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Life Cycle Assessment of a shale gas exploration and exploitation project in the province of Burgos, Spain

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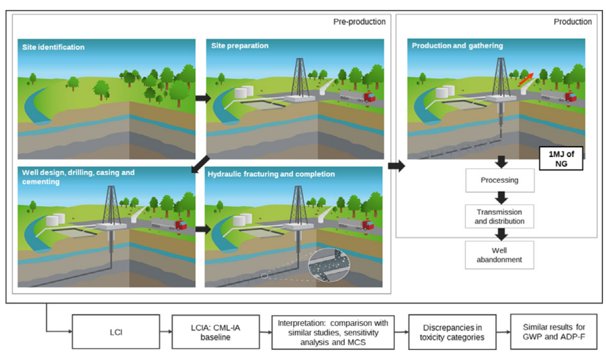
HIGHLIGHTS

- First Life Cycle Assessment (LCA) study of shale gas for a Western European production site under the appraisal phase.
- Global warming potential and abiotic depletion potential of fossil fuels have similar results to those of the literature.
- Water usage in hydraulic fracturing (HF) and the number of workovers with HF are the most sensitive parameters.
- The Monte Carlo simulation (MCS) demonstrates that ecotoxicity related impact categories present the largest uncertainties.

GRAPHICAL ABSTRACT



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ABSTRACT

Natural gas (NG) from shale formations (or shale gas) is an unconventional energy resource whose potential environmental impacts are still not adequately assessed. Hence, this study performs a Life Cycle Assessment (LCA) of shale gas considering a gas well under appraisal in Burgos, Spain.

An attributional model was developed, considering the NG pre-production and production phases in the system boundaries, considering 1 MJ of processed NG as a functional unit. Results were obtained through the CML-IA baseline method (developed by the Center of Environmental Science of Leiden University) and showed that well design, drilling and casing, hydraulic fracturing, NG production, gathering, and processing are critical processes.

To better address the environmental impacts, a comparison with similar studies was carried out, as well as a sensitivity and an uncertainty analysis using Monte Carlo simulation (MCS). The model was found to be particularly sensitive to water usage in hydraulic fracturing and to the number of workovers with hydraulic fracturing.

Limited data availability for shale gas exploration still poses a challenge for an accurate LCA. Even though shale gas remains controversial, it still can be considered as a strategic energy resource, requiring a precautionary approach when considering its exploitation and exploration.

1. Introduction

Natural gas (NG) is considered a reliable, efficient and clean-burning fuel that can be used in a wide variety of applications. It currently accounts for >20% of the total world primary energy demand (IEA,

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2016). Despite the existence of some uncertainty regarding the role of NG in Europe, it is frequently regarded as a transition fuel towards a low-carbon economy (EC, 2011; Johnson and Boersma, 2013).

Markets for NG have undergone important changes in recent years. These changes involve the large expansion of unconventional reserves in the United States of America (USA), more specifically shale gas, the internationalization and growing supply of liquefied natural gas (LNG), and the occurrence of extreme events (such as the Fukushima Daiichi event in 2011), which have changed the energy profile used in some countries (Costa et al., 2017a).

Due to the transformation of the energy industry in the USA following the so-called 'shale boom', the debate on shale gas production in Europe as an energy security issue has increased due to the high dependency on NG imports by European countries (Balitskiy et al., 2014; Erbach, 2014; Johnson and Boersma, 2013). Although shale gas development may not transform Europe into a self-sufficient region for the NG supply, it could contribute to the reduction of imports in coming years (Pearson et al., 2012).

Shale gas exploration and production seems to be viable in Europe based on the extent of technically recoverable reserves, which are reported to be equivalent to 15.5 trillion m^3 of wet shale gas in Eastern Europe and 255.3 trillion m^3 in Western Europe (EIA, 2015). However, concerns over its environmental and public health impacts have led to strong public opposition in European countries, prompting bans on its exploration in several countries (EC, 2013; Lis et al., 2015).

Although the environmental impacts of shale gas have been extensively discussed recently in the literature, the majority of studies only evaluate single environmental categories (Costa et al., 2017b). This can be attributed to the relative immaturity of the shale gas industry worldwide and is reflected in the relatively small number of LCA studies available, considering the many impact categories over the life cycle of a potential shale gas project in Europe (Cooper et al., 2014; Stamford and Azapagic, 2014; Tagliaferri et al., 2016).

To fill this gap, this work assesses the potential environmental impacts of NG from shale formations (or simply shale gas) through the Life Cycle Assessment (LCA) methodology (ISO 14040:2006) considering data from a series of publicly available reports detailing a licensed project for exploration in the Cantabrian basin, located in Burgos province, Spain (BNK, 2014). These data are supplemented with data available from the literature, presented with great transparency, which allows reproducibility and the identification of any discrepancies. To better assess the model parameters, both sensitivity and uncertainty analysis are performed.

Since there was no direct contact or affiliation of any kind with the company in question, this study is an opportunity to estimate future environmental impacts in the event that this project is actually carried out, with no conflict of interest by the authors. On the other hand, beyond its prospective nature, this study also lacks any technical information, since the company deems this confidential, particularly regarding aspects such as geological characterization. The project considered has yet to be implemented and there is no current commercial shale gas extraction anywhere in Spain, to make a case study of a going concern possible.

2. Background

2.1. Shale gas exploration in Spain and the case study

The NG used in Spain in 2015 served distinct demands, mainly in industry (36.3% share), households (23.0%) and for electricity generation (17.7%) (MIET, 2016). Despite the fact that NG consumption has been increasing for several years (Sedigas, 2017), in 2016 approximately 97% of the NG consumed in the country was imported by pipeline or in the liquefied form, from a wide variety of suppliers (BP, 2016; CORES, 2016; Sedigas, 2017).

Due to the increase in NG demand, exploitation of shale gas has been identified as an alternative to reduce energy dependence in the country by 2030 and a way to make the country a net gas exporter by 2050 (Deloitte, 2014; DSN, 2015). Despite widespread public opposition from certain sectors (Costa et al., 2017c), the Spanish government considers the exploitation of unconventional hydrocarbons in the country as an option to ensure energy security and reduce the strong energy dependence (DSN, 2015).

As of April 2017, there were four active investigation licenses issued by the central government, for projects in three Spanish provinces (MINETAD, 2017). This study focuses on the licensed project called Urraca, which is located in the province of Burgos. The Urraca 1 well (Fig. 1), which was selected as a case study since it is in the most advanced state of development in Spain (at the start of the environmental licensing phase as of this writing).

Although no decision on the exploitation of this site has been reached, the license was under the appraisal phase of the environmental impact study at the beginning of this study (ACIEP, 2015; BNK, 2014). This is to say, a large amount of data specific to Urraca 1 is available and was used in the present study. Again, however, it is important to highlight that only technical data are available, from publicly accessible reports, meaning that the data neither come from a project already in commercial exploitation nor contain any information that the company might deem classified.

2.2. Life Cycle Assessment of shale gas in the literature

The growing interest in shale gas is reflected in the increase in the number of shale gas publications between 2010 and 2015, as well as diversification of the geographical coverage (Costa et al., 2017b). There is also an increase in the number of articles looking at future exploration in Europe. The literature review also showed that only a small number of scientific studies focus on the evaluation of environmental impacts caused by shale gas production through a life cycle perspective.

Among the studies that have used the life cycle perspective and assessed the environmental impacts of shale gas, the literature review indicated there are significant differences in the ways the impact of shale gas production is assessed. These choices to assess environmental impacts can be grouped into differences in methodological options or modeling parameter choices.

In the first group, one can account for the difference in the functional unit adopted. It may be the delivery of NG or the production of electricity in the use phase (Stamford and Azapagic, 2014; Stephenson et al., 2011; Tagliaferri et al., 2016). This is also strictly related to the differences observed for the system boundaries considered in the review studies. Additionally, the number of impact categories assessed varies. Most studies focus on just a single environmental aspect, such as emissions of greenhouse gases (GHGs) (e.g., Burnham et al. (2012); Chang et al. (2014b); Howarth et al. (2011); Laurenzi and Jersey (2013); Jiang et al. (2011); Jaramillo et al. (2007)), or water (e.g., Jiang et al. (2014); Laurenzi and Jersey (2013)).

The second group refers to the different model parameters considered (Chang et al., 2014b; Tagliaferri et al., 2016). An example is that the choice of emission factors for diesel consumption does not make a distinction between stationary and mobile emissions from combustion (Chang et al., 2014b; Tagliaferri et al., 2016). In addition, the emissions factors considered may not reflect specific geographical emissions (Chang et al., 2014b). Another example is the exclusion of reduced emission completion (REC) during well completion in several studies (Chang et al., 2014b; Jiang et al., 2011; Raj et al., 2016), even though this technology is being used in more than 90% of shale well completions (ANGA, 2012; EPA, 2017; O'Sullivan and Paltsev, 2012).

Of the studies examined, only three evaluate LCA impacts from shale gas exploration and production considering different environmental impact categories, namely, Cooper et al. (2014); Tagliaferri et al. (2016) and Stamford and Azapagic (2014). However, all of them only