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Understanding GHG in Gas to power value chains

Tags: Climate Change, Energy, Evidence

Overview

When investing in power generation a series of trade offs are made between Greenhouse Gas (GHG) emissions occurring during generation, and GHG emissions created along the energy value chain from extraction to consumption. With natural gas a key resource in many DFID-supported countries, ICED research investigated emissions trade-offs between locating a gas-fired power plant close to a gas field and then transmitting the power generated to a load centre (incurred electrical losses), versus locating the power plant close to a load centre, requiring transmission of the gas. From the analysis it is possible to draw two clear conclusions with implications for donor investments and programming:

- Based on the IPCC emission factors, indirect GHG emissions from natural gas power stations in developing countries could be material, adding ~50% to direct emissions from combustion in our baseline example.
- The incremental emissions from the transmission and storage of gas to get to the power station are likely to be small. Our scenario analysis suggests that it is much more efficient from a GHG emissions perspective to transmit natural gas in a pipeline to a power plant located close to a load centre, than to generate power close to a gas field and transmit the power to the load centre. This conclusion is likely to hold even when the uncertainty ranges for the IPCC emission factors are taken into account.

Greenhouse Gas emissions along the gas-to-power value chain

In addition to the direct GHG emissions that result from the combustion of natural gas, indirect GHG emissions can take place along the gas-to-power value chain, prior to combustion. These indirect emissions come from a number of different sources:

- **Fugitive emissions** – these result from the unintended release of natural gas ahead of combustion, essentially through leaks. These emissions can take place through production, processing, transmission and storage.
- **Flaring** – these are emissions from the combustion of waste gas and vapour streams, which can take place at both the production and processing stages in the value chain.
- **Raw CO_2 venting** – CO_2 emissions can result from the process of sweetening sour natural gas (i.e. natural gas with a high H_2S concentration).

Indirect emissions are also from a range of GHGs. The primary GHG involved is methane (CH_4), but other GHGs involved include CO_2, Nitrous Oxide (N_2O), and non-methane Volatile Organic Compounds (NMVOCs).

These emissions can vary considerably between different locations and situations, for example as a result of the sophistication or complexity of the infrastructure in place. There is therefore no simple assumption that can be adopted regarding these indirect emissions, in the way that direct emissions from natural gas combustion can be easily calculated. However, the Intergovernmental Panel on Climate Change (IPCC) has prepared detailed guidance[1] on the use of emission factors to estimate these emissions, and it is these factors that we reference for the remainder of this note. The IPCC emission factors are summarised in

Table . Note that in addition to % uncertainties, the table shows a range for fugitive emissions, which is a result of the variation in the amount (or complexity) of infrastructure through which gas can be leaked. Both the ranges shown and the level of uncertainty indicate the wide range of potential answers for any given specific context. This uncertainty is particularly significant for the indirect emissions at the exploration stage.

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[1] http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Value chain stage	Category	Developed country emissions (kg/m^3)				Developing country emissions (kg/m^3)			
		CH_4	CO_2	NMVOCs	N_2O	CH_4	CO_2	NMVOCs	N_2O
Exploration – Flaring and venting[2]	Well drilling	1.7 x10^{-4} ±100%	5.0 x10^{-4} ±50%	4.4 x10^{-6} ±100%	N/A	0.2-2.3 x10^{-3} - 12.5% to +800%	0.5-8.5 x10^{-3} - 12.5% to +800%	0.4-7.5 x10^{-5} - 12.5% to +800%	N/A
	Well testing	2.6 x10^{-4} ±50%	4.5 x10^{-2} ±50%	6.0 x10^{-5} ±50%	3.4 x10^{-7} - 10% to +1000%	0.3-4.3 x10^{-3} - 12.5% to +800%	0.5-7.5 x10^{-1} - 12.5% to +800%	0.1-1.0 x10^{-3} - 12.5% to +800%	0.3-5.5 x10^{-6} -10% to +1000%
	Well servicing	5.5 x10^{-4} ±50%	9.5 x10^{-6} ±50%	8.5 x10^{-5} ±50%	N/A	0.6-9.0 x10^{-3} - 12.5% to +800%	0.1-1.6 x10^{-4} - 12.5% to +800%	0.1-1.4 x10^{-3} - 12.5% to +800%	N/A
	Total	**9.8 x10^{-4}**	**4.6 x10^{-2}**	**1.5 x10^{-4}**	**3.4 x10^{-7}**	**8.4 x10^{-3}**	**4.1 x10^{-1}**	**1.3 x10^{-3}**	**2.9 x10^{-6}**
Gas production	Fugitives	0.4-2.3 x10^{-3} ±100%	1.4-8.2 x10^{-5} ±100%	0.9-5.5 x10^{-4} ±100%	N/A	0.0-2.4 x10^{-2} -40% to +250%	0.1-1.8 x10^{-4} -40% to +250%	0.1-1.2 x10^{-3} -40% to +250%	N/A
	Flaring	7.6 x10^{-7} ±25%	1.2 x10^{-3} ±25%	6.2 x10^{-7} ±25%	2.1 x10^{-8} - 10% to +1000%	0.8-1.0 x10^{-6} ±75%	1.2-1.6 x10^{-3} ±75%	6.2-8.5 x10^{-7} ±75%	2.1-2.9 x10^{-8} -10% to +1000%
	Total	**1.4 x10^{-3}**	**1.2 x10^{-3}**	**3.2 x10^{-4}**	**2.1 x10^{-8}**	**1.2 x10^{-2}**	**1.5 x10^{-3}**	**0.7 x10^{-3}**	**2.5 x10^{-8}**
Gas processing[3]	Fugitives	1.5-10.3 x10^{-4} ±100%	0.1-3.2 x10^{-4} ±100%	1.4-4.7 x10^{-4} ±100%	N/A	1.5-3.5 x10^{-4} -40% to +250%	1.2-2.8 x10^{-5} -40% to +250%	1.4-3.2 x10^{-4} -40% to +250%	N/A
	Flaring	2.0 x10^{-6} ±25%	3.0 x10^{-3} ±50%	1.6 x10^{-6} ±25%	3.3 x10^{-8} - 10% to +1000%	2.0-2.8 x10^{-6} ±75%	3.0-4.1 x10^{-3} ±75%	1.6-2.2 x10^{-6} ±75%	3.3-4.5 x10^{-8} -10% to +1000%
	Raw CO_2 venting	N/A	4.0 x10^{-2} - 10% to +1000%	N/A	N/A	N/A	4.0-9.5 x10^{-2} -10% to +1000%	N/A	N/A
	Total	**5.9 x10^{-4}**	**4.3 x10^{-2}**	**3.1 x10^{-4}**	**3.3 x10^{-8}**	**2.5 x10^{-4}**	**7.2 x10^{-2}**	**2.3 x10^{-4}**	**3.9 x10^{-8}**
Gas transmission & storage	Transmission fugitives	0.7-4.8 x10^{-4} ±100%	8.8 x10^{-7} ±100%	7.0 x10^{-6} ±100%	N/A	0.2-1.1 x10^{-3} -40% to +250%	0.9-2.0 x10^{-6} -40% to +250%	0.7-1.6 x10^{-5} -40% to +250%	N/A
	Transmission venting	0.4-3.2 x10^{-4} ±75%	3.1 x10^{-6} ±75%	4.6 x10^{-6} ±75%	N/A	0.4-7.4 x10^{-4} -40% to +250%	3.1-7.3 x10^{-6} -40% to +250%	0.5-1.1 x10^{-5} -40% to +250%	N/A
	Storage emissions	2.5 x10^{-5} - 20% to +500%	1.1 x10^{-7} - 20% to +500%	3.6 x10^{-7} - 20% to +500%	N/A	2.5-5.8 x10^{-5} -20% to +500%	1.1-2.6 x10^{-7} -20% to +500%	3.6-8.3 x10^{-7} -20% to +500%	N/A
	Total	**4.9 x10^{-4}**	**4.1 x10^{-6}**	**1.2 x10^{-5}**	**N/A**	**1.1 x10^{-3}**	**6.9 x10^{-6}**	**2.0 x10^{-5}**	**N/A**

Table 1 IPCC Guidelines on emission factors[4]

[2] The IPCC emission factors for exploration are quoted per m^3 of oil production. We have assumed a gas-to-oil ratio of 200m^3/m^3, but note that this is another assumption that can vary significantly depending on the source of fuel

[3] The IPCC calculated emission factors for gas processing as a weighted average across different types of gas plant

[4] Note that while all of the emissions factors presented are in kg/m^3, the IPCC numbers are stated per m^3 gas production, per m^3 gas feed, and per m^3 marketable gas for gas production, processing, and transmission respectively. Given the errors margins in the emissions factors, and the relatively low loss factors, we have ignored this distinction in our analysis

To simplify these emission factors, we need to consider the CO_2 equivalence of each of the non-CO_2 GHGs. This is normally defined through Global Warming Potential (GWP) parameters, which are set out in the IPCC's Assessment Reports (ARs). GWP metrics indicate how effective a GHG is when compared against CO_2, such that the GWP of CO_2 is 1. Note that NMVOCs do not have a GWP because they are short-lived and localised. We ignore the impact of NMVOCs for the remainder of this note.

GWPs from the IPCC's AR5[5] are set out in **Table 2**. The choice of GWP metric is important, especially for CH_4. CH_4 has a relatively short lifetime in the atmosphere (12.4 years), meaning that its GWP is much higher over short timescales than over the longer-term. There has been significant debate in climate change policy over the appropriate metric to use, but the default view is normally to use 100-year GWP, which is what we will use in this analysis.

Table 2: Global Warming Potential data for non-CO_2 GHGs from IPCC AR5

GHG	20-year GWP	100-year GWP
CH_4	84	28
N_2O	264	265

Combining the data set out in

Table and **Table 2** we can derive a simple estimate for the CO_2 equivalent emissions at each stage in the gas-to-power value chain. This is set out in **Table 3**.

As indirect emissions mostly result from leakage of CH_4 at the exploration, production and transmission stages, and CO_2 emissions from exploration and during the processing of some types of natural gas. Our analysis has required assumptions set out in the footnote below.

- Emission factors to define the amount of emissions for each unit of natural gas consumed. These assumptions are taken from guidance published by the IPCC. There are significant uncertainty ranges indicated for these assumptions, in particular for developing countries. Our analysis has taken a midpoint for the ranges indicated.
- GWP factors, which indicate the relative importance of non-CO_2 GHGs. There has been significant debate over the GWP factors that should be used for CH_4 in particular, given its relative short life in the atmosphere. Our analysis uses 100-year GWPs, which are the default normally used in policy analysis.

Note that N_2O emissions are not shown in the graph given that the analysis indicates that they are ~3 orders of magnitude lower than the CH_4 and CO_2 emissions.

The analysis presented suggests that indirect GHG emissions for the gas-to-power value chain are split evenly between CO_2 and CH_4. However, it is worth noting that the range of emission factors and the level of uncertainty stated for the factors is particularly high for the exploration phase, where the greatest potential for indirect CO_2 emissions is identified. The analysis also shows that emissions can be much higher in developing countries, especially at the exploration and production stages, although it should again be noted that there are significant uncertainties attached to these numbers.

[5] https://www.ipcc.ch/report/ar5/

Value chain stage	Developed country emissions ($kgCO_2e/m^3$)			Developing country emissions ($kgCO_2e/m^3$)		
	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O
Exploration	2.7×10^{-2}	4.6×10^{-2}	9.0×10^{-5}	2.4×10^{-1}	4.1×10^{-1}	7.7×10^{-4}
Gas production	3.9×10^{-2}	1.2×10^{-3}	5.6×10^{-6}	3.4×10^{-1}	1.5×10^{-3}	6.6×10^{-6}
Gas processing	1.6×10^{-2}	4.3×10^{-2}	8.7×10^{-6}	7.0×10^{-3}	7.2×10^{-2}	1.0×10^{-5}
Gas transmission & storage	1.4×10^{-2}	4.1×10^{-6}	N/A	3.1×10^{-2}	6.9×10^{-6}	N/A

Table 3: Estimates CO_2 equivalent GHG emissions in the gas-to-power value chain

As indirect emissions mostly result from leakage of CH_4 at the exploration, production and transmission stages, and CO_2 emissions from exploration and during the processing of some types of natural gas. Our analysis has required assumptions set out in the footnote below.

- Emission factors to define the amount of emissions for each unit of natural gas consumed. These assumptions are taken from guidance published by the IPCC. There are significant uncertainty ranges indicated for these assumptions, in particular for developing countries. Our analysis has taken a midpoint for the ranges indicated.
- GWP factors, which indicate the relative importance of non-CO_2 GHGs. There has been significant debate over the GWP factors that should be used for CH_4 in particular, given its relative short life in the atmosphere. Our analysis uses 100-year GWPs, which are the default normally used in policy analysis.

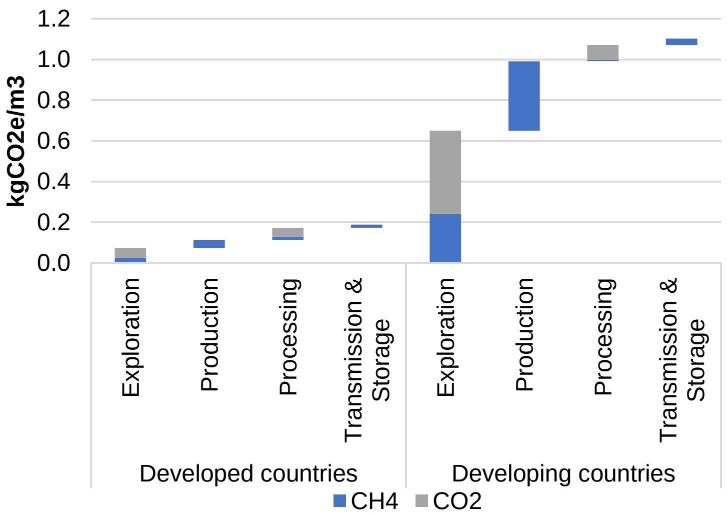

Figure 1: Summary of gas-to-power value chain indirect GHG emissions

To understand the relative importance of these emissions for a potential gas-fired power station in Africa we can consider a simplified example. Let us assume that 3 TWh of power is required to be exported from the transmission system and that this power is being generated by a gas-fired power plant with 58% LHV (Lower Heating Value) efficiency (equivalent to a typical new-build CCGT).

Worked Example

Baseline emissions: The power plant will consume 3,000 GWh / 0.58 = 5,172 GWh of natural gas. An estimated baseline of direct CO_2 emissions from combustion of the natural gas, and the indirect GHG emissions from production and processing of that gas can be established:

- **Direct CO_2 emissions** can be calculated using a standard emission factor of 56.1 $kgCO_2/GJ$ and a Higher Heating Value (HHV) adjustment factor of 0.9: 5,172 GWh / 0.9 * 3,600 GJ/GWh * 56.1 $kgCO_2/GJ$ = **1,161 $ktCO_2$**
- **Indirect GHG emissions** (from exploration, production and processing only) can be estimated using an emission factor of 1.07 $kgCO_2e/m^3$, derived earlier, noting that 1GJ of natural gas = 26 m^3: 5,172 GWh / 0.9 * 3,600 GJ/GWh * 1.07 $kgCO_2e/m^3$ * 26 m^3/GJ = **576 $ktCO_2e$**

Scenario 1 – the power plant is built close to a load centre, requiring a gas pipeline. Additional indirect GHG emissions result from the additional transmission of natural gas. These emissions can again be estimated, using an emission factor of 0.03 $kgCO_2e/m^3$: 5,172 GWh / 0.9 * 3,600 GJ/GWh * 0.03 $kgCO_2e/m^3$ * 26 m^3/GJ = **16 $ktCO_2e$**

Scenario 2 – the power plant is built close to the gas field, requiring transmission of the power. In this case it is assumed that no indirect emissions result from the transmission and/or storage of natural gas. However, electricity transmission losses are suffered, and this results in additional gas being required to deliver the same power. If we assume transmission losses of 5% (similar to losses in kenya and Tanzania), an additional 272 GWh of natural gas is required on an LHV basis. The additional natural gas required leads to further direct CO_2 emissions and indirect GHG emissions from production and processing of the natural gas:

- **Direct emissions** from combustion of the gas can be estimated as follows: 272 GWh / 0.9 * 3,600 GJ/GWh * 56.1 $kgCO_2$/GJ = **61 $ktCO_2$**
- **Additional indirect emissions** from production and processing of natural gas can be estimated as follows: 272 GWh / 0.9 * 3,600 GJ/GWh * 1.07 $kgCO_2e/m^3$ * 26m^3/GJ = **30 $ktCO_2e$**

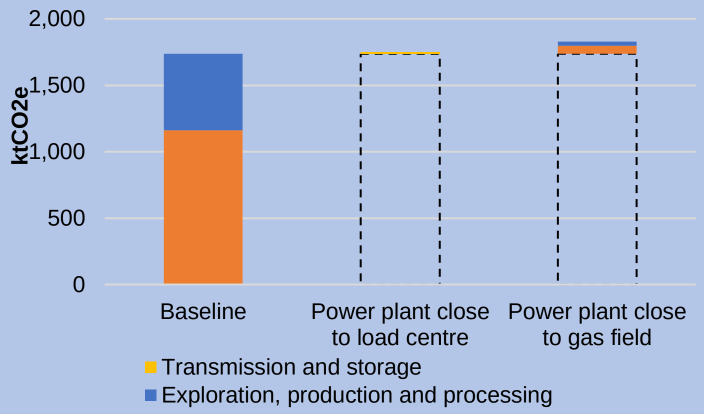

Figure.2: Direct and indirect GHG emissions from a gas-to-power project

For more information on climate-friendly energy programming contact the ICED Facility at:

ICED Facility | iced.programming@uk.pwc.com | @icedfacility | https://medium.com/iced-facility