DBFZ

GUIDANCE DOCUMENT

Technical principles and methodology
for calculating GHG balances of

Biomethane

Version 1.0

2016

Technical principles and methodology for calculating GHG balances of Biomethane

Authors:
Katja Oehmichen
Karin Naumann
Jan Postel
Christian Drache

Maria Braune
Arne Gröngröft
Stefan Majer
Kathleen Meisel
Franziska Müller-Langer

With support from

Federal Ministry
of Food
and Agriculture

FNR
Fachagentur Nachwachsende Rohstoffe e.V

by decision of the
German Bundestag

Content

Preamble

© Andrei Merkulov (Fotolia.com)

In the recent years, the GHG emission saving of biofuels has become an important factor for their market acceptance and competitiveness. As a result, the number of individual calculations based on actual values (often for processing and transport) is increasing. Individual calculations have to be conducted according to the methodology for the calculation of the GHG emission saving defined in the EU RED. Since the derivation of the GHG emission saving of a biofuel is part of the sustainability certification process (to proof compliance with the sustainability criteria defined in the EU RED Directive), auditors need to be able to review the calculated values. Therefore, a competent, independent and reliable audit of the detailed GHG data has to be an essential part of the sustainability certification and forms the basis for fair competition and for the credibility of the biofuels industry. The audit therefore requires the auditors to have first of all a sound knowledge of the technical processes of biofuel production in order to be able to, among other things, assess the material and energy balances that form the basis of the GHG balance and secondly a solid knowledge of GHG balancing to certify the GHG calculations.

This guidance document is the result of a project which has been carried out in order to address the specific demand for documents supporting auditors during the sustainability certification.

The overall objective of this document is, thus, to gather and prepare information on raw material preparation and biofuel production technologies in order to competently support the auditing of submitted GHG balances. Altogether, three guidance booklets have been developed. They cover the main biofuel options currently available in Germany and in Europe: biodiesel, bioethanol and biomethane. They follow the same structure and contain a description of the technology, plausibility tables for typical input and output quantities of production facilities, an example calculation of GHG balances, a section on frequently asked questions (FAQs) in the context of the GHG balance audit (FAQ), and conversion charts. An overview of the referenced literature and further readings is listed at the end of each booklet.

The guidance should be treated as a supplemental and supportive collection of information. It does not replace current certification principles or legal regulations. The corresponding legal regulations, communications and system principles, valid as of October 2015, were used to create the documents.

The principles of biomethane production

The process of biomethane production includes producing biogas, process-ing the biogas into biomethane, and conditioning the biomethane (see Figure 1). After undergoing various decomposition processes (fermenta-tion processes), a methane-rich gas is produced from a raw material, the **feedstock** (primarily cultivated biomass, waste material, residues, and farm manure), in the fermenter of a **biogas plant**. During the fermenta-tion process a gas mixture (biogas) is produced under oxygen deprivation. This gas is a metabolic product produced from the organic substances through microorganisms. This type of fermentation is also referred to as anaerobic digestion. The biogas, which is the main product of the fermenta-tion, mainly consists of methane (CH_4) and carbon dioxide (CO_2), as well as small amounts of water (H_2O) and hydrogen sulphide (H_2S). The undesir-able constituents, such as carbon dioxide, water and sulphur, are separated during **biogas cleaning**, thereby enriching the methane so that it can be fed into the natural gas grid or used as a fuel. Before it can be fed into the natural gas grid, the biomethane must be **upgraded** so that its composition conforms to the quality of the natural gas required locally (L gas or H gas). Other inputs are needed in addition to the fermentation substrate, which is the primary raw material. This includes process energy in the form of heat and electricity, as well as auxiliaries that are added to the process. In addition to the main product, biomethane, the process produces other products, such as residues and waste materials, as well as methane, which escapes unintentionally from the plant units in the form of a methane slip. The remaining fermentation residue, usually referred to as digestate, left over from the fermentation process is usually used as an organic fertiliser. Sometimes the digestate is treated before it can be applied.
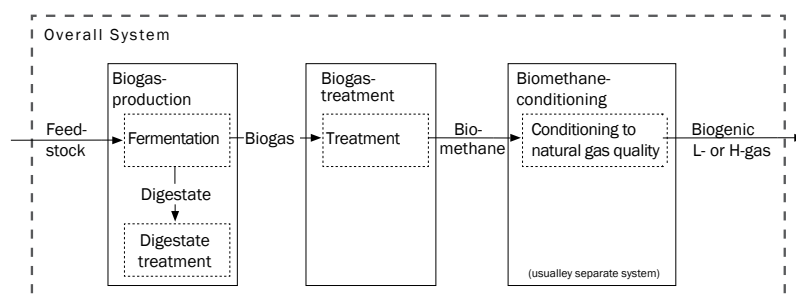
© Martin Dotzauer (DBFZ)

Figure 1: Overview of the biomethane production process

Biogas production

Energy crops, such as corn silage, grass silage, whole crop grain silage, grain kernels and sugar beets, are primarily used as **feedstock** in German biomethane plants. Animal manure (slurry, usually as a co-substrate of the renewable resource), municipal bio-waste, and residual waste from the food and manufacturing sectors, industry, and agriculture (e.g. straw) are also used.
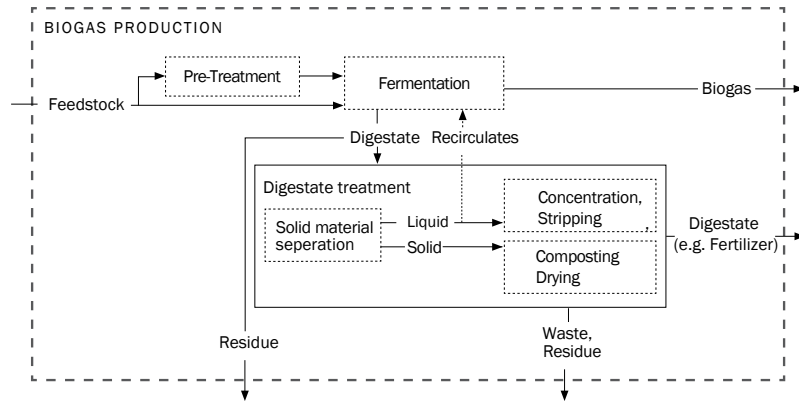
Figure 2: Biogas production

Biogas can be produced using wet or dry fermentation, and in continuous or batch production. During wet fermentation, pumpable substrate-water mixtures are added to a dry substance containing up to 12 % dry matter. During dry fermentation, only stackable fermentation substrates with a higher dry matter content are used. German biomethane plants usually use continuous wet fermentation, which is why this process will be described in more detail below.

An optimum biogas yield requires a fermentation substrate that is a homogenous, damp mass with the largest specific surface as possible. In order to achieve this, the substrates first undergo **pre-treatment**. This may require that the substrates be (I) chopped or defibered, (II) moistened or (III) that solid components be removed. During this process, organic residues and wastes are thermally pre-treated in order to sanitise them in order to lower the amount of undesired germs and pathogens brought into the fermenter. This is done by subjecting the substrates to heat (e.g. steam) and, if necessary, pressure. When natural resources are used, it is not necessary to undergo this sanitisation process prior to anaerobic digestion. However, this is legally required for certain waste.

The fermenter is **fed** with feedstock on a continuous (permanent) basis, semi-continuous basis (one or multiple times daily), or batch-wise. In the case of batch feeding, the fermenter is filled with completely fresh material which remains there for several days or weeks before the digestate is removed (see batch process). Depending on the dry matter content, liquid substrates enter the fermenter through pumps, and stackable substrates are placed in the fermenter using screw conveyors or wheel loaders.

During **fermentation**, all of the biological conversion steps typically occur in one reaction vessel - the fermenter. Multiple fermenters may be connected in parallel or in a series. It is also possible to carry out fermentation sub-processes in two different vessels in order to be able to more fine-tune or more precisely control process conditions (e.g. pH value, temperature). In the case of wet fermentation, a large proportion of the liquid phase remains in the cycle as a recirculate, i.e. it is separated from the fermentation residue and re-added to the process.

Different **process temperatures** are used in the fermentation depending on the microorganisms involved in the decomposition. The thermal optimum of most methane-producing microorganisms is between 37 °C and 42 °C. This temperature range is the one most frequently used in biogas plants. Fermentation at lower temperature saves heating the fermenter; however it leads to lower gas yields so that this is hardly ever done in practice. Higher temperatures ranging from 50° C to 60 °C can be used to ferment substrates when they have already undergone a prior sanitisation process or when the substrates are already at a higher temperature. Plants that process renewable resources operate at a high capacity. This often leads to a strong temperature increase during the fermentation process. The process may have to be cooled down, particularly in the summer months.

The advantage of higher temperatures is that they speed up decomposition, i.e. there are shorter retention times in the fermenter and there is a lower viscosity. This means less energy is used for mixing. However, larger amounts of energy are required to heat the fermentation vessel.

Wet fermentation primarily occurs in fully mixed reactors with an upright, cylindrical design. Stackable substrates are chopped up and wetted before fermentation. Agitators are used to **mix** the substrate while it is fermenting in the fermenter. The fermentation process requires that the substrate is well mixed. Depending on the viscosity of the substrate, shear mixers or kneading agitators are used. Film or concrete ceilings form a gas-tight closure.

Mixing improves:
- Contact between the fresh substrate and the microorganisms that are already in the fermenter
- Even distribution of nutrients and heat
- Prevention of settlements and floating layers
- Release of the biogas from the fermentation substrate

In addition to wet fermentation, there are also dry processes, though these are currently not being used extensively:

■ During the **plugflow process**, a continuous plug carries the substrate through the fermenter which is usually mixed crosswise to the direction of flow. Unlike fully mixed processes there is a lower risk of discharging unfermented substrate.
■ In **batch processes**, the substrate remains in so-called box or garage fermenters for 3 to 6 weeks. The solid material is not mixed. In order to achieve consistent gas production, multiple fermenters operate on a time-delayed basis.

Fermentation supplements. For the process biology of the fermentation it is important that the microorganisms involved in the decomposition processes are optimally supplied with nutrients. Depending on the substrates and the proportions of proteins, carbohydrates and fats contained in them, various supplements, so-called macro- and micronutrients, can be added to the fermenter.

Micronutrients: carbon, nitrogen, sulphur and phosphorus; Micronutrients: primarily cobalt, nickel, molybdenum and selenium; animal excrement already contains sufficient amounts of these. They are responsible for transporting electrons and are ensuring enzyme function.

The **biogas** from the fermenter is commonly stored temporarily for several hours in order to ensure that there is a constant flow of gas when the biogas is later processed into biomethane. Frequently the biogas is stored under a gas-tight fermenter ceiling, or, alternatively, in an external gas storage unit. The biogas mainly consists of methane and carbon dioxide; in the case of biogas made from renewable resources, these elements are of a relatively equal proportion (see Table 1). As it leaves the fermenter, the biogas is saturated with water. It also contains small quantities of hydrogen sulphide and hydrogen. Animal excrement can also have traces of ammonia.

During fermentation, digestate is produced as a co-product. It is withdrawn from the fermenter through a siphon or an overflow, and is stored in a container. The digestate can either be treated first, or applied directly as an organic fertiliser onto farmland. It is more difficult to transport non-treated fermentation residues because of the low nutrient and high water content.

Interim storage of the fermentation residue in a gas-tight secondary fermenter extends the retention time and increases biogas yields.

10

Treatment measures allow the digestate to be modified or specific substances to be separated. First, solids from the digestate are mechanically separated, in other words it is separated into a solid and a liquid phase. Separators are used, such as screw presses, drum sieve presses, belt presses, or decanters. Separating the solids and liquids in biogas plants usually increases the transportability of the solid fraction as well as the storage capacity of the fermentation residue and/or the production of a thin fluid recirculate used in the fermentation process. The separation of downstream treatment measures is described below.

1. **Processing the solid phase**

   a) Composting
   The solid fraction can be composted after phase separation. Enough oxygen must be added to the solid fermentation residue in order to achieve successful composting. It is also partially mixed with a structural material (e.g. bark mulch). The compost produced this way is comparable with conventional compost and can be used accordingly. Fermentation residues obtained from recycling biogenic waste are frequently added to the compost.

   b) Drying
   The solid fraction of the fermentation residue can alternatively be dried using technical drying systems (e.g. drum, belt, or feed and turn dryers). Hot air flows through or above the fermentation residue. The solid fermentation residues thus achieve a dry matter content of at least 80 % and can be stored.

2. **Aufbereitung der Flüssigphase**

   The liquid fraction of the digestate can either be used to inoculate fresh substrate (recirculation) or be used as a liquid fertiliser. The following treatment measures are also possible:

   a) Increasing concentration through membrane technology
   A concentrate that is highly enriched with nutrients is produced through a series of filtration plants followed by reverse osmosis. Pre-treatment with a decanter is a prerequisite. Membrane VL2014, 18.07.2012 9 separation requires electricity, though it doesn't require heat. The remaining water is purified and can be fed into the receiving water.

   b) Ammonia stripping
   During stripping, substances are removed from liquids by conducting gases through the liquids and transferring these substances to a gas phase. Here ammonium is converted to ammonia. Then the ammonia contained in the gas phases is converted into a marketable product or a disposable substance.

Because it requires a lot of energy, drying is performed when either the dried fermentation residues can be sold for profit, or when it is possible to utilise the unused heat.

The proportion of water in the liquid phase can also be reduced by 70 % through evaporation. This is rarely used in practice due to the high heat requirements.

Another option is biological purification which separates the fermentation residue and decomposes biological materials using specific bacteria. It works like a sewage treatment plant, though it is rarely used due to cost.

Biogas treatment

The biogas produced in the fermenter must be prepared before it can be fed into the natural gas grid or used directly as a fuel. The undesired elements of hydrogen sulphide, water and carbon dioxide are removed using the processing steps (i) desulphurisation, (ii) drying and (iii) carbon dioxide separation. Various processes are available for each of these steps. These have to meet different requirements and differ according to the amount of process energy that is needed and the auxiliaries that may be used.

The process of carbon dioxide separation is crucial which is selected based on different influencing factors. These include size and location of the biogas plant, the availability of cost-efficient heat, and the feed-in pressure and natural gas quality required on site. According to the processes used to separate CO2, appropriate upstream and, if necessary, downstream treatment steps are necessary.

The three treatment steps and the respective processes are briefly illustrated below.
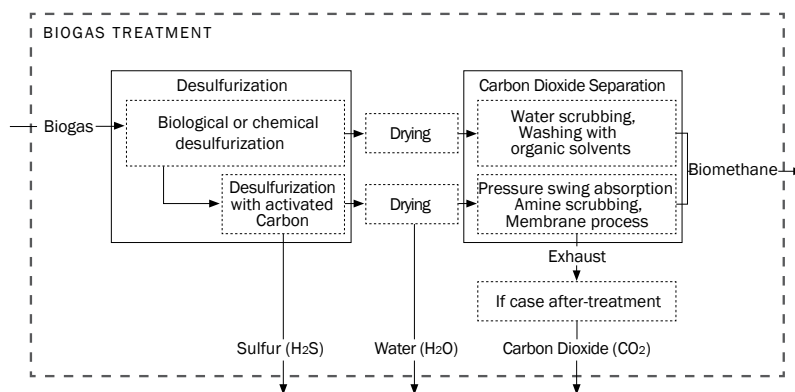
Compression occurs at different points in time depending of the process chain.

Abbildung 3:Processing steps to convert biogas into biomethane

Biological, chemical or sorption catalytic processes (using activated carbon) are used to **desulphurise** the biogas. There is rough and fine desulphurisation depending on the cleaning efficiency of the processes. The degree of desulphurisation necessary depends on the process used in CO_2 separation. During biological desulphurisation, microorganisms are used that consume hydrogen sulphide. This can take place in the fermenter, or later in a bio-scrubber or a trickling filter system. During chemical desulphurisation, reagents are used that bind to the sulphur during or after the fermentation process. When activated carbon is used in the desulphurisation process, a catalytic oxidation of the hydrogen sulphide adsorbed on the surface of the activated carbon occurs. For economic reasons, the loaded activated carbon is disposed of and not regenerated so that this process can only be used for fine desulphurisation.

Drying usually takes place between desulphurisation and CO_2 separation. Drying only occurs afterwards in the case of physical absorption processes (e.g. pressure washing and washing with organic solvents).

The biogas **drying** process is selected based on the amount of gas throughput and the method used to separate the CO_2. The admissible water content during feed-in depends on the dew point, and, thus, the pressure, temperature and gas composition. Cool drying or adsorption processes are used to dry the biogas in addition to gas filters:

- Gas filters remove suspended particles and moisture droplets from the gas and usually consist of gravel (rough filter) and ceramic or plastic insets (fine filter).
- During gas cool drying (cold to condensation drying), the gas is cooled down to a temperature that is below the dew point so that condensate, which primarily consists of water, can collect. Gas cool drying alone is insufficient in achieving the limit value for feeding into the German natural gas grid. Thus subsequent drying must occur before this can be done.
- During adsorption, water molecules accumulate on a solid surface (adsorbent). The filtered biogas flows through the adsorbent (primarily silica gel SiO_2, also aluminium gel or a molecular sieve), onto which the water binds. The loaded adsorbent has to be regularly regenerated, whereby the energy required to do this varies depending on the process.

Various processes are used to **separate carbon dioxide** from the biogas. The CO_2 is typically separated from the methane using the following methods:

a) ***Pressure swing adsorption*** *(adsorption to porous solid materials)*
During pressure swing adsorption (PSA), gas mixtures are separated by adsorbing to activated carbon, molecular sieves or carbon molecular sieves. Before it undergoes PSA, the biogas must be dried, finely desulphurised and compressed. The cooled, dehydrated gas subsequently flows through the adsorbent (molecular sieve or activated carbon), to which the CO_2 adsorbs. The methane-rich product gas is then relaxed and sent to a second column where the adsorption is repeated upon introduction of the ambient air. The absorbent is regenerated by lowering of the pressure with the aid of a vacuum pump. The extracted CO_2-rich gas still contains methane and therefore must undergo a lean gas aftertreatment.

b) ***Absorption in liquid***
Absorptive processes are also called washes because liquids function as absorbers onto which one or more components of the gas mixture are transferred. Crucial for the separation is the varying solubility of the individual gas components in the liquid.

The process of **water scrubbing** takes advantage of the different solubility of methane and carbon dioxide in water under changeable pressure. The biogas, which had been previously compressed, flows up through the absorption column. This is usually designed as a trickling filter in which water flows counter to the gas. Alkaline and acidic components in the biogas, particularly carbon dioxide and hydrogen sulphide, are released, and dust and microorganisms are removed. The cleansed gas leaves the column with a purity of 90 to 99 vol. % methane. The exhaust air contains CO_2 as well as around 1 vol. % methane which has to be separated through lean gas treatment. Electricity requirements for CO_2 separation are relatively high compared to other processes due to the circulation of the wash water and the required biogas compression. The gas does not need to be dried upstream.

When **washing with organic solvents** (e.g. Genosorb® or Seloxol®), the CO_2 binds to the washing agent like in pressure washing. Unlike water, the solvents are not corrosive and have a higher CO_2 and H_2S solubility. This reduces the amount of washing agent that has to be circulated and allows for smaller dimensions. The energy expenditure to regenerate the washing agent is higher than with pressure washing. This is currently the only method in which fine drying, CO_2 extraction and fine desulphurisation are possible within one process step. Simultaneous H_2S extraction increases energy consumption, which is required to regenerate the solvent, and is, thus, rarely used.

Amine scrubbing is a chemical absorption process which cleans in a similar way to pressure washing. Here the biogas flows against the current of the amine water solution at a slightly elevated pressure. The CO_2 reacts to the washing solution and transfers over to this. The amine solution achieves a higher loading than water, which lowers the amount of washing agent that needs to be circulated. The exhaust air contains only low quantities of methane, which is why lean gas cleaning is usually not necessary. Fine desulphurisation is recommended in order to maintain the capacity of the washing performance over the longer term. Amine scrubbing requires large amounts of energy since a lot of process heat is needed to regenerate the amine solution.

Of all the treatment processes, amine scrubbing achieves the highest quality of product gas of up to 99.9 % methane.

c)   *Membrane process*

Currently there are only a handful of membrane separation plants in operation for treating biogas. The solution diffusion membrane system has been the primary process used to treat biogas. The separation occurs as a result of the different solubility and diffusion rates of the gas components. The gas that is fed in to the process must be compressed beforehand. In order to protect the membrane, and to maintain effectiveness, fine desulphurisation and drying are done in an upstream step. Module operation with recirculation can be employed to improve the separation performance and to keep the amount of methane in the exhaust gas as low as possible. The energy requirements of plants with recirculation is considerably higher than those with a single separation step. The exhaust air has a critical methane content and must, therefore, undergo further after-treatment.

The low investment costs of the membrane process enable small volume flows of gas to be treated.

Methane slip as a % of the amount of methane added to the treatment process:
Organic wash: 2.0–2.6 %
Pressure swing adsorption 1–3 %
Pressure washing 0.8–1.8 %
Amine scrubbing < 0.1 %

Biomethane conditioning

The gas grid differentiates between L gas and H gas. These two types of gas differ in many respects from one another, for example the calorific value of H gas is higher than that of L gas.

When biomethane is fed into the natural gas grid, or used as a fuel, guidelines define the relevant key performance indicators in accordance with DVGW and DIN. Therefore, the biomethane must meet the requirements of the respective region in terms of the quality of the natural gas before it can be fed into the natural gas network. These qualities vary according to region, particularly in terms of the calorific value and pressure required. Conditioning involves adjusting the calorific value, compression, and odorisation which give the gas a warning smell.

Usually biomethane is conditioned and fed into the grid by the grid operators, in other words, not by the operators of the biomethane plant.
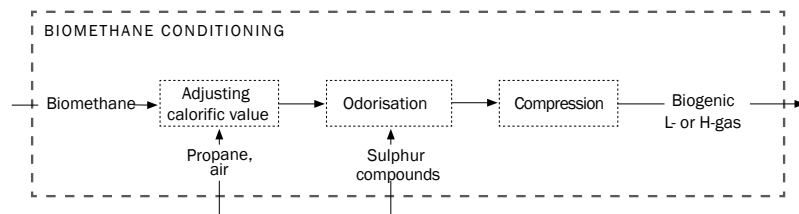
Abbildung 4: Steps for conditioning biomethane

The adjustment of the calorific value is primarily specified by the composition of the natural gas at the supply point. When methane is fed into the L gas grid, the calorific value has to be lowered. This can be done by adding small amounts of air. In contrast, when methane is fed into H gas networks, the calorific value has to be raised. This is predominantly done by adding liquid petroleum gas (LPG), which usually consists of 95 % propane and around 5 % butane.

During the process of odorisation, odorous substances are added to the odourless biomethane. This is a safety measure that allows leakages in the overall network to be more easily identified. Sulphur compounds are predominately used in odorisation.

The expenditure required by the compression depends on the treatment process of the biogas and the operating pressures used during this process, as well as the level of pressure in the gas network at the supply point (low pressure grid: > 0.1 bars; medium pressure grid: 0.1 – 1 bar; or high pressure grid: 1 - 120 bars). Electrically operated reciprocating and rotary piston compressors are used in the compression process. [1]

Table 1: Gas composition of the intermediate and end products

The values are taken from [2][3].

Component	Unit	Biogas (renewables)	Biogas (residues)	Treated biomethane	H gas	L gas
Methane CH_4	Vol. %	50-55	60-70	> 97	67-98	54-83
Carbon dioxide CO_2	Vol. %	45-50	30-40	< 1	0-1,4	0,6-1,3
Oxygen O_2	Vol. %	0-1	0-1	< 0,5	0-4,1	0-4,9
Hydrogen sulphide H_2S	ppmv	100-1.500	100-5.000			
Ammoniac NH_3	mg/Nm³	< 2	< 10			
Calorific value / upper heating value $H_{s,n}$	kWh/Nm³			< 11	11,1-12,5	9,1-11

Typical ranges of the main input and output flows

Note: This section summarises the typical ranges and guide values of the main input materials and products of biomethane plants. This should serve as an aid when checking GHG balances for plausibility. It should be noted that there are different types of process designs all of which cannot be taken into account here. Therefore, there may be deviations to the values listed here, depending on the plant.

Table 2 lists the material and energy flows of biomethane production that are crucial for certification. These primarily include the fermentation substrate, the process heat and electricity of the input and, where applicable, processed fermentation residue and biomethane (including losses) of the output. Auxiliaries are used in both process steps; however, they are often not taken into account in the GHG balance as a result of insufficient availability of emissions factors.

For the overall process, biogas generation and biogas treatment requirements are added together.

Table 2: Material and energy flows of biomethane generation

Biogas production		
	Input	**Output**
Fermentation	Fermentation substrate (kg) = Amount cultivated/collection minus transport losses, silage losses etc. Process energy (kWh) = Electricity (+ fuel) for silage, feeding, mixing etc. Process heat (MJ)	Emissionen/Verluste (CH_4) Gärrest
Processing of fermentation residues	Fermentation residue Process energy (kWh) Process heat (MJ)	Fertiliser
Biogas treatment		
	Input	**Output**
Biogas treatment	Process energy (kWh) = Electricity for treatment processes (desulphurisation, drying, if necessary compression and CO_2 separation) Process heat (MJ) = Heat for treatment processes (drying, CO_2 separation) Auxiliaries	Emissions/losses (MJ CH_4) Possibly waste Possibly fertiliser
Exhaust gas treatment	Process energy (kWh)	Emissions (CO_2, CH_4)

The use of inputs and the considerations regarding the outputs in GHG balances are described in more detail in the section "Sample Calculation".

The ranges for process energy (heat and electricity) are based on the main products of the two consecutive process steps: biogas and biomethane. The original amount of biogas produced and the biogas yield can be calculated based on the amount of the biomethane produced (before conditioning and feed in).

In terms of energy content, the output from the biogas production (MJ_{Biogas}) and the output from biogas treatment ($MJ_{Biomethane}$) are identical, minimised by only the methane loss (slip):

1. **Calculating the reference values of the process steps:**

   Biomethane [MJ] + methane loss in biogas treatment (%) = biogas [MJ]

   Biogas [MJ] + methane loss in biogas production (%) = biogas yield [MJ]

The biogas yield can be used to validate the amount of fermentation substrate(s).

2. **Verifying the amount of substrate:**

   Biogas yield [MJ] = biomethane [MJ] + methane losses [MJ] + biogas for supplying process energy [MJ]

   = amount_1 [kg] x gas yield_1 [MJ/kg] + amount_2 [kg] x gas yield_2 [MJ/kg] + amount_n [kg] x gas yield_n [MJ/kg]

Biogas production

The ranges of the specific substrate input listed in Table 3 are given in kg per MJ of biogas.

Information about the ranges is based on the heating value of methane (39.9 MJ/m^3) as is common in the gas industry. In contrast, when balancing the GHG emissions, the lower heating value of methane (50 MJ/kg or 36 MJ/m^3) is used in the calculation in accordance with the requirements of the RED and the Biofuels Sustainability Ordinance.

Table 3: Specific amounts of input substances (fresh substance) per energy unit of gas that is produced

Input			
Alternative fermentation substrate	Unit	From	To
Renewable resources			
Maize, whole crop silage	kg/MJ (Biogas)	0.21	0.28
Maize, corn cob mix (CCM)	kg/MJ (Biogas)	0.11	0.12
Grain, whole crop silage	kg/MJ (Biogas)	0.21	0.28
Grain kernels	kg/MJ (Biogas)	0.08	
Grass silage	kg/MJ (Biogas)	0.23	0.27
Forage rye silage	kg/MJ (Biogas)	0.32	
Sugar beet pulp	kg/MJ (Biogas)	0.33	0.39
Fodder beets	kg/MJ (Biogas)	0.47	0.63
Animal excrement/farm manure			
Cattle manure	kg/MJ (Biogas)	1.32	2.28
Pig manure	kg/MJ (Biogas)	1.20	2.09
Cow dung	kg/MJ (Biogas)	0.70	0.76
Poultry dung/dry chicken faeces	kg/MJ (Biogas)	0.18	0.36
Horse dung without straw	kg/MJ (Biogas)	0.72	
Residues and wastes			
Spent grain	kg/MJ (Biogas)	0.22	0.41
Distiller's grain	kg/MJ (Biogas)	0.72	1.40
Potato slop	kg/MJ (Biogas)	1.05	2.09
Fruit slop	kg/MJ (Biogas)	2.09	4.19
Raw glycerine	kg/MJ (Biogas)	0.16	0.18
Rapeseed cake	kg/MJ (Biogas)	0.08	0.10
Potato pulps	kg/MJ (Biogas)	0.50	0.57
Sugar beet pulp	kg/MJ (Biogas)	0.47	0.57
Molasses	kg/MJ (Biogas)	0.10	0.12
Apple pomace	kg/MJ (Biogas)	0.25	0.26
Vine pomace	kg/MJ (Biogas)	0.14	0.15
Green cuttings	kg/MJ (Biogas)	0.24	
Biowaste (compost bin)	kg/MJ (Biogas)	0.34	
Old bread	kg/MJ (Biogas)	0.10	
Baking waste	kg/MJ (Biogas)	0.07	
Vegetable waste	kg/MJ (Biogas)	0.79	
Potato peels	kg/MJ (Biogas)	0.72	
Food waste	kg/MJ (Biogas)	0.33	0.56

The ranges are based on minimum and maximum gas yields, as well as the specific methane concentrations of the individual input materials according to [1] [4] [5] [6]

17

The process energies listed below contain expenditures required for operation (stirring, heating, pumps etc.) and for feeding the plant.

Electricity requirements can vary and strongly depend on the systems that are installed. A general tendency, however, is that the requirement increases with increasing proportion of renewable resources due to higher expenditures for adding and mixing solid materials. Falling short of, or exceeding the ranges given, is possible due to conditions in the individual plants. Biogas plants with a high proportion of liquid inputs, especially slurry, tend to have a much higher need for process heat than biogas plants based on renewable resources.

Table 4 lists the ranges for the requirements and the provision of process energy. It can be supplied externally (public electricity grid, e.g. local heating network) or internally. Here part of the biogas that is produced fuels a biogas boiler or a cogeneration unit in order to supply the required process energy. This means biogas output goes down and the specific electricity requirements go up.

Process heat can, above all, be supplied internally using alternative fuels whose specific requirements are listed by way of example in Table 6.

18

The values in Table 4 are based on [7] [8].

Table 4: Specific process energies and process steps in biogas production based on the energy contained in the biomethane.

Input of renewable resources and renewable resources/slurry plants			
Process energy for biogas production (external)	Unit	From	To
Process heat	MJ/MJ$_{Biogas}$	0.054	0.16
Electricity	kWh/MJ$_{Biogas}$	0.0038	0.0059
Process energy for biogas production (internal)			
Electricity (biogas plant incl. CHP)	kWh/MJ$_{Biogas}$	0.0062	0.0072
Input waste plant			
Process energy for biogas production (external)			
Electricity	MJ/MJ$_{Biogas}$	0.042	0.208
Elektrischer Strom	kWh/MJ$_{Biogas}$	0.0029	0.8127
Process energy for biogas production (internal)			
Electricity (biogas plant incl. CHP)[1]	kWh/MJ$_{Biogas}$	0.0053	0.0814
Electricity (only CHP)	kWh/MJ$_{Biogas}$	0.0013	0.0024
Output			
Fermentation residue (100 % slurry input)	m^3/MJ$_{Biogas}$	0.63	1.22
Fermentation residue (100 % maize input)	m^3/MJ$_{Biogas}$	0.01	0.11

Any amounts of biogas that are extracted between the fermenter and the biomethane treatment plant should be noted. This can occur when a CHP or biogas boiler is installed in the biogas plant to generate process heat. The amount of biogas used to supply the biomethane treatment plant with process energy or used in the after-treatment of lean gas should also be taken into consideration. The amount of this biogas and its methane concentration are usually not recorded. At this stage, an estimation and plausibility check of the amounts and qualities of the gas should be carried out in conjunction with the plant operator(s) of the biogas plant and biomethane treatment plant. Once this has been done, these energy amounts are to be added to the energy amount of the product gas (biomethane) in order to verify the plausibility of the input amounts as described.

---

[1] Waste plants are often connected to composting. Depending on the process chain, the operator provides information about mechanical treatment, sanitisation, fermentation residue separation, composting and final composting.

Biogas treatment

The process energy requirements of the different technology options for treating biogas are summarised in Table 5 below. Table 6 lists, by way of example, specific fuel requirements for the provision of heat.

Table 5: Specific process energies of the process step of the biomethane treatment plant based on the energy contained in the biomethane

Input			
Process energy for biogas treatment (desulphurisation, drying, CO_2 separation)	Unit	From	To
Pressure swing adsorption			
Electricity	kWh/MJ$_{Biomethane}$	0.0081	0.0093
Process heat	MJ/MJ$_{Biomethane}$	0	
Water scrubbing (physical absorption with water)			
Electricity	kWh/MJ$_{Biomethane}$	0.0072	0.0112
Process heat	MJ/MJ$_{Biomethane}$	0	
Absorption with organic solvent			
Electricity	kWh/MJ$_{Biomethane}$	0.0097	0.0132
Process heat	MJ/MJ$_{Biomethane}$	Internal heat supply	
Amine scrubbing			
Electricity	kWh/MJ$_{Biomethane}$	0.0038	0.0044
Process heat	MJ/MJ$_{Biomethane}$	0.090	
Membrane separation process			
Electricity	kWh/MJ$_{Biomethane}$	0.0105	0.0122
Process heat	MJ/MJ$_{Biomethane}$	0	0.104
Auxiliaries for biogas treatment			
Activated carbon, desulphurisation (for an average load of 0.45 kg$_{sulphur}$/kg$_{activated\ carbon}$ and the amount of H_2S to be separated of 10 or 100 ppm)	kg/MJ$_{Biomethane}$	0.000667	0.006669

The values in Table 5 are taken from [2].

Electricity and heat demand for biomethane treatment plants according to the individual sources cited: [9] [10] [11] [12] [13] [14]

The assumptions based on the calculation: calorific value of methane: 39.9 MJ/Nm³, Methane content of raw biogas: min. 52 % or max. 60 %; methane slip, max. 0.1 to 5 % (depending of the treatment process).

Table 6: Provision of heat listed according to fuel input

Specific provision of heat according to fuel (lower heating value)						
	Water content	Unit	Degree of effectiveness of heat plant			
			100%	90%	80%	70%
Natural gas	0 %	MJ/kWh	3.6	3.2	2.9	2.5
Fuel oil	0 %	MJ/l	36	32	29	25
Pellets	8 %	MJ/m³	11,115	10,004	8,892	7,781
	8 %	MJ/t	17,101	15,391	13,681	11,971
Wood chips, beech	15 %	MJ/m³	4,503	4,053	3,602	3,152
Wood chips, spruce	15 %	MJ/m³	3,032	2,729	2,426	2,122

The values in Table 6 are taken from [15]

If the amount of energy of the treated gas is not measured between biomethane treatment and the feed meter for biomethane conditioning, the energy content of the treated biomethane can be calculated using the formula below. As liquid gas is used to condition the biomethane, this is necessary in order to comply with the gas quality requirements of DVGW worksheets G 206 and G 262. This causes a change in the calorific value of the conditioned biomethane compared to the treated biomethane.

$$Q \ = \ V_{Biomethane} * c_{methane} * H_{s,methane}$$

where

Q is the amount of energy of the treated biomethane in [MJ/a]

$V_{Biomethane}$ Volume flow of the treated biomethane within the period of observation in m³/a (as measured by the discharge of biomethane from the biomethane treatment process)

$c_{methane}$ Methane concentration of the treated biomethane within the period of observation in % (as measured by the discharge of biomethane from the biomethane treatment process)

$H_{s,methane}$ Calorific value of methane at 39.9 MJ/m³

Using Table 3 and the amount of energy of the treated biomethane calculated or measured on site, the amounts of input material measured by the biogas plant operator can be verified. The proportion of each individual input material to the total substrate mix is required for this.

Biomethane conditioning and grid injection

Electricity requirements depend on the pressure used to run the biomethane treatment plant and the pressure of the natural gas grid which it is injected into. Furthermore, the amount of liquid gas admixture depends on the methane concentration of the treated biomethane and the quality of the target gas. Here a fundamental distinction is made between L gas and H gas. Within these groups there are different natural gases named for their place of origin that have varying qualities in terms of their gas composition, calorific value and the Wobbe index. Consequently, conditioning requirements and the related amounts and requirements differ for adjusting the treated biomethane to the target gas. Ranges are not given here as a result of the many different local conditions.

The Wobbe index is the quotient of the calorific value (seldom the heating value) and the root of the ratio between the fuel gas density and air density.

20

Calculating GHG emissions and GHG emission saving potential

In order to calculate the GHG emissions resulting from the production and use of biomethane, the GHG emissions and the GHG savings along the entire biodiesel production chain are added together. This is done by adding the GHG emissions produced at every interface along this chain to the GHG emissions of the upstream interfaces. Interfaces can also use disaggregated default values as per Directive 2009/28/EC (RED) instead of individually calculating the GHG emissions [16]. The final interface consolidates the GHG emissions of the individual calculations or the disaggregated default values, and issues the GHG emissions value based on one MJ of biomethane. The final interface also calculates the GHG emission saving potential compared to a defined fossil reference value.

The following section explains the principle method of GHG calculation and demonstrates this using a sample process chain.

Interfaces are accredited enterprises along the production and supply chain. They are divided into primary distributors (e.g. dealers and cooperatives that receive the harvested biomass), and other enterprises that process the liquid or gaseous biomass to the required level of quality for end use (e.g. biogas treatment). If a biogas plant and a biogas treatment plant belong to one production site, one certification that is based on the requirements for both plants is sufficient. The interface that processes the biofuel to the required level of quality for end use is called the final interface.

Calculation formulas

If an interface along the process chain of biofuel production chooses to calculate individual GHG savings based on actual values, it must do so in accordance with the methods defined in the RED [16]. The set of regulations contain concrete calculation formulas. A biofuel's GHG emission saving potential is based on the GHG emissions resulting from biofuel production and use, and on a comparison to a fossil reference value. The following section explains the methods of both calculation steps in more detail.

Calculating GHG emissions

Total emissions are calculated using the following, generally binding formula (as per Directive 2009/28/EC (RED). This is based on the GHG emissions and the GHG emissions savings of the biofuel production chain.

$$E = e_{ec} + e_l + e_p + e_{td} + e_u \qquad - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$$

E = Total emissions from using the biofuel

GHG emissions from:

e_{ec} = Raw material production
e_l = Land-use change
e_p = Processing
e_{td} = Transport & Distribution
e_u = Use

GHG emissions savings through:

e_{sca} = Improved agricultural management
e_{ccs} = Carbon capture and geological storage of CO_2
e_{ccr} = Carbon capture and replacement of CO_2
e_{ee} = Excess electricity from CHP

22

Calculating the GHG emission saving potential

Once the total emissions have been calculated, the GHG emission saving potential is calculated by the final interface in the value chain using the formula below:

$$GHG\text{-}reduction = \left[\frac{E_{Fossilfuel} - E_{Biofuel}}{E_{Fossilfuel}}\right] * 100$$

$E_{Fossil\,fuel}$ = total emissions of fossil reference fuel

$E_{Biofuel}$ = total emissions from using the (e.g. biomethane)

The value of the reference fossil fuel is defined by RED as being 83.8 g CO_2eq/MJ.[2]

Calculation procedure

The calculation steps for determining the GHG emissions and the GHG emission saving potential is described below.

Calculating the GHG emissions for each term of the calculation formula

GHG emissions are calculated for each interface and, based on the amount of processed intermediate product and are passed along to the downstream interface. The same calculation principle applies to the terms e'$_{ec}$, e'$_{p}$, e'$_{td}$, e'$_{u}$. In order to determine the GHG emissions of these interfaces, the auxiliaries and energy carriers used in the process chain are multiplied by their emission factors and divided by the amount of intermediate or main product.

$$e'_{ec,p,td,u} = \frac{\sum(Amount\ of\ material\ input * Emission\ factor\ of\ the\ material\ )}{Yield\ or\ quantity\ of\ the\ (intermediate)\ product}$$

Special rules apply to calculating the terms e'$_{l}$, e'$_{sca}$, e'$_{ccs}$, e'$_{ccr}$, e'$_{ee}$, which are explained, in part, in the sample calculation and under frequently asked questions (FAQ).

Allocating the GHG emissions between the biofuel and the co-products

If co-product-products are produced as part of the biofuel production process, the GHG emissions resulting from the production process (until the co-product is produced) are allocated between the main product and the by-product. The lower heating values of the fresh substance (not only the dry substance) of the main products and co-products form the basis for the allocation. The allocated value is passed on to the downstream interface and is calculated as follows:

$$e_{allocated} = GHG\ emissions\ up\ until\ the\ co-product\ is\ produced\ * Allocation\ factor (AF)$$

$$AF = \frac{m_{main\ product} * H_{lower,\ main\ product}}{m_{main\ product} * H_{lower\ main\ product} + m_{by-product} * H_{lower\ by-product}}$$

$$where\ m = mass, H = heating\ value$$

There are three ways to provide GHG emission values: by using i) default values (Annex V, D and E RED) ii) individually calculated values and iii) a combination of default values and an individually calculated value. The calculation scheme for the individual calculation is explained below. The things that need to be taken into consideration when combining partial standard values and individually calculated GHG emissions are explained in the FAQ section.

In accordance with the RED, the GHG emissions related to the use of the fuel (e$_u$) is zero for biofuels.

Emission factors are "emission backpacks" of materials, energies or products. They reveal the environmental impacts (e.g. GHG emissions) connected to the production and use of a material / energy / product. Scientific papers and approved databases serve as sources for emission factors.
The term e' represents the GHG emissions based on the (intermediate) product of the respective process step (e.g. g CO_2-eq./Nm³ of biogas). The term e stands for the GHG emissions based on the product's energy content (e.g. g CO_2 eq./MJ of biomethane).

Additional information about declaring co-products and allocation are found in the FAQ section.

[2] This value is an average value for fossil diesel and petrol, however it is considered a reference for all liquid and gaseous biofuels.

Calculating total emissions and the GHG emission saving potential

The final interface calculates the sum of the GHG emissions. The final interface converts the total emissions of the production and supply chain to one MJ of biofuel taking into consideration the lower heating value of biomethane. It also calculates the GHG emission saving potential using the formula given before.

In contrast to the gas industry, the lower heating value (LHV) of biomethane is used at this stage rather than the higher heating value (HHV).

23

Types and sources of data

Various types of data from different data sources are required as part of the GHG balance. These are summarised in Table 7. Other information about data sources can be found in the FAQ section.

Table 7: Types and sources of data

Types of data	Sources of data
Operating consumption data (raw material production, processing, transport)	Actual measurement required
Emission factors	Taken from literature, databases
Heating values	Taken from literature, databases, actual measurement
Nitrous oxide emissions	Model approaches as per IPCC or GNOC

Sources must be indicated (author, title (journal, volume, year) for values taken from literature sources or databases.

Other information about data sources are found in the FAQ section.

Challenges faced in the certification of biomethane

The RED methodology presented here for calculating the GHG balance was primarily developed with a view to liquid biofuels. However, all of the biofuels are found within the guideline's scope of application which, particularly for biomethane, leads to methodological uncertainties and balancing difficulties. These are discussed in the following sample calculation as well as the practical implementation of the methods used in the biomethane GHG balance.

Exemplary calculation

Operational data is used for this exemplary calculation. Things to consider when using disaggregated default values are explained in the FAQ section.

Based on an example of biomethane production, a step by step process demonstrates how to calculate GHG emissions based on one MJ of biomethane and determine the GHG emission saving potential. The exemplary calculation follows the calculation scheme described above. First the operational data and the corresponding emission factors are listed per term, then this data is entered into the calculation formula. Afterwards typical calculation errors are highlighted.

Illustration of an exemplary process chain

The exemplary process chain shown in Figure 5 consists of biomass cultivation, transport of the biomass to the biogas plant, biogas production, the biogas treatment, and distribution of the biomethane. It forms the basis for the calculation of the GHG emissions, based on one MJ of biomethane, and the determination of the GHG emission saving potential. First the operating consumption data and the corresponding emission factors are listed for each process step. Then the data is entered into the calculation formula and remarks are made about typical calculation errors. In addition to the GHG emissions released as part of this process chain, the GHG emissions from changes in the carbon stocks as part of land-use changes, the GHG emission savings as a result of possible CO_2 capture and geological storage or replacement, and the feed in of excess electricity from the co-generation of heat and electricity also have to be considered.
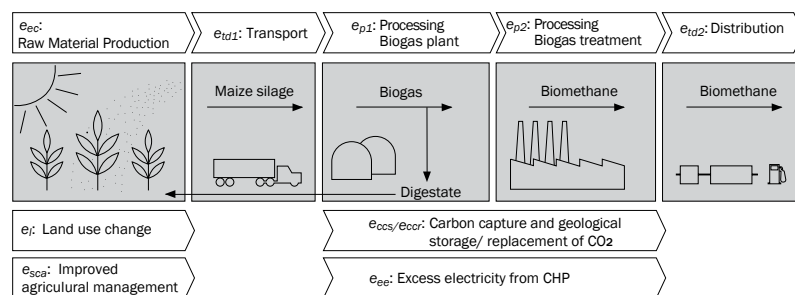
Figure 5: Sample process chain

The sample plant is a energy crops biogas plant with connected biogas treatment. Under normal operation approximately 700 Nm^3 of biomethane is fed into the natural gas grid every hour. Amine scrubbing is used to process the biogas into biomethane. A woodchip-fired boiler provides the heat for both the biogas plant and the amine scrubbing. The electricity needed to operate the plant is taken from the German electricity grid. The digestate generated by the fermentation process is spread as a fertiliser onto the land which supplies the substrate.

Cultivation of raw material e'_{ec}

As described above, the biofuel's GHG emission saving potential can be verified using standard values and partial standard values. The default values for biomethane, however, only apply to biomethane from wet manure, dry manure and municipal organic waste. There are no default values for biomethane from purpose-grown crops, i.e. the GHG emission saving potential for biomethane made from energy crops has to be verified by calculations based on actual values. This results in the first difficulty when applying the prescribed methods to the biomethane balance. Unlike with liquid biofuels, a mix of various substrates is usually used in the production of biomethane. Table 8 below lists the supplied substrate mix for our sample plant.

Table 8: Substrate mix of sample plant

Substrate input	Unit	Value
Silage maize (supplier 1)	t/a	22,220
Silage maize (supplier 2)	t/a	14,500
Silage maize (supplier 3)	t/a	3,300
Silage maize (supplier 4)	t/a	5,500
Whole crop silage	t/a	4,500
Grass silage	t/a	5,500

The information about the amounts and origins of the individual substrates are significant since the different GHG values for the provision of different substrates according to the RED may only be added together when they do not exceed defined maximum values. However, there is currently a lack of default values and disaggregated default values for the cultivation of substrates used in biomethane production (e.g. maize silage). Therefore, the GHG emission saving has to be specifically verified for every substrate used and for the biomethane produced from this. To do this, the plant's biomethane output is allocated to the individual substrates at a later stage (see 5.11.1). First, in the exemplary calculation below, the primary distributor determines the amount of silage maize from supplier 1 that originates from the cultivation listed in Table 9. Data on fertiliser input, diesel and electricity consumption, and harvest yield have to be taken from operational documents.

Table 9: Input data for silage maize cultivation

Input material and energy	Unit	Value
Seeds	kg/(ha*a)	25
N fertiliser, mineral	kg N /(ha*a)	44.9
N fertiliser, digestate	kg N /(ha*a)	161
Calcium oxide fertiliser	kg/(ha*a)	1,000
Pesticides	kg/(ha*a)	7
Diesel (agricultural machinery)	MJ/(ha*a)	3,440 (96 l/(ha*a))
Yield	Unit	Value
Maize yield (fresh matter)	kg/(ha *a)	50,000
Percentage of dry matter	% DM an FM	35

The values for the cultivation of silage maize have been taken from KTBL and Biograce II. [4][17]

In the case of fertiliser it is important to note whether the values refer to the overall fertiliser (e.g. combi-fertiliser) or only to the nutrients used.

In this exemplary calculation the phosphorus and potassium requirements are completely met through the return of the digestate. If P_2O_5 and K_2O fertilisers are used instead, the common EFs can be used as follows. P_2O_5: 1.17/1.18 kg CO_2 eq./kg [17] [18]; K_2O: 0.64/0.66 kg CO_2 eq./kg [17][18]

In accordance with the RED requirements, the characterisation factors (CF) of IPCC 2001 are used to convert nitrous oxide into CO_2 equivalents. Accordingly, N_2O has a GHG potential of 296 kgCO_2 eq./kgN_2O. [21] The calculated N_2O emissions have to be multiplied by this value.

When calculating N_2O emissions, all of the nitrogen applications, both from the mineral and from the organic fertiliser, have to be considered.

N_2O is a greenhouse gas that is emitted when fertilisers containing nitrogen are used in agriculture. There are direct and indirect nitrous oxide emissions. Direct nitrous oxide emissions are generated, for example, through nitrogen input from organic and mineral fertilisers and atmospheric N deposition. Indirect nitrous oxide emissions are caused when nitrogen compounds, like nitrate and ammoniac, make their way into surrounding natural areas, for instance, as a result of N fertiliser input. Nitrous oxide emissions can be calculated according to the IPCC method or the GNOC model. The Biograce II tool provides a nitrous oxide calculator for silage maize and the possibility of adapting the calculator for other biogas substrates. [17] [21]

Common values for the emission factors (EF) of these input materials and energies are listed in Table 10 below:

Table 10: Emission factors (EF)

Input material and energy	Unit	Emission Factor	Source
Seeds	kg CO_2 eq./kg	0.32	[17]
N fertiliser (mineral)	kg CO_2 eq./kg	4.57/ 6.41	[17][18]
N fertiliser, fermentation residue[3]	kg CO_2 eq./kg	0.0075	[19]
CaO fertiliser	kg CO_2 eq./kg	0.89/ 0.30	[17][18]
N2O field emission[4]	kg N_2O eq./ (ha*a)	5.6	[17]
Pesticides	kg CO_2 eq./kg	13.9	[17]
Diesel	kg CO_2 eq./l	3.14/ 2.1	[18][20]

In accordance with the calculation scheme explained above, the quantities of the auxiliaries and the corresponding emission factors are entered into the equation. This produces the following value for the term e'_{ec} for silage maize:

$$e'_{ec} = \frac{\sum EM * EF}{yield\ or\ amount}$$

$$e'_{ec} = \frac{25\,\frac{kg}{ha*a} * 0.32\,\frac{kg\,CO_2\text{eq.}}{kg} + 44.9\,\frac{kg}{ha*a} * 4.57\,\frac{kg\,CO_2\text{eq.}}{kg} + 161\,\frac{kg}{ha*a} * 0.0075\,\frac{kg\,CO_2\text{eq.}}{kg}}{50\,000\,\frac{kg}{ha*a}}$$

$$+ \frac{1000\,\frac{kg}{ha*a} * 0.89\,\frac{kg\,CO_2\text{eq.}}{kg} + 7\,\frac{kg}{ha*a} * 13.9\,\frac{kg\,CO_2\text{eq.}}{kg} + 96\,\frac{kg}{ha*a} * 2.1\,\frac{kg\,CO_2\text{eq.}}{kg}}{50\,000\,\frac{kg}{ha*a}}$$

$$+ \frac{5.6\,\frac{kgN_2O}{ha*a} * 296\,\frac{kg\,CO_2\text{eq.}}{kg}}{50\,000\,\frac{kg}{ha*a}}$$

$$e'_{ec} = 0.06\,\frac{kg\,CO_2\text{eq.}}{kg\,FM} = 61\,\frac{kgCO_2eq}{t\,FM\,silage\,maize\,(supplier\,1)}$$

The primary distributor passes on a value of 61 kg CO_2 eq./t of silage maize to the biogas plant.

---

[3] Takes into account emissions from transport and the spreading of fermentation residue.
[4] The emission factor was calculated using the N_2O calculator as per IPCC as part of the Biograce II tool by entering the parameters specific to cultivation, and does not represent a generally applicable emission factor. [17]

> **Potential calculation errors**
> - The direct and indirect nitrous oxide emissions, calculated using the IPCC or GNOC methods, may not be omitted
> - Some EFs cannot be determined using the trade names of fertilisers. In this case the chemical term for the fertiliser is required.
> - It should be noted whether the EF of the fertiliser/pesticide only refers to the active ingredient (e.g. kg N) or to the amount of fertiliser (e.g. calcium ammonium nitrate consists of 76 % NH_4NO_3 and 24 % $CaCO_3$)
> - Unit conversion errors, for instance:
>   - The amount of input material and the EF of the input material are based on different units of quantity, e.g. 3,440 MJ of diesel/(ha*a) and EF of 2.1 kg CO_2- eq./l of diesel
>   - Input amounts are sometimes given in annual input amounts, e.g. kg/a, while the yield is based on hectares, e.g. kg/(ha*a). In this case there must be a relation to area, i.e. the annual input amount has to be converted into hectares.

Land-use changes e'$_l$

Since the cultivation area for silage maize in the example given was already being used agriculturally before 1 January 2008, the value of the term el is zero.

$e'_l = 0$

Improved agricultural management e'$_{sca}$

In the time period in which the biogas substrates in the given example were cultivated, no measures were implemented that increased the carbon stocks in the soil. Therefore, no emission savings resulting from such improvements could be taken into account.

$e'_{sca} = 0$

Transport e'$_{td1}$

When the substrates are transferred to the biogas plant, the substrate's GHG value from cultivation and data on the transport expenditures have to be provided in order to calculate the specific GHG emissions from delivery. The example uses the following data for this process step:

Table 11: Basic data for the transport process

Input materials and energy	Unit	Value
Volume of the transported biomass (m)	kg	24.000
Means of transport		Tanker 40 t diesel
Transport distance, loaded (d$_{loaded}$)	km	20
Transport distance, empty (d$_{empty}$)	km	20
Fuel consumption loaded (f$_{loaded}$)	l/km	0,41
Fuel consumption empty (f$_{empty}$)	l/km	0,24

In accordance with EU COM 2010/C 160/02, "improved agricultural management" may contain the following practices:

- Shifting to reduced or zero-tillage,
- improved crop rotations and/or cover crops, including crop residue management;,
- improved fertiliser or manure management,
- Use of soil improver (e.g. compost).

This, however, requires proof that carbon stocks in the soil have increased.

The transport values are our own assumptions. The fuel consumptions have been taken from the BLE. [18]

Diesel is used as fuel and the corresponding emission factor is listed in Table 12 below.

Table 12: Emission factors of the materials and energies used in transport

Input materials and energy	Unit	EF	Sources
Diesel	kg CO_2 eq./l	3.14/ 2.1	[18][20]

The GHG emissions from transport are calculated as follows:

$$e'_{td1} = \frac{(d_{load.} * f_{load.} + d_{empty} * f_{empty}) * EF}{transported\ silage\ maize}$$

$$e'_{td1} = \frac{\left(20\ km * 0.41\frac{l}{km} + 20\ km * 0.24\frac{l}{km}\right) * 3.14\frac{kgCO_2 eq}{l}}{24,000\ kg}$$

$$e'_{td1} = 1.7\frac{kgCO_2}{t\ silage\ maize}$$

The values of the biogas plant have been taken from the DBFZ database and KTBL. [22]

Conversion of m³ of methane to kg: 1 Nm³ of methane corresponds to 0.72 kg of methane.
According to RED, Annex V Part C, the GHG potential of methane corresponds to a value of 23 kg CO_2 eq./kg CH_4. [16]

Malfunctions or leakages can result in diffused methane emissions during fermenter operation. In the absence of actual measured values, a lump sum value of 1% of the produced methane is frequently assumed [23], [24]. This value is also found in the system principles of the certification systems (RED cert. and ISCC) and only applies to plants with a digestate storage that has a gas-tight cover. [25], [26] In accordance with these principles, lower emission rates, as well as emissions from digestate storage that do not have a gas-tight cover, have to be verified based on emission measurements. The question of how this verification should occur and which measuring methods and procedures are approved to do this, are covered in the FAQ section.

Since, in this example, the digestate is returned as a fertiliser to the land that provided the substrate, and, therefore, remains in the system, no further co-product is considered. How to treat the digestate as a co-product, is covered in the FAQ section.

Potential calculation errors
• Unit and conversion errors, e.g. diesel consumption and emission factor of diesel must have the same unit of measurement, either l or kg.

Processing e'$_{p1}$: biogas plant

Regardless of whether the entire amount of biomethane or a partial amount (corresponding to the observed substrate amount) are to be certified, emissions from the biogas plant first have to be determined for the total methane yield over the balance period observed (in this case, one year). This is done by relating all of the emissions from biogas production to the amount of methane that is transferred to the biogas treatment process. The specific GHG value e'$_{p1}$ for the intermediate product of methane can be calculated using the information in Table 13.

Table 13: Input data for biogas production

Input materials and energy	Unit	Value
Electricity	kWh/a	1,401,026
Process heat	MJ/a	15,916,991

Methane yield	Unit	Value
Methane yield	Nm³/a	5,526,733

Methane loss	Unit	Value
1% of the methane produced	Nm³/a	55,826
	kg/a	40,194

Digestate	Unit	Value
Digestate	m³/a	34,790

Typical values for the emission factors of these input materials and energies are listed in Table 14 below:

Table 14: Emission factors of the materials and energy used in biogas production

Input materials and energy	Unit	Emission factors	Sources
Electricity mix, Germany (DE)	kg CO_2 eq./kWh	0.61/ 0.60	[20] [22]
Heat (woodchip-fired boiler)	g CO_2 eq./MJ	0.43	[19]

Entering this data into the equation produces the following value for e'_{p1}

$$e'_{p1} = \frac{\left(1{,}401{,}026\,\frac{kWh}{a} * 0.61\,\frac{kgCO_2eq}{kWh}\right) + \left(15{,}916{,}991\,\frac{MJ}{a} * 0.00043\,\frac{kgCO_2}{MJ}\right) + \left(40{,}194\,\frac{kg}{a} * 23\,\frac{kgCO_2eq}{kgCH_4}\right)}{5{,}526{,}733\ m^3\ CH_4}$$

$$e'_{p1} = 0.323\,\frac{kgCO_2 - eq}{m^3\ CH_4}$$

Processing e'_{p2}: biogas treatment and feed in

The biogas treatment plant represents the final interface. This process includes turning the raw biogas into a biomethane that is of natural gas quality, and then subsequently feeding this biomethane into the natural gas grid. Like with biogas production, the emissions from the biogas treatment for the total biomethane yield over the observed balance period are determined in this step regardless of the amount of biomethane to be certified. The biomethane yield is allocated to the substrate amount in question in the section Allocation of the gas yield.

The consumption data for biogas treatment has been taken from the DBFZ database and KTBL. [22]

In the case of other treatment processes, such as pressure swing adsorption (PSA) and pressure washing (PW), this value can be significantly higher (PSA 1 – 5 %, PW 1 %). In these cases, an after-burning unit has to be connected to the treatment process.

Supplying heat through biogas:
When the required process energy is supplied internally through a biogas CHP, the proportion of unburned methane in the exhaust gas flow must be considered. These emissions can be between 0.12 % - 0.5 % of the methane slip in the case of gas motors, and between 0.9 – 1.4 % for dual fuel motors.

Table 15: Input data for biogas treatment

Methane input	Unit	Value
Methane input	Nm^3/a	5,526,733

Methane slip	Unit	Value
Methane slip	%	0,1
Methane loss	Nm^3/a (kg/a)	552 (397)

Einsatzstoffe- und –energie	Unit	Value
Electricity	kWh/a	953,549
Process heat	MJ/a	22,885,178

Output	Unit	Value
Biomethane output	m^3/a	5,526,181

Common values for emission factors for these input materials and energies are listed in Table 16 below. These originate from the literature and approved databases.

Table 16: Emission factors of the materials and energy used in the biogas treatment plant

Input materials and energy	Unit	EF	Source
Electricity mix DE	$kgCO_2$ eq./kWh	0.61/ 0.60	[20] [22]
Heat (boiler) woodchips	gCO_2 eq./MJ	0.43	[19]

Entering this data results in the following specific GHG value e_{p2}' for the intermediate product biomethane.

According to the RED, the characterization factors (CF) of the IPCC 2001 are used to convert the direct methane emissions into CO_2 equivalents. Thus CH4 has a GHG potential of 23 kg CO_2 eq./$kgCH_4$. [21] The determined methane emissions have to be multiplied by this value.

$$e'_{p2} = \frac{\left(953,549\frac{kWh}{a} * 0.61\frac{kgCO_2eq}{kWh}\right) + \left(22,885,178\frac{MJ}{a} * 0.00043\frac{kgCO_2eq.}{MJ}\right) + \left(397.44\frac{kg}{a} * 23\frac{kgCO_2eq}{kgCH_4}\right)}{5,526,181\frac{m^3}{a}}$$

$$e'_{p2} = 0.109\frac{kgCO_2eq}{m^3}$$

Emission saving from carbon capture and geological storage e'_{ccs} and carbon capture and replacement e'_{ccr}

The CO_2 that is captured during biogas treatment typically is not put to any other use, as is the case in this example.

When determining the term eccr , the following is stated in RED Annex V Part C No. 15 : "Emission saving from carbon capture and replacement, eccr, shall be limited to emissions avoided through the capture of CO_2 of which the carbon originates from biomass and which is used to replace fossil-derived CO_2 used in commercial products and services.." The GHG savings may only be assigned to the CO_2 that is actually used commercially, and not to the CO_2 available from the biomethane plant.

$e'_{ccs} = 0$

$e'_{ccr} = 0$

Production of excess electricity e'_{ee}

Since no excess electricity is produced in the biogas plant and during the biogas treatment process, the value for e'_{ee} is zero.

$e'_{ee} = 0$

Distribution e'_{td2}

As the final interface, the biogas treatment plant has to provide verification of the GHG emission saving potential of the biomethane that has been put into circulation. In addition to the upstream processes, the distribution processes downstream from the treatment process also have to be taken into consideration. These include the compression and transport of the biomethane to the petrol station through the natural gas grid, and the compression of the biomethane at the filling station to meet filling station requirements. The corresponding data is listed in Table 17.

30

Table 17: Input data for distribution

Transport of the biomethane through the natural gas grid

Input	Unit	Value
Electricity	kWh/m³	0.0025
Process heat, natural gas	MJ/m³	0.0576

Compression to filling station pressure

Input	Unit	Value
Electricity	kWh/m³	0.164

The balance of emissions from gas transport and compression to filling station pressure is based on inventory data from the DBFZ database and the Ecoinvent database 2.1. [19]

Common values of emission factors of the input materials and energy are listed below in Table 18. These have been taken from the literature and approved databases:

Table 18: Emission factors of the materials and energy used in biomethane distribution

Input materials and energy	Unit	EF	Source
Electricity mix DE	kgCO$_2$ eq./kWh	0.61/0.60	[20] [22]
Heat, natural gas	kgCO$_2$ eq./kWh	0.067	[22]

The GHG emissions from the distribution are calculated as follows:

$$e'_{td2} = \left(0.0025 \frac{kWh}{m^3} * 0.61 \frac{kgCO_2 eq.}{kWh}\right) + \left(0.0576 \frac{MJ}{m^3} * 0.067 \frac{kgCO_2 eq.}{MJ}\right) + \left(0.164 \frac{kWh}{m^3} * 0.61 \frac{kgCO_2 eq}{kWh}\right)$$

$$e'_{td2} = 0.015 \frac{kgCO_2 eq}{m^3}$$

Potential calculation errors
- Unit and conversion errors, e.g. diesel consumption and the emission factor of diesel have to have a uniform unit of measurement, either l or kg.

Total emissions E

Allocating the gas yield to the amount of substrate in question

The substrates used during a balance period are to be considered separately in the balance. Therefore, it is necessary to allocate the amount of biomethane produced accordingly, i.e. to allocate the amount of gas to the substrates used. However, since allocating percentages to the overall methane yield is not possible through measurements on site, methane yield from scientifically recognised literature sources can be used for this purpose. The methane yields listed in Table 19 for all of the substrates used have been taken from annex of the German biomass ordinance [6].

Table 19: Determining the total calculated methane yield

Substrate put into the fermenter	Amount in t FM/a	Methane yield in Nm³/t FM	Methane yield in Nm³ (calc.)
Maize silage	41,000	106	4,346,000
Whole crop silage	3,900	103	401,700
Grass silage	4,920	100	492,000
Total methane yield (calculated)			5,239,700

The amount of 20,000 t FM/a fed into the fermenter is calculated by taking the supplied amount of silage maize (supplier 1) minus the 10 % silage losses assumed in this example.

$$Substrate\ input\ maize\ silage\ (supplier\ 1) = amount\ of\ silage\ maize\ (supplier\ 1) * 0.9$$

$$Substrate\ input\ maize\ silage\ (supplier\ 1) = 22{,}220\frac{t\ FM}{a} * 0.9 = 20{,}000\frac{t\ FM}{a}$$

Using the assumed methane yield for maize silage from Table 19, we calculate the proportion of the substrate in question to be 40 % of the total amount of methane as follows:

$$Proportion\ of\ methane\ yield\ = \frac{amount\ of\ maize\ silage\ (supplier\ 1) * methane\ yield}{total\ methane\ yield\ (calc.)} * 100\%$$

$$Proportion\ of\ methane\ yield = \frac{20{,}000\ \frac{t\ FS}{a} * 106\frac{m^3}{t\ FS}}{5{,}239{,}700\ \frac{m^3}{a}} * 100\%$$

$$\boldsymbol{Proportion\ of\ methane\ yield} = \mathbf{40}\%$$

Summary of the GHG emissions

Based on the percentage (40 %) determined in the previous section, the absolute GHG emissions for the biomethane produced from the amount of substrate in question can be calculated using the specific GHG emissions of the intermediate products and their percentage of product. The specific GHG emissions of the intermediate products and the corresponding amounts of product from the biomethane supply chain are summarised in Table 20. This summary over the balance period (in this case, one year) has to be determined by the treatment plant as the final interface and contains all of the information from the process steps up- and downstream from it. This starts with the GHG emissions from the cultivation of the substrate in question. The GHG emissions for the transport of the maize silage in the previous example, are based on the amount of substrate supplied during the balance period.

The specific GHG emissions of the biogas plant, amounting to 323 g CO_2 eq/ m^3 of methane output, are calculated from the data listed in Table 13. This specific value is only based on the percentage of methane for which, in the given example, the GHG emission saving potential is supposed to be verified and which is assigned to the amount of substrate in question (40 %). This also applies to the GHG emissions of the biogas treatment and its downstream distribution process.

The total usable amount of biomethane from the amount of substrate in question is 2,210,472 Nm³/a. (40% of 5,526,181 Nm³)

Table 20: Determination of the GHG emissions for the partial flow of biomethane from the amount of substrate in question

Raw material provision

	Cultivation [t/a]	$e'_{ec \ (cultivation \ incl. \ siloing)}$ [kgCO$_2$ eq/kg FM]	GHG emissions [kgCO$_2$ eq./a]
Silage maize (supplier 1)	22,220	0.061	1,355,420

Transport of the biomass to the biogas plant

	Supply [t/a]	e'_{td1} [kgCO$_2$ eq/kg biomass]	GHG emissions [kgCO$_2$ eq./a]
Silage maize (supplier 1)	22,220	0.0017	37,740

Emissions from the biogas plant based on the amount of substrate in question

	Methane output [m^3/a]	e'_{p1} [kgCO$_2$ eq/m^3]	GHG emissions [kgCO$_2$ eq./a]
Total methane	5,526,733	0.32	1,785,135
Proportion of substrate amount in question 40 %	2,210,693		714,054

Emissions from the biogas treatment based on the amount of substrate in question

	Biomethane [m^3/a]	e'_{p2} [kgCO$_2$ eq/m^3]	GHG emissions [kgCO$_2$ eq./a]
Total biomethane	5,526,181	0.109	602,353
Proportion of substrate amount in question 40 %	2,210,472		240,941

Emissions from distribution

		e_{td2}' [kgCO$_2$ eq/m^3]	GHG emissions [kgCO$_2$ eq./a]
Total biomethane	5,526,181	0.015	82,893
Proportion of substrate amount in question 40 %	2,210,472		33,157

Using the GHG emissions listed Table 20 (shaded in grey for the partial amount in question) the specific GHG emissions for the terms e'_{ec}, e'_{td1}, e'_{p1}, e'_{p2} and e'_{td2} can be calculated based on 1 Nm^3 of biomethane up to the filling station.

$$Total\ emissions\ per\ m^3\ of\ biomethane = \frac{(1,355,420 + 37,774 + 714,054 + 240,941 + 33,157)\frac{kgCO_2eq.}{a}}{2,210,472\ \frac{m^3}{a}}$$

$$Total\ emissions\ per\ m^3\ of\ biomethane = 1.08\ \frac{kg\ CO_2eq.}{m^3\ biomethane}$$

Taking into account the lower heating value of 36 MJ/m^3, the specific GHG emissions are converted to one MJ of biomethane as follows:

Here it should be noted that, in contrast to the gas industry, the lower heating value LHV is used for biomethane, rather than the higher heating value HHV.

$$Total\ emissions\ per\ MJ\ of\ biomethane = \frac{1.08\ \frac{kg\ CO2eq.}{m^3\ biomethane}}{36\ \frac{MJ}{m^3\ biomethane}}$$

$$Total\ emissions\ per\ MJ\ of\ biomethane = 0.03\ \frac{kg\ CO2eq.}{MJ\ biomethane}$$

$$\boldsymbol{Total\ emissions\ per\ MJ\ of\ biomethane = 30\ \frac{gCO_2eq.}{MJ\ biomethane}}$$

A specific GHG emission of 30 g CO_2-eq/MJ of biomethane is calculated for the partial flow of biomethane for which the GHG emission saving potential was determined in this example (2,210,472 m^3 of biomethane). This value can be compared to the fossil fuel value of 83,8 g CO_2eq/MJ of biomethane.

Calculating the GHG emission saving

The biogas treatment, as the final interface, now calculates the GHG emission saving potential using the specific GHG emissions determined for the provision of biomethane.

$$GHG\text{-}mitigation = \left[\frac{E_{Fossil\ fuel} - E_{Biofuel}}{E_{Fossil\ fuel}}\right]$$

$$GHG\text{-}mitigation = \left[\frac{83.8\frac{gCO_2eq.}{MJ} - 30\frac{gCO_2eq.}{MJ}}{83.8\frac{gCO_2eq.}{MJ}}\right] * 100 = 64\%$$

Thus, with energy crops-based biomethane production, around 64 % of the GHG emissions can be saved compared to the fossil reference.

Frequently asked questions (FAQ)

The section below is a collection of frequently asked questions. Some of these questions relate to areas for which there is currently little empirical data. If the certification systems are unable to offer an official interpretation, the answers to these questions reflect the views of the authors. The regulations that have been established as part of a specific certification system are to be fundamentally observed during the certification process.

Co-products and allocation

Is there an official definition of the terms co-product, processing residue, residual material and waste?

The RED does not contain definition of terms. These terms are partially defined in European Commission Communication No. 2010/C 160/02 and in the EU Directive 2015/1513 [27], [28].

According to these sources, waste is considered to be any material or object that has been disposed of, is intended to be disposed of, or must be disposed of by its owner.

According to 2010/C 160/02, residual materials/residues are residues from agriculture, aquaculture, the fishing industry and forestry, as well as processing residues. A processing residue is, according to 2010/C 160/02 and Directive 2015/1513, not an end product that is meant to be directly produced in a production process. It is not the primary aim of production and the process is not intentionally changed in order to produce it [27], [28].

Is there a basic rule or a decision-making tool for determining whether it is a co-product?

In accordance with EU COM 2010/C 160/02 and EU Directive 2015/1513, the production of co-products must be the primary aim of the production process, i.e. their production is directly intended and the production process is intentionally changed to enable its production [27], [28]. Furthermore, the product must be able to be stored and traded [29].

In order to place a process output in the category of co-product, residue or waste, the question of what it is actually used for and/or its further life-cycle becomes relevant. For example, if the material is sold on, and this can be documented, it can be placed in the category of co-product. Specific materials are explicitly left out of these current policies and may not be defined as co-products. This includes straw, bagasse and corn cobs. The GHG emissions are only allocated between the biofuel (or its pre-product) and the co-product. According to Annex V No. 18 of the RED, no GHG emissions can be allocated to waste, harvest residues or production residues [16]. Their life-cycle GHG emissions are zero until the place of their production.

What are the typical co-products of biomethane production?

Digestate is a typical co-product of the process chain used to produce biomethane.

Is digestate a co-product to which GHG emissions can be allocated?

No, because the digestate generated during the fermentation process usually have such a low DM content that the heating value is lower than zero. According to the EU RED Annex V Part C Point 18 "the energy content of co-products with negative energy content are assigned the value of zero," and can, thus, not be allocated [16]. After implementing the Commission's communication "Note on conducting and verifying actual calculations of GHG emission savings" on 31/12/2016 the energy contents of the biofuel/intermediate product/co-product have to be based on the dry matter during allocation [29]. This avoids the issue of products having negative heating values. The question of whether digestate is a co-product that can be allocated, and at which stage of the process chain a potential allocation happens, is discussed in Section.

At what stage of the process chain does the allocation occur?

According to the EU COM 2010/C 160/02, the allocation should take place after the process step in which the co-product is produced, or at the time when the product undergoes no further downstream processing connected to the upstream part of the process through material or energetic feedback loops [27].

Units and conversion steps

Where can I find help in converting different units of measurement?

There are no officially recognised documents for converting volumes, densities or heating values. We recommend using different accompanying information in the Biograce Tool (www.biograce.net).

Combining disaggregated default values and individually calculated GHG emissions

What has to be considered when one or more interfaces use disaggregated default values from the RED and other interfaces along the process chain conduct their own GHG calculations?

It should be noted that individually determined values and partial standard values cannot simply be added to the total emission value since:

1) Individually determined GHG values e' are based on kilograms of the (intermediate) product, and disaggregated default values e are based on the final product (e.g. 1 MJ of biomethane). This means the disaggregated default values of the process steps (raw material production e_{ec}, processing e_p, transport and distribution e_{td}) must be converted to kg of their corresponding (intermediate) product. This requires conversion factors (CF). Conversion factors indicate the amount of intermediate product that is required for 1 MJ of end product. These conversion factors are depicted in yields.

2) The disaggregated default values can be based on other allocation factors (AFs) than the individually determined GHG value.

The formula below converts e to e' (taking CF and AF into consideration):

$$e' \left[\frac{kgCO_2 eq.}{kg \ intermediate \ product} \right] = \frac{e \left[\frac{kgCO_2 eq.}{MJ} \right]}{AF \left[\frac{MJ}{MJ} \right] * CF \left[\frac{kg \ intermediate \ product}{MJ} \right]}$$

The allocation factors AF and the conversion factors CF, which the disaggregated default values are based on, have been taken from the JRC 2008.

Thus the actual CF and AF, which also form the basis of the individually calculated GHG values, are applied to the partial standard values, and the total GHG emissions can be determined as illustrated in the sample calculation.

According to the recently published Communication "Note on conducting and verifying actual calculations of GHG emissions savings", an adjustment of the partial standard values, e.g. improved efficiencies in the conversion plants, will no longer be possible in the future [29]. Partial standard values (e.g. for cultivation) will then simply be added to the actual values (e.g. for the conversion).

Can disaggregated default values from technology paths be used for paths for which no standard values exist?

Example: a GHG value is individually determined for biomethane made from silage maize up until the biomethane is produced. Can the disaggregated default values for distribution be taken from the existing standard value for biomethane made from organic residential waste and combined with the individually determined value?

These disaggregated default values can be adopted for partial steps in which a product exhibits identical properties to another product and for which partial standard values exist. In this concrete example, this means that, since the distribution does not have its own disaggregated default values, no disaggregated default values can be adopted.

Data and key indicators

Which emission factors and material densities may be used?

Emission factors and material densities used to individually calculate the GHG emissions must originate from scientific publications. Scientific publications can be literature sources or approved databases (e.g. the ecoinvent database, ELCD, NREL). Usually such literature sources are termed scientific literature if they have undergone a peer-review process before publication. The author, title (journal, volume) and year must be cited for every source. If a company determines an emission factor or has the emission factor be determined for its own product, this EF must be published in the literature or in approved databases. In addition, prescribed values from the system principles of the certification system must be complied with, where available.

When can lump sum emission factors be used and when must actual calculations for auxiliaries and energy carriers be individually performed?

If, for example, a company uses pellets or wood chips to supply energy to its processes, the company can use an emission factor from an approved source. This emission factor, however, must represent the process and raw material which resembles that of the process to be reproduced.

Which emission factor should be used when the process has an external power supply? What are the prerequisites for using a lower emission factor?

According to Annex V, No. 11 of the RED, the emission factor of the electricity's respective region must be used in cases where grid power is used [16]. In practice, the national or European electricity mix is used depending on the system. In the recently published Communication "Note on conducting and verifying actual calculations of GHG emissions savings", the use of the EU electricity mix will be required in future balances [29].

If isolated operation is used to generate green electricity, i.e. the plant generating electricity is not connected to the power grid, the emission factor for the average amount of green electricity produced can be applied to this green electricity.

Which lower heating values can be used?

Lower heating values used for individual calculations have to come from scientific publications or actual measurements. Actual measurements have to be documented so that the calculation can be followed. Furthermore, prescribed values from the system principles of the certification systems are to be taken into account where available.

Do infrastructure expenditures, e.g. the construction of the biomethane plant, have to be considered?

No. According to the RED, the emissions that are tied to the construction of the plant are not taken into account [16].

Do low quantities of auxiliaries also have to be indicated in the GHG balance? Is there a "marginality limit"?

According to EU COM 2010/C 160/02, it does not appear necessary to include inputs that have little or no effect on the results in the calculation (like with small quantities of chemicals used for processing) [27]. The Biograce tool (http://www.biograce.net) defines the cut-off criteria for small quantities [20]. Various systems also describe concrete cut-off criteria in their system principles. These are to be used accordingly.

Do empty runs also have to be included in the calculation?

Yes, empty runs are to be taken into account in the emission balances.

Primary sources of GHG emissions in the biomethane process chain

Which processes in the biomethane production process cause the most GHG emissions?

In waste- and residue-based biomethane production processes, most of the greenhouse gases are released during the processing stage (biogas production, biogas treatment). This is primarily due to electricity requirements and diffuse methane emissions.

In biomethane processes based on energy crops, most of the GHG emissions are released during the production of the raw material. The GHG emissions are primarily due to fertiliser input and the diesel used to power the agricultural machinery.

Special considerations and questions relating to GHG calculation (incl. GHG savings, LUC, N_2O)

How are the field emissions for the individual calculations of the GHG emissions coming from the cultivation of raw materials calculated?

The European Commission has approved two methods for determining field emissions: the GNOC Model (Global Nitrous Oxide Calculator) and the IPCC method (Tier 1). The field emissions can be calculated using the GNOC model at http://gnoc.jrc.ec.europa.eu. The Biograce Tool provides a nitrous oxide calculator that uses the IPCC method. This can be found at www.biograce.net. The Biograce II Tool provides a nitrous oxide calculator for silage maize based on the IPCC method, as well as the possibility to adjust the calculator for other biogas substrates. This can also be found at www.biograce.net [17].

How are the GHG emissions from land-use changes calculated when the area of cultivation was not used as farmland before 1 January 2008?

GHG emissions following land-use changes are calculated as follows:

$$e_l' \left[\frac{kg\ CO2\ddot{A}q}{kg\ Ernteertrag} \right] = \frac{CS_R \left[\frac{kg\ C}{ha} \right] - CS_A \left[\frac{kg\ C}{ha} \right]}{Ernteertrag_{Haupterzeugnis} \left[\frac{kg}{ha*a} \right] * 20[a]} * 3{,}664 - \frac{e_B}{AF*KF}$$

e_l' Annualised greenhouse gas emissions from changes in carbon stocks as a result of land-use changes

CS_R Carbon stocks associated with the reference land use per unit of area at the time of reference or 20 years before production of the raw material, depending on which point in time is later.

CS_A Carbon stocks associated with the actual land use per unit of area. When the carbon stocks accumulate over more than one year, the CS_A value is considered to be the estimated carbon stocks after 20 years or at the time when the plants are mature, depending on which point in time is earlier.

e_B Bonus of 29 g CO_2 eq/MJ of biofuel when cultivation occurs on restored degraded land

AF Allocation factor

CF Conversion factor

The values for CS_R and CS_A can be taken from scientific literature (e.g. the IPCC Guidelines) [21]. The values for the conversion factor are taken from the operational data; those for the allocation factor are taken from a calculation based on operational data and the lower heating values. GHG emissions resulting from changes in land use are only allocated to the biofuel. If a co-product is produced, the GHG emissions are not allocated between the biofuel and the co-product.

When can the bonus e_B be taken into account?

According to the RED, a bonus of 29 g CO_2 eq./MJ is conferred when there is proof that the affected area at the time of reference was not used agriculturally or for any other purpose, and falls under the following two categories: i) heavily degraded areas including previous agricultural areas ii) heavily contaminated areas [16]. The bonus of 29 g CO_2 eq./MJ applies for a period of time up to ten years starting when the area was converted into an agriculturally used land if a continuous increase in carbon stocks and a significant decrease in erosion as per Annex V, No. 8, Sentence 1, Letter b Double Letter aa of the RED can be assured and the soil contamination is reduced as per Double Letter bb of the RED. The bonus is only allocated to the biofuel. If a co-product is produced, the GHG emissions are not allocated between the biofuel and the co-product.

How are diffuse methane emissions < 1 % verified?

In the absence of actual measured values, a lump sum value of 1 % of the methane produced is frequently assumed [23], [24]. This value is reflected in the system principles of the certification systems (RED cert and ISCC) [25],[26]. According to these principles, low emissions rates have to be verified based on emission measurements. This can be verified by a measurement protocol that is in accordance with the plant and the operational management.

Return of the digestate (adjustment of substrate cultivation)

During the fermentation process, digestate is produced as a co-product. The digestate is usually used as a fertiliser and can either be spread directly onto the agricultural land, or first be treated and then used.

How is a GHG balance calculated when the consumption data cannot be allocated to the individual process steps like in the case of a super interface (biogas plant and biogas treatment plant as one operational unit) in the sense of a "black box"?

If the biogas plant and the biogas treatment plant form one operational unit, consumption data, particularly for electricity and heat, often cannot be allocated to the individual process steps. If, in the case that there is only data on the substrate input, the total consumption data for electricity and heat, and the amount of biomethane that is fed in, the plant can be considered as a black box. Here the challenge is to take into account diffused methane emissions of the biogas plant and the methane slip of the treatment plant that occur within the process chain. This can be done as follows: The methane yield, determined during calibration over the balance period, is given as the methane output of the treatment plant. The methane losses (proportional, varying according to the treatment technology) enable the amount of methane slip and the methane input of the treatment plant, as well as the output of the biogas plant to be determined. Now the 1 % of the diffuse methane emissions of the biogas plant, based on the biogas output, have to be factored in.

Which conditions have to be fulfilled in order to be able to add the GHG savings e_{sca}?

According to EU COM 2010/C 160/02, "improved agricultural farming practices" may include the following practices [27]:

- shifting to reduced or zero-tillage;
- improved crop rotations and/or cover crops, including crop residue management;
- improved fertiliser or manure management;
- use of soil improver (e.g. compost).

Emissions savings resulting from such improvements can be included if it can be proven that, during the period in which the affected raw material was cultivated,

- the carbon stocks in the soil increased, or,
- when reliable and testable evidence is presented, that shows that there is a reasonable assumption that they have increased.

The GHG savings measured during the time period are to be divided by the time period (in years) in order to obtain the annual basis of GHG savings.

Carbon stock measurements could constitute one such verification, e.g. in the form of an initial measurement taken before cultivation and later measurements taken at regular intervals of several years. In such cases, the increase in carbon stocks in the soil would be estimated before the second measurements are presented, assuming there is a relevant scientific basis. After the second measurement, the measurements form the basis for determining whether carbon stocks have increased in the soil and the extent to which this has occurred.

Which prerequisites have to be considered when including e_{ccr}? Are there positive and negative lists of examples that can be included?

According to the RED Annex V No. 15, it must be proven that the biogenic CO_2 that is captured is used commercially and replaces fossil CO_2. The GHG emission saving eccr is limited to the GHG emissions avoided through the capture of the biogenic CO_2 [16]. There are no official positive and negative lists.

The Communication "Note on conducting and verifying actual calculations of GHG emissions savings" which will go into force on 31/12/2016, requires more concrete burdens of proof for adding eccr. This already applies in some certification systems.

Which prerequisites have to be considered when including e_{ccs}?

There are no officially formulated requirements except for the information from the RED Annex V No. 14 which states: "Emissions saving from carbon capture and geological storage (e_{ccs}), that have not already been accounted for in ep, shall be limited to the emissions avoided through the capture and sequestration of emitted CO_2 directly related to the production, transport, processing and distribution of fuel." It has to be verifiable that the biogenic CO_2 is actually captured and safely stored.

How is the term e'_{ee} calculated and what should be taken into consideration when e'_{ee} is added?

GHG savings as a result of excess electricity from the co-generation of heat and power (CHP) are calculated as follows:

$$e_{ee}`\left[\frac{kg\ CO_2eq}{kg\ main\ product}\right] = \frac{excess\ electricity\left[\frac{kWh}{a}\right] - EF_{fuel}\left[\frac{kg\ CO_2eq}{kWh}\right]}{amount_{main\ product}\ \left[\frac{kg}{a}\right]}$$

According to Annex V No. 16 of the RED, the GHG emission saving generated from excess electricity correspond to the amount of GHG emissions produced when a corresponding amount of electricity is generated from a power station that uses the same fuel [16]. It is also assumed that the size of the CHP plant producing these excesses corresponds to the minimum size needed to produce the heat required for the biofuel.

How are the GHG savings e'_{sca}, e'_{ee}, e'_{ccr}, e'_{ccs} calculated when a co-product is generated during the production process and the GHG emissions are allocated between the biofuel and this co-product?

The GHG savings e'_{sca}, e'_{ccr} and e'_{ccs} are not allocated between the biofuel and the co-product. In fact, they are assigned only to the biofuel after allocation. The expenditures that are generated by adding on the GHG savings are also assigned only to the biofuel. In contrast, the GHG saving e_{ee} is assigned to the overall production process and, thus, allocated between the biofuel and the co-product.

Balancing

When is it allowed to balance the GHG emissions when biomass and biofuels are mixed?

The DE and EU system requirements differ in terms of balancing. According to Section 16 (2) 2 a) of the Biofuels Sustainability Ordinance, in the German systems, the GHG emission saving potentials from different amounts of fuels with different GHG emission saving potentials can only be balanced when all amounts added to the mixture exhibit the necessary GHG emission saving potential before being added (currently 35 %, starting 1 January 2017: 50 %) [30].

According to Section 16 (2) 2 a) of the Biofuels Sustainability Ordinance, the GHG emissions from biomass that is used to produce biofuel and for which no proof of sustainability has been issued, can only be balanced when all quantities added to the mixture exhibit the value that has been established for the production step before they are added. Corresponding maximum GHG values have been published in the Federal Gazette (Bundesanzeiger) [30].

As there are currently no maximum values for renewable resource-based biomethane, it is necessary to separate the mass flows of the individual substrates and to individually calculate the GHG balance. This is because the GHG pre-chain values can vary considerably within a substrate group. (A plant can typically have up to 40 - 50 different suppliers of silage maize and a similar amount for other substrates.) All of the producers have to be recorded and balanced accordingly and an "individual balance" for the mass flow of every producer has to be calculated up until the fuel is delivered to the filling station.

No balancing is possible in EU systems.

Discussion points

How are emissions from open digestate storage determined?

For one thing, the system principles state that, in the case of individual calculations, biogas plants have to have a gas-tight repository for digestate (this requirement was adopted by Fehrenbach, 2010, and is originally based on the use of maximum values for the provision of the substrate as recommended by Fehrenbach in 2010). On the other hand, additional emissions should be taken into account for plants that have open repositories for fermentation residue. The emission values can be taken from scientific publications to balance the methane emissions from open fermentation residue repositories. Often the results of the federal measurement programme are cited in this respect.

Is digestate a co-product to which GHG emissions can be assigned?

The treatment process increases the DM and, hence, the energy content of the digestate. When a positive lower heating value can be ascribed to the digestate, the digestate is an allocable co-product.

At which stage does allocation occur between biomethane as the main product and the digestate as the co-product?

Because individual partial steps of biomethane production are closely connected due to the corresponding feedback loops (e.g. recirculation of the liquid phase from the treatment of the fermentation residue to the fermenter), the refinery approach described in EU COM 2010/C 160/02 is transferable to the biomethane system [27]. The recommendation also states: "if the system is considered as a 'refinery'…the allocation occurs at the point in time when the individual products no longer undergo any further downstream processing connected through a material or energy feedback loop to an upstream part of the process." This would be after the treatment of the digestate as illustrated in Figure 6 (since the treatment of the digestate also represents a feedback loop through the recirculation of the liquid phase).
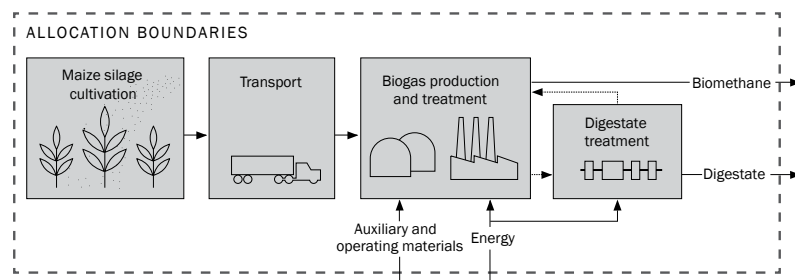

Figure 6: Allocation framework

Can the avoided storage emissions be considered GHG savings when manure is used in biogas plants?

Inevitable methane emissions occur when manure is stored. When the manure is promptly brought to the biogas plant to act as a substrate, these emissions are avoided, and/or the generated biomethane can be captured and used. Through an emissions credit it is possible to take this benefit into account as part of the GHG balance.

Conversion tables

Volumes and mass (weight) of biomethane

1.000 Nm^3 biomethane = 720 kg   = 0,72 t
1 t biomethane   = 1.388,88 Nm^3

Basic formula

$$Density = \frac{Mass}{Volumes} \rightarrow \rho = \frac{m}{V}$$

Density and heating and calorific values

	Density kg/Nm³	Higher heating value MJ/Nm³	Lower heating value MJ/Nm³	Lower heating value kWh/Nm³	Fuel equivalence in kg
Biomethane	0.72	39.9	36	10	1.5

In this document the term heating value means the lower heating value.

The unit Nm^3 or m^3 i.N. describes a cubic metre in a standard state. According to DIN 1343, this is the reference state that is determined by the standard temperature of 0° C (273,15 K) and the standard pressure of 1.01325 bars.

Conversion of energy units

	MJ	kcal	kWh
1 MJ	1	238.80	0.28
1 kcal	0.00419	1	0.001163
1 kWh	3.60	860	1

Conversion of units

	m³	l	barrel	US gal
1 m³	1	1,000	6.3	
1 l	0.001	1	0.0063	
1 barrel	0.159	159	1	
1 US gal	0.00379	3.79		1

References

[1]   Deutsches Biomasseforschungszentrum gemeinnützige GmbH (DBFZ); Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (KTBL); Johann Heinrich von Thünen-Institut (TI); Rechtsanwaltskanzlei Schnutenhaus & Kollegen: Leitfaden Biogas - Von der Gewinnung zur Nutzung. 6. Aufl.: FACHAGENTUR NACHWACHSENDE ROHSTOFFE E. V. (FNR), 2013 — ISBN 3-00-014333-5

[2]   Deutsches Biomasseforschungszentrum gemeinnützige GmbH (DBFZ); Schnutenhaus & Kollegen Rechtsanwälte: Leitfaden Biogasaufbereitung und -einspeisung. 5. Aufl.: FACHAGENTUR NACHWACHSENDE ROHSTOFFE E. V. (FNR) — ISBN 3-00-018346-9

[3]   Krayl, Petra: Einspeisung von Biomethan in das Erdgasnetz - Erfahrungsberichte der Biomethananlagen. In: DVGW energie | wasserpraxis Bd. 04/2009 (2009)

[4]   KTBL: Faustzahlen Biogas. 3.Aufl.: KTBL, 2013 — ISBN 978-3-941583-85-6

[5]   Biogasausbeuten verschiedener Substrate - Programm Berechnung - LfL. URL http://www.lfl.bayern.de/iba/energie/049711/?strsearch=bioabfall&pos=middle&anker=substratanker#substratanker. - abgerufen am 2015-10-16

[6]   Bayerische Landesanstalt für Landwirtschaft (LfL) und Fachverband Biogas e.V.: Einsatzstoffe nach Biomasseverordnung (2011)

[7]   Scheftelowitz, M.; Daniel-Gromke, J.; Rensberg, N.; Denysenko, V.; Naumann, K.; Stinner, W.; Hillebrand, K.; Peetz, D.; Hennig, C.: Stromerzeugung aus Biomasse (Vorhaben IIa Biomasse) (preliminary report). Leipzig: Deutsches Biomasseforschungszentrum, 2015

[8]   BHKW-Kenndaten 2011 - Module Anbieter Kosten. Frankfurt am Main: ASUE e.V. (Hrsg.), Stadt Frankfurt am Main (Hrsg.), 2011

[9]   Schmack Carbotech GmbH: Technische Aspekte zur Druckwechseladsorption. Herstellerangaben (2012)

[10]   Malmberg Bioerdgastech GmbH: Technische Aspekte zur Druckwasserwäsche. Herstellerangaben (2012)

[11]   Greenlane Biogas GmbH: Technische Aspekte zur Druckwasserwäsche. Herstellerangaben (2012)

[12]   Haase Energietechnik GmbH: Technische Aspekte zur Genosorbwäsche. Herstellerangaben (2012)

[13]   MT-Biomethan GmbH: Technische Aspekte zur Aminwäsche. Herstellerangaben (2012)

[14]   Axiom GmbH: Technische Aspekte zum Membrantrennverfahren. Herstellerangaben (2012)

[15]   Hackschnitzel-Heizungen - Marktübersicht. Gülzow: FACHAGENTUR NACHWACHSENDE ROHSTOFFE E. V. (FNR), 2012

[16]   EUROPEAN PARLIAMENT & EUROPEAN COUNCIL. Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, 2009

[17]   Institut für Energie- und Umweltforschung Heidelberg (IFEU): BIOGRACE II; Harmonised calculations of greenhouse gas (GHG) emissions for electricity, heat and cooling from biomass throughout the European Union. URL http://www.biograce.net/biograce2/. - abgerufen am 2015-10-09

[18]   Bundesanstalt für Landwirtschaft und Ernährung (BLE): Leitfaden Nachhaltige Biomasseherstellung. 1. Aufl. Aufl. Bonn, 2010

[19]   Swiss centre for life cycle inventories: Ecoinvent v2.1 for umberto 5.5, 2009

[20]   Institut für Energie- und Umweltforschung Heidelberg (IFEU): Bio-grace. Harmonized calculations of biofuel greenhouse gas emissions in Europe. — www.biograce.net

[21]   Eggleston, H.S; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K.: IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4 agriculture, forestry and other land use, prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan, 2006

[22]   KTBL: Online Anwendung - Wirtschaftlichkeitsrechner Biogas : Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), Darmstadt, 2015

[23]   Vogt, Regine: Basisdaten zu THG-Bilanzen für Biogs-Prozessketten und Erstellung neuer THG-Bilanzen. Heidelberg: Institut für Energie- und Umweltforschung, 2007

[24]   Vetter, Armin; Arnold, Karin: Klima- und Umwelteffekte von Bio-methan, Anlagentechnik und Substratauswahl, Wuppertal Paper Nr. 182, 2010

[25]   REDcert: Ergänzende Systemgrundsätze für den Bereich Biomethan zur Umsetzung der BioKraft-NachV (2012)

[26]   ISCC: Ergänzende Systemgrundlagen für die Zertifizierung von gas-förmigen Biokraftstoffen aus Biogasanlagen (2013)

[27]   EUROPEAN COMMISSION: Communication from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels (2010/C 160/02), 2010

[28]   THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION: Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources, 2015

[29]   European Commission: Note on the conducting and verifying actual calculations of the GHG emission savings, 2015

[30]   Verordnung über Anforderungen an eine nachhaltige Herstellung von Biokraftstoffen (Biokraftstoff-Nachhaltigkeitsverordnung - Biokraft-NachV) vom 30.09.2009, 2009

Legal notice

This guide was developed as part of the project
"Creation of Guides for Auditing the GHG Balances of Biofuels"