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Fugitive emissions of methane from abandoned, decommissioned oil and gas wells

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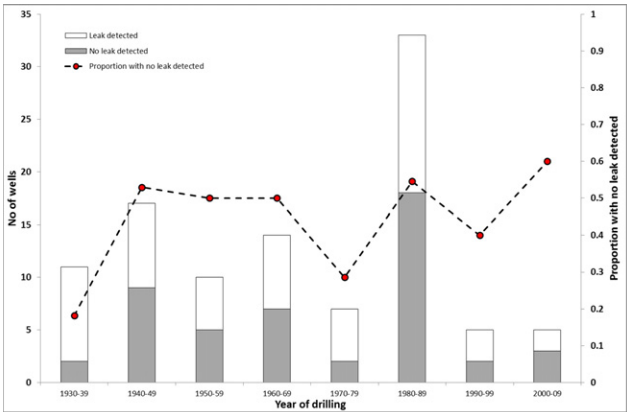
HIGHLIGHTS

- This study considered the fugitive emissions from former oil and gas wells.
- 30% had CH4 at the soil surface that was significantly larger than their respective control.
- 39% of well sites had significant lower surface soil gas CH4 than their respective control.
- Where integrity failure occurred it appeared within a decade of well decommissioning.
- Flux of CH4 from wells was 364 ± 677 kg CO_{2eq}/well/yr with a chance that a well was a net sink.

GRAPHICAL ABSTRACT



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ABSTRACT

This study considered the fugitive emissions of methane (CH_4) from former oil and gas exploration and production wells drilled to exploit conventional hydrocarbon reservoirs onshore in the UK. This study selected from the 66% of all onshore wells in the UK which appeared to be properly decommissioned (abandoned) that came from 4 different basins and were between 8 and 79 years old. The soil gas above each well was analysed and assessed relative to a nearby control site of similar land use and soil type. The results showed that of the 102 wells considered 30% had soil gas CH_4 at the soil surface that was significantly greater than their respective control. Conversely, 39% of well sites had significant lower surface soil gas CH_4 concentrations than their respective control. We interpret elevated soil gas CH_4 concentrations to be the result of well integrity failure, but do not know the source of the gas nor the route to the surface. Where elevated CH_4 was detected it appears to have occurred within a decade of it being drilled. The flux of CH_4 from wells was 364 ± 677 kg CO_{2eq}/well/year with a 27% chance that the well would have a negative flux to the atmosphere independent of well age. This flux is low relative to the activity commonly used on decommissioned well sites (e.g. sheep grazing), however, fluxes from wells that have not been appropriately decommissioned would be expected to be higher.

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1. Introduction

There are numerous environmental concerns surrounding the oil and gas industry, including the production and discharge of wastewater leading to environmental violations (Manda et al., 2014); the fugitive emission of CH_4 to the atmosphere (Caulton et al., 2014; Miller et al., 2013); and contamination of groundwater supplies (Rivard et al., 2014). It has been suggested that hydraulic fracturing, as a means of exploiting unconventional hydrocarbon resources, could be a cause of elevated CH_4 concentrations in groundwater (Osborn et al., 2011), yet it has been argued that rather than being caused by hydraulic fracturing, groundwater contamination could have been caused by other processes, one of which is well integrity failure (Davies, 2011). Well integrity refers to the zonal isolation of liquids and gases (King and King, 2013) and failure occurs when cement and/or casing barriers fail, causing a loss of zonal isolation that creates pathways for the migration of fluids, including CH_4, to groundwater, surface water and the atmosphere (Ingraffea et al., 2014). Oil and gas wells are typically constructed with multiple barriers to maintain well integrity and prevent leaks, thus well integrity failure is a consequence of complete barrier failure (King and King, 2013). Darrah et al. (2014) determined well integrity failure was the likely cause of groundwater contamination of drinking water wells overlying Marcellus and Barnett shales by CH_4 due to faulty casings and migration of hydrocarbons along the well annulus because of cement failure. Vengosh et al. (2014) also identified well integrity failure as one of the four possible risks from unconventional shale gas production to water quality and that includes well failure during and after operation and includes the risk from CH_4 leaking into groundwater. A loss of well integrity is important because it represents an uncontrolled release of fluids – whether liquid or gas – which could pose a risk to groundwater supplies and air quality. Where there is a catastrophic loss of well integrity it can cause fatalities for those close to the site. Given that natural gas is predominantly composed of CH_4, its leakage can have important consequences given its global warming potential of 24 over a 100 year timescale (Myhre et al., 2013).

There are multiple causes of a loss of well integrity. Jackson (2014) suggested that faulty casing and cementing were the cause of most leaks, with casing leaking at connections or where it has been damaged from acid corrosion. Cement can shrink (Dusseault et al., 2000) and develop cracks or channels (Jackson, 2014). Poor cement bonding between the casing and borehole has been cited as another mechanism by which wellbores lose integrity (Calosa et al., 2010; Ziemkiewicz et al., 2014) and cement bonds can deteriorate due to pressure and temperature cycling (Chilingar and Endres, 2005). Based upon the works of Celia et al. (2005); Davies et al. (2014) indicated there were seven routes by which fluid can leak from oil and gas wells: (1) between cement and surrounding rock formations; (2) between casing and surrounding cement; (3) between cement plug and casing or production tubing; (4) through cement plug; (5) through the cement between casing and rock formation; (6) across the cement outside the casing and then between the cement and the casing; and (7) along a sheared wellbore. King and King (2013) suggested that to prevent well failure pressure, temperature and corrosive environments should be properly assessed during the design phase of wells. Furthermore, Ziemkiewicz et al. (2014) argued that action to prevent integrity failure should be made appropriate to the local geology.

Reported well integrity failure rates have varied between studies. For example Erno and Schmitz (1996) found of 435 wells tested for surface casing vent leakage, 22% were leaking. Chilingar and Endres (2005) found 75% leak rates of 50 wells studied in the Santa Fe Springs oilfield which was drilled in the 1920s. Watson and Bachu (2009) analysed data from 316,439 wells drilled between 1910 and 2004 for surface casing vent flow (SCVF) through wellbore annuli and soil gas migration (GM) in Alberta and determined that 4.6% of wells suffered from surface casing vent flow or gas migration. They found that the most important cause in determining wellbore failure rates was uncemented casing.

Various estimates exist of well integrity failure in Pennsylvania. Using notices of violation from the Pennsylvania Department of Environmental Protection between January 2008 and August 2011, Considine et al. (2013) determined that of 3533 wells drilled, 2.6% experienced well integrity failure. This included four instances of blowout and venting, two instances of gas migration and 85 cement and casing violations wherein gas migration was observed. Using a similar dataset but between 2008 and March 2013, Vidic et al. (2013) found a failure rate of 3.4% from 6466 wells. Ingraffea et al. (2014) assessed 32,678 producing oil and gas wells between 2000 and 2012, finding 1.9% lost integrity during that period. Beyond the well integrity failure rate, Ingraffea et al. (2014) found that unconventional wells had six times the number of cement and casing issues compared to conventional wells. Age was also likely to increase risk of failure, with the risk increasing by 18% with each additional inspection. There were geographic factors affecting hazard risk as well, with wells drilled in north east Pennsylvania 8.5 times as likely to experience problems compared to the rest of the state. Jackson (2014) suggested that local geology and different drilling practices may have been the cause of the geographical differences in hazard risk.

Davies et al. (2014) assessed 8030 wells in Pennsylvania, indicating 6.26% had well barrier or integrity failure and 1.27% leaked to the surface. Compiling a review of all the available published sources of well barrier and integrity failure rates, Davies et al. (2014) unsurprisingly found a significant range of 1.9–75%. In the UK, of the 143 active onshore wells, only two confirmed cases of well integrity failure were found yet no monitoring of abandoned wells takes place and Davies et al. (2014) called for surveying of abandoned wells to be conducted to determine whether abandoned wells show higher rates of well integrity failure than can be determined currently. Here the term abandoned is technically correct and consistent with the literature on the subject (e.g. Davies et al., 2014). In most UK cases an abandoned well is defined as those that have been cut-off, sealed and then buried under soil and in the UK this means ~2 m of soil — in most circumstances an abandoned well might better be referred to as a decommissioned well.

Overtime it is expected that the condition of abandoned wells will deteriorate (Miyazaki, 2009) and Bishop (2013) stated that because of deterioration of well casings and cement over time, it is necessary to ensure that wells are not only properly plugged and abandoned but inspected and repaired when necessary. Post 1995, oil and gas wells in Alberta, Canada, have to undergo testing for SCVF and GM prior to final abandonment, for which wells are cut and capped (Watson and Bachu, 2009).

Little is known about the long-term integrity of abandoned wells in the UK. Of 2024 onshore wells in the UK included in the analysis of Davies et al. (2014), 65.2% were not visible as they were sealed, cut and the land reclaimed, while the remaining sites (34.8% of all known wells) retained some degree of evidence of previous drilling activity at the surface. Davies et al. (2014) suggested that surveying soils above abandoned well sites would be an important step in establishing whether there was a loss of integrity and fluid migration following well abandonment.

The aim of this study was therefore to assess whether abandoned, but properly decommissioned, wells represented an ongoing source of CH_4 to the atmosphere. The wells studied could have been exploration dry holes where no hydrocarbons were found or long-term production wells.

2. Methodology

This study selected 103 wells from across the 4 onshore UK oil and gas basins with proven oil and gas accumulations where there was more than one productive well (Fig. 1). The wells within each basin were chosen to give a range of conditions and to span the range of possible well ages (i.e. to include the oldest as well as the youngest available). One hundred and three wells were measured in this study, 102