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Life cycle assessment of shale gas in the UK

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Abstract

The remarkable US growth of shale gas and the associated decrease in the US natural gas prices has catalysed an increasing interest of shale gas resource exploration in other areas of the world. Commercial drilling operations have not yet commenced, but exploration is taking place in some European countries, including the UK. Major environmental concerns, regarding the amount and the handling method of the emissions associated with hydraulic fracturing, the disposal of waste water and the low well productivity, have pushed some countries to ban exploration and trials. We contextualized the shale gas extraction to the UK condition where the estimate of recoverable gas has made the debate on shale gas highly interesting. We used the methodology of Life Cycle Assessment (LCA) and estimated the environmental burden of shale gas production, processing and distribution at low pressure to the consumer. In this paper we have reported the detailed hot spot analysis of the impact of shale gas on the watersheds.

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Keywords: UK shale gas; life cycle assessment; hydraulic fracturing

1. Introduction

The remarkable US growth of shale gas and a decrease in the US natural gas prices has catalysed an increasing interest of shale gas resource exploration in other areas of the world. Several European countries hold significant recoverable reserves of shale gas [1]. Apart from the US, commercial drilling operations have not yet commenced, but exploration is taking place in some European countries, including the UK. European shale gas exploitation could potentially completely transform the world-wide energy market but an eventual commercial development needs to be rooted on solid knowledge about its environmental impacts, according to the European geological characteristics and legislation. Major environmental concerns, regarding the amount and the handling method of the emissions associated with hydraulic fracturing, the disposal of waste water and the low well productivity, have pushed some

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countries to ban exploration and trials. Our study contextualizes the shale gas extraction to the UK condition where the estimate of recoverable gas has made the debate on shale gas highly interesting.

Environmental concerns associated with the shale gas extraction, determined in 2011 an increased scientific activity in the US focused on the estimate of the carbon footprint associated with this new technology [2,3,4]. [2] were between the first authors to estimate the global warming potential of US shale gas production and use. The use of a high GWP for methane and the expression of the results per MJ of gas and kWh of electricity, led them to the highly contested statement that shale gas may determine a carbon footprint even higher than that of coal [5-6]. In the following US literature, some studies claim that the burden of shale gas is few percent higher than that of conventional gas [3] and some others claim the opposite results [6] but none of them confirm the results reported by [2]. Some country related studies on the environmental impact caused by the shale gas extraction have also been conducted in countries, other than the US, that might develop their national shale gas reserves, such as China [7] and the UK [8].

The main focus of all the studies previously mentioned is limited to the estimation of the carbon footprint of shale gas production and use. To date, only three studies also explore other impacts of shale gas: [9] and [10] study the water life cycle of US shale gas extraction whereas in the UK, [8] analyse different impact indicators (depletion of energy sources, acidification potential etc.).

To the author's knowledge, this work is the first one of this type that performs a detailed life cycle hot spot analysis of the UK shale extraction process. We consider conventional environmental impacts including as well water use, degradation and consumption. This paper focuses in particular on the results concerning the impact of shale gas on watersheds.

1.1. An overview on the shale gas extraction process

The entire process of shale gas extraction and production involves the following steps: site exploration and preparation, road and well pad construction, vertical and then horizontal drilling, well casing, perforation, hydraulic fracturing, completion, production and abandonment and reclamation of the site. In vertical drilling, once the depth of the shale formation is reached, then, directional drilling is used to curve the well bore to the horizontal, in order to follow the shale formation. Steel casing pipes are installed in the borehole and cemented to the surrounding rock formation. The casing of the horizontal well is then perforated and the phase of hydraulic fracturing takes place. This consists of pumping fracturing fluids down the well bore under high pressure to create fractures in the producing rocks along the horizontally drilled hole to increase productivity. The fracturing fluid comprises almost 99% of water and proppant (usually silica sand), the rest being a blend of different chemicals. Flowback water is the water produced from the well immediately after the pressure of fracturing fluids is released and before gas production commences. This flowback water is collected and must be disposed of safely as it contains part of the chemicals injected with the fracturing fluids and also substances naturally present in the reservoir, such as: salt, radioactive materials, hydrocarbon, metals, etc. The phase of well completion includes the preparation of the borehole, the installation of pipes, the escape of gas to clear the debris and also the flowback period. The completion emissions associated with shale gas are different from those associated with conventional natural gas, because of the hydraulic fracturing phase. The estimated ultimate recovery (that is the amount of gas recovered throughout the entire life of the well, EUR) is a key characteristic of shale gas wells, as this is usually lower than conventional wells.

2. Life cycle assessment methodology

Life cycle assessment can support decisions in any type of environmental management. The entire life cycle of valuable goods, products, and services, from 'cradle' to 'grave', is accounted for in the environmental impact study. LCA helps identifying the process 'hot spots' that are the process units prevalently contributing to the environmental burden. The International Standard Organization ISO 14040 [11] provides standard guidelines on how to perform an LCA analysis for improving decision support. It consists of four stages: i) Goal and scope definition; ii) Inventory analysis; iii) Impact assessment; iv) Interpretation. In the goal and scope definition, the purpose of the study is defined and also the following points are addressed: i) what political or technical decision will depend on the results of the study; ii)what are the system boundaries for the study iii) what is the basis for comparison between different alternatives (i.e. what is the functional unit). During the inventory analysis phase all the environmentally relevant inputs and outputs of the process are identified on the basis of the functional unit. In the impact assessment phase the inputs and outputs previously collected are classified in different groups according to the type of environmental impact they contribute to and assigned to specific impact categories. According to the mass flow, each environmental intervention is transformed into an environmental burden through a common unit, specific for the environmental category. The last phase includes the analysis of the results obtained in the previous phases and the drawings of the conclusion based on the points reported in the goal and scope definition. The ISO standard recommends that the environmental benefits of recovered resources should be accounted using the method of "system expansion". The system boundaries are broadened to include the avoided burdens of conventional production processes [12]. We follow a pragmatic distinction between the foreground and the background; the foreground is the set of processes whose selection or mode of operation is directly affected by decisions based on the study, whereas the background is defined as all other processes which interact with the foreground, usually by supplying or receiving material or energy.

In this work we use the LCA methodology to analyse the impact of shale gas on water, including use, consumption and degradation. According to [13] water use is the measured amount of water input into a product system or process (this usually is the total water withdrawn from environment). Fresh water use is further differentiated in consumptive water use and degradative water use. The freshwater consumption includes all fresh water losses on a watershed level which are caused by evaporation, release of fresh water into sea (as fresh water is a limited natural resource), etc. Degradative water use identifies the use of water that determines quality degradation and pollution. If the polluted water is released again to watershed then this use of water does not have to be considered consumptive. All indirect burdens included in the inventory are UK country specific. Calculations are performed using GaBi 6 LCA software [14].

3. Objectives of the work: system boundaries and functional unit

The objective of this work is to perform the life cycle assessment of UK shale gas extraction taking account of the prevailing European geological conditions and environmental legislation. The following points are addressed in this paper: i) Building a detailed mass and energy balance of the UK shale gas production process; ii) Performing the hot spot analysis of shale gas production in the UK according to the water modeling principles [13]. A broader analysis of other impact indicators and a sensitivity analysis on key parameters have also been performed but are not reported here. As widely reported in literature, [3,8] we assume that the extraction of shale gas involves exactly the same processes as the extraction of conventional gas except for all the operations associated with the hydraulic fracturing. Therefore, two models have been built: the first model (identified as the base model) accounts for the extraction of conventional gas and includes all the common processes between conventional and unconventional extraction. The second model (identified as the hydraulic fracturing model) includes all the processes specific to shale gas extraction (that are: horizontal drilling, fracking of the rocks, flowback disposal and handling of emissions associated with hydraulic fracturing). The modelling approach and the system boundary are reported in Fig. 1. The results are reported according to the delivery of 1MJ of natural gas to the final consumer at low pressure (< 7 bar and > 0.75 mbar).

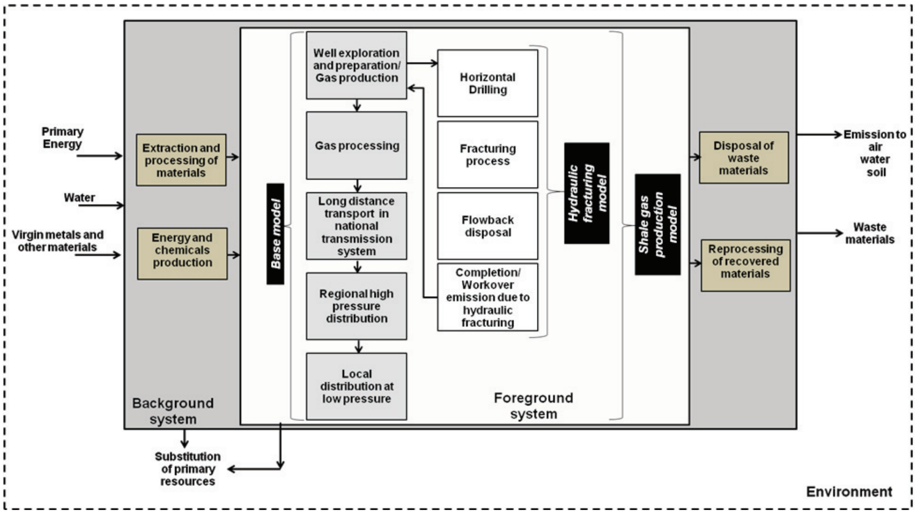

Fig. 1. System boundaries.

4. Life cycle inventory

This paper originally develops the LCA of shale gas supply to the UK; literature data for production and supply have been collected and shaped according to the chosen system boundaries and LCA models.

4.1. Base model

The base model includes the processes of gas field exploration, conventional natural gas production, natural gas purification, long distance transport and regional distribution. The inventory accounts for energy and material requirements, production, treatment and disposal of wastes, transport, emissions to atmosphere and infrastructure production. The inventory data are based on the Ecoinvent database [15].

4.2. Hydraulic fracturing model

The inventory for the hydraulic fracturing model is based on data reported in literature. We assume that the flowback ratio is 25%, flowback water is disposed to proper industrial treatment, emissions associated with the hydraulic fracturing process are captured and gathered into the pipelines and the EUR is $85 \cdot 10^6$ m^3 [16]. A sensitivity analysis, not reported in this paper has been performed on the most environmentally criticised operations in shale gas production, such as flowback disposal method and emission handling, considering a series of possible solutions. Inventory data for horizontal drilling are taken from [6]. The emissions due to diesel machineries used during hydraulic fracturing and horizontal drilling are included in the model and these are based on the amount of diesel consumed. The amount of water and sand needed for the rocks fracturing process are taken as an average of the values reported in literature [3-9-8-16].The chemicals are assumed to be ~0.05% of the fracturing fluid. Transport of the materials used during the shale gas extraction operation is included in the analysis.

5. Results

The *water use* of shale gas extraction is due to the hydraulic fracturing model for 91%, see Fig. 2a. The detailed hot spot analysis of the process associated with hydraulic fracturing (Fig. 2b) shows that the main contributors to the water use are the fracking of shale formation and, also the flowback disposal process, whereas the other operations have a negligible influence. Given the assumption that all the flowback is disposed through proper industrial treatment, the use of water can be either degradative or consumptive, depending on the flowback ratio. If the flowback ratio is lower than 100% then the direct disposal always determines a consumptive use of water. Conversely, when the flowback ratio is higher than 100%, the use of water is not consumptive but only degradative. In this study, the use of water is consumptive (25% of flowback ratio) and at the same time degradative. The hot spot analysis of the fracturing process (Fig. 2c) shows that the water use is due to: the production of sand used in the fracturing liquids (60%), to the withdrawal of fresh water used for cracking the rocks (23%) and to the production of fracturing chemicals (17%). Regarding the 60%, fracking sand must be of uniform size and shape and to achieve this, a complex processing after mining is needed [17]. The processing plants wash, dry, sort, and store the sand and waste water is produced. This explains the burden associated to the process of sand mining and processing. In particular the water used for sand mining involves a degradation of water. The water used to produce diesel for transport is negligible.

The *water consumption* in shale gas extraction is associated with the hydraulic fracturing model for more than 50% (Fig. 2d) (the consumption of water in conventional onshore gas extraction is less than half of the water consumed in shale gas extraction, see the base model of Fig. 2d). The hot spot analysis of the hydraulic fracturing model (Fig. 2e) identifies the two main contributors to the water consumption: fracturing itself and flowback disposal. The detailed hot spot analysis of the flowback disposal methods (see Fig. 2f) shows that the transport represents a negligible contribution to the burden with the consumption of water being mainly associated with the disposal treatment. The value of water consumption for this operation is negative because this unit operation implies a net release of lower quality water to fresh watersheds. The water consumed to treat the flowback is offset by the degradate water released to environment. Regarding the injection process of fracturing fluids into the shale formation, the consumption of water is for 99%, due to the background process of withdrawal of fresh water used in the fracturing fluids. In this case the production of sand and chemicals are negligible (the graph is not reported).

The *degradation of fresh water* in shale gas extraction (the figure is not reported because this represents the difference between water use and water consumption) is almost due for 100% to the model of hydraulic fracturing.

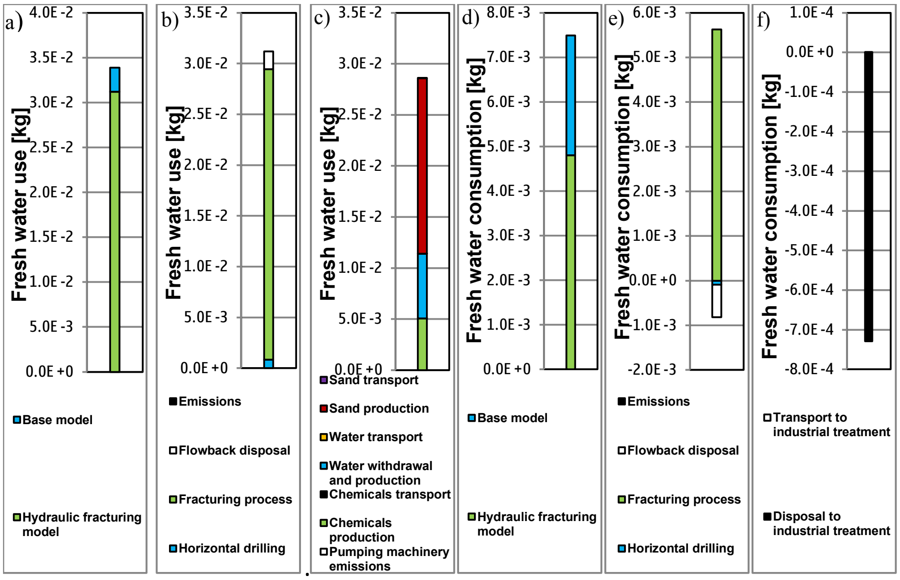

Fig. 2. Water use of: (a) shale gas production; (b) the hydraulic fracturing model; (c) the fracturing process. Water consumption of: (d) shale gas production; (e) the hydraulic fracturing model; (f) the flowback disposal.

6. Conclusions

Shale gas in Europe is in its early stage of exploration and research, and is pushed by the promising development it had in the US where hydraulic fracturing is already a well-known technology. In the UK, exploration and trials of UK shale gas reserves have just started but commercial production has not begun yet. We have performed a broad environmental assessment of UK shale gas exploitation including exploration, production and transmission at low pressure to the consumer. Our LCA analysis was based on UK or EU inventory based data, as much as possible. In this paper we reported the results on a detailed hot spot analysis of the impact of shale gas on watershed. Mining of the sand used in fracking fluids and water withdrawal have been shown to determine the main impacts on water use and degradation.

Governmental bodies in countries that are seeking to develop their shale gas reserves need to ensure that appropriate legislation, mainly regarding waste water discharge and fracturing chemicals production is in place. This will minimize the use and consumption of fresh water.

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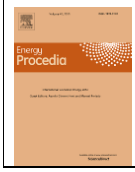

Biography

Carla Tagliaferri is a PhD of the Chemical Engineering Department at UCL (UK). Her research interests include the study of the environmental burden of energy production systems from renewable and fossil resources.