communications
earth & environment

COMMENT

https://doi.org/10.1038/s43247-023-00794-6 OPEN

# How to quantify anthropogenic methane emissions with aircraft surveys

Grant Allen [1]✉

A comprehensive aircraft survey of onshore oil and gas infrastructure in British Columbia finds that methane emissions may be 1.7 times higher than the official inventory and introduces a framework for compiling measurement-led regional greenhouse gas emissions data.

Greenhouse gas emissions reported in national inventories to the United Nations Framework Convention on Climate Change (UNFCCC) are currently best estimates based on uncertain emission factors. They also depend on the accuracy of available activity data. Global climate agreements commit signatories to improved emissions accounting and, crucially, measurement-led emissions verification. However, robust emissions verification is extremely challenging, both logistically and technically. To this end, writing in *Communications Earth & Environment*, Johnson and colleagues[1], describe a novel framework to compile a regional emissions inventory for the oil and gas sector in British Columbia using aerial remote sensing surveys.

The Paris Agreement, signed at the United Nations Climate Change Conference in 2016 (COP21), commits signatories to the verification of national greenhouse gas emissions. This important step forward will improve the accuracy of reported emissions for climate prediction and monitoring of progress on emissions reduction. Emissions measurement may also help to identify appropriate mitigation targets by sector and site if the official inventory is found to be in error. Verification includes methane as the second-largest contributor to radiative forcing after carbon dioxide ($CO_2$), not least because current methane inventories are often more uncertain than those for $CO_2$ (ref.[2]). Human-induced emissions of methane in some sectors (typically referred to as fugitive emissions) are often controllable with best practice but are often unidentified, much less quantified[3].

The Paris Agreement's requirement for measurement-led verification has presented governments, regulators, industry, and indeed scientists, with a complex challenge. While there are a great many publications comparing measurement-led emissions case studies (known as top-down approaches) with official inventories (compiled using bottom-up approaches), it remains extremely difficult to derive directly comparable and meaningful inventories from top-down measurements alone. Put simply, it is impossible to measure everything, everywhere, all of the time. Even if we had such data, disentangling them to give accurate methane emissions by sector at high spatial and temporal resolution requires precise understanding of atmospheric transport in order to invert greenhouse gas concentrations to emission fluxes: a measurement in the atmosphere at any location is the net total of all greenhouse gas sources and sinks that occurred in the history of an airmass, natural and anthropogenic. Therefore, emissions verification will always be a compromise, requiring the design of suitable and optimal sampling and modelling approaches that minimise uncertainty whilst still yielding information useful for verifying, challenging and comparing to bottom-up inventories.

[1] Department of Earth and Environmental Science, University of Manchester, Manchester, UK. ✉email: grant.allen@manchester.ac.uk

National greenhouse gas measurement networks, such as the UK Deriving Emissions linked to Climate Change tall tower system, which samples greenhouse gas concentrations from broadcast towers around the UK, can provide mapped emissions data at the national scale using optimised transport inversion models[4]. However, sector-specific emissions cannot be deconvolved easily. New and forthcoming satellite observations offer much promise in this regard, with the potential to quantify emissions from very strong individual methane sources like large landfill sites and refineries, but have a relatively high limit of detection, which reduces their sensitivity to smaller sites with cumulatively large total emissions[5]. Autonomous aerial vehicles can also offer intensive surveys of single sites with very high sensitivity[6]. However, aircraft surveys can offer highly targeted sampling of many sites in a single survey flight, also with high sensitivity. With a representative sample size, it can be possible to derive measurement-based inventories by sector, such as for the oil and gas industry (Fig. 1).

Johnson and colleagues[1] present methane LiDAR surveys sampled from a small aircraft, to create an inventory for oil and gas infrastructure in British Columbia, complete with a thorough uncertainty analysis and confidence intervals. Importantly, the framework they describe could be transferrable and adapted for other methods of sampling and instrumentation, as well as other emission sources, other gases, and other regions.

The article and its method are a response to a key challenge facing the greenhouse gas flux measurement community: how snapshot surveys and case studies can be extrapolated to representative regional and annual inventories and thus be made more directly comparable to UNFCCC-reported official emissions inventories and regulatory imperatives. The study by Johnson and colleagues embraces that challenge and recognises that simply conducting expensive surveys ad infinitum is not practicable. Instead, it defines a statistical approach to make the best use of what can be sampled and to quantify uncertainty accordingly.

Johnson and colleagues develop and demonstrate a protocol that considers sample-size uncertainties and finite population effects in highly skewed and time-varying source distributions, because it is well known that a small number of sites can account for a disproportionately large amount of emissions—so called super-emitters. However, the largest emitters are correspondingly easier and typically more attractive to measure. As a result, the cumulative sum of a much larger number of typically undersampled smaller emitters can be equally, if not more, important for inventory verification.

Aerial surveys can offer important insights in this regard, because they are able to detect smaller methane sources as well as the larger emitters, and surveys can be designed to optimise the flux inversion problem for specific sites and sectors. Johnson and colleagues derive a measured inventory that is a factor 1.7 higher than the corresponding official inventory for onshore oil and gas infrastructure in British Columbia. They also find that the methane intensity of produced natural gas, that is, fugitive emissions as a fraction of total methane produced is less than 0.5%, much lower than comparable estimates for other regions. Segregating emissions by source type, such as gas plants versus compressor stations, the study also identifies potential mitigation targets to inform regulators and industry.

The analysis framework proposed by Johnson and colleagues[1] is an exciting demonstration of a way to compile surveys limited in time and space into measurement-led (top-down) inventories for official (bottom-up) inventory verification. The methodology is an example of a Tier 3 emissions quantification approach as defined by the IPCC[7], which represents the most demanding but typically more accurate inventory, recognising that incorporating such inventories into official data is challenging but important. The method described by Johnson and colleagues therefore lays a foundation for others to build on and offers a novel way to verify, challenge, and update, official inventories by sector.

**Fig. 1 An oil refinery at night.** Onshore oil and gas is a substantial source of methane to the atmosphere. Credit: Kanenori/Pixabay.

Received: 4 April 2023; Accepted: 5 April 2023;
Published online: 25 April 2023

## References

1. Johnson, M. R., Conrad, B. M. & Tyner, D. R. Creating measurement-based oil and gas sector methane inventories using source-resolved aerial surveys. *Commun. Earth Environ.* https://doi.org/10.1038/s43247-023-00769-7 (2023).
2. Riddick, S. N. & Mauzerall, D. L. Likely substantial underestimation of reported methane emissions from United Kingdom upstream oil and gas activities. *Energy Environ. Sci.* **16**, 295–304 (2023).
3. Nisbet, E. G. et al. Methane mitigation: methods to reduce emissions, on the path to the paris agreement. *Rev. Geophys.* https://doi.org/10.1029/2019RG000675 (2020).
4. Stanley, KieranM. et al. Greenhouse gas measurements from a UK network of tall towers: technical description and first results. *Atmos. Meas.Techn.* **11**, 1437–1458 (2018).
5. Maasakkers, J. D. et al. Using satellites to uncover large methane emissions from landfills. *Sci. Adv.* **8**, eabn9683 (2022).
6. Shaw, J. et al. Methods for quantifying methane emissions using unmanned aerial vehicles (UAVs): a review'. *Philos. Trans. Royal Soc. A.* **379**, 20200450 (2021).
7. IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (eds. Calvo Buendia, E., et al.) (IPCC, 2019).

## Acknowledgements

Grant Allen holds current funding from the Natural Environment Research Council (NE/X014649/1) to conduct unmanned aerial vehicle surveys of UK onshore greenhouse gas sources.

## Author contributions

G.A. conceptualised and wrote the article.

## Competing interests

Grant Allen holds current funding from the Natural Environment Research Council (NE/X014649/1) to conduct unmanned aerial vehicle surveys of UK onshore greenhouse gas sources. Grant Allen is a minor shareholder in SurveyAR Ltd.

## Additional information

**Correspondence** and requests for materials should be addressed to Grant Allen.