Geological life cycle inventory model development for shale gas resources

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Abstract
Reducing the environmental impact of oil and gas extraction is a key priority for the Oil and Gas (O&G) sector. In relation to the extraction of fossil fuels, the industry needs to evaluate options for reducing greenhouse gas (GHG) emissions, develop project plans and implement emissions reduction options either voluntarily or to comply with regulatory requirements. Published life cycle studies of shale gas production are estimating greenhouse gas (GHG), and sometimes other emissions, considering only the surface engineering design and operational activities (surface constraints) while disregarding completely the subsurface geological constraints, as well as lacking engineering design detail (Brown et al., 2016; Howarth et al., 2011; Hultman et al., 2011; Jiang et al., 2011; Burnham et al., 2011; Stephenson et al., 2011).

This paper presents an innovative life cycle assessment approach for shale gas production, which integrates geological system characteristics with a surface emission model to estimate the overall GHG emissions. Firstly, the model developed incorporates a Volumetric Estimation technique, Flowing Material Balance and Advance Decline Curve analysis to estimate the field gas in-place and estimated ultimate resource (EUR). Next, this geological model is integrated with the surface emission model, which is 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, drilling, hydraulic fracturing, well completion, well head operations, gas gathering and gas processing. Figure 1 demonstrates the subsurface Life Cycle Inventory Model workflow for shale gas as an example.

The cradle to gate LCA model developed was applied to the Fayetteville shale gas field using public domain data. The Fayetteville Shale is situated in the Arkoma Basin of Northern Arkansas and Eastern Oklahoma at a depth range of around 1,000 to 7,000 ft (300 to 2,100m) with a net pay thickness of 20-200 feet (Hayden and Pursell, 2005). Development of the Fayetteville shale began in the early 2000’s following earlier success in the Barnett Shale of the Fort Worth Basin and the implementation of adapted horizontal drilling and hydraulic fracturing techniques. The gas content for the Fayetteville shale has been measured at 60 to 220 scf/tonne, which is less than the 300 to 350 scf/tonne gas content of the Barnett shale (Browning, 2014).
In order to assess the life cycle performance of the Fayetteville shale gas resource, an area of operations within the basin, featuring a total of 4,741 wells in the play since its commencement in 2004, was selected. The first part of the analysis involved using the publicly available data (Middleton et al., 2017) for the volumetric estimation analysis using the model developed in this research. The estimated value for recoverable reserves of 3.30 Tcf is in good agreement with the reported 2.99 Tcf natural gas produced until 2016.

In the second step, the Flowing Material Balance Equation (FMBE) analysis was implemented to determine the initial gas inplace per well for the play; the production history was matched by tuning the power law decline parameters; and the matched parameters were used to predict the future well production performance. Based on these analyses, the estimated EUR per well was determined as approximately 680 MMscf.

The subsurface model developed was then used to predict the number of wells and expected well life. The power law decline curve model results provided a good estimate of the number of wells required to exploit the resource (4,858), which is in good agreement with the reported numbers (4,741) in the literature.

Three possible field development strategies were developed and implemented in the life cycle inventory model developed. They all comply with the outputs of the subsurface constraint inventory model but differ in terms of selected parameters in well construction, well drilling, hydraulic fracturing, well completion, well head and surface facilities operations.

Figure 2 illustrates the annual GHG emissions of Fayetteville shale gas field production with a sensitivity analysis for three different field development strategies. The resulting life cycle GHG emissions range between 12.79 and 21.09 CO₂ equivalents per Mscf of gas produced or 13.65 to 22.51 CO₂ equivalents per MJ of gas produced. The water consumption is estimated in the range of 18 litres of water per Mscf of gas production.
Figure 2. Annual and cumulative GHG emissions for the three Fayetteville shale development case studies.

References