BIP Europe
Biomethane Industrial Partnership

BIOMETHANE INDUSTRIAL PARTNERSHIP

METHODOLOGY
TO IDENTIFY SUSTAINABLE BIOMETHANE FEEDSTOCKS

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A methodology for identifying sustainable biomethane feedstocks

Executive Summary

The urgency to boost biomethane production in Europe has intensified due to the need to reduce dependency on natural gas imports from non-EU sources, combat the risk of rising energy costs, and address the critical challenges of climate change. In May 2022, the European Commission introduced a target of 35 bcm of sustainable biomethane production by 2030 as part of its REPowerEU Plan. Policymakers and industry stakeholders are collaborating within the Biomethane Industrial Partnership (BIP) to achieve the target. According to the latest European Biomethane Map in 2024, Europe has reached an installed capacity of 6.4 bcm of biomethane per year. Over 80% of the reported biomethane plants are connected to the gas grid, with nearly half of them (49%) connected to the distribution grid and 14% to the transportation grid. Of the total installed capacity, 81% (5.2 bcm) corresponds to plants in the European Union. The EU-27 countries' growth has reached 37%, while the capacity of the non-EU countries analysed grew by 20% compared with the 2022-2023 dataset.

The strategic choice of feedstocks, particularly biomass, is crucial to achieving the target of 35 bcm by 2030. Meeting the demands of substantially expanding biomethane production requires a significant effort to ensure an adequate supply of feedstock for biogas and biomethane production and acquire sustainable biomass sources. The BIP was established to actively support the achievement of this target and pave the way for further expansion through 2050 in line with the REPowerEU Plan.

This report focuses on identifying sustainable feedstocks for biomethane production. It employs a multi-criteria approach to evaluate the suitability of feedstocks for biogas and biofertiliser and provides selection criteria for identifying and selecting innovative and sustainable feedstock for biogas and biomethane production. Some of the most important selection criteria include:

TABLE 1 THE ASSESSMENT CRITERIA FOR SUSTAINABLE BIOMETHANE FEEDSTOCK IDENTIFICATION

Assessment criterion	Key areas & questions
Description of feedstock	• Biomethane yield perspective: is this feedstock good from a strict biomethane yield perspective? • Suitability for anaerobic digestion: is this feedstock suitable for anaerobic digestion?
Biomethane yield and AD process efficiency	• Calculated values: based on chemical composition of biomass. • Experimental assessment: includes both biomethane potential (BMP) and residual gas potential (RGP).
Suitability for anaerobic digestion	• Component necessity: does the feedstock contain the necessary components for efficient digestion in adequate amounts and proportions? • Digestion factors: factors affecting the biological digestion of biomass.
Accessibility of feedstock	• Geographical accessibility: the geographical accessibility of biomass. • Physical accessibility: the physical form of the biomass and how easy it is to access and utilise. • Seasonal variations: how accessibility varies throughout the year and the implications of these variations.
Amount of biomethane production	• Biomass contribution: is the estimated total amount of biomass substantial enough to make a significant contribution to the overall biomethane production?
Nutrient content and suitability for biofertilisers	• Nutrient content: does the selected biomass possess a desirable nutrient content? • Biofertiliser production: is the biomass suitable for biofertiliser production?
Amount and value of biofertilisers and soil improvers	• A concise description of digestate as biofertiliser in terms of nutrient and microorganism content.
Technological feasibility	• Technology and infrastructure: availability and applicability of required technologies and infrastructure for both biogas and biofertilisers produced from the selected biomass.
Profitability or cost-efficiency	• Profitability: whether a standalone biogas and biofertiliser production is profitable. • Cost-efficient waste treatment: whether biogas and biomethane production may primarily serve as a cost-efficient waste treatment solution. • Economic accessibility: whether it is possible to sustain the production, ensuring long-term economic success.

Control and competition	• Provision control: the extent to which biogas and biofertiliser producers can control or secure the provision of a specific type of feedstock. • Competition evaluation: evaluation of competition for feedstock.
Institutional support and societal acceptance	• Government and institutional support: is biogas and biomethane production from a biomass supported by the government and other institutions? • Public opinion: is the public opinion about biogas and biomethane production from a biomass positive?
Environmental and greenhouse gas impact	• Sustainability requirements: sustainability requirements for biogas and biomethane in terms of reducing greenhouse gas (GHG) emissions.

EU legislation establishes a series of criteria for certifying biogas and biomethane production as sustainable. These criteria include sustainability standards based on the type and origin of the feedstock used, and GHG emission savings criteria apply depending on the installation's date of entry into operation and the end use of the biogas and biomethane. It is important to note that the suitability of these feedstocks can vary depending on factors such as regional availability, local regulations, and specific biogas plant requirements.

Biomethane is a flexible and sustainable energy source that can be used across various sectors, including transportation (road and shipping), heating (for industrial and residential use) and power generation. Its versatility allows biomethane to directly substitute fossil fuels in these sectors, offering the potential for substantial reductions in greenhouse gas emissions.

For biogas and biomethane production, using residues and waste is particularly effective in reducing overall carbon intensity, resulting in zero GHG emissions attributed to the production. There remains a significant, untapped potential from various feedstock sources that could sustainably contribute to the REPowerEU target. However, this category requires careful monitoring due to the difficulties in categorising such feedstocks, their wide geographical distribution, uncertainties related to contaminations and homogeneity and possible regulatory constraints. Careful monitoring of characteristics and traceability of the supply chain is essential to ensure both profitable biomethane production and compliance with legislative specifications.

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1.

Introduction

to the assessment method

1 Introduction to the assessment method

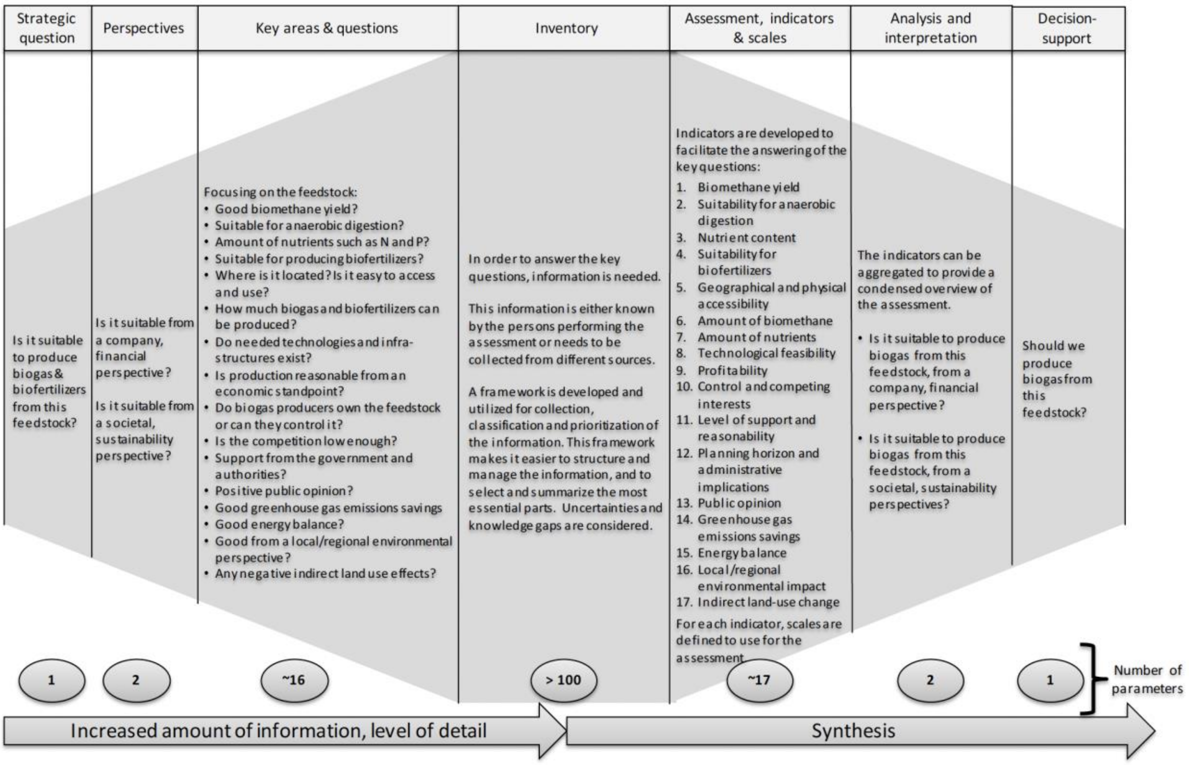
The urgency to boost biomethane production in Europe has intensified to reduce dependency on natural gas imports from non-EU sources, combat the potential risk of rising energy costs and address the critical challenges of climate change. On the 8th of March 2022, the European Commission released a communication on the REPowerEU Plan, aiming to significantly raise the annual EU production and use of sustainable biomethane to 35 billion cubic metres by 2030 — a tenfold increase from the levels in 2022. On 18th of May 2022, the Commission proposed an action plan to operationalise the REPowerEU Communication. The strategic choice of feedstocks, particularly biomass, is crucial to achieving this target. For the target to be reached sustainably, sourcing of organic matter is key.

Meeting the demands of substantially expanding biomethane production requires a significant effort to ensure an adequate supply of feedstock for biogas and biomethane production and to acquire sustainable biomass sources. The Biomethane Industrial Partnership was established to actively support the achievement of this target and pave the way for further expansion through 2050 in line with the REPowerEU Plan. In the subtask group Task Force 3.4, the primary focus is on defining selection criteria for identifying sustainable and innovative feedstocks for biogas and biomethane production, including wastes and residues.

The report draws upon a multi-criteria approach originally developed by the Biogas Solutions Research Centre (BSRC) to evaluate the suitability of feedstock for biogas and biofertiliser production in Sweden [1]. Through the application of this approach and the collective expertise of task group members, the report adapts to the specific scope of Task Force 3.4. It provides selection criteria for identifying and selecting innovative and sustainable feedstock for biogas and biomethane production.

1.1 Key areas and questions

The assessment method was built upon two primary perspectives, serving as the foundation for identifying key areas (see Figure 1.1 for an overview). Each key area was paired with one or a few key questions to provide clarity on the focus. Figure 1 illustrates the 10 identified key areas and the accompanying 13 key questions, which serve as the cornerstones of the established assessment method.



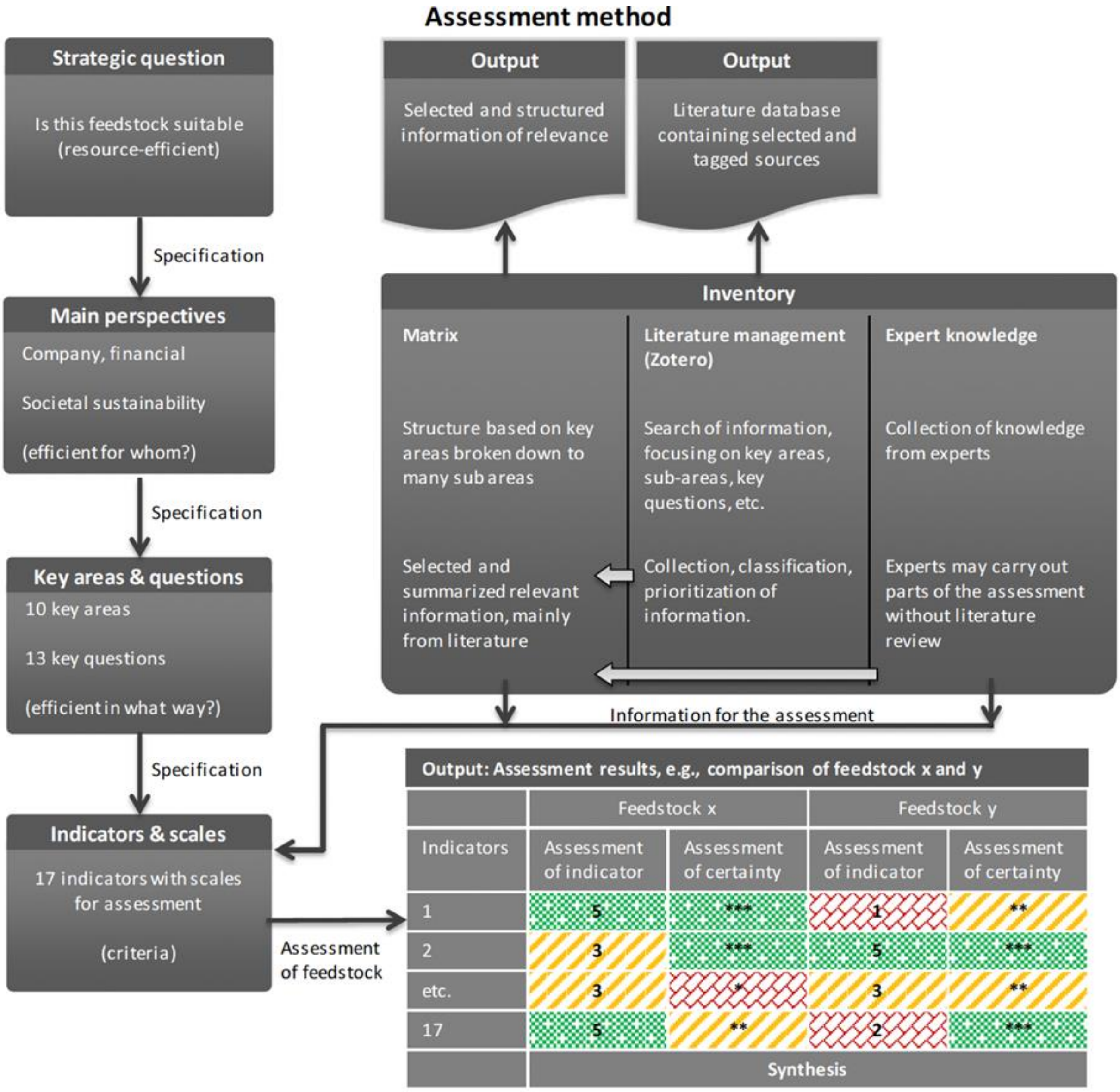
Strategic question	Perspectives	Key areas & questions	Inventory	Assessment, indicators & scales	Analysis and interpretation	Decision-support
Is it suitable to produce biogas & biofertilizers from this feedstock?	Is it suitable from a company, financial perspective? Is it suitable from a societal, sustainability perspective?	Focusing on the feedstock: • Good biomethane yield? • Suitable for anaerobic digestion? • Amount of nutrients such as N and P? • Suitable for producing biofertilizers? • Where is it located? Is it easy to access and use? • How much biogas and biofertilizers can be produced? • Do needed technologies and infra-structures exist? • Is production reasonable from an economic standpoint? • Do biogas producers own the feedstock or can they control it? • Is the competition low enough? • Support from the government and authorities? • Positive public opinion? • Good greenhouse gas emissions savings • Good energy balance? • Good from a local/regional environmental perspective? • Any negative indirect land use effects?	In order to answer the key questions, information is needed. This information is either known by the persons performing the assessment or needs to be collected from different sources. A framework is developed and utilized for collection, classification and prioritization of the information. This framework makes it easier to structure and manage the information, and to select and summarize the most essential parts. Uncertainties and knowledge gaps are considered.	Indicators are developed to facilitate the answering of the key questions: 1. Biomethane yield 2. Suitability for anaerobic digestion 3. Nutrient content 4. Suitability for biofertilizers 5. Geographical and physical accessibility 6. Amount of biomethane 7. Amount of nutrients 8. Technological feasibility 9. Profitability 10. Control and competing interests 11. Level of support and reasonability 12. Planning horizon and administrative implications 13. Public opinion 14. Greenhouse gas emissions savings 15. Energy balance 16. Local/regional environmental impact 17. Indirect land-use change For each indicator, scales are defined to use for the assessment	The indicators can be aggregated to provide a condensed overview of the assessment. • Is it suitable to produce biogas from this feedstock, from a company, financial perspective? • Is it suitable to produce biogas from this feedstock, from a societal, sustainability perspectives?	Should we produce biogas from this feedstock?
1	2	~16	> 100	~17	2	1

FIGURE 1 THE ASSESSMENT METHOD FOR IDENTIFYING SUSTAINABLE BIOMETHANE FEEDSTOCKS

Figure 1 overviews the assessment method, showing how the strategic (main) question is gradually expanded into a detailed inventory containing extensive information, which is then synthesised into a few key parameters and potentially a decision [1].

1.2 Introduction to indicators and scales

The key areas and key questions provide pivotal guidance for information management and assessment. However, they do not serve as the criteria that are integral to the multi-criteria analysis (MCA) methodology. Consequently, the described assessment framework was enhanced by introducing one or more indicators for each key question. Quantitative and/or qualitative scales were then defined for each of these indicators and used to facilitate the assessment process. These scales function as the criteria when evaluating a feedstock in relation to a specific indicator, with both a generic and a case-specific scale developed for each indicator. All the scales have been formulated consistently, featuring the levels: very poor, poor, satisfactory, good and very good.



Output: Assessment results, e.g., comparison of feedstock x and y

	Feedstock x		Feedstock y	
Indicators	Assessment of indicator	Assessment of certainty	Assessment of indicator	Assessment of certainty
1	5	***	1	**
2	3	***	5	***
etc.	3	*	3	**
17	5	**	2	***
	Synthesis			

FIGURE 2 OVERVIEW OF THE ASSESSMENT METHOD SHOWING HOW THE VARIOUS PARTS DESCRIBED ARE RELATED [1]

2.

Description of selection criteria

for identifying sustainable feedstocks

2 Selection criteria for identifying feedstocks for biogas and biomethane production

The availability and characteristics of biomass, biomass residue and waste are heavily influenced by regional and seasonal variations, economic conditions, as well as changes in biological characteristics of feedstock during transportation and storage. For instance, biogas and digestate processing solutions are influenced by the demand for end products in a given area or region, with different processing techniques chosen based on the end-product market.

In the EU-27, the EU Renewable Energy Directive (RED), recently updated by Directive (EU) (2023/2413), provides specific targets for biofuels and biogas for transport from low-ILUC risk feedstocks (e.g. municipal sewage sludge, animal by-products), as reported in Annex IX part A of the Directive. Biogas derived from food and feed crops faces a specific cap (7% on the overall energy share) for use in the transport sector. Consequently, the use of biowastes and residues is driven not only by regulation but also cost competitiveness, making it particularly attractive for biomethane operators aiming to sell biomethane for transportation use.

The profitability of a biogas and biomethane facility is influenced by its investment and operational costs (capital expenditure – CAPEX, and operating expenditure – OPEX) and the income from selling products (e.g. gas, fertiliser products) or waste recycling services and gate fees. Numerous key aspects should be considered when identifying potential feedstocks for biogas and biomethane production and use, and the following aspects can be considered for the development of a biogas and biomethane project:

- Production, harvesting, collection and storage: evaluating the methods and processes involved in production, harvesting, collection and storage of feedstocks at various stages of their life cycle.
- Transportation: considering the logistics and transportation aspects to ensure efficient delivery to biogas plants.
- Pre-treatment, hygienisation and conditioning: assessing the need for pre-treatment techniques to optimise the feedstock for the anaerobic digestion process and the requirement for hygienisation and conditioning processes.
- Reactor configuration and digestion process: understanding the impact of the type of feedstock on the process configuration and anaerobic digestion technologies applied for biogas plant design, construction and operation.
- Biogas cleaning, upgrading and post-treatment: considering the methods and technologies used for biogas, cleaning, upgrading and post-treatment, such as impurity removal and increasing methane concentration.
- Digestate handling: managing and using the residue left after anaerobic digestion to ensure proper handling and potential benefits.
- Distribution and transportation of gas, digestate and co-products: evaluating the transportation and distribution logistics of produced biogas, digestate and any other by-products.

- Utilisation of biogas and digestate: exploring potential applications and utilisation to maximise the benefits of biogas production.

2.1 Description of feedstock

When detailing feedstock for biogas production, it is essential to include the following information:

- Name of the feedstock
- Type: agricultural residues (including manure), residues from industrial processing of agricultural material, wastewater and sewage sludge, industrial and municipal waste (organic fraction), etc.
- Key components
- Dry matter content or total solids (TS) percentage
- Volatile solid (VS) percentage in TS
- Carbon-to-nitrogen ratio (C/N ratio)

Naturally, the feedstock must be anaerobically digestible and exhibit a favourable biomethane yield. The first key question pertains to the biomethane yield per unit of feedstock, which can be assessed by analysing the feedstock's biomethane potential (BMP).

The second key question addresses additional feedstock-related aspects relevant to biogas production, specifically focusing on anaerobic digestibility and whether the feedstock contains the necessary components for efficient digestion in bioavailable and suitable amounts/proportions. This key area is evaluated through two indicators, as outlined in the table below. The respective scales for these indicators are detailed in the following sections.

TABLE 2 KEY QUESTIONS AND INDICATORS FOR BIOMETHANE YIELD AND SUITABILITY FOR ANAEROBIC DIGESTION [1]

Key question	Indicator
Is this feedstock good from a strict biomethane yield perspective?	Biomethane yield
Is this feedstock suitable for anaerobic digestion?	Suitability for anaerobic digestion

Additionally, it is crucial to determine if the potential feedstock contains undesirable substances such as high concentrations of heavy metals, plastics and other materials that would inhibit further processing and the use of the digestate.

2.2 Biomethane yield

Information regarding methane yield may be found in the extensive scientific literature [2], [3] on selecting feedstocks. Factors influencing the analysis can vary, even within the same feedstock categories. Often, the analytical conditions and protocols are not clearly specified. For instance, the literature may present biomethane yield as the volume of gas per unit of weight for each feedstock, but confusion may arise as the gas volume could include additional content (e.g. CO_2, moisture, etc.), and tests may have been conducted under varying temperature and pressure conditions. Moreover, the weight may be reported in terms of wet weight (ww, i.e. including all content), dry matter or total solids (DM or TS, i.e. excluding water content), or organic dry matter or volatile solids (ODM or VS). Additionally, the values provided may range from theoretical values based on the chemical composition of the substrate to results from small-scale lab tests, pilot-scale tests and full-scale practical applications. Furthermore, methane gas volume may be presented with or without normalisation in standard conditions (i.e. 0°C, 1 atm and zero moisture).

In the past, various authors [4], [5], [6] have developed approaches (regression models) to calculate biomethane yield of various feedstocks such as dedicated energy crops and residues. In general, these models used the chemical composition of these biomasses as the explanatory variables for the biomethane yield. The main advantage is that calculating the biomethane yield of various feedstocks is easy and inexpensive. Some examples of calculated biomethane can be found online from the LfL [7]. However, it is important to note that microbial aspects and many practical factors such as physical and chemical properties cannot be considered when estimating biomethane yield.

In addition, theoretical values can overestimate the practical methane yield, as some of the carbon is used by the microbes for growth, leading to incomplete digestion of the feedstock. For certain biogas feedstock types with unknown chemical composition, theoretical values cannot be calculated.

The most realistic and commonly used assessment for biomethane yield is the biomethane potential (BMP) assay, which provides crucial insights into design parameters for anaerobic digesters and the quality control of feedstock for biogas plant operation. Notably, inter-laboratory tests conducted by universities, research centres, and private companies have aimed to standardise and harmonise BMP tests. Key norms governing batch fermentation tests include ISO 11734 (1995), German VDI 4630 (2016) and Italian UNI/TS 11703 (2018).

The BMP test provides information regarding:

- Fundamental evaluation of the maximum biomethane yield and the anaerobic biological degradability of a material or mixture of materials;
- Qualitative appraisal of the speed of anaerobic degradation of the material under investigation;
- Qualitative assessment of the inhibitory effect of the material under investigation within the range of concentrations in the test.

On the other hand, the BMP test does not provide information about:

- Process stability at full scale level. Continuous fermentation tests in reactors continuously fed with the material or mixture under investigation are mandatory to provide information about process stability;
- Biogas yield under practical conditions due to potential negative or positive synergistic effects;
- The mono-fermentability of the substrate under real process conditions;

- The limits of the organic loading rate per unit volume.

As stated earlier, numerous factors can influence the analysis. The outcome of a fermentation test primarily depends on:

- The microbiological activity of the utilised inoculum, which is influenced by test conditions such as temperature, substrate availability and the efficiency of the biologically active mass or inoculum used;
- Accurate gas measurement and data evaluation of the biogas and biomethane quantities produced.

This entails precise definition of the fermentation batch creation, gas measurement, and data evaluation, all crucial for achieving comparable results in fermentation tests.

The outcome of a fermentation test reflects the methane yield in normalised gas volume of biomethane per g, kg or tons of organic dry mass of the input substrate, under the specific test conditions and realised test duration. Common units for BMP test results include NmL CH_4/g VS, NL CH_4/kg VS and Nm^3CH_4/tVS. Typically, the achieved yield corresponds to values realised in practical biogas plants maintaining sufficiently long hydraulic retention times. For challenging-to-degrade substrates (e.g. feedstock with high lignocellulosic content), the degree of input substrate size reduction can directly impact degradation kinetics and consequently, biomethane yield.

To determine the maximum gas yield, the biogas or biomethane potential and the velocity constant, analysts can rely on curve matching and assumptions about kinetics, such as the first-order reaction model, based on a single result from BMP tests. However, when BMP assays incorporate continuous data measurement, the resulting data can provide both the maximum biomethane yield and a comprehensive biodegradation kinetic profile, offering a superior analytical approach compared with simulation based solely on a simple first-order equation. Under certain assumptions, both simulated and measured results can then be applied to continuous processes, providing valuable insights for forecasting biogas or biomethane formation. However, using batch test results to predict continuous processes entails uncertainties due to differences in substrate mass fractions and the impact of substrate/inoculum ratio on kinetics. For reliable research and optimisation of continuously operated processes, it is highly recommended to conduct anaerobic fermentation tests using a continuous procedure, with a solid understanding of the feedstock and appropriate quality control measures. The guidelines and procedures for such tests are outlined in VDI 4630 as an example.

Practical experience and disciplined routine in conducting BMP tests and interpreting results are also essential for obtaining reliable outcomes.

Residual gas potential (RGP)

Operating biogas plants at high biological efficiency is essential for achieving environmental goals and optimising economic output. This involves obtaining a high biomethane yield per reactor volume and facilitating a fast anaerobic conversion of organic feedstock, leading to well-digested material that reduces greenhouse gas (GHG) emissions associated with subsequent digestate storage. Managing critical operational factors such as the organic loading rate (OLR), hydraulic retention time (HRT), digester temperature and nutrient balance, including the carbon-to-nitrogen ratio and elements concentration, plays a vital role in achieving a successful anaerobic digestion process.

Furthermore, the RGP serves as a reliable and innovative indicator of the organic matter degradation rate, allowing for the evaluation of biological process efficiency, particularly in full-scale biogas plants. These factors collectively contribute to the overall success of the anaerobic digestion process and can significantly impact environmental sustainability and economic viability.

Assessing the RGP of the digestate from a biogas plant can address the following questions:

- What quantity of biogas or methane is lost after leaving the gas-tight part of the biogas plant?
- How significant is the emission potential?

According to technical guidelines for BMP measurement, the same fermentation test apparatus used for determining methane yield can also be used to determine the RGP.

2.3 Suitability for anaerobic digestion

Determining the suitability of feedstock for anaerobic digestion involves assessing whether it contains the necessary components for efficient digestion in adequate amounts and proportions. Factors to consider include the C/N ratio (refer to Table 3), C:N:P ratio, biodegradability within the common digestion incubation period, nutrient and trace element content, presence of contaminants or inhibitors and other properties that may impact digestion efficiency. These factors are listed below:

- *Carbon-to-nitrogen ratio (C/N ratio)*: provides crucial insight into the availability of essential macronutrients. Table 3 provides an overview of the scales for assessing the C/N ratio.
- *C:N:P ratio*: while a standard guideline of 100:5:1 is often considered optimal, it is crucial to be mindful of the bioavailability of macronutrients, which can lead to variations in the ratio.
- *Biodegradability*: assess the biodegradability of feedstock within the common digestion incubation time at full-scale plants.
- *Nutrient and trace element content*: evaluate the content and bioavailability of other essential trace elements.
- *Contaminants and inhibitors*: check for the presence of contaminants or components that could inhibit digestion.
- Other properties: consider other properties affecting digestion, as summarised in Table 4.

TABLE 3 OVERVIEW OF THE SCALES FOR ASSESSING THE C/N RATIO [1]

C/N ratio	Scale
C/N = 20-30	Biomethane yield
High C/N value	Leads to rapid consumption of available nitrogen, leaving remaining carbon unprocessed, which results in reduced overall yield.
Low C/N value	Leads to release of nitrogen and formation of ammonium which further increase the pH and may cause toxic effects. Therefore, a substrate with a low C/N value might be more effectively digested when combined with feedstocks that have a high C/N ratio in a co-digestion process.

TABLE 4 PROPERTIES THAT AFFECT BIOLOGICAL DIGESTION OF BIOMASS [8]

Characteristics/elements	Effect on
Cutting length, degree of shredding	Fermentation process
Type of feedstock preservation	Fermentation process
Contamination (i.e. sand content)	Fermentation process
Dry matter and organic dry matter	Fermentation process and fertilising effect
N content	Fermentation process, fertilising effect and emissions (gas utilisation, substrate storage, digestate spreading)
S content	Fermentation process, fertilising effect, and emissions (gas utilisation, substrate storage, digestate spreading)
Lignin content, degree of lignification	Fermentation process
Co, Ni, Mo, Se, and other	Fermentation process

The assessment of a specific feedstock's suitability for biomethane or biogas production through anaerobic digestion is influenced by various factors, as discussed earlier. It is crucial to recognise that the focus of this evaluation is on the inherent properties of the feedstock, rather than the digestion technology being used (not assessed in Task Force 3).

In this context, it is assumed that the feedstock undergoes optimal pretreatment. However, it is important to emphasise that this assumption does not imply an unconditional endorsement of complex and economically impractical pretreatment techniques that are operationally impossible to implement in full-scale production. If achieving suitability for anaerobic digestion relies solely on costly pretreatment methods, it may be reasonable to conclude that the feedstock is less suitable for anaerobic digestion. Additionally, the presence of undesirable materials that act as toxins or inhibitors for anaerobic digestion will also diminish the suitability of the feedstock for biogas or biomethane production.

As outlined above, it is essential to consider both the feasibility of pretreatment and the presence of potential inhibitors when assessing the suitability of a feedstock for anaerobic digestion and subsequent biomethane or biogas production. Table 5 offers a classification of assessment for feedstock suitability based on these considerations.

TABLE 5 THE SCALE FOR ASSESSING FEEDSTOCKS' SUITABILITY FOR BIOGAS PRODUCTION [1]

Value	**Scale definition (generic and case-specific)** *Assuming that an optimal technical pretreatment has been performed*
Very good	Highly digestible feedstock: this feedstock is very digestible and contains all necessary components for digestion in suitable amounts and proportions. There are no undesirable substances or materials that inhibit the process.
Good	Digestible feedstock: this feedstock is digestible and contains most of the necessary components for digestion in suitable amounts and proportions. Additives may be needed. There are no undesirable substances or materials that inhibit the process.
Satisfactory	Moderately digestible feedstock: this feedstock is somewhat digestible and contains some of the necessary components for digestion in suitable amounts and proportions. Co-digestion with another feedstock containing the lacking components, or addition of additives, may be required. There may be some undesirable substances or materials present, but they are not significantly inhibiting.
Poor	Complementary feedstock: this feedstock may be used as a complementary feedstock for co-digestion, as it contains one or a few of the necessary components. There may be some undesirable substances or materials present, but they are not significantly inhibiting.
Very poor	Unsuitable feedstock: this feedstock cannot contribute to the digestion process or may act as an inhibitor. There are undesirable substances or materials present that will significantly inhibit the digestion process.

In summary, regardless of the source and type of biomass/biowaste, it is crucial that it is readily biodegradable and possesses a high biomethane potential. This ensures cost-effective biogas/biomethane production within a reasonable degradation period in full-scale biogas plants. Numerous studies at the full-scale level have shown adequate anaerobic digestion efficiency in wet fermentation processes with long retention times for agricultural feedstocks (>60 days), while typically around 40-45 days for mono-digestion of livestock slurries seem to be sufficient [9], [10], [11], [12].

Consequently, conducting a comprehensive feedstock quality check for all forms of biomass/biowaste becomes critically important to assess its suitability for biogas and biomethane production. Given the presence of variations in region, season and delivery, as well as potential changes in the biological characteristics of feedstock during transportation and storage, it is crucial to carry out regular and frequent feedstock quality checks. These checks are essential in ensuring effective feedstock quality control. By conducting feedstock quality checks at a sufficiently high frequency, businesses can identify any variations or changes in the characteristics of the feedstock, allowing for timely adjustments and interventions to maintain consistent and desirable feedstock quality standards.

The assessment of the suitability of biomass or biowaste as a potential feedstock for biogas and biomethane production should encompass the following aspects:

- Biomethane yield (or biomethane potential): a standard batch fermentation test performed in the laboratory for any new batch delivery and type of biomass.
- Suitability for anaerobic digestion: factors include biodegradability evaluation, C/N and even C:N:P ratios, other nutrient and trace element content and the presence of toxins or inhibitors.
- Production of feedstock: includes harvesting, collection, and storage.
- Transportation of feedstock and digestate: includes handling and post-processing.

Other factors may encompass:

- Pre-treatment, hygienisation, conditioning
- Reactor configuration, digestion process
- Digestate handling
- Use of biogas and digestate

Given that the biodegradability and energy content of biomass can vary over time and during harvesting, storage, and transportation, it is crucial to routinely analyse biomethane yield and biodegradability for each batch of feedstock delivery before feeding it into the biogas digester. This practice ensures efficient operation of the biogas plant and maximises the potential of the feedstock for energy generation.

2.4 Accessibility of feedstock

The level of accessibility differs between the various types of biomass. This is an important consideration in the assessment. It is essential to include the following two aspects of accessibility:

- Geographical accessibility: this involves assessing how distributed the biomass is. For instance, some types of industrial waste/residues may be concentrated at a few production sites, making them easily accessible from a geographical perspective. In contrast, other sources, such as algae, may be spread out over very large areas.
- Physical accessibility: this aspect considers the physical form of the biomass, focusing on how easy it is to access and use. For example, it is easier to collect algae from naturally occurring piles on the shore than to gather very diluted algae in the sea. The focus involves assessing the density, purity and other physical characteristics of the biomass. The physical form of the biomass also affects its transportability, thus influencing accessibility. High moisture content can add weight and volume, affecting transportation efficiency.

It is also relevant to consider how accessibility varies throughout the year and the implications of these variations. Additionally, the possibility of co-digesting various feedstocks with different methanogenic contents must be factored in. Assessing feedstock accessibility entails an evaluation of the compatibility and synergies among various feedstock sources, each with differing levels of accessibility.

The key question and indicator for the key area of accessibility is provided below:

- Key question: is the biomass suitable considering the physical and geographical accessibility?
- Indicator: geographical and physical accessibility

TABLE 6 THE SCALE FOR ASSESSING GEOGRAPHICAL AND PHYSICAL ACCESSIBILITY OF FEEDSTOCK [1]

Value	Scale definition (generic and case-specific)
Very good	Highly accessible biomass: most of the biomass is located within small or connected areas and is easily accessible. Assuming technological feasibility, biogas production appears favourable considering collection and transportation. This means that biogas production requires very limited organisational effort and investment for most of this type of feedstock.
Good	Largely accessible biomass: a large share of the biomass is located within small or connected areas and is easily accessible. Assuming technological feasibility, biogas production appears favourable within these areas considering collection and transportation. This would require limited organisational effort and investment.
Satisfactory	Moderately accessible biomass: a significant share of the biomass is located within small or connected areas is easily accessible. Assuming technological feasibility, biogas production is possible within these areas considering collection and transportation. This would require a certain level of organisational effort and investment.
Poor	Minimally accessible biomass: a small share of the biomass is located within small or connected areas and is easily accessible. Assuming technological feasibility, biogas production is possible within these areas considering collection and transportation. This would require a high level of organisational effort and investment.
Very poor	Poorly accessible biomass: most of the biomass is spread over large or unconnected areas or is in a form that is hard to access. This would potentially require as very high level of organisational effort/investment.

2.5 Amount of biomethane production

To estimate the overall biomethane potential for each potential feedstock, the biomethane yield (per unit of biomass) must be combined with an estimated biomass quantity. The key area is evaluated using one indicator:

- Key question: is the estimated total amount of this biomass substantial enough to make a significant contribution to the overall biomethane production?
- Indicator: amount of biomethane

In this context, the term "significant" in the key question needs to be clearly defined for the assessment. To address this, a case-specific scale definition is introduced for proper assessment. Furthermore, it is crucial to consider the timing of feedstock production and availability, whether it can be continuously supplied or has seasonal variations, and to analyse the effects of these temporal variations.

Table 7 illustrates the scale indicator for the amount of biomethane. It is important to note that the definition of the current generic scale is based on Sweden and serves as an example. Adaptation of value may be necessary according to regional and national specifics.

TABLE 7 THE SCALE FOR ASSESSING THE AMOUNT OF BIOMETHANE FROM THE TOTAL AMOUNT OF BIOMASS [1]

Value	**Scale definition (generic)** *The biomethane production from the estimated available amounts of feedstock is…*	**Scale definition (case-specific)** *In comparison with existing/planned production, the biomethane production from the estimated available amounts of feedstock corresponds to … of the biomethane production:*
Very good	≥ 500 GWh/year (≥ 50 million Nm^3/year)	≥ 70%
Good	300 - 500 GWh/year (30 - 50 million Nm^3/year)	40 – 70%
Satisfactory	100 - 300 GWh/year (30 - 50 million Nm^3/year)	10 – 40%
Poor	10 - 100 GWh/year (1 - 10 million Nm^3/year)	1 – 10%
Very poor	≤ 10 GWh/year (≤ 1 million Nm^3/year)	≤ 1%

2.6 Nutrient content and suitability for biofertilisers

The digestate can be repurposed as biofertilisers and soil improvers, making it a valuable by-product alongside biogas. Biogas feedstock contains essential nutrients, and the biogas process enhances their bioavailability, playing a central role in nutrient cycling.

The value and quality of the digestate as a biofertiliser depend on the type of feedstock, the digestion process and the digestate treatment methods used. Since this area is not assessed here, the description primarily focuses on biomass characteristics, nutrient content, and the presence of undesirable substances/materials that may impact biofertiliser quality. The key area is evaluated through two indicators:

TABLE 8 KEY QUESTIONS AND INDICATORS FOR NUTRIENT CONTENT AND SUITABILITY FOR BIOFERTILISERS [1]

Key question	Indicator
Does this biomass possess a desirable nutrient content?	Nutrient content (with a focus on nitrogen and phosphorus levels for simplicity and relevance)
Is this biomass suitable for biofertiliser production?	Suitability for biofertilisers

The value of biofertilisers is influenced by the content of undesirable substances/materials and their persistence. For instance, depending on the initial input material, digestate can carry potentially harmful elements for the environment or plastics when applied to the soil. However, certification and quality assurance systems are implemented in the EU to ensure that operators comply with high quality standards. At European level, the Fertilising Products Regulation (EU 2019/1009 [13]) defines limits for the contaminants accepted in products used as fertilisers and soil improvers. Post-treatment of digestate can also be effective in addressing these challenges (e.g. solid/liquid fraction separation or use of sulphuric acid).

Two perspectives are considered: the level of negative impact (contamination level) and the persistence of contamination over time.

Given that the focus of Task Force 3.4 does not specifically delve into nutrient content and suitability for biofertilisers, only a concise description is provided here. For more detailed information, please refer to the reports from Task Forces 2 and 5.

2.7 Amount and value of biofertilisers and soil improvers

The high value of digestate as biofertiliser stems not only from its nutrient content (nitrogen, phosphorus and potassium) but also from its rich organic matter and microbial content. It supports life in the soil and contributes to a well-balanced microbiome that enhances plant resistance to pests. While the assessment of biofertilisers and soil improvers primarily focuses on the total nitrogen and phosphorus content, other nutrients are also considered. The nutrient values per unit (from the key area "suitability for biofertilisers") are combined with the estimated amount of feedstock to assess the extent to which production based on a specific feedstock can contribute to nutrient recycling. Biofertilisers such as digestate and compost have the potential not only to replace other fertilisers, but also to be more effective than mineral fertilisers in restoring soil quality and biodiversity.

It is crucial to consider the timing of feedstock production and availability, particularly whether it can be continuously supplied or exhibits seasonal variations, and to analyse the effects of these variations.

Since the primary focus of Task Force 3.4 does not focus on the amount and value of biofertilisers, only a concise description is provided here. For more detailed information, please refer to the report from Task Force 3.3.

2.8 Technological feasibility

This key area specifically addresses the technological possibilities and challenges related to the production of biogas from a specific type of feedstock. The key question and indicator for technological feasibility are as follows:

- Key question: are the required technologies and infrastructures available and applicable, considering the entire life cycle for biogas and biofertilisers produced from this biomass?
- Indicator: technological feasibility

Technological feasibility focuses on determining whether the necessary technologies and infrastructures exist and if they are both available and applicable. This includes the management of biomass in the anaerobic digestion plant (storage, pre-treatment, dosing, feeding methods), the fermentation technology suitable for the feedstock (wet, semi-dry, dry anaerobic digestion) and the data measurement and recording systems compliant with certification schemes.

It also encompasses the valorisation of biogas (cogeneration, upgrading to biomethane, liquefaction of biomethane, recovery of carbon dioxide, conversion to different molecules and integration into other processes), the post-treatment of the digestate for recovery and valorisation of nutrients and the distribution systems of the digestate at high efficiency and low ammonia and greenhouse gas emissions.

Additionally, it considers the varying levels of readiness for technological solutions, from early research and development phases to pilot testing and those fully developed and available on the market. Furthermore, it accounts for potential challenges for which there are currently no known technological solutions.

Table 9 illustrates the scale indicator for technological feasibility. This scale is suggested both for generic and case-specific assessments.

TABLE 9 THE SCALE FOR ASSESSING TECHNOLOGICAL FEASIBILITY [1]

Value	**Scale definition (generic and case-specific)** *Considering the full life cycle of producing biogas and biofertilisers and focusing on the specific technologies required for the evaluated feedstock, the general opinion of biogas production experts is that:*
Very good	Mature technological solutions: solutions exist on the market, and are applicable, and commonly implemented in an optimised way. This means that biogas production from this feedstock faces no technological barriers and there is no significantly underdeveloped technology at any stage of the life cycle.
Good	Technological solutions with areas for improvement: solutions exist on the market, are applicable and implemented, but there are areas that could be improved. This means that while biogas production from this feedstock faces no technological barriers, there are significantly underdeveloped technologies that could be enhanced.
Satisfactory	Technological solutions needing significant improvement: solutions exist on the market, are applicable and implemented, but there are areas that require significant improvement. This means that although

	biogas production from this feedstock does not face technological barriers, a few underdeveloped technologies need substantial enhancement.
Poor	Promising research or development activities: existing market solutions are not applicable or are very inefficient, or no technological solutions exist on the market. However, there are promising research and development activities expected to solve the problems within 10 years. This means that biogas production from this feedstock faces technological barriers and many underdeveloped technologies need significant improvement.
Very poor	No feasible technological solution: no technological solutions exist on the market or relevant research and development activities are ongoing but are not expected to solve the problem within 10 years. This means that biogas production from this feedstock is not feasible.

2.9 Profitability or cost-efficiency

To sustain and expand biogas production, it is crucial for the stakeholders involved to thrive economically. This key area has a broader scope than the previous areas, incorporating insights from earlier assessments. Ultimately, it is important to remember that sustainability drives profitability, ensuring long-term economic success for all stakeholders.

The key question revolves around the economic feasibility of producing biogas from a specific biomass, recognising that perspectives and opportunities vary based on the context. Standalone biogas and biofertiliser production should be profitable. However, in other contexts, biogas production may primarily serve as a cost-efficient waste treatment solution. For instance, a biogas plant processing wastewater from an on-land fish farm may not be individually profitable but could represent a cost-effective solution for the farm. This, in turn, enhances overall company profitability and contributes to climate goals by reducing reliance on fossil fuels.

The focus is not solely on costs or income related to biogas but also encompasses economic considerations tied to biofertilisers and other products. This analysis can expand to cases where a biogas solution contributes to enhanced environmental performance for products or services, potentially increasing their overall value.

Table 10 illustrates the scale indicator for profitability or cost-efficiency. This scale is suggested for both generic and case-specific assessments.

TABLE 10 THE SCALE FOR ASSESSING PROFITABILITY OR COST-EFFICIENCY [1]

Value	Scale definition (generic and case-specific)
Very good	Biogas production from this feedstock will likely contribute to significant profitability or cost-efficiency, even if investments in new plants or facilities are required. The economic situation is characterised as stable. This means that, from an economic perspective, producing biogas from this feedstock appears very favourable, even if investments in production facilities are needed.
Good	Biogas production from this feedstock will likely contribute to profitability or cost-efficiency, even if investments in new plants or facilities are required. The economic situation is characterised as stable.

	Alternatively, biogas production from this feedstock will likely contribute to significant profitability or cost-efficiency if the feedstock is used within existing biogas facilities. The economic situation is characterised as stable. This means that, from an economic perspective, producing biogas from this feedstock appears very favourable if no investment in production facilities is needed, or at least acceptable even if investments are required.
Satisfactory	Biogas production from this feedstock might contribute to profitability or cost-efficiency, even if investments in new plants or facilities are required. The economic situation is characterised as uncertain or varying. Alternatively, biogas production from this feedstock will likely contribute to profitability or cost-efficiency if the feedstock is used within existing biogas facilities. The economic situation is characterised as stable. This means that, from an economic perspective, producing biogas from this feedstock appears reasonable if no investments in production facilities are needed and it might be good even if investments are required. However, the latter is uncertain.
Poor	Biogas production from this feedstock will likely lead to losses or cost-inefficiency if investments in new plants or facilities are required. Alternatively, biogas production from this feedstock might contribute to losses or cost-inefficiency if the feedstock is used within existing biogas facilities. The economic situation is characterised as uncertain or varying. This means that, from an economic perspective, it does not seem reasonable to utilise this feedstock for biogas production, at least not to a large extent. There is a significant risk of losing money, or there are other more cost-efficient options.
Very poor	Biogas production from this feedstock will likely lead to significant losses or cost-inefficiency if investments in new plants or facilities are required. Alternatively, biogas production from this feedstock might contribute to losses or cost-inefficiency even if the feedstock is used within existing biogas facilities. This means that, from an economic perspective, it would be very unwise to utilise this feedstock for biogas production. There is a large risk of losing money.

2.10 Control and competition

Closely intertwined with profitability, particularly crucial for long-term assessments, is the consideration of the extent to which biogas and biofertiliser producers can control or secure the provision of a specific type of feedstock. Additionally, it is vital to examine and assess the competition for feedstock. This evaluation should also encompass exploration of the potential for producing other types of products or services and their value in existing and future markets.

Table 11 illustrates the scale indicator for control and competing interests. The scale is suggested both for generic and case-specific assessments.

TABLE 11 THE SCALE FOR ASSESSING PROFITABILITY OR COST-EFFICIENCY [1]

Value	Scale definition (generic and case-specific)
Very good	Existing biogas and biofertiliser producers have control over this feedstock, and this is expected to remain for a long period (at least for 7 years). Alternatively, if existing biogas and biofertiliser producers would like to produce biogas from this feedstock, they are able to sign very long-term contracts (at least for 7 years) to secure the access during this period. Except for biogas and the by-products from that production, there seems to be no realistic competing options for production and valorisation. Regarding control and competition, the terms for access are reasonable, considering a period of at least 7 years.
Good	If existing biogas and biofertiliser producers would like to produce biogas from this feedstock, they are able to sign long-term contracts (at least for 5 years) to secure access during this period. The feedstock might be used for some other applications, and competition might increase in the future. Regarding control and competition, the terms for access are reasonable, considering a period of at least 5 years, but the long-term picture is a bit uncertain.
Satisfactory	If existing biogas and biofertiliser producers would like to produce biogas from this feedstock, they are only able to sign very short-term contracts (at least for 1 year) to secure access during this period. The feedstock is used for some other applications, and many others are possible, so competition is expected to increase significantly in the near future. Regarding control and competition, the terms for access are only reasonable for a period of 1 year, but the long-term picture is very uncertain.
Poor	If existing biogas and biofertiliser producers would like to produce biogas from this feedstock, they are only able to sign very short-term contracts (at least for 1 year) to secure the access during this period. The feedstock is used for some other applications, and the competition is expected to increase significantly in the near future. Regarding control and competition, the terms for access are only reasonable considering a period of 1 year, but the more long-term picture is very uncertain.
Very poor	Existing biogas and biofertiliser producers cannot get access to this feedstock because they do not control it and/or the competition for it is too tough. Regarding control and competition, this feedstock is not realistic to utilise for biogas production.

2.11 Institutional support and societal acceptance

The perception of biogas within institutions and society is of significant relevance. Means of control are widely acknowledged by biogas actors as highly influential, making them a focused area in this assessment. Public opinion also wields a significant impact in numerous ways, influencing decision-makers and shaping the choices of organisations and individuals.

This key area encompasses two key questions and three indicators:

TABLE 12 KEY QUESTIONS AND INDICATORS FOR INSTITUTIONAL SUPPORT AND SOCIETAL ACCEPTANCE

Key question	Indicator
Is biogas production from this biomass supported by the government and other institutions?	• Level of support and administrative implications • Planning horizon and clarity of business implications
is the public opinion about biogas/biomethane production from this biomass positive?	Public perception

The first indicator considers the present level of support and administrative implications, assessing the efficiency of the support system from an administrative viewpoint and its socio-economic feasibility. Additionally, it explores the clarity and stability of the rules and conditions over time. The second indicator evaluates public opinion regarding the production of biogas from a specific feedstock.

The third indicator concerns public opinion regarding production of biogas from a certain type of feedstock. As the primary focus of Task Force 3.4 does not focus on institutional support and societal acceptance, only a concise description is provided here.

2.12 Reduction of environmental and greenhouse gas emissions

The Renewable Energy Directive ((EU) 2023/2413 [14]) extends the sustainability requirements for biogas and biomethane, leading operators to prioritise feedstocks that yield the best results in terms of reducing greenhouse gas (GHG) emissions. Additionally, Directive (EU) 2018/2001 [15] promotes the use of degraded or contaminated agricultural land to improve the environmental performance of those areas. To drive strong reduction of GHG emissions, strict limit values are set for the various applications of biomethane (further details can be found in Chapter 4).

3.

Classes of sustainable feedstocks

3 Sustainable feedstocks

EU legislation lays down a series of criteria for certifying biogas production as sustainable. These criteria are detailed in the Renewable Energy Directive and can be divided into two categories, including sustainability criteria and greenhouse gas emission savings criteria:

- Sustainability criteria: these apply according to the type and origin of the feedstock used to produce biogas. Depending on whether the feedstock comes from agricultural biomass, forest biomass, or waste and residues derived from agricultural land, the producer must prove that the feedstock meets criteria relating to land conservation, sustainable forest management and harvesting practices and the implementation of soil quality management plans.
- GHG Emission Savings Criteria: different greenhouse gas emission reduction rates must be achieved depending on whether the biogas is used in the transport sector or to produce electricity, heating and cooling, and depending on when the installation came into operation.

Based on the criteria mentioned above regarding the suitability for biogas production, feedstock may be categorised into the groups under paragraph 3.1. It is important to note that the suitability of these feedstocks can vary depending on factors such as regional availability, local regulations and specific biogas plant requirements. The mentioned examples serve as general categories, and the specific suitability of a feedstock should be evaluated based on its biomethane potential, biodegradability, nutrient content and the absence of toxins or inhibitors for anaerobic digestion. The Renewable Energy Directive also refers to the growing recognition of the need to align bioenergy policies with the principle of the cascading use of biomass and the waste hierarchy established in Directive 2008/98/EC of the European Parliament and of the Council. This principle particularly applies to residual biomass from the processing of agricultural material, given that RED sustainability criteria primarily address biomass from forests and agricultural lands. The cascading principle aims to achieve the resource efficiency of biomass use by prioritising, wherever possible, the material use of biomass over its energy use, for example, animal feed. The EU has set ambitions to enhance EU feed autonomy by making better use of biomass available in the EU to reduce reliance on imported feed materials. The sustainable use of feedstock in biomethane should therefore also be seen considering impacts on EU feed autonomy.

3.1 Classes of feedstocks

Based on those principles, feedstocks could be categorised into different classes (sequential/rotational crops and feedstock production on marginal and contaminated land are discussed and validated in Task Force 3.1 and 3.2):

1. Agricultural residues (including manure)
2. Residues from industrial processing of agricultural material
3. Wastewater and sewage sludge
4. Industrial and municipal waste (organic fraction)
5. Innovative feedstock

3.2 Agricultural residues (including manure)

Agricultural residues comprise crop and harvesting residues (e.g. straw, corn cobs, leaves), fodder crops (e.g. grasses, legumes), as well as liquid and solid manure (from pigs, cows, poultry). These residues also include plant biomass on marginal and contaminated land. Biomethane yield and biodegradability need to be evaluated to ensure this type of biomass can truly be used as feedstock for biogas production. For high-solid-content plant materials, pre-treatment is often needed to balance the nutrient content, enhance biodegradability, and shorten degradation time. Additionally, due to the high C/N ratio and lack of micronutrients from plant material, co-digestion with biowaste, manure or low C/N value biomass is often required.

To assess this kind of waste as feedstock for biogas production, the following factors need to be evaluated:

- Biomethane yield and biodegradability
- C/N ratio
- Production of feedstock, harvesting, collection and storage
- Transportation of feedstock
- Pre-treatment and conditioning
- Digestate handling and utilisation
- The facility's finances (OPEX, CAPEX) and the demand for end products

3.3 Residual biomass from processing of agricultural material

The processing of agricultural material generates not only main products and by-products, such as food and feed, textiles, pulp and paper and biochemicals, but also residues and wastes. Handling this residual biomass generally poses challenges for further processing into by-products, as these solid or liquid streams contain mixtures of carbohydrates, lignocellulose, protein, fat, oil, organic acids, and alcohols. Some examples include starch slurry, steepwater, thin stillage, filtration retentate, pulp from beet, potato and wood, citrus peel, bagasse, non-processed biomass, vinasses, head and tails, and residues from animal products processing.

To assess these kinds of residues and wastes as feedstock for biogas production, the following factors need to be evaluated:

- Biomethane yield and biodegradability
- Toxicity or inhibition assessment
- C/N ratio
- Transportation of feedstock
- Digestate handling and utilisation

3.4 Wastewater and sewage sludge

Already frequently in place, wastewater from various sources with a high carbon content is a perfect feedstock for biomethane production. Examples include industrial effluents from starch, sugar and pulp and paper processing units, and waste from chemical and pharmaceutical production. Other industrial production plants such as the meat and milk industry, ethanol production and wastewater from food and beverage production are also valuable. Municipal wastewater and sewage sludge (primary and secondary sludges, or sludge mixtures) complete this type of waste for biomethane production.

To assess this kind of waste as feedstock for biogas production, the following factors need to be evaluated:

- Biomethane yield and biodegradability
- C/N ratio
- Transportation of feedstock
- Digestate handling and utilisation
- The facility's finances (OPEX, CAPEX) and the demand for end products

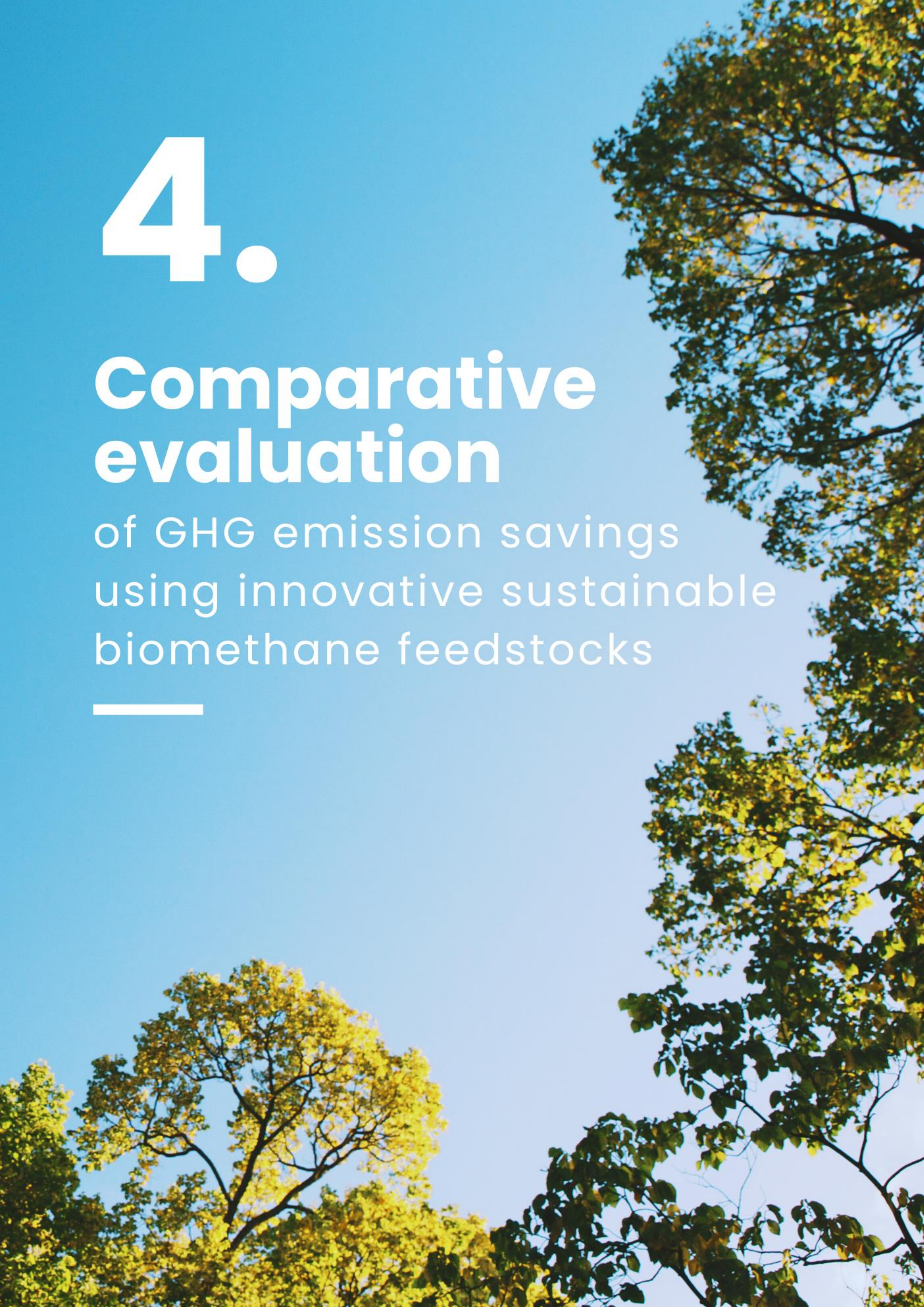
3.5 Organic fraction of municipal waste

The organic fraction of municipal solid wastes (OFMSW), including household food waste, food and vegetable waste from restaurants and supermarkets, large-scale catering establishments, and food shops, could be an important source of feedstock for biomethane production.
To assess this kind of waste as feedstock for biogas production, the following factors need to be evaluated:

- Biomethane yield and biodegradability
- Toxicity or inhibition assessment
- C/N ratio (optional)
- Collection and storage
- Transportation of feedstock
- Hygienisation
- Digestate handling and utilisation
- The facility's finances (OPEX, CAPEX) and the demand for end products

3.6 Innovative feedstocks

Marginal lands, polluted soils and waters, and industrially affected areas are subject to remediation approaches, including phytoremediation. Innovative feedstocks such as plant biomass or aquatic biomass produced in areas unsuitable for food and feed production could help expand the feedstock base for biomethane production. Currently, these feedstocks do not have the technical readiness level to be used in large-scale industrial plants and require further research activities. Nevertheless, in the long term, these feedstocks could play an important role in replacing other feedstocks that may become difficult to generate due to changes in agricultural and industrial practices or markets.



4.

Comparative evaluation

of GHG emission savings using innovative sustainable biomethane feedstocks

4 Comparative evaluation of GHG savings using innovative sustainable biomethane feedstock

Biomethane is a flexible and sustainable energy source that can be used across various sectors, including transportation (road and shipping), heating (for industrial and residential use) and power generation. Its versatility allows biomethane to directly substitute fossil fuels in these sectors, offering the potential for substantial reductions in greenhouse gas emissions. Compliance with sustainability and GHG emissions criteria of Directives EU 2023/2413 and EU 2001/2018 for gaseous biomass fuel, including biomethane, is necessary to:

- Be recognised as renewable and count towards the Renewable Energy target and subtargets
- Be "zero-rated" under the EU ETS system
- Be eligible for public support

The Directives provide a comprehensive framework of sustainability requirements to ensure that the production of biogas is environmentally sustainable. The use of residues and waste is particularly suited to reducing carbon intensity overall, since the impact of their production is allocated to the previous use, and therefore, they come with zero GHG emissions attributed to the production (excluding transport and pre-treatments from the place of disposal). Additionally, RED Annex IX part A classifies some feedstocks as low-ILUC risk biomass sources, which can contribute towards the renewable energy targets of advanced biofuels and biogas for transport. This list is subject to periodic review by the European Commission, following an analysis of the potential feedstock, which considers the principles of the circular economy and the waste hierarchy to avoid significant distortive effects on markets, negative impacts on the environment and biodiversity, and creating additional demand for land.

Biogas and biomethane pathways supplied by waste and residues should generally be able to fulfil the GHG saving thresholds as shown in the pre-calculated carbon intensities reported in the RED, Annex VI. Prioritising the recovery of bio-derived wastes and residues for sustainable biomethane production is widely recognised both by biogas operators and NGOs, offering new opportunities to further decarbonise the biogas sector and contribute to waste disposal [16]. There is still a huge, unlocked potential from various feedstock sources, i.e. 24 bcm by 2030 according to ICCT estimations [17] or 111 bcm by 2040 according to Guidehouse, which can substantially contribute to the REPowerEU target. However, due to the difficulties in categorising such feedstocks, wide geographical distribution, uncertainties related to contaminations and homogeneity, and possible regulatory constraints, this category requires careful monitoring of characteristics and traceability of the supply chain, to ensure both profitable biomethane production and compliance with legislative specifications.

To deliver sustainable biomethane from innovative waste streams, the following sections show the methods to evaluate the carbon intensity of biogas using both default and actual values for GHG emission calculations. For EU operators, there are also additional, growing reporting obligations such as the Corporate Sustainability Reporting Directive (CSRD), which require companies now and in the future to report in detail the environmental impacts of their business operations. Note that CO_2 calculation rules of the RED are slightly different from the internationally accepted GHG protocol rules. When reporting on the climate impacts of business operations, it is customary to classify emissions into scope 1, 2, and 3 categories in accordance with the GHG protocol. Classification of emissions reduces the risk of double counting between emission calculations of different companies and helps the company and the company's stakeholders to understand the most significant emission sources of the company's business in its own and value chain operations.

4.1 Determination of GHG emission intensity for biomethane from waste and residues according to the latest version of the RED

This section outlines the procedure that a biogas operator should follow to determine the carbon intensity of biomethane using either the pre-calculated default values available in the RED (EU 2018/2001) Annex VI (for biowastes or manure) or actual values representing the real emissions calculated for their specific case study. GHG emission savings are then calculated by considering the carbon intensity of the fossil fuel comparator (FFC), set at 94 g CO_2e/MJ for liquid biofuels and biomethane used in the transport sector. The FFC is set at 80 g CO_2e/MJ if the biomethane is used to produce heat or cooling, and at 183 g CO_2e/MJ to produce electricity. The emission savings are calculated using the following formula:

$$GHG\ emissions\ savings\ (\%) = \frac{Efossil - Ebiogas}{Efossil}$$

FIGURE 3 THE FORMULA FOR CALCULATING GHG EMISSION SAVINGS

Where E_{biogas} is the carbon intensity of biogas or biomethane and E_{fossil} is the carbon intensity of the FCC depending on the application. For liquid biofuels and biomethane for transport, the requirements for GHG emission saving are set at 65% (i.e. 32.9 g CO_2e/MJ). For other uses such as heat and electricity, the GHG reduction is set at 80% (i.e. 36.6 g CO_2e/MJ for electricity and 16 g CO_2e/MJ for heating and cooling), with a grandfather clause for existing installations phased out until 2030. It is worth noting that installations of biogas for electricity built before 31 December 2025 and installations of biomethane production built before 31 December 2021, have lower GHG reduction thresholds.

The EC verifies the sustainability requirements using accredited certification bodies, named voluntary schemes and national certification schemes, which are available for EU countries to certify biofuels, bioenergy and biomethane supply chains [18].

The following is the procedure to follow in order to calculate GHG emissions for biomethane sustainability certification:

1. Check whether the waste or residue is a real end-life product that can be recovered by other purposes without requiring further post-treatment (e.g. hygienisation, etc.).
2. Check if the feedstock meets requirements for wastes hierarchy and disposal (referring, for example, to Waste Framework Directive 2008/98/EC and amendments, specific national regulations, etc.).
3. Check if the feedstock falls under RED Annex IX part A to be eligible as a preferred biomass for use as transport fuel.
4. The GHG emission savings from the use of biofuels can be calculated either using the pre-calculated default values or by adopting a combination of actual values and disaggregated default values (as shown in RED Annex V and VI). The emissions from the biofuel in use (combustion) are considered to be zero for biofuels, due to the biogenic origin of the fuels. The methodology takes into account all other GHG CO_2 equivalent emissions as CH_4 (e.g. from biogas fugitive emissions) and N_2O (e.g. from fertilisers). Emissions from the manufacture of machinery and equipment are not considered.
5. Wastes and residues come with zero GHG emissions for the extraction or cultivation of raw materials and processing until the point of collection, but emissions for transport and pre-treatments before anaerobic digestion are included.
6. In the case of manure, a GHG emissions credit is given, since its recovery to produce biogas considerably decreases methane emissions associated with the storage of manure in open tanks and its use as fertiliser on agriculture fields. The credit of 45 g CO_2eq per MJ of manure has been calculated for "wet manure" with a moisture content of 90%. Further explanations on the calculation methodology are provided in the JRC report [19].
7. When the residues or wastes lead to higher biomethane productivity than the baseline scenario assumed for the calculations of the default values, actual values can be used. As explained in section 4.1, the measure of BMP can be used to estimate the biomethane production and therefore to re-calculate its carbon intensity.
8. Depending on the origin of waste and residues, digestate can be assumed to be: (1) organic fertiliser; (2) waste to be disposed.
9. Finally, if biomethane productivity from wastes and residues is equal or higher than the one assumed within the JRC calculation [19] and biomethane fugitive emissions are limited (e.g. digestate closed storage; low methane leaks at the biomethane upgrading section; etc.), GHG savings of biomethane are well below 32.9 CO_2eq per MJ.

4.2 ILUC-risk biomass and biomethane

While biofuels are important in helping the EU meet its greenhouse gas reduction targets, conventional biofuels are also produced from croplands that are also used (or were previously used) for feed and food production. As explained in section 2.12, to address the issue, high ILUC-risk biofuels have been limited at 2019 levels and will gradually be reduced to zero by 2030 at the latest. The European Commission published in 2019 a report on the status of production expansion of relevant food and feed crops worldwide [20] to support this initiative. The Delegated Regulation on indirect land use change [21] set provisions to determine the high ILUC-risk feedstock for which a significant expansion of the production area into land with high carbon stock is observed. It also set out criteria to certify low ILUC-risk biofuels, bioliquids and biomass fuels. Furthermore, specific rules and methodological guidance for certification of low ILUC-risk biofuels, bioliquids and biomass fuels have been included in implementing the regulation on sustainability certification proposed by the Commission in line with Article 30(8) of RED, which entered into force on 14 June 2022 [22].

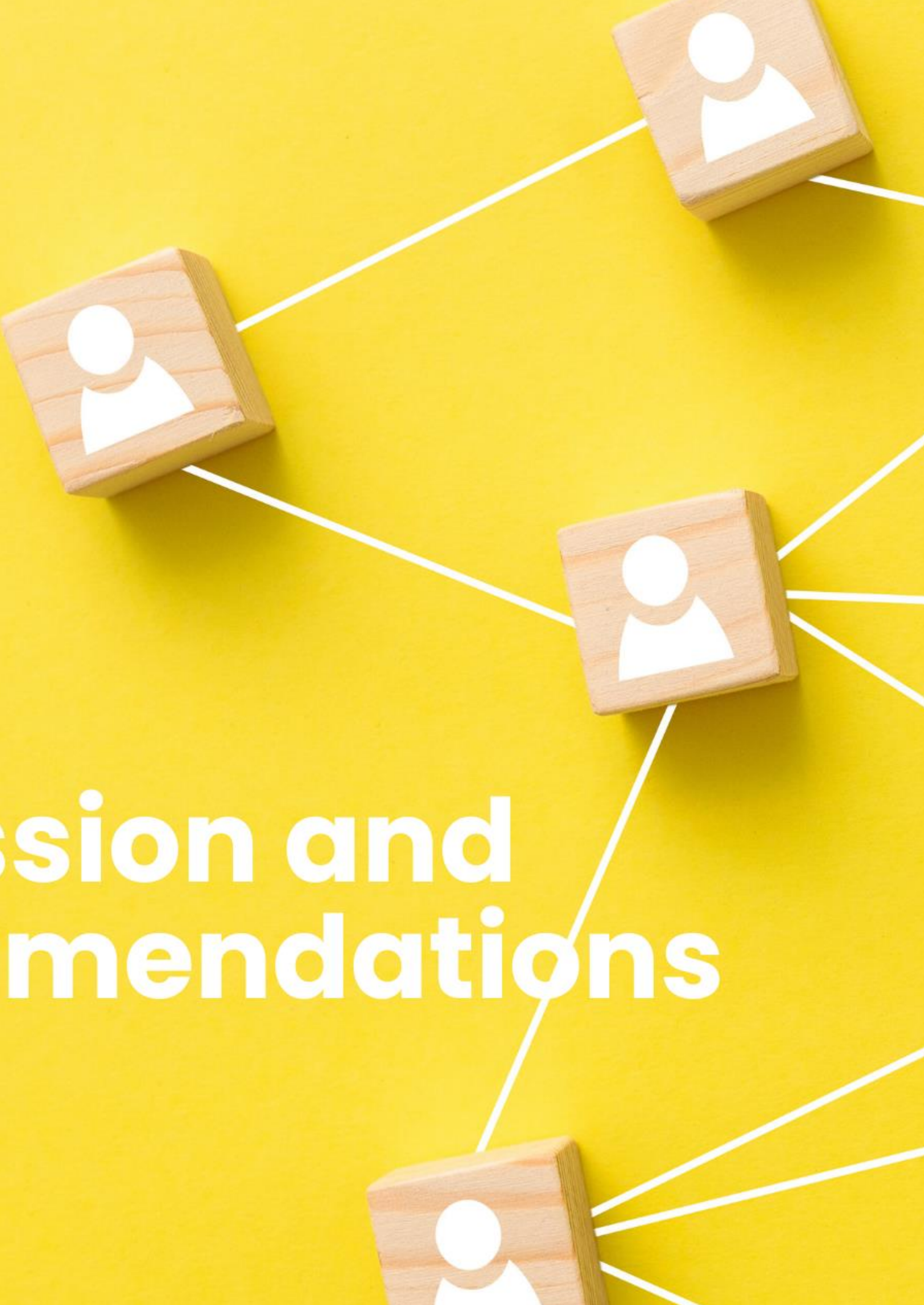
To translate these policies into practical information for the operators producing advanced biofuels, in March 2024, the Commission released the Delegated Directive (EU) 2024/1405 amending Annex IX (RED) list for eligible feedstocks [23]. This list is subject to periodic review by the European Commission, following an analysis of the potential feedstock which considers the principles of the circular economy and of the waste hierarchy to avoid significant distortive effects on markets, negative impacts on the environment and biodiversity, and creating additional demand for land. After the final adoption in March 2024 there is an 18-month transition period for Member States.

4.3 Biomethane in the EU ETS

The European Union Emissions Trading Scheme (ETS) (2003/87/EC) [24] is a cap-and-trade system that limits the GHG emissions of energy-intensive industries, as well as aviation and maritime transport. An important part of the ETS is that biomethane is only counted as renewable if the user demonstrates, via certification under voluntary and national schemes as mandated by the Renewable Energy Directive III and the ETS, compliance with the GHG savings required in the RED. Users can obtain the necessary evidence from the biogas or biomethane supplier or obtain certification to issue proofs of sustainability themselves and manage their own mass balance system. This could be particularly beneficial for EU ETS operators who produce the biomethane themselves. Within this system, the cost of carbon (€/t CO_2eq) traded in the EU Emissions Trading Scheme (ETS) incentivises the operator to reduce GHG emissions and costs by offsetting with the use of biomethane. Biomethane upstream emissions are still calculated using the RED methodology. All biogas and biomethane consumed by companies under the EU ETS will be reported as zero emissions if they comply with sustainability and GHG emission savings requirements of the RED, thus avoiding the purchase of emission allowances.

5.

Discussion and recommendations



5 Discussion and recommendations

In recent years, several modelling exercises have provided biomethane estimates towards 2030 and beyond, based on current and upcoming EU policy targets, biomass and biowaste potential and economic factors. For instance, a recent study by IFEU [25] reviewed multiple scenarios proposed by various institutions and highlighted differences in estimates between biowaste and crops for biogas production (including all crop categories). Following the release of Commission Delegated Directive (EU) 2024/1405 amending the RED Annex IX, the European Commission clarified the rules for defining low-ILUC feedstock for both biogas for transport and advanced biofuel production. This includes cases where intermediate crops and crops coming from severely degraded lands are eligible for the purpose of producing aviation fuels only (referring to Annex IX part A). On the other hand, more recent biomethane potential estimates towards 2040 [26] proposed scenarios where these opportunities are considered for sourcing additional biomass. It will depend upon the needs of MS and the EC if others can be considered or not (as reported in the Article 27 point 3 of the Directive (EU) 2023/2413). The Task Force 3.4 deliverable is not intended to guide decisions regarding potential business models for biogas plants or to promote the use of specific feedstock categories. It does not address the potential advantages of adopting particular feedstock sources but instead emphasises the importance of identifying sustainable feedstocks and ensuring flexible sourcing of feedstocks. Moreover, the report does not delve into the complexities of digestate use or its associated benefits and challenges within the economic framework of the plant (these aspects are covered in other BIP reports dedicated to digestate use). By clarifying and making transparent the issues surrounding sustainable feedstock sourcing, this report aims to ensure the long-term viability and efficiency of biomethane production.

Building upon this foundation, the authors encourage stakeholders and operators in the biogas sector to continually seek sustainable feedstock supplies, following the guidelines proposed in EU legislation. Each case study, defined by the choice of feedstock and plant operations, requires a careful evaluation of its specific context. This includes considering characteristics and suitability of the feedstock, national policies that may influence feedstock availability and incentives, climate conditions affecting aspects such as digestate storage and logistics, and economic factors that determine the financial viability of biogas production. Additionally, assessing GHG emissions in accordance with RED guidelines using real data, can help determine whether innovative practices lead to greater GHG savings compared with standard default values cited in legislation. For instance, emission savings from advanced agro-practices as outlined in Commission Regulation (EU) 2022/2472 provide potential opportunities for creating new supply chains.

Conclusion

The urgency to bolster biomethane production in Europe, driven by imperatives to diminish dependence on non-EU natural gas imports, mitigate escalating energy costs and confront climate change challenges, has prompted the introduction of the REPowerEU plan by the European Commission. The Task Force 3.4 report harnesses the multi-criteria approach developed by the BSRC project, leveraging the collective expertise of task group members to furnish selection criteria for identifying and selecting sustainable feedstocks for biogas and biomethane production.

To achieve the envisioned scale-up of biomethane production by 2030, a diverse array of feedstocks must be deployed. This encompasses residues and waste from diverse biomass processing units as well as innovative feedstocks slated to reach technological readiness levels by 2030. Given the heterogeneous climate zones in Europe, a region-by-region screening for the most valuable available feedstocks becomes imperative, spanning residues, wastes and marginal, contaminated and innovative biomass sources.

Critical to this endeavour is the availability of feedstocks in ample volumes in close proximity to minimise long-distance transport, thereby optimising the greenhouse gas mitigation potential of biomethane production and use. However, ensuring the consistent quality of feedstocks is paramount. Regular and frequent feedstock quality checks are crucial to evaluate suitability for biogas and biomethane production, particularly considering variations in region, season and delivery.

Irrespective of biomass and biowaste origin, ensuring readily biodegradable materials with high biomethane potential is paramount for cost-effective biogas and biomethane production within reasonable degradation periods in full-scale biogas plants. Thus, comprehensive feedstock quality checks again emerge as indispensable to evaluate suitability for biogas and biomethane production, particularly considering variations in region, season and delivery.

Underpinned by the robust regulatory framework of the Renewable Energy Directive (EU 2018/2001), feedstock selection aligns with stringent sustainability criteria, excluding options with adverse environmental impacts and suboptimal greenhouse gas emission balances. Moreover, the final application of produced biomethane significantly influences feedstock selection, with varying greenhouse gas emission savings compared with fossil alternatives across various sectors.

This report underscores the pivotal role of biomethane as a sustainable, versatile energy source across diverse sectors, with emphasis on its potential to replace fossil fuels and significantly curtail greenhouse gas emissions. Sustainability requirements mandated by the Renewable Energy Directive (EU) (2001/2018) and it update (RED 2023/2413) play a pivotal role in ensuring compliance and sustainability along biogas and biomethane pathways. Despite the substantial potential of residues and waste streams for biomethane production, careful monitoring is essential to balance profitability with regulatory compliance, given the geographical dispersion and regulatory complexities surrounding these sources. The methodology outlined for determining the carbon intensity of biomethane underscores the importance of feedstock characterisation, traceability, supply chain evaluation, and compliance with obligations stipulated in the European Union Emissions Trading Scheme.

In conclusion, the recommendation of the authors in addition to the methodology proposed within this report, is a detailed case-by-case assessment that considers the specificities of feedstock availability, biogas plant location, size and operations, and the broader socio-economic and policy context to ensure the sustainable and economically viable production of biomethane.

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