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(Review Article)

Parallel role played by tight gas resource in fulfilling United States' Energy requirement and reducing emission profile from hydrocarbon exploration and production industry (Life cycle analysis lens)

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Abstract

Tight gas has revolutionized the energy picture in North America. The US energy information agency states that the tight gas and oil in the USA has boosted the production of natural gas by around 35% in recent years. This has reduced the need for gas imports. Thousands of meters underground, tight gas trapped in microscopic pores of very dense rocks requires hydraulic fracturing to fracture the rock and releases the gas into the well, known as tight gas. Environmental impact of producing tight gas has caused concerns related to air emissions, water contamination and disposal of waste generated by the tight gas production. There are also concerns related to the possibility of methane escaping into the air during tight gas production and development of this resource class causing minor earth tremors. The advancements in the drilling technologies have recently enabled greater volume of gas to be produce from a single drilling site. This reduces the operational footprint, which is directly proportional to emission profile of tight gas resource. There is a knowledge gap in understanding of Green House Gas (GHG- CO2 equivalent) footprint of tight gas' resource development because of lack of operational constraints in previous environmental impact assessment of this resource. The objective of this study is to add value and reduce the scientific gap with respect to understanding of tight gas' resource development techniques, related environmental, and land impact.

There remain concerns about development of tight gas related to chemical and methane release into the local water and air, seismic events because of hydraulic fracturing and waste disposal. In order to understand this phenomenon better the work establishes the tight gas production foundation by in depth understanding of 1) Features of Tight gas reservoirs; 2) Geological environment, deposition and generation of tight gas resource; 3) Field development techniques of tight gas resource including construction, production and processing. The work then uses methodology of accounting input and out parameters of cradle to grave tight gas system boundary throughout its life cycle and understands previous GHG (CO2 equivalent) number of tight gas resource development. The work does systematic analysis and summarizes the previously published life cycle analysis to understand further the potential environmental impacts of resource development of tight gas.

This will help hydrocarbon exploration and production operators to optimize the operations of tight gas production by better understanding of each sub block of tight gas field development in terms of C02 numbers by using low carbon technologies thus reducing the potential impacts.

Keywords: Tight Gas; GHG; Life Cycle analysis (LCA); Energy Mix; CO_2 footprint

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1. Introduction

A major challenge encountered by the present age economies is to ensure environmental protection along with economic growth by decoupling environmental degradation from economic development (Commission 2008). For the sake for preserving the Mother Nature, environmental policies and frameworks have been formulated by many nations, aiming to transform environmental obstacles to growth opportunities.

Life cycle analysis (LCA) is an environmental accounting and planning methodology that addresses all forms of energy use and environmental concerns involved with an industrial system from cradle to grave (Curran 2008). In broader aspect, it is an all-inclusive approach of environmental interactions that take place in various industrial and manufacturing activities including extraction of raw material from earth, energy conversion, production and distribution through the usage, recycle and final disposal (Curran 2008).

LCA is a well-established and widely recognized tool. It was first introduced in 1969, and since then it has been considered the most reliable and effective method for analyzing the environmental impact of any product or process (Contadini, Moore et al. 2002).

2. Life cycle assessment in Tight Gas Reservoirs

2.1. Definition

According to ISO 14040 (1997), LCA is defined as compilation and estimation of inputs and outputs and their environmental effects of a product system during the course of its life cycle. Ideally, LCA evaluates the environmental effects encompassing the entire life cycle of a material system, from crude material extraction all the way up to production, processing, and utilization, recycling and handling the waste of the disposed item (Carlson and Pålsson 2001).

LCA basically provides a method that enables identification, assessment and comparison of the environmental effects of a product system or competing product systems through all phases of their life cycle (Tillman 2000).

2.2. The methodological framework of life cycle

Life Cycle Analysis (LCA) comprises of four phases:

- Stage 1: The first stage is to define the goal and scope of the study. It basically refers to how much of the product life cycle would be taken into account as well as the extent up to which the assessment would be applicable. The metrics used to evaluate the process and the different time steps are defined in this section (Muralikrishna and Manickam 2017).
- Stage 2: In this step, the inventory analysis provides a depiction of the material and energy conversion within the product system and, in particular, its interactions with the environment, materials used and emissions to the atmosphere. Subsequently, all relevant processes and supplementary energy and material flows are listed (Muralikrishna and Manickam 2017).
- Stage 3: The third stage is the impact assessment in which the results from inventory analysis are used. Indicator outcomes of all impact categories are described in this step; the value of each impact class is measured by standardization and, essentially, by weighting (Muralikrishna and Manickam 2017).
- Stage 4: The last stage is the interpretation of the life cycle that includes critical review, assessment of the quality of the information and demonstration of the findings (Muralikrishna and Manickam 2017).

2.3. Applications of life cycle assessment

Life cycle analysis (LCA) is a method for determining the environmental repercussions of a product or procedure over its life cycle. The major applications of LCA are (Muralikrishna and Manickam 2017):

- Review of the role of the product’s life-cycle stages to the entire environmental liability, typically with the goal of giving priority to improving the product and processes.
- Comparing products for internal consumption
- Finding and choosing the product life cycle that causes minimum damage to the environment.
- Aiding the decision making in business, government bodies or NGOs that set course and goals for strategic planning, product design or system change.

- Selecting essential indicators of the environmental conduct of the organization, including assessment and evaluation techniques, especially in relation to the assessment of the state of the environment
- Marketing and advertising with a reference to the creation of an environmental statement or eco-labelling

In addition to the above application, LCA uses are widespread at the public and industrial scale around the globe. For instance, The Netherlands utilizes LCA as the framework of legislative and licensing programs ((ACLCA) 2004). Integrated Product Policy (IPP) was introduced in the European Union (EU) using LCA approaches (Commission 2008). Furthermore, Vattenfall, EDF, Shell and other prominent energy companies practice LCA to assess the environmental impact of their operations or new ventures aimed at improving their environmental performance (Nie 2009).

2.4. Limitations of life cycle assessment

LCA is a comparative instrument of evaluation, not an actual measure. It lets decision makers consider all major environmental effects while deciding between different courses of action (Curran 2008).

LCA is an environmental management mechanism which advises policy-makers; however, other decision-making factors, such as cost and performance, should also be weighed in order to make a well-balanced judgment (Curran 2008).

Scarce data availability and uniqueness of each new project poses a considerable challenge (Costa D 2018). For instance, shale gas is an abundant resource; however, each shale gas play is unique. It is not necessary that a successful application of one exploitation technique would be fruitful for other plays. Although shale gas remains controversial, it can still be considered a strategic energy resource requiring a precautionary approach when considering its exploitation and exploration.

2.5. Why life cycle assessment is relevant for unconventional hydrocarbons development

Unconventional gas reserves are differentiated from conventional gas deposits by the physical characteristics of the reservoir rock and the technology and processes required for the extraction of gas from the sub surface. The complex geological properties and structures make it too complicated or uneconomic for the gas to be produced; however, the technological advances in horizontal drilling and hydraulic fracturing have paved the way for producing gas from the unconventional resources.

The notable growth of shale gas in the US and the decline in US gas prices have catalyzed the growing interest in unconventional gas exploration in other parts of the world. Many European countries hold substantial recoverable shale and tight gas reserves; besides the US, commercial drilling operations have not yet begun anywhere, but exploration activities are going on in some European countries, including the United Kingdom. Exploitation of unconventional gas resources may theoretically completely transform the global energy industry, but the future commercial development has to be focused on thorough understanding of its environmental impacts and it should be in compliance with European geological characteristics and regulations, and this is where LCA gains significance. Major environmental issues, with respect to the quantity and manner of treatment of pollutants connected with hydraulic fracturing, waste water disposal, contamination of fresh water and low well productivity, have driven several countries to prohibit unconventional gas exploration and exploitation (Tagliaferri, Lettieri et al. 2015).

The environmental apprehensions around tight-gas exploitation are close to those concerning shale gas production. This is attributed to the fact that both require horizontal drilling and fracking process for commercial production. Firstly, the drilling and fracking of these wells requires a significant quantity of water which can affect water availability for other uses or impact marine life. Additionally, drilling and fracking operations generate vast amounts of contaminated water that may involve hazardous pollutants, thereby needing treatment prior to disposal or reuse. The management and storage of waste water is a complex issue. Moreover, fracturing fluid may pollute the subsurface environment if spills or leaks occur that could result in contamination of groundwater with harmful chemicals and additives (GN&I 2005).

Environmental concerns about acidization in tight gas carbonate reservoirs are also common. The use of hydrofluoric acid for the extraction of tight gas in these reservoirs is potentially a problem precisely because of its toxic nature. A spill or leak may hurt workers and pollute groundwater for domestic usage (Kennedy 2013).

Methane gas is generated during the process of coal formation and is present in all coal seams in varying quantities. Similar to other carbon-based fossil fuels, burning CBM releases carbon dioxide into the atmosphere. Moreover, CBM extraction from coal seams also includes release of fugitive methane into the atmosphere.

In order to determine the best course of action for exploiting and producing unconventional gas with minimum environmental damage, LCA is required. The implementation of LCA in the construction, production and processing of unconventional gas resources helps in designing methods and utilizing techniques that are sustainable, thereby reducing the overall environmental impact. With the application of LCA, the process can be redesign to minimize the release of toxic and harmful waste material. LCA studies identify key materials and processes in product and process life cycles that are expected to have the major effects, including the need for capital and human health impacts. These analyses provide the complete benefits and costs of a product or system and enable decision-makers to choose the most effective solution (Brusseau 2019).

3. Tight Gas exploration and development

3.1. Characteristics of Tight Gas reservoirs

Tight gas reservoirs typically have low to ultra-low permeability. These reservoirs lack natural connectivity within the formation and can only be commercially producible after massive stimulation treatments or utilizing particular gas production techniques (Zou 2013). These unconventional gas resources are wrapped in extremely impermeable, hard rock, thereby resulting in an extremely “tight” underground formation. The matric permeability of tight gas reservoirs is generally less than 0.1 millidarcy (mD) whereas matrix porosity is less than 10% (Rajput and Thakur 2016c). Tight gas can also be trapped in sandstone or limestone formations that are atypically impermeable or nonporous, also known as tight sand (Rajput and Thakur 2016c).

Unlike conventional gas that is easily extracted from the subsurface, tight gas requires additional measures to be produced, since it is located in extremely tight formation. The formation in which the gas is trapped either has irregularly distributed pores or badly connected pores with narrow pore throats resulting in restricting the path of fluid flow (Bahadori 2014). Therefore, without implying secondary production methods, gas would flow at very slow rates and the reservoir cannot attain commercial value.

3.2. Generation and distribution of Tight Gas reservoirs

Tight gas is similar to conventional gas in terms of composition and geological setting; however, the reservoir formation has extremely low permeability, making it difficult to extract the gas than is the case for conventional high-permeability sands (Rajput and Thakur 2016c). Tight-sandstone gas are mostly continuous gas accumulation spread across a large. The gas is mostly distributed in the basin center or the deep part of the basin structure. Thus, tight gas is also known as deep-basin gas, basin-center gas, or a continuously distributed gas reservoir (Zou 2013).

Tight gas is mostly found in older formations. It is usually located in palaeozoic formations that are deposited some 248 million years ago With the passage of time, the rock formations undergo cementation and recrystallization resulting in compaction and reduction in permeability (Zou 2013).

3.3. Key techniques for Tight Gas reservoirs construction, production, and processing

Exploiting a tight gas reservoir is challenging owing to its low permeability; however, with the advancement is technology, there are new techniques and methods that can be incorporated to help produce tight gas. Artificial stimulation techniques such as fracturing and acidizing, directional drilling along with utilizing more specific seismic data can assist in tapping tight gas (Rajput and Thakur 2016c).

A significant aspect of drilling for any resource is to predetermine the success rate of the operation. Drilling a well at a certain location is not just trial and error but requires comprehensive study. Extensive seismic data is gathered and analyzed to determine where to drill and just what might be located below the earth's surface. The seismic surveys assist in identifying the sweet spot to tap tight gas reserves. Based on the survey results, the operator can determine the zone of highest porosity and permeability within the pay zone. The cost of development can minimized if wells directly hit the sweet spot (Majid 2014).

Majority of tight gas reservoirs are found onshore and can benefit from transformations undergoing in the land seismic techniques to map out drilling and development spots within the unconventional plays. Usually land seismic techniques include exploding dynamite and vibroseis, or measuring vibrations produced by purpose-built trucks Furthermore, advancements in marine seismic technologies are now being applied to land seismic surveys, enhancing the information available about the subsurface. Additionally, extensive seismic surveys help engineers in determining where and to what degree wells should be deviated (Joshi 1991).

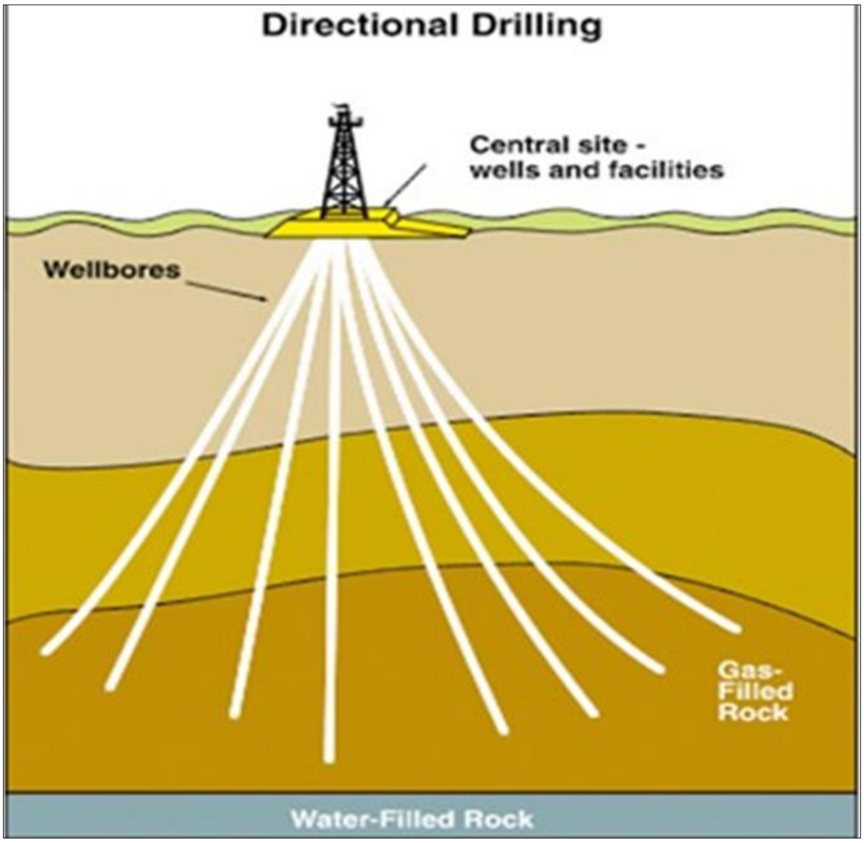

Figure 1 Schematics of directional drilling

Although vertical wells are easier to drill and incur less costs, they are not most conducive in developing tight gas. In tight gas, the aim is to maximize the contact area between the wellbore and the formation, hence making horizontal or deviated wells essential. The well can run parallel to the formation, opening up more opportunities for the natural gas to enter the wellbore.

A well-established technique for developing tight gas reserve is to drill multiple wells. The more the formation is tapped, the more the gas will be able to escape the formation. This can be achieved by using multi pad. Drilling numerous directional wells from one location reduces the operator's footprint and lowers the costs (Zou 2013). Figure 1 shows a schematic of directional drilling.

Once the well locations are chosen and wells have been drilled, stimulation techniques are employed to enhance the gas flow rate. Production stimulation can be either achieved through fracturing or acidizing the wells in tight gas reservoirs.

Hydraulic fracturing commonly known as fracking involves breaking the rock in the formation apart thereby creating a network of cracks and fractures. It is performed after the well has been drilled and completed. Fracturing fluid is injected under high pressure to break the rock and induce secondary permeability. The fractures provide the path pf least resistance for the flow of gas, thus improving the gas rate (Schlager 2004).

Another method to improve the permeability and production rates of tight gas formations is acidizing the well. It involves the pumping the well with acids that dissolves carbonates i.e., limestone, dolomite, and calcite cement between the sediment grain of the reservoir rock. This helps to revive permeability by reestablishing the natural fissures that were present in the formation before compaction and cementation (Al-Anazi, Assiri et al. 2009).

Additionally, de-liquification of the tight gas wells can help to overcome some production obstacles. In many tight gas formations, the reservoirs are filled with small amounts of water. This water can collect and undermine production processes. Artificial lift techniques such as beam pumping system to remove the water from the reservoir is usually incorporated to achieve de-liquification (James F. Lea 2011). Nonetheless, this has not proven to be the most effective way to overcome this hurdle.

Researchers and engineers are striving to develop new techniques and technologies to better produce tight gas. With their efforts, maybe one day tight gas will no longer be considered an unconventional play.

4. Previous life cycle assessment applications in tight gas reservoir

Tight and shale gas exploitation is typically opposed due to the potential impacts of hydraulic fracturing on public health and the environment. The typical environmental concerns are regarding the potential impacts of technologies on surface water and groundwater and greenhouse gas emissions. Possible ground effects, including earthquakes (or induced seismicity) have also attracted public attention (NRC 2016).

In our study, we assessed the environmental impacts and cumulative greenhouse gas (GHG) emissions associated with tight gas production. To estimate these impacts in a comprehensive way (i.e. cradle to grave) we developed a life cycle assessment (LCA) model of a representative tight gas field. The scope of the study includes setting up of well and related infrastructure, drilling and production operations up to gas compression and processing. The three major phases of resource development i.e. construction, production and processing are considered in this study.

Prior to describing the developed Life cycle inventory model of the tight gas field under study in the subsequent chapters, we will first discuss some previously existing studies of GHG emissions pertaining to tight gas plays.

Laurenzi et al. conducted a comprehensive study (i.e. cradle to grave) of a tight reservoir to estimate the environmental impacts associated with drilling and production including flaring. This LCA study is conducted in accordance with International Organization for Standardization (ISO) guidelines. LCA provides scenarios of the environmental impacts of the goods and processes in terms of their purpose or use, thereby allowing comparisons between alternatives. According to their study, over recent years, hydraulic fracturing and horizontal drilling have been used to produce crude oil and gas from tight deposits, including the formation of Bakken. There is an increasing interest in recognizing the greenhouse gas (GHG) emissions associated with the production of tight oil and gas. In this study, a life cycle assessment of Bakken crude using data from operations throughout the supply chain, including drilling and completion, refining, and use of refined products has been performed. The results conclude that if the associated gas is collected throughout the Bakken well life cycle, then the well to wheel GHG emissions are estimated to be 89 g CO2eq/MJ (80% CI, 87–94) of Bakken-derived gasoline and 90 g CO2eq/MJ (80% CI, 88–94) of diesel. On the other hand, if associated gas is flared for the first 12 months of production, then life cycle GHG emissions increase by 5% on average (Laurenzi, Bergerson et al. 2016).

Another significant study is conducted by Sell et al. to estimate the energy return over energy invested for tight gas wells in the Appalachian Basin. The upstream energy cost of providing gas has been assessed. Among the material examined, steel and diesel fuel comprised of over two-thirds of the energy cost for well construction. According to their findings, average energy cost per foot for a tight gas well in Indiana County is 0.59 GJ per foot. The energy return over energy invested ratios (EROI) are calculated using the available production data. The EROI are between 67:1 and 120:1, depending upon the material consumed, drilling time and varying production. Nonetheless, taking into account inputs such well treatment chemicals, manufacturing of drill bits and drill pipe, post-gathering pipeline construction, and well completion maintenance would reduce EROI by an unknown amount (Sell, Murphy et al. 2011).

National Energy Technology Laboratory published a report regarding Life Cycle Analysis of tight gas extraction and power generation. This research builds on previous life cycle analysis (LCA) of tight gas generation technologies conducted by the National Energy Technology Laboratory (NETL). This describes in detail the GHG pollution from the production, refining and distribution of various sources of tight natural gas to end users and the combustion of that gas for power generation. The greenhouse gas emission inventories are generated for the 2010 average combination of natural gas production and also for natural gas extracted from the next highly productive well for each natural gas resource (NETL 2014). The setting up of a tight gas well include well drilling, followed by the installation of the well casing. Directional drilling is performed for exploiting tight gas reserves where hydrocarbons are stored throughout a matrix of shale or coal or are present in ultra-low permeability carbonate or sandstone in case of tight gas. Typically, a modern drilling rig has a drilling speed of 17.8 meters per hour that results in the drilling of a 7,000 foot well in approximately 10 days (NETL 2014). Moreover, a diesel engine used for oil and gas operations has a power of 700 horsepower and a heat rate of 7,000 Btu/hp-hour (EPA 1995). The methane emissions from well installations are a combined outcome of heat rate of the drilling engine (7,000 Btu/hp-hour), methane emission factor for diesel combustion in stationary industrial engines (6.35E-05 lb/hp-hour) (EPA 1995), and total drilling time in hours (NETL 2014). The emissions of gas during well completion occur during the construction of the well before the production of natural gas has commenced and mounting of other equipment at the well. Well completion is an occasional emission; it is not part of a day-to-day, steady-state well activity; however, it is a major emission that occurs once in a well's lifespan.

As stated in the report, conventional wells produce 37 Mcf/completion, tight gas wells produce 3,600 Mcf/completion, shale wells produce 9,000 Mcf/completion, and coal bed methane wells produce 50 Mcf/completion (NETL 2014).

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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