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An assessment of the footprint and carrying capacity of oil and gas well sites: The implications for limiting hydrocarbon reserves

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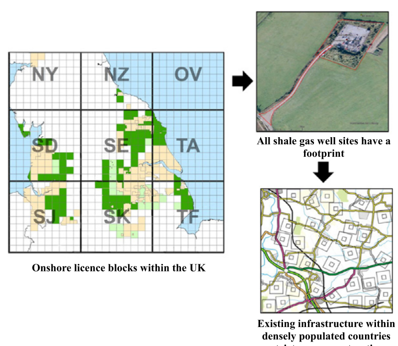
HIGHLIGHTS

- Surface carrying capacity limits access to shale gas reserves.
- The average footprint for a conventional well site in the UK is 10,800 m^2.
- The average setback for a UK house was 447 m.
- When setbacks are used 73% of well pads overlap immovable infrastructure.
- The average carry capacity was 26%; this would limit recoverable resources by 74%.

GRAPHICAL ABSTRACT



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ABSTRACT

We estimate the likely physical footprint of well pads if shale gas or oil developments were to go forward in Europe and used these estimates to understand their impact upon existing infrastructure (e.g. roads, buildings), the carrying capacity of the environment, and how the proportion of extractable resources maybe limited. Using visual imagery, we calculate the average conventional well site footprints to be 10,800 m^2 in the UK, 44,600 m^2 in The Netherlands and 3000 m^2 in Poland. The average area per well is 541 m^2/well in the UK, 6370 m^2/well in The Netherlands, and 2870 m^2/well in Poland. Average access road lengths are 230 m in the UK, 310 m in The Netherlands and 250 m in Poland.

To assess the carrying capacity of the land surface, well pads of the average footprint, with recommended setbacks, were placed randomly into the licensed blocks covering the Bowland Shale, UK. The extent to which they interacted or disrupted existing infrastructure was then assessed. For the UK, the direct footprint would have a 33% probability of interacting with immovable infrastructure, but this would rise to 73% if a 152 m setback was used, and 91% for a 609 m setback. The minimum setbacks from a currently producing well in the UK were calculated to be 21 m and 46 m from a non-residential and residential property respectively, with mean setbacks of 329 m and 447 m, respectively. When the surface and sub-surface footprints were considered, the carrying capacity within the licensed blocks was between 5 and 42%, with a mean of 26%. Using previously predicted technically recoverable reserves of 8.5×10^{11} m^3 for the Bowland Basin and a recovery factor of 26%, the likely maximum accessible gas reserves would be limited by the surface carrying capacity to 2.21×10^{11} m^3.

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1. Introduction

The rapid growth of shale gas developments within the United States (US) and the possibility of developments within Europe have raised concerns about the potential environmental impact (McGowan, 2014; Bomberg, 2013). Landscape disturbance from shale gas developments is inevitable (Drohan et al., 2012) as numerous wells (10 wells each with multiple laterals) from many well pads are required to intersect the gas bearing formation(s) for the resource to be economically viable (Baranzelli et al., 2015). Land disturbance will vary depending on, amongst other considerations, the number of wells per pad, the well pad size, the well pad density (pads per area), and the specifics of the shale play that is being developed (Baranzelli et al., 2015). Furthermore, the pattern of land ownership, public engagement and development regulations may cause higher or lower densities of well pads.

The spatial footprint of shale gas developments consists of the well pad and the area required for access roads. In part, the number of wells on each pad defines the size of the well pad. In recent years the mean and maximum number of wells per site has been increasing, this trend has been attributed to advancements in technology and an understanding that greater consolidation of infrastructure is more efficient and economical (Drohan et al., 2012). In Pennsylvania, Johnson et al. (2010) document a mean of two producing wells per pad, Drohan et al. (2012) reported over 75% of pads to have just one or two wells per pad, whilst Jantz et al. (2014) found a mean of 2.45 wells per pad. When including producing and permitted wells there was a higher mean of 4.67 wells per pad. Jantz et al. (2014) focused on the more recently developed Bradford County, Pennsylvania, thereby giving a more recent picture of current development patterns and consolidation of infrastructure. In the UK, Cuadrilla Resource Ltd., herein termed Cuadrilla, who are currently investigating potential shale gas production from the Bowland Shale in Lancashire, have stated that they intend to have 10 wells per pad (Regeneris Consulting, 2011). The UK's Institute of Directors (IoD) suggested several potential development scenarios, one of which was based on the development of pads with 10 vertical wells and 40 laterals (four laterals per vertical well – Taylor et al., 2013). The US Inner City Fund (2009) summarised planning information requested by the New York Department of Environmental Conservation from three active Marcellus Shale operators and showed that a multi-well pad with six to eight wells would be between 10,000 m^2 to 23,000 m^2 (1 ha to 2.3 ha), with a typical site being 19,000 m^2 (1.9 ha). The US Inner City Fund has suggested a 'rule-of-thumb', based on discussions with operators: assume an initial single-well pad size of 13,000 m^2 (1.3 ha) that increases by approximately 1600 m^2 (0.16 ha) per well, i.e. according to these guidelines, a six well pad would have a footprint of 21,000 m^2 (2.1 ha) (US Inner City Fund, 2009). In the UK, Cuadrilla is planning to develop 10 wells on a 7000 m^2 (0.7 ha) well pad (Broderick et al., 2011). However, Taylor et al. (2013) suggest future scenarios with shale gas pads of 20,000 m^2 (2 ha).

It is difficult to review the additional footprint required for well site access roads as many researchers have not distinguished between the area required for general infrastructure (e.g. pipelines and storage ponds) and the area specifically required for roads. However, Jantz et al. (2014) made this distinction and found the mean additional area for access roads to be 12,000 m^2 (1.2 ha), with a range of 200 m^2 to 68,000 m^2 (0.02 ha to 6.8 ha). Jiang et al. (2011) recorded a lower average of 5800 m^2 (0.58 ha), with a range of 400 m^2 to 11,100 m^2 (0.04 ha to 1.11 ha). Access road widths generally range from 6 m to 12 m during the drilling and fracturing phase and from 3 m to 6 m during the production phase (NYS DEC, 2015). Calculations show that for every 46 m by 9 m access road, ~400 m^2 (0.04 ha) is added to the total well site surface acreage (NYS DEC, 2015). Permit applications for Marcellus horizontal wells prior to 2009 recorded road lengths ranging from 40 m to approximately 900 m (NYS DEC, 2015).

The physical footprint of the well pads and access roads do not necessarily represent the entire surface area as many regulatory bodies have proposed setbacks from the edge of the physical well pad. Setbacks are defined as the distance that well pads have to be away from existing infrastructure, they are enforced to provide additional protection to water resources, personal and public property, and the health and safety of the public (Eshleman & Elmore, 2013). The UK and several other European countries have no legislative or planning policy requirements on minimum setback distances; they are designated on a site to site basis (Cave, 2015). In the US, restrictions vary from state to state and are often based on local conditions such as population density (Richardson et al., 2013). Of the 20 sites surveyed in Richardson et al. (2013), 65% have building setback restrictions ranging from 30 m to 305 m from the wellbore, with an average of 94 m.

Surface footprint should be considered alongside the subsurface footprint. Geology, planning permits and legal requirements, along with the current onshore drilling technology, limits lateral well extent and therefore the well pad spacing (NYS DEC, 2015). Currently maximum lateral length cannot greatly exceed the depth of the well, however as drilling technology evolves this is likely to change (NYS DEC, 2015). In the UK, Broderick et al. (2011) and Hardy (2014) note that typical horizontal wellbores extend 1 km to 1.5 km laterally, but agree it can be more. The Maryland Department of the Environment indicates that spacing multi-well pads in dense clusters located as far apart as is technically feasible makes maximum use of horizontal drilling technology and could minimise the surface footprint (Eshleman & Elmore, 2013). Composite Energy (cited in Broderick et al., 2011) estimates laterals of 1 to 1.5 pads per 1 km^2 (100 ha) should be sufficient in a UK setting. However, even spacing of well pads is often impossible, as it does not account for geology and above ground constraints, such as existing infrastructure (Broderick et al., 2011).

At the time of writing, few shale gas wells have been drilled in Europe. However, the 'big four' plays (the Barnett, the Fayetteville, the Hayneville, and Marcellus Shale) in the US host >30,000 wells, consequently the literature is based mostly on US experiences (Inman, 2014). With a nascent shale gas industry in the UK and the rest of Europe, resource estimates are beginning to be published (e.g. Andrews, 2013; The Geological Society, 2012). However, accessible resource estimates around the world have not considered the carrying capacity of the surface or subsurface footprint and how well site placements are restricted by the current surface environment, e.g. proximity to domestic housing. It will not be possible to drill where these are located without substantial and potentially unacceptable disruption. The limit on accessible surface locations and how this impacts recoverable resources has not been included in any resource evaluation. This study aims to determine the likely physical footprint of well pads if shale gas developments were to go forward in Europe. Using these estimates, we hope to better understand the carrying capacity of the environment and the associated limitations on recoverable resources.

2. Approach and method

To estimate the likely footprint of any shale gas development and the likely restriction this would cause to recoverable resources we considered the likely size of well pads and the size of potential setbacks. Without a shale gas industry currently operating within Europe, information has been drawn from the US and analogues within Europe (conventional wells in the UK, The Netherlands and Poland). The assessment of carrying capacity based on the well pad footprints was applied to the Bowland Shale, UK. The surface area above the Bowland Shale is split into blocks which are generally 100 km^2 (10,000 ha) (Fig. 1). The UK government grants licences for designated blocks and invites exploration companies to bid for the right to explore that block for hydrocarbon resources. At the time of writing, 127 blocks over the Bowland Shale are licensed to various operators (Fig. 1). To assess whether the likely footprint from well pads represents an impact unique to shale gas extraction, comparisons to other types of currently operating comparator