 2012.[351] In the UK, around 40,000 deaths are attributable to exposure to outdoor air pollution.[352] The OECD estimates that the value of lives lost and ill health due to ambient air

---

[344] Kjellstrom, T, Holmer, I, and Lemke, B. Workplace heat stress, health and productivity—an increasing challenge for low and middle-income countries during climate change. Global Health Action. 2009; 2 (10.3402/gha.v2i0.2047.)

[345] Porter, JR, Xie, L, Challinor, AJ et al. Food security and food production systems. in: CB Field, VR Barros, DJ Dokken, (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014: 485–533

[346] DARA and the Climate Vulnerability Forum. Climate vulnerability monitor 2012: a guide to the cold calculus of a hot planets. Fundacion DARA Internacional, Barcelona; 2012

[347] Ebi, K and Mills, D. Winter mortality in a warming climate: a reassessment. Wiley Interdiscip Rev Clim Change. 2013; 4: 203–212

[348] Russo, S, Dosio, A, Graversen, RG et al. Magnitude of extreme heat waves in present climate and their projection in a warming world. J Geophys Res D Atmospheres. 2014; 199: 500–512

[349] Ryazantzev, S. Demographic and socio-economic consequences of heat wave and forest fires of 2010 in European Russia. Ecol Life. 2011; 5: 80–85

[350] Lipp, EK, Huq, A, and Colwell, RR. Effects of global climate on infectious disease: the cholera model. Clin Microbiol Rev. 2002; 15: 757–770

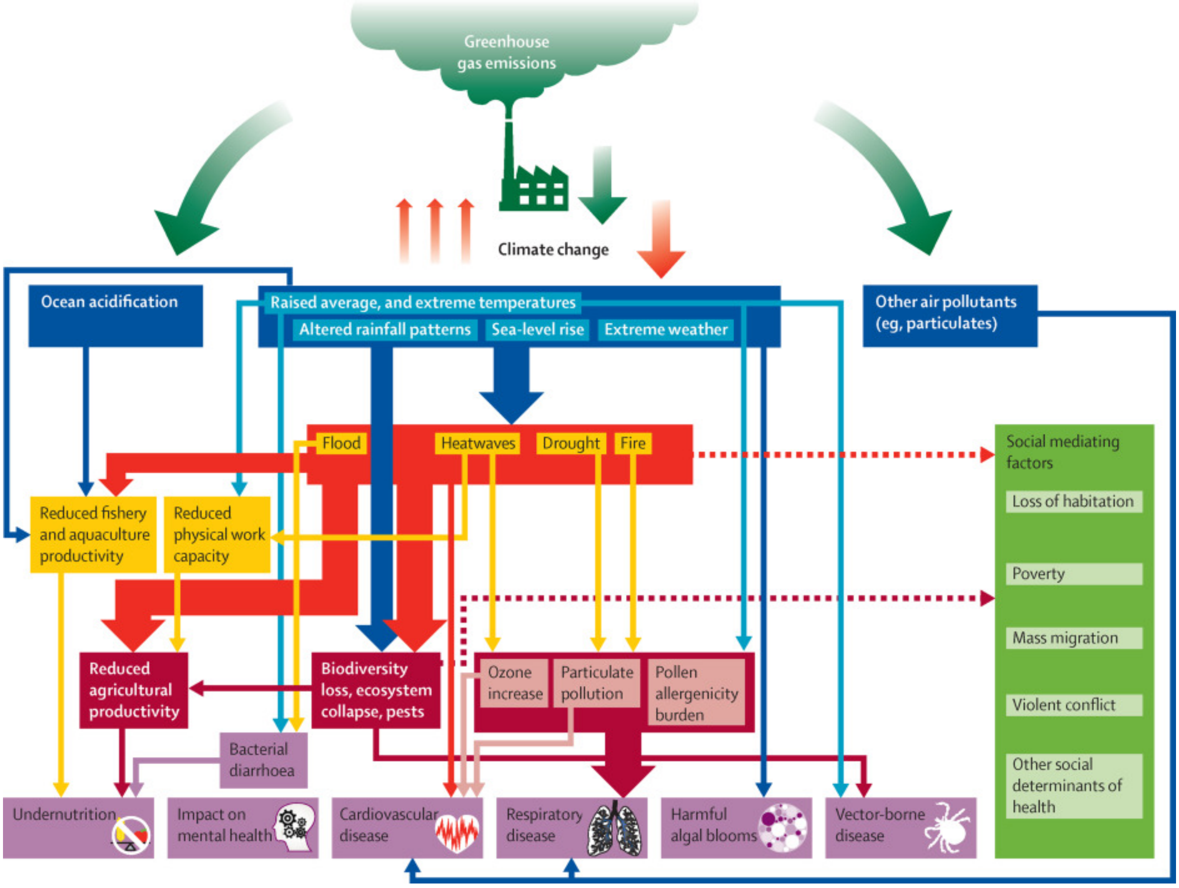
[351] WHO. Burden on disease from air pollution in 2012. http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf; 2014.

[352] Royal College of Physicians. *Every breath we take: the lifelong impact of air pollution*. Report of a working party. London: RCP, 2016.

pollution in OECD countries, plus India and China, is more than $3·5 trillion annually (about 5% gross world product), with India and China accounting for 54% of this total.[353]

350. By altering temperature and precipitation frequency, climate change can further elevate levels of atmospheric particulate matter and ground level ozone in certain regions.[354] [355] [356] One study estimates that ozone-related acute mortality in the USA could rise by 4·5% from 1990 to 2050 through climate change alone.[357]

351. Most climate-related health impacts are mediated through complex ecological and social processes as shown in the diagram below.



---

[353] Organisation of Economic Co-operation and Development, 2014.The cost of air pollution: health impacts of road transport. Paris: OECD.

[354] Giorgi, F and Meleux, F. Modelling the regional effects of climate change on air quality. C R Geosci. 2007; 339: 721–733

[355] Tagaris, E, Manomaiphiboon, K, Liao, K-J et al. Impacts of global climate change and emissions on regional ozone and fine particulate matter concentrations over the United States. J Geophys Res, D, Atmospheres. 2007; 112: D14312

[356] Jiang, H, Liao, H, Pye, HOT et al. Projected effect of 2000–2050 changes in climate and emissions on aerosol levels in China and associated transboundary transport. Atmos Chem Phys. 2013; 13: 7937–7960

[357] Knowlton, K, Rosenthal, JE, Hogrefe, C et al. Assessing ozone-related health impacts under a changing climate. Environ Health Perspect. 2004; 112: 1557–1563

352. The impact of climate change on pushing up food prices and affecting food availability and affordability will be substantial, especially for regions and populations that are already food insecure.[358] Policies related to polices on food stocks, reactions to food prices by producer countries, and demand for land to hedge against climate shifts may further increase volatility within the global food system and compound the threat of reduced food productivity for many populations.[359]

353. Added to the challenge of worsening food security, is the critical factor of water availability. Groundwater resources are already in a critical state in many regions[360] [361] and increased exposure to drought-like meteorological conditions over the coming decades is a considerable threat. One analysis shows that climate change, when combined with population changes, could lead to 1·4 billion additional person drought exposure events per year by the end of the century.[362]

354. The potential impact of increased frequency of floods, storm surges and hurricanes is exemplified by the 6000 plus fatalities that resulted from typhoon Haiyan in the Philippines in 2013. Floods also have long-term and short-term effects on wellbeing through disease outbreaks, mental health burdens, and dislocation. [363] [364] The involuntary displacement of populations as a result of extreme events has major health and policy consequences as evidenced recently in the UK.

355. The IPCC concludes that climate change will directly affect poverty, resource uncertainty and volatility, and the ability of governments to fulfil their obligations to protect settlements and people from weather extremes.[365] [366]

---

[358] Grace, K, Davenport, F, Funk, C, and Lerner, AM. Child malnutrition and climate in Sub-Saharan Africa: An analysis of recent trends in Kenya. Appl Geogr. 2012; 35: 405–413

[359] Porter, JR, Xie, L, Challinor, AJ et al. Food security and food production systems. in: CB Field, VR Barros, DJ Dokken, (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014: 485–533

[360] Taylor RG, Scanlon B, Doll P et al. Ground water and climate change. Nature Clim Change. 2013; 3: 322–329

[361] Schewe, J, Heinke, J, Gerten, D et al. Multimodel assessment of water scarcity under climate change. Proc Natl Acad Sci USA. 2014; 111: 3245–3250

[362] Watts N, Adger WN, Agnolucci P et al, 2015. Health and climate change: policy responses to protect public health. The Lancet, Vol. 386, No. 10006, p1861–1914

[363] Ahern, M, Kovats, RS, Wilkinson, P, Few, R, and Matthies, F. Global health impacts of floods: epidemiologic evidence. Epidemiol Rev. 2005; 27: 36–46

[364] Paranjothy, S, Gallacher, J, Amlôt, R et al. Psychosocial impact of the summer 2007 floods in England. BMC Public Health. 2011; 11: 145

[365] Adger, WN, Pulhin, JM, Barnett, J et al. Human security. in: CB Field, VR Barros, DJ Dokken, (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014: 755–791

[366] Olsson, L, Opondo, M, Tschakert, P et al. Livelihoods and poverty. in: CB Field, VR Barros, DR Dokken, (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY; 2014: 793–832

356. The continued movement of migrant populations into cities, the potential for climate hazards in high-density coastal mega-cities, and impaired air quality create significant public health challenges, not least for migrants themselves.[367] [368] The effects of food and resource insecurity, migration, displacement, uncertainty and poverty all combine to make climate change a threat to peace and human security.[369]

357. Scientists are also highly confident that climate change is bleaching coral on reefs worldwide; affecting river flows; forcing plant and animal species towards the poles and to higher elevations around the world; and negatively impacting those living in the Arctic. There has been a negative effect on the growth in productivity of some key crops, including for wheat and maize.

358. Although the magnitude and nature of future health impacts are hard to predict with precision, unless action is taken to stop the net increase in GHG emissions, all plausible futures resulting from anticipated emissions trajectories will expose the global population to serious health consequences.

359. Furthermore, there is a real risk of unforeseen interactions and the amplification of known climate risks. Of great concern is the risk of crossing thresholds and tipping points which would produce accelerations in warming and larger-than-expected chances of catastrophic outcomes.[370] [371]

360. According to the Lancet-UCL Commission on Climate Change and Health, climate change could be “sufficient to trigger a discontinuity in the long-term progression of humanity”[372] and that on the basis of current emission trajectories, “temperature rises in the next 85 years may be incompatible with an organised global community”.[373]

361. Whilst initially certain regions and communities will suffer disproportionately, the interconnected and global nature of climate systems, ecosystems and human society will mean that all parts of the world will be affected.[374] Regions that might be less affected by the direct

---

[367] McMichael, C, Barnett, J, and McMichael, AJ. An ill wind? Climate change, migration, and health. Environ Health Perspect. 2012; 120: 646–654

[368] Black, R, Arnell, NW, Adger, WN, Thomas, D, and Geddes, A. Migration, immobility and displacement outcomes following extreme events. Environ Sci Pol. 2013; 27: S32–S43

[369] Gleditsch, NP. Whither the weather? Climate change and conflict. J Peace Res. 2012; 49: 3–9

[370] Rockström, J, Steffen, W, Noone, K et al. Planetary boundaries: exploring the safe operating space for humanity. Ecol Soc. 2009; 14: 32

[371] Lenton, TM, Held, H, Kriegler, E et al. Tipping elements in the Earth's climate system. Proc Natl Acad Sci USA. 2008; 105: 1786–1793

[372] Watts N, Adger WN, Agnolucci P et al, 2015. Health and climate change: policy responses to protect public health. The Lancet, Vol. 386, No. 10006, p1861–1914

[373] Anderson, K and Bows, A. Beyond ‘dangerous’ climate change: emission scenarios for a new world. *Philos Trans A Math Phys*. Eng Sci. 1934; 2011: 20–44

[374] Smith KR, Woodward A, Campell-Lendrum D et al. Human health—impacts adaptation and co-benefits. Climate change 2014: impacts, adaptation, and vulnerability Working Group II contribution to the IPCC 5th Assessment Report. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014

effects of climate change will be negatively affected by the economic and social disruption in those regions that are more directly affected.[375]

362. Although there is some uncertainty in understanding the earth's future climate system and how further global warming will impact on weather patterns, biodiversity, food production and water stress, the risks outlined above indicate the need to take climate change as a serious and potentially existential threat to organised and peaceful civilisation.

O. Global GHG emissions and carbon budgets

363. While we know that GHG emissions are unequivocally linked to an increase in surface temperature, it is difficult to forecast with any certainty the future pattern of GHG emissions, energy use or global temperature rise. However, climate scientists have constructed various risk models that relate GHG emission targets to future temperature rise. These 'integrated assessment models' are highly complex and incorporate multiple assumptions about costs, markets, human behaviour, population growth and the physics of climate change.

364. A key output of their analyses has been the construction of 'global carbon budgets' that are associated with various probabilities for limiting the rise in global temperatures to below a defined limit. The table below shows the estimated carbon budget for the period 2011 to 2100 that would be consistent with various probabilities of limiting global warming to less than 1.5°C and 2°C.

Cumulative carbon dioxide emissions consistent with warming targets at different levels of probability

Net anthropogenic warming	**< 1.5°C**			**< 2°C**		
Probability	66%	50%	33%	66%	50%	33%
Cumulative CO_2 emissions from 2011 -2100 ($GtCO_2e$)	400	550	850	1000	1300	1500
Cumulative CO_2 emissions from 1870 ($GtCO_2$ e)	2250	2250	2550	2900	3000	3300

(Source: IPCC Fifth Assessment Report, 2014)

365. To have a better than 66% chance of limiting global warming to below 2°C, cumulative GHG emissions from 2011 onwards would need to be limited to around 1,000 (630–1180) $GtCO_2e$.[376] To have a better than 50% chance of limiting global warming to below 1.5°C, cumulative GHG

---

[375] Adger WN, Pulhin JM, Barnett J et al. Human security. in: CB Field, VR Barros, DJ Dokken, (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014: 755–791

[376] Clarke L, Jiang K, Akimoto K et al. Assessing transformation pathways. In Edenhofer, Pichs-Madruga, Sokona (Eds.) Climate change 2014: Mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the IPCC. Cambridge University Press; 2014

emissions from 2011 onwards would need to be limited to around 500 $GtCO_2e$. [377] A global carbon budget of about 850 $GtCO_2e$ for the period 2011-2100 would equate with an "unlikely" (<33%) chance of staying below 1.5°C.

366. Estimates about future emissions trajectories, including carbon cycle feedbacks, and their impact on the rate and scale of global temperature rises are uncertain, being based on multiple assumptions and limits in knowledge. However, many models used may be optimistic because they tend to assume relatively early peaks in global emissions and that 'negative emission technologies' will be practically and economically viable in removing CO_2 from the atmosphere.[378] [379]

367. The 850 to 1000 $GtCO_2e$ budget range is commonly used in policy circles. This refers to the global budget we have for all emissions from all sectors for the period 2011 to 2100. To understand what emissions are available from 2016 onwards, it is necessary to subtract those emissions released between 2011 and 2016. Based on CDIAC data, this is *at least* 150 $GtCO_2$ which leaves a budget of 700-850 $GtCO_2e$ for the period 2016-2100.

368. Although energy production is a major source of GHG emissions, agriculture, deforestation, and cement use are also important sources. An optimistic estimate of emissions from deforestation and cement process for 2016 to 2100 would be in the region of 60 $GtCO_2$ and 150 $GtCO_2$ respectively, leaving an 'energy-only' global budget of 490-640 $GtCO_2e$ for the period 2016 to 2100.[380]

369. Combining optimistic assumptions about curtailing deforestation and cement emissions with the IPCC's headline budget of 1,000 $GtCO_2$ would equate with global reductions in energy-related emissions of at least 10% per annum from 2025, transitioning rapidly towards zero emissions by 2050.[381] [382]

370. Current GHG emissions trends are not reassuring. Globally, since 2000, GHG emissions have been rising at around 2% every year, powered largely by growth in China and other emerging economies.[383] Overall global energy demand grew by 27% from 2001 to 2010, largely concentrated in Asia (79%), the Middle East and Africa (32%), and Latin America (32%) on the

---

[377] Clarke L, Jiang K, Akimoto K et al. Assessing transformation pathways. In Edenhofer, Pichs-Madruga, Sokona (Eds.) Climate change 2014: Mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the IPCC. Cambridge University Press; 2014

[378] Anderson K, 2015. On the Duality of Climate Scientists. **Nature Geoscience, DOI: 10.1038/ngeo2559.**

[379] Fuss, S. *et al.* Betting on negative emissions. *Nature.* **4.** 850-853 (2014)

[380] Anderson K, 2015. On the Duality of Climate Scientists. Nature Geoscience, DOI: 10.1038/ngeo2559.

[381] Krey, V, Masera, G, Blanford, T et al. Annex II: metrics & methodology. in: O Edenhofer, R Pichs-Madruga, Y Sokona, (Eds.) Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the IPCC. Cambridge University Press; 2014

[382] Even stabilising CO_2e concentrations to between 450–650 ppm (which would be consistent with 2-4°C of warming), the global emission rate would need to fall by 3–6% per year, a rate that so far has only been associated with major social upheaval and economic crisis. See: Beyond 'dangerous' climate change: emission scenarios for a new world. *Philos Trans A Math Phys*. Eng Sci. 2011(1934): 20–44

[383] Summary for policymakers. In: Edenhofer, Pichs-Madruga, Sokona (Eds.) Climate change 2014: Mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the IPCC. Cambridge University Press; 2014.

basis of territorial accounting.[384] However, consumption-based accounting shows that most of the recent growth in energy expenditure has been driven by consumption in high-income regions.[385]

371. According to one assessment, energy expenditure in non-OECD countries will double by 2035 from 2010 levels, with OECD countries seeing a 14% increase over the same period.[386] While most of the increase in primary energy demand occurs in emerging economies, most of the future projected growth in energy expenditure is expected to be driven by consumption in high-income regions.

372. At the current global emission rate, the 'carbon budget' described above could be depleted within as little as 24 years, possibly sooner. The window of opportunity to prevent potentially catastrophic climate change is therefore small.

373. The Paris Agreement (December 2015) has been heralded as marking a new level of international commitment to addressing the threat of global warming. The principal aim 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".*

374. The Paris Agreement also notes that countries will aim to reach global peaking of GHG emissions *"as soon as possible"*, whilst recognising that peaking *"will take longer for developing country parties".*

375. However, the voluntary pledges made by individual countries to reduce their GHG emissions do not match the ambition of the Agreement's goal. The US, for example, has only pledged to reduce its emissions by 12-19% from 1990 levels. Even if all countries deliver on their current pledges, the predicted level of global warming arising from cumulative emissions would be between 2.8^{o}C and 4^{o}C above pre-industrial levels.

376. Analysis of the latest UN pledges by Climate Action Tracker suggests that global emissions are on track to reach 53-59 $GtCO_2e$ in 2030, which is significantly above present global emissions of about 48 $GtCO_2e$. Furthermore, there are gaps between current policy projections and country pledges meaning that current policies are not strong enough to achieve these conservative pledges.[387]

---

[384] Bruckner, T, Bashmakov, I, Mulugetta, Y et al. Energy Systems. in: O Edenhofer, R Pichs-Madruga, Y Sokona, (Eds.) Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY; 2014

[385] Barrett J, Le Quéré, Lenzen M, Peters G, Roelich K, and Wiedmann T, 2011. Consumption-based emissions reporting. Memorandum submitted by UKERC (CON 19). http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/writev/consumpt/con20.htm;.

[386] International Energy Agency (IEA). World energy outlook 2013. IEA, Paris; 2013

[387] See: http://climateactiontracker.org/global/173/CAT-Emissions-Gaps.html

377. The gap between the climate science and the actual policies and plans to reduce GHG emissions is therefore considerable. This partly reflects a reluctance to abandon our dependence on both fossil fuels and unsustainable consumption patterns. It also reflects a faith in future technologies being developed to sequester GHGs from the atmosphere.[388]

The role of natural gas in mitigating global warming

377. Proponents of natural gas argue that it is a clean form of energy when compared to coal and oil and that its use for electricity generation instead will help reduce the rate at which the carbon budget is depleted. In order to assess the potential future impact of natural gas on carbon budgets and global warming, life cycle analyses (LCAs) are conducted to determine the amount of GHGs emitted across all stages of gas production and end-use.[389]

378. These LCAs are inevitably influenced by a number of variables which produce a wide range of measures of the global warming potential of natural gas. The variables include: i) the amount of fugitive emissions released directly into the atmosphere; ii) whether the gas produced is liquefied and transported before use (because both liquefaction and transportation required energy); iii) the efficiency of the power stations used to convert gas into electricity; iv) the use of CCS technologies; and v) the time horizon over which the global warming potential of methane and carbon dioxide are assessed. When comparing the global warming potential of gas against other energy sources, the relative efficiencies of coal power stations and the impact of gas on coal, oil and renewable energy are also relevant.

379. A key factor in LCAs of natural gas is fugitive emissions. According to Howarth, while for a given unit of energy produced, carbon dioxide emissions are less for shale gas and conventional natural gas than those for oil and coal, the total GHG footprint of shale gas may be greater than other fossil fuels when methane emissions are included.[390]

380. Sanchez and Mays (2015) modelled what leakage rate of natural gas in electricity generation would cause CO_2e emissions of natural gas to become equivalent to those of coal, and found that the leakage rate must be lower than 3.9% in the life-cycle of its production, distribution and

---

[388] In particular, biomass energy carbon capture and storage (BECCS) has become prominent after Paris. BECCS involves covering large areas of the planet with bio-energy crops that will absorb carbon dioxide through photosynthesis. Periodically these crops would be harvested; processed for worldwide travel; and eventually combusted in thermal power stations. The carbon dioxide would then be extracted from the waste gases, compressed (almost to a liquid); pumped through large pipes (potentially over very long distances); and finally stored deep underground in various geological formations (e.g. exhausted oil and gas reservoirs or saline aquifers).

[389] Note that LCAs do not include measures of "indirect fugitive emissions", i.e. the geological seeps induced by fracking, which may be large enough to negate the claim that fracking is cleaner than coal.

[390] Howarth R, 2015. Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy. Energy and Emission Control Technologies 2015:3 45–54

use, when looked at over a 20-year time horizon. Above this threshold the GHG footprint advantage of natural gas is eliminated.[391]

381. The GWP of shale gas relative to conventional natural gas is contentious. Burnham et al's analysis of lifecycle GHG emissions concluded that shale gas life-cycle emissions were 6% lower than conventional natural gas (23% lower than gasoline and 33% lower than coal). However, the range in values for shale and conventional gas overlap, so the difference is not statistically significant.[392] Key factors, highlighted by this study, are the assumptions made about the use of 'green technologies' and the rate of upstream fugitive emissions, as well as the relative efficiency of power stations.

382. Laurenzi and Jersey's (2013) LCA of shale gas from the Marcellus shale for power generation found that a typical gas life cycle yields 466 kg CO2eq/MWh (80% confidence interval: 450−567 kg CO2eq/MWh) of GHG emissions. Their results were influenced strongly by the estimated ultimate recovery (EUR) of the well and the power plant efficiency (their results were based on electricity generation at a combined cycle gas turbine power plant and a 100 year time horizon). They found that the carbon footprint of Marcellus gas is 53% (80% CI: 44−61%) lower than coal, and comparable to that of onshore conventional natural gas.[393] Operations associated with hydraulic fracturing constituted only 1.2% of the life cycle GHG emissions.

383. Weber and Clavin's review of the LCA literature concluded that the upstream carbon footprints of different types of gas production are likely to be similar. However, they found that the upstream footprint is less than 25% of the total carbon footprint of gas, and note that the efficiency of producing heat, electricity, and transportation services is of equal or greater importance when identifying emission reduction opportunities. They also note, as do most other authors, that better data are needed to reduce the uncertainty in natural gas's carbon footprint, and that understanding system-level climate impacts of shale gas through shifts in national and global energy markets is also important and requires more detailed energy and economic systems assessments.[394]

384. Regardless of any measure of the GWP of natural gas per unit of energy service (e.g. electricity or heating), the total volume of gas production and consumption is also important. For example, according to McLeod at el's (2014) model, if gas prices are kept low (as anticipated)

---

[391] Sanchez N & Mays D, 2015 Effect of methane leakage on the greenhouse gas footprint of electricity generation, *Climatic Change* November 2015, Volume 133, Issue 2, pp 169-178

[392] Burnham, A. et a, 2012. Life-cycle greenhouse gas emissions of shale gas, natural gas,coal, and petroleum. Environ. Sci. Technol. 46, 619–627.

[393] Laurenzi IJ. And Jersey GR, 2013. Life cycle greenhouse gas emissions and freshwater consumption of Marcellus shale gas. Environ. Sci. Technol. 47, 4896–4903.

[394] Weber C and Clavin C. Life cycle carbon footprint of shale gas: Review of evidence and implications. Environ. Sci. Technol. 2012, 46, 5688−5695.

a global warming potential of methane of 72 over 20 years generates overall energy system GHG emissions in 2050 that are 6% higher than in 2010.[395]

385. Using simulations of five state-of-the-art integrated assessment models of energy–economy–climate systems, McJeon et al (2014) indicate that a future scenario of globally abundant gas would lead to an overall increase in 'climate forcing'.[396] The models found that while gas substitutes largely for coal, it also substitutes nuclear and renewable energy, and tends to increase economic activity. This finding echoes the 'Golden Age of Gas' scenario presented by the IEA which indicated a projected 3.5°C warming as a consequence.[397]

386. There is evidence that while US shale gas displaced coal use for electricity generation (and helped reduce GHG emissions from the energy sector by 12% between 2005 and 2012), the displaced US coal was exported and burnt abroad.[398] As a result, CO_2e emissions from the combustion of all fossil fuels generated from the US actually rose by approximately 10%.[399]

387. The point about new gas reserves *increasing* the threat of global warming by simply adding to the available stock of fossil fuel was made by DECC's former Chief Scientific Advisor who noted: "*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.*"[400] The Environmental Report published by DECC in relation to the 14th onshore licensing round also points to the dangers of shale gas merely displacing coal and oil rather than replacing them altogether as a source of energy.[401]

388. Fossil fuel 'reserves' are known fossil fuels that are economically 'extractable'. The volume of fossil fuel reserves is therefore partly a function of the fossil fuel price which is highly volatile. Some reports distinguish between the concepts of 'carbon bubble' being a financial issue, and 'unburnable carbon' being a technological issue.

389. The estimated amount of 'unburnable carbon' ranges from 49% to 80% of overall reserves.[402] McGlade and Ekins (2015) concluded that 50% of existing global gas reserves are

---

[395] McLeod et al, 2014, Emissions Implications of Future Natural Gas Production and Use in the US and in the Rocky Mountain Region, Environ Sci Technol 2014;48, 13036-13044

[396] McJeon, H et al (2014) Limited impact on decadal-scale climate change from increased use of natural gas, Nature 514, 482–485, doi:10.1038/nature13837

[397] IEA, *World Energy Outlook 2011 Special Report: Are We Entering A Golden Age of Gas?*, International Energy Agency, Paris, France, 2011

[398] Broderick and Anderson, 2012. Has US Shale Gas Reduced CO2 Emissions? Examining recent changes in emissions from the US power sector and traded fossil fuels, Tyndall Manchester, University of Manchester

[399] US EIA December 2014 Monthly Energy Review

[400] DJ MacKay & TJ Stone Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use (DECC, 2013)

[401] Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing Environmental Report (December 2013) – p.88.

[402] Budinis, Krevor, MacDowell et al, 2016. Can Technology unlock 'unburnable' carbon? London: Sustainable Gas Institute

'unburnable' (including >80% of global potential unconventional gas reserves), in addition to a third of oil and 80% of coal reserves.[403]

390. McGlade and Ekins (2015) note that CCS has the largest effect of any technology on cumulative fossil fuel production levels. CCS could enable countries to continue to include fossil fuels in their energy mix and therefore can unlock assets that would otherwise be stranded.[404] According to the World Energy Outlook (2012), without CCS, less than a third of global carbon reserves can be burnt in the 2°C scenario.[405] One study estimated that CCS could enable 65% of reserves to be used instead of 33%.[406]

391. The UK Energy Research Centre concluded that while there is a potential for natural gas to support a transition towards a low-carbon energy system, the bridging period is strictly time-limited and only holds true if any absolute and relative increase in gas consumption occurs alongside a much greater reduction in coal consumption in both absolute and relative terms.[407] Furthermore, it must be accompanied by a much larger increase in low-carbon energy sources. Importantly, the ability for gas to play a bridging role varies from one region to another and is dependent also on the availability of CCS. Of 13 regions studied, gas had limited or no potential to act as a transition fuel in six regions (Africa, Canada, Central and South America, the Middle East and Mexico); good potential in three (Australia, Other Developing Asia, and the US), and strong potential in four (China, Europe, India and Japan and South Korea) *if* CCS is available. If CCS is not available, natural gas may act as a strong bridge in only China.

392. The Lancet-UCL Commission on Climate Change and Health was more cautious and noted that the time when fuel switching could decarbonise the global economy sufficiently quickly to avoid dangerous climate change has almost certainly passed.

393. Regardless of the availability and affordability of safe *and effective* CCS technologies, there is still a limited carbon budget and a timeframe within which the world needs to achieve net zero GHG emissions. According to Howarth (2015), the imperative to reduce methane emissions to slow global warming over the coming few decades means that the only path forward is to reduce the use of all fossil fuels as quickly as possible. There is no bridge fuel, and switching from coal to shale gas is accelerating rather than slowing global warming.

394. A key argument against the development of more shale gas reserves is that investment in efficiency and renewables would be a more cost-effective solution than coal-to-gas substitution.

---

[403] McGlade C and Ekins P (2015) The geographical distribution of fossil fuels unused when limiting global warming to 2°C, Nature 517, 187—190, doi:10.1038/nature14016

[404] IPCC (2005). IPCC Special Report: Carbon capture and storage. Available online: www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf

[405] IEA (2012). World Energy Outlook 2012. www.worldenergyoutlook.org/publications/weo-2012/

[406] Budinis, Krevor, MacDowell et al, 2016. Can Technology unlock 'unburnable' carbon? London: Sustainable Gas Institute

[407] McGlade C, Bradshaw M, Anandarajah G, Watson J and Ekins P. (2014) A Bridge to a Low-Carbon Future? Modelling the Long-Term Global Potential of Natural Gas - Research Report (UKERC: London).

395. One concern is that the deployment of natural gas risks delaying the deployment of renewable energy systems. According to Zhang et al (2016), this could offset all the potential climate benefits derived from replacing coal energy systems with natural gas energy systems.[408] They note that the risks are higher when the natural gas energy system is inefficient and the coal energy system is efficient. In addition, they highlight the importance of the choice of time horizon because methane is a much stronger GHG than carbon dioxide but which acts for a much shorter time.[409]

396. Zhang et al's analysis shows that natural gas *can* provide climate benefit as a 'bridging fuel' if the coal energy system is inefficient; the natural gas energy system is efficient; the natural gas leakage rate is low; and the evaluation time horizon for the global warming potential of methane is longer than 40 years. However, in the absence of CCS, natural gas use cannot provide the deep reductions in GHG emissions needed to prevent dangerous climate change. They warn that "If the introduction of natural gas substantially delays the transition to near-zero emission systems, there is potential that the introduction of natural gas could lead to greater amounts of warming than would have occurred otherwise.

Q. The UK: GHG emissions and energy policy

The UK's carbon budgets

397. Government's policy on GHG emissions is based on recommendations made by the Committee on Climate Change (CCC). The CCC's first report, which built on the IPCC's fourth assessment report (2007), concluded that economic and political constraints made it impossible to ensure *"with high likelihood"* that a temperature rise of more than 2°C can be avoided.[410] Instead, it offered two national and century-wide carbon budgets: one gave a 56% chance of exceeding 2°C while the other gave a 63% chance of exceeding 2°C. The government chose the latter, along with an obligation to reduce emissions in 2050 by 80% compared to 1990 levels.

398. The CCC has subsequently published a series of carbon budgets for a set of sequential five-year periods. The fourth carbon budget (2023-2027) capped emissions at 1,950 $MtCO_2e$, which is equivalent to an average 52% below 1990 levels. The fifth carbon budget (2028-2032) of 1,765 $MtCO_2e$ (including emissions from international shipping), which would limit annual emissions to an average 57% below 1990 levels, has recently been enacted into law.[411]

399. The past and projected emissions trajectory is shown in the diagram below. The trajectory proposed by the CCC involves a smooth and incremental reduction in emissions across the

---

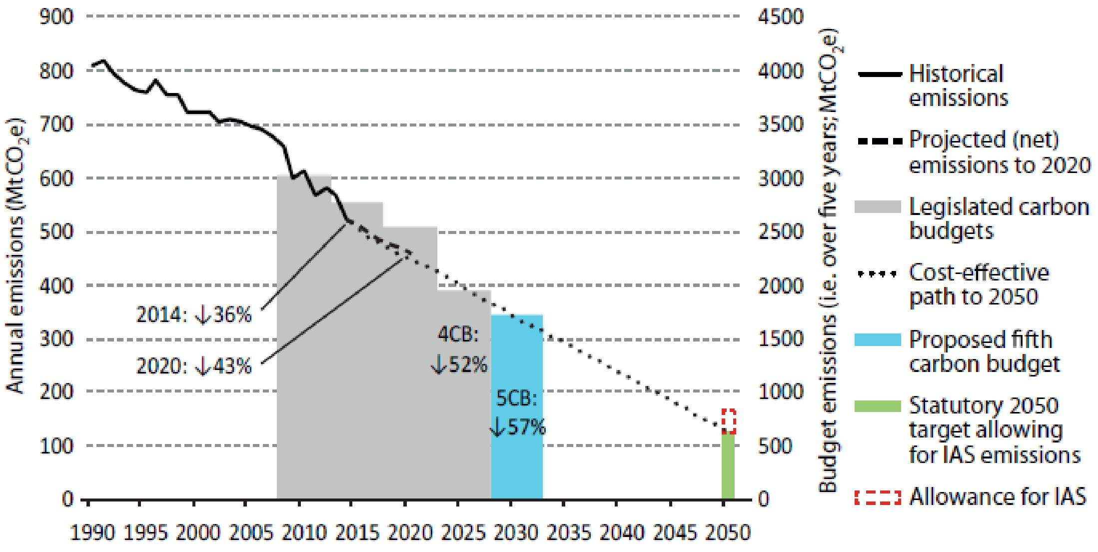
[408] Zhang X, Myhrvold N, Hausfather Z, Caldeira K (2016) Climate benefits of natural gas as a bridge fuel and potential delay of near-zero energy systems, Applied Energy 167 (2016) 317–322

[409] According to Howarth, the GWP of methane is 86 more than that of carbon dioxide when averaged over 20 years (for two equal masses of the gases emitted into the atmosphere).

[410] CCC, 2008. Building a low-carbon economy - the UK's contribution to tackling climate change.

[411] CCC, 2015. The Fifth Carbon Budget – The next step towards a low-carbon economy

economy of around 13 MtCO$_2$e (3%) per year from 2014 to 2030. The target set for the first carbon budget (2008-2012) has been met, and the target for the second budget (2013-2018) is on course to be met.[412]



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013*; DECC (2015) Provisional UK greenhouse gas emissions national statistics; DECC Energy Model; CCC analysis.
Notes: Data labels show reductions in annual emissions relative to 1990. Historical emissions are on a 'gross' basis (i.e. actual emissions). Projections and carbon budgets are on the current budget accounting basis: net carbon account excluding international aviation and shipping (IAS), but allowing for IAS to be included in the 2050 target.

400. Although the UK's statutory target to reduce GHG emissions in 2050 by 80% compared to 1990 sounds ambitious, there are reasons why the target is inadequate.

401. First, the targets are based on the integrated assessment models of the IPCC which are (as explained earlier) believed to be over-optimistic.

402. Second, the budget is based on a dangerous level of risk that accepts a 63% chance of exceeding 2°C.

403. Third, the budget represents an unfair share of the global carbon budget, making little allowance for historical responsibility for GHG emissions, or the considerably superior financial and technical capability of the UK compared to most other countries.[413]

404. Fourth, the GHG emissions targets are calculated as 'territorial emissions' and do not take into account the GHGs emitted elsewhere to produce goods and commodities that are

---

[412] The carbon budget for 2014 was 520 MtCO$_2$e, excluding emissions from international aviation and shipping.
[413] Friends of the Earth, 2015. Why the UK must commit to its fair share of emissions cuts ahead of the Paris climate talks. November.

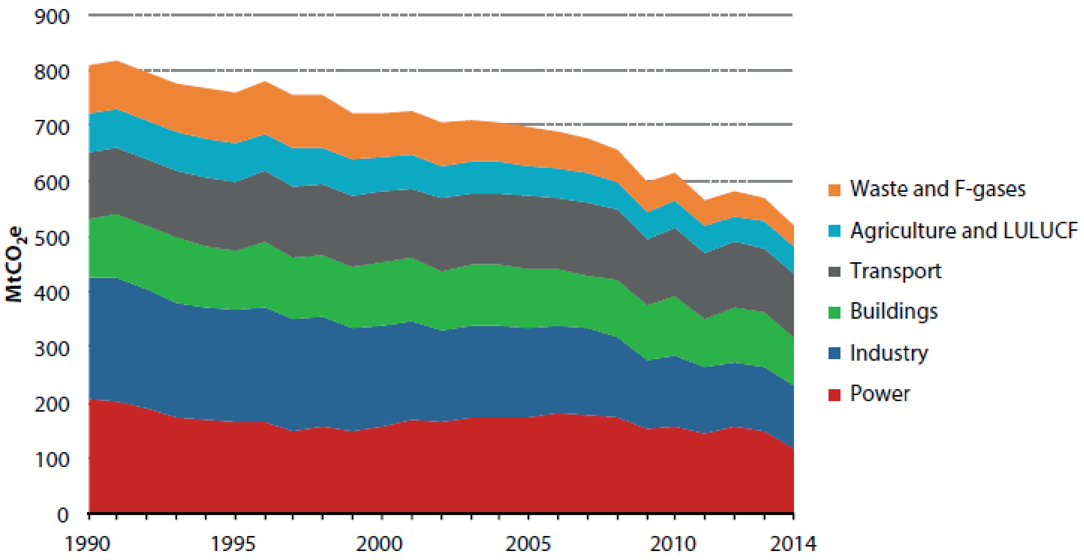
eventually imported into the UK. In the UK, while territorial-based emissions have shown a 19% reduction between 1990 and 2008, consumption-based emissions have increased by 20% in the same period (driven by GHGs embodied in imported products, particularly from China).[414]

405. Fifth, the planned reduction of emissions is spread across the period to 2050 rather than front-loaded. This runs counter to the clear message from climate scientists that we need to frontload as much of our GHG emissions reductions as possible.[415]

406. Early emissions reduction will delay climate disruption and reduce the overall cost of abatement by avoiding drastic and expensive last-minute action. Furthermore, it allows the window of opportunity for the development and deployment of new technologies to be held open for longer. Delayed emission reduction could also force the uptake of riskier and unproven mitigation technologies with increased risk of unintended consequences for human wellbeing and ecosystems.[416]

Trends in energy use

407. The pattern of energy production and consumption has changed considerably since 1990 in terms of GHG emissions, energy mix and energy use. The figure below shows the pattern of UK GHG emissions by sector since 1990, and indicates a steady fall in GHG emissions since 1990.



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013;* DECC (2015) *Provisional UK greenhouse gas emissions national statistics*; CCC analysis.

---

[414] http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/1646/1646vw13.htm

[415] Edenhofer, Pichs-Madruga, Sokona (Eds.) Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the IPCC. Cambridge University Press; 2014.

[416] Mills, E. Weighing the risks of climate change mitigation strategies. Bull At Sci. 2012; 68: 67–78

408. The fall in GHG emissions is due to a combination of factors: a move away from coal and oil towards gas and renewables in generating electricity; contraction of energy-intensive industries (including iron and steel); improved efficiency of boilers and buildings; economic recession post-2008; a reduction in cattle numbers, synthetic fertiliser application and biodegradable waste sent to landfill; and the implementation of methane recovery systems.

409. Importantly, the graph above denotes the pattern for territorial GHG emissions and does not reflect the GHG emissions of goods and products produced elsewhere but consumed in the UK. So a proportion of the UK's reduction in GHG emissions has essentially resulted from GHG emissions being exported oevrseas.

410. In spite of improvements in the average fuel efficiency of vehicles, transport sector emissions (excluding emissions from international aviation and shipping) have not decreased substantially and actually increased by 1.1% between 2013 and 2014.[417]

411. In 2014, direct domestic energy consumption in the UK was 142.8 million tonnes of oil equivalent (Mtoe). The two largest sources of fuel were petroleum liquids (86% of which were used for transport) and natural gas (60% of which was used in the domestic sector). Overall, fossil fuels accounted for 84.5% of the UK's energy supply.[418]

412. UK emissions for 2014 were split between six sectors by the CCC as follows: power/electricity generation (23%), industry (21%), buildings (16%), transport (23%), agriculture and land-use, land-use change and forestry (9%), and waste and fluorinated gases (7%).

413. The pattern of primary fuels used to generate electricity in the UK has changed significantly over the years, reflecting a lower dependence on coal and greater reliance on gas and renewable energy. The substitution of coal by gas has been occurring since the major reductions in coal use over 1970-1980; and the so-called 'dash for gas' in the 1990s. In the fourth quarter of 2015, the mix of fuels to generate electricity was: gas (29.7%), renewables (26.9%), coal (19.9%), nuclear (15.6%), and oil and other sources (2.3%).[419]

414. The share of coal in UK primary energy consumption has fallen from 40% in 1970 to 16% by 2014, while gas use increased from 5% to 47%. Of the coal used in 2014, nearly 80% was used to generate electricity.[420] Projections to 2030 show that coal-based electricity generation will fall by

---

[417] DECC, 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416810/2014_stats_release.pdf

[418] DECC, 2015. Energy Consumption in the UK. https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

[419] Statistics- National Statistics. Energy Trends Section 5: Electricity. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/437802/Electricity.pdf

[420] DECC, 2015. Energy Consumption in the UK. https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

63% from 2015 levels in 2020. The government has committed to phase out all coal use for electricity generation by 2025.

415. Because most coal plants will have been retired before any substantial production of shale gas occurs, the GHG footprint of shale gas relative to coal is not relevant. Rather, shale gas needs to be compared with other potential sources of electricity and heating including biogas, conventional gas, biomass and renewables.

416. Of the total natural gas consumed in 2011, about 52% was used to provide heat for buildings and industry, while 34% was burned in power stations to generate electricity.[421] In 2010, 85% of homes were heated by gas.[422]

417. In 2013, 11.2 Mtoe of primary energy use was accounted for by renewables, 75% of which was to generate electricity, and 15% was used to generate heat.[423] In 2013, 70% of renewable energy came from bioenergy (including wood, wood waste and agricultural by-products), while about a fifth came from wind. Hydro-electric and solar PV contributed less than 10%.

Achieving the UK's 2050 target for GHG emissions reductions

418. Three aspects of decarbonisation are crucial: energy efficiency, energy conservation, and a shift to low-carbon electricity.

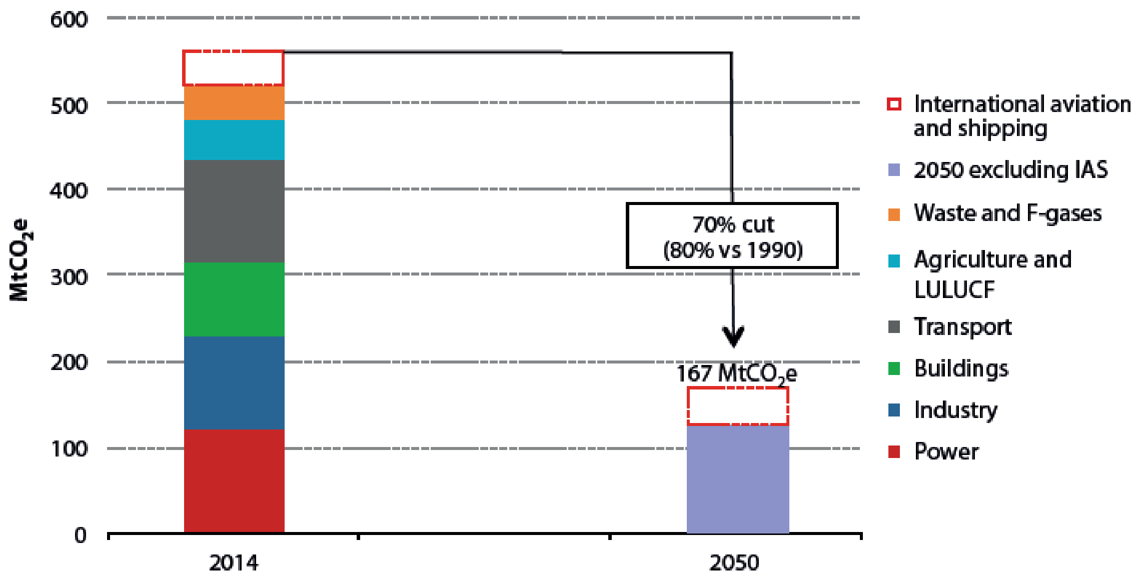
419. The current pattern of GHG emissions sources in 2014 and the statutory target for 2050 are shown in the diagram below.

---

[421] Department of Energy and Climate Change. (2013). The Future of Heating: Meeting the Challenge. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECCThe_Future_of_Heating_Accessible-10.pdf

[422] National Grid. (2014). UK Future Energy Scenarios; UK Gas and Electricity Transmission. [Online] Available at: http://www2.nationalgrid.com/uk/industry-information/future-ofenergy/future-energy-scenarios/

[423] Department of Energy and Climate Change. (2014c). UK Energy in Brief 2014. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/350941/UK_Energy_in_Brief_2014_revised.pdf



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013*; DECC (2010) *Final UK greenhouse gas emissions national statistics: 1990-2008*; CCC analysis. **Notes:** International aviation and shipping data are for 2013.

420. A projection from October 2015 suggests that GHG emissions will fall by 15% between 2014 and 2020, driven largely by a significant reduction in power sector emissions due to the 2020 renewables target and the shift away from coal. Further reductions are also expected in transport due to the impact of the EU new car and van CO_2 targets for 2020, and a partial replacement of oil-based fuels with biofuels.[424]

421. The UK is set to meet its third carbon budget target in 2022. However, maintaining progress beyond this towards the 2050 target will become increasingly difficult. According to DECC, achieving the target set for 2027 and beyond "will be much more challenging". Although primary energy demand is projected to fall 11% over the next 10 years, demand may start to increase again because further improvements in energy efficiency may be unable to offset the impact of economic and population growth.

422. While DECC's future projections assume that current policies to reduce emissions are delivered in full, the CCC noted in their 2014 and 2015 Progress Reports that a number of policies are at risk of failure due to design and delivery problems, or because they are unfunded. These include the Agricultural Action Plan, policies to improve the fuel efficiency of HGVs, the Renewable Heat Incentive post-2016, Zero Carbon Homes and the Renewable Transport Fuels Obligation.

---

[424] It remains to be seen what impact the recent referendum result on Europe will have in terms of EU directives that underpin the UK's emissions reductions targets.

423. The CCC highlights that reaching the 2050 target would require: a) continued take-up of ultra-low emission vehicles and low-carbon heat (e.g. heat networks and heat pumps); b) improved home insulation; and c) *deep* reductions in emissions from electricity generation.[425]

424. The early decarbonisation of the power generation sector and the electrification of end-use sectors from 2030 are deemed critical by the CCC and will require a strong policy framework, including electricity market reform[426] and radical changes in energy vectors including switching from gas to heat pumps for heating.[427] Industry will also need to be decarbonised through increased electrification or combustion of hydrogen from low-carbon sources.

425. The CCC also emphasises the need for investment in developing heat networks, electric vehicle charging networks and potentially, infrastructure for hydrogen applications. Electricity networks will also need to be strengthened to cope with new demands (e.g. from heat pumps) and increasing generation from low-carbon sources. Options deemed to represent good value investments before 2030 include onshore and offshore wind, ground-mounted solar, and nuclear.[428]

426. According to the CCC, carbon capture and storage is "very important in meeting the 2050 target at least cost, given its potential to reduce emissions across heavy industry, the power sector and perhaps with bioenergy, as well as opening up new decarbonisation pathways (e.g. based on hydrogen)".

427. Other themes in the CCC's scenario planning for meeting the 2050 target include: agriculture emissions falling due to changed farming practices (e.g. on-farm efficiencies, improved animal fertility), reduced food waste and adjustment of diet towards less carbon-intensive foods; and a switch to sustainable bioenergy providing around 10% of primary energy in 2050. The CCC assumes that demand for international aviation is likely to grow considerably and that there will therefore need to be strong efficiency improvements in that sector.

The role of gas in generating electricity

428. The CCC's scenarios for the power sector in 2030 includes a role for unabated gas generation to continue. In the CCC's central scenario for the power sector, unabated gas-fired power generation increases to about 38% of supply in the mid-2020s before reducing to 22% by 2030, as CCS starts to play a bigger role. However, according to the CCC, this brief increase in gas consumption for power generation does not require UK shale gas production, as it "could be met through a temporary increase in gas imports, for which the UK already has adequate infrastructure".

---

[425] The Committee on climate change. Fourth Carbon Budget Review – technical report – Chapter 2

[426] Depending on the extent of electrification in transport, heat and other applications, the level of electricity consumption in 2050 could be 50-135% above the level in 2014.

[427] CCC, 2015. The Fifth Carbon Budget – The next step towards a low-carbon economy

[428] CCC, 2015. Power sector scenarios for the fifth carbon budget

429. To effectively decarbonise power, transport and heat generation by 2050, it will be necessary to decarbonise all new investment by 2020 for power with the exception of new gas power stations for back-up and as balancing plant. This makes it important that the UK does not build too many new gas power stations.

430. According to the CCC, to meet the carbon budget targets, the mean carbon intensity for electricity generation needs to be below 100gCO_2/kWh by 2030, and probably as low as 50gCO_2/kWh.[429]

431. Mean carbon intensity for electricity generation was about 450gCO_2/kWh in 2014 and projected to drop to 200-250gCO_2/kWh by 2020. Projections from DECC, released in November 2015, have a central scenario of 100g/kWh in 2030[430], which is at the upper end of the CCC-recommended range. The CCC's own scenario for energy production have also move towards the upper end of the 50-100 gCO_2/kWh range because of delays to new nuclear and CCS projects.[431]

432. Two crucial factors determining the future role of gas are the availability of CCS and the efficiency of gas-fired power stations.

433. Currently, an efficient new-build gas-fired electricity power station (combine cycle gas turbines, CCGT) emits around 345gCO_2/kWh (this figure can be higher depending on the efficiency of the particular plant and whether life-cycle emissions are taken into account). To put this in perspective, the life-cycle emissions for mature renewables and nuclear can be in the region of 5-30gCO_2/kWh.[432] However, a scenario of efficient gas power stations combined with CCS could produce lifecycle emissions of 50-80gCO_2/kWh.[433] [434] [435]

434. According to UKERC, the risk of carbon lock-in needs to be considered with modern CCGT plants having a technical lifetime of at least 25 years and policy measures are needed to ensure that any CCGTs still required by 2040 are either fitted with CCS or operate at much lower load factors.[436]

---

[429] The Committee on climate change. Fourth Carbon Budget Review – technical report – Chapter 2

[430] DECC, 2015. Updated energy and emissions projections: 2015. Nov 18th

[431] CCC, 2015. Power Sector Scenarios for the Fifth Carbon Budget.

[432] Turconi R, Boldrin A, Astrup T (2013) Life cycle assessment (LCA) of electricity generation technologies: overview, comparability and limitations. Renew Sust Energ Rev 28:555–565

[433] Odeh, Hill and Forster, 2013. Current and Future Lifecycle Emissions of Key 'Low Carbon' Technologies and Alternatives. See https://www.theccc.org.uk/wp-content/uploads/2013/09/Ricardo-AEA-lifecycle-emissions-low-carbon-technologies-April-2013.pdf

[434] Hammond GR, Howard HR and Jones CI, 2013. The energy and environmental implications of UK more electric transition pathways. Energy Policy 52, 103-116

[435] CCC, 2015. Power Sector Scenarios for the Fifth Carbon Budget.

[436] McGlade C, Pye S, Watson J, Bradshaw M and Ekins P, 2016. The future role of natural gas in the UK. London: UK Energy Research Centre

The role of gas in generating heat

435. In terms of heat, gas emits approximately 200gCO_2/kWh of heat, a level which also cannot be reconciled with the UK's carbon budget. Consequently, gas has a marginal and rapidly declining role in generating electricity post-2030.

436. Neither DECC nor the CCC have been able to develop low-carbon (~2°C) post-2030 scenarios that maintain a significant role for gas in supplying domestic, commercial and industrial heat.[437]

The future role of gas

437. Following recent modelling work[438] designed to analyse a range of possible future energy scenarios the UK Energy Research Centre, concluded that gas is unlikely to act as a cost-effective 'bridge' to a decarbonised UK energy system except for a short period of time from 2015 till about 2020. For this reason, they suggest that it is more appropriate to characterise gas as "a short-term stop-gap until low- or zero-carbon energy sources can come on stream" and that without CCS, "the scope for UK gas use in 2050 is little more than 10% of its 2010 level". [439]

438. CCS emerges as a critical technology if gas is to have a significant role, consistent with UK carbon reduction targets, out to 2050. *But even with CCS*, because any new gas-fired power stations would need to operate on relatively low load factors, the economic viability of investments in such new gas-fired power stations is questionable and there may be limited cost-effective scope for gas use in power generation beyond 2030.

439. The CCC has also examined the potential role that shale gas may play within future energy scenarios that are compatible with the UK's carbon budgets. In July 2016, it published a report which concluded that "onshore petroleum extraction on a significant scale is not compatible with UK climate targets unless three tests are met".[440] The three tests were:

- Well development, production and decommissioning emissions must be strictly limited.
- Gas consumption must remain in line with carbon budgets requirements.
- Emissions from shale gas wells will need to be offset through reductions elsewhere in the UK economy

440. The CCC's headline conclusions merely state that SGP is safe to develop if it doesn't breach the UK's emissions targets. However, the analysis conducted by the CCC to assess the potential impact of SGP on GHG emissions is worth discussing in some detail.

---

[437] AEA for the CCC. Decarbonising heat in buildings: 2030–2050

[438] Two models were used. One was used to generate a large number of sensitivity scenarios incorporating a variety of technological, resource and price assumptions and key uncertainties about the development of the future energy system. A second was used to project future UK energy use.

[439] McGlade C, Pye S, Watson J, Bradshaw M and Ekins P, 2016. The future role of natural gas in the UK. London: UK Energy Research Centre

[440] CCC, 2016. The compatibility of UK onshore petroleum with meeting the UK's carbon budgets.

441. In order to estimate the possible impact of SGP on GHG emissions, the CCC constructed a model based on a number of scenarios and assumptions that involved a number of variables:

- Global warming potential (GWP) of methane
- Production scenarios (number of wells and rate of well construction)
- Well productivity
- Fugitive emissions rates

442. Methane was assumed to have a GWP100 of 25 which equates to a tonne of methane having the same effect as 25 tonnes of CO_2 over a period of 100 years.

443. To estimate the rate of fugitive emissions, the CCC constructed four regulatory scenarios:

- A 'no regulation' scenario which acts as a baseline.
- A 'current position' scenario which reflects the stated position of the EA regarding the use of RECs.
- A 'minimum necessary regulation' scenario which involves deployment of low cost mitigation options including liquid unloading technologies and semi-annual monitoring of fugitive emissions.
- A 'fuller technical mitigation' scenario which involves deployment of additional mitigation options including electrification of control valves and some compressors.

443. The CCC then produced low, central and high estimates of emissions that might occur under each of these four regulatory scenarios based on various recent bottom-up studies from the US, noting that there is a large range in results and that the applicability of these rates to the UK are questionable.[441] These were calculated for the four regulatory scenarios as follows:

Table B4.4: Range of methane emissions as a percentage of throughput

	No Regulation	Current UK Position	Minimum necessary regulation	Further technical mitigation options
High	4.9%	2.2%	0.9%	0.6%
Central	1.8%	1.3%	0.5%	0.3%
Low	0.7%	0.6%	0.3%	0.2%

Source: Various, with CCC calculations.

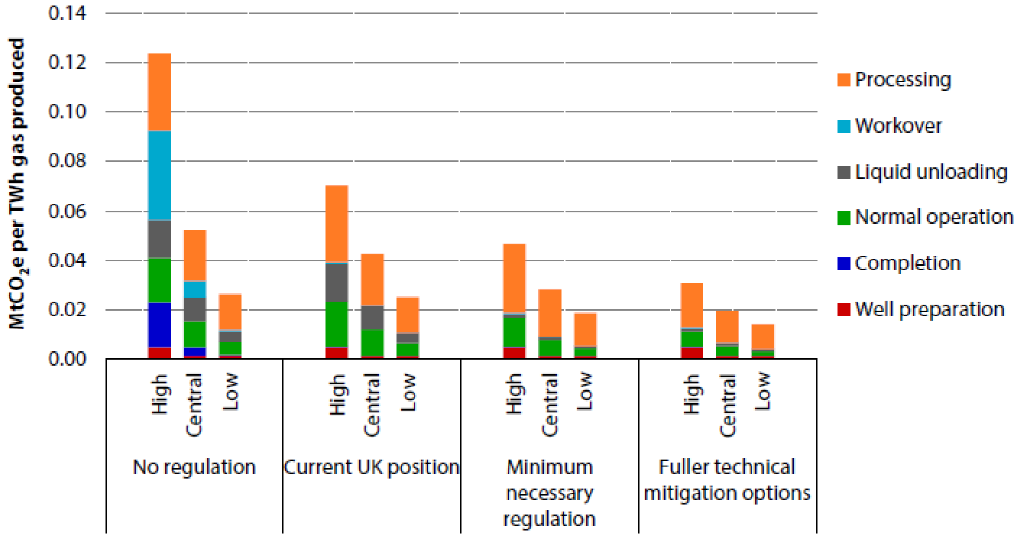
---

[441] The precise estimates used in the CCC's analysis and how these relate to data in the literature are outlined in a supporting annex.

444. The CCC then developed production scenarios based on the number of wells drilled and the productivity of wells in the UK.[442] High levels of productivity mean lower emissions per unit of energy produced (and also lower costs per unit energy), but higher overall levels of emissions.

445. The amount of actual methane emitted is influenced by the type of regulatory framework adopted (and its actual effectiveness in the field), as well as the assumptions made about fugitive emission rates. The diagram below shows the actual amounts of methane emitted into the atmosphere for the four regulatory scenarios with high, central and low assumptions about emissions rates under a 'central' scenario of well productivity.

Figure 4.3: Total emissions with central well productivity assumptions under different regulation cases



Source: CCC analysis.
Notes: Data on per-well emissions (Figure 4.1) and per-TWh emissions (Figure 4.2) have been combined using a central assumption on median well productivity of 0.52 TWh per well.

446. Under high production scenarios, the increase in GHG emissions due to SGP was estimated be 24 MtCO2e/year under the 'current regulation' scenario, 17 Mt in the 'minimum necessary regulation' scenario; and about 10 Mt in the 'fuller technical mitigation' scenario. Under central estimates of production the emissions were estimated to be 11 Mt under the 'Minimum necessary regulation' scenario and 7 Mt in the 'fuller technical mitigation' scenario.

447. Under central estimates for the 'minimum necessary regulation' case it was estimated that additional emissions could be around 27 Mt and 52 Mt over the fourth and fifth carbon budgets respectively.

---

[442] Some emissions scale with the number of wells drilled (e.g. well preparation, completion, liquid unloading and workover), while others scale with the amount of gas produced (e.g. processing and normal operation).

448. The CCC then examined the extent to which these additional GHG emissions could be accommodated within the UK's carbon budgets up to 2030, and concludes that accommodating additional emissions from SGP "may be possible, although it would require significant and potentially difficult offsetting effort elsewhere". However, the room for manoeuvre is limited and should emissions in other sectors extend beyond the proposed 'central' future scenarios developed by the CCC (e.g. uncontrolled expansion of aviation, little or no CCS, or failure to decarbonise heat), it becomes "very unlikely that there would be scope for additional emissions from shale gas exploitation consistent with meeting carbon budgets or the 2050 target".

449. The CCC also state that should the emissions impact of SGP in 2050 be similar to that in 2030, it would be "considerably more difficult and expensive to find ways to offset this". And as with the UK Energy Research Centre, the CCC underlines the critical importance of CCS by noting that "even without additional emissions from onshore petroleum extraction, the absence of CCS is likely to require near-full decarbonisation of surface transport and heat in buildings by 2050.

450. The CCC concludes that while the GHG footprint of SGP is subject to considerable uncertainties, it is clear that "tight regulation with a strong legal foundation" would be needed to shift the estimated range for emissions downwards. However, even if GHG emissions could be reduced, there remain uncertainties about whether SGP is compatible with the UK's GHG emissions reduction targets.

451. The current evidence base suggests that well-regulated domestic production could have an emissions footprint slightly smaller than that of imported liquefied natural gas (LNG).

452. On top of this, it should be noted that certain aspects of the CCC's analysis may be biased in favour of SGP. For example the CCC's use of a GWP100 of 25 for methane has not used the more updated formula of the IPCC's Fifth Assessment which gives methane a GWP100 of 28 *and* 34 to account for the feedback effect of warming in decreasing the effectiveness of natural CO_2 sinks.

453. The CCC has also did not model the impact of SGP over a shorter time horizon which is relevant because methane is a short lived GHG whose global warming effect is more concentrated across a shorter period. While a GWP100 formula overplays the relative importance of methane emissions over a century-scale, it underplays its effect in the near term. Some scientists advocate using a GWP20 formula which would give methane a GWP that is 72 times greater than CO_2 over 20 years. Given the concerns about positive feedback loops associated with global warming, this may be a more appropriate approach to take, or one that should have been used as well as GWP100.

454. The CCC's use of bottom-up studies to estimate fugitive emissions rates may also err on the conservative side given that top-down studies have consistently calculated higher fugitive emissions rates.

455. Finally, while the CCC's report was focused on the potential impact of SGP on the UK's carbon budgets, it is imperative that the impact of SGP is assessed at the global level. The possibility that increased fossil fuel production in the UK might lead to higher overall emissions globally was not explored in the CCC's report (although it planning to do so later in 2016).[443]

456. A final point worth noting is that the CCC's analysis included examining the emissions associated with land-use changes arising from SGP. They noted a lifecycle analysis conducted for the Scottish Government which suggested that land-use change emissions arising from SGP in areas with deep peat soil could be very high[444] and led the CCC to recommend that the development of wells in areas with deep peat soils "should not be allowed".

Q. Carbon Capture and Storage (CCS)

444. Uncertainty remains over whether CCS can be deployed at the scale required, at reasonable cost, and with the required level of effectiveness. The government's withdrawal of support for the development of CCS, may therefore compromise the UK's decarbonisation ambitions.

445. According to the CCC, the government's cancellation of the CCS Commercialisation Programme has raised doubts about the future role of CCS and implies a substantial delay in its deployment at scale. A "significant delay could lead to less feasible CCS deployment over the period to 2050, reducing its role in decarbonisation and implying a lower level of fossil fuel consumption compatible with meeting the 2050 target". The CCC state that "a UK approach to delivery of carbon capture and storage (CCS) is urgently needed".

446. CCS refers to a process involving three main steps: 1) the separation of CO_2 from a gas stream; 2) CO_2 compression and transport (via pipeline or shipping); and 3) CO_2 storage in a suitable geological site (e.g. saline aquifers and depleted oil and gas reservoirs).

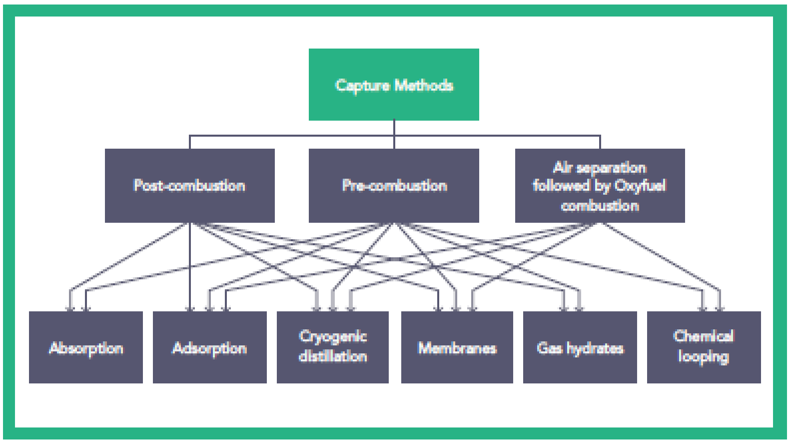
447. CCS technologies are categorised according to the class of capture process (post-combustion, pre-combustion, and oxy-combustion) and type of separation technology (absorption, adsorption, membranes, cryogenic distillation, gas hydrates, and chemical looping).[445]

---

[443] Other issues linked to ongoing gas consumption and carbon budgets, but not specific to SGP, such as fugitive emissions from the storage and transportation of gas and the future use of the gas grid, were also not considered in the CCC report but will be in future reports.

[444] Bond et al. (2014), *Life-cycle Assessment of Greenhouse Gas Emissions from Unconventional Gas in Scotland*, http://www.climatexchange.org.uk/files/2514/1803/8235/Life-cycle_Assessment_of_Greenhouse_Gas_Emissions_from_Unconventional_Gas_in_Scotland_Full_Report_Updated_8.Dec.14.pdf

[445] Budinis, Krevor, MacDowell et al, 2016. Can Technology unlock 'unburnable' carbon? London: Sustainable Gas Institute.



(Source: Budinis, Krevor, MacDowell et al, 2016. Can Technology unlock 'unburnable' carbon? London: Sustainable Gas Institute).

448. Post-combustion capture involves the separation of CO_2 from a flue stream after a fossil fuel has been combusted. Pre-combustion CCS separates CO_2 from a hydrogen-rich gas called syngas prior to combustion. The syngas is obtained by gasification of a fuel. Oxy-combustion capture is characterised by the combustion of a fossil fuel with enriched oxygen which generates a flue stream without impurities, where CO_2 can be separated more easily by condensing the water vapour.

449. CCS can also be combined with Negative Emission Technologies (NETs) such as reforestation, afforestation, agricultural soil carbon storage, biochar and bioenergy with carbon capture and storage (BECCS). BECCS technologies which combine biomass with CCS can be deployed for processes in the bio-refining sector, biofuel sector, power and heat sector, and in industrial processes for the cement, steel and paper sector.

450. The *technical potential* of NETs has been estimated to be 120 $GtCO_2$ until 2050. This would represent an extension of the 2050 carbon budget by 11–13% for a 50–80% probability of remaining below a 2°C temperature increase.[446] Another higher end projection of the future potential of BECCS sees negative GHG emissions being generated by up to 10.4 $GtCO_2e$/yr by 2050.[447]

451. A key issue about CCS and BECCS is the extent to which it is viable and affordable, and the speed at which it can be deployed in light of the shrinking carbon budget available.

452. The International Energy Alliance (IEA) which considers CCS a key option for mitigating CO_2 emissions, highlights the uncertainty of its pace of deployment and concludes that its effect

---

[446] Caldecott, B., et al. (2015). Stranded Carbon Assets and Negative Emissions Technologies. Available online: www.smithschool.ox.ac.uk/research-programmes/stranded-assets/Stranded%20Carbon%20Assets%20and%20NETs%20-%2006.02.15.pdf

[447] Koornneef, J., et al. (2012). Global potential for biomass and carbon dioxide capture, transport and storage up to 2050. *International Journal of Greenhouse Gas Control*, 11, 117–132.

before 2050 is likely to be modest.[448] A proposed IEA roadmap to assist governments and industry to integrate CCS into their emissions reduction strategies suggests CCS being able to store a total cumulative mass of approximately 120 $GtCO_2$ between 2015 and 2050. This is equivalent to about 3.5$GtCO_2$/yr (which is less than 10% of the current annual amount of CO_2e emissions).

453. Questioning the validity of many projections about the future of CCS and BECCS is important given the vast and powerful vested interests involved in maintaining and prolonging the role of fossil fuels in energy systems worldwide.

454. Key barriers to the uptake up of CCS are cost, energy penalty, and location as well as capacity of storage sites.[449] Several barriers are non-technical, including:

- Lack of market mechanism/incentive
- Few effective mechanisms to penalise major CO_2 emitting sources
- Inadequate legal framework allowing transport and storage (both inland and offshore)
- Public awareness and perception.

455. Major potential supply chain constraints include hydrogen turbines for the capture step, pipelines for the transport step, geo-engineers and drilling rigs for the storage step as well as a shortage of petroleum engineers across the full CCS chain.[450] Private investment in CCS is hampered by various risks including technology and construction issues, high up-front capital costs, infrastructure barriers, and operating costs (also affected by a fuel price risk).

456. According to the Global CCS Institute, one major barrier to CCS in the power industry is the high capital cost and 'energy penalty' compared to traditional fossil fuel fired generators. At the moment, a plant with CCS is more expensive (in terms of capital and operating costs) than the same plant without CCS.

457. Reports of the cost of CCS show a great variability, with a lack of data for specific processes or capture technologies. The capture step is the most expensive step of the CCS chain, with a cost of carbon equivalent to 20–110 \$2015/tCO_2. Transport cost ranges between 1.3 and 15.1 \$2015/tCO_2/250km, depending on the location and length of the pipeline. Storage cost depends on the type of storage site and the possible reuse of existing facilities and is between 1.6 and 31.4 \$2015/tCO_2.[451]

---

[448] IEA (2013). Technology Roadmap: Carbon Capture and Storage 2013. Online. Available online: www.iea.org/publications/freepublications/publication/technology-roadmap-carbon-captureand-storage-2013.html

[449] Global CCS Institute (2014). Summary report. http://hub.globalccsinstitute.com/sites/default/files/publications/180928/global-statusccs-2014-summary.pdf

[450] IEAGHG (2012). *Barriers to implementation of CCS: capacity constraints*, Report IEAGHG 2012/09.

[451] Budinis, Krevor, MacDowell et al, 2016. Can Technology unlock 'unburnable' carbon? London: Sustainable Gas Institute

458. Budinis et al hypothesise that the constraint on CCS is not cost related or supply chain related (particularly in later years) but that CCS is not adequately effective in reducing residual emissions to make it a favourable option in climate change mitigation scenarios. Developers have so far focussed on 85–90% capture rates which would not be sufficient with tighter global emission limits. However, higher capture rates from 2050 onwards (even greater than 95%) may lead to natural gas becoming viable again as a safe fossil fuel.

459. Factors determining the feasibility of location and capacity of storage sites include: a) cumulative capacity of carbon storage; b) rates of release and uptake; c) connection from source to store; and d) climate impact of storage timescale.

460. Global geo-storage capacity is believed to be larger than the CO_2 embodied in present-day fossil fuel reserves.[452] However, reservoir pressurisation in saline aquifers will limit the accessible CO_2 geo-storage capacity in the absence of pressure management strategies. The exact fraction of available space has complex dependencies on reservoir, rock, and fluid properties.

461. It is estimated 1,000 Gt of storage capacity is available in oil and gas (hydrocarbon) reservoirs alone which would mean little in the way of storage capacity limits affecting the first generation of commercial CCS deployment in scenarios involving less than 500 Gt of CO_2.

462. A study of sources and sinks shows that CCS will not be constrained by *local* availability of storage resources in North America, Europe and Brazil. Outside these areas, storage availability is uncertain, although the global distribution of sedimentary basins is such that it is possible that there will be few locations where local storage availability will be a limiting factor.[453]

463. Technology Readiness Levels (TRLs) is a metric used to assess the stage of development of new technologies. TRLs range from 1 to 9, where TRL1 means "basic principles observed and reported" and TRL 9 means "actual system flight proven through successful mission operations". According to one study, post-combustion capture processes lie between TRL 1 and TRL 5 (due to the early stages of technology development for this capture process); pre-combustion capture processes are "likely (to be) decades away from commercial reality"; and oxy-combustion processes are "at the early stages of development", without a clear possibility to understand its future development.[454]

464. While post-combustion and pre-combustion capture technologies are widely used, at the moment there is only one full-scale installation of a coal-power plant, the Boundary Dam Carbon Capture Project.[455] According to the Global CCS Institute, there are currently 55 large-scale CCS

---

[452] IEAGHG (2016). *Can carbon capture and storage unlock 'unburnable carbon'?*, Report IEAGHG 2016/05.

[453] Koelbl BS, et al, 2014. Uncertainty in Carbon Capture and Storage (CCS) deployment projections: a cross-model comparison exercise. *Climatic Change*, 123, 461–476.

[454] Rubin ES et al, 2012. The outlook for improved carbon capture technology. *Progress in Energy and Combustion Science*, 38, 630–671.

[455] Budinis, Krevor, MacDowell et al, 2016. Can Technology unlock 'unburnable' carbon? London: Sustainable Gas Institute

projects worldwide in either ‘identify’, ‘evaluate’, ‘define’, ‘execute’ or ‘operate’ stage. However, the total number has reduced from 75 (2012) to 65 (2013) to 55 currently (2014).[456]

465. Policy options to increase the deployment of CCS include: carbon trading or taxation; targeted investment support; feed-in schemes which guarantee a fixed fee; a guaranteed carbon price for CCS; and minimum standards, such as a CCS obligation for new installations.

466. In the UK, government encouragement of CCS has waned. In 2007, the government launched a competition for demonstrating post-combustion capture of CO_2 on a coal-fired power plant. In 2010, the competition was opened to gas and in 2013, two bidders were announced: the White Rose project (a coal-fired power plant) and the Peterhead project (a full-scale gas CCS project). However, in November 2015, the £1 billion ring-fenced capital budget for the CCS Competition was withdrawn by the government.

467. Although CCS appears important in underpinning any role for fossil fuels in the future, CCS has not been adopted to a great extent. For some people, BECCS and reforestation are attractive options for creating negative emissions.[457] However, Estimations of NETs potential until 2100 are affected by great uncertainties, especially with regard to the availability and accessibility of geological storage, and are therefore difficult to estimate. They almost certainly do not offer a viable alternative to mitigation in the coming decades.[458]

Renewable Energy

468. Future scenarios outlined by the CCC include some continued role for fossil fuel in the medium to long term future. But this is heavily dependent on CCS and negative emissions technologies (NETs). The scenarios also highlight the central importance of renewable energy, and nuclear power.[459] [460]

469. The notes presented here do not cover the subject of nuclear energy which produces fewer GHG emissions than fossil fuels, but which carries risks in terms of radioactive waste, accidents and the proliferation of nuclear weapons. The exorbitant costs associated with Hinckley C also point to nuclear energy presenting considerable economic and fiscal threats to society.

470. The contribution of RE to the total energy mix in the UK is growing. The UK has increased its generation from renewables from 25TWh in 2010 to 73TWh in 2015.[461] Currently renewables supply around 20-25% of UK electricity and DECC estimates that they will supply more than 40%

---

[456] Global CCS Institute (2014). Summary report. http://hub.globalccsinstitute.com/sites/default/files/publications/180928/global-statusccs-2014-summary.pdf

[457] van Vuuren D, et al, 2013. The role of negative CO2 emissions for reaching 2 °C - insights from integrated assessment modelling. *Climatic Change*, 118, 15–27.

[458] McLaren D, 2012. A comparative global assessment of potential negative emissions technologies. *Process Safety and Environmental Protection*, 90, 489–500.

[459] International Energy Agency. Energy technology perspectives 2012. IEA, Paris; 2012

[460] International Energy Agency. Coal medium-term market report 2012. IEA, Paris; 2012

[461] DECC, 2015. Updated energy and emissions projections. Annex J

by 2030.[462] In the National Grid's 2015 projection of the UK's Future Energy Scenarios, RE supplies 11-30% of the annual power demand by 2030.[463] [Note: More recent FESs are now available.]

471. However, groups such as Friends of the Earth believe that an electricity mix comprising over 75% renewables by 2030 would be a feasible and more appropriate target.

367. The industry-funded Task Force on Shale Gas has argued that we should embrace "a long term evolutionary approach" towards renewable energy, rather than "a short term revolution". The reasons they give for this slow approach include: a) inadequate grid infrastructure for absorbing wind, tidal and wave energy; b) public disapproval of bigger onshore transmission pylons; c) investors having limited funds; d) renewable energy being economically unviable; e) the intermittency of RE; f) RE technology being under-developed and socially unacceptable.

472. However, according to the CCC, it will be possible "to ensure security of supply in a decarbonised system with high levels of intermittent and inflexible generation".[464] Parts of the solution include achieving greater inter-connection to systems beyond the UK; making it easier for energy demand to respond more effectively and efficiently to short-term price signals; increasing the capacity for electricity storage; and ensuring that back-up capacity is flexible enough to increase generation without having to run part-loaded.

473. Two studies used by the CCC indicate that the UK could generate over 80% of electricity demand from renewables without jeopardising security of supply, through the use of storage, interconnectors and demand side management.[465] [466]

474. Renewables are providing electricity at increasingly lower costs. Recent agreed contracts for future power (Contracts for Difference) signed by onshore wind and solar (£79/MWh for 15 years), and offshore wind (£115/MWh for 15 years) are already cheaper than new nuclear (£92.50/MWh for 35 years).[467] Offshore wind's cost is also falling fast; and projected to cost less than £100/MWh by 2020.[468] The CCC say onshore wind and large-scale solar will be cheaper than new gas which pays its pollution costs before 2025.[469] Furthermore, since wind and solar produce electricity at zero marginal cost, they have the potential to lower electricity prices.[470]

---

[462] DECC, 2015. Updated energy and emissions projections. Annex J

[463] National Grid. (2015). UK Future Energy Scenarios; UK Gas and Electricity Transmission. Available at: http://investors.nationalgrid.com/~/media/Files/N/National-Grid-IR/reports/future-energy-scenarios-2015.pdf

[464] CCC, 2015. Power sector scenarios for the fifth carbon budget

[465] Garrad Hassan, 2011. UK generation and demand scenarios for 2030. March.

[466] Poyry, 2011. Analysing technical constraints to renewable generation to 2050.

[467] CCC, 2015. Power Sector Scenarios for the 5th Carbon Budget. Box 4.1

[468] Catapult, 2015. Cost of wind energy falls sharply. Feb 26th

[469] CCC, 2015. Power Sector Scenarios for the 5th Carbon Budget.eg Figure 2

[470] Good Energy, 2015. Wind and solar reducing consumer bills.

475. The CCC notes that the rate and extent of change needed to stay within our carbon budget indicates a need for much greater efforts to reduce our consumption of energy as well as rapidly expanding on the delivery of renewable energy.

476. The feasibility of moving rapidly towards a decarbonised energy system has been substantiated by other studies. Two studies for the states of New York[471] and California[472] have demonstrated the possibility of moving towards an economy driven totally by RE sources (largely solar and wind) in a cost-effective way using technologies that are commercially available today within the next 15-35 years.

Overall energy consumption and energy efficiency

477. Given the context of climate change, consuming less energy may be better than seeking new sources of fossil fuels.

478. Reduced levels of energy consumption may be achieved in part through improvements in energy, although this may not be the case if money 'saved' through energy efficiency is then spent on further energy services. This is a phenomenon referred to as "Jevons' paradox" " or the 'rebound effect.'

479. Nonetheless, there are clearly opportunities for reducing both overall energy consumption and improving efficiency.

480. Most energy services are highly inefficient. For example, cars in the UK street have emissions of over 160gCO_2/km on average, even though there are over 200 model variants of standard-engine cars (i.e. not electric or hybrid) with emissions of under 100gCO_2/km being sold at little to no price premium. Televisions and IT equipment have huge variations in energy consumption for essentially the same level of service. An A rated refrigerator consumes in the region of 80% more energy than an A+++ alternative; again at very little price penalty. A vast amount of the UK housing stock has an Energy Performance Certificate rating of D or below.

481. A Green Alliance report that describes the failure of the UK to harness the potential for saving electricity proposes a strategy to create incentives for companies to benefit from energy efficiency measures by making two changes to the electricity market: a) a 'negawatts feed-in tariff' paid on the basis of avoided energy consumption, with recipients competing in an auction to deliver energy savings in homes and businesses at lowest cost; and b) opening the capacity market to competition from demand-side response and energy demand reduction on an equal basis with electricity generation.[473]

---

[471] Jacobson MZ, Howarth RW, Delucchi MA, et al. Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight. *Energy Policy*. 2013;57:585–601

[472] Jacobson MZ, Delucch MA, Ingraffea AR, et al. A roadmap for repowering California for all purposes with wind, water, and sunlight. *Energy*. 2014;73:875–889.

[473] Green Alliance, 2015. Getting more from less

Energy security

477. One of the important arguments in favour of SGP is that it will improve the UK's energy security. *This is a complex topic which is deal with here in incompletely and briefly, and will be expanded in due course.*

478. Energy security typically has two dimensions: having enough energy to meet need and demand; and avoiding being overly-reliant on other countries for energy.

479. Since 1999, there has been a sharp rise in fossil fuel imports in the UK. The highest level of imported energy since 1974 was reported in 2013 due to an ongoing decline in domestic oil and gas production. Nearly half of the UK's net energy supply came from imports.[474]

480. Currently, about 46% of the UK's natural gas comes from the North Sea. The remainder is imported from Norway (about 30%), the Netherlands (about 8%) and Belgium (about 4%).The remaining 20% of imported gas is liquefied natural gas (LNG), mainly from Qatar.[475] [476]

481. According to estimates of recoverable shale gas reserves, SGP could help eliminate the UK's reliance on gas imports. However, this would require a large onshore gas industry: Bloomberg New Energy Finance estimated in 2013 that eliminating imports would require the drilling of around 10,000 wells over a 15-year period, based on optimistic assumptions for flow rates. A lower flow rate might mean up to 20,000 wells, draining an area twice the size of Lancashire.[477]

482. One aspect of 'energy security' is the affordability of energy. The hope that SGP in the UK will reduce gas prices, as it did in the US, has been shown to be unlikely because of the integrated nature of the gas market in Europe. However, a domestic gas industry could reduce dependence on imports (if sufficient quantities of gas can be produced) and impact positively on national balance of payments issues.

The economics of the energy sector more generally

483. The economics of the energy sector is an important dimension of any debate about the energy mix of the future, here in the UK and elsewhere.

---

[474] Department of Energy and Climate Change. (2014c). UK Energy in Brief 2014. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/350941/UK_Energy_in_Brief_2014_revised.pdf

[475] Department of Energy and Climate Change. (2014c). UK Energy in Brief 2014. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/350941/UK_Energy_in_Brief_2014_revised.pdf

[476] Department of Energy and Climate Change. (2014d). UK Energy Statistics. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296183/pn_march_14.pdf

[477] Bloomberg New Energy Finance, 2013. UK shale gas no "get out of jail free card". Feb 21st

484. Crucially, the fossil fuel industry is heavily subsidised.[478] According to the IMF, pre-tax subsidies to the fossil fuel sector have declined from about 0.7% of global GDP in 2011 to about 0.4% in 2015. This still amounts to a large subsidy of about 333 billion. The estimated post-tax subsidy to fossil fuels is much larger and was calculated to be about 6.5% of global GDP in 2015 ($5.3 trillion). About three-quarters of the post-tax-subsidy are from the externalisation of the costs of air pollution and a quarter is from the externalisation of the costs of global warming.[479]

485. For petroleum, total subsidies were broken down as follows: externalised costs of congestion, accidents and road damage (39%); pre-tax subsidies (17%); global warming (13%), air pollution (18%), and foregone consumption tax revenue (14%). For natural gas, total subsidies were broken down as follows: global warming (53%), pre-tax subsidies (26%), and forgone consumption tax revenue (10%).[480]

486. Energy subsidies for the fossil fuel sector currently damage the environment; cause premature death through local air pollution; exacerbate congestion and other adverse side effects of vehicle use; increase GHG concentrations; impose large fiscal costs on taxpayers; discourage investments in energy efficiency, renewables, and more efficient energy infrastructure; and increase the vulnerability of countries to volatile international energy prices.

487. According to the IMF, the removal of post-tax energy subsidies could reduce premature deaths from local air pollution by more than 50% and generate a substantial fiscal dividend in government revenues, estimated at $2.9 trillion (3.6% of global GDP) in 2015.[481]

488. The Stern Review called the market externality of GHG emissions in the global economy “the greatest and widest-ranging market failure ever seen”.[482] In addition, it describes how it would be cheaper to prevent GHG emissions than to manage the effects of global warming.

489. Another aspect of market failure in the energy sector is the lack of large-scale ‘positive investment’ in a clean energy system.

490. For new technologies in the earlier stages, concerted R&D efforts are required.[483] Such efforts may be analogous to the Manhattan Project for nuclear technology, the Apollo Program for space flight, or the Marshall Plan for the post-war reconstruction of Europe.

---

[478] Victor, D. The politics of fossil-fuel subsidies: global subsidies initiative & the international institute for sustainable development. Global Subsidies Initiative, International Institute for Sustainable Development, Geneva; 2009

[479] Coady D, Parry I, Sears L and Shang B, 2015. How Large Are Global Energy Subsidies? Washington DC: IMF.

[480] Coady D, Parry I, Sears L and Shang B, 2015. How Large Are Global Energy Subsidies? Washington DC: IMF.

[481] Coady D, Parry I, Sears L and Shang B, 2015. How Large Are Global Energy Subsidies? Washington DC: IMF.

[482] Stern, N. Stern Review on the economics of climate change. HM Treasury, London; 2006

[483] Mazzucato, M. The entrepreneurial state: debunking public *vs* private sector myths. Anthem Press, London; 2013

491. Many climate adaptation measures that require capital-intensive investments and which have uncertain prospects for direct and immediate returns also require public finance because private finance will not be interested.[484]

492. The IEA estimated that to have an 80% chance of remaining on a 2°C stabilisation pathway, *additional* cumulative investment of $36 trillion is required by 2050, roughly $1 trillion per year (in the order of 1% GDP under moderate growth assumptions), with low-carbon technologies and energy efficiency accounting for around 90% of energy system investment by 2035 (currently, this value is around 23%).[485] Another estimate has suggested a lower value of $270 billion per year.[486]

493. In 2013, only 0·1% of institutional investor assets (excluding sovereign wealth funds) were in low-carbon energy infrastructure projects ($75 billion).[487]

494. There are many policy options available for correcting market failures in the energy sector. Taxes on energy products (such as transport fuels) can applied to shape the pattern of energy demand so that it is aligned to carbon budgets. Corrective taxation that internalises CO_2 emissions, air pollution, and transport-related externalities (such as congestion and accidental injury) arising from fossil fuel could also raise additional revenues of 2·6% GDP globally, whilst simultaneously reducing CO_2 emissions by 23% and pollution-related mortality by 63%.[488]

495. Carbon pricing can also better internalise the costs of social and environmental damage of fossil fuels and help establish the market signals required to disincentivise continued fossil fuel use.

496. By increasing the burden of taxation on environmentally damaging activities and reducing it on desired inputs, such as labour, an increase in energy prices could in principle be neutralised from a macroeconomic perspective. Although fossil-fuel subsidies and the presence of externalities tend disproportionately to benefit the wealthiest in society (in both national and international contexts), the introduction of carbon pricing and the removal of fossil fuel subsidies may be regressive, as the poorest in society spend a greater proportion of their disposable income on energy. Additional fiscal interventions will therefore be required to protect low-income or vulnerable households.

---

[484] See, for example: Mariana Mazzucato, 2013. The Entrepreneurial State: debunking public vs. private sector myths. London: Anthem Press.

[485] International Energy Agency. World energy outlook. IEA, Paris; 2012

[486] The New Climate Economy. Better growth, better climate. The Global Commission on the Economy and Climate, New York; 2014

[487] Kaminker, C, Kawanishi, O, Stewart, F, Caldecott, B, and Howarth, N. Institutional investors and green infrastructure investments: selected case studies. Organization for Economic Co-operation and Development, Paris; 2013

[488] Parry, IWH, Heine, D, and Lis, E. Getting the prices right: from principle to practice. International Monetary Fund, Washington, DC; 2014

497. Additionally, feed-in tariffs (FiTs), used in the electricity sector to provide a guaranteed rate of return to low-carbon generators, have been shown to be an effective policy instrument that has helped install a large proportion of existing global renewable power capacity.

498. Other interventions to correct market failure in the energy sector include demand-side regulation such as mandatory energy efficiency standards and supply-side prohibition such as the prohibition of unabated coal burning. Examples of the former include a cap on CO_2 emissions from passenger cars per kilometre driven, or on the annual energy consumption of a new building per unit of floor area. Other examples of the latter include technology standards can also be employed to proscribe the use of certain components in products, or prevent the sale of the least efficient models of a product type.

499. The global picture of heavy subsidisation of fossil fuel and under-investment in clean energy is apparent in the UK. National pre-tax subsidies to fossil fuel production have been estimated at an annual average of $9 billion in 2013 and 2014.[489] In the 2015 Budget, Chancellor George Osborne awarded a further £1.3b in tax cuts to the oil industry.[490]This makes the UK one of the few G20 countries that is *increasing* its fossil fuel subsidies.[491]

500. At the same time, the UK is cutting back on incentives for private investment in renewable energy investments, whilst implementing tax reforms that would make renewable energy generators pay more tax.[492] As noted earlier, the government largely removed support from solar power in 2015 (causing the loss of up to 18,700 jobs).[493]

501. The large subsidisation of fossil fuel continues despite the government agreeing with the IPCC and other international bodies that the removal of subsidies from the fossil fuel industry is important. At the 2014 climate summit in New York, David Cameron himself described fossil fuel subsidies as “economically and environmentally perverse", as they “distort free markets and rip off taxpayers”.[494]

502. At the same time, oil companies in the UK North Sea that have made vast profits (33% rate of return) from 2008 and 2014 have paid relatively little in the way of tax. According to Platform,

---

[489] Bast E, Doukas A, Pickard S, van der Burg L and Whitley S, 2015. Empty promises: G20 subsidies to oil, gas and coal production. London: Overseas Development Institute and and Oil Change International.

[490] See here: http://platformlondon.org/wp-content/uploads/2016/03/NorthSea_Oil_Tax_Facts.pdf

[491] See, for example, here:
- https://www.theguardian.com/environment/2015/nov/12/uk-breaks-pledge-to-become-only-g7-country-increase-fossil-fuel-subsidies
- http://www.telegraph.co.uk/finance/newsbysector/energy/10189932/George-Osborne-pledges-most-generous-tax-regime-for-shale-gas.html
- http://www.neweconomics.org/blog/entry/the-looking-glass-world-of-fossil-fuel-subsidies

[492] See here: http://www.ey.com/Publication/vwLUAssets/EY-RECAI-47-May-2016/$FILE/EY-RECAI-47-May-2016.pdf

[493] Calculations show that industries like wind, wave and tidal and could employ 40,000 more North Sea workers than the existing fossil economy.

[494] See here: http://blueandgreentomorrow.com/2014/09/24/un-climate-summit-cameron-calls-for-ending-fossil-fuel-subsidies-and-a-strong-climate-deal-in-paris/

the UK takes a lower share of revenue from its oil resources than most other countries. On average, governments receive 72% of net revenue from oil production, compared to 50% from most UK fields. Norway, operating in the same fields in the North Sea, takes 78%.[495]

T. Broader Development Policy and Co-Benefits of CC Mitigation

503. Transforming the global economy within the required timescale demands unprecedented action in both industrialised and developing countries. According to the Lancet-UCL Commission, industrialised countries need to embark immediately on CO_2 reduction programmes "with a high level of ambition". Put another way, transition to a low-carbon energy infrastructure implies a radical transformation of not just the energy sector, but the behaviours and consumption patterns that feed off our burning of fossil fuel.

504. The Lancet-UCL Commission on Climate Change and Health also noted that transition to a low-carbon infrastructure "requires challenging the deeply entrenched use of fossil fuels". Decarbonisation and reducing energy demand is not a simple challenge of cleaning up pollutants or installing new equipment: it requires systemic transformations of energy infrastructures and associated systems.

505. A collective political, policy and scientific failure is exemplified by the recent expansion of coal use across the world that reversed the global pattern through most of the 20th century of shifting towards less carbon intensive and less polluting fossil fuels.

506. The fact that global emissions have risen over the past decade demonstrates a remarkable inability to respond effectively and collectively to the threat of climate change. It also demonstrates that most of our institutions are built around narrow, short-term horizons, and vested interests; and that we are locked into a model of economic growth that is centred around material consumption and tied to fossil fuel.[496]

507. Other reasons why effective action has been prevented include the fact that climate science is complex and unavoidably involves a degree of uncertainty which creates room for equivocation and misunderstanding,[497] and that climate change is psychologically distant in temporal, social and geographic terms for many people which dampens concern and willingness to act.[498]

---

[495] See here: http://platformlondon.org/wp-content/uploads/2016/03/NorthSea_Oil_Tax_Facts.pdf

[496] Unruh, GC. Understanding carbon lock-in. Energy Pol. 2000; 28: 817–830

[497] Hulme, M. Why we disagree about climate change: understanding controversy, inaction and opportunity. Cambridge University Press, Cambridge; 2009

[498] Spence, A, Poortinga, W, and Pidgeon, N. The psychological distance of climate change. Risk Anal. 2012; 32: 957–972

508. Finally, as noted by the Lancet-UCL Commission, “the active promotion of misinformation, motivated by either ideology or vested economic interests” has hindered effective action.

509. In the past two decades, much of the bold and innovative policy-making to address climate change have been driven at the level of cities, which have created the platform for new advocacy coalitions and even for new cross-border para-diplomatic links (e.g. through Local Governments for Sustainability, the World Mayors Council on Climate Change and the Climate Leadership Group).[499] [500], [501] [502] These experiences point to the emerging importance of sub-national leaders in global environmental governance.[503]

510. As a wealthy nation with a skilled workforce and a world-leading renewable energy resource base, choosing to develop a new fossil fuel industry would not only threaten to break our national targets to reduce GHG emissions, but also damage the UK’s international reputation and undermine the delicate negotiations being undertaken to strengthen international resolve to prevent runaway global warming and climate collapse.

511. Although the primary reason for decarbonising of our energy system is to mitigate climate change, various positive social, ecological and health dividends could also arise.

512. Several links between climate mitigation practices and technologies and improved health and wellbeing have been established.[504] [505] From a global perspective, crop yields have much to gain from the mitigation of short lived climate pollutants such as methane, black carbon, hydrofluorocarbons, and tropospheric ozone.[506]

513. The health benefits of reduced air pollution in the EU alone (to mitigate climate change) have been valued at €38 billion a year by 2050.[507] Another estimate suggests that a doubling of RE use from 2010 to 2030 could avoid up to $230 billion of external health costs annually by

---

[499] Roman, M. Governing from the middle: the C40 Cities Leadership Group. Corp Gov. 2010; 10: 73–84

[500] Bulkeley, H. Betsill. M. Cities and climate change: urban sustainability and global environmental governance. Routledge, New York; 2003

[501] Boutiligier, S. Cities, networks, and global environmental governance. Routledge, London; 2013

[502] Curtis, S. Global Cities and the Transformation of the International System. Rev Int Stud. 2011; 37: 1923–1947

[503] Gordon, DJ. Between local innovation and global impact: cities, networks, and the governance of climate change. Can Foreign Pol J. 2013; 19: 288–307

[504] Proust, K, Newell, B, , H et al. Human health and climate change: leverage points for adaptation in urban environments. Int J Environ Res Public Health. 2012; 9: 2134–2158

[505] Shaw, MR, Overpeck, JT, and Midgley, GF. Cross-chapter box on ecosystem based approaches to adaptation—emerging opportunities. in: CB Field, VR Barros, DJ Dokken, (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA; 2014: 101–103

[506] Scovronick, N, Adair-Rohani, H, Borgford-Parnell, N et al. Reducing global health risks through mitigation of short-lived climate pollutants: scoping report for policymakers. World Health Organization and Climate and Clean Air Coalition, Geneva; 2015

[507] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: a roadmap for moving to a competitive low carbon economy in 2050. European Commission, Brussels; 2011

2030 globally.[508] Similarly, it has been estimated that the health benefits of reducing methane emissions in industrialised nations would exceed the abatement costs even under the least aggressive mitigation scenario.[509]

514. Clearly, there are potential risks from decarbonisation and policies and technologies aimed at reducing energy consumption such as reduced access to energy and unintended consequences caused by poorly designed home insulation improvements.[510]

515. Policies that encourage active travel (eg, walking and cycling) would produce significant reductions in cardiovascular disease, dementia, obesity, diabetes, several cancers, and in the duration and severity of depressive episodes.[511] [512] One study estimates that increased levels of active travel coupled with increased fuel efficiency in the UK's urban areas could lead to a cumulative net saving to public funds of more than £15 billion by 2030, whilst achieving GHG reductions of over 15% in the private transport sector.[513]

516. In the UK, retrofits aimed at improving the energy performance of houses could offer substantial health benefit provided adequate ventilation to control indoor pollutants is installed. Increased energy efficiency will also help reduce fuel poverty, limit excess winter mortality rates, and reduce respiratory illness in children.[514] Nicol and colleagues estimated that improved housing in England alone could save the NHS more than €700 million per year in treatment avoidance.[515]

517. According to Copenhagen Economics, improvements in housing energy efficiency in Europe would produce both energy and healthcare savings, and reduce public subsidies for energy consumption by €9–12 billion per year.[516] A modelling study by Hamilton et al. assesses the potential health benefits of 5.3m loft insulations, 6.5m solid wall insulations, 5.7m cavity wall

---

[508] International Renewable Energy Agency. REmap 2030: a renewable energy roadmap. IRENA, Abu Dhabi; 2014

[509] West, J, Fiore, A, and Horowitz, L. Scenarios of methane emission reductions to 2030: abatement costs and co-benefits to ozone air quality and human mortality. Clim Change. 2012; 114: 441–461

[510] Davies, M and Oreszczyn, T. The unintended consequences of decarbonising the built environment: a UK case study. Energy Build. 2012; 46: 80–85

[511] Woodcock, J, Edwards, P, Tonne, C et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. 2009; 374: 1930–1943

[512] Patz, JA, Frumkin, H, Holloway, T, Vimont, DJ, and Haines, A. Climate change: challenges and opportunities for global health. JAMA. 2014; 312: 1565–1580

[513] Jensen, HT, Keogh-Brown, MR, Smith, RD et al. The importance of health co-benefits in macroeconomic assessments of UK greenhouse gas emission reduction strategies. Clim Change. 2013; 121: 223–237

[514] Liddell, C and Morris, C. Fuel poverty and human health: A review of recent evidence. Energy Pol. 2010; 38: 2987–2997

[515] Nicol, S, Roys, M, Davidson, M, Ormandy, D, and Ambrose, P. Quantifying the economic cost of unhealthy housing—a case study from England. in: M Braubach, DE Jacobs, D Ormandy (Eds.) Environmental burden of disease associated with inadequate housing: a method guide to the quantification of health effects of selected housing risks in the WHO European Region. World Health Organization Regional Office for Europe, Copenhagen; 2011: 197–208

[516] Copenhagen Economics. Multiple benefits of investing in energy efficient renovation of buildings: impact on public finances. Renovate Europe, Copenhagen; 2012

insulations, 2.4m double-glazing installations, 10.7m high-efficiency condensing boiler installations and several ventilation system installations.[517]

518. While a transition to a decarbonised energy and economic system would affect employment in fossil fuel-related and emission-intensive industries, low-carbon technology industries would, over time, expand and increase employment. IRENA estimate a net global increase of 900 000 jobs in core activities alone (i.e. not including supply chain activities) if the level of renewable energy in global final energy consumption doubles from 18% in 2010 to 36% of by 2030.[518]

---

[517] Hamilton IG, Milner J, Chalabi Z, et al. The health effects of home energy efficiency interventions in England: a modelling study. BMJ Open 2014; 5 (4).

[518] International Renewable Energy Agency. REmap 2030: a renewable energy roadmap. IRENA, Abu Dhabi; 2014

Acknowledgements

These notes were compiled by David McCoy and Alice Munro of Medact.

Thanks to Patrick Saunders (independent Public Health specialist), Dave Powell (New Economics Foundation, Jo Hawkins (Sheffield University), Grant Allen (University of Manchester) and Michael Bradshaw (UK Energy Research Council) for making helpful comments and observations.

Responsibility for the manuscript, including errors and omissions, lie entirely with the primary authors.