Conceptual framework for discussing methane leakage

draft, 8/15/2020, by Tad Anderson, Ph.D., tadand99@gmail.com (comments welcome)

Abstract. A simple equation is derived to quantify the climatic impact of natural gas leakage in terms of two key parameters: the methane leakage rate (LR) and methane's global warming potential (GWP). (Methane is the primary component of natural gas). For plausible values of these two parameters, the increase in effective carbon emissions (CO2e) arising from methane leakage ranges from small (~10%) to dramatic (>100%). This highlights the importance of establishing appropriate values for these two parameters in environmental assessment policies.

Introduction. Burning natural gas produces energy with about half the carbon dioxide (CO2) emissions as coal. For this reason, natural gas is often thought of as a bridge fuel in the transition to a low-carbon economy. However, non-trivial amounts of methane leak to the atmosphere during production and distribution of natural gas. Because methane (CH4) is a powerful greenhouse gas, these so-called "upstream emissions" must be taken into account in order to fully assess the climate impact of burning (or otherwise using) natural gas. This essay attempts to provide a simple framework for discussing this issue among stakeholders.

Conceptual framework

The essential science can be quickly explained given a few simplifying assumptions, as described below. The primary assumption is that natural gas is pure methane (CH4).

Let CO2e be the effective CO2 emissions from burning a specified amount of natural gas (e.g. to produce energy at a power plant). CO2e is the sum of direct and indirect (upstream) components:

Eq. 1: CO2e = CO2burn + CO2e_leak

where: CO2burn is the direct emission of CO2 due to burning natural gas, assuming complete oxidation
CO2e_leak is the equivalent CO2 emission associated with upstream methane leakage

At issue is the size of CO2e_leak relative to CO2burn. I will call this the Leak Effect (LE), defined as:

Eq. 2: LE = CO2e_leak / CO2burn

CO2burn is easily calculated for pure methane because each molecule of CH4 results in one molecule of emitted CO2. Therefore, the mass of CO2 emitted to the atmosphere is simply the mass of CH4 that was burned times the ratio of their respective molecular weights:

Eq. 3: CO2burn = CH4burn * MWCO2 / MWCH4 = CH4burn * 2.75

where: CH4burn is the mass of methane burned (kg)
MWCO2 is the molecular weight of carbon dioxide (44)
MWCH4 is the molecular weight of methane (16)

Next, let the leak rate (LR) be defined as:

Eq. 4: LR = CH4leak / CH4burn

where: CH4leak is the mass of methane leaked to the atmosphere prior to combustion

To calculate CO2e_leak, we need to convert CH4leak into the climatically equivalent mass of CO2. The conversion factor is called the Global Warming Potential of methane (denoted simply GWP, here):

Eq. 5: CO2e_leak = CH4leak * GWP

We can re-write Eq. 4 as: CH4leak = LR * CH4burn

Substituting this result into Eq. 5 we get:

Eq. 6: CO2e_leak = LR * GWP * CH4burn

Finally, substituting this result into Eq. 2, we can express the Leak Effect, LE, in terms of the key parameters LR and GWP:

Eq. 7: LE = LR * GWP / 2.75

<u>Range of values for key parameters</u>

GWP: Because methane has a much shorter lifetime in the atmosphere (~10 years) than carbon dioxide (centuries), its global warming potential depends on the assumed timeframe. According to the latest IPCC report (IPCC, 2013), the values of GWP for 100- and 20-year time frames are 28 and 84, respectively. Which timeframe is appropriate to a given policy depends on the goals of that policy. If only long-term goals (decades-to-centuries) are important, then a lower value of GWP would be appropriate. On the other hand, if near-term goals (years-to-decades) are important, a higher value of GWP (corresponding to a shorter timeframe) would be more appropriate. Note that the choice of timeframe (and, thus, GWP) is a policy question, not a question of scientific knowledge or accuracy.

LR: In contrast, scientific knowledge of the methane leak rate is highly uncertain due to the difficulty of measuring and/or estimating this quantity. In other words, while a true number exists (for any given time and region), scientists are unsure what that number is. Policy choices in this context involve the desired level of confidence (e.g. 95%) that the actual value is not greater than the value chosen for legal purposes. This, in turn, requires assessing the state scientific knowledge and uncertainty with regard to this parameter. Values in the current peer-reviewed literature for the U.S. natural gas industry range from ~1% to almost 10%, with most values below 5%. Here we use a range of 1% to 5% to represent plausible values consistent with current scientific knowledge.

<u>Results:</u> See Table 1.

Table 1: The effect of methane leakage on the global warming impact of natural gas. Calculated values of the Leak Effect (LE) based on Eq. 7 and its underlying assumptions. The chosen values of GWP correspond to 100-year and 20-year times frames, respectively, according to the latest IPCC report (IPCC, 2013). The extreme values of LR (1% and 5%) roughly represent the range of values found in recent literature. The two central values (2.3% and 3.2%) come from studies by Alvarez et al. as explained in notes [1] and [2].

	LR=1%	LR=2.3% [1]	LR=3.8% [2]	LR=5%
GWP=28	10%	23%	39%	51%
GWP=84	31%	70%	116%	153%

[1] 2.3% is the central estimate found by Alvarez et al. (2018) for methane leakage from the U.S. oil and natural gas industry with respect to gross U.S. natural gas production.

[2] 3.8% is the value of LR where, according to Alvarez et al. (2012, Fig. 2c), natural gas has the same climate impact as coal, if referenced to a 20-year time frame (i.e. GWP=84).

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