Publishable Summary for 21GRD04 isoMET
Metrology for European emissions verification on methane isotopes

Overview

Atmospheric observations provide a reality check on the true efficacy of climate change mitigation policy. Methane is a potent greenhouse gas (GHG) with multiple complex sources and stable isotope ratios provide a fingerprint needed to verify emissions by source type. This project seeks to improve 1) ambient air monitoring capabilities; 2) the quality of source signature information; and 3) the modelling information necessary to direct the measurement strategy and make top-down emissions estimates.

Need

Methane is a GHG with anthropogenic and natural sources. Its anthropogenic contribution to climate change is only second in importance after carbon dioxide (CO_2) in terms of its radiative forcing and current emission rates. It also contributes to air quality problems through its role in tropospheric ozone formation. Key source categories for anthropogenic CH_4 emissions in Europe estimated with ‘bottom-up’ methods suggest a breakdown as: Agricultural sector (~50 %), waste (~22 %), and energy (~15 %). These three sectors account for up to 95 % of global anthropogenic CH_4 emissions and are therefore the focus of mitigation action within the EU through the European Green Deal, and the EU Methane Strategy that describes stronger actions to address CH_4 emissions in each sector. Verifying the efficacy of mitigation policy related to each sector’s influence on total CH_4 emissions is not yet possible, yet the measurement and modelling technologies exist. Metrology research is the missing link to bring isotope ratio measurements into operational use for top-down emissions estimation by source category. Integrated Carbon Observation System (ICOS) is the foremost GHG monitoring network for tracking Europe’s GHG composition, however, currently formal protocols for measurements and calibration of deployed laser spectrometers do not exist, in turn limiting end-users' confidence to operate such instruments and collaborate as a network of sensors (objective 1). The source signature information needed to interpret atmospheric isotope ratio measurements is lacking. Defined measurement methods that are dependent on the source under study and a centralised system to accrue and disseminate the measurements are needed (objective 2). Further, highly promising new ‘clumped’ isotope measurements could provide additional observables yet metrology research in Europe in this area is yet to begin. For isotope ratio measurements to have impact on policy and for the measurement strategy to be based on evidence, atmospheric transport modelling activities also need to be stepped up. Understanding the gaps and requirements in measurement for emissions estimation requires a collaboration between metrologists and modellers (objective 3).

Objectives

The overall objective of the project is to develop and deliver an infrastructure for the use of CH_4 isotope ratios in improving emission estimate of CH_4 in Europe.

The specific objectives of the project are:

1. To develop a harmonised in situ CH_4 isotope dataset of ambient air in Europe to resolve compatibility issues of datasets when combining measurements of $\delta_{13}C(CH_4)$ and $\delta_{2}H(CH_4)$. This harmonisation includes a) improved methodologies and procedures for comparability of independent in situ analyses of ambient air CH_4 for $\delta_{13}C(CH_4)$ and $\delta_{2}H(CH_4)$ by Optical Isotopic Ratio Spectroscopy (OIRS) to the Vienna Pee Dee Belemnite (VPDB) and Vienna Standard Mean Ocean Water (VSMOW) scales, respectively, and b) Isotope Ratio Mass Spectrometry (IRMS) and OIRS methodologies validated through interlaboratory comparisons across participants.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

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2. To develop a sustainable metrological infrastructure for a dataset for $\delta_{13}C(CH_4)$ and $\delta_2H(CH_4)$-emissions source measurements in Europe and to evaluate the potential for source apportionment through clumped isotopes. This will include developing the analytical protocols for measurements of sources, especially those underrepresented in current databases, and the data analysis and uncertainty estimates for input of new and existing source signature data into inverse modelling for emissions estimation.
3. Use atmospheric chemistry transport modelling to inform objectives 1 and 2, creating estimates of the minimum measurement requirements for deployed instruments. The full dataset of measurements across Europe from objectives 1 and 2 will be used in atmospheric transport models and inverse statistical methods, to enable a first demonstration of estimates of emissions from the new datasets.
4. To facilitate – in cooperation with the EMN for Climate and Ocean Observation and the EMPIR JRP 20NET03 POLMO – the take up of the data and measurement infrastructure developed in the project by key stakeholders such as the global monitoring networks WMO GAW and ICOS and the inclusion in the ICOS and MEMENTO databases.

Progress beyond the state of the art and results

Developing a harmonised in situ CH_4 isotope dataset (objective 1)

Following the success of GHG mixing ratio determination using OIRS, the development of precise real time, in situ field measurements is at hand. The calibration procedures, reference materials and analysis protocols, however, are not sufficiently developed to allow efficient harmonisation of measurements to provide a compatible dataset needed for input in atmospheric transport models. For the first time the consortium will develop such a framework and allow isotope ratio measurements to be used as a complete dataset over a significant spatial and temporal range.

Developing metrological infrastructure for a dataset for $\delta_{13}C(CH_4)$ and $\delta_2H(CH_4)$-emissions source measurements (objective 2)

For scientific interpretation of ambient air measurements from objective 1, improvements in source signature information are needed. Several studies have looked at sources across Europe, however, the approaches often entail use of different sampling, measurements and data analysis techniques. Improvements are needed in standardisation of measurements, including full uncertainty analyses, and the methods to curate and disseminate results. Attempts have been made at the global level and this project will look to create a more detailed European domain-based database. As with analysis of $\delta_{13}C(CH_4)$ and $\delta_2H(CH_4)$, OIRS techniques offer another route towards more routine and robust measurements of the rarer isotopologues. This area of research is in its infancy, however, progress in the fundamental metrology behind spectroscopic measurement of these rare ratios will help accelerate advancement and lead to discovery of potentially powerful new observables for source identification.

Using atmospheric transport models to direct monitoring strategy and improvements (objective 3)

Uniquely the project will use state-of-the-art atmospheric chemistry transport modelling techniques to help understand the measurement requirements and plot the course of future expansion. Atmospheric modelling is a prerequisite to translating amount fraction and isotope ratio measurements into policy relevant information. Not all measurements are equal in value for use in a modelling framework. Likewise, the uncertainty requirements on measurements can be relaxed in certain instances (where a measurement site is particularly sensitive to emissions) or required to be improved (e.g. for clean air sites that are needed to constrain the amount of CH_4 already present in the atmosphere before additional regional influences). The consortium will use more than one model to quantify where model uncertainty is an important factor to consider in interpretation – the first such detailed study for CH_4 isotope ratios.

Outcomes and impact

Outcomes for industrial and other user communities

This project will lead to confident uptake of the new methods, from using the calibration and measurement protocols to inform how instruments are developed and calibrated by manufacturers, through to the confident use of atmospheric flux estimates by governments and other communities. In development of the protocols for pushing the limits of precision and accuracy of measurement, the project will define the limitation of current instrumentation, therefore finding the most efficient and practical lines for improvement by manufacturers.

Instrument manufacturers will also benefit from the supply of the next generation of accurate calibration standards for isotopic composition, which will enable their instruments to be traceable and provide valid data for atmospheric monitoring. The IPCC has set out the best practises for use of top-down emissions estimates to verify emissions estimates and their reporting to the United Nations Framework Convention on Climate Change (UNFCCC). For these aims governments need to use data established confidently in networks that are linked internationally. The work of this project will inform the practises of such networks based on metrological principles. Other organisations aiming to help governments and industry will be very interested in both the details of this project's work (they themselves make measurements) through to the longer-term outcomes - improved top-down emissions estimates will help direct their mitigation efforts and monitoring strategies (e.g. Environmental Defence Fund (EDF) and International Methane Emissions Observatory (IMEO)).

Outcomes for the metrology and scientific communities

The Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology (CCQM) strategy document (2021-2030) is aligned to the aims of this project including for 2022-2023 'developing an extended global GHG measurement system' and beyond 2023 'interfacing with and providing technical solutions to global stakeholder communities'. The project will extend the remit of ICOS to measurement of isotope ratios of CH_4 and create the solutions required by the stakeholder community through its focus on using atmospheric transport modelling. The consortium will therefore be able to realise the aims of the CCQM strategy within the timeframe of this project and include the contribution to standards.

Through this effort other scientific groups will have the confidence to operate more instruments, thus bringing more measurements to a combined dataset, ultimately improving the quantity of high quality in situ observations which are critical for scientific research and for eventual routine top-down assessment of CH_4 emissions. There is also a wider isotope ratio measurement community looking to use OIRS techniques for measurement of GHGs and other species. Stable isotope ratios and radioactive isotope ratios across other GHGs (name CO_2 and N_2O) also hold significant value for understanding the carbon and nitrogen cycles and the sources of emissions. Many of the techniques and approaches that will be developed for CH_4 isotopes could be adapted across other measurement systems.

Outcomes for relevant standards

In terms of standardisation, the project activities are broad, ranging from the preparation of gas standards to the methods of emissions estimation. The ISO technical committees targeted will be ISO/TC 158 (Analysis of gases), ISO/TC 146 (Air quality) and ISO/TC 207 (Environmental management). The project participants that have connections via their institute or direct memberships of these committees will ensure that the knowledge developed within the project is fed into the committee meetings. The project will have a strong impact in the CCQM and also stakeholder-led standardisation activities (e.g. the reports from outputs of the WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases, and Related Measurement Techniques (GGMT) or the ICOS Monitoring Station Assembly (MSA) Atmosphere Meeting).

Longer-term economic, social and environmental impacts

Economic

An increasingly rapid policy response will be vital to enhance responsiveness on the move towards net zero in under 30 years while ensuring any possible negative economic costs are minimised. The EU 2030 Climate Target Plan Impact Assessment suggests an accelerated effort to tackle CH_4 emissions: A requirement of 35 % to 37 % CH_4 emission reductions by 2030 compared to 2005 – a significant step up for effectiveness of policy action. With binding emission targets being set accounting for emission changes is now inherently linked with decision making by local, regional, and country level governments regarding the wider economy. Issues of trade-offs e.g. in policies that might limit CH_4 emissions but increase CO_2 emissions and perverse incentives (for example in the biogas industry) are further detailed economy-related reasons to improve the transparency behind emissions reported, including top-down verification. The EU aims to spend 30% of its overall budget for 2021-2027 on tackling climate change and its effects (www.consilium.europa.eu/en/infographics/recovery-plan-mff-2021-2027/). Targeting the right mitigation measures for investment will enhance the effectiveness from this budget and prevent unnecessary spending on mitigation measures that are ineffective. If emissions can be broken down by sector/industry it will lead to greater engagement with the relevant industries responsible for those emissions, making way for direct economic impact through improvements in GHG mitigation efficiency at the industry level. Air pollution can also considerably benefit from mitigation of CH_4

emissions (being a major cause of ground-level ozone pollution), affecting health, including both mortality and morbidity, and agricultural productivity. This has knock-on effects for the economy and the welfare costs from premature deaths and pain and suffering are quantitatively assessed.

Environmental

Methane makes up a significant part of the anthropogenic radiative forcing that is driving the global rise in temperature (now around ~1 °C above preindustrial). The IPCC have reported that limiting a temperature rise this century to 1.5 °C could avoid the most harmful effects of climate change, which include huge changes to the environment and loss of biodiversity in terrestrial ecosystems (Masson-Delmotte et al., 2018); above this threshold the chances of loss of unique and already threatened ecosystems become very likely. Other areas of the planet are already under significant strain from rising temperatures due to the rising total of global anthropogenic GHG emissions. Methane is an especially strong greenhouse gas with the effective radiative forcing in 2019 from 1750 at 0.54 W m^{-2}, second only to CO_2 at 2.16 W m^{-2} (IPCC, 2021). The global warming potential for every mass unit of emissions of CH_4 is 27-30 times greater relative to CO_2, making significant emission reduction of CH_4 vital for reaching climate targets. Europe therefore has a role to play in limiting these global environmental problems by leading the way in climate mitigation action. Objective measurement and understanding of these issues can help to make the right balance of decisions to protect the environment.

Social

Methane emissions mitigation policy will impact how we grow food through to how we heat our homes. Outcomes from projects like this to understand the primary sources of methane emissions will ultimately accelerate changes that need to be made in one sector over another. Climate change mitigation policy is also an opportunity to address societal equity, ensuring that emissions mitigation measures do not burden the most vulnerable through unfair policies. Direct GHG emissions mitigation measures will complement other developments for policies aimed at the agriculture sector and rural areas, in particular an expected societal shift to more balanced diets, with less red and processed meat, more fruits, vegetables and plant-based protein sources, in line with the EU Farm to Fork Strategy.

Future uses

Developing the protocols and methods for this new measurement network will allow CH_4 isotope ratios to be an integral part of established country-scale operational emissions verification systems that are now considered ‘best practice’ for reporting to the UNFCCC. The project provides a scientific platform to expansion of isotope ratio networks to higher resolution spatial coverage or different areas of the planet.

List of publications

n/a

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

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<tr><td colspan="2">Project start date and duration:</td><td>1 October 2022, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Volker Ebert, PTB   Tel: +49 (0)531-592-3401   E-mail: volker.ebert@ptb.de
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<tr><td>Internal Beneficiaries:
1. PTB, Germany
2. TUBITAK, Türkiye
3. VTT, Finland</td><td>External Beneficiaries:
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5. UHEI, Germany
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