Uncertainty analysis of methane emissions from natural gas production

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Introduction

Natural gas (NG) use is expected to increase significantly over the next decades in the U.S. and worldwide due to an unprecedented expansion of unconventional NG production: shale gas, coal-bed methane, and tight sands gas. For example, EIA expects global NG consumption to increase from currently 110 Tcf to about 170 Tcf in 2035. With this increase in NG production and the fact that many coal-fired power plants in the U.S. will need to be overhauled, replaced, or substituted with other sources within the next 10-20 years, EIA projects that over the next 30 years an additional 100 GW NG-fired net electricity capacity will be installed compared to only 5 GW for coal.

The U.S. electricity sector is responsible for about 40% of energy related CO_2 emissions. Transitioning from coal fired electricity generation towards a greater share of NG is perceived as a low cost alternative to decarbonizing the energy system. While many studies indicate associated reductions in GHG emissions, there are **significant uncertainties regarding the CH_4 emissions from NG leakage and venting**. Furthermore, some climate modeling studies suggest the distinct possibility that replacing coal with NG could lead to temporarily (decadal time scales) higher global warming due to increased emissions of 25 times more potent CH_4 in addition to greenhouse effects from CO_2 *(1)*. However, the uncertainty in the transient climate response – particularly in comparison to CH_4 uncertainty – remains to be quantified.

Research questions:

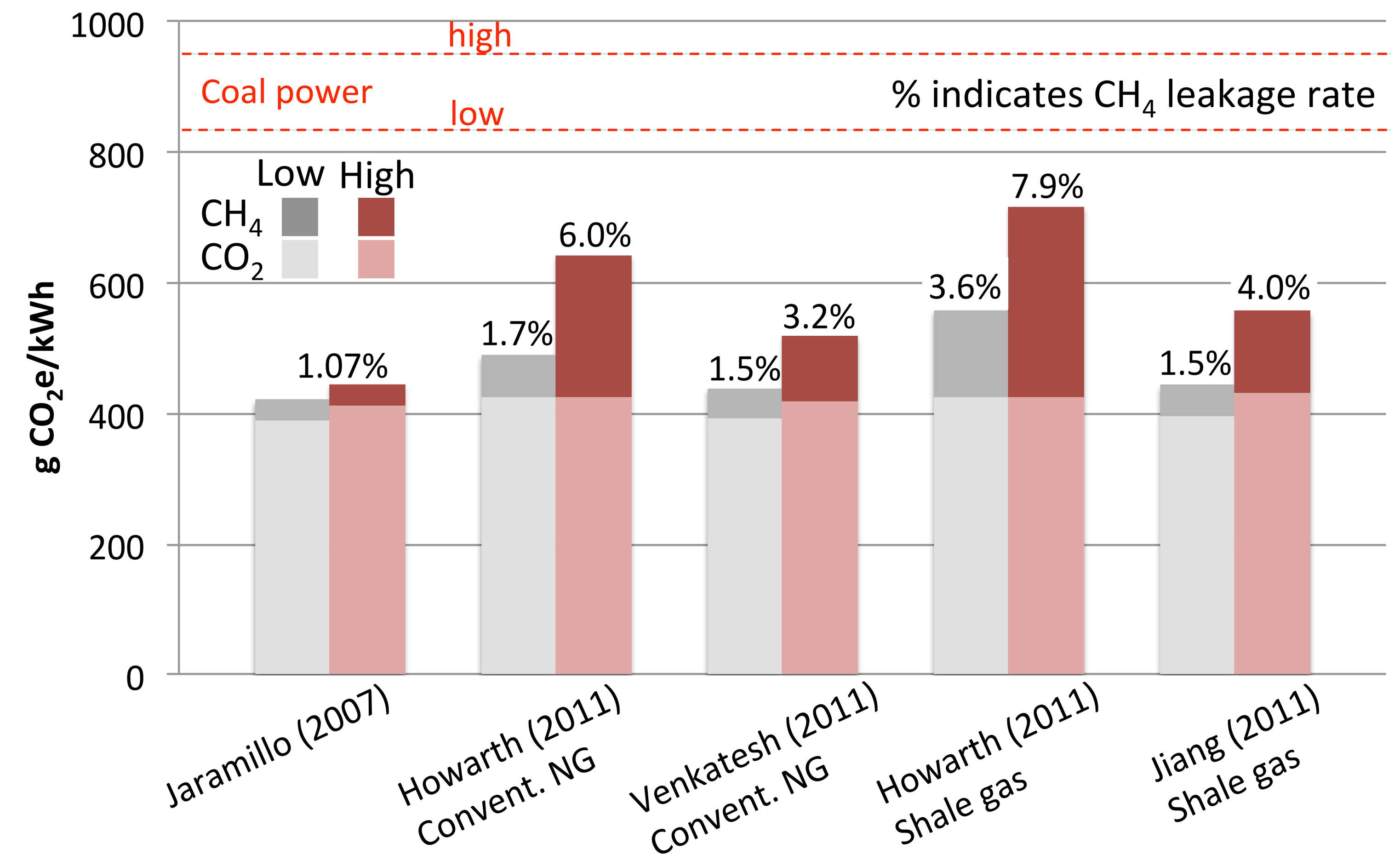
- After considering differences in GHG accounting among studies, what is the overall range of reported CH_4 emissions (g CH_4/kWh) from NG power?
- What is a reasonable range of CH_4 leakage from the NG power life cycle when taking into account analyses of atmospheric CH_4 measurements?

Life cycle CH_4 estimates (bottom-up approach)

The GHG emissions reductions from the coal-to-gas transition have been estimated using life cycle assessment (LCA), a widely used accounting tool, which compares technologies based on the GHG emissions over their life cycle. Results indicate that CH_4 leakage appears to be a major contributor to life cycle GHGs from NG power generation *(2-4)*. Methane leakage is defined as fugitive CH_4 emissions from sources such as equipment leaks, venting, and accidental leaks. Given its potency, it is also one of the most influential parameters in the GHG difference between power generation from NG and coal.

Overall GHG emissions from NG are highly uncertain, both on an absolute scale and compared to coal emissions uncertainty. Most fossil fuel technologies emit mainly CO_2, which are relatively easy to estimate from combustion and other processes. In contrast, **the fugitive CH_4 emissions from NG are difficult to quantify as monitoring and measuring data is often not available**. Values from the life cycle literature for NG lost during production, processing, transmission, and storage range from 1.1-6.0% and 1.5-7.9% of total NG produced for conventional and shale gas, respectively. Figure 1 summarizes the results of a literature review with values adjusted for the same functional unit, global warming potential, and power plant efficiencies. **Given the low and high leakage rate estimates, overall GHG reductions range from about 27-50% relative to coal (18-50% for shale gas).**

Figure 1: Literature review of life cycle GHG estimates from NG power generation. All data is adjusted to the same functional unit (kWh of generated power) and to include the same 100-yr global warming potentials (GWP) and power plant efficiencies. More sources to be added.



Atmospheric CH_4 inversions (top-down)

Methane emissions can also be estimated using atmospheric inversions, which is useful for validating life cycle estimates. **Inversion techniques are based on a combination of (i) measuring CH_4 concentrations from a global observation network, (ii) measuring CH_4 isotope ratios to distinguish emissions sources, (iii) prior bottom-up emissions inventories, and (iv) employing atmospheric emissions transport models *(5)*.** In this process, air flask samples are collected at least weekly from a global network of up to 68 observation towers at 15-500 m height, the $^{13}C/^{12}C$ isotope ratio of the sampled CH_4 is measured to distinguish emissions sources, such as NG production and wetlands, and inverse modeling is used to solve for spatial and temporal CH_4 distributions that give optimal agreement between observations and simulations. Analyzing top-down and bottom-up estimates, I will bound the uncertainty range of CH_4 leakage estimates by eliminating bottom-up leakage rates that appear incompatible with top-down inversions.

Preliminary results

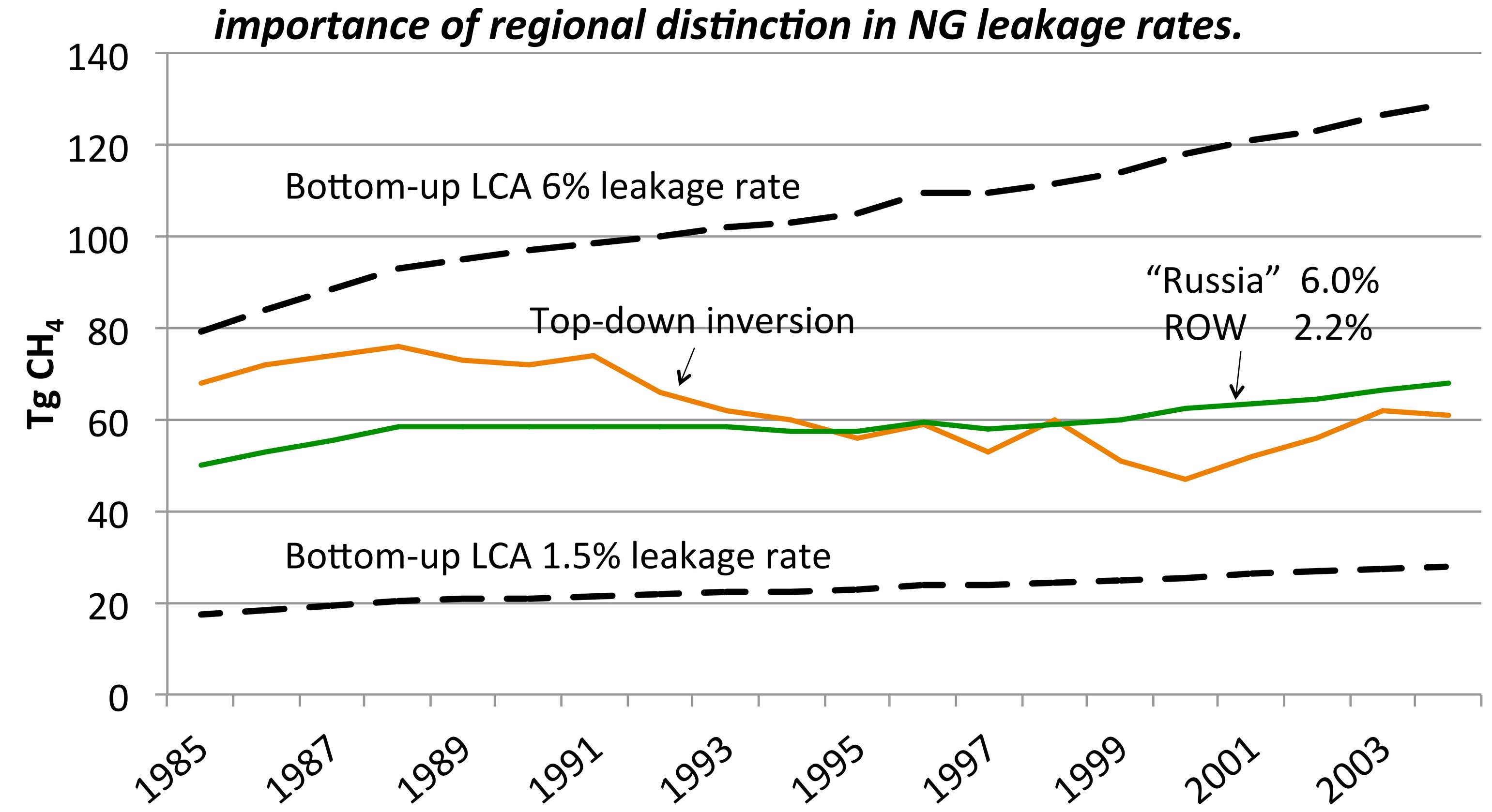
Figure 2 shows NG related CH_4 emissions trajectories using both bottom-up and top-down approaches. The orange line shows best estimate global mean top-down CH_4 emissions from NG leakage. Bottom-up estimates are shown in black, which are estimated from global NG production data and low and high leakage rate values from the literature. While my objective is to constrain the very large bottom-up uncertainty (factor of 4), top-down emissions are within this range, i.e., not contradicting the bottom-up range. During the late 1980s, observation supports high leakage rates. However, global CH_4 emissions decreased significantly after 1989, presumably due to collapsing production of high leakage NG in the former Soviet Union *(5)*. In contrast, observations during the early 2000s coincide better with the low end of the leakage rate spectrum. In fact, the higher bound leakage rate overestimates observations by 75-100%. Reduced CH_4 emissions may be the result of improved industry practices.

Further analysis will focus on reviewing the uncertainty in the top-down emissions estimates in order to evaluate whether or not top-down and bottom-up flux estimates truly do not overlap. Since the gap between low and high bottom-up estimates is wide (about 300% difference between low and high), it is likely that top-down estimates will be inconsistent with some of the bottom-up estimates.

I will gather two available global CH_4 inversions and evaluate the posterior uncertainties as provided from each inversion, and the prior flux estimates and atmospheric chemistry and transport characteristics for each inversion to evaluate whether there could be biases among the inversions due to these inputs to the inversions.

Finally, I will discriminate global average leakage rates among world regions, over time, and among NG sources (conventionally and unconventionally produced NG). These distinctions in bottom-up data will help better explain CH_4 observations, thereby leading to more certainty in leakage rates.

Figure 2: Preliminary bottom-up and top-down CH_4 emissions estimates from NG production. The green line illustrates the importance of regional distinction in NG leakage rates.



References

(1) Wigley, T. M. L. Coal to gas: the influence of methane leakage. Climatic Change 2011, 108, 601-608.
(2) Jaramillo, P. et al. Comparative life-cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation. Environ. Sci. Technol. 2007, 41, 6290-6296.
(3) Venkatesh, A. et al. Uncertainty in Life Cycle Greenhouse Gas Emissions from United States Natural Gas End-Uses and its Effects on Policy. Environ. Sci. Technol. 2011, 45, 8182–8189.
(4) Howarth, R. et al. Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic Change 2011, 106, 679-690.
(5) Bousquet, P. et al. Contribution of anthropogenic and natural sources to atmospheric methane variability. Nature 2006, 443, 439-43.

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