European Biogas Association

# Design, build, and monitor biogas and biomethane plants to slash methane emissions

*Pursuing an efficient and sustainable scale-up of the sector*

# Table of contents

# Abbreviations

| | |
|---|---|
| AD | Anaerobic Digestion |
| ATEE | Association Technique Energie Environment |
| BAT | Best Available Techniques |
| BU | Bottom-Up |
| $CH_4$ | Methane |
| CHP | Combined Heat and Power |
| CO2 | Carbon Dioxide |
| CO2EQ | Carbon Dioxide Equivalent |
| DBFZ | Centre Technique National Du Biogaz Et De La Méthanisation |
| DIAL | Deutsches Biomasseforschungszentrum gemeinnützige GmbH (German Biomass Research Center) |
| DIAL | Differential Absorption Lidar |
| EBA | European Biogas Association |
| EC | European Commission |
| EC-JRC | European Commission's Joint Research Centre |
| EEG | Erneuerbare-Energien-Gesetz (German Renewable Energy Sources Act) |
| EF | Emission Factor |
| EN-ISO | European Norm International Organisation for Standardisation |
| ERA-NET | European Research Area Networks |
| EU | European Union |
| EVEMBI | Evaluation And Reduction of Methane Emissions From Different European Biogas Plant Concepts |
| FID | Flame Ionisation Detector |
| GHG | Greenhouse Gas |
| GREET | Greenhouse Gases, Regulated Emissions, And Energy Use In Transportation |
| GRI | Global Reporting Initiative |
| GWH/YR | Gigawatts Hour per Year |
| GWP | Global Warming Potential |
| HFS | High Flow Sampling |
| IC | Interband Cascade |
| IDM | Inverse Dispersion Modelling Method |
| IEA | International Energy Agency |
| IPCC | Panel On Climate Change |
| IR | Infrared |
| LCA | Life Cycle Assessment |
| LDAR | Leak Detection And Repair |
| LDM | Laser Methane Detector |
| METHARMO | European Harmonisation Of Methods To measure Methane Emissions From Biogas Plants |
| MJ | Mega Joule |
| MS | Member States |
| $N_2O$ | Nitrous Oxide |
| NG | Natural Gas |
| $NH_3$ | Ammonia |
| $NO_x$ | Nitrogen Oxides |
| OGI | Optical Gas Imaging |
| PRV | Pressure Release Valves |
| RED | Renewable Energy Directive |
| RTO | Regenerative Thermal Oxidizers |
| SCC | Substantial Contribution Criteria |
| TA LUFT | Technische Anleitung Zur Reinhaltung Der Luft (Technical Instructions On Air Quality Control) |
| TD | Top Down |
| TDLAS | Open Path Tunable Diode Laser Absorption Spectrometer |
| TDLAS | Tunable Diode Laser Absorption Spectroscopy |
| TDM | Tracer Dispersion Method |
| TLS | Tunable Laser Spectrometer |
| VDI | Verein Deutscher Ingenieure (Association Of German Engineers) |
| WWT | Wastewater Treatment |

# Executive summary

The European Biogas Association (EBA), in collaboration with biogas experts, has conducted a review of methane emissions originating from anaerobic digestion (AD) plants to support and advise the industry, European policymakers, and AD operators. This paper provides a solid technical review of occurring emissions (*Chapter 1*), leakage detection and emissions measurement (quantification) (*Chapter 2*), mitigation strategies (*Chapter 3*) and results from measurement campaigns (*Chapter 4*). Taking into consideration the current policy context[1] and technical background, the EBA has formulated a set of actionable-policy recommendations (*Chapter 5*).

Fugitive methane emissions are responsible for approximately 12% of total greenhouse gas emissions (GHG)[2] in the EU and must be avoided to achieve Europe's climate objectives by 2030 and 2050. Biogases have a pivotal role in reducing EU methane emissions in the agricultural, energy and waste sectors, as recognised by the 2020 EU Methane Strategy.[3] Methane emissions are avoided when methane emitted from organic matter, such as manure and biowaste, are brought to the closed and controlled environment of an AD plant. For example, without AD, manure might be stored on farms and generate uncontrolled release of methane. In a biogas production facility, methane is captured and utilised instead of being released into the atmosphere. The biogas industry is therefore a large net reducer of methane emissions. Nevertheless, occurring emissions must be reduced to a minimum.

Besides climate change mitigation,[4] minimising methane emissions at AD facilities has several additional beneficial effects. Reducing methane emissions is cost-efficient in most cases, as small losses of the energy contained in methane gas can lead to considerable financial losses. Moreover, avoiding methane leakages is important as well both for safety aspects (avoidance of risk of explosion) and odour avoidance. Therefore, biogas plants are planned, built, and operated specifically to prevent methane losses. Fugitive methane emissions addressed in this paper include accidental leakages and diffuse emissions that involve an unintentional, negative phenomenon at a certain point along the biogas and biomethane supply chain. The most common and relevant sources are feedstock intake and pre-processing, the digestion process, gas utilisation, digestate storage and digestate post-treatment *(Chapter 1).* Accurate and comparable methods identifying leakages from biogas producing facilities are the first step towards methane emission mitigation (*Chapter 2*).

The state of the art of biogas plants and affected plant components (gas-tight covers, permeation of gas holder membranes, gas flares, etc.) has significantly advanced and AD plant developers and equipment manufacturers are continuously working on further improvements. Methane leakages at biogas plants can be further avoided using technical knowledge, best available technologies (BAT), leak detection and measurement campaigns and operational mitigation strategies (*Chapter 3*).

Although AD-related methane emissions cannot be completely avoided, according to voluntary and mandatory measurements these emissions remain minimal when appropriate measures are taken. Thanks to the implementation of methane emission mitigation measures in EU member states, methane leakages in modern AD plants (i.e. newest facilities) have been lastingly reduced. The comparison of the methane emissions rate of the current AD plants in operation (median value of 2.5% emissions according to a recent EC-JRC analysis), with measurement results from the monitoring and mitigation program in place in Denmark (estimative average total emissions at 1.31±0.16%), demonstrates the necessity and success of appropriate mitigation measures (*Chapter 4*).

[1] https://www.state.gov/wp-content/uploads/2021/09/Global-Methane-Pledge.pdf
[2] https://www.eea.europa.eu/articles/methane-gas-emissions-a-key
[3] COM, 2020. COM/2020/663 final Communication from the commission to the European Parliament, the council, the European economic and social Committee and the committee of the regions on an EU strategy to reduce methane emissions. https://energy.ec.europa.eu/system/files/2020-10/eu_methane_strategy_0.pdf
[4] The contribution of the biogas and biomethane industries to medium-term greenhouse gas reduction targets and climate neutrality by 2050 (2020); https://www.europeanbiogas.eu/the-contribution-of-the-biogas-and-biomethane-industries-to-medium-term-greenhouse-gas-reduction-targets-and-climate-neutrality-by-2050/

**Therefore, to ensure the sustainability of the scale-up of biomethane production facilities to reach 35 bcm by 2030, new plants will naturally need to be built, designed and monitored to have the lowest possible methane emission rates.**

The paper concludes that the biogas industry is well advanced in developing strategies to mitigate methane emissions. Strategies (e.g., Leak Detection and Repair) from related sectors have been tailored to the specificities of AD. Successful monitoring programmes have been established in EU Member States (MS), such as Denmark and Sweden (*Chapter 3*). 15 years of on-site experience show that:

- the most cost-effective manner to reduce methane emissions at AD plants is the combination of regular self-inspections of critical control points with leak detection campaigns and the repair of any leaks encountered;
- the periodic reporting of methane emissions can document the success of mitigation measures and monitoring programmes and establish the basis for emission factors for the national inventories;
- the organisation of training courses for plant operators is crucial for the success of methane emission mitigation programmes.

Methane emission mitigation can be further encouraged by:

- improving the understanding of methane emissions at the technical level. For this, the EU should support studies, research, and innovation regarding emission assessment on biogas plants;
- a sound update of the default values in the Renewable Energy Directive Annex VI. This can include a disaggregation of the default values to accommodate mitigation measures already undertaken by individual plants, such as membership in a methane monitoring scheme. Furthermore, an update of the default values should acknowledge the improvements in design and operations from the past decade and should thus be based on recent measurement campaigns only.

*Fugitive methane emissions are responsible for approximately 12% of total greenhouse gas emissions (GHG) in the EU and must be avoided to achieve Europe's climate objectives by 2030 and 2050.*

# Policy context

The EU Climate Law[5] was adopted in 2021, setting a net zero emission target for the middle of the century. In order to correct the emissions trajectory and be able to become climate-neutral, the European Commission proposed to revise the entire EU energy and climate policy including a GHG reduction target of 55% by 2030, compared to 1990 levels.[6] Last year, as an emergency measure in the context of the energy crises, the REPowerEU plan featured a biomethane production target of 35 billion cubic meters a year by 2030 and launched a multistakeholder partnership to abate present barriers and quickly scale up production.[7,8]
Following the adoption of the 2020 EU Methane Strategy as a part of the Green Deal, the Commission also adopted, on 15th December 2021, a proposal to regulate methane emission mitigation from the agriculture, waste management and energy sectors. Biogas is not specifically included in the scope of the proposal, but work is ongoing as part of the Renewable Energy Directive to better incentivise the reduction of methane emissions. Biomethane is included in the scope of the proposal once it is injected into the grid.

By providing a list of environmentally sustainable economic activities and compliance requirements, EU taxonomy[9] is playing a key role in helping the EU scale up sustainable investment and implement the European Green Deal. To date, biomethane production is not clearly included in the "Climate Delegated Act", and this would be a key factor in order to scale up investments. In this context, the technical screening criteria should be clarified. This white paper will provide guidance on monitoring and contingency plans to minimise methane leakage. This will further strengthen the biomethane sector's substantial contribution criteria (SCC)[10] towards sustainable production and further enable its substantial contribution to climate change mitigation and the growth of a circular, sustainable bioeconomy in the EU.

Finally, biogas and biomethane must demonstrate compliance with the requirements set by the Renewable Energy Directive, including substantial GHG emissions savings compared to fossil fuels. The Directive provides default values, which are being used by plant operators to calculate the GHG emissions savings. Those default values are included in Annex VI of the REDII. At the time of publication of this Paper, the European Commission is preparing a revision of the Annex VI to update the default values and provide additional drivers to minimise methane leakage from AD plants.

For reference, the Renewable Energy Directive defines three possibilities for biogas plant operators to prove their compliance with the sustainability criteria:

1. Default values can be used. A number of default values for various bioenergy carriers are included in Annex VI A of the Directive. A distinction is made between default values and disaggregated default values. Default values specify the GHG emissions and emission savings for a defined value chain.
2. Alternatively, emissions can be calculated individually, based on information from the market actors, with calculations thus based on actual values.
3. Thirdly, a combination of disaggregated default values for single processes (e.g. Transport or Processing) can be combined with the calculations based on actual information. The disaggregated standard values provide the GHG emissions of individual interfaces in the value chain. This

[5] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law) https://eur-lex.europa.eu/eli/reg/2021/1119/oj
[6] European Commission. (2020). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: Stepping up Europe's 2030 Climate Ambition https://knowledge4policy.ec.europa.eu/publication/communication-com2020562-stepping-europe%E2%80%99s-2030-climate-ambition-investing-climate_en
[7] Commission Staff Working Document implementing the REPowerEU Action Plan: investment needs, hydrogen accelerator and achieving the bio-methane targets, SWD (2022) 230 final, 18/05/2022.
[8] Biomethane Industrial Partnership https://www.europeanbiogas.eu/about-us/partnerships/biomethane-industrial-partnership/
[9] Taxonomy of sustainable activities. According to the EU Taxonomy Regulation (Reg (EU)2020/852), an environmentally sustainable activity is one that makes a "substantial contribution" to at least one of six environmental objectives, whilst ensuring that this activity will "do no significant harm" (DNSH) to any of the other five objectives and also meet minimum social safeguards. The six environmental objectives are: climate change mitigation; climate change adaptation; the sustainable use and protection of water & marine resources; the transition to a circular economy; pollution prevention and control, and the protection and restoration of biodiversity & ecosystems. https://commission.europa.eu/system/files/2020-03/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf
[10] Substantial contribution to climate change mitigation – a framework to define technical screening criteria for the EU taxonomy https://publications.jrc.ec.europa.eu/repository/handle/JRC123355

combination can thus show the GHG emissions savings of the entire value chain.

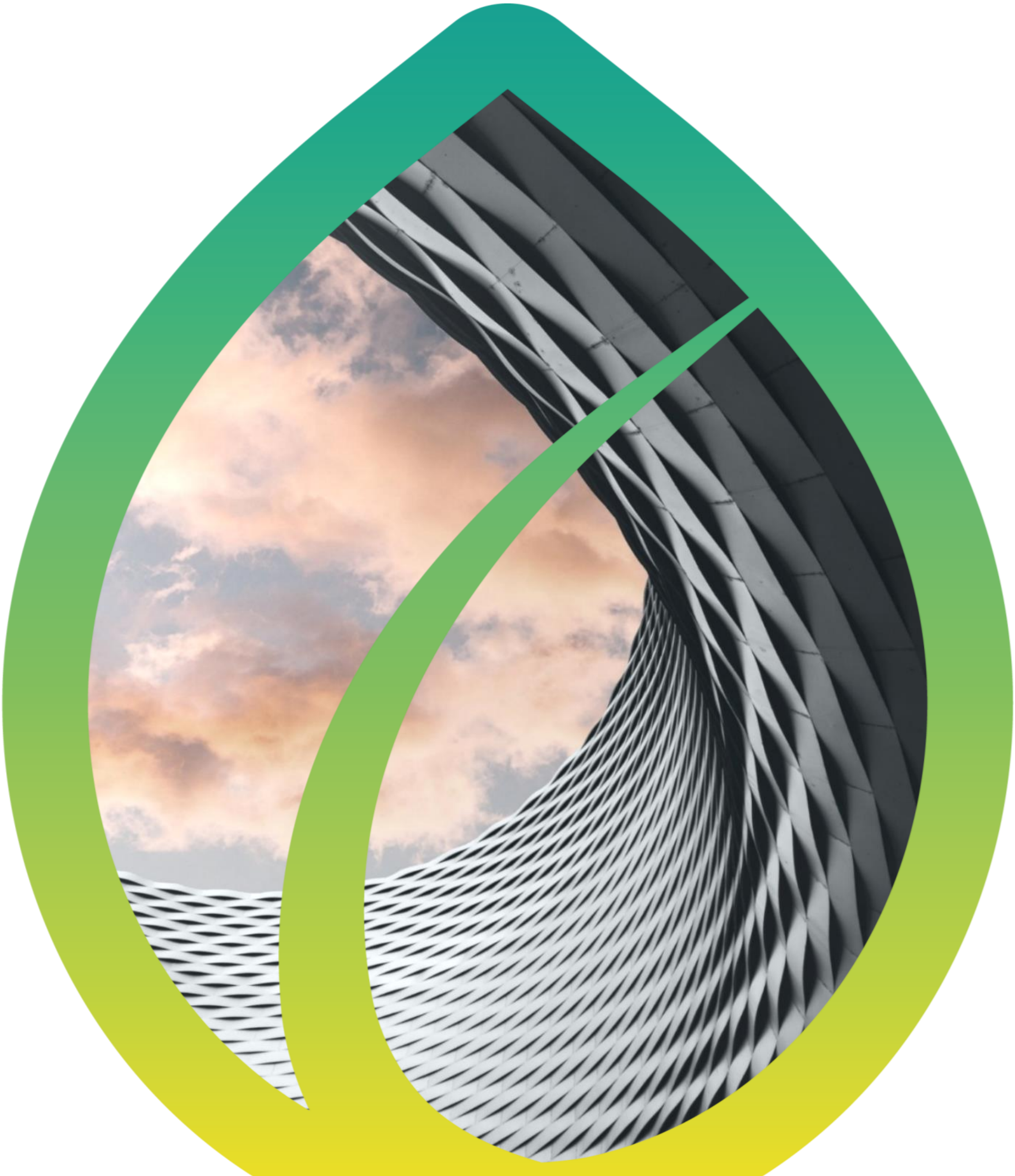
If, on the one hand, the use of the default value can be convenient and efficient since no calculation has to be carried out by market actors, on the other hand, drawbacks are often mentioned. The main limitation of the default values is that they cover only a restricted amount of feedstock options, whereas biogas and biomethane production across Europe is based on a wide range of feedstocks. Moreover, the conservative assumption behind the default values of GHG emissions savings limits their use, as individual calculations can yield greater savings. Default values are available for biogas used for electricity generation and for biomethane used as a fuel in the transport sector.[11] The input data for the existing biogas and biomethane default values are published by European Commission Joint Research Centre (2017).[12]
The description of the basic methodology in the RED II on how biogas producers should calculate the individual GHG savings are discussed in detail in *Chapter 2.*

*Biogases have a pivotal role in reducing EU methane emissions in the agricultural, energy and waste sectors, as recognised by the 2020 EU Methane Strategy.*

[11] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001&qid=1678463876007
[12] Solid and gaseous bioenergy pathways: input values and GHG emissions – Calculated according to the methodology set in COM(2016) 767 https://publications.jrc.ec.europa.eu/repository/handle/JRC104759

# Chapter 1

## Fugitive methane emission source



## 1.1. What are fugitive methane emissions?

Fugitive methane emissions include accidental leakages and diffuse discharges that unintentionally involve a negative phenomenon along the biogas and biomethane supply chain, but unrelated to the end use of the gas. The International Environment Agency (IEA)[13] provided a classification of fugitive emissions that differentiates between structural causes (due to the technologies deployed) and operational causes (due to management issues).

A second distinction can be made based on the **duration or frequency of the methane emissions**. When they are **intermittent,** the release of methane gas happens in short bursts or sporadically over time. These emissions may be associated with specific events or activities, such as the flow of biogas through a pipeline, the agitation of manure, or changes in the flow of gas and pressure levels during biogas production. On the other hand, **continuous** methane emissions refer to the release of methane over a longer period of time, which may stem from sources such as biogas storage tanks or other equipment that operates continuously.

A range of methane emissions sources may be present in biogas production facilities. There are point sources, areal sources, and sources that occur only under certain operational conditions. Methane emissions can arise from handling compartments, gas engine exhausts, gas flaring, leaks from pipes and connections, biogas upgrading units (vent and compressors), storage tanks, pressure release valves (PRV) or venting. Localising methane emissions can be challenging, as they can occur at any point along the whole biogas production process.

The most common and relevant sources are:
1. Feedstock intake and pre-processing
2. The digestion process
3. Gas utilisation
4. Digestate storage
5. Digestate post-treatment

In the following subsections, the benefits of reducing methane emissions are described together with the possible methane emission sources at AD facilities.

## 1.2. Benefits of reducing methane emissions

Besides **climate change mitigation,** minimising methane emissions has several additional beneficial effects.

- **Cost-efficiency:** plant operators aim to use the largest possible amount of the methane produced, as this energy-containing gas is, in most cases, the main source of income. Small losses of methane can lead to considerable financial losses.
- **Safety aspects:** avoiding methane leakages is important for safety reasons, because if the concentration of biogas in the air is between 6 and 22 vol%, this entails a risk of explosion in the presence of an ignition source.
- **Odour avoidance:** methane is an odourless gas; nevertheless, reducing the fugitive methane emissions of a biogas plant site can also reduce the emission of odorants, such as sulphur compounds. This can, in turn, increase the public acceptability of biogas facilities.

[13] Liebetrau J, Reinelt T, Agostini A, Linke B, Murphy JD, IEA Bioenergy Task 37. Methane emissions from biogas plants: methods for measurement, results and effect on greenhouse gas balance of electricity produced. https://www.ieabioenergy.com/

## 1.3. Feedstock intake and pre-processing

There are several factors (type of feedstock, storage time, pre-processing, temperature, pH, etc.) that can cause emissions from receiving tanks, open storage tanks and buffer tanks. Certain feedstocks do not inherently emit during their storage (silage, agricultural residues), however, others do (manure, foodwaste, waste water). In this case, various emissions ($CO_2$, $CH_4$, NOx, $NH_3$, $N_2O$) can occur when the feedstocks are not properly stored. For example, manure can cause $NH_3$ emissions when stored in the open. Additionaly, pre-processing in non gas-tight mixing or hydrolysis tanks (where substrates are mixed before feeding to the digester) can cause emissions regardless of the feedstock used. Furthermore, runoff ponds and screw conveyors should be points of attention.

## 1.4. The digestion process

Anaerobic digestion takes place in sealed, gas-tight vessels. Nevertheless, minor emissions can occur. The main sources identified are unintentional leaks, diffusion of biogas through the gas-holder membranes and emissions via the pressure release valves (PRV). PRV are safety devices that protect the biogas network from excess overpressure and/or underpressure. They are usually mounted near gasholders. As PRV are safety devices, leaks and emissions via PRV valves should not occur under normal operational conditions[14].

Critical spots where leaks can often be identified are:

- Roof constructions such as gas holder membranes, specifically the transition between the digester wall and the membrane dome
- Rope feed-throughs for the submerged digester mixers
- Cracks in concrete/steel digesters and tears in roof foils
- Gaskets and flange joints, especially in case of poor seal maintenance

An excessive filling of the digester can result in overpressure in the vessel. As a first safety reponse, the gas flare will automatically be started to avoid further pressure buildup. However, in case of inproper operation of the flare or overpressure, the PRV will open as a second-option safety measure, which will cause methane emissions. Smaller amounts of methane emisisions can also be generated from the incomplete combustion of flares.

## 1.5. Gas utilisation

Biogas can either, A., be utilised in a Combined Heat and Power (CHP) unit to generate electricity and heat, or B., be upgraded to biomethane, for injection into the gas grid or for liquefaction and compression.

A. The exhaust gas of a CHP unit can contain small amounts of methane. This is due to incomplete combustion of the biogas. In some cases, the exhaust gas is sent to a thermal post-combustion unit before its release into the atmosphere, in order to further minimise emissions. The methane slip from the uncombusted biogas depends on the design of the combustion chamber, settings such as the ignition time and the oxygen fuel ratio, and on regular maintainance.
B. Different technologies exist to upgrade biogas into biomethane. The separation efficiency of each technology affects the percentage of methane in the off-gas. This is the methane slip left in the seperated carbon dioxide stream (the exhaust gas). Methane emissions from upgrading units (such as membranes) can sometimes be linked to the reduced performance that materials and components exhibit when their replacement is due. For other types of upgrading units, such as water scrubbers, the methane slip is inherent to the technology and post-treatment of the exhaust gas is therefore necessary. A post-treatment of the exhaust gas reduces methane emissions from upgrading units. Amine scrubbers have a very low methane slip. An overview of methane emissions from the different types of upgrading units will be further discussed in *Chapter 4*.

[14] Leak emissions via PRV valves belong to the OTNOCs category (Other Than Normal Operation Conditions)

## 1.6. Digestate storage

When the breakdown of digestible organic matter is not fully completed in the biogas digester, methane generation may still continue downstream of the digester. In a gas-tight, covered digestate storage tank connected to the gas system, the residual biogas can be collected and utilised. The use of non-gas-tight digestate storage tanks can cause undesired emissions. Several parameters affect the magnitude of methane emission during digestate storage, such as the volume of digestate, ambient air temperature, and the temperature and hydraulic retention time of the digestate during the digestion step. Cooling and proper retention times can minimise the emissions. Moreover, agitation and other disturbances including increased wind speeds and precipitation can cause methane emission to increase. As discussed later in *Chapter 3*, technologies for methane emission mitigation, such as digestate degasing and cooling, play a key role in limiting emissions.

## 1.7. Digestate post-treatment

Digestate post-treatment is a common practice in AD plants to ensure hygiene and the quality of the end product, to facilitate composting after the AD and to reduce the digestate volume. Digestate post-treatment technologies consist primarily of solid–liquid separation (e.g. centrifugation, screw press, etc.). Further purification of the liquid fraction is sometimes performed via biofilters and membrane technologies. During the digestate separation, methane emissions can occur because of the remaining methanogenic activity.

*Besides climate change mitigation, minimising methane emissions has several additional beneficial effects: cost-efficiency, safety aspects and odour avoidance.*

# Chapter 2

## Methane emission detection and measurement techniques

Accurate and comparable methods identifying and (then) measuring methane emission from biogas-producing facilities are the first step towards methane emission mitigation strategies and improving the accuracy of the methane emission inventories database. Methane emission mitigation strategies are built on a combination of detection and measurement techniques. While detection refers to the actions to identify the presence of leaks, measurement techniques try to provide a measure of the observed methane loss. Both parameters employ levels and thresholds (depending on the technique adopted), representing the limit of the lowest possible concentration at which detection is possible, or the lowest concentration level at which a measurement is quantitatively meaningful.

Several scientific studies have adopted various approaches to try measuring methane emissions, with the two main approaches being: **bottom-up (on-site/component scale)** and **top-down (off-site/facility scale)**. The following sections outline methods to detect and measure methane emissions from AD plants and describe their technological challenges and strengths.

This chapter also covers the standardised measurement procedures to determine the gas emission rates in other industries, with the objective of knowledge transfer between stakeholders of the gas value chain, on a technical level.

## 2.1. Methane emission detection

Leak detection devices rely on different types of measurement techniques (Figure 2). Typically, the equipment employed to detect the methane emission sources include advanced leak detection instruments such as the **OGI (Optical Gas Imaging) camera**, particularly the infrared (IR) camera (e.g., FLIR GFX-320 or Esders GasCam SG)[15,16] and the **portable gas analyser**, also known as a gas leak detector or "sniffer". Moreover, technologies that use lasers to detect methane include **methane sensor lasers** (e.g. Tunable Laser Spectrometer -TLS or IC laser), which are typically used in laboratory settings, and the **laser methane detector** (LMD), which is typically handheld and widely employed in industrial and field settings to quickly identify methane leaks and potential safety hazards.

An OGI camera visualises biogas emitted from a source as a gas cloud image and makes it possible to detect leaks in large plants relatively quickly. OGI cameras are used to inspect biogas-bearing plant components such as digesters, storage tanks, gas pipes, biomass pipes and valves. They also help detect leaks in hard-to-access areas. Plant operators can choose between various commercially available cameras, with different resolution levels and detection limits. The use of OGI cameras is a valuable method, which can be used during the annual leak inspection.

Currently, IR camera cannot measure leaks very precisely. Certain companies offer software to generate estimations, which can give an order of magnitude of the emission rate of a source.

The portable gas analyser, or "sniffer", based on either a Flame Ionization Detector (FID) or Fourier Transform Infrared Spectroscopy (FTIR), typically used for gas analysis and not specifically produced for quantifying emissions from biogas plants, is very useful for emission detection. Moreover, this tool is portable, thus it can be easily carried and used to detect gas leaks in hard-to-reach areas.

## 2.2. Methane emission measurement techniques

Methane leakage detection is the basis for repairs and avoidance of methane emissions. It can be followed by measurements (a quantification) of the methane emissions, either at each individual emission source or from a whole plant. To determine the emission rate, both flow volume and concentration must be defined. The different methods used for measurements are outlined in Table 2.1.

[15] https://www.flir.com/products/gfx320/
[16] Esders GmbH. (2017). Mobile gas leak detection with GasCam SG.; https://www.esders.com/2021/12/measuring-biogas-leak-detection/

Briefly, for **channelled sources**, gas extraction-based methods are used. These sources include, for example, off-gas (methane slip) from CHP and upgrading units, exhaust air of substrate receiving halls and emissions from air-inflated double membrane domes. The flow volume and methane concentration are measured according to various different standards (e.g. EN ISO 25139, EN 15259:2007).

To measure **emissions from area sources**, such as open digestate storage tanks, either the floating static/closed chamber method or the air-injection/air-inflation method (in the case of a non-gastight cover or tank) can be used depending on the accessibility of the source. The dynamic (open) chamber, or air flow method involves an open chamber with an input and output pipe allowing for a constant airflow through the chamber. This method has been used extensively on digesters, biomass storage tanks, liquid manure storage facilities and gas storage units.

Furthermore, the air flow-based method (dynamic or flow-through chambers method) is implemented as high flow sampling (HFS).[17] To ensure consistency of the data collected over different timeframes, a calibration procedure is necessary to reduce variability in the analyser's detection limit.

The total emissions from biogas plants can be assessed with remote sensing methods such as the tracer gas dispersion method. Hence it is possible to use either a bottom-up or a top-down approach to quantify the methane emissions.

**Table 2.1** Measurement methods to quantify emissions by source type

| Sources | Recommended method | Specifications and standards |
|---|---|---|
| Channelled Sources | • Air extraction-based methods<br>• Air flow-based method (dynamic or flow-through chambers method) implemented as high flow sampling (HFS) | • The flow is measured directly with pitot tubes or anemometers within the pipe<br>• The flow volume and methane concentration are measured according to different standards<br>• EN ISO 25139<br>• EN 15259:2007<br>• EN ISO 16911-1:2013<br>• EN ISO 25140:2010<br>• EN ISO 25139:2011 |
| Area Sources<br>• Receiver-, mixing- or hydrolysis tanks<br>• Non-gastight covered digestate storage tanks<br>• Aerobic post-composting of digestate<br>• Biofilter | • Floating static/closed chamber method<br>• Air-injection/air-inflation method<br>• Dynamic (open) chamber<br>• Air flow-based method | • VDI 4285 Sheet<br>• VDI 3880 |

[17] Recommendations for reliable methane emission rate measurement at biogas plants https://www.dbfz.de/en/press-media-library/publication-series/dbfz-reports; European Biogas Association, EBA supporting the MetHarmo project – European harmonisation of methods to measure methane emissions from biogas plants. https://www.europeanbiogas.eu/eba-supporting-the-metharmo-project-european-harmonisation- of-methods-to-quantify-methane-emissions-from-biogas-plants/

### 2.2.1. Bottom-up (on-site) versus top-down (off-site) approaches

The **bottom-up approach** takes place on site and investigates the methane emissions at every single emission source on the facility site. The overall emissions of the facility are then determined by calculating the sum of the emissions from each individual source. The **top-down approach,** on the other hand, takes place off-site using remote sensing. The method relies on the measurement of the methane concentration in the air at a certain distance from the site and compares this concentration with a baseline. The plant is considered as one single emission source.

The two approaches are complementary and the choice between them depends on the purpose of the measurements, the location and size of the plant. The main advantage of the bottom-up approach is that it provides additional information to the plant operator on the location and size of the emission sources. It is therefore an easy approach that personnel at the biogas plant can employ in view of remediation. However, specific emission sources can be overlooked or originate from locations where on-site measurement is not possible. This does not apply to the top-down approach. The bottom-up approach can become cumbersome for larger sized plants, whereas the top-down approach requires similar resources regardless of plant size. However, it gives rise to a degree of uncertainty in the measurements, as they might be influenced by weather conditions, for example, or other unknown methane emission sources nearby.

Overall, the most information can be obtained when comparing results from both approaches for a specific facility. This concept is called emission reconciliation, where multiple different estimates are combined into a single stronger estimate, to overcome the difference in results from the bottom-up and top-down measurements.
Both approaches, with their advantages and limitations, are further detailed in the report "European harmonization of methods to measure methane emissions from biogas plants".[17] The report summarises the results from the MetHarmo project funded by the ERA-NET Bioenergy Program 2016-2019.

### 2.2.2. Methane emission detection and measurement techniques at individual point sources (bottom-up)

A first step for measuring methane emissions using the bottom-up approach is to create an emission sources inventory covering all plant components to be evaluated. This is done, for example, through a leakage survey completed by the plant operator and by performing an initial leakage detection campaign. The main strengths and limitations of the on-site approach are listed in Table 2.2.

**Table 2.2** Strengths and limitations of the bottom-up approach (source DBFZ)

| Method Approach | Strengths | Limitation |
|---|---|---|
| On-site | • Identification of single emission sources<br>• Low detection limit<br>• The most common individual on-site methods are easy to implement except for long term measurement at PRVs or non-accessible sources<br>• Execution of the emission measurement does not depend on wind conditions<br>• Effort can be adjusted to the purpose<br>• Specific components can be monitored by the plant operator<br>• Leakage detection included | • Effort is proportional to size<br>• Emission sources have to be identified and need to be accessible for measurement<br>• A variety of methods for different source types is necessary<br>• Leakage detection by OGI is dependent on weather conditions (in particular temperature and wind) and it can potentially fail to detect a leak in unfavourable conditions.<br>• Precipitation and low atmospheric temperatures hinder the encapsulation and consequently the measurement of biogas leakages<br>• Intrusive method, which may in some cases influence the emission condition |

### 2.2.3 Methane emission measurement by remote sensing methods (top-down)

The top-down approach takes place off-site using remote sensing. In the top-down approach, the AD facility is considered as one emission source. The atmospheric methane concentration is measured at an appropriate distance from the plant. Upwind and downwind atmospheric concentrations are compared to determine the methane emissions of the plant site as a whole. Top-down measurement campaigns have the main advantage of being able to measure the overall emissions of a biogas site. Nevertheless, they do not precisely identify the leak location, and they can be expensive depending on the technology used.[18]

The most commonly employed top-down methods are briefly described below. The main advantages and limitations can be found in documentation from the Metharmo project[17], which summarises the performance and applicability of the most common off-site procedures and remote sensing techniques to perform methane emission measurements.

- The **Inverse Dispersion Modelling** (IDM) has been used worldwide for over 20 years in different configurations and is able to indirectly determine methane emission rates by using an atmospheric dispersion model (i.e. backward Lagrangian stochastic (bLS) model)[19] and instruments such as the open-path tunable diode laser absorption spectrometer (OP- TDLAS)[20]. IDM based on TDLAS measurements is the best choice for long-term measurements over several hours with steady wind conditions.
- The **Tracer Dispersion Method** (TDM) is based on the release of a tracer gas, e.g., acetylene, near the biogas facility, and utilises a mobile vehicle for analytical measurements of the methane taken downwind of the plant.
- The **Differential Absorption Lidar** (DIAL) is a sophisticated, optical-laser-based remote sensing technique that operates at different wavelengths. The laser produces packets/beams of laser light alternating between two different wavelengths, which are absorbed differently by methane molecules. The difference in the absorption of the two wavelengths makes it possible to calculate the methane concentration and the emission rates when the data are combined with meteorological data. The DIAL technique has been used for over 30 years and is the basis of a method that has recently been standardised in Europe with the standard EN 17628 (2022).[21]

Results from recent experimental scientific studies have demonstrated that the promising technology of Unmanned Aerial Vehicles (UAVs), also known as drones, equipped with methane sensors, combined with the use of remote sensing modelling techniques can detect leakages and identify emission sources.[22]

[18] Methodology to Assess Methane Leakage from AD Plants-Part 1 and Part 2: Report on proposed categorisation of AD plants and literature review of methane monitoring technologies-Final Report 1230/10/2016(1) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/786756/Methodology_to_Assess_Methane_Leakage_from_AD_Plants_final_report_part1.pdf; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/786757/Methodology_to_Assess_Methane_Leakage_from_AD_Plants_final_report_part2.pdf

[19] Hrad M, et al., (2022) Comparison of forward and backward Lagrangian transport modelling to determine methane emissions from anaerobic digestion facilities. Atmospheric Environment: 12, 100131 https://doi.org/10.1016/j.aeaoa.2021.100131

[20] Hrad, M., Piringer, M., & Huber-Humer, M. (2015). Determining methane emissions from biogas plants – Operational and meteorological aspects. Bioresource Technology, 191, 234-243. doi:10.1016/j.biortech.2015.05.016

[21] CEN EN 17628. Available online: https://www.cencenelec.eu/

[22] Jońca J, Pawnuk M, Bezyk Y, Arsen A, Sówka I, Drone-Assisted Monitoring of Atmospheric Pollution—A Comprehensive Review Sustainability 2022, 14(18), 11516; https://doi.org/10.3390/su141811516

## 2.3. Procedures and approaches for methane emission calculations

Regulatory authorities, operators and stakeholders in several Member States (MSs) have developed a wide range of approaches to assess the emission releases from biogas plants. According to the Intergovernmental Panel on Climate Change (IPCC) guidelines, the use of high-quality and comparable emission factors (EF)[23] is essential for a proper assessment. While a single methodology for the calculation of the EF has not yet been defined, there are different services that provide this assessment to the industrial sector with their own methods. Some of these approaches are briefly summarised in this part.

### 2.3.1. Standard methodologies

A wide range of methodologies are available to assess the climate effects of bioenergy, and there are different standards and tools used across the world that give guidelines to measure and report emissions. One of the most used and well-known is the **Greenhouse Gas Protocol** (GHG Protocol), A Corporate Accounting and Reporting Standard[24] released by the Greenhouse Gas Protocol Initiative and started in 1998. Newer editions have been published and continue to be a valid reference.

Following the publication of the GHG Protocol, the **International Organization for Standardization** (ISO) also proceeded to develop a standard. Even though it is not specifically designed for fugitive emissions quantification and calculation, this well-known approach for emission measuring and reporting includes scientific standards such as ISO 14040, ISO 14044, ISO 14067:2018 and the UNI EN ISO 14064-1. The standard describes the basic steps to estimate methane emissions: (I) adequate scoping and setting boundaries, (II) determining the type of potential emission sources (III) quantification and calculation methods.

The GRI 305: EMISSIONS (2016) is a standard published by **Global Reporting Initiative** (GRI), an independent international organisation founded in 1997 with the aim of helping industries in the assessment of their economic, environmental and societal impacts. Compared to the GHG Protocol and to the standard ISO 14064-1, this standard is more focused on the intensity of emissions, calculated by dividing the absolute values by a specific parameter relative to the production or to the revenue. Finally, assumptions can be made based on models and calculators such as **BioGrace I & II**.[25]

### 2.3.2. The REDII calculation method

The biogas sector must comply with the sustainability criteria set out in the REDII Directive 2018/2001/EU to have access to public support, be zero-rated under the EU Emission trading system and to be accounted towards the Renewable energy targets. Sustainability requirements include the reduction of GHG emissions in comparison to a fossil fuel. Emissions are measured along the value-chain: a life-cycle approach (LCA) determines whether biogas production pathways meet the GHG reduction thresholds. The GHG emission requirements differ according to the starting date of operations, and the final use of the biogas/biomethane. Table 2.3 shows the minimum GHG savings thresholds required.

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[23] Methane EF (%) is defined as the fraction percentage of the methane produced by a biogas plant that is lost to the environment, expressed as CH4 emitted (kg/h) in relation to the total CH4 production (kg/h) on the day of measurement and calculated as:

$$EF\ (\%) = \frac{CH4\ emitted\ from\ the\ plant}{CH4\ produced\ at\ the\ plant + CH4\ emitted\ from\ the\ plant}$$

[24] The Greenhouse Gas Protocol, A Corporate Accounting and Reporting standard, revised edition, WRI https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

[25] BioGrace II Calculation Rules. Harmonised Greenhouse Gas Calculations for Electricity, Heating and Cooling from Biomass. Version 4a. Available online: http://www.biograce.net

| Table 2.3 Greenhouse gas savings thresholds in the RED II[26] | | | |
|---|---|---|---|
| Plant operation start date | Transport biofuels | Transport renewable fuels of non-biological origin | Electricity, heating and cooling |
| Before October 2015 | 50% | - | - |
| After October 2015 | 60% | - | - |
| After January 2021 | 65% | 70% | 70% |
| After January 2026 | 65% | 70% | 80% |

For example, if the biomethane is intended for the transport sector, the facility must achieve a GHG emission savings rate of 50-65% compared to the fossil fuel comparator of 94 g CO2eq/MJ biofuel. On the other hand, if the biomethane is intended to produce electricity, heating, and/or cooling, the facility must achieve a GHG reduction of at least 70-80% compared to the comparator of 80 g CO2eq/MJ (useful heat) or 183g CO2/MJ (electricity).

The REDII[26] framework establishes calculation methodology with the aim of producing robust and comparable results for GHG accounting. This methodology also includes a set of **default values**. The default values currently used are based on a set of modelling assumptions developed by the Joint Research Centre (JRC) of the European Commission and published in a report "Solid and gaseous bioenergy pathways: input values and GHG emissions" by Giuntoli et al., (2017).[27] The report considers a limited number of substrates (i.e. manure, silage maize and biowaste).

**Table 2.4** Rules for calculating the GHG impact of biomass fuels and their fossil fuel comparators (source Annex VI, Directive (Eu) 2018/ 2001 of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources -REDII)

| BIOMETHANE FOR TRANSPORT (*) | | | |
|---|---|---|---|
| Biomethane production system | Technological options | Greenhouse gas emissions savings – typical value | Greenhouse gas emissions savings – default value |
| Wet manure | Open digestate, no off-gas combustion | 117% | 72% |
| | Open digestate, off-gas combustion | 133% | 94% |
| | Close digestate, no off-gas combustion | 190% | 179% |
| | Close digestate, off-gas combustion | 206% | 202% |
| Maize whole plant | Open digestate, no off-gas combustion | 35% | 17% |
| | Open digestate, off-gas combustion | 51% | 39% |
| | Close digestate, no off-gas combustion | 52% | 41% |
| | Close digestate, off-gas combustion | 68% | 63% |
| Biowaste | Open digestate, no off-gas combustion | 43% | 20% |
| | Open digestate, off-gas combustion | 59% | 42% |
| | Close digestate, no off-gas combustion | 70% | 58% |
| | Close digestate, off-gas combustion | 86% | 80% |

(*) The greenhouse gas emissions savings for biomethane only refer to compressed biomethane relative to the fossil fuel comparator for transport of 94 g CO2eq/MJ.

[26] https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en#:~:text=SUSTAINABILITY%20CRITERIA,financial%20support%20by%20public%20authorities.
[27] Giuntoli, J, Agostini, A, Edwards, R, Marelli, L, 2017 Solid and gaseous bioenergy pathways: input values and GHG emissions-Calculated according to methodology set in COM(2016) 767: Version 2, 2017. European Commission JRC https://publications.jrc.ec.europa.eu/repository/bitstream/JRC104759/ld1a27215enn.pdf

# Chapter 3

## Existing methane emission mitigation strategies

Once the methane emission sources at biogas production sites have been detected, measures and remediation should follow. This chapter describes the variety of technological solutions and frameworks for reducing methane emissions at AD plants. In addition, it provides an overview of ongoing actions and efforts from the biogas and biomethane industries and summarises legislative mitigation measures in addition to the RED II guidelines.

Strategies to reduce methane emissions can be divided into:

- **technical measures**, which are those related to design or interventions on the biogas plant itself. These measures include, for example, technical choices in the design phase and encompass overall and preventative maintenance to avoid loss of performance. Technical measures are mostly in connection with costs.
- **operational measures**, which are mainly actions during plant operation. These strategies promote and foster best practices in the management and operation of biogas plants. Such systems are explained further in detail within the following sections, where the experiences of the EvEmBi[48] project consortium are presented.
- **secondary mitigation measures**, which are initiatives that support the effectiveness of the primary measures (technical and operational). They may include knowledge transfer activities (such as workshops, publications) and the implementation of voluntary schemes for self-inspections.

In addition, **there are various legislative actions** included in a variety of European and Member State legislations that regulate technical and operational mitigation measures. In this context, the biogas industry has been working on various mitigation measures for quite some time already. The EBA, in collaboration with the European Commission's Joint Research Centre (EC-JRC) launched a survey from September 2022 to October 2022, gathering information on current actions and regulations at the EU MS level to monitor and mitigate fugitive methane emissions. The main results are presented in *Sections 3.3 and 3.4.*

## 3.1. Technical mitigation strategies

The state of the art of AD plants and components (gas-tight covers, valves, permeation of gas holder membranes, gas flare etc.) has developed significantly and manufacturers are continuously working on further technical improvements. The most important technical mitigation strategies for each stage of the biogas production process are described in the following sections.

### 3.1.1. Feedstock intake and pre-processing

Methane emission during feedstock intake and pre-processing can be avoided by installing gas-tight covers on receiving tanks and on mixing/incorporation tanks, and by implementing appropriate temperature and pH control. Special attention should be given to liquid feedstocks, such as manure, as they are known to have higher emissions. For liquid manure, it is recommended to take it directly into a gas-tight part of the biogas plant upon arrival.

### 3.1.2. The digestion process

Methane emission mitigation during the digestion process starts during the design phase. The plant components should naturally be designed to be technically leak-proof in the long term, especially for components which are subject to mechanical, chemical, or thermal stresses. Special attention should be paid to the transition between the digester wall and membrane dome, as well as to flange joints on pipes with some movement.
During the digestion process, the release of biogas via pressure release valves (PRVs) needs to be prevented as much as possible and only used as a last-resort safety option. In any case, the gas flare must be automatically activated before the release valves respond. Release via the PRVs can be avoided by adjusting the filling level, and consequently the pressure, of the digester tank. It is important that the filling level of the gasholder is appropriate (50% or lower), to allow for compensation for weather conditions, and that the gas system is dimensioned to ensure that the produced biogas can go to the storage tank, engine or upgrading unit. Indeed, the volume of the biogas already contained

therein dramatically increases when solar radiation heats the digester and the gasholder.[28]

Finally, to achieve the lowest possible emissions during flaring, an enclosed flare or a gas burner is recommended, beside the use of an adjustable flare to prevent an unnecessary amount of gas from being flared.

### 3.1.3. Gas utilisation

Upgrading technologies for separating the methane from the carbon dioxide can leave a certain level of methane in the off-gas. Such inherent methane slip can be reduced by making use of the best available technique (BAT) combined with frequent monitoring. For new plants, preference should be given to upgrading technologies with inherently low methane emissions. Equipment for the post-treatment of the off-gas can further reduce methane slip. Examples of innovative technologies to reduce slip are Regenerative Thermal Oxidizers (RTOs) or SlipRec units (Airco Process Control). Additionally, it is worth mentioning that, if the $CO_2$-rich stream after upgrading is liquefied, the methane contained in it is recycled and methane slip is reduced to almost 0. Finally, piping connections, expecially close to moving equipments, are succeptible to leaks and should be closely monitored.

### 3.1.4. Digestate storage and post-treatment

Achieving a nearly complete breakdown of the digestible organic matter is listed as the most important mitigation measure downstream of the digester (and thus for both digestate storage and post-treatment). Therefore, it is important to ensure a sufficient hydraulic retention time (HRT) for all the substrates present in the digester or for there to be appropriate pre-treatment of specific feedstocks, or inline or offline treatment of the digestate to ensure the necessary digestion. The methane-formation process of the digestate can be reduced by cooling the digestate to temperatures below 17°C.[29] Furthermore, emissions from digestate can be reduced by a gas-tight, covered digestate storage tank that is connected to the gas system.

## 3.2. Operational mitigation strategies

Operational mitigation measures describe the change of action sequences during plant operation. The most important operational mitigation strategy includes Leak Detection and Repair (LDAR). The practice of LDAR campaigns is already implemented in sectors other than biogas and biomethane. The basic principle is that it combines mitigation action with data gathering. Source detection is conducted, followed by effective reduction practices such as immediate on-site repair of the component units that emit methane. This work practice allows to respond with a prompt intervention to reduce emissions through the continual control and repair of equipment. The high benefit-to-cost ratio is broadly recognised.

It is of paramount importance that the flare starts automatically when the filling level of the gas storage container exceeds a defined level. Furthermore, operational mitigation measures include the implementation of regular and scheduled inspections and a maintenance plan, the adjustment of substrate feeding before planned maintenance, mass balance calculations to identify losses, and the analysis of the residual methane potential of digestate.

## 3.3. Legislative actions: Examples across European MSs

Most EU Member States have implemented legislative measures to reduce methane emissions from biogas production in addition to the REDII sustainability criteria. Most notably, a strong set of standards for AD plant components is currently in place in Germany and Austria, for example. In addition, legal measures are accompanied by a range of specific protocols, national guidelines on safety, technology requirements for the construction and design of plants, regulations on inspections and

[28] Liebetrau, Jan; Reinelt, Torsten; Agostini, Alessandro; Linke, Bernd (2017): Methane emissions from biogas plants. Methods for measurement, results and effect on greenhouse gas balance of electricity produced. ed. by Jerry D. Murphy. IEA Bioenergy Task 37. URL: http://task37.ieabioenergy.com/files/datenredaktion/download/Technical%20Brochures/Methane%20Emission_web_end_small.pdf

[29] Ericsson N., Nordberg Å, Berglund M., (2020) Biogas plant management decision support – A temperature and time-dependent dynamic methane emission model for digestate storages Bioresource Technology Reports 11, 100454. https://doi.org/10.1016/j.biteb.2020.100454

verifications, as well as standards for upgrading systems.

### 3.3.1. Legislative actions regarding digestate storage

Examples of measures in place that regulate digestate storage can be found for example in France, Germany and Italy. **France** requires digestate storage in a closed system until the HRT has reached 80 days. In **Germany**, a minimum of 150 days within a gas-tight covered system is mandatory unless a residual gas potential limit of the digestate is reached. The German TA Luft limit value for the remaining methane emission potential from digestate is at 3.7% (at 37°C) of the gas produced. The rules apply to new digestate storage units. The **Italian** technical specification UNI-TS 11567 requires a minimum of 30 days covered storage.

### 3.3.2. Legislative actions in Germany and France

In **Germany**, the mitigation of fugitive methane emissions from biogas plants is a part of extensive legal requirements, laws, ordinances, and technical regulations. The specific requirements depend on the plant concept and factors such as the starting year of the operation, the type and amount of substrate input, as well as the share of manure and the utilisation route (electricity, gas feed-in or transportation fuel). The mitigation of methane emissions in Germany is regulated in the following legal documents and regulations:

- The air pollution control regulation titled **"Technical Instructions on Air Quality Control"** (Technische Anleitung zur Reinhaltung der Luft), commonly referred to as the 'TA Luft'.
- The **44th BImSchV** (national implementation of the EU Medium Combustion Plant Directive 2015/2193) which indicates a threshold for methane emissions from CHP units (e.g. as of 2023, a new exhaust gas limit value in CHPs of 1.3 g/m³ total carbon).
- The guideline **TRAS 120**, which provides technical rules and safety requirements for biogas plants.
- The **Renewable Energy Sources Act or EEG** (Erneuerbare-Energien-Gesetz) (introduced in 2000, amended since) as a series of German laws.
- The GasNZV[30] sets limitations for methane slip from upgrading units, defined at 0.2% methane in the off-gas. As a consequence, post-combustion is necessary in most cases.


Additionally, the German biogas association promotes activities such as working groups and maintenance training to improve the expertise of the operators and specialised companies with regard to emission reduction measures.

In **France**, as of 2025, methane slip in the off-gas from the biogas upgrading stage will be limited to 0.5% methane for injection plants bigger than 4.5 GWh/year, and to 1 % methane for injection plants below this threshold

## 3.4. Actions from the biogas industry

Besides the development of technological efficiency improvements and national regulations, in several European countries the biogas sector has established schemes for the self-inspection of methane emissions,

[30] GasNZV. Verordnung über den Zugang zu Gasversorgungsnetzen; Deutscher Bundestag: Berlin, Germany, 2017

complemented by external measurement campaigns. Three examples of such initiatives come from Denmark, Sweden and Switzerland, which were the first countries to launch methane monitoring programmes, in cooperation with their national agricultural, waste and biogas associations.[31,32] The report "Methane emission mitigation strategies"[31] released by the EBA provides a good summary of such initiatives. A clear description of a voluntary self-inspection agreement is provided by the Swedish report "Self-inspection of methane emissions" (Swedish Waste Management - Avfall Sverige) [33].

### 3.4.1. Methane mitigation strategies in Sweden

In **Sweden,** the introduction of a voluntary agreement on self-inspection and self-monitoring represents a clear example of the commitment of biogas plant operators towards methane emissions reduction. The scheme is based on systematic leak detection and regular measurement campaigns, with attention also being paid to awareness raising for operators and increasing the credibility of the sector. While systemic leak detections are performed by the plant operators, the periodic measurement campaigns are carried out by an external measurement company. On occasions where the plant's methane loss exceeds 2% of the annual production, the external company will suggest mitigation actions and a new measurement campaign must be performed 1 year from the time of such third-party consultancy. The Swedish scheme (EgMet system)[34] in place since 2007 has delivered successful results: the table below shows the results of methane emission measurement campaigns performed during different periods as a function of the upgrading technology.

**Table 3.1** Methane losses in % relative to the amount of gas treated in the upgrading plants during periods 2007-2015 (Source: Avfall Sveriges)

| | Mean Methane losses (%) | | |
|---|---|---|---|
| **Upgrading technology** | Period 1 2007-2009 | Period 2 2010-2012 | Period 3 2013-2015 |
| Chemical scrubber | 0.36 | 0.21 | 0.17 |
| RTO | 1.7 | 0.42 | 0.16 |
| PSA | 2.5 | 1.1 | 0.97 |
| Water Scrubber | 3.2 | 1.6 | 1.7 |
| All Plants | 2.7 | 0.99 | 0.90 |

[31] European Biogas Association, Methane emission mitigation strategies: Information sheet for biogas industry, https://www.europeanbiogas.eu/wp-content/uploads/2020/05/Methane-emission-mitigation-strategies-info-sheet-for-biogas-industry.pdf

[32] Fredenslund, A. and Scheutz, C.: Maximising climate protection through minimising gas leakage – the Danish biogas measurement programme, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16061 CO Meeting Organizer EGU21 (copernicus.org)

[33] Avfall Sverige (Ed.): 'Self-inspection of methane emissions- A description of the system for inventorying and reducing methane emissions from co-digestion plants, wastewater treatment plants and biogas upgrading plants Avfall Sverige's Development Initiative ISSN 1103-4092 (2019) https://iwa-network.org/wp-content/uploads/2015/12/Self-Inspection-of-Methane-Emissions.pdf

[34] Details on the Swedish EgMet are described on the webpage of the Swedish Waste Management Association and the Swedish Water Associations, who are the owners of the system.

In addition, there are currently various scientific initiatives in Sweden to monitor fugitive methane emissions via measurement campaigns in the open environment. Recent studies[35] demonstrate the potential of using drones for efficient and accurate methane monitoring at specific plants. The results of such works will further help mitigate emissions and improve the understanding of methane emission sources.

### 3.4.2. Methane mitigation strategies in Denmark

In **Denmark**, a voluntary methane monitoring programme was launched in 2016 by the Danish Biogas Association and the Danish Energy Agency. The programme is based on the following three aspects:

- self-check inspections of critical control points (e.g. pressure valves and flanges);
- leakage detection, mainly through optical gas imaging cameras by third parties;
- measurement of total leakages by experts via trace gas method or similar.

In 2021, it was decided by the Parliament that measures to minimise methane emissions should be a prerequisite to obtain subsidies. As a result, the Danish voluntary scheme was implemented as a mandatory regulation issued by the Energy Agency and came into force on 1st January 2023. It introduced the obligations that thus became necessary for the payment of subsidies.

The Danish scheme includes mandatory self-check programmes for biogas plants and a yearly leak detection inspection by a third party, as well as a plan for repair and maintenance that must be drawn up in cooperation with a technically competent third party. Finally, a maximum target of 1% was introduced for the upgrading units on biogas plants producing biomethane for injection into the gas grid. Due to the uncertainties in the quantifications of methane loss from the whole plant, the fulfilment of the repair plan is a prerequisite to receive subsidies.

The voluntary programme in Denmark showed that the choice of technology has a high impact and that making use of the best available technologies, regular inspections and daily maintenance should be strongly recommended. The experiences revealed that unexpected methane leakages may occur, but that they can be eliminated with relative ease.

### 3.4.3. Voluntary scheme for reducing methane emissions in Switzerland

In **Switzerland**, a specific voluntary programme[36] was launched within climate protection projects more than a decade ago. It relies on an external measuring company that delivers to the biogas operators participating in this programme a report with the calculation of the methane emissions from the whole biogas plant, which is then used to take action for the implementation of mitigation measures. In 2019, there were 35 agricultural biogas plants participating in the emission measurements carried out annually using the on-site approach.

### 3.4.4. Voluntary scheme for reducing methane emissions in France

In **France**, several companies offer leakage detection services to biogas plants. Some of these companies were involved in awareness-raising detection campaigns, in which several dozens of biogas plants operated by farmers were monitored. These campaigns made it possible to set up recommendation guidelines:

- careful monitoring of PRVs and flares, flanges, valves, openings in the digester walls, biogas covers, methane split in the upgrading stage and digestate, which are the main emission sources;
- a periodic self-check of the installation at the main sources of leakage
- a yearly control by experts with highly sensitive OGI cameras to detect all leakages on site;
- when possible, an increase of the HRT and/or recovering of the biogas emitted by digestate storage.

[35] Gålfalk et al. (2021) Sensitive Drone Mapping of Methane Emissions without the Need for Supplementary Ground-Based Measurements, *ACS Earth Space Chem.* 2021, 5, 10, 2668–2676. https://doi.org/10.1021/acsearthspacechem.1c00106
[36] https://oekostromschweiz.ch/projekte/

Biogas operators have thus been made aware, over last couple of years, of the importance of controlling emissions and the best way to do it. An increasing number of biogas plants apply self-checks and repair processes, while specialised companies, supported by the ADEME (Government Agency for Energy and Environment,) such as INRAE[37] and INERIS,[38] are involved in detection and quantification programmes to learn more about fugitive emissions and their sources. The last web conference from the ATEE Club Biogaz – CTBM in autumn 2022 testified to such actions.[39] Moreover, the AAMF, an association of the farmers producing biogas with their agricultural residues, is committed to sharing and applying the best possible practices to detect and reduce emissions and has published a charter.[40]

*15 years of on-site experience show that the most cost-effective manner to reduce methane emissions at AD plants is the combination of regular self-inspections, periodic reporting of methane emissions as part of monitoring programmes and training courses for plant operators.*

[37] FELeaks project, INRAE, 2023, https://feleaks.inrae.fr/
[38] Methanemis project, INERIS, 2021 – Rapport-Ineris-20-167265-2515796_MethanEmis-version-finale-v1.pdf
[39] Emissions fugitives de méthane: détections et actions, Club Biogaz – CTBM, 17 oct. 2022, https://atee.fr/energies-renouvelables/club-biogaz/emissions-fugitives-de-methane-detections-et-actions
[40] Chart Association des Agriculteurs Méthaniseurs de France (AAMF), https://aamf.fr/4-charte/

# Chapter 4

## Results from measurement campaigns

With the goal of presenting a highly reliable synthesis of the fugitive emission estimates from biogas plants at European level, this study focused on three levels, each with a distinct context. The results and ranges of values collected from literature and from the available dataset of the existing biogas value chain were evaluated and the figures obtained are discussed in the following three sections.

The first part describes a recent study elaborated by the EC-JRC and includes a comparison between observations found in literature and REDII default values.

The second section examines the impact of effective mitigation practices in place, focusing on Denmark as a specific case study. Denmark was chosen as it is one of the frontrunner countries in the EU for implementing methane emission mitigation measures and preventing leakages. The figures are elaborated to specifically assess methane emissions from biogas plants participating in the Danish methane emission monitoring scheme.

In the third part, information is collected to understand to what extent methane emissions can be reduced through technical and operational mitigation measures. To this aim, the EBA has created a comprehensive database based on literature. This information is valuable, considering that newly built biogas and biomethane production facilities necessary to scale up production to reach 35 bcm by 2030 will naturally need to be designed and built with the aim of a maximum reduction of methane emissions.

## 4.1. EC-JRC overview of emission factors within different process stages in biogas plants

A recent study, elaborated by the EC-JRC[41] and based on several on-site experimental campaigns conducted at different European biogas plants, provides a summary of the median and mean values of methane loss (% of produced methane) occurring throughout the different stages of the production process. The values include both older plants with limited mitigation measures in place and newer AD production facilities.

The data gathered is intended to establish a range of emissions and is illustrated in Figure 4.1 below. Overall, the median of the JRC emission values fall within the values ranges provided in the Annex VI of the REDII regulations. It must be kept in mind that the emissions from digestate storage should be compared to the emissions without AD.

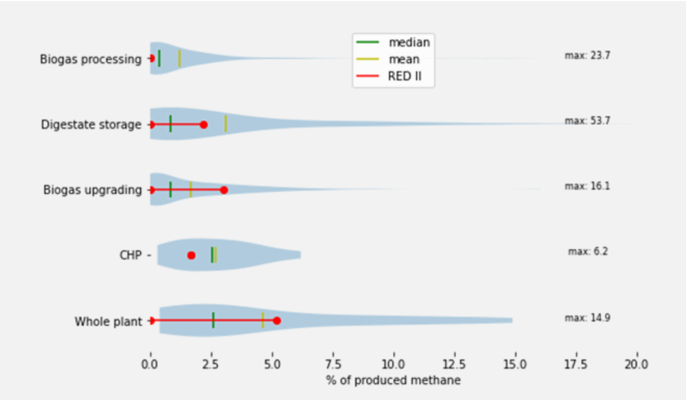


**Figure 4.1** – Summary of literature and RED II default values. JRC summary of emission sources from on-site experimental campaigns, including the figures reported in the RED II calculations (biogas pathways, Annex VI) Component-specific EF within different process stages (Source: EC-JRC)[41]

[41] Hurtig O., Buffi M., Scarlat N. (EC-JRC Unit C.2 Ispra) 'Fugitive emissions from anaerobic digestion: GHGs methodology'- [presentation at the European Biogas Association Conference 2022 – parallel event: Fugitive methane emissions from biogas plants: effect on GHG emissions] Oct. 2022 Brussels.

## 4.2. Case study: Fugitive methane emissions from biogas plants in Denmark

The recent Danish study "The Danish national effort to minimize methane emissions from biogas plants",[42] co-funded by the Danish Parliaments' Finance Act of 2019, as part of the GHG reduction initiative and the national effort to minimise methane loss from biogas plants, provides an inventory of measured methane emission rates at different facilities representing more than half of the Danish biogas production. Authors compared the magnitude of the methane leaks and individual emission point sources from wastewater treatment and agricultural-based plants in Denmark. The EBA combined the inventory of the above-mentioned study with data received from national stakeholders and extensive datasets from different literature references[43]. Finally, a dataset including 65 agricultural-based plant measurements, 35 measurements at wastewater treatment-based (WWT) plants and 10 measurements pertaining to organic waste was established. To achieve a robust representation of the overall methane emissions, weighted average figures were then determined by considering the proportion of biogas plants in Denmark running on agricultural, WWT, and organic waste sources (46%, 48%, and 6%, respectively). Emission values are thus calculated and presented using the weighted average approach. Based on the established dataset, Figure 4.2 was developed showing the methane emissions occurring throughout the different stages of the production process for Danish plants. Following the above-mentioned approach, the average total methane emission rate of biogas plants in Denmark are estimated at 1.31±0.16%.

*The sustainable scale-up of biomethane production to reach the 35 bcm by 2030 will be ensured with new AD plants that are built, designed and monitored to prevent fugitive emissions.*

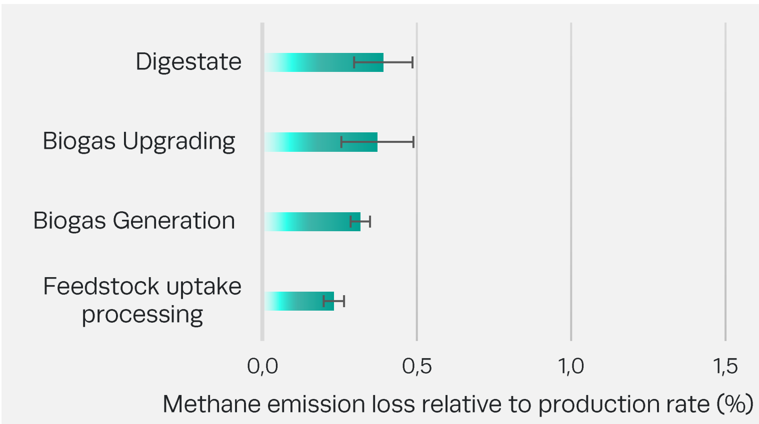


**Figure 4.2** – Fugitive methane emissions (% of produced methane) from different stages of the biogas supply chain in Danish biogas plants.

[42] Fredenslund A.M., Gudmundsson E.,Falk J.M. , Scheutz C. (2023) Waste Management 157 321–329 The Danish national effort to minimise methane emissions from biogas plants
[43] Bakkaloglu S et al., (2022). Methane emissions along biomethane and biogas supply chains are underestimated. One Earth 5:724 36. https://doi.org/10.1016/j.oneear.2022.05.012.

## 4.3. Overview of emission factors at different process stages

The EBA has created a comprehensive and representative database with a large sample size by collecting fugitive methane emissions data from a variety of recent sources[44,45], including academic papers, reports and estimations from AD plants that are participating in voluntary programmes. The data from the available experimental observations were combined with the gathered information and subjected to a rigorous analysis by reducing the effects of outliers, ensuring accurate outcomes.

The range of estimated fugitive methane emissions across the whole biogas supply chain is large, having been shown to lie between 0.1% and 10%[44,45] of the total methane produced. The large range is due to differences in the plant size, age and quality of the technology employed. Data shows that improvements in design and operations focused on preventing leakages resulted in significantly lower emissions for newer plants.

### 4.3.1. Feedstock intake and pre-processing

When best practices are applied during the substrate receiving, storage and incorporation phases, the range of methane emissions can be low or even negligible (0.1-0.3%),[28] particularly at bio-waste treating facilities where emission rates lower than 0.1% have been observed.[19,20] Nevertheless, since emissions at this stage are influenced by factors such as volume mixing ratio, substrate type, storage filling level and agitation, studies[20,44,45] have identified these steps as important points for monitoring with regard to the implementation of mitigation measures.

### 4.3.2. Digestion process

At the digestion process stage, most methane emissions (in a range of 0.6-1.8%) originate from pressure relief valves on digesters, which typically represent a significant source of emissions[44] and belong to the major areas where mitigation efforts should be concentrated. Interestingly, results show that well-maintained, upright metal digesters, soft-top digesters equipped with undamaged double membrane domes and intact concrete roof digesters have negligible emissions[20,46].

### 4.3.3. Gas utilisation

As explained in *Chapter 1*, methane emissions from biogas utilisation include the emissions from upgrading units or combined heat and power (CHP) units. While the emissions from CHP units are estimated to amount to approximately 2.5%[41] (Figure 4.1), the emissions attributed to the residual gas from upgrades largely depend on the technology employed.

A range of upgrading techniques are currently deployed in Europe. Membrane separation (39%), water scrubbing (22%) and chemical scrubbing (18%) are the most common ones in use today.[47] Other technologies include pressure swing adsorption (PSA), physical scrubbing, chemical absorption, cryogenic separation, and biological upgrading techniques. Table 4.1 shows the methane emission rates for each upgrading technology. Chemical scrubbing using amine or water scrubbers equipped with catalytic post-treatment, known as regenerative thermal oxidation (RTO), result in the lowest or negligible fugitive emissions. Membrane separation shows methane emissions ranging between 0.4 and 0.7%.

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[44] Reinelt, T., Liebetrau, J., 2020. Monitoring and Mitigation of Methane Emissions from Pressure Relief Valves of a Biogas Plant. Chem. Eng. Technol. 43, 7–18. https://doi.org/10.1002/ceat.201900180
[45] Wechselberger V., Reinelt T., Yngvesson J., Scharfy D., Scheutz C., Humer M.H., Hrad M., (2023) Waste Management 157, 110-120.
[46] Westerkamp, T., Reinelt, T., Oehmichen, K., Ponitka, J., Naumann, K., 2014. KlimaCH4 – Klimaeffekte von Biomethan, DBFZ-Report No. 20. Deutsches Biomasseforschungszentrum gemeinnützige GmbH (DBFZ), Leipzig, p. 167. https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_20.pdf
[47] European Biogas Association, Statistical Report 2022, Figure 7.23.4 – Relative use of the different upgrading technologies in 2021 – https://www.europeanbiogas.eu/eba-statistical-report-2022/

| **Table 4.1** Upgrading technology-specific ranges of methane emissions (% of biomethane produced) | |
|---|---|
| **Biogas Upgrading Technology** | **Range of methane loss [% of biomethane produced]** |
| Chemical scrubbing: | 0.0% – 0.1%[48] |
| Cryogenic separation: | 0.0% - 2.0%[49] |
| Membrane separation: | 0.4% - 0.7%[13] |
| Pressure swing absorption: | 0.0% - 2.4%[13] |
| Water scrubbing: | 2.0% - 3.8%[32,33] |

### 4.3.4. Digestate storage and post-treatment

Due to the continued anaerobic digestion of residual biodegradable organic matter in the digestate, precautions should be taken to avoid methane emission from digestate storage. Emissions from digestate storage can be prevented either by using closed storage tanks, or in some cases by reducing the digestate temperature or increasing HRT in the digester so that the residual methane potential of the digestate is reduced. Indeed, the extent of these emissions vary depending on feedstock, storage volume, HRT and seasonal variations in ambient temperature. Many researchers have concluded that the handling of digestate plays a major role in the impact of methane emissions.

To provide representative results, the EBA's database included only biogas pants having started operation in the last 10 years. According to the EBA's database (81 observations), plants with closed digestate storage reach emission rates below 1% (Figure 4.3). Interestingly, the EBA's database reveals statistically significant differences (P< 0.01) in the methane emissions between open and closed digestate storage (see attached in Appendix). This stresses the importance of implementing specific measures to reduce emissions from digestate. Indeed, closed digestate storage is a measure which is becoming a requirement in many EU countries (especially for larger plants).

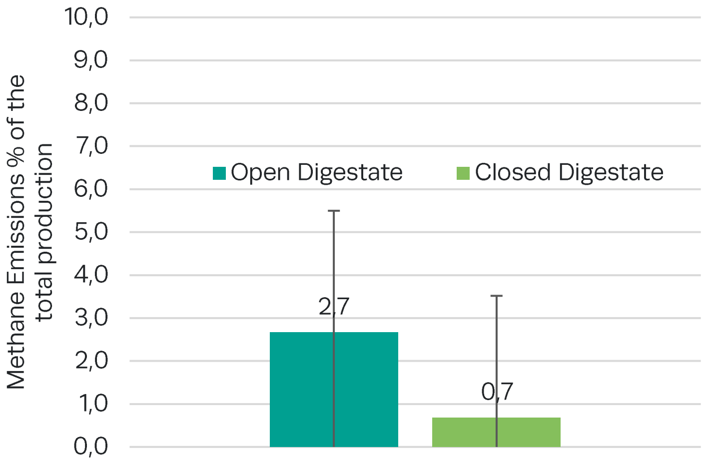



**Figure 4.3** – Fugitive methane emissions (% of produced methane) from open and closed digestate storage (Source: EBA database)

[48] Yngvesson, J., 2022. Utvardering och minskning av metanutsl¨app från olika europeiska biogasanl¨aggningskoncept (EvEmBi), in: Sverige, A. (Ed.). Avfall Sverige, https://vattenbokhandeln.svensktvatten.se/produkt/utvardering-och-minskning-av-metanutslapp-fran-olika-europeiska-biogasanlaggningskoncept-evembi/

[49] Adnan A.I, et al. , (2019) Technologies for Biogas Upgrading to Biomethane: A Review. Bioengineering (Basel). 6(4):92,. https://pubmed.ncbi.nlm.nih.gov/31581659/

# Recommendations

## 1) Recognising the pivotal role of biogas in reducing EU methane emissions

Anaerobic Digestion has a pivotal role in reducing EU methane emissions in agriculture, energy, waste and wastewater management. Methane emissions are avoided when methane emitted from organic matter, such as manure and biowaste, are brought to the closed and controlled environment of an AD plant. In a biogas production facility, methane is captured and utilised instead of being released into the atmosphere. For example, without AD, manure might be stored on farms and generate uncontrolled release of methane. A holistic approach to emissions accounting should therefore take into consideration the impact caused by the absence of AD.

## 2) Building on existing mitigation programme results: best practices and a detection/repair approach

The implementation of mitigation programmes should be encouraged at MS level. This includes the application of best practices in plant design and operations.

The biogas industry is well advanced in developing strategies to mitigate methane emissions. Strategies (e.g., Leak Detection and Repair) from related sectors have been tailored towards the specificities of AD. Successful monitoring programmes have been established in EU Member States (*Chapter 3*).
On-site experience shows that:

- the most cost-effective manner to reduce methane emissions at AD plants is the combination of regular self-inspections of critical control points with leak detection campaigns and repair of found leaks;
- the periodic reporting of methane emissions can document the success of mitigations and monitoring programmes and establish the basis for emission factors for national inventories;
- the organisation of training for plant operators is crucial for the success of methane emission mitigation programmes.

The combination of such actions enables biogas plants to effectively control and prevent fugitive emissions.

Considering the specificities of the biogas markets in each country, Member States should be empowered to develop their adapted mitigation strategies.

## 3) Improving the understanding of methane emissions at the technical level

In parallel to that which is proposed in §5.2, quantification on a representative sample of AD plants is important to establish reliable Emission Factors (EF). Considering current limitations to doing so, the methods and technologies must be improved. Dedicated programmes and campaigns could be supported to meet this goal in the mid-term.

The EU should support studies, research, and innovation regarding methane emission detection and assessment at biogas plants. In the last decade, scientific literature has intensively investigated methane emissions from AD plants.[43] Although thousands of measurements across the EU have been published, to date, only a few studies reported total methane emissions from AD facilities to an extent where national EFs can be calculated. Additional large-scale measurement campaigns are necessary to define EFs that fully accommodate different plant types, applied technologies, operational conditions, and plant sizes. Research should lead to harmonised detection and measurement methods between Member States. Furthermore, the understanding of methane emissions at the technical level requires the dissemination of best practices across European regions.

In summary, the definition of a broad set of Emission Factors for the AD industry will be key to:

1) Better identifying larger contributors;
2) Prioritising mitigation efforts;
3) A harmonised reporting of methane emissions at the EU level.

In the absence of a European standard to determine the overall methane emission rate from biogas plants, a harmonised procedure should be determined in the EU to ensure comparability between the different existing measurement methods. When doing so, the diversity of AD sizes and types must be taken into consideration.

## 4) A sound update of default values in the Renewable Energy Directive Annex VI

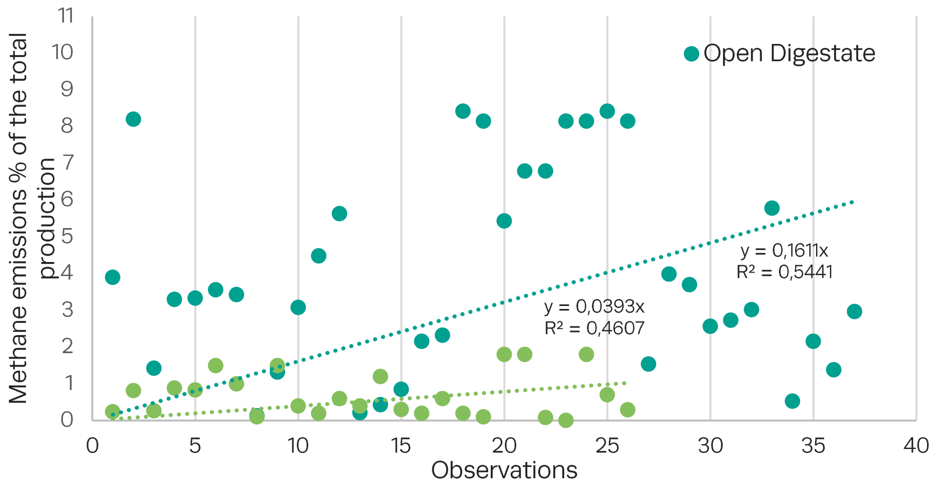
Methane emission mitigation can be further encouraged by tailoring the calculation methods for demonstrating compliance with the sustainability criteria:

- inclusion of additional biogas & biomethane production pathways covering additional feedstocks (e.g., catch/cover crops, grass, fast growing perennial, industrial residues) and new technologies (e.g., RTO, categorisation of upgrading technologies, methanation)[50];
- disaggregation of the default values to accommodate mitigation measures already undertaken by individual plants such as membership in a methane monitoring scheme, implementation of mitigation technologies (BAT) and specific measures to reduce emissions from digestate such as gas-tight covering, increased HRT in the biogas digester and reduced digestate temperature;
- an update of the default values should acknowledge the improvements in design and operations from the past decade and should be based on recent measurement campaigns only.

*In terms of legislative measures, methane emission mitigation should be further encouraged by a sound update of the default values of the Renewable Energy Directive Annex VI.*

[50] Combination of $CO_2$ with $H_2$ of renewable origin, to produce methane that can be injected into existing natural gas networks

# Appendix




**Appendix Figure 1**: Fugitive methane emissions (% of produced methane) of open and closed digestate storage (Source: EBA database)

**Appendix Table 1** Fugitive methane emissions (% of produced methane) of open and closed digestate storage from the EBA's database, including a total of 81 observations

| | Methane Emission (% of total production) | |
|---|---|---|
| | *Open digestate* | *Closed digestate* |
| Mean | 3.96 | 0.69 |
| Standard Error | 0.44 | 0.11 |
| Median | 3.33 | 0.50 |
| Mode | 8.15 | 0.20 |
| Standard Deviation | 2.68 | 0.59 |
| Range | 8.29 | 1.79 |
| Minimum | 0.13 | 0.01 |
| Maximum | 8.42 | 1.80 |
| Largest | 8.42 | 1.80 |
| Smallest | 0.13 | 0.01 |

**Appendix Table 2** ANOVA single factor results for methane emissions from two groups of plants with varied digestate storage (i.e. closed vs. opened)

| SUMMARY | | | | | | |
|---|---|---|---|---|---|---|
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| 3.9 | 62 | 160.5633 | 2.58973 | 7.025831 | | |
| 2 | 62 | 98 | 1.580645 | 0.247488 | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 31.56584 | 1 | 31.56584 | 8.679899 | **0.003855** | 3.918816 |
| Within Groups | 443.6725 | 122 | 3.63666 | | | |
| Total | 475.2383 | 123 | | | | |

# List of tables and figures

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## About the EBA

The EBA is the voice of renewable gas in Europe. Founded in February 2009, the association is committed to the active promotion of sustainable biogas and biomethane production and their use across the continent. The EBA today counts on a well-established network of over 250 national organisations, scientific institutes and companies from Europe and beyond.

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