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Life-cycle Assessment of Greenhouse Gas Emissions from Unconventional Gas in Scotland

Non-Technical Summary

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For the full report see: Bond C.E., Roberts J., Hastings A., Shipton Z.K., João E.M., Tabyldy Kyzy J., Stephenson M. 2014 Life-cycle assessment of greenhouse gas emissions from unconventional gas in Scotland. A ClimateXChange Report, Scotland, http://www.climatexchange.org.uk/reducing-emissions/life-cycle-assessment-ghg-emissions-unconventional-gas1/

Key Findings

- The key factors influencing the lifecycle emissions of unconventional gas in Scotland are:
  - Methane that could escape when the borehole is being prepared for gas production, or servicing a borehole during production;
  - The impact of building associated infrastructure (such as drilling platforms, pipelines and roads) in areas with peat soil. This is because peat soil holds carbon which will be released when the soil is removed or drained when preparing the land for being built on;
  - Fugitive methane emissions that escape from valves and pipes, which are difficult to capture.
- There are potentially significant opportunities to mitigate greenhouse gas emissions by:
  - Avoiding unconventional gas exploration and development on peatland. Emissions could also be reduced by avoiding areas of deep peat, minimising the area of land to be built upon, and maximising the number of boreholes at each well pad; and
  - Applying Best Available Techniques to capture and use the methane, thereby preventing it from being emitted to the atmosphere. These techniques should be applied at the exploration and production stage; and
  - Improving equipment performance and rigorous monitoring for early leak identification and intervention.
- The life-cycle greenhouse gas emissions per unit of energy from unconventional gas extraction in Scotland are likely to be equivalent to those of conventional gas extraction in Europe if best practice is followed and building on peat is avoided. This is dependent on the total quantity of gas recovered from extraction operations.

1. Introduction

This report presents a desk-based study of the estimated life-cycle greenhouse gas (GHG) emissions associated with the exploration and extraction of unconventional gas (specifically shale gas and coal bed methane) in Scotland.

There is significant interest in developing the unconventional gas industry in Scotland. Given the Scottish Government's ambitions for a low carbon economy, it is important to understand the potential GHG emissions associated with the extraction of the Scottish unconventional gas, resource and what could be done to mitigate or reduce these emissions.

This research was requested by the Scottish Environment Protection Agency (SEPA) and is intended to assist those involved in regulating unconventional gas developments to understand the potential sources and scale of greenhouse gas emissions. While this this study does not collect and analyse new data, it is intended to help to bridge knowledge gaps and to identify where mitigation measures may be necessary.

2. Unconventional Gas Sources

Unconventional gas resources are distinguished from conventional resources by both the geological properties of the reservoir rock and the technologies and processes necessary to produce the gas. These geological properties rendered the gas too difficult or uneconomic to extract prior to technological advances in horizontal drilling and hydraulic fracturing.

This study conducts a life-cycle assessment of greenhouse gas (GHG) emissions for the onshore unconventional gas sources that are currently under consideration for exploitation in Scotland: coal bed methane and shale gas.

2.1 Shale gas

Shale gas refers to natural gas trapped within very fine-grained low permeability sediments, such as shales, mudstones and silty mudstones.

Extraction

Shale gas is produced by drilling vertically into, and then horizontally along, layers of shale. Because the gas is trapped within the impermeable rock, the rock needs to be fractured to provide pathways for the gas to escape. The fractures create permeability in the rocks. This requires a technique called hydraulic fracturing (‘fracking’), whereby fluids such as water are pumped into horizontal wells through the shales at pressures high enough to induce fractures in the rock. These hydraulic fractures are ‘propped’ open by proppant materials, such as sand, which are pumped into the well as particles suspended in the fracture fluid. Post-fracturing, the pressure at the well head is dropped by pumping any water from the borehole (a process called clean-up) and the gas flows into the ‘propped’ fractures and on into the wellbore where it is extracted along with the fracture fluids. The produced gas is collected at the wellhead, processed if necessary, and then either combusted to generate electricity, used for petrochemical feedstock or fed into the national gas grid.

2.2 Coal Bed Methane

Coal Bed Methane (CBM) (also called Coal Seam Gas in Australia) refers to natural gas adsorbed within coal seams. This is different from Coal Mine Methane, which is natural gas extraction from worked coal seams.

Extraction

Coal bed methane is produced by drilling vertically into and then horizontally along coal seams. Depending on the geology of the coal seam, there are two options for CBM extraction:

- If the coal seams are thin, shallow, or already fractured there is no need to hydraulically fracture the seam. Gas is extracted by 'dewatering' the seam. The coal seam is drained by pumping out the formation water, which allows the methane to flow from the coal bed. It is not possible to subsequently hydraulically fracture coal from a well that has been designed for dewatering, without first refilling cleats with water and re-designing the well completion.

- If the coal seams are thicker, deeper, or less fractured, then hydraulic fracturing may be required to release the gas. This requires a different well design and more horizontal wells to be drilled. Hydraulically fracturing coal seams requires less pressure than that required for shale gas, and therefore less water. In CBM, a foam is often more effective as a fracturing fluid and reduces the volumes of water used in the process.

The produced gas is collected at the surface, processed if necessary, and then either combusted to generate electricity on site, or fed into the national gas grid. In Scotland, CBM is already being exploited without the need for hydraulic fracturing.

3. Life-Cycle Assessment

Life-cycle assessment (LCA) refers to the aggregate quantity of greenhouse gas emissions including direct emissions and significant indirect emissions. This LCA includes everything from exploration to the point of injection into a gas pipeline. The distribution and use of the gas is not included in the LCA.

The LCA uses a Scottish scenario as the basis for the calculation of the greenhouse emissions and considers that exploration would be within the Central Belt of Scotland. This region has a long history of coal mining and shale oil extraction and, therefore, has the most comprehensive data on the geological formations at depth. Although this is a desk-based study, industry, regulatory and academic experts were consulted in order to inform this report with regards to the most up to date geological, technological, planning and policy aspects specific to the Scottish context.

3.1 Stages of Development

Within the scope of this LCA for unconventional gas, GHG emissions could be associated with a range of activities:

- *Direct GHG emissions* - from the exploration and production activities, which would include the direct release of produced gas to atmosphere (from controlled venting or venting of fugitive emissions, i.e. leakage); the combustion of produced gas as part of controlled flaring or to power onsite machinery; and combustion of other fuels to power onsite machinery or to transport equipment and materials to and from the site.

- *Indirect GHG emissions* - that are a consequence of the exploration and production activities and gas processing, for example removal of peat to build well pads, electricity consumption, or the emissions embedded in the sourcing of purchased materials and fuels, and outsourced activities (such as waste treatment and disposal).

Table 1 shows the different stages for the development of unconventional gas, from initial site appraisal to abandonment and reclamation. The potential greenhouse gas emissions associated with each stage are reported and compared in the main report to identify where in the life-cycle options to mitigate emissions would be most effective.

Table 1. Stages of the life cycle for unconventional gas exploration and production, modified from Forster and Perks (2012). Example activities that have potential GHG emissions at each stage of the life cycle are annotated. Well plugging and abandonment (stage 6) would occur after exploration or appraisal, if the outcome of the exploration stage shows no resource or a non-economic resource.

	Stage	Example activities and potential GHG emission sources
1	**Non-intrusive exploration**	• *Securing of necessary development and operation permits.* • *Site identification, selection, characterisation* • *Exploration surveys (seismic etc)*
2	**Intrusive exploration**	• *Establishing baseline conditions (geochemical, microseismic)* • *Land preparation (land use change)* • *Access road construction* • *Equipment transportation (including water)* • *Exploration well pad construction* • *Exploration drilling: vertical well design and construction.* • *Appraisal drilling: horizontal well design and construction.* • *Logging, and well testing* • *Hydraulic fracturing (including flaring) for shale gas.* • *Well completion* • *Dewatering (for CBM)* • *Flow testing, and gas (& oil) production (and processing)* • *Disposal of construction and drilling wastes, and water treatment.*
3	**Appraisal**	
4	**Production development**	• *Monitoring baseline conditions (e.g. geochemical, microseismic)* • *Land preparation (land use change)* • *Construction of road and pipeline connections* • *Equipment transportation* • *Development well pad and facility construction and installation.* • *Well design construction and completion* • *Disposal of construction and drilling wastes* • *Water treatment (or recycling)*
5	**Production operation and maintenance**	• *Gas/oil production and processing* • *Well work-overs and integrity testing* • *Environmental monitoring*
6	**Well plugging and abandonment**	• *Well plugging and testing* • *Site equipment removal* • *Pre-relinquishment survey and inspection* • *Site restoration and reclamation.* • *Environmental monitoring*

4. Life-Cycle Emissions

The study adapts previously published work to produce an LCA that is relevant to a Scottish scenario. This scenario considers exploration and development of shale and coal resource in the Central Belt of Scotland, within the context of the Scottish regulations, infrastructure, and social-political and environmental landscape. For example, UK legislation requires that Best Practice for any oil and gas operations is followed and that the Best Available Technology for any process is adopted. This means that some operational practices and the associated emissions that have been considered in previously published LCAs are not relevant for operations in Scotland.

The study takes conservative estimates of emissions to generally overestimate where there are uncertainties and thus consider the worst-case scenario. The conservative emissions for each stage of exploration and development are shown in figure 1.

The key factors that influence the overall greenhouse gas emissions associated with unconventional gas exploration and development include land use change, the method of methane disposal during well clean-up, and the fugitive emissions from small leaks from valves and flanges. Methane leaks have a large impact on the life-cycle emissions since methane is 36 times more potent than CO_2 as a greenhouse gas.

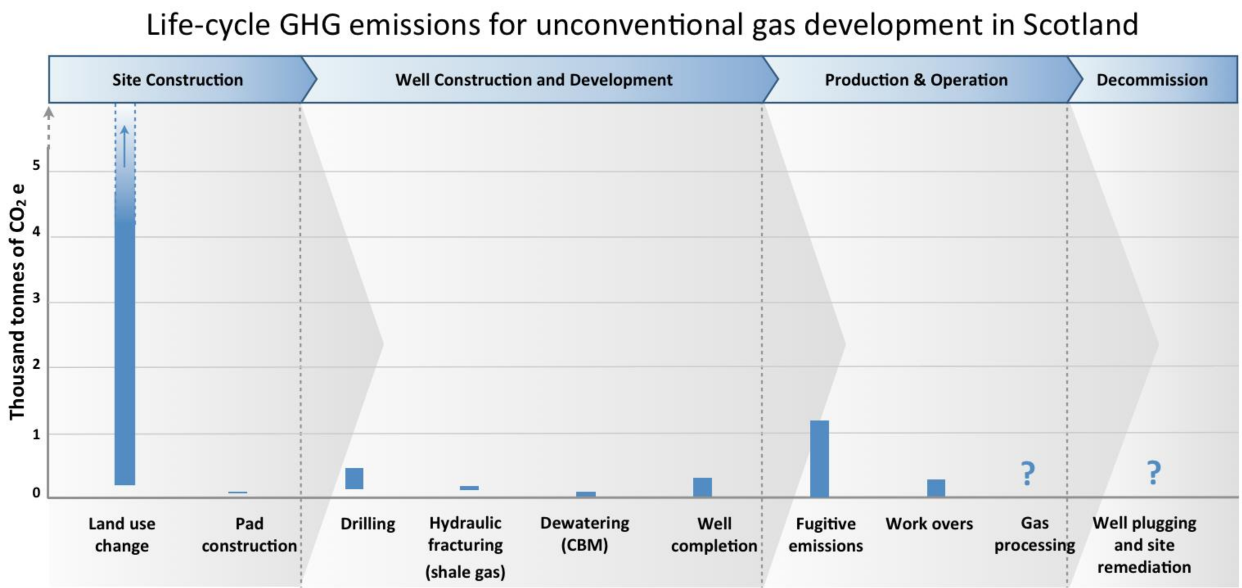


Figure 1. Estimated life-cycle emissions per well (in thousand tonnes of CO_2 equivalent) for each stage of unconventional gas development for a ten-well pad. The bars show the maximum and minimum estimated emissions for each stage. Where there is not currently enough data to estimate the emissions, a question mark is shown. The hydraulic fracturing stage is only relevant to shale gas, and the dewatering stage is only relevant to coal bed methane for this LCA. Emissions from clean-up (well completion and work overs), and fugitive sources are dependent on the ultimate quantity of gas that is recovered from the well, which we assume here to be the moderate scenario for the UK (3 billion cubic feet per well). Emissions from clean-up are zero where Best Available Technology is applied to ensure 100% capture and utilisation, and emissions only occur when the clean-up gas is captured and flared rather than utilised and is shown here as a worst case scenario. The potential emissions associated with land use change for three different vegetation types were considered: grassland; arable land and peatland. The potential emissions from land use change in peatland areas are very large (up to 11,370 tonnes of CO_2 equivalent per well) and this maximum is not able to be fully shown in this graph. This study was unable to estimate the potential emissions from gas processing and site-decommissioning and restoration since information about these stages is not currently available for the Scottish context.

5. Key Opportunities for Greenhouse Gas Mitigation

This life-cycle assessment identified two particular activities with potentially high associated GHG emissions that could be mitigated. These activities are relevant to the exploration and appraisal stage for both shale gas and coal bed methane.

5.1 Organic soils and peat

The regions of Scotland that may be considered for the extraction of unconventional gas are situated on organic soils or peatland. Peatland is a natural carbon storage system. The excavation of the peat to build the hard standing of the pad and cellars for the wells, as well as the building of the access roads and pipeline connections, and the construction of borrow pits[1], would result in the oxidation of that peat. It would also result in a loss of photosynthesis for the area affected and oxidation of peatland around the pad and road due to drainage.

These emissions could be mitigated by avoiding unconventional gas exploration and development on peatland. The emissions could also be reduced by avoiding deeper areas of peat, minimising the area of land to be built upon (including new roads and pipelines), and maximising the number of boreholes at each well pad (i.e. using a lower number of surface installations to access a larger volume of the subsurface).

5.2 Methane emissions during well completion

Methane can be emitted while a well is being completed and during clean-up[2]. The term 'green completion' or 'reduced emission completion' has been used to describe the Best Available Techniques employed for well completion which ensure that greenhouse gases that flow to the surface before the well is ready for production are captured and utilised. The approach to wellhead management mandated in the UK (and enforced by HSE) is to avoid any such emissions of methane because of the mortal explosion risks this poses to the workforce and due to environmental considerations. A 'green completion' is thus equivalent to a standard UK well completion that would be acceptable on the grounds of workforce safety.

The use of Best Available Techniques would ensure minimal emissions associated with well completion, including emissions from dewatering coal beds for CBM and emissions associated with the flowback of hydraulic fracturing fluid. It is also Best Practice to use the captured methane rather than to simply flare it, although flaring reduces the potency of the gas emissions.

5.3 Other Opportunities

Other opportunities for reducing greenhouse gas emissions are identified, though the impacts are smaller. In addition to the above, this report recommends that:

- Operators aim to minimise GHG emissions from operations where the health and safety and social penalties of doing so are minor.

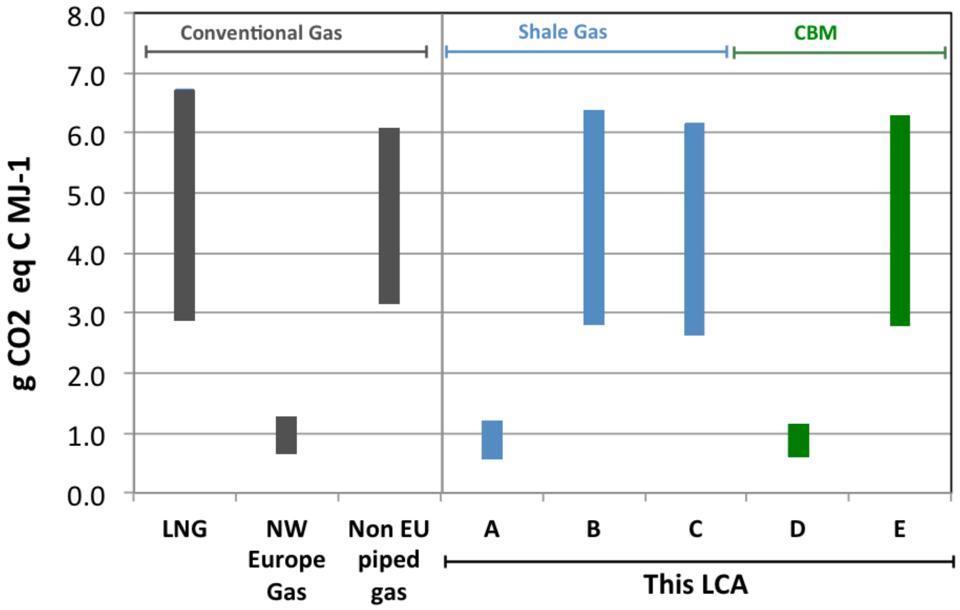
[1] Construction 'borrow pits' are where material from one location is excavated for use at another site. The material excavated is often sand or gravel, and is used for example as hard standing for further construction (e.g. a well pad or road).

[2] 'Well completion' refers to the process of preparing a cased well for production. 'Clean-up' is a period of controlled production to clean out the well in advance of gas production after drilling, well completion and workovers. Clean-up removes drilling debris, drilling fluids and flowback fluids from wells that have been hydraulically fractured; allowing dry gas to flow.

- Where possible, existing roads should be utilised, though these will have to be maintained appropriately.
- Operators should consider running spurs off existing gas and/or waterpipeline networks to well sites to minimise construction of new gas and water pipelines. Where necessary, it may be preferable to construct surface-routed (unburied) pipelines to minimise the area of land disturbance and to reduce the embedded carbon in the pipeline infrastructure.
- Operators should consider a centralised processing facility that would process gas from several well pads, and mechanisms for shared access to such a facility.
- Operators should work towards Leak Detection and Repair (LDAR) programmes that would permit rapid remediation of any leaks to minimize fugitive emissions.
- Where possible, the site equipment should be powered by produced or captured natural gas rather than diesel (which is noisier and produces more black carbon pollutants) or electricity (due to transmission losses – unless generated from renewable sources on site). Operators should consider supplying water to the site via polyplastic unburied pipeline, to minimise land disturbance and embedded carbon in the pipeline infrastructure.
- The number of boreholes at each well pad should be maximised to enhance recovery for a single well pad and reduce the area of land use change.
- Water and materials (e.g. drill mud and proppant) should be recycled as best practice.
- Where possible, material should be sourced locally to reduce transport distances (i.e. procurement should consider the embedded carbon emissions).

6. Emissions Comparison with other Gas Extraction Technologies

The results of this study are compared with previous life-cycle assessments, summarised in figure 2.



A. **Shale gas** development well on **grassland**, transport of water by **pipeline**, and methane disposal during clean-up by **capture**.

B. **Shale gas** exploration well on **peat**, transport of water by **truck**, and methane disposal during clean-up by **flaring** *(worst-case scenario for a shale gas well).*

C. **Shale gas** development well on **peat**, transport of water by **pipeline**, methane disposal during clean-up by **capture**.

D. **CBM** development well on **grassland**, transport of water by **pipeline**, methane disposal during clean-up by **capture**.

E. **CBM** exploration well on **peat**, transport of water by **truck**, methane disposal during clean-up by **flaring** *(worst-case scenario for a CBM well).*

Figure 2. Comparison of the life-cycle assessment of the greenhouse gas emissions of the unconventional gas estimates derived from this LCA study (for both shale gas and coal bed methane (CBM)), with other gas sources from Mackay and Stone (2013). The carbon intensity of the emissions are expressed in terms of grams of CO_2 equivalent Carbon per MJ of energy of combustion (g CO_2 eq C MJ^{-1}). The ranges presented assume low and high gas recovery rates (as used by MacKay and Stone, 2013).

Figure 2 shows that conventional natural gas extracted from offshore NW Europe has the lowest associated emissions. However, if onshore unconventional gas is developed on brownfield, grass or arable land, then the emissions are similar to NW Europe offshore gas. The unconventional gas scenarios with higher emissions than Liquefied Natural Gas and Non EU piped gas are where peat land is disturbed by shale gas or CBM exploration and appraisal, or development activities.

It is important to note that many factors such as the total gas recovery, the depth of the resource rocks, and the extraction requirements must be defined, or refined, before the greenhouse gas emissions estimated here could be confidently applied to any future Scottish onshore unconventional gas industry.

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