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Methane emissions from oil and gas transport facilities – exploring innovative ways to mitigate environmental consequences

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ABSTRACT

Climate change impacts are increasingly becoming more evident e.g. through heavy rainfall episodes and subsequent flooding. Methane is a significant greenhouse gas that has been linked to these impacts and the oil and gas industry is a major source of anthropogenic methane emission. Recent studies have suggested that the tropical region hold some unexpectedly high methane concentration and that the recent changes in the global methane burden are poorly understood. To address this research gap, we present a first effort to quantify methane emissions from one of the most vulnerable oil and gas infrastructures in Nigeria (a tropical country). A combination of the Intergovernmental Panel on Climate Change tier-1 approach and an adapted Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model was used to estimate methane emissions from the system 2C transport pipeline. We then tested the hypothesis of no significant change in methane emissions trend from the pipeline using the between group *t*-test inferential analysis. Key findings include: (a) a crude oil throughput of 55,143 to 1,500,500 barrels (8767 to 238,561 m^3) emitted methane ranging from 0.04734 to 1.288MT (± 50 to 200%) respectively, and (b) surprisingly, methane emissions along the system 2C pipeline seem to have continued without significant change between 2005, and 2008 to 2012 despite the low crude oil throughput in 2009. This indicates the likelihood of continuous but rising methane emissions from the pipeline network over a six-year period; and only further research can ascertain if similar trend can be observed elsewhere in the tropical region. These findings are unique and contribute to the current global debate on methane emissions from the largely unmonitored tropical region. Therefore, we recommend that stakeholders should set up a study plan for the identification and continuous monitoring of methane emissions from the key oil and gas infrastructure and explore opportunities for geoengineering applications as part of climate change mitigation. Coordinated engagement in international schemes such as the Natural Gas STAR program, Climate and Clean Air Coalition, Global Methane Initiative amongst others would promote strategic and measurable methane reduction plans in Nigeria and other countries within/outside the tropical region.

1. Introduction

Methane (CH_4) is one of the six greenhouse gases (GHGs) being mitigated under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). The others are carbon dioxide (CO_2), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Atmospheric concentration and sources of CH_4 are not particularly well understood or well quantified, and they are highly disputable (Frankenberg et al., 2005; Miller et al., 2013). Also, official inventories underestimate actual CH_4 emissions (Brandt et al., 2014) despite, yet again, a rising global trend of CH_4 (Nisbet et al., 2014).

Although CO_2 emissions account for 55–60% of present man-made radiative forcing (IGSD, 2013), recent studies have identified non-CO_2, but short-lived, climate pollutants such as CH_4, black carbon aerosols (BC), tropospheric ozone (O_3) and HFCs as equally important in reducing climate change impacts (e.g. IGSD, 2013; Xu et al., 2013). Radiative forcing is caused when CH_4 and CO_2 absorb thermal radiation from the earth system (Frankenberg et al., 2005). Approximately 20% of the increase in radiative forcing by anthropogenic

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GHGs since 1750 is due to CH_4 emissions (Nisbet et al., 2014). According to the Intergovernmental Panel on Climate Change (IPCC) (2007), the global atmospheric concentration of CH_4 rose from a pre-industrial value of 715 parts per billion (ppb) to 1732 ppb in the early 1990s and 1774 ppb in 2005, i.e. a rise of about 150%. This is of concern given that the lifetime of CH_4 once released into the atmosphere is about 12 years (Xu et al., 2013), and it is 25 times more potent at trapping atmospheric heat than CO_2 over a 100-year timescale (IPCC, 2007). Clearly, methane is crucial in the mitigation of global warming as its reduction will support an average global temperature rise of not greater than 2 °C (US EPA, 2013a).

However, the United Nations Environment Program/World Meteorological Organisation (2011) projected an increase in CH_4 emissions due to rising oil and gas extraction, production and transportation; growth in agricultural activities; population boom; and municipal waste generation. For instance, Nigeria is the largest oil producer in Africa with an average of 2.68 million barrels per day (Idemudia, 2012), and an estimated 180 trillion cubic feet of natural gas reserve (BP, 2014) — one of the largest in the world. In addition, Nigeria's potential natural gas reserve is put at 600 trillion cubic feet (KPMG, 2014). Also, Nigeria's high population (about 170 million) is accompanied by intensive agricultural systems in most of the country's rural and peri-urban areas (Maconachie, 2012) and farming is a key source of CH_4 emissions (e.g. Nie et al., 2010); especially with unregulated manure/fertiliser application in developing countries (see Thu et al., 2012). China is another prominent developing country ranked amongst the largest fossil consumers in the world and the second largest GHG emitter — with a 46.6% reliance on oil importation as of 2007, large-scale agricultural systems and organic fertiliser utilisation (Zhang et al., 2012; Wang et al., 2014). China has the largest population in the world; and according to Wan et al. (2014) it has the single largest natural gas reserve and a technically recoverable volume put at 67% more than that of the US.

Furthermore, as microorganisms decompose plant and animal residues in soils, the organic mineralization process is further enhanced in warm and moist tropical climates thereby releasing CH_4, CO_2 and nitrogen but this process is hindered in temperate and arctic climates due to limited microbial activities (Wiloso et al., 2014). This occurs mostly during agriculture/soil cultivation and land transformation (Bartl et al., 2011). Other sources of global CH_4 emissions include animal husbandry, landfills, coal mining, wastewater treatment plants, and stationary and mobile combustion (Miller et al., 2013; Suberu et al., 2013). Wetlands, biomass burning and termites are some of the sources of tropical methane (Frankenberg et al., 2005). Similarly, enteric fermentation from livestock and feeding on rain grown tropical pastures lead to CH_4 emissions (Bartl et al., 2011; Nahed-Toral et al., 2013); and northern Nigeria is predominantly known for traditional pastoral cattle production while goat/sheep rearing is common in the south. Also CH_4 emissions from feedlot manure and enteric fermentation in temperate regions (e.g. the highlands and coast of Peru; and, part of the US) contribute to global CH_4 budget but emission data are very scarce and uncertain in tropical and arid regions (Bartl et al., 2011; Dudley et al., 2014).

The majority of emission models is designed for industrialised states and temperate climates (Bartl et al., 2011). Unlike in most developing countries, more detailed studies in the arctic region have shown that rising temperatures which thaw permafrost could generate more CH_4 emissions (Shaefer et al., 2011; NRC, 2011) and the loss of ice from Antarctic and Greenland could contribute a further 1 foot to sea level rise (NRC, 2011). Methane emissions from semi-arid and desert biomes are among the least researched of all regions of the world but Hou et al. (2012) suggest that wetted desert soils temporarily increase CH_4 uptake in a short period. However irrespective of biomes or regions, the global mean temperature by 2100 is likely to be twice as warm as the last 100 years (IPCC, 2007) and mean yearly precipitation is expected to increase with variability in volume and intensity by region (Meehl, 2007). There are, however, some innovative climate engineering or geoengineering approaches that could mitigate these climate change impacts (Zhang et al., 2014). Geoengineering is a scheme that artificially cools the earth (Royal Society, 2009) and may include carbon-dioxide removal and/or solar radiation management deployable on land, ocean, atmosphere and space (Zhang et al., 2014). Geoengineering has different impacts on regional climate patterns (Niemeier et al., 2013) but solar radiation management provides greater opportunity for impact mitigation though its discontinuation may lead to extremely rapid climate warming called termination effects (Keller et al., 2014; Zhang et al., 2014).

Methane emissions from oil and natural gas systems worldwide are expected to increase by 26% between 2010 and 2030 (US EPA, 2013a). These systems are a significant source of anthropogenic CH_4 emissions, especially as upstream pipelines (e.g. see Anifowose et al., 2014) are highly susceptible to leaks due to corrosion and abrasion, and are not frequently inspected, thereby making them one of the largest sources of CH_4 emissions in the gas industry (Fernandez et al., 2005). Some studies have identified oil and natural gas transportation systems as one of the main sources of CH_4 emissions (e.g. Dlugokencky et al., 2011; Burnham et al., 2012; Miller et al., 2013). The IPCC (2006) details emission sources of fugitive CH_4 throughout the oil and gas value chain as shown in Fig. 1.

As shown in Table 1, the transportation and distribution industry sectors alone constitute more than 60% and 48% of total CH_4 emissions from natural gas and crude oil industries' emissions sources, respectively. Of particular significance are emissions from compressor stations, pneumatic devices, pipeline maintenance, pipeline accidents such as interdiction (see Anifowose et al., 2012), transportation tanker operations, and crude oil storage tanks. The inadequate knowledge of what controls the global atmospheric CH_4 budget, and its poorly understood recent changes (Nisbet et al., 2014), as well as the suggestion by Dlugokencky et al. (2011) that a reduction in CH_4 emissions would rapidly benefit the earth's climate, are a vital impetus for this present research.

Therefore, this paper focuses on CH_4 emissions, broadly from transportation and distribution systems within the oil and gas industry, with particular reference to Nigeria. We focus on Nigeria for two distinct reasons viz: (i) recent studies have suggested that the tropical region (Fig. 2) or East Asia hold some unexpectedly high CH_4 concentrations (see Frankenberg et al., 2005; Nisbet et al., 2014); and, (ii) Nigeria is characterised by vast oil and gas developments (Agha et al., 2002; Nwokeji, 2007) and remains a key location for extreme oil pollution and environmental impacts, particularly in the Niger Delta (UNDP, 2006, UNEP, 2011; Anifowose et al., 2012). Hence, there is the need to address synergistic impacts that may arise from a combination of extreme oil pollution and GHG emissions (e.g. CH_4) which could lead to an impact greater than the sum of their individual impacts. Samarakoon and Gudmestad (2011) argue that there is now an amplified pressure on governments and oil companies to minimise negative environmental impacts. New discoveries and substantial growth in the oil and gas industry are profound in developing countries (e.g. Ghana, Nigeria, Venezuela, Brazil, Cuba, Trinidad and Tobago, Sudan) within the tropical region (Fig. 2) and cannot be overlooked.

1.1. Research gap

There is limited understanding of emission rates from oil and gas transportation, distribution and storage facilities, including in the United States (Howarth et al., 2011). The first in a series of CH_4