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Highwood Emissions Management | MiQ

The MiQ-Highwood Index™ : A national-scale measurement-informed methane intensity for the United States

The MiQ-Highwood Index ™ : A national-scale measurement-informed methane intensity for the United States

Authors

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A natural gas methane intensity index benchmark is critical for progress towards emissions reductions across the energy sector and differentiating environmental performance across basins and operators. A new preprint by Sherwin et al. featuring over one million independent aerial measurements offers the opportunity to update our understanding of the average U.S. natural gas methane intensity.[1] The methodology presented by Sherwin et al. combines aerial measurements with a bottom-up inventory model. Using the data presented in Sherwin et al., we calculate a national average methane intensity of 1.0% (173.9 g CH_4 MMBtu NG^{-1}) for the production segment and 2.2% (361.8 g CH_4 MMBtu NG^{-1}) for the full natural gas supply chain, both allocated to the natural gas product.

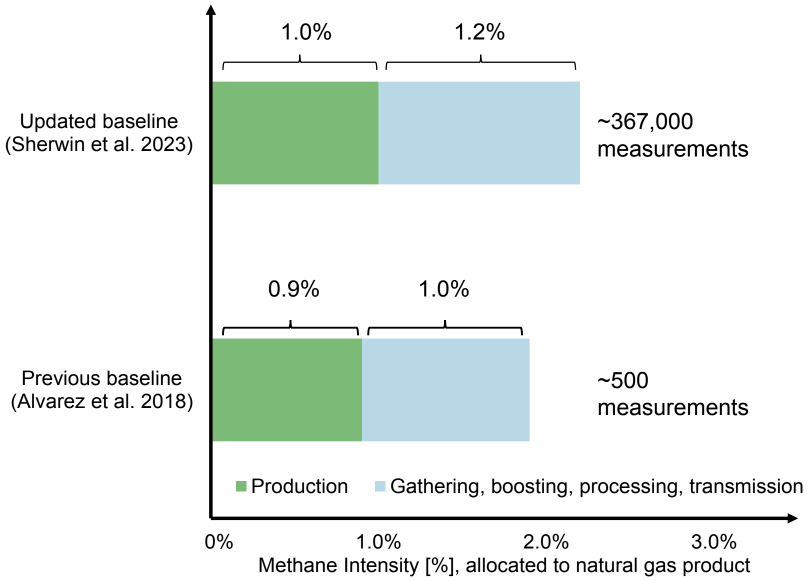

Figure 1: Comparison of updated baseline with what was previously considered to be the most accurate assessment of U.S. methane intensity by Alvarez et al. (2018)

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[1] Here, an independent aerial measurement includes both detects and non-detects. Sherwin et al. features aerial surveys that covered over 1 million assets, of which a fraction of these assets yielded quantified emissions volumes.

1 = Highwood Emissions Management, 2 = MiQ

Background and Objectives

Oil and natural gas related methane emissions are a significant concern for the climate due to methane's global warming potential, which is over 80 times that of CO_2 on a 20-year timeframe.[2] Methane emissions from the oil and gas sector are commonly reported in terms of methane intensity, defined as methane emitted normalized to the methane produced (methane is the primary constituent of natural gas). Methane intensity, like carbon intensity, is a useful metric as it compares emissions performance between operators of various sizes and the climate impact of energy products from various regions. Determining an average methane intensity is critical, not only for "benchmarking" the emissions performance of individual gas sources against, but for tracking regional progress over time. Until recently, our ability to understand the average methane intensity was severely limited by insufficient data quantity and quality.

Quantifying emissions spanning the millions of production wells and millions of kilometers of transmission pipelines in the U.S. was historically the job of ground-based approaches which did not provide a complete emissions picture. The U.S. Environmental Protection Agency's Greenhouse Gas Inventory (EPA GHGI), which is based on a bottom-up approach of equipment-counts and emission factors, estimates a total supply chain methane intensity of 0.88% (allocated to the natural gas product excluding oil refineries and the distribution system, 1.0% for unallocated emissions).[3] Just five years ago, Alvarez et al. published a summary of ground-based campaigns including about 500 independent downwind measurements.[4] The Alvarez et al. summary and estimated supply chain methane intensity of 1.9% (allocated to the natural gas supply chain, 2.3% unallocated) are considered to be the most accurate assessment of U.S. average emissions.

Newer and more comprehensive data have emerged since the Alvarez et al. field campaigns. Sherwin et al. have released the most comprehensive set of aerial measurement data to date (one million independent aerial measurements are included in the preprint), which we believe presents the most accurate assessment of methane intensity for the basins surveyed.[5] It also presents an opportunity to update our understanding of U.S. average methane intensity. The aerial survey technologies applied in Sherwin et al. (Kairos and Carbon Mapper aerial remote sensing) are already widely adopted by industry and accessible by interested third parties, such as governments and civil society for assessing regional emissions. Aerial survey technologies can independently gather larger datasets in a shorter amount of time compared to ground surveys. Based on these large datasets, aerial campaigns have broadened our understanding of the "heavy tail" of methane emission distributions, capturing large point source emitters up to three orders of magnitude larger than those discovered during ground-based surveys.

In this article, we describe the Sherwin et al. preprint, outline our method for scaling the Sherwin et al. results to a national industry average, and present a contiguous (onshore and lower 48 states) U.S. methane intensity index allocated to the natural gas product. This report is an independent analysis of the Sherwin et al. data and not that of the original author. While this document only presents an index for a snapshot in time (2021, although some earlier campaigns are used by Sherwin), future work could develop an annually updated index, particularly as more measurements from aerial and satellite campaigns from individual basins are deployed.

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[2] Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, ... B. Zhou (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[3] EPA (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-andsinks-1990-2021.

[4] Alvarez, Ramón A., Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley, Adam R. Brandt, Kenneth J. Davis et al. "Assessment of methane emissions from the US oil and gas supply chain." Science 361, no. 6398 (2018): 186-188

[5] Sherwin, Evan, Jeffrey Rutherford, Zhan Zhang, Yuanlei Chen, Erin Wetherley, Petr Yakovlev, Elena Berman et al. "Quantifying oil and natural gas system emissions using one million aerial site measurements." (2023)

Methodology

Review of Sherwin et al. 2023

While aerial remote sensing technologies can cover larger areas in a shorter amount of time, they can also have high minimum detection limits (MDLs) and measurements of zero kg hr^{-1} in fact miss small- to medium-sized emitters. By fusing aerial measurements with bottom-up simulations (based on the model described in Rutherford et al.) that capture emissions below aerial MDLs, the Sherwin et al. approach rigorously accounts for the full distribution of methane emissions.[6] Sherwin et al. apply this reconciliation methodology to six U.S. O&G producing basins.

Sherwin et al. present distributions covering the production and midstream (including compressor stations, gas processing plants, and pipelines) segments. Both Carbon Mapper and Kairos are capable of attributing plumes to assets using “a combination of automated and manual processes” (Sherwin et al.). Below-MDL emissions are based on Rutherford et al. for the production segment and the national and state-level EPA GHGI for the midstream segment.

Applying Sherwin et al. measurement data to a national index

Basins covered by Sherwin et al. include the Permian, San Joaquin, Denver Julesburg, Appalachia (only high productivity Pennsylvania zone), Forth Worth, and Uinta basins. The Permian, San Joaquin, and Denver Julesburg were covered two or more times in the same or different years. To calculate a national average methane intensity, we examine the most recent campaign for those basins with > 80% coverage of natural gas production (summarized in Table 1). No other surveys exist for Carbon Mapper’s 2021 Pennsylvania survey, which only covered 44% of gas production. The campaigns in this subset contain ~367,000 site visits and account for 29% of U.S. natural gas production. This is still nearly 3 orders of magnitude more site visits compared to Alvarez et al.

Methane intensity (MI) is calculated as a function of emissions (E, metric ton CH_4 yr $^{-1}$) and production (P, Bscf yr $^{-1}$) according to the Natural Gas Sustainability Initiative protocol (NGSI)[7], where methane density ρ_{CH_4} = 19.2 g/scf $^{-1}$ and methane content X_{CH_4} = 90% (volume fraction, from Sherwin et al.).

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[6] Rutherford, Jeffrey S., Evan D. Sherwin, Arvind P. Ravikumar, Garvin A. Heath, Jacob Englander, Daniel Cooley, David Lyon, Mark Omara, Quinn Langfitt, and Adam R. Brandt. “Closing the methane gap in US oil and natural gas production emissions inventories.” Nature communications 12, no. 1 (2021): 4715

$$MI = \frac{E}{P * X_{CH_4} * \rho_{CH_4}}$$

The volume-weighted average methane intensity (total, unallocated emitted methane divided by total methane in produced natural gas) for areas surveyed by Sherwin et al. is 1.7% for the production segment and 3.0% for the full supply chain incorporating midstream emissions.

To extrapolate the results of the Sherwin et al. study to a U.S. index, we extrapolate for areas not surveyed in Sherwin et al. The results of Sherwin et al. are applied to the remaining US production basins by first binning according to gas-to-oil ratio (cut-off of 100 Mscf bbl^{-1}, consistent with the U.S. EPA GHGI) and then calculating oil-rich and gas-rich weighted average production segment methane intensities, 0.64% and 2.60%, respectively. The same is done for midstream emissions, 0.33% and 2.02%, respectively. For the top 23 gas-producing basins (representing 99% of total production) we assign production and midstream methane intensities, first based on Sherwin et al. for all basins surveyed ($n_{surveyed}$) and then based on the weighted average if it was not surveyed ($n_{non-surveyed}$). Total emissions (E_{total}, metric ton CH_4 yr^{-1}) are calculated as follows as a function of basin-level production totals, P_{basin}, and methane intensity, for both surveyed basins, MI, and non-surveyed MI':

$$E_{total} = \left[\sum_{i=1}^{n_{surveyed}} (MI_{basin} * P_{basin}) + \sum_{i=1}^{n_{non-surveyed}} (MI'_{basin} * P_{basin}) \right] * X_{CH_4} * \rho_{CH_4}$$

The resulting methane intensities by basin are shown in Table 2, for both production and midstream segments. The updated volume-averaged production methane intensity aggregating both oil-rich and gas-rich US basins (representing 99% of contiguous natural gas production) is 1.6% for production and 2.7% for the full supply chain.

For supply chains that produce multiple products, it is important to approximate how the environmental burdens are allocated across the multiple co-products.[8] Thus, in life cycle assessment of petroleum products we must allocate emissions between crude oil and natural gas products. Following NGSI, emissions are allocated using the ratio of the energy content of the natural gas (E_{gas}, MMBtu yr^{-1}) and the energy content of total hydrocarbons ($E_{gas} + E_{oil}$, MMBtu yr^{-1}). In NGSI, this is referred to as the gas ratio, GR.

$$GR = \frac{E_{gas}}{E_{gas} + E_{oil}}$$

For the production segment, GR is calculated based on basin-specific production totals. For the midstream segments, $GR=1$. This is an approximation, as processing facilities do produce some natural gas liquids.

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[7] M.J. Bradley & Associates, an ERM Group Company. "(NGSI) Natural Gas Sustainability Initiative Methane Emissions Intensity Protocol". (2021).

[8] (ISO) International Organization for Standardization, "Environmental management–Life cycle assessment–Goal and scope definition and inventory analysis (ISO Standard No. 14041:1998)," 1998.

Total emissions for the natural gas product is then calculated as:

$$E_{total,ng} = \left[\sum_{i=1}^{n_{surveyed}} (MI_i * P_i * GR_i) + \sum_{i=1}^{n_{non-surveyed}} (MI_i' * P_i * GR_i) \right] * X_{CH_4} * \rho_{CH_4}$$

This calculation is performed separately for production and midstream segments ($E_{total,produps,ng}$, $E_{total,mids,ng}$).

Our final national average methane intensity for the natural gas industry, as allocated to the natural gas supply chain, is then calculated as follows where P_{total} is total natural gas production for all surveyed and non-surveyed basins.

$$MI_{ng,ave} = \frac{E_{total,produps,ng} + E_{total,mids,ng}}{P_{total}}$$

The resulting U.S. onshore methane intensity applying the NGSI methodology is 1.0% (173.9 g CH_4 MMBtu NG^{-1}) for the production segment and 2.2% (361.8 g CH_4 MMBtu NG^{-1}) for the full natural gas supply chain.

Discussion of results

This approach represents a first step towards a U.S. methane intensity index for the contiguous onshore O&G industry. Despite being limited to six U.S. basins (five out of six with > 80% US coverage), we believe the Sherwin et al. study represents the most accurate summary of measurement data to date. The sample size presented in Sherwin et al. (nearly one million site visits) is approximately three orders of magnitude higher than the Alvarez et al. summary of Environmental Defense Fund's (EDF) ground-based campaign (about five hundred site visits). The Alvarez et al. summary, up until recently considered to be the most accurate assessment of U.S. average emissions, was also limited to measurements in six basins.

Comparison of unallocated and allocated methane intensity for the U.S. O&G industry calculated from the latest U.S. EPA GHGI, Alvarez et al., and this work is given in Table 3. Interestingly, despite the methodological differences and more recent data compared to Alvarez et al. (whose data spans the 2010s), our estimated methane intensity (no allocation) for the production segment (1.6%) is within the error bounds of Alvarez (95% confidence interval of 1.1% - 1.7%). However, our estimated methane intensity (no allocation) for the full supply chain (2.7%) is not within the error bounds of Alvarez (95% confidence interval of 1.9-2.6%, excluding Alvarez estimates for oil refineries and the distribution system) although the error bounds do overlap. These results also suggest a convergence of campaigns finding consistently lower methane intensity in gas rich basins like Appalachia (0.9% based on Omara et al., who assess the same dataset as Alvarez), and consistently higher methane intensities in liquids rich basins like the Permian (2.5% based on Omara et al).[9]

There are some caveats that should be taken into consideration in interpreting this index. While we believe this approach represents a best approximation of an index today, based on the best available data, there is still uncertainty in extrapolating to other basins. Further, we used our best judgment in selecting the most recent campaigns from the Sherwin et al. dataset with comprehensive coverage (defined in Sherwin et al. as a campaign that covers 80% of gas production in a basin). Based on this criteria, the 2019 campaign by Carbon Mapper was applied for the Permian basin over the 2021 campaigns which only surveyed the highest productivity regions. However, even with the limited coverage, it is clear that there has been a substantial decline in methane intensity in the Permian basin since 2019, and thus our index is likely conservatively high for oil-rich regions. For gas-rich regions, our estimate may be biased in the opposite direction. Carbon Mapper's survey of the Appalachia basin covered only 44% of Pennsylvania gas production and focussed on the high-productivity Pennsylvania zone, which is very likely to have a lower methane intensity compared to the lower-productivity outskirts. Further, there is a significant gap in the 10- ~300 kg hr^{-1} range between the largest simulated emissions and the smallest detected emissions by Carbon Mapper. This evidence suggests that our methane intensity for the Pennsylvania zone of Appalachia is likely an underestimate.

Improvements to this national average over time should include additional coverage of basins not surveyed as well as more complete coverage of basins to include both high productivity and low productivity regions. These indices may be updated as new top down data is collected and new activity data for bottom up inventories are computed.

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[9] Omara, Mark, Naomi Zimmerman, Melissa R. Sullivan, Xiang Li, Aja Ellis, Rebecca Cesa, R. Subramanian, Albert A. Presto, and Allen L. Robinson. "Methane emissions from natural gas production sites in the United States: Data synthesis and national estimate." Environmental science & technology 52, no. 21 (2018): 12915-12925.

Table 1. Summary of the most recent surveys with > 80% coverage of natural gas production of the six basins presented in Sherwin et al. No other surveys exist for Carbon Mapper's 2021 Pennsylvania survey, which only covered 44% of gas production.

Basin	Surveyed gas production [Bscf yr^{-1}]	GOR of surveyed assets [Mscf bbl^{-1}]	Gas Ratio of surveyed assets	Average methane intensity Unallocated Production [%]	Average methane intensity Unallocated Midstream [%]	Survey technology	Year of survey
Marcellus-Pennsylvania	5179	1754.8	1.00	0.49%	0.25%	CM*	2021
Fort Worth	322	681.5	0.99	3.04%	1.49%	Kairos	2021
Denver Julesburg	1004	8.3	0.60	0.74%	0.39%	CM	2021**
Uinta	177	6.8	0.55	4.68%	1.05%	CM	2020
Permian	5322	3.5	0.39	2.90%	2.38%	CM	2019
San Joaquin	100	1.1	0.17	1.75%	0.77%	CM	2021

*CM = Carbon Mapper
**Average of two campaigns (Summer and Fall)

Table 2. Extrapolation of Sherwin et al. (2023) results to remaining major gas producing basins in the United States. Top 23 gas producing basins shown in this table are based on production volumes reported in Rutherford (2022)[10].

Basin	Percent total gas	GOR [Mscf bbl $^{-1}$]	Gas Ratio	Gas/ Oil	Methane intensity from survey Production (Midstream) [%]	Extrapolated methane intensity Production (Midstream) [%]	Final methane intensity Unallocated Production (Midstream) [%]	Final methane intensity Allocated Production (Midstream) [%]
APPALACHIAN BASIN (MARCELLUS) - OTHER	16%	201.2	0.97	GAS		0.64% (0.33%)	0.64% (0.33%)	0.62% (0.33%)
APPALACHIAN BASIN (MARCELLUS) - PENNSYLVANIA	13%	1754.8	1.00	GAS	0.49% (0.25%)		0.49% (0.25%)	0.49% (0.25%)
PERMIAN BASIN	14%	3.5	0.39	OIL	2.90% (2.38%)		2.90% (2.38%)	1.13% (2.38%)
GULF COAST BASIN	8%	5.6	0.51	OIL		2.60% (2.02%)	2.60% (2.02%)	1.32% (2.02%)
ARKLA BASIN	8%	128.8	0.96	GAS		0.64% (0.33%)	0.64% (0.33%)	0.62% (0.33%)
ANADARKO BASIN	6%	14.3	0.72	OIL		2.60% (2.02%)	2.60% (2.02%)	1.88% (2.02%)
ARKOMA BASIN	6%	1151.8	1.00	GAS		0.64% (0.33%)	0.64% (0.33%)	0.64% (0.33%)
EAST TEXAS BASIN	4%	88.9	0.94	OIL		2.60% (2.02%)	2.60% (2.02%)	2.45% (2.02%)
GREEN RIVER BASIN	3%	90.2	0.94	OIL		2.60% (2.02%)	2.60% (2.02%)	2.46% (2.02%)
WILLISTON BASIN	3%	2.1	0.27	OIL		2.60% (2.02%)	2.60% (2.02%)	0.71% (2.02%)
DENVER BASIN	3%	5.2	0.49	OIL	0.74% (0.39%)		0.74% (0.39%)	0.36% (0.39%)
SAN JUAN BASIN	2%	103.7	0.95	GAS		0.64% (0.33%)	0.64% (0.33%)	0.61% (0.33%)
PICEANCE BASIN	2%	117.7	0.96	GAS		0.64% (0.33%)	0.64% (0.33%)	0.61% (0.33%)
STRAWN BASIN	2%	6605.7	1.00	GAS		0.64% (0.33%)	0.64% (0.33%)	0.64% (0.33%)
PARADOX BASIN	1%	112.1	0.95	GAS		0.64% (0.33%)	0.64% (0.33%)	0.61% (0.33%)

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[10] Rutherford, Jeffrey Scott. "Characterizing the Greenhouse Gas Impacts of Natural Gas Resources: A Life-cycle Assessment and Evaluation of New Aerial Technologies." PhD diss., Stanford University, 2022.

FORT WORTH SYNCLINE	1%	123.3	0.96	GAS	3.04% (1.49%)		3.04% (1.49%)	2.91% (1.49%)
SOUTH OKLAHOMA FOLDED BELT	1%	12.7	0.70	OIL		2.60% (2.02%)	2.60% (2.02%)	1.82% (2.02%)
APPALACHIAN BASIN (UTICA)	1%	19.3	0.78	OIL		2.60% (2.02%)	2.60% (2.02%)	2.03% (2.02%)
POWDER RIVER BASIN	1%	5.4	0.50	OIL		2.60% (2.02%)	2.60% (2.02%)	1.29% (2.02%)
MID GULF COAST BASIN	1%	11.7	0.68	OIL		2.60% (2.02%)	2.60% (2.02%)	1.77% (2.02%)
CHAUTAUQUA PLATFORM	1%	9.7	0.64	OIL		2.60% (2.02%)	2.60% (2.02%)	1.66% (2.02%)
UINTA BASIN	1%	8.1	0.60	OIL	4.68% (1.05%)		4.68% (1.05%)	2.79% (1.05%)
SACRAMENTO BASIN	0%	1792.0	1.00	GAS		0.64% (0.33%)	0.64% (0.33%)	0.64% (0.33%)
SAN JOAQUIN BASIN	0%	1.2	0.18	OIL	1.75% (0.77%)		1.75% (0.77%)	0.31% (0.77%)

Table 3. Comparison of calculated methane intensity for the U.S. onshore O&G industry, with and without allocation to the natural gas product.

	Emissions Year	**Methane intensity Production Unallocated [%]**	**Methane intensity Production Allocated [%]**	**Methane intensity Full Supply Chain Unallocated [%]**	**Methane intensity Full Supply Chain Allocated [%]**
EPA GHGI (2023)	2015	0.86%	0.57%	1.5%	1.2%
	2021	0.49%	0.33%	1.0%	0.88%
Alvarez et al. (2018)	2015	1.4%	0.92%	2.3%	1.9%
This work	2021	1.6%	1.0%	2.7%	2.2%

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