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Measuring methane emissions from abandoned and active oil and gas wells in West Virginia

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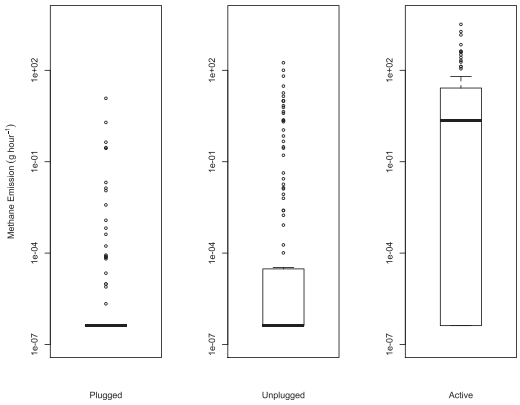
HIGHLIGHTS

- WV CH_4 emissions of plugged, unplugged and active wells were 0.1, 3.2 and 138 g CH_4 h^{-1}.
- Methane emissions were higher at active wells compared to plugged and unplugged abandoned wells.
- We estimate the number of abandoned wells in WV at between 60,000 and 760,000.
- Average emission from active wells was 7.5 times larger than the EPA emission factor.
- Well emission can vary along geologic formation and be affected by state regulations.

GRAPHICAL ABSTRACT



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ABSTRACT

Recent studies have reported methane (CH_4) emissions from abandoned and active oil and gas infrastructure across the United States, where measured emissions show regional variability. To investigate similar phenomena in West Virginia, we measure and characterize emissions from abandoned and active conventional oil and gas wells. In addition, we reconcile divergent regional CH_4 emissions estimates by comparing our West Virginia emissions estimates with those from other states in the United States. We find the CH_4 emission factors from 112 plugged and 147 unplugged wells in West Virginia are 0.1 g CH_4 h^{-1} and 3.2 g CH_4 h^{-1}, respectively. The highest emitting unplugged abandoned wells in WV are those most recently abandoned, with the mean emission of wells abandoned between 1993 and 2015 of 16 g CH_4 h^{-1} compared to the mean of those abandoned before 1993 of 3×10^{-3} g CH_4 h^{-1}. Using field observations at a historic mining area as a proxy for state-wide drilling activity in the late 19th/early 20th century, we estimate the number of abandoned wells in WV at between 60,000 and 760,000 wells. Methane emission factors from active conventional wells were estimated at 138 g CH_4 h^{-1}. We did not find an emission pattern relating to age of wells or operator for active wells, however, the CH_4 emission factor for active conventional wells was 7.5 times larger than the emission factor used by the EPA for conventional oil and gas wells. Our results suggest that well emission factors for active and abandoned wells can vary within the same geologic formation and may be affected by differences in state regulations.

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Therefore, accounting for state-level variations is critical for accuracy in greenhouse gas emissions inventories, which are used to guide emissions reduction strategies.

1. Introduction

Methane (CH_4) is a greenhouse gas and the largest component of natural gas. In 2013, bottom up approaches estimated over 6 Tg of CH_4 leaked from US natural gas systems, including emissions from production, processing, transmission, storage and distribution (US EPA, 2017). Discrepancies have been found between top-down and bottom-up CH_4 emission estimates (Schwietzke et al., 2014; Caulton et al., 2014; Zavala-Araiza et al., 2015), and recent studies suggest inventories may be missing sources (Brandt et al., 2014) or emission variability may exist (Lavoie et al., 2017) resulting in unrepresentative emission factors used to generate bottom up estimates from active CH_4 extraction processes. Many recent studies have focused on CH_4 emissions from unconventional oil and gas production. However, to make a comprehensive CH_4 emission estimate, improved emissions estimates are needed from other parts of the oil and gas sector such as the conventional oil and gas industry. Here, we focus on abandoned and active conventional oil and gas wells and state-level variations in their CH_4 emissions.

One recent addition to GHG inventories is the CH_4 emission from abandoned oil and gas wells. This may be a significant omission and it is estimated that between 40 and 70 Gg CH_4 $year^{-1}$ is emitted from abandoned wells in Pennsylvania (PA) alone (Kang et al., 2016). Even though West Virginia (WV) neighbors PA, differences in state law lead us to suspect that emission factors, used in bottom up inventories, for plugged and unplugged abandoned wells in WV may differ from those estimated for PA, for example, state regulation for plugging abandoned wells differs between PA and WV. In PA all wells plugged in the coal areas must be vented, whereas in WV only wells that have the protective casing inside the wellbore cemented to the surface have to be vented (WV Code, 2015). Measured emissions from plugged abandoned wells in PA coal areas (43 g CH_4 h^{-1} $well^{-1}$) are significantly larger than estimates of 0.045 g CH_4 h^{-1} $well^{-1}$ for plugged wells in non-coal areas (Kang et al., 2016) and we investigated if this is similar for WV, given the differences in state regulations. Methane emission factors from unplugged abandoned wells in the Appalachian Basin are reported as 17 g CH_4 h^{-1} $well^{-1}$ in northwestern PA (Kang et al., 2016), 24 g CH_4 h^{-1} $well^{-1}$ in Hillman State Park, PA (Pekney et al., 2018) and 28 g CH_4 h^{-1} $well^{-1}$ in Ohio (OH) (Townsend-Small et al., 2016).

In addition to the effects of differences in state regulations, the actual numbers of abandoned wells in WV is highly uncertain and could significantly affect the CH_4 emission estimates. Currently, the PA Department of Environmental Protection lists 31,000 abandoned wells state-wide; this is in contrast to a recent estimate of between 470,000 and 750,000 abandoned wells (Kang et al., 2016). In Appalachia, the first oil wells were drilled in the mid 19th century with oil fields mainly found in rural areas. Drilling was enthusiastically pursued throughout the late 19th and early 20th centuries with few records kept on the numbers and locations. In 2016, the WV Department of Environmental Protection (WV DEP) recognized 11,000 unplugged and 58,000 plugged abandoned gas and oil wells. Accurate well numbers are critical for estimating total state-wide CH_4 emissions from abandoned wells.

Fugitive CH_4 emissions from active conventional wells in WV are also important, given that it is the 8th largest natural gas producing state in the US. West Virginia produced nearly 30 Tg of CH_4 in 2015, with 3 Tg of CH_4 extracted by the 58,000 active conventional wells and the remainder by unconventional methods (DUKES, 2015). Currently, an average CH_4 leakage emissions factor of 18 g CH_4 h^{-1} (US GHG Inventory, 2015) per active conventional wellhead is used by the EPA to estimate fugitive CH_4 emissions from conventional oil and gas wells (EPA GHG BAAM, 2015). This emission factor is not state-specific and is used across the country. Methane leakage from active conventional wells in Doddridge county, WV is estimated at of 11% of production with the main cause of CH_4 leakage attributed to avoidable process operating conditions, i.e. unresolved equipment maintenance issues (Omara et al., 2016). We conducted additional measurements to investigate patterns in fugitive emissions, such as age, flow rate and operator, and expanded geographic coverage to include 13 counties other than Doddridge: Tyler, Marion, Taylor, Braxton, Barbour, Webster, Gilmer, Ritchie, Lewis, Wetzel, Harrison, Upshur and Wood Counties (Fig. 1).

To put these CH_4 emission estimates into a state-wide context, in 2014 it was estimated that 1.15 Tg CH_4 was emitted from WV (WRI CAIT 2.0, 2013). Most of the CH_4 was emitted from the energy sector, 95%, with smaller amounts from industrial processes, agriculture and waste, 2.5%, 1% and 1.5%, respectively. Using the EPA emissions factor of 18 g CH_4 $year^{-1}$ $wellhead^{-1}$, it is estimated that 58,000 active wellheads in WV emit 9 Gg CH_4 $year^{-1}$, or 0.8% of the annual WV CH_4 emissions.

In this study, we measure CH_4 emissions from active and abandoned conventional gas and oil wells in WV. Our objectives are to: 1) Investigate the magnitude of CH_4 leaks from abandoned (plugged and unplugged) wells in WV and compare these emissions to neighboring states to investigate inter-state differences; 2) evaluate CH_4 leakage at operating conventional gas wells in WV at the wellhead and 3) use observations at a historic mining area as proxy for state-wide drilling practices to estimate the total number of wells drilled in WV between 1860 and the present generating under reporting factors, which can be used to scale-up historical reported data to an estimate of the total number of wells drilled. To our knowledge this is the first time that fugitive CH_4 emissions from active and abandoned conventional gas production activities in WV have been comprehensively investigated.

2. Methods

2.1. Methane emission factors – West Virginia

To calculate an emission factor for CH_4 emissions from plugged abandoned, unplugged abandoned and active oil and gas wells, methane emissions are measured from wells throughout West Virginia. The emission factor corresponds to the mean of the individual emission rates, because when it is multiplied by the total number of wells, it should give the total overall emissions. Therefore, following the methods of Kang et al. (2014, 2016) and Townsend-Small et al. (2016) that already calculate emission factors in this field, we will add up the individual emission values in the data set and then divide by the number of wells. This mean will be presented as the emission factor with the 95% upper confidence limit as calculated by a statistical bootstrapping analysis (R package 'boot'). We also note that, from previous studies (Kang et al., 2014; 2016; Townsend-Small et al., 2016), it is anticipated that these data will be heavy right-skewed and will not be normally distributed.

2.1.1. Site selection

We measured CH_4 emissions from active and abandoned oil and gas wells in WV and focused our efforts on counties in the north central region of the state where the first oil and gas wells were drilled and which still has the highest concentration of oil and gas production, as shown in Fig. 1. For the purposes of this study we classify our measurement targets into three types: 1) plugged and abandoned conventional wells