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Resource classification of coal bed methane and its contribution in energy transition and decarbonization path of oil and gas industry (A synopsis of CBM Life Cycle Analysis)

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Abstract

World economies are becoming increasingly more dependent on energy and countries have a voracious appetite for energy therefore, the need for an abundant clean energy is becoming a necessity. Energy companies are challenging environmental costs of coal bed methane as with advancement of new technology the impact from production of coal bed methane can reduce and to a certain extent avoided or offset. Production of coal bed methane results in changes to the land, to surface water and to ground water systems. Carbon quantification is required to understand, monitor and manage these changes. Previous life cycle analysis for this resource class has lack of process design details because of which there is a knowledge gap in understanding of emission profile of coal bed methane's production. The objective of this study is to add value and reduce the scientific gap with respect to the production techniques of coal bed methane and its environmental impact.

Removal of water continuously from coal seams depletes ground water and may eventually lower surface water flows (streams and rivers). It can also change the flow of groundwater drawing fresh water into the coal seams. To better understand this phenomenon the work establishes the Coal Bed Methane production foundation by in depth understanding of

- Coal Bed Methane reservoir types;
- Coal Bed Methane depositional environment, generation, and geological distributions;
- Coal Bed Methane resource energy supply methods by understanding its construction, production and processing.

The study then uses Life Cycle Assessment approach and understands previous emission numbers of Coal Bed Methane's 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 Coal Bed Methane.

This will help energy companies to understand the field development, production, and operations of coal bed methane's resource in terms of carbon numbers thereby optimizing the operations through carbon management thus reducing the potential impacts.

Keywords: Life Cycle Analysis; Energy Transition; Sustainability; Coal Bed Methane; Decarbonization

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1. Introduction

Life cycle assessment enables us to make informed choices in any kind of environmental management. The entire life cycle of valuable goods, products and services, and processes from cradle to gate is considered in the environmental impact study. LCA aids in identifying the process key elements that are the process units that often add to the environmental burden (Tagliaferri, Lettieri et al. 2015). The technologies and processes that have contributed to the recent boom in unconventional gas production have also drawn attention to the environmental impacts of their use. Using the existing state of knowledge of the production, processing, and distribution of shale gas, tight gas and coal bed methane and conventional natural gas, we have assessed life-cycle greenhouse gas emissions associated with construction, production, and processing phases. This life-cycle analysis provides insight into the major stages in the unconventional gas exploitation. The life cycle assessment essentially provides the insights about processes responsible for emissions and the opportunities to reduce the carbon footprint (C.E. Clark 2011). This chapter presents the methodological outline proposed for an LCA model for extracting unconventional gas.

2. Guiding Principles in Development of Coal bed Methanne LCA methodology

The aim of this research is to develop a new and unique integrated LCI model for unconventional gas mainly shale gas, tight gas and coal bed methane in a consistent and transparent manner, which integrates geological system characteristics with a surface operations emission model. The purpose of the LCI model is to estimate the overall GHG emissions during the life of the field and corresponding facilities (Nie 2009). The essential principle used in the development of this methodology can be summarized as:

Transparency – To depict accurately how life-cycle impacts are measured, the variability involved with the outcomes and the degree to which inputs / outputs of any unit process have been completely quantified.

Comprehensiveness – To identify all inputs / outputs that may result in significant environmental impacts.

Consistency of methodology – Consistent models and underlying assumptions in order to have fair comparison between different techniques of construction, production and processing of unconventional gas.

In order to conform to the above listed guidelines, much of the research effort has been made to identify and characterize the potential sources of emissions associated with the whole gas extraction process by taking into account the complex subsurface features, development strategy, modelling approach and production techniques necessary for exploiting an unconventional gas resource. The key factors considered to have an important role in assessing the extent of the emissions and the environmental impacts are:

- Subsurface (geological) structure and reservoir features of each unconventional gas resource
- Initial gas in-place and production rates
- Number of wells, life span of wells and design of production facility that has a direct effect on the emission profile during the life time of the project
- Calculating EUR (Estimated Ultimate Recovery) using analytical and numerical modeling

Surface emissions model based on engineering design and operational parameters to estimate the GHG as well as other emissions (direct and indirect; gaseous, liquid, solid waste) and resource use (materials, energy, water) from site construction, well drilling, hydraulic fracturing, well completion, well head operations, gas gathering and gas processing

3. Coal bed Methane System Boundaries and Level of Detail Considered

3.1. System Boundaries

The system boundaries determine which life-cycle stages and the processes attributable to those stages are included in the assessment. The findings of the research including emissions and environmental impacts of the activities involved largely depends upon the life cycle boundaries.

The entire life cycle of the unconventional gas production including exploration, drilling, fracturing, well production, processing, and combustion has been taken into account. Further attributable process associated with each activity include indirect activities of energy, chemicals and water production and recovery and final disposal of toxic waste material. The following phases are considered during the construction, production and processing domains,

- Field and well site exploration and investigation
- Preparation and construction of road and pathways
- Construction of well pad
- Well drilling – transportation of materials; production using raw material; energy required during drilling; Emissions from equipment; emissions during drilling; casing and cementing; disposal of drilling wastes
- Fracking – transportation and production of water, chemicals and sand needed for fracturing; energy used during fracking operations and emissions from machinery; disposal of wastes
- Well completion - Energy and materials required; installation of well head, disposal of produced water from the well; emissions of natural gas during well completion, workovers, liquid unloading; re-fracturing
- Production – Processing, separation, dehydration
- Pipeline construction and transmission
- Postproduction - Decommissioning, plugging, and removing of equipment

3.2. Environmental Flows Quantified

This research is aimed at considering all the elements/substances of environmental concern from their point of entry to their partition and final emission into all environmental compartments (atmosphere, soil or water) during unconventional gas construction, production and processing. The key pollutants and sources of emissions are listed in Table 2.

Table 1 Major Emissions during various development phases of an unconventional gas field (Tagliaferri, Clift et al. 2017)

Activity/ Component	**Unit**
Water for hydraulic fracturing	M3
Sand for fracturing (silica, quartz, sand)	kg
Additives of fracking fluids	
Acid: hydrochloric acid or muriatic acid	kg
Friction reducer: petroleum distillate	kg
Surfactant: isopropanol	kg
Clay stabilizer/controller: potassium chloride	kg
Gelling agent; guar gum or hydroxyethyl cellulose	kg
Gelling agent; guar gum or hydroxyethyl cellulose	kg
Scale inhibitor: ethylene glycol	kg
PH-adjusting agent: sodium bicarbonate and sodium potassium hydroxide	kg
Breaker: ammonium persulfate	kg
Cross linker: borate salts	kg
Iron control: citric acid	kg
Bactericide/biocide: glutaraldehyde	kg
Corrosion inhibitor	kg
Flow back disposed to industrial treatment	kg
Energy requirements for the freeze-thaw evaporation process	kWh
Energy requirements for pumping the hydraulic fracturing fluids in the well – Diesel	kg
Emissions for pumping the hydraulic fracturing fluids in the well	
CO_2	kg
SO_2	kg

Nox	kg
PM	kg
CO	kg
NMVOC	kg
Materials used for horizontal drilling	
Steel	kg
Portland cement	kg
Gilsonite (asphaltite)	kg
Diesel fuel	kg
Bentonite	kg
Soda ash	kg
Gelex	kg
Xanthum gum	kg
Water throughput	kg
Emission due to horizontal drilling	
CO_2	kg
SO_2	kg
Nox	kg
PM	kg
CO	kg
Potential emission due to well completion and workover	
CH_4	g CH_4
CO_2	g CO_2
C_2H_6	g C_2H_6
C_3H_8	g C_3H_8
N_2	g N_2

3.3. Functional Units

Functional units for LCA directly affect the interpretation of the findings of LCA. In our report, we used three functional units: per megajoule (MJ) of fuel burned, per kilowatt-hour (kWh) of electricity produced, considering that electricity generation is an end-use of shale gas and natural gas, and per mile for transport services, aiming the transport sector for expanded gas use. The latter two units take into account the efficiency of energy conversion into energy supplies, as well as the output and pollution of energy generation (C.E. Clark 2011).

4. Coal Bed Methane (CBM) exploration and development

4.1. Characteristics of CBM reservoirs

Coal Bed Methane is a type of unconventional gas that is found in coal deposits or coal seams. Contrary to unconventional reservoirs, coal seams serve as the source, trap and reservoir for coal bed methane. There are significant differences in terms of reservoir characteristics, gas storage mechanisms, flow mechanisms and production profiles between conventional gas reservoirs and CBM (Rogers 1994).

CBM is stored is a in a layered structure having an orthogonal fracture set called cleats, which are perpendicular to bedding. CBM can only be produced economically if there is sufficient fracture permeability, since coal matrix is essentially impermeable. Coal seam permeabilities are usually low and with permeability contrast of three orders of magnitude in wells separated by distances of less than 500 m (Rajput and Thakur 2016c). Hydraulic fracturing or cavity completions are needed for efficient production of CBM.

A dual porosity system is found in coal seams i.e. micro pores (within the coal matrix) and macro pores (fractures, coal cleats). Gas is stored in the following ways (Rajput and Thakur 2016b),

- Free gas within the pores and fractures
- Adsorbed to the coal surface
- Adsorbed within the molecular structure of coal

Coal gas is generated in-situ and is adsorbed physically to the coal surface. Since coal has significant micro porosity, there is plenty of surface area available for sorption. It is estimated that one kilogram of coal contains a surface area of more than 100,000 m2 (Rogers 1994). Cleats present in coal seams are initially filled with water and/or gas that keeps gas adsorbed to the coal matric. As the water is produced, pressure is lowered in the cleats, allowing gas to desorb from the coal surface. Many of the CBM wells initially produce large volumes of water and small volume of gas. As the production continues, water volume decreases and the gas rate increases (Tushar Ghosh 2009).

4.2. Generation and distribution of CBM reservoirs

When plant material deposited in swamps or swampy lakes undergo chemical and bacterial changes and forms peat. As the layers of mud and sand are deposited over peat and it is buried deeper, over the geologic time scale, peat changes to brown coal then bituminous coal and eventually hard anthracite coal. This process is known as coalification process that generates CBM as well. A huge portion of methane gas generated by the coalification process escapes to the surface or migrates into adjacent reservoir or other rocks, but a significant volume remains trapped within the coal itself (Rajput and Thakur 2016c).

During the coalification process, the decomposed organic material produces methane gas, along with nitrogen, carbon dioxide, and additional gases. The pressure on coal increases which helps in storing the gas in the coal. CBM contains negligible amount heavier hydrocarbons fractions, such as propane or butane, and no natural gas condensate, which is often found in conventional natural gas. Although, it may contain carbon dioxide (Rajput and Thakur 2016c).

Unlike conventional reservoirs, the primary trapping mechanism for CBM is hydraulic pressure rather than a pressure seal or closed structure. The gas content increases with the depth of coal seam and also with its geological age. As the depth of the coal seam increases, the pressure level also increases thereby reducing the permeability, causing the methane to be much more tightly bound to the coal and surrounding rock (Rajput and Thakur 2016c).

4.3. Key techniques for CBM reservoirs construction, production and processing

Coal bed methane can be extracted from subsurface coal deposits prior to mining operations as well as during the process and after it. It can also be recovered from un-minable coal deposits that are comparatively deep, thin or of varying quality (EIA 2017).

A horizontal or vertical well is drilled into a coal seam in the similar manner as drilled in other gas reservoirs. Cased hole completions are employed where the sides of the wells are cased with cemented steel pipe. Perforations are then created into the casing to allow the natural gas to flow through the well bore and up the casing to the surface. The well is typically equipped with a large water pump to reduce the hydrostatic pressure within the coal seam and release the adsorbed gas. Water is produced to surface up the production tubing, whereas CBM gas is produced up the annulus. Produced gas is then sent to a compressor station. Produced water is either reinjected into isolated formations, released into streams, used for irrigation, or sent to evaporation ponds (Rajput and Thakur 2016c).

The production trend of coal bed methane is complex and it is hard to predict the production profile in the early stages of recovery. Reservoir engineering principles along with reservoir simulation can be useful to assess gas content, sorption time, thickness and hydrostatic pressure among other factors. Although this is considered an optimum development strategy, any individual factor can be affected by unpredictable circumstances in sub surface profile (Pramod Thakur 2014) .

Another concern regarding CBM production is the potential effect of water discharge on downstream water resources. The produced water along with gas is highly saline and disposal of this water is challenging. The reinjection of this water could have adverse effects on fresh water ecosystem (Council 2008).

5. Previous life cycle assessment studies in coal bed methane (CBM)

Coal bed methane is extracted by drilling a vertical well and then drilling directionally along the coal seam. Depending on the geology of the coal seam, CBM can be extracted in two ways:

- Gas can be extracted by 'dewatering' without hydraulic fracturing, if coal seams are thin, shallow and already fractured. The coal seam is drained by pumping out the formation water, which allows the methane to flow from the coal bed.
- Hydraulic fracturing is required to produce the gas if the coal seems are deeper, or less fractured, then hydraulic fracturing. This requires a different well design and more horizontal wells to be drilled.

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 our study, we assessed the environmental concerns and cumulative greenhouse gas (GHG) emissions accompanying CBM extraction by developing a life cycle assessment model according to ISO standards. Life-cycle assessment (LCA) refers to the aggregate quantity of greenhouse gas emissions including direct emissions and significant indirect emissions. This LCA includes all the process related to construction, extraction and processing of coal bed methane.

Prior to developing our model, we conducted a thorough review of the literature and publications regarding the emissions and environments concerns regarding CBM extraction. The below paragraphs summarize the extraction of authentic publications and reports which contain cradle-to-gate assessment of greenhouse gas emission of Coal bed methane, covering; production values, emission values and processes applied to achieve these values.

According to the research study by Hardisty et al., the total GHG emissions for Australian CSG exported from Queensland to China, were 0.069 t CO_2-e pa/GJ for the production of 10 Mtpa. The operations included; drilling, sampling, hydraulic fracturing, gas treatment, compression, high pressure transmission, transportation, regasification and combustion (Paul E. Hardisty 2012). In another study by Skones & Littlefield regarding the environmental impact of CBM, it has been stated that the total emissions were 7.8 g CO_2e/MJ. The sources for the emissions include well construction, well completion, workovers, extraction, acid gas removal, dehydration, processing, pipeline construction and fugitive emissions (Tim Skone 2013). Clark et al. published a report that concludes that the total CSG emissions of Australia were 4.268 t CO_2-e/ton product for the production value of 10 Mtpa. Life cycle processes comprise; exploration, construction of processing plant, pipeline operation, plant operation, shipping, regasification and combustion (T. Clark 2011). A discussion paper published by Kember O, states that between year 2012 and 2020, production of CSG in Eastern Australia would be ~750-2600 PetaJoules, whereas, possible estimated emissions would be ~7.5 to 22 Mt CO_2-e. In this paper, Kember O. challenges the accuracy of the production value (i.e. 241370 MJ per annum) provided by Hardisty et al. in 2012 due to lack of availability of data. Moreover, processes applied throughout the cycle involves vertical, horizontal or directional drilling, fracturing, processing, transportation and consumption (Kember 2012).

A report published by Day et al. in 2012 compiles that the main sources that triggered fugitive GHG emissions from CSG of Australia involve; exploration drilling, well construction, hydraulic fracturing, venting, flaring, equipment malfunctions or failures, transmission, storage and distribution. According to the authors, the emission value is ~28.7MtCO_2-e per annum while the production value is 900 kg CO_2-e/MWh (Stuart Day 2012).

Another significant study has been conducted by Pace Gobal in 2015. It compares the data of LCA-CBM of five major countries i.e. Japan, South Korea, Western Europe, India and China. Potential sources that caused GHG emissions includes earthmoving, shaft/drift access and ventilation development, underground drilling and blasting, the breakage and sizing of coal, workshop, power plant operations, extraction and transport of coal at the mine site, wind erosion, transportation through road/ rail/ship either within the country of origin or for export purposes and power generation. Comparing the total GHG emission value of each country clearly proves that China has the highest emission values for both average plant case i.e. 1.499 tons/MWh and new plant case i.e. 1.158 tonnesCO_2e/MWh. On the other hand, Europe has the lowest value for average plant case i.e. 1.071 tonsCO_2e/MWh and India has the lowest emission value for new plant case i.e. 0.87 tonsCO_2e/MWh. After China, for average plant case; South Korea, Japan and India have emission values 1.391 tonsCO_2e/MWh, 1.304 tonsCO_2e/MWh, and 1.279 tonsCO_2e/MWh respectively. Excluding China, for the new plant case; Japan, South Korea and Europe have emission values 1.117 tonsCO_2e/MWh, 1.112 tonsCO_2e/MWh, and 0.95 tonsCO_2e/MWh respectively (Gobal 2015).

(S&T)2 consultants Inc. created a model considering the emissions data of almost a decade i.e. from year 2000 to 2011. The study involves comparison of upstream GHG emissions and the total reported CBM emissions are 7201 gCO_2eq/GJ at Burner. According to the study, processes that caused these emissions were fuel distribution and storage, feedstock recovery, gas leaks and flares and CO_2 and H_2S removed from NG (Inc. 2011).

6. Conclusion

In conclusion, coal bed methane (CBM) extraction in the United States and around the globe offers a multifaceted benefit by positively impacting both the economy and emission reductions. Economically, CBM extraction stimulates local economies through job creation, royalties, and tax revenues, thereby enhancing economic growth and energy security. Moreover, CBM serves as a bridge fuel, providing a cleaner alternative to traditional coal while complementing the transition to renewable energy sources. Overall, the responsible development of coal bed methane represents a valuable opportunity to foster economic prosperity while advancing environmental sustainability in the United States.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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