Onshore oil and gas monitoring: a structured approach to quantifying whole-site methane emissions

Chief Scientist's Group report

Date: October 2021

Version: SC200002/R

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Published by:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

Further copies of this report are available from our publications catalogue: www.gov.uk/government/publications or our National Customer Contact Centre: 03708 506 506

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Keywords:
methane, emissions, quantification, onshore oil and gas.

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Project number:
SC200002

Citation:
Environment Agency (2021) Onshore oil and gas monitoring: a structured approach to quantifying whole-site methane emissions. Environment Agency, Bristol.

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Professor Doug Wilson
Chief Scientist

Contents

Executive Summary

Methane is an important greenhouse gas and the onshore oil and gas (OOG) sector contributes to the UK's overall emissions of methane to the atmosphere. Reducing methane emissions from the sector will contribute to dealing with the climate emergency and improved monitoring systems for methane emissions are an important element in achieving this. This scoping study has produced an outline framework that would inform decision-making on the most appropriate and cost-effective whole-site methane emission quantification systems.

Whole site methane emissions are the overall emissions from a site. These may be made up of a range of emission sources within an area, including leaks and engineered releases during normal or non-routine operations. These emissions may vary over time and according to the activities taking place at the facility. The emissions from different sources can mix in the air above the site to form a combined discharge, so whole-site emissions can be obtained by measuring and adding together the individual sources or by measuring their combined plume.

In this study, the importance of first understanding the reasons for the measurement has been highlighted. Three categories of monitoring purpose are suggested: scoping assessments; routine monitoring; and monitoring for research purposes. The purpose of the monitoring will help determine the level of certainty needed in the methane emission quantification. The total uncertainty in the methane emission rate will include: the uncertainties in methane concentration measurements; in other measurements such as wind speed and direction; in the computer modelling undertaken; and in the methods used to extrapolate from monitoring campaigns to the time period of interest (for example to derive an annual emission from a short measurement survey). Three uncertainty levels for the methane emission rate have been defined for the study: high uncertainty - greater than 70%, medium uncertainty - up to 70% and low uncertainty - up to 30%.

Some examples of the type of OOG facility for which the Environment Agency has a regulatory remit are set out in the report. These are: wells, central gathering stations; gas processing sites; and compressor stations. Each is described in terms of their typical dimensions, activities, and functions with suggestions on common types of emission sources and characteristics. In addition to the site type, there are a number of other factors that influence the emission characteristics. These are: size of the site; geometry and topography; potential emission sources; emission type (e.g. diffuse, point, fugitive); emission rates; and variability. A glossary is included at the end of the report defining the terms used within the report including those used to describe the emission characteristics. Determination of the emission characteristics will help determine the appropriate measurement technique.

The available techniques for methane emission quantification are identified and outlined. The methods included are: open-path / fence-line monitoring; imaging; point concentration sampling; Differential Absorption Lidar (DIAL); tracer; solar occultation flux; concentration scoping measurements; satellite; and air quality towers. The ancillary data needed to

calculate an emission rate (for example wind speed and direction) and any requirements for dispersion modelling are identified for each approach.

The approaches are categorised as to whether they are a continuous monitoring approach or used in measurement campaigns. The uncertainty level that each approach could provide is set out. No continuous measurement approach was identified as being able to achieve a low level of uncertainty. Measurement campaigns using the tracer technique or DIAL do have the potential to provide a low level of uncertainty.

The study outlines how the factors such as: monitoring purpose; site type; and emission characteristics can be used in deciding on the most appropriate measurement technique. This is illustrated through two simple case studies.

One recommendation arising from this scoping study is that the structured approach outlined here should be used as the basis for the development of a selection tool to determine the optimum and most suitable technologies for the quantification of methane emissions from OOG facilities. It would be beneficial to develop more detailed case studies of the selection of measurement techniques.

A further recommendation is for research on the evaluation of the combined uncertainty in a quantified emission.

It is also recommended that the relevance of the approach to other sectors and facility types, and emissions of other greenhouse gas or pollution species should be investigated.

1 Introduction

1.1 Background

Methane is an important greenhouse gas and the onshore oil and gas (OOG) sector contributes to the UK's overall emissions of methane to the atmosphere [1]. The Committee on Climate Change's 6th carbon budget notes that emissions from oil and gas production can be reduced by measures including reduced venting and flaring of gas and notes that monitoring systems are important to catch methane leaks from the gas network quickly [2].

Much of the methane monitoring that has been undertaken at OOG facilities has either focussed on Leakage Detection and Repair (LDAR) technologies or on ambient concentrations of methane. We do not therefore have a clear understanding of the quantities of methane emitted from facilities, the relative contribution from different sources, nor how this varies over time. To better understand the amount of methane being emitted, we would need measurements of facility wide (whole-site) methane emissions to be undertaken.

The oil and gas industry has committed to a new framework (the Oil and Gas Methane Partnership 2.0) to monitor, report and reduce methane emissions [3]. The level 5 monitoring in that framework relates to site-level measurements which are intended to reconcile source- and site-level emissions estimates, providing improved confidence in reported emissions [4].

This project focuses on the measurement approaches that could allow for the quantification of whole-site methane release rates from OOG facilities.

1.2 Aims

This project is a scoping study which aims to produce an outline framework that would inform decision-making on the most appropriate and cost-effective whole-site methane emission quantification systems.

The project aims to develop a structured approach to decision-making to ensure that each of the following main features are considered:

- The spatial scale of the whole-site and its component activities.
- The time scales of the whole-site emissions and the component activities.
- Metadata to translate methane measurements into quantified emissions, for example, activity data to extrapolate monitoring campaign data into annual releases.

1.3 Scope

The work will focus on the quantification of whole-site methane emissions from OOG facilities that fall within the regulatory remit of the Environment Agency.

1.3.1 Whole-site emissions

Methane measurements are often made for particular activities and locations on a site, but the measurements are not usually sufficient to estimate the site's overall emissions. However, recent advances in methods of monitoring and data analysis have made it more feasible to estimate such 'whole-site' emissions. What constitutes whole-site emissions may need to be adapted to the situation at each site but will generally cover emissions from:

- A particular area that contains one or more activities (e.g. within a fence-line).
- Intended engineered sources (e.g. stacks), and unintended sources (e.g. leaks and fugitive discharges), occasional intended discharges during non-routine operations (e.g. flares).
- A particular period of time (e.g. a year), and/or a particular phase of activities (e.g. drilling, extraction).
- Several nearby sources that emit and mix in the air above the site to form a combined discharge, so whole-site emissions can be obtained by adding the individual sources, or by measuring their combined plume.

Values of whole-site emissions can be compiled from measurements for individual sources at a site, or from a combination of measurements and estimates. This report focuses on field-based monitoring methods that can provide, or contribute to, the quantification of whole-site emissions. It does not consider other methods of estimating emissions (e.g. using emission factors) or techniques for combining measured and estimated values.

1.3.2 Facilities

Examples of the facilities within the scope of the study include: exploration, drilling and production sites, central gathering stations; gas processing sites; and pumping and compression stations. High pressure hydraulic fracturing, in line with the moratorium on the use of this technology, is not included in the scope of this work. Sub-surface emissions, for example from boreholes or migratory emissions from buried assets, and associated soil to atmosphere flux monitoring techniques such as flux boxes and eddy correlation are also not covered in this document.

There are other industry sectors where facilities within the regulatory remit of the Environment Agency emit methane to the atmosphere, for example, anaerobic digestion (AD) plant and landfill. Although beyond the direct scope of this work, the structured approach to selecting methane quantification systems should be transferable to these other sectors. This would be consistent with the CCC 6th carbon budget which notes that waste sector greenhouse gas emissions can be reduced through action including higher landfill methane capture rates, improvements to wastewater treatment and composting facilities. The CCC also note that the evidence base on how to decarbonise the waste sector in the UK is more limited than the evidence available for other sectors [5] and so direct measurement of emission rates would be beneficial.

The approach set out in this report should aid decision-making on how to quantify whole-site methane emissions but does not address: when such monitoring may be necessary; who might be responsible for undertaking the measurements; or who might be responsible for regulating methane emissions from different sources within a facility.

1.4 Project report

This project report outlines a structured approach for defining what needs to be measured, how the measurements should be taken and how these measurements can be interpreted to provide meaningful quantification of whole-site methane emissions.

The report describes and aligns definitions of recognised and specific terminologies to establish a common language for this area of work and provide standardised terms.

This report provides an outline framework to allow the following points to be considered when quantifying methane emissions:

- Overarching purpose: what the monitoring is for and the desired outcome.
- What's being measured: defining what site or functional elements are being measured.
- Monitoring objectives: defining what is needed to know both spatially and temporally and the desired measurement uncertainty.
- Measurement requirements: defining system capabilities and performance requirements including the spatial, temporal and detection requirements for methane instruments and for ancillary measurements.
- Measurement system parameters: which are the important parameters to select for different methane quantification requirements and measurement systems.
- How the measurements are translated into quantifying the methane emission rate and how these can be used to determine annual emission rates.
- The uncertainties in the final estimates which will be composed from uncertainties in measurements and metadata, and in the methods used to extrapolate from monitoring campaigns to the period of interest.

The report provides simple examples of approaches for quantifying emissions and illustrates how these can be matched to methane characteristics.

Finally, this scoping report provides recommendations for how the structured approach set out here could be built on in future work.

The report structure is as follows:

- Section 2: Reason for Measurement

- Section 3: Site Types
- Section 4: Emission Characteristics
- Section 5: Quantification of Methane Emissions
- Section 6: Selection of Measurement Techniques
- Section 7: Conclusions and Recommendations

A glossary is included at the end of the report defining the terms used within the report including those used to describe the emission characteristics.

2 Reason for measurement

The reason for quantifying the emission of methane is fundamental to the selection of any measurement technique or system. Examples of reasons for quantifying whole-site methane emissions could include:

- Estimating the emissions from a site category or type
- Estimating emissions from a particular activity across facilities
- Understanding annual emissions from a facility
- Identifying the performance of a facility in terms of emissions at a point in time
- Informing policy
- Informing emissions remediation strategies for an activity
- Routine reporting of emissions
- Audit of emissions performance
- Developing emission factors

Whole-site emissions, as the name suggests, are the total emissions from the site over a specified time. The time period may be specified to cover a particular activity on the site or just averaged over a year. Further detail on the emissions associated with particular functional elements on the site or the identification of specific emission sources may be required.

How representative the measurements of the whole-site emissions are should be considered. A short-term measurement will generally be representative of the whole-site emission at the time the measurements are taken; however, care should be taken when these results are then annualised. For example, if the results of the monitoring will be used to report “representative” annual emissions e.g. for comparison with other years/sites then they must cover all activities that occur during the year. Activities data should be recorded and linked to the monitoring results. This will help to assess how “representative” the results are and to “annualize” the data from short-term campaigns if needed. A short-term measurement period may not be appropriate; however, recording/linking activity data could allow an assessment of how representative one or more short-term measurement periods are.

2.1 Uncertainty levels

The total uncertainty in the final methane emission rate will be made up of the uncertainties in methane concentration measurements and the ancillary data (for example wind speed and direction); in the modelling undertaken; in the methods used to extrapolate from monitoring campaigns to the time period of interest (for example an annual emission); the use of emission factors and the measurement of limited samples of component emissions to be multiplied to calculate the whole site emissions. The overall uncertainty on the methane emission rate is termed the ‘expanded uncertainty’ giving an approximate level of confidence of 95%. Further explanation of uncertainty definitions can be found in ‘NPL’s The Beginner’s Guide to Uncertainty of Measurement’ [6]. The monetary budget available will also be a factor that needs consideration with respect to the uncertainty achievable and this may affect the time available to carry out the measurements.

The expanded uncertainty required for the quantification of methane emissions will depend on the reason for the measurement and suggested uncertainty limits are proposed. For the purposes of this document three uncertainty levels of monitoring are defined as high, medium and low uncertainty.

- High uncertainty: from techniques that typically provide an expanded uncertainty of the emission rate greater than 70%.
- Medium uncertainty: from techniques that typically provide an expanded uncertainty of the emission rate up to 70%.
- Low uncertainty: from techniques that typically provide an expanded uncertainty of the emission rate up to 30%.

2.2 Categories of measurement purpose

Potential categories of measurement purpose are set out below.

2.2.1 Scoping assessment

If the emissions from a site are unknown and knowledge is limited, an initial scoping, reconnaissance survey of the site may be required to determine if monitoring is needed and to determine what type of measurement system may be best suited for a particular site. The level of uncertainty may not be as important for this category if subsequently more accurate measurements are to take place. An alternative is to estimate the emissions using data from sites of similar type, size and throughput.

2.2.2 Routine monitoring/reporting

If measurements are required for reporting of the quantity of emissions, then the use of medium or low uncertainty techniques is recommended.

2.2.3 Research study /reconciliation

If a specific investigation is being carried out for research or a detailed survey to determine emission factors, or for site level reconciliation of reported emissions [7] (analogous to OGMP 2.0 Level 5 measurements), then the use of low uncertainty techniques would be required.

2.2.4 Annual emissions

If the measurements are required to be translated into an annual emission rate then further knowledge is required on the activities that take place at a site over that period, their associated emission rates and if they vary with throughput. This can either be achieved by continuous measurement or campaign type measurements carried out for each activity and various throughputs.

3 Site Types

Some examples of the type of OOG facility for which the Environment Agency has a regulatory remit [8] are outlined below. Each is described in terms of their typical dimensions, activities, and functions. Common types of emission sources and characteristics are suggested but will vary and should be determined through a survey of the site and its functional elements either by a site visit or an assessment from site information if the required detail is available.

3.1 Wells

Oil and gas wells will vary in size and will go through a number of activity stages during their lifetime. An individual onshore oil well in the UK will generally be of a small scale and cover an area approximately 50 m x 50 m. There may be other wells in the vicinity. A single well may have a “nodding donkey” type pump or well head tree. The product may be exported by pipe or, in the case of oil, stored on site prior to collection by road tanker. Dissolved gasses may be stripped from the oil prior to storage by passing through a separator. The separated gas may be utilised for heat and/or power generation or simply flared. Where no separation is carried out, tank vapours are simply vented to atmosphere. Emissions may also occur during back balancing where collection of the vapour from the tanker’s tank during filling is recovered. The lifetime stages of a well are:

- **Exploration:** The drilling of test wells to find oil or gas reservoirs
- **Drilling:** The drilling of the final well.
- **Proving:** The wells are tested to determine their viability which will involve flow testing taking up to 180 days.
- **Development (production):** The well is producing product while the reservoir is viable. It may involve bringing new wells online or reworking of existing wells.

- **Decommissioning:** Emissions may be produced as wells are decommissioned and capped wells may need to be monitored.

Emissions may be present from the well itself, tank vents or components such as valves and pumps. If there is any processing such as condensate removal this would contribute to further emissions. A flare is also a source of methane emissions.

3.2 Central gathering stations

Gathering stations collect oil and gas from multiple wells to a central point where it may be stored temporarily before being collected or piped for processing. Some initial processing may take place at this stage where gas, oil and produced water are separated. Sites will vary in size and can be effectively small gas processing sites. Emissions may be present from tanks and their vents or components such as valves and pumps.

3.3 Gas processing sites

Unprocessed gas is piped from wells or well fields to sites where it is processed to a level where it is suitable for export and use. This may involve removing impurities such as water, carbon dioxide, volatile organic compounds (VOCs) and other heavy hydrocarbons and condensates. Heavy hydrocarbons are removed using a sludge catcher comprising a series of long sloping parallel pipes. These condensates are often then exported by ship or pipeline for further processing. In some cases, antifreeze chemicals such as Mono Ethylene Glycol (MEG) or methanol also have to be removed. Other gases such as ethane, propane and butane etc are often separated from the methane using a series of fractionation towers and stored in tanks for export. The methane gas may then be compressed and exported to the high-pressure national transmission pipes. The plants can vary in size and can be up to 300 m x 800 m.

The plants are complex with a high density of different functional elements and components. Emission sources can be at a variety of elevations and difficult to access. Areas of the plant can be surrounded by open areas. Emissions can come from, for example, pipe components, compressors and power generation turbines.

Flaring is minimised but if pilot lights are used these will result in emissions. Flaring is still used for maintenance reasons and when there are plant trips, faults or emergencies. The flares will be at high elevations and emissions are normally calculated from assumed flare efficiencies. These emissions are difficult to measure directly, and the metering of flow rates may have large uncertainties, be out of calibration or not measured at all.

3.4 Pumping and compressor stations

Compressor stations are required throughout the high-pressure gas transmission network to maintain the pressure and move the gas. The gas is not odorized at this stage. Odorant is added to the gas after the pressure has been reduced for domestic use and this can often take place adjacent to a compressor station. A typical compressor station can comprise 2 to 3 gas compressors and cover an area of about 200 m x 200 m surrounded by a high security fence. In the UK, these use gas turbine engines housed in sound proofed buildings. Emissions are present from slippage through seals, and unburnt fuel gas. Methane gas is periodically vented to atmosphere for maintenance reasons or purging of pipelines from high level vents. There are also above ground gas components which are sometimes operated pneumatically using the gas pressure which is then vented to atmosphere leading to emissions of methane [9,10,11].

4 Emission characteristics

The variety of site types and functional elements lead to differences in emission characteristics. Determination of the emission characteristics and site topography will help determine the appropriate measurement technique.

The emission characteristics that will influence the optimum measurement methods and which must be considered when selecting techniques are outlined in the following sections. Other descriptive terms that can be used to describe the emission types and characteristics are defined in the Glossary.

4.1 Site type

The type of site to be measured for methane emissions will provide some information on the typical emissions that may be present, for example, the typical equipment and functional elements used on a site and their distribution (see section 3 above). The emissions seen from similar sites of this type will provide a range of potential emission rates from the common functional elements.

4.2 Size of site

The size of a site and the density of functional elements and potential leak sources can determine the most appropriate measurement technique and, for some techniques, the number of sensors and their distribution. The elevation of equipment and plant and their associated emissions will also have a bearing on the monitoring solution. Emissions from elevated sources may “overfly” ground-level sensors at a boundary close to the source.

4.3 Geometry and topography

The location of a site and the surrounding topography can influence the best measurement technique. For example, a site may be surrounded by trees which will influence the wind flow at the site boundaries, this may make a fence-line measurement system inappropriate [12]. The distance from the emission sources to the site boundary will also influence the most appropriate technique and its configuration.

4.4 Potential emission sources

Any component or piece of plant that handles methane can be a potential methane emission source [13]. Some plants are known to emit methane during normal operation such as flares [14], compressor or power generation turbines and pneumatically operated valves. Other known methane emissions will occur during routine maintenance tasks and are often released through purpose designed vents. These emissions often have to be reported and can be calculated with a reasonable uncertainty. Unintentional leaks from pressurized equipment can be considered fugitive emissions (see Glossary). A fugitive leak is defined as ‘a loss of process fluid to the environment past a seal, threaded or mechanical connection, cover, valve seat, flaw or minor damage point on equipment components in hydrocarbon service’.

4.5 Emission rates

The mass rate of the emission, per emission source and in total, will determine the local concentration of methane in the atmosphere and determine the sensitivity of the methane sensor required. Wind speed will also affect the concentrations observed, due to dilution, and the distance of the sensor and the emission source will have to be accounted for. Sensors vary significantly in their sensitivity and uncertainty.

4.6 Emission type (e.g. point, elevated, diffuse)

The relative position and geometry of the methane emission will be a factor influencing the type of measurement technique that is optimum. Certain emission sources will have specific issues when defining monitoring requirements for example, elevated emissions will be difficult to measure with ground-based sensors. Diffuse sources will be difficult to locate and result in low methane concentrations even with large total emission rates.

4.7 Variability

The variability of the emissions and the timescale over which these variations take place will be important to the type of measurement technique selected. The variability may be a result of different activities on the site or changes in the site throughput. Continuous sources arise from processes that can be measured in their typical operating status with an emission rate that is not expected to vary frequently. Specific, one-off or short-lived emissions from an otherwise typically continuous source can be defined as a non-continuous event. Apart from these non-typical, one-off events, non-continuous sources may only exist for a short period of time, for example during ship loading or unloading, or they may manifest a frequent variation of their emission rate due to frequent changes in their operational status. Flares are an example of these of non-continuous sources which could be measured either during normal conditions or during flaring with an increased flow rate.

5 Quantification of methane emissions

A quantified methane emission is a mass emission rate in units of mass/time, for example kg/h or t/yr. Any system to quantify methane emissions must have as its output a mass emission rate and an associated uncertainty. The mass emission rate is generally derived from a combination of methane concentration and meteorological measurements including windspeed and direction, modelling and in some cases temperature and pressure. The time resolution or measurement frequency required will depend on the reason for the methane emission quantification and the time variation of the emission.

5.1 Quantification of emissions from measurements

The emission rate is not a directly measured quantity and is normally calculated from a number of individual measurands such as methane concentration, at a point, in a plane or as a concentration along a pathlength, and wind speed and direction. Here these measurands are considered direct measurements. The emission rate is then calculated by combining the methane measurements with meteorological or other measurements. These are defined here as combined measurements. Modelling techniques are often used to determine the wind fields required to calculate the emissions rates. Individual emission rates from these calculations can then be used in conjunction with site activities and product throughput to calculate for example a total emission over a period i.e. an annual emission rate. These annual emission rates are defined here as derived quantities.

5.2 Measurement period

The period an emission rate is measured over can vary from instantaneous to hourly and beyond. The type of measurement technique is divided here into two categories, continuous and campaign.

5.2.1 Continuous measurements

A continuous or high frequency measurement system will monitor emissions at a sampling rate sufficient that any significant variation in the emissions are recorded. This may be continuously, every 10 minutes to perhaps hourly, depending on how a site and the systems operate. The minimum sampling rate will be dependent on the reason for the measurement. Measurements are taken over an extended period, for example, over several months to a year or they could potentially be a permanent installation.

5.2.2 Periodic or campaign measurements

Campaign measurements will typically provide a more detailed, higher resolution and lower uncertainty characterisation of the emissions of a site depending on the measurement technique, but this will only be a snapshot of the emissions at the time of the measurements. The length of the campaign will depend on the size of the site and its complexity. Periodic, repeat measurements can be made under different operating conditions to determine any variability. Campaigns can typically take a few weeks, but they can be shorter e.g. over a working week.

5.3 Methods and technology

The following sections describe the available methods and technologies used for the measurements of methane that can be combined with ancillary measurements and modelling to calculate the methane emission rate. Further knowledge and expertise on the site operating conditions will be required to, derive an annual emission rate. Many of the technologies and methods described here will have to be tailored for the reasons for measurement, the desired uncertainty, and the type of site.

5.3.1 Open-path / fence-line monitoring

Open-path methane measurements rely on optical techniques to measure the absorption of methane along a line between a source and receiver. Sometimes this path is folded by a corner cube reflector enabling the source and receiver to be co-located. Common methods to measure the absorption are the use of tuneable diode laser absorption spectrometers (TDLAS), Fourier transform infrared (FTIR) spectrometers or dual frequency comb spectrometers [15]. These techniques are ideally suited to measuring along perimeter fence-lines to measure methane as it crosses the beam path, although it can sometimes be used with optical paths crossing the site. These techniques cannot resolve plumes within the beam, but only measure integrated absorption along the path, so they are not well suited to identify the precise location of an emission source if that is an additional requirement. For a complete picture of the measurements, and to take into account upwind sources, the whole perimeter of a site needs to be covered.

The methane concentration multiplied by the pathlength is generally directly measured; knowledge of wind conditions and source height are required to calculate the emission rate and source location using inverse plume modelling.

Open-path fence-line monitors can be used for long term continuous measurements and can be suitable for either high or medium uncertainty measurements. The location of emission sources may take time, and require wind from a variety of different directions, before the location of the source could be identified accurately.

5.3.2 Imaging

Optical Gas Imaging (OGI) is usually a passive technique that uses thermal imaging cameras filtered at specific wavelengths where the gas of interest absorbs. For methane this is normally at wavelengths around 3.3 µm [16,17]. It relies on the gas having a different temperature to an emitting or reflecting background. If the gas is colder it will appear as a black absorbing smoke. If it is at a higher temperature it will appear as a white smoke (assuming the imager display is set to white = hot). The bigger the temperature difference the more sensitive the system will be. Systems can be portable or in fixed installations. Portable systems are used to carryout walkover campaign surveys and have the advantage that they can be used at a short distance from a component being investigated for a leak. Fixed installations to monitor a site will provide continuous monitoring but may be a significant investment.

Other imaging techniques use an active source to illuminate a scene and measure the transmission at methane absorption wavelengths including 1.53 µm and may be able to resolve the range of the absorbing plume.

Knowledge of the temperature difference is required to quantify the amount of gas and further imaging processing and/or knowledge of the wind speed and direction can be used to determine an emission rate.

The potential use of OGI to determine whole-site emissions would require a detailed campaign to measure all components or functional elements or sampling of components and extrapolation to the whole site. This would lead to high expanded uncertainties in whole-site methane emission rates.

5.3.3 Point concentration and distributed sampling

Direct measurements of the methane concentration at points surrounding a site are used in combination with wind speed and direction measurements to determine methane emission rates. The probable emission locations can be triangulated using a reverse Gaussian dispersion model. Once these locations are identified, a second model calculates the emission rates required to account for the concentrations measured.

The measurements are often made using individual sensors [18] or sampling points where air is pumped to a central methane measurement instrument. The sensitivity of individual sensors is generally proportional to the cost. Having a distributed sampling system has the advantage that only one high sensitivity instrument is required however the measurement interval will be higher, for example hourly rather than continuous.

Sensors will have to be positioned at all points surrounding a site to give a full picture of the emissions and their locations. Upwind sources surrounding a site can also be measured.

The required spacing of the sensors will be specific to a system’s design, but can determine the spatial resolution of the emission location. The distance from the sources and the wind speed will affect the concentration present at a sensor and hence the required concentration sensitivity of the sensor.

5.3.4 Mobile measurement

Individual methane concentration sensors can be deployed in a variety of ways. Fixed installations are self-explanatory; however, methane concentration sensors can also be deployed on mobile platforms such as unmanned aerial vehicles (UAVs or drones), aircraft, ground vehicles or by humans on foot. Sensors can be both active and passive including OGI, spectrometers and TDLAS. Mobile platforms would normally be deployed on a campaign basis. The use of mobile platforms will measure methane concentration directly at points covered by the mobile platforms path but reliance on modelling will be required to translate these measurements into whole-site emission rates. This will likely result in high uncertainties.

They can have application for mapping of methane concentration and have the ability to access areas which are hard to reach with ground-based sensors. The quantification of the emission rate may have high associated uncertainties [27,28,29].

5.3.5 Differential Absorption LIDAR (DIAL)

The DIAL technique [19,20] is a remote sensing method capable of making spatially resolved measurements of concentrations of a target gas along the path of an eye-safe laser beam transmitted into the atmosphere. In the DIAL technique, the laser is operated alternately at two adjacent wavelengths (in the ~3.3 µm region for methane). One of these, the ‘on-wavelength’, is chosen to be at a wavelength which is absorbed by the target species. The other, the ‘off-wavelength’, is chosen to be a wavelength which is not absorbed significantly by the target species. The difference in the absorption of the two wavelengths allows the concentration of the gas to be calculated. Spatial resolution is obtained by pulsing the laser beam.

Emissions rates are determined by scanning the laser beam through the atmosphere to build up a 2D concentration map and combining this with measurements of the wind speed and direction. Range-resolved remote DIAL measurements enable total site emissions and area-specific emissions to be measured, with no disruption to normal operational activities.

The system is mounted on a mobile platform and the measurements are taken from fixed locations on a campaign basis providing a snapshot of the emission rates during the measurement period.

The technique provides the uncertainties required for enhanced measurements however the costs are relatively high with limited providers of the service. The site to be measured should also have good access to suitable locations to measure (which do not need to be on the site) for a large vehicle.

5.3.6 Tracer

The tracer method [21,22,23] is a campaign technique where a tracer gas, commonly acetylene, is released at a known rate close to points where emissions are known or expected. Simultaneous measurements are then made of methane and the tracer gas downwind of the emission source using an instrument mounted on a mobile platform (van or car). The concentration ratio of the two gases is then used to calculate the methane emission rate.

The technique is simple in its approach but can be limited where multiple sources are present or the location of the emission source is unknown. The tracer technique needs good mixing of gases i.e. ideally it will measure a long distance downwind of the source rather than along the fence-line. For accurate measurements, it also requires an accurate analyser (ppb level) and that there are no other “offsite” sources overlapping the “target” source. With careful deployment, low uncertainties should be possible.

5.3.7 Solar Occultation Flux (SOF)

SOF [24] uses the sun as an infrared source and measures the absorption spectra of the atmosphere. The instrument is mounted on a vehicle which is driven in order to intercept a plume between the sun and the vehicle and is a campaign-based measurement. By combining this concentration measurement with wind measurements, an emission rate can be calculated. Other volatile compounds can be measured simultaneously and can be used to distinguish the source of the methane i.e. agricultural or natural gas sources. As the technique measures the total methane concentration in the atmosphere between the ground and the sun, the sensitivity is limited by the background methane concentration of the total column between the sensor and the sun so that the technique is expected to have a high uncertainty. A direct unobscured line of site is required between the system and the sun and so it is limited by the weather conditions.

5.3.8 Concentration screening measurements

The term “sniffing” [25,26] is used here to describe techniques where a human operator uses an instrument that samples the air around a component that is suspected of leaking. These are often used in what are called “walk-over” surveys. For instance, a flame ionisation detector (FID). The methane concentration in the air is then measured. Two possible techniques are used to derive an emission rate. The first is commonly used in Leak Detection and Repair (LDAR) surveys where the emission rate is estimated from the concentration measured, the type of component and an associated emission factor. Other instruments are available which use a “bagging” technique where a leak is enclosed, and an emission rate can be calculated from the flow from the bag. Large sites with many components will take time to measure in detail and some emissions sources will not be accessible. In some cases, a sample of the components on a site are measured and a total emission rate for a site is estimated from an extrapolation from the total number of components and type present. If all components are not measured for leaks, then there is always the possibility that significant leaks are not accounted for. Any survey must be representative of the potential emission sources and elevated sources are difficult to measure with this technique. The expanded uncertainty on any whole-site emission rates would be high if extrapolation is used. If all potential emission sources are accessible, and can be measured, then a medium uncertainty can be expected.

5.3.9 Satellites

Satellites that have recently been launched [30], are under construction or are at the concept stage, have instruments with improved spatial resolution and coverage. They have the potential to measure methane concentration columns to an accuracy and resolution that could potentially be used to identify and quantify methane sources at a local or facility scale. They measure the total methane column concentration by measuring the methane absorption of the reflected sunlight from the earth's surface.

Some satellites have a high resolution (~ 25 m x 25 m) but the sensitivity may not be high enough for the applications described here. Other proposed satellites are designed to detect emissions averaging 2.25 kg/hr/km^2. A detection threshold of 100 kg/h is stated with a possible resolution of 400 m x 400 m pixel size.

At present the use of satellites could be used for scoping applications where high levels of emissions are suspected (>250 kg/h from a small area) [31]. They are limited in their measurement frequency by their orbit and weather conditions. They cannot measure methane through clouds.

5.3.10 Air Quality Towers

Air quality towers are generally used to determine the atmospheric composition and concentrations at a point and by the use of reverse dispersion modelling and wind measurements can determine the likely source of the measured components. They could be used where there are many potential sources over a wide area such as those seen in the USA but would have limited use for methane measurements in the UK. A measurement technique called eddy covariance is often used [32].

5.4 Combining measurements into emission rates

The majority of measurement techniques are combined measurements and require measurements of wind speed and direction to be combined with a concentration measurement for the quantification of the mass emission rate. The accuracy of the wind measurement and modelling of the wind fields that the emissions are subject to will affect the total (expanded) uncertainty of the calculated emission rate. The exception is the tracer technique where the emission rate is corelated with a controlled tracer release rate. In some cases, imaging techniques do not rely on a windspeed measurement and use imaging processing techniques to track parts of a plume. In the case of DIAL there is a direct relationship between the concentration measurement in a 2D plane to the calculated emission rate. When concentration is measured at specific points or along a path then modelling of plumes and inverse modelling are required to arrive at an emission rate and probable location. There are a number of different techniques used to estimate an emission rate from point or open-path concentration measurement. The most common techniques are Gaussian plume and Bayesian inverse modelling [33] or Lagrangian stochastic-based dispersion models [34].

5.5 Technique Summary

A summary of the different measurement techniques is tabulated below with their associated advantages, disadvantages and a rough measurement expanded uncertainty (high >70%; medium up to 70%; low up to 30%).

Table 5-1. Continuous measurement techniques

Measurement Technique	Data and processing requirements	Advantages	Disadvantages	Uncertainty
Open-path / fence-line*	Wind speed & direction Plume and reverse modelling	Can cover large lengths of fence line. Good for large sites. Low operating costs.	Elevated sources difficult to measure. Expensive installation costs.	Medium
Imaging	Wind speed & direction or image processing & plume tracking	Low operating costs. Good identification of source locations.	Expensive installation costs especially for large sites	High
Point concentration / distributed sampling*	Wind speed & direction Plume and reverse modelling	Low operating costs.	Elevated sources difficult to measure. Lots of sensors for large sites	Medium
Air Quality towers	Eddy covariance	Can cover large areas	Can only measure when emission is upwind	High

**could be deployed on a short-term basis as a campaign measurement technique but may rely on a variety of wind directions over the period for accuracy.*

Table 5-2 Campaign measurement techniques

Measurement Technique	Data and processing requirements	Advantages	Disadvantages	Uncertainty
DIAL	Wind speed & direction. Direct conversion to emission rate	Comprehensive measurement of emissions. Elevated sources can be measured.	Relatively high cost and limited operators	Low

Tracer	Tracer release rate, vehicle position	Detailed measurement. Doesn't require wind measurements	Doesn't handle multiple or unknown sources well	Low to medium
SOF	Wind speed & direction	Passive technique for campaign measurements. Medium cost. Can provide speciation.	Not generally used for methane measurements. Relies on good weather (sunshine)	High
Concentration screening measurements		Quick for sites with limited and accessible components	Difficult for large sites. Emission rate is estimated. Not all emissions will be accessible	Medium to high
Mobile measurement	Wind speed & direction	Good at mapping concentrations and identifying leak locations	High cost for airborne platforms**	High
Satellite	Wind speed & direction, plume modelling	Can cover large areas	Limited by weather and, currently, sensitivity**	High

*** Development in these areas is increasing and it is recommended that the latest developments are investigated in particular the use of unmanned aerial vehicles*

6 Selection of the measurement technique

There are several steps in deciding on the most appropriate measurement technique. These are described below.

6.1 Defining the requirement and information gathering

The reason for the measurement should first be decided and this will determine:

- The required uncertainty and
- If continuous or campaign measurements are appropriate.

For example, are the emissions required to be measured associated with a particular activity, at a specific time or period or are they to be used to calculate an annual emission rate? Are lots of sites to be monitored or just a few representative examples? Should the representative examples cover the range of sizes and what proportion? Another example of the reason for measurement could be to support an emissions reduction programme.

The site characteristics will influence the most suitable measurement technique. This includes:

- The site type
- The functional elements and activities
- The emission characteristics

The site type will provide information on the typical size and areas that measurements are required to cover. The functional elements present on a site and activities, and how they vary, need to be determined. A survey of the site is highly recommended to gather this information. Sites covering large areas could require a significant number of sensors or open path lengths to capture all the emissions.

The emission characteristics, as defined in the Glossary, include the size of site, type and size of equipment on site (plant/component density) and will determine the campaign duration or detail (resolution) or number of sensors. The emission rates present will determine sensitivity (minimum detection threshold). Sensitivity may also determine the number of sensors required. Site activity may lead to emission variation which will determine whether campaign measurements are applicable and will also determine the duration needed for a “representative” measurement campaign.

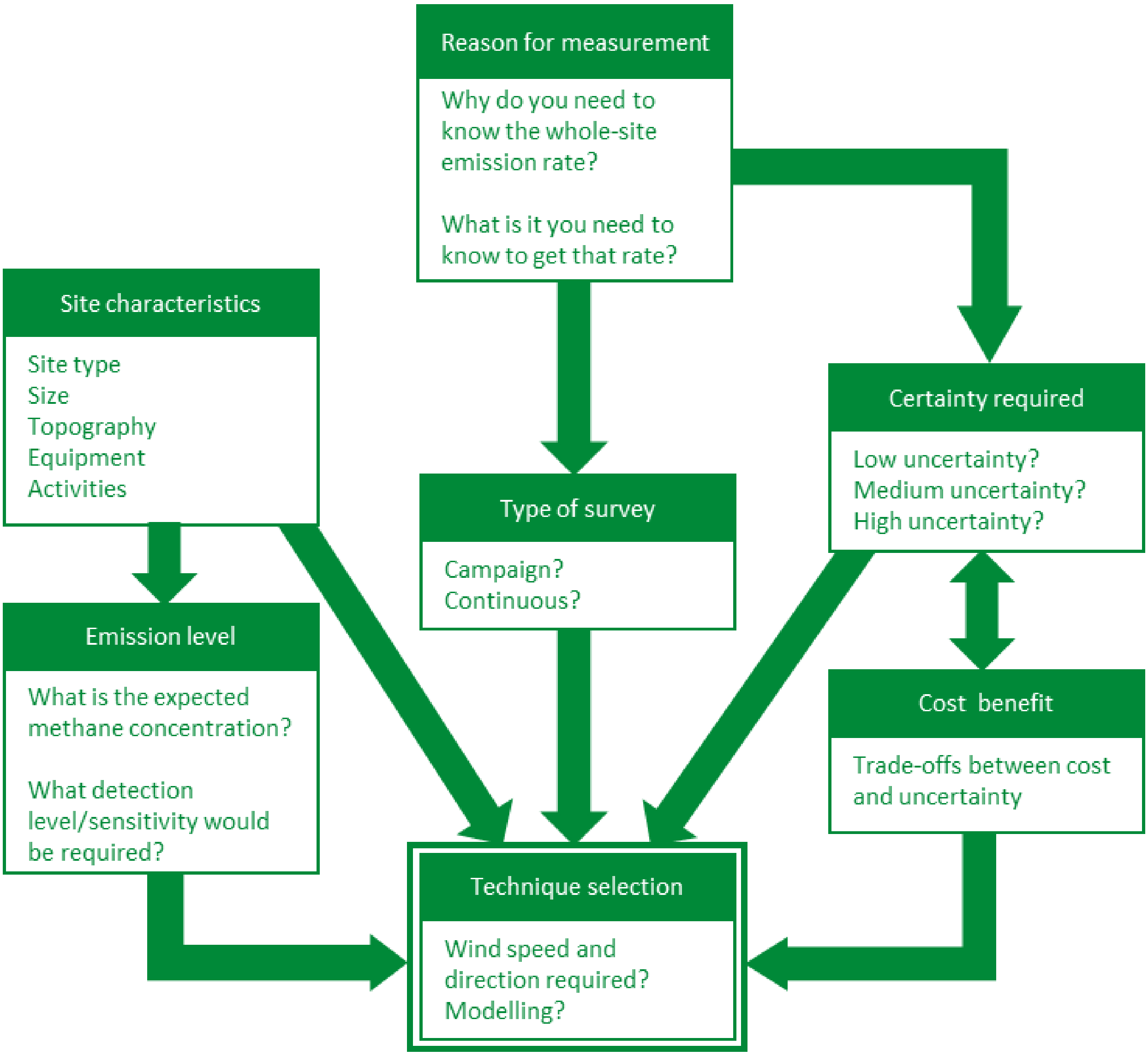
The format of the output data and the purpose of the monitoring will define how the emission rates are calculated and how often the measurements are made or calculated, for example, if an annual emission rate is to be derived.

6.2 Technique Selection

Once the above requirements have been defined and the relevant information on the site to be measured has been gathered then the most appropriate technique can be chosen. Figure 1 illustrates the considerations for technique selection. Reference to tables 5.1 and 5.2 can be used as a first aid to select specific technologies.

The maturity of the technique and the level of validation data available should be considered as part of the selection process.

Figure 1 Illustration of the questions for technique selection



Two examples of the selection of the most appropriate techniques for two types of sites and scenarios are given below.

6.2.1 Small oil/gas well

The site type is a small oil and gas well. The functional elements are a single nodding donkey pump, oil storage with road tanker collection and gas separation which is then flared. The well is in the production phase with a constant throughput and therefore with presumed low variability in emission rates.

The reason for the whole site methane quantification is to determine the mass emission rate from a site of this type under normal operational conditions and therefore an uncertainty level appropriate for research purposes is required i.e. a low level of uncertainty.

As the throughput and conditions are constant, campaign measurements would be most appropriate. The site is small and (non-leak) methane emissions will effectively be limited to slippage through the flare and emissions from the vent stack on the storage tank.

Assuming the flare is a modern enclosed unit there is limited scope for reducing slippage therefore the main emissions will be from the tank vent. Separation has already taken place prior to storage so tank emissions are likely to be low in volume and high in non-methane VOCs. Determining whether additional intervention is required will require an accurate quantification but accurate quantification may entail excessive cost.

As the required uncertainty level requires a low uncertainty the DIAL or Tracer techniques would be most suited but are expensive. If measurements are required for each individual functional element, then DIAL will have a higher spatial resolution to determine individual emission rates.

6.2.2 Gas processing plant

A large gas processing plant covering an area 500 m x 300 m processes gas from offshore wells with a capacity of 25 million m^3 per day. Condensate is removed using slug catchers and exported by road tanker. The gas is dried before being compressed for injection into the National Transmission System. Other LPG are fractionally separated and stored on site.

The site is being modernized and there is an emission reduction program in place where the emission rate improvements need to be monitored. A quality level equivalent to that required for routine monitoring is being applied with a medium or low level of uncertainty.

As modernisation is taking place, emissions are expected to be reducing and information on where these improvements are taking place are required. This will be a long-term program so a continuous monitoring system is expected to be the most appropriate. Distances from likely emission sources to the fence line are 50 m or greater. The site covers a large area, and this may mean that an open-path technique would be more suitable rather than a large number of point measurement sensors.

7 Conclusions and Recommendations

7.1 Conclusions

A scoping investigation into the process of selecting the appropriate measurement method and technology for the quantification of whole-site methane emissions has been undertaken. The types of site covered by the study have been outlined including descriptions of the emission characteristics expected. Information on the available methane emission quantification techniques has been summarised and a description of a structured approach, and the steps required for the selection of the most appropriate one, has been set out.

During the study, the importance of first understanding the reasons for the whole-site measurement has been highlighted. This will define the uncertainty level needed and whether continuous or campaign type measurements are required.

The process described here is aimed at OOG facilities however the approach should be relevant and transferable to other types of facility where whole-site emissions are required to be quantified.

7.2 Recommendations

The main recommendations arising from the study are as follows:

1. The structured approach outlined here should be used as the basis for the development of a selection tool to determine the optimum and most suitable technologies for the quantification of whole-site methane emissions from onshore oil and gas facilities. This could include:
    a. a detailed decision tree or flow chart
    b. a screening system to characterise the sites.
    c. a weighted scoring system
    d. a cost benefit assessment

2. Research should be undertaken to evaluate the combined uncertainty in a quantified emission for a particular site/period. This would include uncertainties in
    a. ambient pollution measurements
    b. meteorological data
    c. inverse dispersion modelling – as used to infer emissions from ambient data
    d. representativeness of the period monitored
    e. completeness of site metadata.

3. More detailed examples or test cases of the selection of measurement techniques and on the evaluation of the combined uncertainty should be developed.

4. The applicability of the process described here, and any future selection tool, to other sectors and facility types should be investigated.

5. The relevance of the approach to the quantification of emissions of other greenhouse gas or pollution species (for example ammonia and particulates) should be investigated.

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Glossary

General Terms

Continuous measurement – measurements of emission rate at a frequency that resolves emission variability and significant short-term emissions.

Diffuse emission - to the atmosphere from an identified site or facility, not specifically directed to identified stack emission points. This term comprises the sum of various unaccounted channelled emissions, fugitive emissions and area emissions.

Emission rate – The mass of methane emitted over time; normally kg/h or t/yr.

Emission - discharge of substances into the atmosphere. This term comprises four types of emission sources:

- Accounted channelled emissions (from monitored stacks)
- Unaccounted channelled emissions (from, e.g., vents, flares)
- Fugitive emissions (leaks from, e.g., valves, seals)
- Area emissions (from, e.g., water treatment basins, coke storage)

Emission source – The component, sub-system, vent or functional element where a methane emission is present.

Fugitive emissions - Fugitive emissions are specifically defined within EN 15446 as an ‘emission to the atmosphere caused by loss of tightness of an item which is designed to be tight’. These can therefore be considered leaks and are often the subject of LDAR programmes which aim to identify and fix the leaks.

Functional element - A defined area, spatially separable, of an oil/gas facility related to an identified function. For example, storage, processing, waste treatment. Functional elements may be further sub-categorised, for example Storage – LNG, Storage – condensate.

Measurement interval – The time resolution of the measurement of the emission rate.

Measurement sensitivity – For this application it is the lowest emission rate that can be measured with the stipulated uncertainty rather than the concentration sensitivity.

Measurement uncertainty – The expanded uncertainty expressed at the 95% confidence level of the emission rate measurement.

Open-Path – A line of site between two points in space through the atmosphere over which the methane concentration is measured.

OOG site – Onshore Oil and gas site or facility relating to the production of oil and or gas.

Optical Gas Imaging – Optical imaging technique to observe a gas, in this case methane.

Production rate / throughput – The amount of gas produced or processed over a fixed time at a site.

Quantification – The value of mass emission rate derived from measurements.

Time response – The time taken to calculate the emission rate.

Emission characteristics

Area emission - Area emissions are releases to the atmosphere from an extended area, for example the surface of a wastewater treatment pond.

Continuous emission – An emission that is always present and uninterrupted.

Constant emissions – Emissions that are always present but not necessarily at a constant rate.

Diffuse emission - Emissions arising from a number of, generally small, sources within an extended area. The resultant emission can be considered an extended plume. In general, this term is used to contrast small unintended leaks and process emissions from identified ducted emissions in large vent stacks or chimneys. The majority of methane emissions from an oil and gas site are diffuse. The draft standard prEN 17628 defines diffuse emission as '*an emission to the atmosphere from an identified site or facility, not specifically directed to identified stack emission points' with a note that 'this term comprises the sum of various unaccounted channelled emissions, fugitive emissions and area emissions.'*

Point emissions - Those arising from a specific localised release, generally a vent stack. In practical terms a point source is one giving rise to a narrow plume of emissions.

Surrounding emissions – methane emissions that are from surrounding areas not associated with the site being measured but that may be picked up by the sensors when they are upwind of the site and which need to be accounted for.

Unplanned emissions – Emissions that may arise from process errors or faults.

Vented emissions – Emissions which have a purpose-built vent or stack to which a piece of equipment or functional element is connected to. Vents are normally at a high elevation, usually intermittent and are sometimes monitored.

Elevated emissions – Emissions at heights above ground greater than, for example, 5 m.

Periodic emissions – Emissions that are not continuous, often associated with a particular process or regular event.

Known Emissions – Emissions which have previously been identified but not necessarily measured.

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