RHODIUM GROUP

Untapped Potential

Reducing Global Methane Emissions from Oil and Natural Gas Systems

Kate Larsen, Michael Delgado and Peter Marsters

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Key Findings

SIGNIFICANT GLOBAL METHANE LEAKAGE

Based on the best currently available data, around 3.6 trillion cubic feet (Tcf) of natural gas escaped into the atmosphere in 2012 from global oil and gas operations. This wasted gas translates into roughly $30 billion of lost revenue at average 2012 delivered prices, and about 3% of global natural gas production.

Because the primary component of natural gas, methane, is an extremely potent greenhouse gas (GHG), methane leakage has important climate implications. Methane escaping from oil and gas operations totaled approximately 1,680 million metric tons of carbon dioxide equivalent ($MtCO_2e$) in 2012, calculated based on methane's 100-year global warming potential (GWP). If it were a country, oil and gas methane emissions would rank as the world's seventh largest emitter, coming in just under Russia. Using methane's 20-year GWP – a measure of the short-term climate impact of different GHGs – increases the share of oil and gas methane to over 8% of global GHG (with emissions of 5,650 Mt CO_2e), the equivalent of about 40% of total CO_2 emissions from global coal combustion in 2012.

The 3.6 Tcf of lost natural gas across the world would rank as the world's seventh largest natural gas producer, with nearly as much escaped gas globally as Norway's total production in 2012.

The majority of oil and gas methane leakage comes from a handful of countries: the top seven emitting countries were responsible for over half of the global total in 2012; the top 30, including the EU, accounted for three-quarters.

The global methane emissions estimates included in this report, while more detailed and robust than anything currently available, are limited by the lack of credible, up-to-date estimates for most countries. Better national inventory practices and more regular reporting are critical to improve our understanding of the scale of the methane leakage challenge and to inform effective mitigation strategies.

A GROWING PROBLEM ABSENT NEW EFFORTS

Global oil and gas methane emissions will grow absent further efforts to reduce leakage. For example, in our central oil and gas production growth scenario (and using currently available leakage data), emissions increase 23% between 2012 and 2030. A 23% increase would add over 380 $MTCO_2e$ in 2030 (using a 100-year GWP), equivalent to Poland's total GHG emissions in 2012. By comparison, the International Energy Agency (IEA) projects global energy-related CO2 emissions will grow by only 15% between 2012 and 2030.

COST-EFFECTIVE ABATEMENT OPPORTUNITIES

For oil and gas producing countries, controlling methane emissions can provide a significant and potentially low-cost opportunity to achieve additional GHG abatement in 2020 and beyond. If just the top 30 oil and gas methane emitting countries were to reduce those emissions 50% below 2012 levels by 2030, this would prevent the loss of 1.8 Tcf of natural gas supply worldwide. Additionally, a 50% decrease would reduce overall global emissions by roughly 700 $MTCO_2e$ using a 100-year GWP, nearly the equivalent of total Canadian GHG emissions in 2012. Reductions of 75% below 2012 levels in 2030 would increase natural gas supply by 2.7 Tcf and achieve over 1,000 $MTCO_2e$ of GHG abatement using a 100-year GWP, nearly the equivalent of Germany's total GHG emissions in 2012. Using a 20-year GWP for methane, the 50% goal would achieve reductions of over 2,300 $MTCO_2e$ (the equivalent of India and the EU's combined CO_2 emissions from coal combustion in 2012) and the 75% goal would reduce emissions by around 3,400 $MTCO_2e$ (nearly as much as all CO_2 emissions from coal combustion from OECD countries in 2012).

WHAT IT MEANS

Methane emissions from oil and gas operations worldwide represent a significant loss of natural gas resources and is a material contributor to total GHG emissions and global climate change. Despite its climate significance, very few countries have taken steps to regulate methane emissions from the oil and gas sector or set specific goals to reduce emissions in the future. This leaves a potentially cost-effective source of GHG abatement on the table, one that complements and reinforces other GHG reduction efforts. For many countries, tackling oil and gas methane emissions, including as a component of their Intended Nationally-Determined Contributions to the UN agreement to be adopted this year in Paris, could make a meaningful contribution to their overall GHG reductions by 2030.

Due to methane's short-term climate impact, reduction of methane leakage today can deliver immediate climate benefits while nations pursue longer-term strategies to reduce CO_2. However, unless methane emissions are taken into account, the overall GHG benefits of natural gas will be overestimated. It will be essential for countries to integrate better measurement and management of oil and gas methane emissions into the development, assessment and implementation of long-term GHG mitigation plans to maximize GHG reductions from those policies.

To do this, countries and their oil and gas industry partners need to significantly improve measurement and accounting of methane emissions from the sector. Improved estimation methods and more frequent reporting is critical both to improve our understanding of the magnitude of the oil and gas methane challenge and to enhance the effectiveness of GHG mitigation strategies.

Top 30 oil and gas methane emitting countries in 2012

Excluding major oil and gas producers for which no data is available

	100-year GWP			20-year GWP	
	MT CO2e	% global o&g CH4	% country total GHG	MT CO2e	% country total GHG
Russia	387	23%	21%	1301	39%
US	192	11%	3.4%	647	8.7%
Uzbekistan	97	5.8%	42%	326	65%
Canada	54	3.2%	7.1%	180	17%
Mexico	43	2.6%	5.4%	146	11%
Azerbaijan	43	2.6%	53%	145	72%
EU	43	2.5%	1.0%	143	2.6%
Iran	43	2.5%	7.2%	143	18%
Venezuela	38	2.3%	16%	128	32%
Turkmenistan	37	2.2%	33%	126	47%
Algeria	30	1.8%	19.3%	99	38%
UAE	29	1.7%	9.8%	98	25%
Ukraine	29	1.7%	7.4%	96	17%
Nigeria	27	1.6%	8.1%	91	14%
India	25	1.5%	1.1%	85	2.3%
Indonesia	16	0.9%	0.8%	53	1.9%
Malaysia	14	0.8%	3.0%	46	7.7%
Thailand	12	0.7%	3.6%	41	7.4%
Pakistan	10	0.6%	3.2%	35	5.7%
Egypt	10	0.6%	3.3%	34	7.9%
Argentina	10	0.6%	3.4%	34	6.2%
South Korea	10	0.6%	1.5%	33	4.4%
Saudi Arabia	10	0.6%	1.9%	32	5.3%
Kazakhstan	8.6	0.5%	3.2%	29	7.1%
Côte d'Ivoire	8.2	0.5%	3.1%	27	8.4%
Australia	7.4	0.4%	1.3%	25	2.7%
Colombia	7.2	0.4%	3.2%	24	6.0%
China	6.4	0.4%	0.1%	22	0.1%
Brazil	4.7	0.3%	0.2%	16	0.5%
Vietnam	4.6	0.3%	1.8%	16	3.2%
Total Top 30	1,251			4,205	
World Total	1,682		3.7%	5,650	8.8%

Untapped Potential

Reducing Global Methane Emissions from Oil and Natural Gas Systems

Over the past decade, a growing number of countries have established national policies or plans for reducing greenhouse gas (GHG) emissions. In doing so, most have focused on carbon dioxide (CO_2) emissions generated from the combustion of fossil fuels. As the largest source of GHG emissions (at around 60% of the world total[1]), energy-related CO_2 is a logical place to focus abatement activity. But as countries look to integrate lower-carbon alternatives into their energy systems, it is important to consider not only the CO_2 benefits of those choices, but the implications for other GHGs as well. The viability of natural gas as a bridge fuel in many countries will depend on a full lifecycle accounting of associated CO_2 and methane emissions.

One of the most consequential GHG byproducts of energy production is methane (CH_4), an extremely potent gas with as much as 28 times the climate impact of CO_2 over a 100-year period[2], and more than 84 times greater over a 20-year period.[3] If not properly controlled, methane can leak from all stages of the oil and gas process, from exploration and production at the well site to the distribution pipelines that deliver natural gas to homes and businesses. Methane emissions occur in both oil and natural gas systems, but effective leakage rates are considerably higher for the latter.

In the US, low cost natural gas from shale formations has helped reduce CO_2 emissions by displacing coal in power generation.[4] The ultimate climate benefit of this switch, however, will depend on the rate at which methane from oil and gas production, distribution and consumption is released into the atmosphere. Methane emissions from oil and gas systems are also an important climate issue beyond the US. Global natural gas production and consumption grew by 128% between 1982 and 2012, and now accounts for 24% of global energy supply (compared to 20% in 1982).[5]

In addition to being an important consideration in evaluating the climate implications of different energy choices, controlling methane can be a low-cost abatement strategy. Because methane is the primary component of natural gas (i.e. 95% of pipeline quality gas), recovering and using leaked methane can increase sales revenue. That can offset some, if not all, of the cost of leak detection and repair. A number of proven technologies and practices are available to reduce methane from all stages of the oil and gas system, from well-head to distribution, often at low or no-net cost.[6] The US Environmental Protection Agency (EPA) estimates that of the over 70 technologies and practices identified in their Natural Gas STAR Program, all but one pay back within three years, and over half pay back within one year.[7]

Incorporating methane considerations into energy policy decision making and developing effective methane abatement strategies is strengthened with an accurate understanding of the sources and magnitude of methane emissions from oil and natural gas systems. Yet relative to energy-related CO2 emissions, information on global methane emissions is limited, both in coverage and in quality.

This report attempts to improve understanding among both policymakers and civil society by 1) surveying available information on current and historical methane emissions from oil and gas systems worldwide; 2) highlighting significant gaps in country-level data and the wide disparities in the effective emission factors used by countries that do track and report methane emissions; 3) projecting methane emissions growth between now and 2030, both for the top oil and gas producing countries and top global companies, under a range of oil and gas price scenarios with what limited data is currently available; and 4) quantifying the global climate

[1] Rhodium Group analysis available at: www.rhg.com.

[2] The UNFCCC, and therefore most countries, has adopted a 100-year GWP value from the IPCC's Fourth Assessment Report (AR4) for reporting GHG inventory data starting in 2015 and tracking progress toward country commitments (a GWP value of 25). To maintain consistency, we use the AR4 100-year value throughout this report.

[3] The IPCC in its 2014 5th Assessment Report (AR5) revised the 20-year GWP estimate upward to 84. We use this value for 20-year GWP calculations throughout the report.

[4] Houser and Mohan, 2014.

[5] BP Statistical Review of World Energy 2014.

[6] IEA Special Report: Are we entering a golden age of gas? (2011) available here, and WRI's Clearing the Air (2013) available here.

[7] EPA Natural Gas STAR Recommended Technologies and Practices, available here. EPA estimates pay back times using a natural gas price of $5/Mcf.

impact of action by the top emitting countries and companies to control methane emissions.

CURRENTLY AVAILABLE DATA

As the old business adage goes, "you can't manage what you don't measure," and a lack of comprehensive and credible methane emissions measurement has been a major barrier to the development of serious methane emission reduction strategies. Methane emission sources are smaller and more diffuse than many other greenhouse gases. Measuring methane leaks from the millions of oil and gas wells and countless miles of natural gas distribution lines is a challenge, even for the most technologically advanced. As a result, country-level GHG inventories often include only very approximate information about emissions from the oil and natural gas systems, most of which is aggregated for the sector as a whole rather than separated by oil and gas or broken down by specific stages of the production and distribution process. Those countries, like the US, that provide relatively complete and regular methane emissions estimates, rely on approximations rather than direct measurement. Many countries simply do not report GHG emissions at all.

The quality of available information on oil and gas methane emissions is largely a factor of whether a country is considered developed ("Annex I") or developing ("non-Annex I") under the UN Framework Convention on Climate Change (UNFCCC). The requirements for reporting national GHG inventories apply differently to these country groups, resulting in significant differences in the level of detail of reported information and in the frequency of reporting.

All Annex I countries report emissions on an annual basis, with fuel-specific data (i.e. separated by oil and gas), as well as annually updated emissions and activity data for each stage of the oil and gas value chain going back to 1990. Non-Annex I countries report much more sporadically, often with a lag of as much as ten years (e.g. reporting 2000 emissions data in 2012). Non-Annex I countries are not required to break down their emissions by fuel or stage of the oil and gas process, which means that the majority report only aggregate oil and gas methane emissions without the underlying activity data.

Table 1 provides an overview of currently available oil and gas methane data reported to the UNFCCC for the top oil and gas producing countries. Several major oil and gas producers have never reported to the UN (including Iraq, Angola and Libya). For all but four non-Annex I countries on the list, the most recent data is from over 10 years ago. Five countries last reported data for emissions that occurred over 20 years ago.

Table I: Nationally reported oil and gas methane estimates

Top oil and gas producing countries

	Data Reported	Fuel-Specific	Stage-Specific	Year of most recent available data	Oil & Gas Production (Quads)
Annex I Countries					
All	X	X	X	2012	118
Non-Annex I Countries – Top Producers					
Saudi Arabia	X			2000	24
China	X			2005	12
Iran	X			2000	12
Qatar	X			2007	8
UAE	X			2005	8
Mexico	X			2006	7
Nigeria	X			1994	7
Kuwait	X			1994	6
Iraq					6
Venezuela	X			1999	6
Algeria	X			2000	6
Brazil	X			2005	5
Indonesia	X			2000	4
Angola					4
Libya					3
Egypt	X			2000	3
Malaysia	X			1994	3
India	X			2000	3
Turkmenistan	X			2004	3
Oman	X			1994	3
Argentina	X			2000	3
Azerbaijan	X			1990	3
Colombia	X			2004	2
Equatorial Guinea					1
Brunei Darussalam					1
Syria					1

Source: UNFCCC.

LEAKAGE MEASUREMENT AND UNCERTAINTY

For those countries that do report methane emissions estimates, there is a wide variation in reported emissions leakage rates. In its most recent 5th Assessment Report, the IPCC found large variation in estimates of global average methane leakage rates from the entire natural gas value chain (measured as a percent loss of total produced gas). They found that estimates range from as low as 1% to as high as 5%, with central estimates between 2-3% (+/-1%).[8] Reported leakage rates can vary due to type of oil and gas produced (offshore generally has lower leakage rates than onshore), the state of national infrastructure, air quality and safety policies, and industry management practices, as well as differences in measurement accuracy. For example, using EPA emissions estimates, the US natural gas leakage rate is 1.3%. China's national methane emissions estimates imply a leakage rate of about 0.02%.[9]

Developing an inventory to track methane emissions from oil and gas systems is a complex and highly uncertain exercise. There are a vast number of emission sources, with significant variability across geographies, facilities and equipment types. In preparing their GHG inventories for submission to the UNFCCC, countries rely on a mix of default emission factors provided by the IPCC (Tier 1 emission factors) and country-specific and process-specific emission and activity data.

The uncertainty estimates associated with both default and country-specific emission factors is quite high. The IPCC Tier 1 default emission factors used to calculate fugitive oil and gas emissions by some developing countries range from +75% for gas flaring to +500% for gas distribution and as high as +800% for venting from gas wells and fugitive emissions from oil production.[10] Some countries have developed methods to assess technology-specific emission factors (e.g. for hydraulic fracturing) and activity data (e.g. number of wells or miles of pipeline) and use these to generate more accurate emissions estimates than IPCC default values provide. Even so, uncertainty levels remain high. The US, which employs one of the most advanced approaches, provides uncertainty estimates for its natural gas methane emissions (+30%/-19%) and for oil systems (+149%/-24%) that are at least an order of magnitude larger than their uncertainty estimates for CO_2 emissions from fossil fuel combustion.[11]

Even within countries that use their own country-specific emission factors, there is significant debate about whether those estimates accurately reflect on-the-ground conditions. A number of recent studies have attempted to provide independent estimates of US emissions using measurements ranging from the device and facility level ("bottom-up" measurements) to continental-scale atmospheric studies ("top-down" measurements).[12] [13]

Improving confidence in methane emission estimates requires integrating information from high-quality independent studies along with better activity and emissions data reported by the industry itself. The EPA has begun doing so and acknowledged in its recent draft inventory for 2015 that stakeholder input helped inform recalculations of specific emission factors (e.g. for gas well completions with hydraulic fracturing). EPA indicated that planned improvements in the future would rely on new information generated from these channels, among others.

It is difficult to predict, however, how future oil and gas developments will affect leakage rates as they are measured today. Improvements are expected in measurement and reporting accuracy, as well as more widespread use of abatement technologies and practices as the sector grows and modernizes over the next 20 years. Improved information may raise emission rates in some countries, while new regulation or more expansive use of leak detection and repair may lower them.

COMPARING CURRENT LEAKAGE RATES

Using the most recently-reported national methane emissions estimates and oil and natural gas production, transmission, and consumption information from the energy consultancy Rystad and the US Energy Information Administration (EIA) for 2012, we assessed and compared methane leakage rates by and across countries (see Methodological Appendix for details).

Figure 1 compares upstream natural gas methane leakage rates (i.e. fugitive emissions from exploration, production and associated venting and flaring) for the 20 largest natural gas producing countries that report methane emissions to the UNFCCC. Three of the four largest gas producing countries (the US, Russia, and Canada) have relatively similar upstream leakage rates (around 2-3 kg CH_4/MMBtu produced). Many of the other major gas producers report significantly lower

[8] Bruckner et. al. (2014) Energy Systems. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available here.

[9] US EPA (2014) U.S. Greenhouse Gas Inventory Report: 1990-2012., available here. China's most recent GHG inventory available here.

[10] IPCC (2006) Guidelines for National Greenhouse Gas Inventories Volume 2: Energy. Available here.

[11] US EPA (2014) U.S. Greenhouse Gas Inventory Report: 1990-2012. Available here.

[12] Brandt et. al. (2014), Methane Leaks from North American Natural Gas Systems, *Science*, v343. Available here.

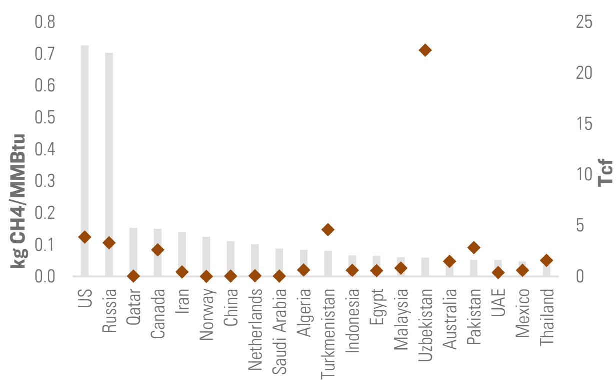
[13] Turner et. al. (2015). Available here.

emission rates, with 14 of the 20 top producers reporting emission factors less than half that of the US, and several countries (Qatar, Saudi Arabia, China, Netherlands and Norway) at less than 5% the US rate. Uzbekistan is an outlier with extremely high upstream leakage rates.

Much of this discrepancy is likely explained by differences in the composition of gas production by country. Onshore gas production (94%, 97% and 99% of US, Russian and Canadian output, respectively) generally has higher emission rates than offshore production (100% of output in Qatar and Norway and half of total production in Iran). Differences in the application of leak detection and repair and other abatement technologies and practices may also play a role, particularly in explaining Uzbekistan's extremely high leakage rate. But measurement and data quality is likely also an important factor, particularly in explaining significantly different leakage rates between countries with a similar gas production profile.

Figure 1: Upstream gas methane leakage rates

Leakage rate (left axis, dots) and production (right axis, bars)



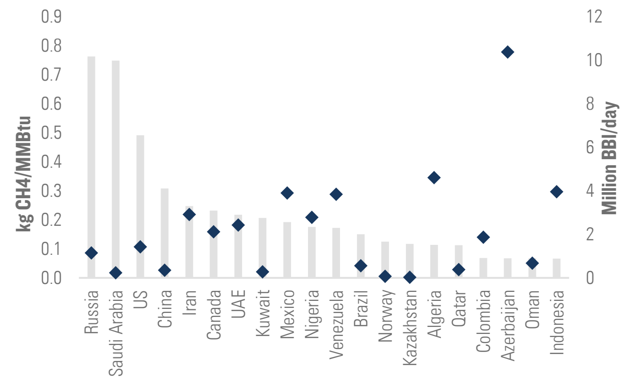
Source: UNFCCC, EIA, Rystad and RHG estimates.

There are also large disparities in the reported upstream oil leakage rates of the 20 largest oil producing countries that report methane estimates (Figure 2), even within a single region. In the Middle East, for example, leakage rates range from 0.02 kg CH_4/MMBtu of oil produced in Saudi Arabia to around twice that rate in Oman and Qatar, to more than ten times that rate in Iran and the UAE. It is not clear the extent to which these differences are a result of different on-the-ground conditions or a result of different measurement approaches.

In assessing the total climate impact of natural gas or oil versus other energy sources, it's not just the upstream leakage rate that matters, but leakage from the transportation and distribution of that oil and gas. Natural gas system leakage rates are generally assessed by dividing total system leakage by national production. This measure is imperfect, as it doesn't control for imports and exports, but is the most commonly used.

Figure 2: Upstream oil methane leakage rates

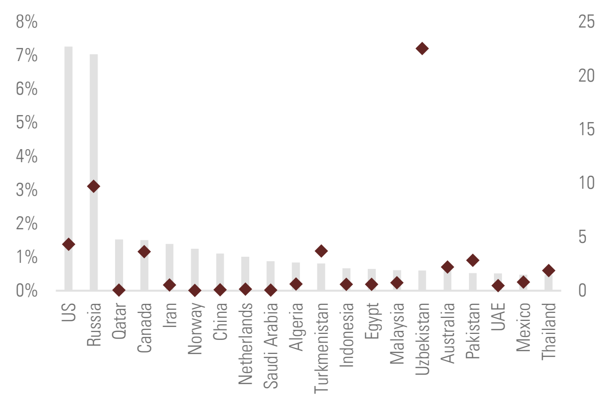
Leakage rate (left axis, dots) and production (right axis, bars)



Source: UNFCCC, EIA, Rystad and RHG estimates.

Figure 3: Natural gas system leakage rates

Leakage (left axis, dots) as % of production in Tcf (right axis, bars)

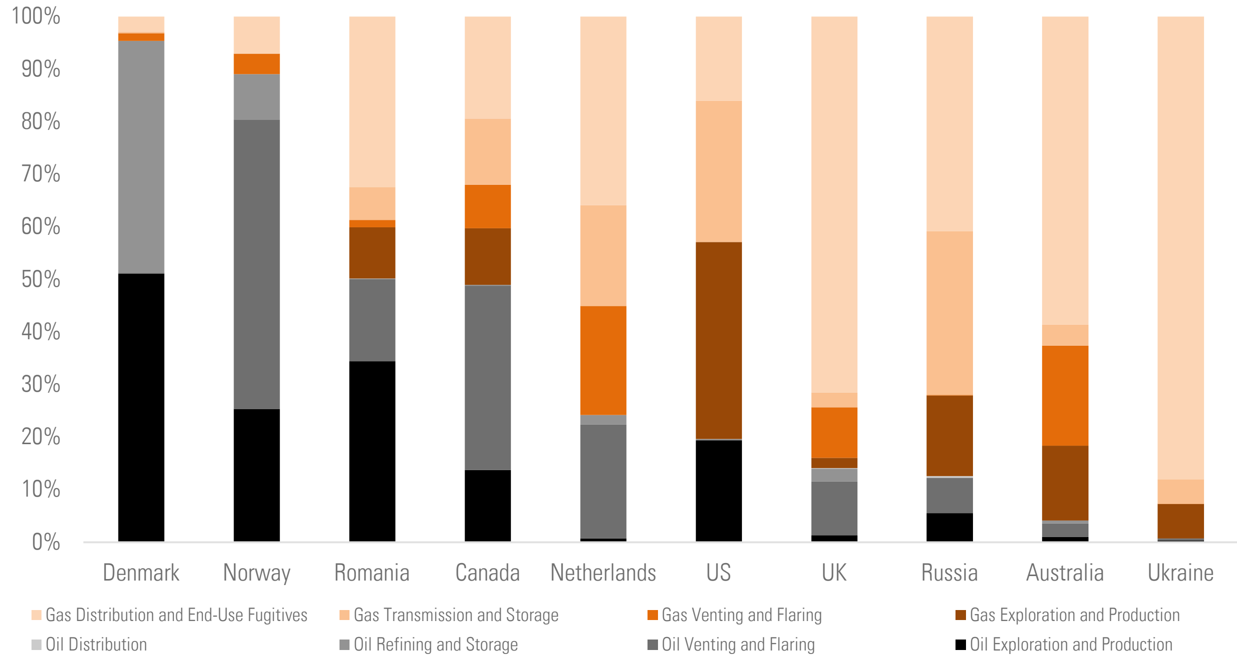


Source: UNFCCC, EIA, Rystad and RHG estimates.

Using nationally reported natural gas system emissions and Rystad natural gas production data, we find considerable variation in leakage rates across countries. Uzbekistan continues to top the list, with a leakage rate of 7%, followed by Russia with 3%, and the US, Canada, and Turkmenistan with around 1.3%. Several countries report nearly zero leakage, including Norway, the Netherlands, China, Saudi Arabia and Qatar, with the remaining countries clustering around the 0.2% level. As with upstream leakage rates, it is difficult to fully explain these differences based on currently available data.

Figure 4: Distribution of methane emissions from oil and gas systems

Share of total in 2012, top 10 developed country oil and gas producers



Source: UNFCCC national GHG inventories.

TODAY'S METHANE LANDSCAPE

Annex I countries report methane emissions every year and from each stage of the oil and gas production and distribution process. These data suggest that for oil, the vast majority of methane emissions occur during exploration and production, primarily the result of venting from pneumatic devices and storage tanks. Emissions from natural gas systems are much more widespread throughout the supply chain. During field production, wells, gathering pipelines, and well-site gas treatment facilities such as dehydrators and separators all leak methane. At the natural gas processing stage, compressors are the primary source of emissions. Pneumatic devices and compressor stations are the biggest culprits in the transmission and storage stage, with additional emissions coming from distribution pipelines that deliver gas to end users.

The distribution of emissions across the oil and gas system varies greatly between countries with different production and consumption profiles (Figure 4). For most Annex I country oil and gas producers, the majority of methane emissions come from upstream activities, including exploration and production. For large countries with expansive transport networks like Ukraine, Russia and Australia, emissions from gas transmission, storage and distribution are the largest sources. All Annex I countries combined emitted 717 Megatons CO2e of methane from oil and gas systems measured based on a 100-year global warming potential (GWP), 83% of which came from gas and the remaining 17% from oil.

For non-Annex I countries, we estimate 2012 emissions using oil and natural gas system leakage rates from the last year in which they reported, scaled using Rystad production and EIA refining and consumption data (see Methodological Appendix for more detail). Using this approach, non-Annex I countries emitted 964 MT of CO_2e of methane in 2012, 83% from oil and 17% from gas.

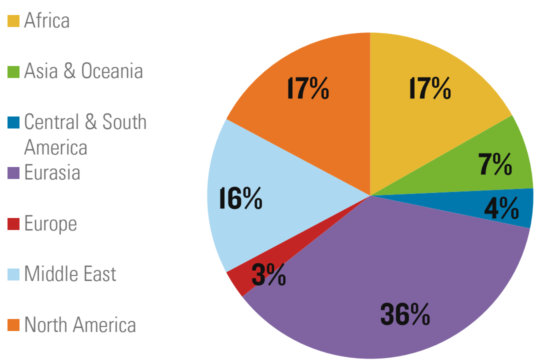
That brings the global oil and gas methane total to 1,681 MT CO_2e in 2012, using a 100-year GWP. If it were a country, oil and gas methane emissions would rank as the world's seventh largest emitter, coming in just under Russia. Measuring GWP over a 20-year period, oil and gas sector methane emission accounted for over 8% of global GHG's in 2012 (or around 5,650 Mt CO_2e), the equivalent of about 40% of total CO_2 emissions from global coal combustion in 2012.[14] This equates to a global leak rate of

[14] Based on estimates from IEA's CO_2 Emissions from Fuel Combustion: Highlights 2014, available here.

around 3% of global natural gas production[15], or 3.6 trillion cubic feet (Tcf) of natural gas. This wasted gas translates into roughly $30 billion of lost revenue at average 2012 delivered prices.[16] Of this, 45% came from natural gas production and 55% from associated gas from oil production.

Breaking these global estimates down by region, Eurasia accounted for 36%, North America for 17%, Africa for 17% and the Middle East for 16% (Figure 5), with Europe, Asia and Latin America playing a relatively minor role. Within these regional groups, a handful of counties are responsible for the majority of global emissions. In 2012, the seven biggest oil and gas methane emitters (for which self-reported data from any year is available) were responsible for over half of the world's total. The top 30 emitting countries accounted for three quarters of the global total (Table 2). The EU is presented as a bloc, aggregating emissions across its 28 member states, the top five of which are Romania, Germany, the UK, Italy, and Poland (see Appendix for EU member state results).

Figure 5: Current oil and gas methane emissions by region



Source: UNFCCC, EIA, Rystad and RHG estimates. For region definitions, see the Appendix.

There are some surprising absences from this top 30 list. Several major oil and gas producers were excluded because no emissions data have been reported to the UNFCCC. This includes Iraq, Angola, Libya, and Syria. Also, as noted in the previous section, many countries' reported leakage rates are extremely low when compared to countries with similar resource and technology profiles. With exceptionally low reported leakage rates these countries rank lower than their overall oil and gas production profiles would suggest. For example, based on nationally reported leakage rates, China and Colombia emitted the same amount of methane in 2012.

Table 2: Top 30 emitting countries in 2012

Excluding major oil and gas producers for which no data is available

	100-year GWP			20-year GWP	
	MT CO2e	% global o&g CH4	% country total GHG	MT CO2e	% country total GHG
Russia	387	23%	21%	1301	39%
US	192	11%	3.4%	647	8.7%
Uzbekistan	97	5.8%	42%	326	65%
Canada	54	3.2%	7.1%	180	17%
Mexico	43	2.6%	5.4%	146	11%
Azerbaijan	43	2.6%	53%	145	72%
EU	43	2.5%	1.0%	143	2.6%
Iran	43	2.5%	7.2%	143	18%
Venezuela	38	2.3%	16%	128	32%
Turkmenistan	37	2.2%	33%	126	47%
Algeria	30	1.8%	19%	99	38%
UAE	29	1.7%	10%	98	25%
Ukraine	29	1.7%	7.4%	96	17%
Nigeria	27	1.6%	8.1%	91	14%
India	25	1.5%	1.1%	85	2.3%
Indonesia	16	0.9%	0.8%	53	1.9%
Malaysia	14	0.8%	3.0%	46	7.7%
Thailand	12	0.7%	3.6%	41	7.4%
Pakistan	10	0.6%	3.2%	35	5.7%
Egypt	10	0.6%	3.3%	34	7.9%
Argentina	10	0.6%	3.4%	34	6.2%
South Korea	10	0.6%	1.5%	33	4.4%
Saudi Arabia	10	0.6%	1.9%	32	5.3%
Kazakhstan	8.6	0.5%	3.2%	29	7.1%
Côte d'Ivoire	8.2	0.5%	3.1%	27	8.4%
Australia	7.4	0.4%	1.3%	25	2.7%
Colombia	7.2	0.4%	3.2%	24	6.0%
China	6.4	0.4%	0.1%	22	0.1%
Brazil	4.7	0.3%	0.2%	16	0.5%
Vietnam	4.6	0.3%	1.8%	16	3.2%
Total Top 30	1,251			4,205	
World Total	1,682		3.7%	5,650	8.8%
OTHER MAJOR PRODUCERS					
Kuwait	3.2	0.2%	4.4%	11	12.7%
Oman	2.6	0.2%	3.5%	8.8	14.5%
Qatar	2.6	0.2%	3.0%	8.8	8.1%
Bahrain	2.2	0.1%	6.6%	7.3	13.8%
Norway	0.7	0.0%	1.2%	2.2	5.6%

Source: UNFCCC, EIA, Rystad and RHG estimates. 100-year GWP from AR4, 20-year GWP from AR5.
Note: Countries for which there was no reported emissions were excluded from this list, including: Iraq, Angola, Libya, Equatorial Guinea, Syria, Brunei, and Chad.

[15] This is in line with a recent study by Schwietzke et al 2015, which found most likely global methane leakage rates from oil and gas systems of 2-4% since 2000, with an upper bound of 5%.

[16] See Methodological Appendix for details.

ROUGH ESTIMATES OF COMPANY-LEVEL OIL AND GAS METHANE EMISSIONS

We estimate that two-thirds of all oil and gas system methane emissions in 2012 came from upstream exploration and production. A relatively small number of companies are likely responsible for a significant share of this emissions activity. While several international oil and gas companies do report their methane emissions and reduction activities, it is not yet standard practice among all companies to do so. More robust, standardized, and comparable, company-specific reporting can help provide emissions data at a more granular level and may provide valuable insights into company emissions and performance. Until that data is available, a rough estimation of company-level methane emissions can be derived; we applied national leakage rates to a given company's production in each country based on geographic allocation of production. In addition to the underlying uncertainty in national leakage estimates, this approach does not take into company-level differences in technology, practices, or resource base within a given country.

With these caveats in mind, we estimate that 20 companies were responsible for around 40% of the world's upstream oil and gas methane emissions in 2012, and over a quarter of total methane emissions from all stages of the oil and gas value chain (Table 3). As with our country-level estimates, a number of large oil and gas producing companies didn't make the list. This is primarily due to the fact that a large share of their production occurs in countries that either do not report emissions data (e.g. both Iraqi national oil companies) or use extremely low emission factors for calculating their national emissions.

Table 3: Top 20 methane emitting oil and gas companies

In alphabetical order based on estimated 2012 upstream emissions distributed by companies' ownership share of oil and gas projects

Company Name	Headquarters
Abu Dhabi National Oil Company	UAE
BP	UK
Chevron	US
Eni	Italy
ExxonMobil	US
Gazprom	Russia
Lukoil	Russia
National Iranian Oil Company	Iran
Nigerian National Petroleum Corporation	Nigeria
ONGC	India
PDVSA	Venezuela
Pemex	Mexico
Petronas	Malaysia
Rosneft	Russia
Saudi Aramco	Saudi Arabia
Shell	Netherlands
Socar	Azerbaijan
Sonatrach	Algeria
Turkmengas	Turkmenistan
Uzbekneftegaz	Uzbekistan
OTHER MAJOR PRODUCERS	
South Oil Company	Iraq
North Oil Company	Iraq
Libya National Oil Company	Libya

Source: UNFCCC, EIA, Rystad and RHG estimates. Note: Oil companies with the majority of operations in countries for which there is no emissions data were excluded from the top 20 list. They are reported here as "other major producers." Estimates of aggregate emissions for companies distributed by "operator share" (the proportion of each project controlled by a specific operating company) is available in the Methodological Appendix.

Yet China produced more than four times as much oil and nine times as much natural gas that year. Because China's reported leakage rate is one fifth Columbia's, China ranks lower on the list. Many other major oil producing countries, like Kuwait, Oman, and Qatar, did not make the top 30 because of their very low leakage rates, but are included in Table 2 to highlight the importance of variability in effective leakage rates in determining overall methane emissions estimates.

Methane from oil and gas systems plays an outsized role in national GHG emissions for some countries. For example, oil and gas methane represented over 20% of total Russian emissions in 2012, over 30% of Turkmenistan's emissions, over 40% of in Uzbekistan's emissions, and over 50% of Azerbaijan's emissions.

Emissions highly sensitive to leakage rate estimates

Given the uncertainty surrounding the accuracy of reported emissions data, it's possible that national methane emissions from some countries are considerably higher than the estimates included in this report. To understand the sensitivity of methane emissions to estimated leakage rates, we assessed the effect of a 50% increase in average global leakage rates.[17] This translates into an increase of 840 $MTCO_2e$ of methane emissions in 2012 (more than Canada's total GHG emissions), bringing the total to 2,520 $MTCO_2e$ using a 100-year GWP, boosting oil and gas methane's share of global GHG emissions from 3.7% to 5.6%.

Perhaps a more informative way of testing the sensitivity of emissions to estimated leakage rates is to compare countries with extremely low leakage rate outliers to other countries with similar oil and gas production profiles (i.e., similar geology and shares of onshore and offshore production). China and the US have a relatively similar production profiles in terms of on and offshore shares, yet China's effective leakage rate for upstream oil and natural gas production is four and 66 times lower, respectively, than the effective US rates. Applying US leakage rates to Chinese oil and gas production figures produces an overall Chinese methane emissions figure six times larger than the official Chinese estimate. This would increase total Chinese emissions by nearly 30 $MTCO_2e$, bumping China from the bottom of the top 30 list to number 11. Similarly, oil production in Russia and Kazakhstan is roughly similar to Canada (in terms of off versus onshore production), yet their leakage rates are two times and 55 times smaller, respectively. Applying the effective Canadian methane leakage rates for upstream oil production increases Russian oil and gas methane emissions by nearly 40 $MTCO_2e$ (or 10%) and Kazakh emissions by 13 $MTCO_2e$ in 2012 (or 250%).

The most significant variation in effective leakage rates among countries with similar production profiles is found in the Middle East. Aligning leakage rates for countries with extremely low outlier values with rates from countries with more central leakage rate estimates shifts total emissions from the region considerably. Bahrain, Kuwait and Oman have similar natural gas production profiles, yet Oman and Kuwait's leakage rates are 11 and 26 times lower than Bahrain, respectively. Saudi Arabia and the UAE have similar onshore/offshore profiles for gas production, yet Saudi Arabia's effective upstream leakage rate is 12 times smaller than the UAE. In the oil sector, despite similar profiles, the UAE's effective leakage rate is 10 times higher than Saudi Arabia, 9 times Kuwait, 6 times Qatar, and 4 times Oman. Applying the UAE and Bahraini emission rates to countries that match their production profiles for oil and gas production increases 2012 emission estimates for Saudi Arabia from 10 $MTCO_2e$ to 97 (bumping it from 23rd to third on the top emitting countries list). Total Kuwaiti oil and gas methane missions increase by a factor of ten, and Oman and Qatar, which did not make the original top 30 list, jump from around three to 10 $MTCO_2e$ and 15 $MTCO_2e$, respectively, placing them among the top 20 emitting countries. The overall result is an increase of Middle Eastern oil and gas methane emissions by a factor of eight in 2012.

When taken as a whole, aligning the upstream leakage rates of extremely low outlier countries with countries with similar production profiles increases total global emissions significantly. Even when applied to a limited number of countries in this illustrative exercise (i.e., a handful of Middle Eastern countries, China, Russia and Kazakhstan), total global oil and natural gas methane emissions rise by over 210 $MTCO_2e$ in 2012, an increase of nearly 13%. Given the sensitivity of methane emissions to national leakage rates estimates, we can infer from this exercise that if conducted for all outlier countries, aligning leakage rates with comparable countries would increase global emissions estimates from their current levels. The exact magnitude of this difference is not possible to assess, however, given the lack of information on measurement uncertainty across countries.

PROJECTED METHANE EMISSIONS GROWTH

The methodology used in this report to estimate current methane emissions can be used to explore future pathways as well. There are two main factors that will determine global oil and gas system methane emissions in the years ahead: a) changes in the quantity and composition of global oil and gas production and consumption; and b) changes in methane emission rates throughout the oil and gas system. We explore the first category by assessing the methane implications of a range of global oil and gas market scenarios using current nationally-reported leakage rates to quantify the magnitude of potential emissions savings from reducing leakage in the years ahead.

Dramatic changes in the global oil and gas market in recent years – from the US shale boom, to international sanctions, to a sharp slow-down in oil demand growth – make predicting future production and consumption levels more difficult than ever. Therefore we explore the methane implications of three oil and gas market scenarios – Low, Mid and High (Figure 6).

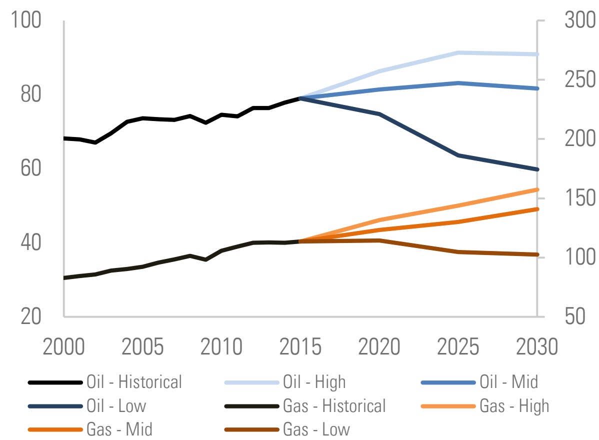
Global oil and natural gas production grew by roughly 1% and 2% respectively per year, on average, between 1990 and 2014. These growth rates continue between 2014 and 2030 in the High scenario on average, though oil

[17] Similar to Miller et. al. 2013's estimate of the degree to which EPA inventories may underestimate US leakage rates.

production plateaus in 2025. In the Mid scenario, average annual oil and natural gas production growth between 2014 and 2030 slows to 0.3% and 1.4%, respectively. In the Low scenario, oil and natural gas production fall by an average of 1.6% and 0.6% per year between 2014 and 2030. The geographical allocation of production under each scenario is derived from Rystad. The geographical allocation of consumption is derived from EIA projections. For more detail see the Appendix.

Figure 6: Global production scenarios

Oil (million Bbl/d, left) and natural gas (Tcf, right)

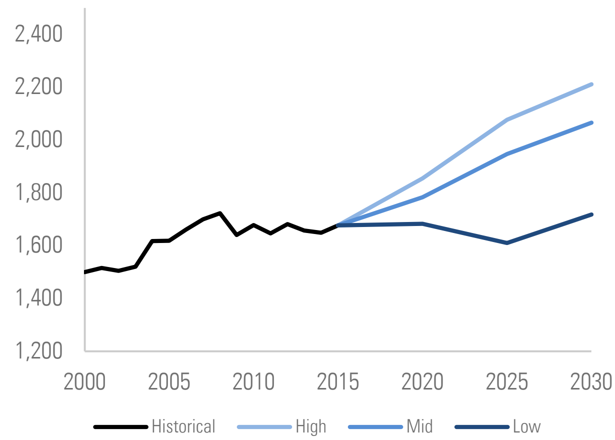


Source: Rystad and RHG estimates.

Using business-as-usual national emission rates (assuming no policy-based or voluntary improvements from the most recently-reported rates), global methane emissions from oil and gas systems rise by 0.1% between 2012 and 2020 in our Low scenario, 6% in our Mid scenario and 10% in our High scenario (Figure 7). Between 2020 and 2030, methane emissions rise by 2% in the Low scenario, even though both oil and gas production decline as the share of production in countries with high leakage rates grows. Emissions rise by 16% in the Mid scenario and 19% in the High scenario. That puts total 2030 emissions at anywhere between 1,700 (Low) and 2,200 (High) MT CO_2e (measured in 100-year GWP terms), a 2% to 32% increase from 2012 levels. The Mid production scenario is used as the baseline scenario for the remainder of the report. In this scenario, global methane emissions will likely increase by 6% between 2012 and 2020 and 23% between 2012 and 2030. These projections are based only on changes in future oil and gas production, and do not take into account potential leakage rate changes from evolving industry practice or technologies, aging infrastructure, or new regulations that take effect after 2012.

Figure 7: Global oil and gas methane emissions

$MTCO_2e$ under three production scenarios, 100-year GWP

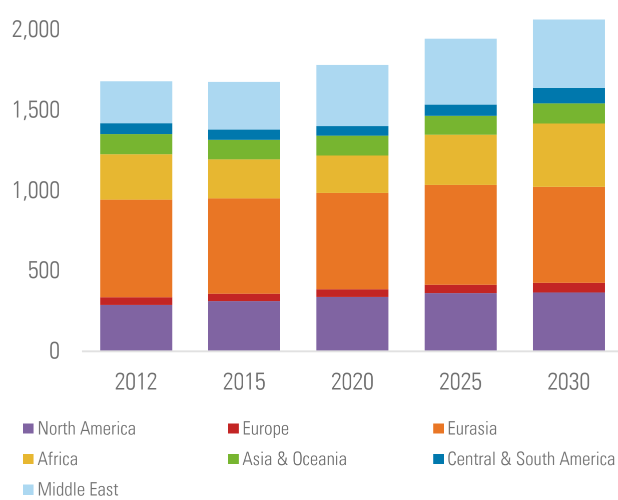


Source: UNFCCC, EIA, Rystad and RHG estimates.

The regional distribution of methane emissions will likely change in the coming years as well as a result of shifting oil and gas production activities (Figure 8). In our Mid scenario, Eurasia remains the largest regional source of oil and gas methane, but its share declines from 36% in 2012 to 29% in 2030. North America's share rises from 17% in 2012 to 19% in 2020, but then falls to 18% in 2030. The Middle East's share grows from 16% in 2012 to 21% in 2020, where it remains through 2030. Africa's share falls from 17% in 2012 to 13% in 2020, but then grows to 19% in 2030. Central & South America's share rise modestly between 2012 and 2030, while Europe and Asia & Oceania's share remains relatively flat.

Figure 8: Regional distribution of oil and gas methane

Mid scenario, $MTCO_2e$, 100-year GWP

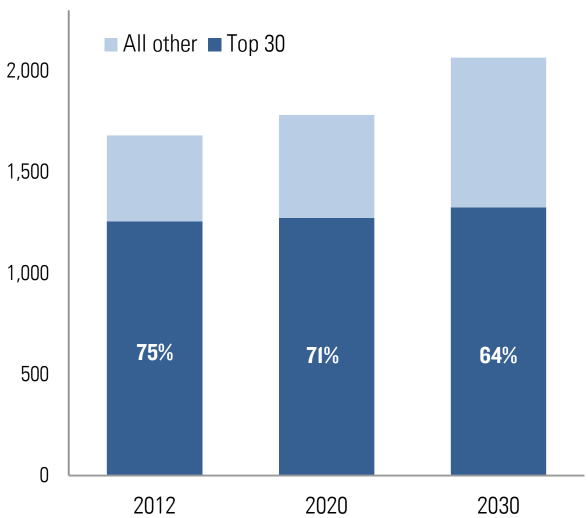


Source: UNFCCC, EIA, Rystad and RHG estimates. For region definitions, see Methodological Appendix.

The top 30 countries continue to account for the majority of global oil and gas methane emissions in all three production scenarios through 2030, though their share of the global total declines over time. In the Mid scenario, top 30 countries account for 64% of global methane emissions in 2030, down from 75% in 2012 (Figure 9).

Figure 9: Top 30 countries' share of global total

Mid scenario, oil and gas methane emissions, $MtCO_2e$, 100-year GWP



Source: UNFCCC, EIA, Rystad and RHG estimates.

Within the top 30 countries, emissions remain relatively concentrated among a handful of countries (Table 4). The seven largest oil and gas methane emitters in 2012 (excluding countries that do not report GHG emissions), continue to be responsible for roughly half of the global total through 2030. In our Mid scenario, absent policy or technology developments, we project double digit oil and gas methane emissions growth for a third of top 30 countries between 2012 and 2030, many of whom are starting from a relatively high emissions base (e.g. North America, the EU and Venezuela). North America's emissions are projected to increase by more than 17% by 2020, and 27% by 2030, though these projections do not reflect recently adopted air pollution standards[18] or policies put in place from 2012 forward.

REDUCING OIL AND GAS METHANE EMISSIONS

With the upcoming UNFCCC talks in Paris later this year, 2015 is poised to be a watershed moment for national and international commitments to reduce GHG emissions. At the UN climate talks in Warsaw in 2013, countries agreed to put forward "nationally determined" mitigation commitments for the period after 2020 and to announce those "intended contributions" well in advance of the Paris talks. Building on the Copenhagen agreement in 2009, an even greater number and wider diversity of countries is expected to submit commitments under the Paris agreement.

Exploring the potential for GHG abatement from one of the largest and fastest growing sources – methane from the oil and gas sector – should be central to the development, assessment and implementation of post-2020 mitigation contributions. For countries seeking to reduce GHG emissions from energy production and consumption, incorporating oil and gas methane estimates will help ensure their policies effectively reduce all gases, not just CO_2. For major oil and gas producing countries, controlling methane emissions can provide a significant and potentially low-cost opportunity to achieve additional abatement in 2020 and beyond. For many non-Annex I countries that have not yet adopted sectoral or national GHG goals in the UN context, establishing an oil and gas methane goal may be a cost-effective first step toward broader climate policies going forward.

The aggregate climate impact of a concerted global effort to reduce oil and gas methane emissions could be considerable. For illustrative purposes, we quantify the impact of a 25%, 50% and 75% reduction in oil and gas methane emissions below 2012 levels by 2030 from our top 30 countries (Table 4). This is not intended as a suggestion of what level of methane abatement is cost-effective or politically feasible, but rather to provide a general sense of magnitude and an indication of which countries' oil and gas methane reduction efforts could significantly alter overall GHG emission levels. The recently announced US goal of reducing oil and gas methane emissions 40-45% from 2012 levels by 2025 suggests that goals in this 25-75% range may be feasible.

Figure 10 shows the impact of varying top 30 country reduction goals on global oil and gas methane emissions in 2020 and 2030. If all top 30 countries reduced oil and gas methane emissions by 25% below 2012 levels by 2030, global GHG emissions would fall by roughly 380 MTCO2e relative to business-as-usual in our Mid scenario (about 1,290 MTCO2e using a 20-year GWP). A 50% reduction would yield roughly 700 $MTCO_2e$ (2,300 $MTCO_2e$ with 20-year GWP) and a 75% reduction 1,000 $MTCO_2e$ (3,400 $MTCO_2e$ with 20-year GWP).

[18] EPA estimates that the 2012 New Source Performance Standards and National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry will collectively reduce methane emissions by over 25 MT CO_2e in 2015.

Table 4: Top 30 countries in detail

Mid scenario, oil and gas methane emissions in $MTCO_2e$ and % change from 2012

	2012		2020			2030		
	100-year GWP	20-year GWP	100-year GWP	20-year GWP	% change	100-year GWP	20-year GWP	% change
Russia	387	1301	381	1280	-2%	400	1343	3%
US	192	647	235	790	22%	250	841	30%
Uzbekistan	97	326	88	297	-9%	74	247	-24%
Canada	54	180	72	242	34%	84	282	56%
Mexico	43	146	32	107	-26%	33	110	-24%
Azerbaijan	43	145	39	131	-10%	29	96	-34%
EU	43	145	44	149	2%	52	174	20%
Iran	43	143	46	153	7%	55	184	28%
Venezuela	38	128	34	115	-10%	48	162	27%
Turkmenistan	37	126	35	117	-7%	33	111	-12%
Algeria	30	99	20	68	-31%	13	45	-55%
UAE	29	98	34	115	17%	30	102	5%
Ukraine	29	96	28	94	-3%	31	105	9%
Nigeria	27	91	24	82	-10%	25	83	-9%
India	25	85	22	75	-11%	20	67	-21%
Indonesia	16	53	13	42	-21%	9.2	31	-42%
Malaysia	14	46	16	55	19%	16	55	19%
Thailand	12	41	9.0	30	-25%	7.4	25	-39%
Pakistan	10	35	8.4	28	-19%	9.8	33	-5%
Egypt	10	34	7.5	25	-26%	6.0	20	-41%
Argentina	10	34	7.2	24	-28%	9.4	32	-6%
South Korea	9.7	33	11	36	9%	16	52	59%
Saudi Arabia	9.7	32	9.0	30	-7%	8.9	30	-8%
Kazakhstan	8.6	29	11	37	27%	12	42	44%
Côte d'Ivoire	8.2	27	8.9	30	9%	13	44	60%
Australia	7.4	25	11	38	53%	18	59	139%
Colombia	7.2	24	6.3	21	-12%	3.0	10	-58%
China	6.4	22	5.9	20	-9%	5.4	18	-16%
Brazil	4.7	16	8.6	29	84%	12	40	156%
Vietnam	4.6	16	4.2	14	-10%	2.2	7.3	-53%
Total Top 30	1,256	4,222	1,273	4,276	1.3%	1,324	4,449	5.4%
Total World	1,682	5,650	1,783	5,992	6.1%	2,066	6,940	23%
OTHER MAJOR PRODUCERS								
Kuwait	3.2	10.6	3.1	10.3	-2%	2.6	8.8	-17%
Oman	2.6	8.8	1.8	6.0	-32%	1.3	4.3	-51%
Qatar	2.6	8.8	2.4	8.0	-9%	2.1	6.9	-21%
Bahrain	2.2	7.3	2.7	8.9	22%	2.0	6.9	-7%
Norway	0.7	2.2	0.7	2.4	9%	0.8	2.8	26%

Source: UNFCCC, EIA, Rystad and RHG estimates. 100-year GWP from AR4, 20-year GWP from AR5.

Note: Countries for which there was no reported emissions were excluded from this list, including: Iraq, Angola, Libya, Equatorial Guinea, Syria, Brunei, and Chad.

Table 5: Oil and gas methane emissions reductions for Top 30 countries and other major producers

Mid scenario, $MTCO_2e$

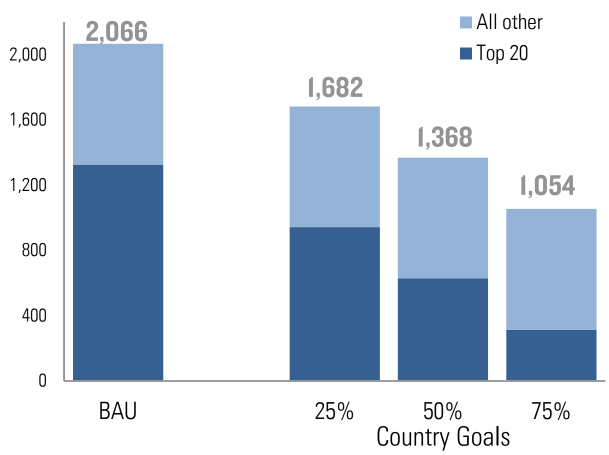
	25% below 2012		50% below 2012		75% below 2012	
	100-year GWP	20-year GWP	100-year GWP	20-year GWP	100-year GWP	20-year GWP
Russia	109	367	206	692	303	1018
US	106	356	154	517	202	679
Uzbekistan	0.9	2.9	25	84	49	166
Canada	44	147	57	192	70	237
Mexico	0.3	1.0	11	37	22	74
Azerbaijan	-3.8	-13	7.1	24	18	60
EU	21	71	32	107	43	143
Iran	23	76	33	112	44	148
Venezuela	20	66	29	98	39	130
Turkmenistan	5.0	17	14	48	24	80
Algeria	-8.9	-30	-1.5	-5.1	5.9	20
UAE	8.6	29	16	53	23	78
Ukraine	10	33	17	57	24	81
Nigeria	4.3	14	11	37	18	60
India	0.9	3.1	7.2	24	14	45
Indonesia	-2.6	-8.8	1.3	4.5	5.3	18
Malaysia	6.1	20	10	32	13	44
Thailand	-1.7	-5.7	1.3	4.4	4.3	15
Pakistan	2.0	6.9	4.6	16	7.2	24
Egypt	-1.7	-5.6	0.9	3.0	3	12
Argentina	1.9	6.4	4.4	15	6.9	23
South Korea	8.2	28	11	36	13	44
Saudi Arabia	1.7	5.7	4.1	14	6.5	22
Kazakhstan	6.0	20	8.1	27	10	34
Côte d'Ivoire	6.9	23	9.0	30	11	37
Australia	12	41	14	47	16	53
Colombia	-2.4	-8.1	-0.6	-2.0	1.2	4.0
China	0.6	1.9	2.2	7.3	3.8	13
Brazil	8.4	28	10	32	11	36
Vietnam	-1.3	-4.4	-0.1	-0.5	1.0	3.4
Total Top 30	384	1,289	698	2,344	1,012	3,399
Other Major Producers						
Kuwait	0.2	0.8	1.0	3.5	1.8	6.1
Oman	-0.7	-2.2	0.0	0.0	0.6	2.1
Qatar	0.1	0.3	0.7	2.5	1.4	4.7
Bahrain	0.4	1.4	0.9	3.2	1.5	5.0
Norway	0.3	1.1	0.5	1.7	0.7	2.2

Source: UNFCCC, EIA, Rystad and RHG estimates. Note: Countries for which there was no reported emissions were excluded from this list, including: Iraq, Angola, Libya, Equatorial Guinea, Syria, Brunei, and Chad.

For many countries, tackling oil and gas methane emissions could make a significant contribution to their overall GHG reductions by 2030. A 50% reduction by 2030 would reduce overall projected Russian emissions by more than 200 million tons – a significant sum given that total Russian GHG emissions were over 2,600 $MTCO_2e$ in 2012. An oil and gas methane pledge would play an even larger role in reducing overall GHG emissions in Uzbekistan, Turkmenistan and Azerbaijan, where oil and gas methane emission make up the majority of total national GHG emissions. Action on oil and gas methane in North America, Venezuela, UAE, Côte d'Ivoire, Ukraine, and Nigeria would also have a significant impact on overall GHG emissions given their anticipated magnitude and growth in emissions from the sector going forward.

Figure 10: Impact of achieving Top 30 goals in 2030

Mid scenario oil and gas methane emissions, $MTCO_2e$, 100-year GWP



Source: UNFCCC, EIA, Rystad and RHG estimates.

For several countries, production declines between 2012 and 2030 in our Mid scenario, which makes a commitment relative to 2012 levels less meaningful. Indeed for a number of our top 30 countries (those with negative values in Table 5), a 25% or 50% goal would not deliver any abatement beyond business-as-usual, though the 75% goal would. In Algeria, emissions fall by more than half by 2030 in our Mid scenario due to a production decline, delivering nine MTCO2e of abatement beyond what the 50% goal would achieve. For Algeria and other countries where declining production is likely, BAU-based goals may be more appropriate for driving emission reductions beyond what would already occur.

CONCLUSIONS

Despite its climate significance, very few countries have taken steps to regulate methane emissions from the oil and gas sector or set specific goals to reduce emissions in the future. This not only leaves a potentially cost-effective source of abatement on the table, but could also reduce the effectiveness of efforts to reduce GHG emissions across the energy sector, from power generation to transportation.

A proper understanding of current and future methane emissions is necessary for enhancing the effectiveness of efforts to manage emissions across the sector. Unfortunately existing estimates are severally lacking both in quality and coverage. As demonstrated in this report, there is a wide variation in effective national methane leakage rates and insufficient information to diagnose the extent to which these differences stem from variation in resource type (e.g. onshore versus offshore oil and gas), production practices, policy and technology, or are the result of poor or incomplete measurement. Many countries report only aggregate methane emissions numbers and at infrequent intervals. Some countries don't report GHG emissions at all.

This report highlights some of the most significant shortcomings in currently available data in the interest of raising awareness and helping to guide efforts to improve measurement and reporting systems to ultimately enhance the effectiveness of GHG mitigation strategies.

Using what data is available, we have provided the best estimates of current and projected oil and gas methane emissions by country and the role of the leading countries in current and projected global totals. While this approach is still limited by the quality of underlying national emission estimates, it highlights the probability of significant methane emissions growth in the years ahead if steps are not taken to reduce emission rates. It also highlights the potential for significant reductions in global methane emissions through action by the top-emitting countries. We hope this helps inform national and international efforts to reduce methane emissions in the years ahead and spurs measurement and reporting improvements that provide an even better estimate of both the challenge and abatement opportunity methane presents.

References

Brandt et. al. (2013). Methane Leaks from North American Natural Gas Systems. *Science*, v343.

Bruckner et. al. (2014). Energy Systems. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

EIA (2013). International Energy Outlook 2013. US Energy Information Administration. Report Number: DOE/EIA-0484(2013). http://www.eia.gov/forecasts/archive/ieo13. Accessed 24 February, 2015.

EIA (2015). International Energy Statistics. US Energy Information Administration. Online database. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm. Accessed 2 February, 2015.

EPA (2004). Unit Conversions, Emissions Factors, and Other Reference Data. http://www.epa.gov/cpd/pdf/brochure.pdf. Accessed 30 March, 2015.

EPA (2012). Global Anthropogenic Non-CO2 GHG Emissions: 1990 – 2030. US Environmental Protection Agency. http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html. Accessed 5 March, 2015.

EU Commission (2013). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2FT2010. European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. http://edgar.jrc.ec.europe.eu. Accessed 23 October, 2014.

FAO (2013). FAOSTAT Emissions Database. United Nations Food and Agriculture Organization. http://faostat.fao.org. Accessed 23 October, 2014.

IEA (2014a). Energy Prices and Taxes. International Energy Agency. Report, v. 2014 (4). DOI 10.1787/energy_tax-v2014-4-en. Accessed 31 March, 2015.

IEA (2014b). Natural Gas Information 2014. International Energy Agency. Report. DOI 10.1787/nat_gas-2014-en. Accessed 31 March, 2015.

IEA (2014c). CO_2 Emissions from Fuel Combustion: Highlights 2014 Edition. Accessed 8 April, 2015.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html. Accessed 16 March, 2015.

Miller et. al. (2014). Anthropogenic emissions of methane in the United States. *PNAS*, v.110, n.50.

Rystad (2015). UCube (Upstream Database). Rystad Energy. Database. Accessed 11 March, 2015.

Schwietzke et. al. (2014). Natural Gas Fugitive Emissions Rates Constrained by Global Atmospheric Methane and Ethane. *Environmental Science and Technology*, v.48 (14), pp 7714–7722.

Turner et. al. (2015). Estimating global and North American methane emissions with high spatial resolution using GOSAT satellite data. *Atmospheric Chemistry and Physics Discussions*, v.15, pp. 4495-4536.

UNFCCC (2015). Flexible GHG data queries. United Nations Framework Convention on Climate Change. Online database. Accessed 3 February, 2015.

Methodological Appendix

The Untapped Potential report explores the current landscape of methane emissions data from the oil and gas sector, and provides insight into the currently-reported estimates provided by national governments to the United Nations Framework Convention on Climate Change (UNFCCC). This appendix describes the methods used in analyzing the available data, as well as the motivations behind the approach that was taken.

HISTORICAL NATIONAL EMISSIONS FACTORS

A number of approaches are used by governments, academics, and industry in calculating oil and gas sector methane emissions, each with advantages and disadvantages. Each method reflects an attempt to navigate a key challenge: estimating methane emissions must weigh the accuracy of a small-scale study against the utility of a national or international estimate.

The IPCC (2006) defines three approaches, or "tiers" available to countries for estimating their emissions:

- Tier 1 employs a default emissions factor to the respective "activity level" at each stage of a country's oil and natural gas production, processing/refining, storage, transmission, distribution, and consumption sector;

- Tier 2 is identical to Tier 1 with the exception that the emissions factors are country-specific, built either from studies and measurement or from a Tier 3 study conducted in a previous year; and

- Tier 3 uses a "bottom-up" approach, in which studies of methane emissions factors and leakage rates are conducted at the facility, well, or pipeline level and are applied to facility-level activity data, such as quantities of specific types of wells, miles and throughput of pipelines, and refining throughput.

All countries categorized by the UNFCCC as developed countries (often referred to as "Annex I" countries) are required to submit annual emissions estimates using a Tier 3 methodology. Developing countries ("non-Annex I") are discouraged from using a Tier 1 approach for any sector which is classified as significant under the 2006 IPCC guidelines.

The Tier 3 approach provides the highest data quality, but relies on detailed industry data which is in many cases not publicly available. Therefore, independent analysis of international emissions data frequently makes use of a hybrid of Tier 1 and nationally reported figures. EPA's *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2030* (EPA 2012) uses reported emissions data when available. When data is missing in some years but not others, EPA interpolates between reported years and extrapolates into the future by scaling reported data using changes in Tier 1 estimates. Where no data is reported, EPA uses Tier 1 estimates exclusively.

In this report we use a similar approach to EPA, but incorporate additional data submitted to the UNFCCC since 2012, as well as new production estimates that incorporate recent shifts in oil and gas production. Furthermore, we use an approach that provides not only aggregated emissions estimates for the entire oil and gas sector each year, but also broken down by fuel and within eight stages of the oil and gas sector process (i.e. exploration, production, gathering/processing (gas), transport/transmission, refining (oil), storage, distribution, and other end-use emissions). These stages are mapped to the detailed sectors reported under the UNFCCC Common Reporting Format (see Table A1).

To accommodate the various levels of data quality and availability by country and year, we use the following steps to determine the method for estimating current and future emissions from each country:

1. If a country has reported detailed sector-level methane emissions to the UNFCCC, and if those data are consistent with the aggregate oil and natural gas sector data, we use UNFCCC-reported data at the sector and stage level for all reported years. This describes Kazakhstan and all Annex I countries, with the exception of Iceland and Hungary, which submitted stage-specific data that was inconsistent with the oil and gas sector totals (see countries marked "NC-Detail" in table A3).

2. If a country fails to meet method (1) but has reported oil and gas emissions separately, and if those data are consistent with the submitted aggregate oil and natural gas data, we distribute aggregated emissions reported to the UNFCCC across oil and gas stages using the distribution of emissions provided by IPCC Tier 1 estimates. No countries submitted qualifying separate oil and gas data except those meeting method 1.

3. If a country fails to meet method (2) but has reported aggregate oil and gas sector-level methane emissions, we distribute UNFCCC-reported data for reported years across oil and gas stages using Tier 1 estimates of oil and gas stage-specific data for those years. This describes all countries marked "NC-Total" in table A3, most notably Uzbekistan, Azerbaijan, Mexico, Iran, Venezuela, and Turkmenistan.

4. Finally, if a country fails to meet method (3), that is, they have never submitted any data to the UNFCCC, we use Tier 1 estimates to calculate emissions for all historical years (1990 – 2012). These emission factors are significantly higher than most country-specific methods. This describes all countries marked "Tier 1" in table A3, most notably Iraq, Angola, and Libya.

Using these emissions estimates, we derived oil and gas stage-specific methane emissions factors for the years in which data was available. This was done by dividing the emissions estimates by the corresponding "activity levels" for each oil and gas stage. To calculate upstream oil and gas emissions, we used production volumes of oil (crude oil and condensates) from Rystad (2015), oil refining from EIA refining data (EIA 2013), gas transmission from an average of Rystad production and EIA consumption data (2015), and oil and gas distribution/use from EIA consumption data. In each case, as well as for the production projections described in the following section, EIA refining and consumption data was scaled so that global EIA production equaled global Rystad production, to adjust for scenario differences.

Table AI: UNFCCC Greenhouse Gas Inventory Sectors Used in this Study

UNFCCC Sector	Description	RHG Oil & Gas Stage
1.B	Fugitive Emissions From Fuels	
1.B.2	Oil and Natural Gas	
1.B.2.A	Oil	
1.B.2.A.1	Exploration	Oil - Upstream - Production
1.B.2.A.2	Production	Oil - Upstream - Production
1.B.2.A.3	Transport	Oil - Upstream - Production
1.B.2.A.4	Refining / Storage	Oil - Downstream - Refining/Storage
1.B.2.A.5	Distribution of oil products	Oil - Downstream - Distribution/Use
1.B.2.A.6	Other	Oil - Downstream - Distribution/Use
1.B.2.B	Natural Gas	
1.B.2.B.1	Exploration	Gas - Upstream - Production/Processing
1.B.2.B.2	Production / Processing	Gas - Upstream - Production/Processing
1.B.2.B.3	Transmission	Gas - Downstream - Transmission
1.B.2.B.4	Distribution	Gas - Downstream - Distribution/Use
1.B.2.B.5	Other Leakage	Gas - Downstream - Distribution/Use
1.B.2.C	Venting and Flaring	
1.B.2.C.1	Venting	
1.B.2.C.1.1	Oil	Oil - Upstream - Venting & Flaring
1.B.2.C.1.2	Gas	Gas - Upstream - Venting & Flaring
1.B.2.C.1.3	Combined	Oil & Gas - Upstream - Venting & Flaring
1.B.2.C.2	Flaring	
1.B.2.C.2.1	Oil	Oil - Upstream - Venting & Flaring
1.B.2.C.2.2	Gas	Gas - Upstream - Venting & Flaring
1.B.2.C.2.3	Combined	Oil & Gas - Upstream - Venting & Flaring
1.B.2.D	Other	[No Countries Reported]

Source: Rhodium Group, UNFCCC.

To arrive at a complete set of emissions estimates for every country and every year from 2000–2012, we interpolated and extrapolated emissions factors in years in which data was not available. Specifically, for methods 1, 2, and 3 that use data submitted to the UNFCCC, we interpolated between years by applying the most recent emissions factor. For years in which a country had not yet reported any qualifying data, we applied the earliest available emissions factor. And for years after which a country did not report data, we assume the emissions factor does not change from the most recent available factor.

When calculating the Tier 1 emissions estimates – used to extrapolate and distribute reported data for methods 1, 2, and 3, as well as the actual emissions estimates for method 4 – we applied the default emission factor for each development group (IPCC, 2006). In some cases, these emissions factors are supplied at a greater level of granularity than can be applied to the activity data used in this report and emissions reported to the UNFCCC. In these cases, the 'default weighted total' factors were used.

Additionally, the most recent IPCC Common Reporting Format (CRF) separates venting and flaring emissions into a separate category which is undifferentiated by the stage of oil and gas systems (see table A1), while IPCC (2006) supplies venting and flaring emission factors for each stage of production. To reconcile this discrepancy, we attribute venting & flaring emissions for each sector to upstream emissions in our Tier 1 estimates, and similarly we consider all venting and flaring data submitted to the UNFCCC as upstream emissions. This upwardly biases upstream emissions relative to downstream emissions in our Tier 1 estimates, as in reality some venting and flaring emissions occur further downstream.

Finally, to calculate the carbon dioxide equivalent (CO_2e) of the resulting methane emissions estimates – provided in megagrams (Mg) or gigagrams (Gg) of methane – we converted using a 100-year GWP from AR4 (25) in line with UNFCCC reporting requirements and established metrics for assessing 2020 mitigation pledges. We also calculated the results using the 20-year GWP value of 84 from the most recent IPCC Assessment (AR5).

A number of countries have never reported their emissions to the UNFCCC, including major oil and gas producers like Angola, Brunei, Chad, Equatorial Guinea, Iraq, Libya, and Syria (see Table A3). To calculate emissions from these countries, we use IPCC Tier 1 default emission factors for non-Annex I countries. IPCC default values are often an order of magnitude higher than most country-specific estimates, potentially biasing the results for these countries when compared to countries using Tier 2 or 3 methods. For this reason, we exclude these countries from our list of top 30 countries, though we include their emissions in the global totals presented in this report.

EMISSIONS PROJECTIONS AND GOALS BY COUNTRY

To project oil and natural gas emissions in future periods (2015, 2020, 2025, and 2030) we assume that the oil and gas stage-specific emissions factors remain constant from their 2012 values. Our projections use three oil and gas price/production scenarios (Rystad 2015), referred to in this report as "Low," "Mid," and "High." As in the historical emissions estimates, we use oil refining and oil and gas consumption data by country to estimate the activity level to which the stage-specific emissions factors are applied. The activity data developed for 2012 using the historical methodology formed the basis for our activity data projections. Starting with this 2012 data, we used the EIA's International Energy Outlook (2013) growth rates by stage, fuel, and region to project changes in production, refining, and consumption levels, then scaled these values by the difference between the global total value of this extrapolated production value and the global Rystad scenario production for each of the three scenarios by year. This gave us three internally-consistent projections of oil and gas production, oil refining, and oil and gas consumption by year. The 2012 emissions factors were then applied to these activity levels to derive the national emissions projections by stage and year.

The illustrative emission reduction goals are based on reductions below 2012 levels in the year 2030. Therefore, the reductions that result from achieving the goals in 2030 represent the difference between BAU emissions in 2030 and the emissions levels associated with achieving the goal in that year (which is calculated as a percentage reduction from 2012). Specifically:

$$Reduction_{2030} = BAU_{2030} - Emissions_{2012}[1 - goal\ \%]$$

For example, Russia's 2012 emissions are 387 Mt CO_2e, and 2030 BAU emissions are 400 Mt CO_2e. For the 25% goal, the reduction is equal to 400-387*(1-0.25) which equals 109.8 Mt CO_2e.

EMISSIONS ESTIMATES BY COMPANY

The Rystad database (2015) provides detailed production by product (oil and gas), company (by owner and operator), project, and country. To develop emissions estimates by company, we applied the national product-specific upstream emissions factor for each year of production to all production, then aggregated this emissions estimate to the company level. This allowed us to rank companies by emissions estimate. Because Rystad production data is proprietary, we report only aggregated emissions for the top 20 companies.

Table A2: Top 20 oil and gas methane emitting companies by operator share

In alphabetical order, based on estimated 2012 upstream emissions

Company Name	Headquarters
Abu Dhabi Company for Onshore Oil Operations (ADCO)	UAE
Azerbaijan International Operating Company (AIOC)	Azerbaijan
BP	UK
Chevron	US
Eni	Italy
ExxonMobil	US
Gazprom	Russia
Lukoil	Russia
National Iranian Oil Company	Iran
ONGC	India
PDVSA	Venezuela
Pemex	Mexico
Petronas	Malaysia
Rosneft	Russia
Saudi Aramco	Saudi Arabia
Shell	Netherlands
Sonatrach	Algeria
Turkmengas	Turkmenistan
Turkmennebit	Turkmenistan
Uzbekneftegaz	Uzbekistan
OTHER MAJOR PRODUCERS	
South Oil Company	Iraq
North Oil Company	Iraq
Libya National Oil Company	Libya

Source: UNFCCC, EIA, Rystad and RHG estimates. Note: Oil companies with the majority of operations in countries for which there is no emissions data were excluded from the Top 20 list. They are reported here as "other major producers."

To compute emissions at the company level by ownership share, production at each project was split according to the working interest of each company in a production asset. Therefore, we assumed that the emissions associated with each project are distributed across all companies owning a stake in that project according to their financial stake. Table 3 gives the top 20 companies according to ownership share. Emissions can also be tallied by operator share – that is, according to the companies operating a given production asset. Table A2 gives the top 20 companies according to operator share. For the reasons described in the discussion of historical emissions above, when calculating top 20 emitting oil and gas companies, we excluded emissions from countries for which national emissions data is unavailable. The list of top 20 companies includes only emissions from projects in countries with nationally reported data. This means that companies with significant production in Angola, Iraq, and Libya are underrepresented here. If emissions from those countries were included in the ranking of top companies, Iraq's South Oil Company and North Oil Company and the Libyan National Oil Company would be included in the top 20 list.

It should be noted that these estimates are based only on nationwide reported data, and that actual emissions by company will vary significantly based on practices used at each location. Furthermore, emissions factors can vary greatly, based on the type of well, resource, and other factors. However, because countries do not report data at this level of detail, we were not able to extend the analysis to consider the resource type. Additional data giving insight into the character of emissions by resource type could significantly increase the quality of independent international emissions tracking. There are several ongoing efforts to improve oil and gas methane data, including the UN's Oil and Gas Methane Partnership, a voluntary initiative to get better data on and reduce methane emissions in the oil and gas sector.

ESTIMATES OF NATURAL GAS LOSS

Estimates of the equivalent volume of natural gas (in trillion cubic feet) as well as the value of this gas are based on the 2012 combined all-stage methane emissions from oil and natural gas systems. The volumes are calculated on a country basis by converting from methane leaked (Mt CO_2e) into the equivalent energy content (in quads) using the average carbon content of natural gas – 14.47 kg C per MMBtu (EPA, 2004) – and assumes that methane constitutes 95% of natural gas by volume. Leaked methane is converted to volumes using country-specific dry natural gas gross heat content data from EIA's *International Energy Statistics* (EIA, 2015).

Estimating the value of this lost natural gas is difficult for a number of reasons. First, unlike oil, there is no truly representative international benchmark price for natural gas. Furthermore, the significant expense of transportation, transmission, and distribution of natural gas makes the margin between well-head and consumption large. The value of leaked gas can be thought of not only in terms of lost revenues to oil and gas producers, but also lost revenues to intermediate suppliers, pipeline operators, utilities, and other elements along the oil and gas supply chain. Therefore, we quantify the end-use value of the lost gas, that is, the amount that would be spent by the final consumers of natural gas (i.e., residences, industry, and electric power producers).

For the global average price paid by end-use consumers, we used end-use residential, industrial, and electric power natural gas prices in OECD countries, the only countries for which data is available for 2012 (IEA, 2014a). We weighted end-use prices by final natural gas consumption (IEA, 2014b) in each sector and country to arrive at an average global end-use price per MMBtu. This was applied to the lost natural gas volumes (quads) to arrive at a value in billions of 2012$.

It should be noted that these volume and value estimates assume that only methane that is currently emitted as methane from oil and gas systems is captured and marketed. If gas that is currently flared or lost through other oil and gas system inefficiencies, the lost gas estimates provided here would be higher, with uncertain impacts on overall methane emissions.

REGION DEFINITIONS

To the extent allowed by the available data, this study uses the latest version of ISO 3166 country definitions.

Production in regions jointly administered by two or more countries is split according to the terms of the relevant treaties, and the emissions factors of the respective parties are applied to each country's share of the production.

Individual countries/territories are aggregated into the seven regions in Figures 5 and 8 using regional definitions as follows:

Africa

Algeria, Angola, Benin, Botswana, Burundi, Cameroon, Central African Republic, Chad, Congo, Congo, Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, and Zimbabwe

Asia & Oceania

Afghanistan, Australia, Bangladesh, Brunei Darussalam, Cambodia, China, Hong Kong, India, Indonesia, Japan, North Korea, South Korea, Laos, Malaysia, Mongolia, Myanmar, Nepal, New Caledonia, New Zealand, Pakistan, Papua New Guinea, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Timor-Leste, and Vietnam

Central & South America

Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Falkland Islands, French Guiana, Guatemala, Guyana, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, and Venezuela

Eurasia

Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan

Europe

Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Faroe Islands, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Macedonia, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom

Middle East

Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, and Yemen

North America

Canada, Mexico, United States of America

GHG emissions from the French overseas territory of French Guiana are included in France's annual GHG inventory submitted to the UNFCCC. French Guiana's oil and gas methane emissions are negligible in 2012 and are projected to remain so until 2025. Oil production is expected to spike in 2030, as do its emissions. We exclude

French Guiana's emissions from France's total because of the lack of historic emissions data from the territory and the high uncertainty around its potential emission leakage rate. Because of the likely differences in production profile and effective leakage rates of France in 2012 and French Guiana in 2030, we chose not to apply the current French effective methane leakage rate for calculating future emissions for French Guiana. Instead, we use Tier 1 emission factors to calculate French Guiana's oil and gas methane emissions and report these separately. However, should the spike in oil production come to pass, France will be required to incorporate the associated emissions in their GHG inventory totals, which will also affect EU emissions totals.

GLOBAL GREENHOUSE GAS ESTIMATES

Global greenhouse gas (GHG) estimates, used in calculating the share of total GHGs from oil and gas methane, were compiled from multiple sources by the Rhodium Group in order to provide coverage of national-level emissions for all countries (available at www.rhg.com/reports/ghgs). These totals include emissions of all six Kyoto gases as well as emissions and removals from land use/land use change and forestry. When available, we use emissions data reported by countries to the UNFCCC. Otherwise, we use the following method. Historical (1990 – 2011) energy, industrial, and waste CO_2 emissions data for all countries are from EDGAR (EU Commission 2013). Historical land use/land use change and forestry emissions data (for all GHGs) are from the UN Food and Agriculture Organization (FAO 2013). Non-CO_2 emissions (with the exception of oil and gas fugitive methane emissions, which are calculated using the methods described above, and land use/land use change and forestry) are drawn from the EPA's Global Anthropogenic Non-CO_2 Emissions Projections: 1990-2030 (EPA, 2012). See the EPA report's methodology section for additional detail.

LIMITATIONS AND FUTURE WORK

This report uses historical emission factors in its projections of future emissions. In reality, these emissions factors may change upward and downward for a number of reasons. While our methodology does account for projected changes in the mix of oil and gas production, processing, and consumption by country, it cannot account for changes in the type of resource. For example, changes in the balance between conventional onshore oil, offshore oil, tight oil, oil shale, oil sands, and other development types may have a large effect on the effective emissions factors seen at a national level, as these require meaningfully different drilling, processing, storage, and transportation technologies, each with their own emissions characteristics. Similarly, changes in a country's demand landscape, such as an increase in rural gas distribution or a shift from pipeline imports to LNG imports could have meaningful impacts on downstream emission rates. Finally, these factors represent a baseline. Policy could have a meaningful impact on the rates of methane emissions, as wells switch from venting to flaring or from flaring to production, or as pipeline operators check for and repair leaks, among many other measures.

Additionally, a great deal of uncertainty surrounds even the reported historical data. As is discussed in the body of this report, better data and greater transparency is needed before independent assessments of national bottom-up emissions estimates can take place. Therefore, this report seeks to provide clarity on the nationally-reported values themselves. In this context, error bounds on the values presented here do not have a meaningful interpretation, as we do not have a means of quantifying the probability that the nationally-reported values are accurate. Additional work clarifying probability distributions on best estimates of current methane leakage would be valuable in developing a better understanding of this important subset of greenhouse gas emissions

Table A3: Data availability and oil and gas methane emissions by country

Country	Data Method	Submission of Most Recent GHG Inventory	Reported Years	Oil & Gas Methane Emissions (Mt CO2e) 100-year GWP 2012	2020	2030	20-year GWP 2012	2020	2030
Afghanistan	Tier 1			0.1	0.1	1.0	0.3	0.2	3.5
Albania	NC - Total	2009	1994	0.0	0.0	0.0	0.0	0.0	0.0
Algeria	NC - Total	2010	1994, 2000	29.5	20.4	13.3	99.3	68.4	44.5
Angola	Tier 1			95.0	76.8	77.8	319.3	258.2	261.5
Argentina	NC - Total	2008	1990, 1994, 1997, 2000	10.0	7.2	9.4	33.6	24.3	31.6
Armenia	NC - Total	2014	1990, 2000, 2006	1.0	0.9	1.2	3.4	3.2	4.1
Aruba	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Australia	NC - Detail	2013	1990-2012	7.4	11.3	17.6	24.7	37.9	59.1
Austria	NC - Detail	2014	1990-2012	0.3	0.2	0.2	1.0	0.8	0.6
Azerbaijan	NC - Total	2011	1990	43.3	38.9	28.7	145.4	130.7	96.4
Bahamas	Tier 1			0.0	0.0	0.2	0.0	0.0	0.6
Bahrain	NC - Total	2012	1994, 2000	2.2	2.7	2.0	7.3	8.9	6.9
Bangladesh	NC - Total	2012	1994, 2001, 2005	0.9	0.7	0.7	3.0	2.5	2.4
Barbados	Tier 1			0.0	0.0	0.1	0.1	0.0	0.3
Belarus	NC - Detail	2015	1992, 1995, 1999	1.9	1.6	2.1	6.5	5.4	6.9
Belgium	NC - Detail	2014	1990-2012	0.4	0.4	0.5	1.5	1.5	1.6
Belize	Tier 1			0.1	0.0	0.5	0.5	0.0	1.7
Benin	Tier 1			0.0	0.2	1.0	0.0	0.6	3.4
Bolivia	NC - Total	2009	1990, 1994, 1998, 2000	1.5	1.5	1.1	5.0	4.9	3.7
Bosnia and Herzegovina	Tier 1			0.0	0.0	0.0	0.1	0.1	0.1
Botswana	Tier 1			0.0	0.0	0.1	0.0	0.0	0.4
Brazil	NC - Total	2010	1990-2005	4.7	8.6	11.9	15.6	28.9	40.0
Brunei Darussalam	Tier 1			7.6	10.0	8.3	25.7	33.5	27.9
Bulgaria	NC - Detail	2014	1990-2012	0.7	0.7	0.9	2.5	2.3	3.0
Burundi	Tier 1			0.0	0.0	0.0	0.0	0.0	0.1
Cambodia	Tier 1			0.0	0.0	0.1	0.0	0.0	0.4
Cameroon	NC - Total	2005	1994	0.0	0.0	0.0	0.0	0.0	0.0
Canada	NC - Detail	2014	1990-2012	53.6	72.1	83.8	180.2	242.2	281.7
Central African Republic	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Chad	Tier 1			5.7	6.7	3.9	19.0	22.6	13.1
Chile	NC - Total	2011	2000, 2006	2.0	1.6	1.8	6.7	5.3	5.9
China	NC - Total	2012	1994, 2005	6.4	5.9	5.4	21.6	19.7	18.1
Colombia	NC - Total	2010	1990, 1994, 2000, 2004	7.2	6.3	3.0	24.2	21.2	10.1
Congo	NC - Total	2009	1994, 2000	0.2	0.2	0.2	0.5	0.5	0.6
Costa Rica	NC - Total	2014	1990, 2000, 2005	0.0	0.0	0.0	0.0	0.0	0.0
Côte d'Ivoire	NC - Total	2010	2000	8.2	8.9	13.1	27.4	29.9	43.9
Croatia	NC - Detail	2014	1990-2012	1.5	1.0	1.0	4.9	3.5	3.3

Country	Data Method	Submission of Most Recent GHG Inventory	Reported Years	Oil & Gas Methane Emissions (Mt CO2e) 100-year GWP 2012	2020	2030	20-year GWP 2012	2020	2030
Cuba	NC - Total	2001	1990, 1994, 1996	1.4	0.2	1.6	4.8	0.8	5.4
Cyprus	NC - Detail	2013	1990-2004	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	NC - Detail	2014	1990-2012	0.6	0.6	0.7	2.2	2.1	2.4
Dem. Rep. of the Congo	Tier 1			1.1	0.5	1.5	3.6	1.5	5.2
Denmark	NC - Detail	2014	1990-2012	0.1	0.1	0.1	0.4	0.4	0.4
Djibouti	Tier 1			0.0	0.0	0.2	0.0	0.0	0.6
Dominican Republic	NC - Total	2009	1990, 1994, 1998, 2000	0.0	0.0	0.0	0.0	0.0	0.0
Ecuador	NC - Total	2012	1990, 1994, 2000, 2006	0.0	0.0	0.0	0.1	0.1	0.1
Egypt	NC - Total	2010	1990, 2000	10.2	7.5	6.0	34.3	25.3	20.1
El Salvador	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Equatorial Guinea	Tier 1			18.4	10.1	7.1	61.7	33.9	23.8
Eritrea	Tier 1			0.0	0.0	0.1	0.0	0.0	0.2
Estonia	NC - Detail	2014	1990-2012	0.1	0.1	0.1	0.3	0.3	0.3
Ethiopia	Tier 1			0.0	0.0	0.6	0.0	0.0	2.0
Falkland Islands	Tier 1			0.0	0.1	9.6	0.0	0.2	32.4
Faroe Islands	Tier 1			0.0	0.0	0.4	0.0	0.0	1.3
Finland	NC - Detail	2013	1990-2012	0.0	0.0	0.0	0.2	0.2	0.2
France	NC - Detail	2013	1990-2012	1.4	1.4	1.6	4.7	4.5	5.2
French Guiana*	Tier 1			0.0	0.0	4.2	0.0	0.0	14.0
Gabon	NC - Total	2011	2000	0.2	0.1	0.1	0.6	0.4	0.4
Gambia	Tier 1			0.0	0.0	0.1	0.0	0.0	0.4
Georgia	NC - Total	2009	2000-2006	1.2	11.3	13.3	4.1	37.9	44.6
Germany	NC - Detail	2014	1990-2012	6.9	6.3	8.1	23.2	21.2	27.3
Ghana	Tier 1			3.8	11.9	9.7	12.8	40.0	32.5
Greece	NC - Detail	2013	1990-2012	0.2	0.3	0.3	0.7	0.9	1.1
Greenland	Tier 1			0.0	0.0	0.2	0.0	0.0	0.8
Guatemala	NC - Total	2002	1990	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Tier 1			0.0	0.0	0.7	0.0	0.1	2.2
Guinea-Bissau	Tier 1			0.0	0.0	0.3	0.0	0.0	1.1
Guyana	Tier 1			0.0	0.0	0.1	0.0	0.0	0.3
Honduras	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Hong Kong	Tier 1			0.3	0.3	0.3	1.1	1.1	1.1
Hungary	NC - Total	2014	1990-2012	2.4	1.9	2.5	8.1	6.2	8.3
Iceland	NC - Total	2014	1990-2012	0.0	0.0	0.0	0.0	0.0	0.0
India	NC - Total	2012	1994, 2000	25.2	22.5	19.8	84.8	75.5	66.7
Indonesia	NC - Total	2012	1994, 2000	15.8	12.6	9.2	53.1	42.2	31.1
Iran	NC - Total	2011	1994, 2000	42.6	45.7	54.7	143.3	153.4	183.7
Iraq	Tier 1			159.6	267.9	304.7	536.1	900.1	1023.9
Ireland	NC - Detail	2014	1990-2012	0.0	0.0	0.1	0.1	0.2	0.2
Israel	Tier 1			0.6	2.1	3.2	1.9	7.2	10.7
Italy	NC - Detail	2014	1990-2012	5.9	5.8	6.0	19.7	19.4	20.3
Jamaica	NC - Total	2011	1994	0.0	0.0	0.0	0.0	0.0	0.0

Country	Data Method	Submission Date of Most Recent GHG Inventory	Reported Years	Oil & Gas Methane Emissions (Mt CO2e) 100-year GWP 2012	2020	2030	20-year GWP 2012	2020	2030
Japan	NC - Detail	2014	1990-2012	0.4	0.1	0.2	1.3	0.5	0.6
Jordan	NC - Total	2014	2000	0.2	0.9	8.5	0.6	3.0	28.6
Kazakhstan	NC - Detail	2014	1990-2012	8.6	10.9	12.4	28.9	36.7	41.7
Kenya	NC - Total	2002	1994	0.0	0.0	0.0	0.1	0.1	0.1
Kuwait	NC - Total	2012	1994	3.2	3.1	2.6	10.6	10.3	8.8
Kyrgyzstan	NC - Total	2009	1990-2005	0.2	1.0	0.5	0.8	3.5	1.6
Laos	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Latvia	NC - Detail	2013	1990-2012	0.1	0.1	0.1	0.2	0.2	0.3
Lebanon	Tier 1			0.0	0.0	0.0	0.0	0.0	0.1
Liberia	Tier 1			0.0	0.0	2.7	0.0	0.0	9.0
Libya	Tier 1			75.1	50.5	62.1	252.5	169.5	208.8
Lithuania	NC - Detail	2014	1990-2012	0.3	0.3	0.5	1.0	1.1	1.6
Luxembourg	NC - Detail	2014	1990-2012	0.0	0.1	0.1	0.2	0.2	0.3
Macedonia	NC - Total	2009	1990-1998, 2000-2002	0.1	0.1	0.1	0.2	0.2	0.2
Madagascar	Tier 1			0.0	0.2	9.8	0.0	0.6	33.0
Malawi	Tier 1			0.0	0.1	0.2	0.0	0.4	0.8
Malaysia	NC - Total	2011	1994	13.8	16.4	16.4	46.3	55.1	55.2
Mali	Tier 1			0.0	0.0	0.0	0.0	0.0	0.1
Malta	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Mauritania	Tier 1			0.3	0.2	1.9	1.1	0.7	6.5
Mexico	NC - Total	2012	1990-2002 (even years), 2006	43.3	31.9	32.8	145.5	107.2	110.1
Moldova	NC - Total	2014	1990-2010	0.9	1.0	1.5	3.1	3.4	5.0
Mongolia	Tier 1			0.5	1.4	2.6	1.7	4.7	8.6
Montenegro	Tier 1			0.0	0.0	0.1	0.0	0.0	0.3
Morocco	NC - Total	2010	2000	3.7	3.5	103.4	12.6	11.9	347.5
Mozambique	Tier 1			0.3	0.4	13.0	1.1	1.2	43.7
Myanmar	NC - Total	2012	2000-2005	0.2	0.1	0.2	0.5	0.4	0.6
Namibia	Tier 1			0.0	0.0	0.4	0.0	0.0	1.4
Nepal	Tier 1			0.0	0.0	0.0	0.0	0.0	0.1
Netherlands	NC - Detail	2013	1990-2012	0.9	0.9	0.9	2.9	3.0	3.1
Netherlands Antilles	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
New Caledonia	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
New Zealand	NC - Detail	2013	1990-2003	0.6	0.6	0.7	2.2	2.1	2.4
Nicaragua	Tier 1			0.0	0.0	0.4	0.0	0.0	1.2
Niger	Tier 1			0.4	1.0	0.7	1.2	3.3	2.4
Nigeria	NC - Total	2014	1994	27.0	24.4	24.6	90.8	81.9	82.5
North Korea	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Norway	NC - Detail	2014	1990-2012	0.7	0.7	0.8	2.2	2.4	2.8
Oman	NC - Total	2013	1994	2.6	1.8	1.3	8.8	6.0	4.3
Pakistan	NC - Total	2003	1994	10.4	8.4	9.8	34.8	28.3	33.0
Panama	NC - Total	2012	1994	0.0	0.0	0.0	0.0	0.0	0.0
Papua New Guinea	Tier 1			1.6	2.9	4.8	5.4	9.7	16.2

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Paraguay	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Peru	NC - Total	2010	1994, 2000	0.5	0.6	1.0	1.6	2.0	3.4
Philippines	NC - Total	2014	1994	0.1	0.1	0.1	0.4	0.3	0.4
Poland	NC - Detail	2014	1990-2012	5.7	6.4	7.7	19.0	21.5	25.7
Portugal	NC - Detail	2014	1990-2012	0.4	0.5	0.6	1.5	1.7	2.0
Qatar	NC - Total	2011	2007	2.6	2.4	2.1	8.8	8.0	6.9
Romania	NC - Detail	2013	1990-2012	7.7	8.7	9.0	26.0	29.2	30.1
Russia	NC - Detail	2014	1990-2012	387.3	381.0	399.7	1301.4	1280.2	1343.1
Saint Pierre and Miquelon	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Sao Tome and Principe	Tier 1			0.0	0.0	0.4	0.0	0.0	1.2
Saudi Arabia	NC - Total	2011	1990, 2000	9.7	9.0	8.9	32.5	30.3	30.0
Senegal	NC - Total	2010	2000	0.0	0.0	18.0	0.0	0.0	60.6
Serbia	NC - Total	2010	1990, 1998	3.5	3.0	4.3	11.6	10.1	14.3
Seychelles	Tier 1			0.0	0.0	0.3	0.0	0.0	0.9
Sierra Leone	Tier 1			0.0	0.0	3.1	0.0	0.0	10.3
Singapore	Tier 1			1.1	1.0	1.3	3.7	3.5	4.5
Slovakia	NC - Detail	2014	1990-2012	0.9	0.9	1.3	2.9	3.0	4.2
Slovenia	NC - Detail	2014	1990-2012	0.0	0.0	0.0	0.1	0.1	0.1
Somalia	Tier 1			0.0	0.0	0.1	0.0	0.0	0.3
South Africa	NC - Total	2011	1990, 1994	0.2	0.2	0.8	0.7	0.8	2.8
South Korea	NC - Total	2012	1990, 2001	9.7	10.6	15.5	32.7	35.6	52.2
South Sudan	Tier 1			1.5	9.2	5.8	4.9	30.8	19.4
Spain	NC - Detail	2013	1990-2012	0.7	0.7	2.2	2.3	2.5	7.4
Sri Lanka	NC - Total	2012	1994, 2000	0.0	0.0	0.0	0.0	0.0	0.0
Sudan	NC - Total	2013	2000	0.0	0.0	0.0	0.1	0.0	0.0
Suriname	Tier 1			0.8	0.5	0.9	2.7	1.7	3.1
Sweden	NC - Detail	2014	1990-2012	0.1	0.1	0.1	0.2	0.2	0.3
Switzerland	NC - Detail	2014	1990-2012	0.2	0.2	0.2	0.7	0.7	0.7
Syria	Tier 1			9.1	10.3	8.0	30.7	34.6	26.8
Taiwan	Tier 1			2.0	2.2	2.2	6.8	7.4	7.3
Tajikistan	NC - Total	2014	1990-2003	0.1	0.0	0.0	0.2	0.2	0.1
Tanzania	NC - Total	2003	1990, 1994	0.0	0.0	0.0	0.0	0.0	0.0
Thailand	NC - Total	2011	1994, 2000	12.1	9.0	7.4	40.6	30.3	24.7
Timor-Leste	Tier 1			4.9	1.8	0.7	16.4	6.0	2.4
Togo	Tier 1			0.0	0.0	0.0	0.0	0.0	0.0
Trinidad and Tobago	NC - Total	2013	1990	0.0	0.0	0.0	0.0	0.0	0.0
Tunisia	NC - Total	2014	1994, 2000	1.4	1.6	1.6	4.8	5.4	5.5
Turkey	NC - Detail	2013	1990-2012	0.3	0.2	0.4	1.2	0.6	1.3
Turkmenistan	NC - Total	2010	1994, 2000, 2004	37.4	34.9	33.0	125.8	117.3	111.0
UAE	NC - Total	2013	1994, 2000, 2005	29.1	34.1	30.4	97.8	114.6	102.3
Uganda	Tier 1			0.0	0.0	9.3	0.0	0.0	31.1
UK	NC - Detail	2014	1990-2012	6.2	6.8	8.8	20.9	23.0	29.7

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Ukraine	NC - Detail	2013	1990-2012	28.6	27.9	31.3	96.2	93.8	105.0
Uruguay	NC - Total	2010	2004	0.0	0.0	0.0	0.0	0.1	0.1
US	NC - Detail	2014	1990-2012	192.4	235.2	250.2	646.5	790.1	840.7
Uzbekistan	NC - Total	2008	1990-2005	97.0	88.3	73.6	325.8	296.7	247.2
Venezuela	NC - Total	2005	1999	38.0	34.3	48.2	127.7	115.4	162.1
Vietnam	NC - Total	2010	1994, 2000	4.6	4.2	2.2	15.6	14.0	7.3
Western Sahara	Tier 1			0.0	0.0	0.1	0.0	0.0	0.2
Yemen	NC - Total	2013	1995, 2000	0.3	0.2	0.2	1.2	0.8	0.5
Zambia	Tier 1			0.0	0.0	0.2	0.0	0.0	0.6
Zimbabwe	Tier 1			0.0	0.0	0.0	0.0	0.0	0.1
European Union	NC - Detail	2014	1990-2012	43.2	44.2	51.6	145.0	148.5	173.5
World Total				**1681**	**1783**	**2066**	**5650**	**5992**	**6940**

Data Quality Definitions:

- NC - Detail: Country submitted qualifying data at the product-by-stage level. No Tier 1 data used.
- NC - Total: Country submitted data at the oil and gas sector level. Tier 1 estimates used to distribute across products and stages.
- Tier 1: No data submitted to UNFCCC during historical period – Tier 1 estimate used.

* French Guiana is an overseas territory of France. We report its emissions separately from France's total because of the lack of historic emissions data from the territory and the high uncertainty around its potential emission leakage rate. French Guiana's GHG emissions are typically included in France's annual GHG inventory submitted to the UNFCCC. Because of the likely differences in production profile and effective leakage rates of France and French Guiana, however, we chose not to apply France's 2012 effective methane leakage rate to French Guiana. Instead, we use Tier 1 emission factors to calculate French Guiana's oil and gas methane emissions.

Source: Rhodium Group, Rystad, UNFCCC.
Notes: Columns may not sum to totals due to independent rounding. EU member states do not sum to EU total due to overseas territory accounting by member states. Hungary and Iceland submitted NC - Detail emissions data by stage to the UNFCCC, but these data were excluded because they were significantly inconsistent with their reported oil & gas sector totals.