

GUIDANCE DOCUMENT

Technical principles and methodology
for calculating GHG balances of

Bioethanol



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Preamble



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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 GHG data detailed in the sustainability certificate of the respective interface forms the necessary 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, 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 bioethanol production

Bioethanol is predominantly produced from raw materials containing sugar (e.g. sugar beet, sugar cane) or starch (e.g. wheat, rye, triticale, maize). This requires a series of different process steps (Fig. 1). First, a fermentable sugar solution is obtained as part of the raw material processing. Various mechanical, thermal, chemical and biochemical processes are used to do this. Yeasts are used in the fermentation process to convert the sugar solution into ethanol (alcohol) and into carbon dioxide, which can be further processed into a co-product. Water and residues from the raw material are removed from the ethanol in the subsequent distillation and rectification process. The ethanol is dehydrated up to a concentration of 99.9 wt.% and then marketed. The main co-product is vinasse or stillage if raw materials containing sugar or starch respectively were used. These co-products are treated and can be used as animal feed, fertiliser or to produce biogas. Other co-products, such as bran, gluten and germ oil, can be produced from raw materials that contain starch, and the co-products beet pulp and carbonation lime ("Carbokalk") can be produced from raw materials containing sugar.

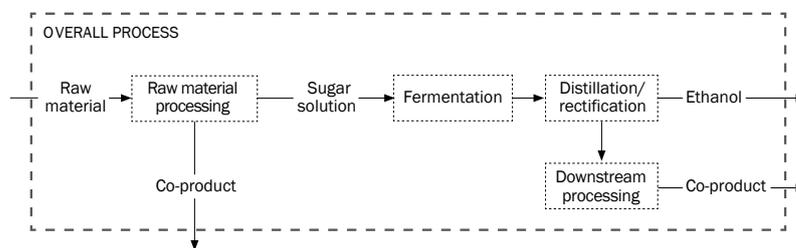


Figure 1: Overview of the bioethanol production process

To support the sustainability certification process, a detailed explanation of the raw material processing, fermentation, distillation as well as the downstream processing of the co-products is given below. In the section that describes the processing of the raw material, the processes used to treat raw materials containing sugar will be looked at separately from those used to process raw materials containing starch. The sugar solution is processed into ethanol in a similar way for both raw materials from the fermentation process onwards and, thus, both raw materials will be looked at together in this section. The treatment of the co-products at the end of the process will, once again, be described separately since they differ with regard to the unfermented elements contained in the raw materials.



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The generations of bioethanol production:

Bioethanol production based on raw materials that contain starch or sugar (e.g. wheat, sugar beet or sugar cane) is an established process which is sometimes labelled *first generation ethanol*. In contrast, *second generation* bioethanol is when raw materials containing lignocellulose are used in the production. Processing raw materials containing lignocellulose (e.g. straw, wood residue or material from landscape management) is linked to a higher technological expenditure and has yet to be commercially realised. However, major advances have been made in recent years in developing suitable technologies. This means that increased use of agricultural and forestry residues is likely over the medium to long term. The special features of the production of second generation bioethanol are not explicitly covered in this guidance document.

Processing of the raw materials to produce sugar solutions

The aim of the raw material processing is to produce a fermentable sugar solution from the raw material.

Sugar beet processing. During the raw material processing, sugar is extracted from the raw materials, cleaned when necessary, and preserved. These process steps are also required to produce sugar for the food industry. This is why ethanol plants that process raw materials containing sugar are typically connected to sugar factories and use the same processing equipment. Only sugar beet are processed into bioethanol in Germany; sugar cane or, occasionally, sorghum is used in other countries depending on climactic conditions.

Dry matter content (DM) of different beet pulps:

- Wet pulp (DM: 8 - 10 %)
- Pressed pulp (DM: approx. 25 %)
- Dry pulp (DM: approx. 90 %)

- Limestone (calcium carbonate, CaCO_3)
- Burnt lime (calcium oxide, CaO)
- Limewater (calcium hydroxide, Ca(OH)_2)

Molasses contain many more nutrients than the other sugar juices and, thus, serve as a source of nutrients. Thick juice and molasses can be easily stored and used throughout the year in the bioethanol plant. During the sugar campaign from September to January/February (pasteurized) raw juice or thin juice can also be used.

Sugar content of the sugar juices:

- Raw juice (13 - 16 %)
- Thin juice (approx. 16 %)
- Thick juice (60 - 70 %)
- Molasses (35 - 53 %)

After delivery, the sugar beet are washed and cut up into beet pulp (Fig. 2). Then the sugar is washed out of the beet pulp with hot water (extraction). The desugared beet pulp (also called wet pulp) is pressed (pressed pulp) and can be used directly as animal feed or to produce biogas or it can be dried to dry pulp, pelletized and marketed as animal feed (mostly with the addition of molasses).

The extracted sugar juice (raw juice) perishes quickly and must be processed directly into ethanol. In order to extend the storage life, the dry matter content is thickened from 65 to 68 %. Before it is thickened, the raw juice must be cleaned by a carbonatation. For this, the raw juice is mixed with lime milk. Then carbon dioxide is introduced which turns the dissolved calcium ions into calcium carbonate. The impurities from the raw juice are mostly bound to the generated particles and can be separated as lime mud. The accrued lime mud is dewatered into carbonatation lime and used as fertiliser. The required lime milk for this process step is produced on-site. This is done by burning limestone in a coke-fired lime kiln to turn it into limewater. Some of the carbon dioxide that is produced is directly used in the carbonatation process; the rest escapes into the environment.

The clear, thin, light-grey juice produced through carbonatation is condensed into a golden yellow thick juice in a multi-stage evaporation. This thick juice is long lasting thanks to its high sugar content and can easily be stored. To produce granulated sugar/household sugar, the thick juice is boiled until sugar crystals form. The salts, which were also washed out of the sugar beet during the extraction of the beet pulp, are enriched in a liquid phase and discharged from the process as molasses. The molasses also contain significant a portion of sugar which can no longer be cost-effectively separated.

Raw juice, thin juice, thick juice and molasses are used in the ethanol fermentation depending on the design and operating state of the plant. The sugar molecules contained in the sugar solution can be directly converted by the yeasts into ethanol.

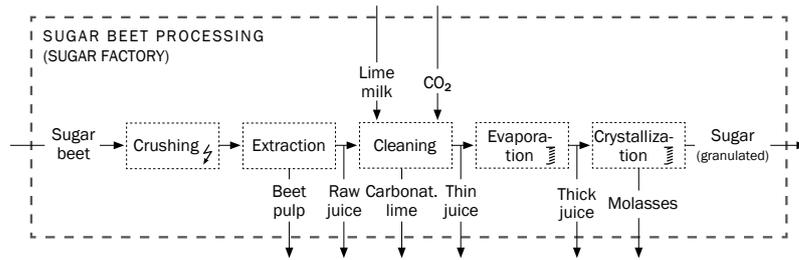


Figure 2: Overview of sugar beet processing in a sugar factory

Sugar cane processing. Sugar cane is essentially processed using the same processing steps as for sugar beet, although the equipment is different. Sugar is either extracted with hot water, or by grinding and pressing the sugar out of the sugar cane. After sugar is extracted, the so-called bagasse – a fibrous material of the sugar cane – is left over (equivalent to the beet pulp in the sugar beet process). The bagasse is typically burned in steam generators and, thus, used to generate electricity and heat (CHP process) for the plant. Efficient plants are able to generate additional electricity which can be sold. The raw juice that is obtained is then cleaned. In addition to the thin juice, a lime mud is generated which is pressed into a filter cake to become a co-product. The filter cake mainly consists of suspended particles and fibres, and can be used as a fertiliser.

Grains processing. Raw materials containing starch (grains) are first ground to flour using dry or wet grinding (Fig. 3). In many plants, grain components, such as bran, gluten or germ oil, are already separated during a more elaborate grinding process and separately processed into co-products. After this the starch contained in the flour has to be converted into fermentable sugars (e.g. glucose).

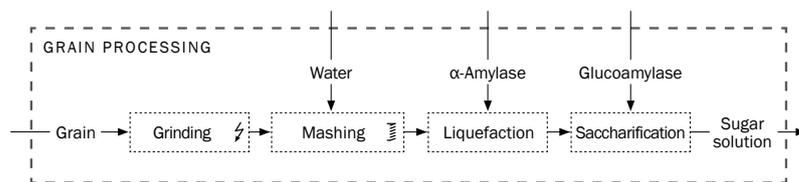


Figure 3: Overview of grain processing

To do this, the flour is mixed with water (maceration) and warmed up to approx. 90 °C until the starch gelatinises. The gelatinisation causes a sharply increase of viscosity because the starch molecules absorb water and swell. In order to convert starch molecules into sugar molecules, two different starch-decomposing enzymes are required. During liquefaction, α -amylases are added that break down the very long starch molecules into short chain molecules. During subsequent saccharification, glucoamylases are added which further break down the shorter molecular chains into single sugar molecules. The sugar solution that is produced is now accessible for yeasts and can be used in this form in the fermentation process.

Energy-intensive processes:

- ⚡ Electricity
- 🌀 Steam

Dry matter contents (DM) of various sugar cane co-products:

- Bagasse (DM: 52 - 60 %)
- Filter cake (DM: 25 - 32 %)
- Vinasse (DM: 1 - 4 %)

Cogeneration of heat and power (CHP)

describes the simultaneous production of electricity and heat (e.g. burning of bagasse in a steam boiler in order to run a steam turbine for generating electricity.)

Starch is made of long chains of glucose molecules. These have to be cleaved into single molecules in various steps so that the glucose can be utilized by the yeasts.

Dry grinding is primarily done to process wheat, barley or rye using hammer mills or roller mills.

Wet grinding is mostly used to process grains from which the germ oil, bran and/or gluten are to be separated (e.g. wheat and maize).

Enzymes are (mostly protein) substances, which accelerate biochemical reactions.

Yeasts are single cell fungi. The genus *Saccharomyces cerevisiae* (baker's yeast) is primarily used in German ethanol plants.

Dry yeasts are powdery (DM = 90 - 95 %) and are activated through soaking in water or saline solution in a yeast cultivation vessel.

Liquid yeasts do not need to be activated and can be used directly in a pre-fermenter.

Fermentation

During fermentation, the sugar solution is converted into ethanol by yeasts (Fig. 4). Dry and liquid yeasts can be used. Before fermentation, yeasts are cultivated in a small yeast cultivation vessel. Then the yeasts are adapted to the substrate. Air is introduced in the pre-fermenter and the yeasts propagate (aerobic conditions). In order to support the yeast growth, nutrients and minerals are added. These include urea, diammonium phosphate, magnesium sulphate or zinc sulphate. Sometimes acids (e.g. sulphuric acid, phosphoric acid, nitric acid) or bases (e.g. sodium hydroxide) are added to the process to adjust the pH value. Once a sufficient cell density has been achieved in the pre-fermenter, the yeasts are placed in the main fermenter along with the sugar solution.

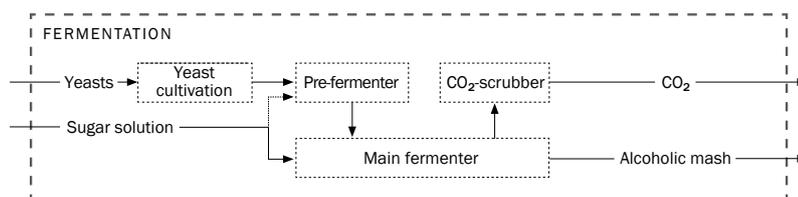
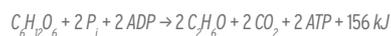


Figure 4: Overview of the fermentation process

Reaction equation for converting glucose into ethanol:



The aim is to achieve the highest ethanol content possible during fermentation. However, an ethanol content of over 13 wt.% is seldom achievable because when the sugar content at the start of fermentation is too high, and the ethanol content at the end of fermentation is too high, cell growth may be stunted and cell viability of the yeast cells may be inhibited. Ongoing research aims to steadily improve the yeast's substrate- and product tolerance.

Around 0.51 kg of ethanol and 0.49 kg of carbon dioxide are generated from 1 kg of sugar in the main fermenter under the exclusion of air (anaerobic conditions). Other metabolic products are also generated which accrue as fusel oils, for example. The yeasts release heat as part of the metabolic process, which has to be discharged through a cooling system in order to maintain the ideal fermentation temperature of approx. 32 °C. The ethanol content in the alcoholic mash is 9 – 13 wt.% after fermentation. The alcoholic mash can be fed directly into the distillation column or temporarily stored in a mash tank. The mash tank is the size of an additional main fermenter and usually serves as a storage or buffer tank for the mash ahead of the distillation unit. It is meant to hydraulically decouple the fermentation and distillation.

CO₂ scrubbing. The carbon dioxide generated during the fermentation process is purified of any existing ethanol and odorous substances in a CO₂ scrubber and released into the atmosphere. Sometimes an additional bio-filter must be fitted to purify the exhaust air. There is also the possibility of capturing the carbon dioxide and, in an additional process, to compress, liquefy and market it as a food-grade co-product (liquid CO₂). Another option is to use the carbon dioxide to cultivate plants or aquacultures.

Distillation and Rectification

The distillation process serves to separate the alcoholic mash into an almost alcohol-free fraction (max. 0.16 wt.% ethanol) containing all the solids and a solid-free alcohol-water mixture (Fig. 5). The alcohol-water mixture has an ethanol content of 44 – 49 wt.%. It is removed at the head of the distillation column and fed into the rectification column. The solid phase is called vinasse when it comes from raw materials containing sugar, and stillage when the raw materials contain starch. It is removed from the bottom of the distillation column and then processed further. After distillation the alcohol-water mixture is split up in a rectification column. This leads to an ethanol concentration of 88 – 95 wt.%. Water cannot be completely separated from the ethanol during rectification since the substances form an azeotrope. In the rectification column it is also possible to separate fusel alcohols (also called fusel oils), as well as medium and high value alcohols as co-products. The latter water that accrues in the bottom of the rectification column can partly be reused in the process as process water (for maceration, fermentation etc.). Finally, the ethanol is dehydrated (dried). Any remaining water is removed until the specification that allows the ethanol to be used as a fuel is reached (max. 0.5 wt.% H₂O). Molecular sieves are frequently used. After distillation, rectification and dehydration, there is a pure ethanol flow, a co-product flow (vinasse or stillage) and optional a fusel oil flow.

Ethanol and water form an azeotropic mixture in which the composition of the gas phase corresponds to that of the liquid phase (condensation and boiling curves touch). This means that separation through evaporation is no longer possible. At atmospheric pressure the azeotrope of ethanol and water has a boiling temperature of 78.5 °C and an ethanol concentration of 95.63 wt.% (96.5 vol.%).

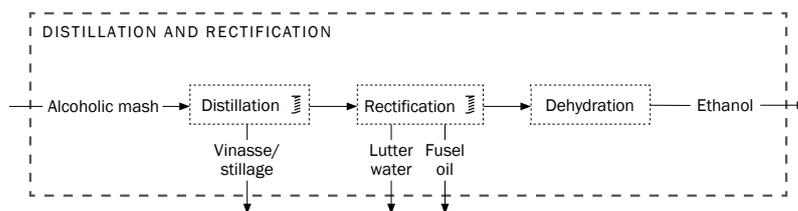


Figure 5: Overview of the distillation and rectification process

Treatment of the co-products

Vinasse. Vinasse is a co-product that is produced when bioethanol is made from sugar beet. It has a dry matter content of between 5 – 15 % (thin vinasse) depending on the sugar juice used (see Fig. 2). Up to 15 litres of vinasse per litre of ethanol can accrue. Vinasse can be used as animal feed, organic fertiliser in agriculture, or as a substrate for biogas plants. Due to its low dry matter content, and in order to save on transport costs, a multi-stage thickening process using separators and evaporators is often carried out to achieve a dry matter content of 60 – 80 % (Fig. 6).

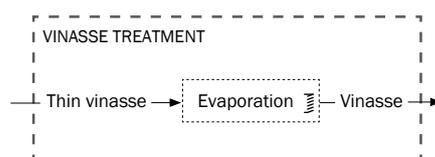


Figure 6: Overview of the vinasse treatment process

DDGS (Dried distillers grains with solubles): Dried stillage from grain-based ethanol production that includes soluble components.

More literature on bioethanol production: [1] - [4].

Stillage. Stillage is a nitrogen-rich co-product that is produced when bioethanol is made from grain. It has a dry matter content of between 10 – 15 % (thin stillage) depending on the grain used. Up to 20 litres of stillage per litre of ethanol can accrue, depending mainly on the ethanol concentration after fermentation. It contains solids, such as proteins or cellulosic components from the gluten and bran of the grain kernel, which are not fermented by the yeasts. The thin stillage can be used as an untreated fertiliser on farmland, or as a fresh liquid animal feed. Stillage can also be marketed as protein-rich dried distillers grains with solubles (DDGS) when the water gets evaporated and the remaining solids get dried and pelletized (Figure 7). If the stillage is evaporated and dried, decanting is usually required before evaporation in order to separate the insoluble components (decanter cake) from the stillage. The decanter cake is re-added to the DDGS before drying and pelletizing. Another possibility is to ferment the accrued thin stillage to produce biogas (more information about this can be found in the biomethane guidance document).

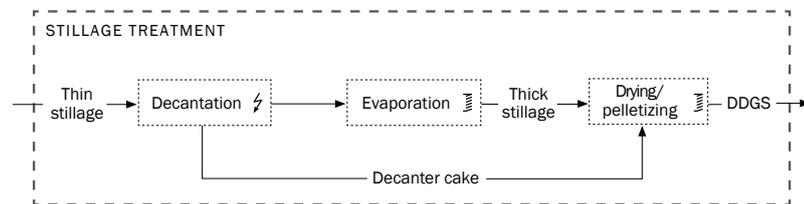


Figure 7: Overview of the treatment process of stillage

Typical ranges of the primary input and output flows

Note: This section lists typical ranges and reference values for the amount of the primary inputs, products and co-products of bioethanol plants. These can help in checking GHG balances for plausibility. It should be noted that there are many ways to design the bioethanol production processes, all of which cannot be taken into account here. Therefore, depending on the plant, values may deviate from the ones given here.



The description differentiates between sugar- and starch-based bioethanol plants. The underlying data sources and assumptions are compiled in the list of references.

The amount of ethanol that can be produced from the raw materials depends on the proportion of fermentable components. The maximum ethanol yields can be derived from the sugar and starch content (Table 1). The ethanol yield decreases for less-efficient processes or when other products are being processed simultaneously. For example, in addition to producing ethanol, the co-products bran, gluten or germ oil can also be produced from grain, which can lead to losses in starch.

Table 1: Starch and sugar contents (based on the dry matter of the raw material) with corresponding ethanol yields (based on the fresh matter of the raw material)

Raw material input	Starch/sugar content		Ethanol yield	
	kg (starch/sugar)/ kg DM (raw material)		kg (ethanol)/ kg FM (raw material)	
	From	To	From	To
Raw materials containing starch				
Maize	0.70	0.75	0.35	0.37
Wheat	0.67	0.71	0.32	0.35
Rye	0.61	0.63	0.31	0.32
Barley	0.58	0.59	0.29	0.30
Triticale	0.67	0.71	0.32	0.35
Raw materials containing sugar				
Sugar beet	0.56	0.72	0.06	0.09
Sugar cane	0.05	0.20	0.05	0.07

The figures presented here are sample values based on scientific publications [5] - [12].

- DM: Dry matter content
- FM: Fresh matter content

For the GHG balance it should be noted whether dirty or clean sugar beet are being referred to the calculation. The earth stuck to the sugar beet can make up to 140 kg in weight per tonne, depending on the type of soil [4], [13].

The figures listed here are sample values based on scientific publications [4], [14].

Bioethanol from sugar beet

When sugar beet are used, it is important to make sure that the conversion factors are consistently determined since the sugar beet are covered in soil when they are delivered. Table 2 lists the guide values for the amounts of products and intermediate products resulting from sugar beet processing. The different sugar juices can be further processed into ethanol.

Table 2: Products and intermediate products that are produced when sugar beet are processed into sugar juice and granulated sugar: reference values for total yield and sugar yield, as well as exemplary sugar concentrations based on cleaned sugar beet with 16.5 % sugar content

Products and intermediate products	Total yield (t/t clean sugar beet)	Sugar yield (kg/100 kg clean sugar beet)	Sugar concentration (wt.%)
Beet juices			
Raw juice	1.05	16.2	15.4
Thin juice	1.048	16.15	15.4
Thick juice	0.23	16.15	70.2
Molasses	0.035	1.68	48.0
Granulated sugar	0.145	14.47	99.8
Beet pulp (fresh)	0.132	0.25	1.9
Beet pulp (pellets)	0.048	0.25	5.2

Process steam is used in the sugar factory primarily to heat the evaporators for thick juice production and when drying and conditioning beet pulp during the sugar campaign. Process steam is mainly used in the ethanol plant in the distillation and rectification of the alcoholic mash into ethanol and during vinasse evaporation. The amount of process steam needed can vary according to plant and operating conditions and depends, for example, on the extent of evaporation of the accrued thin vinasse (approx. 10 % DM) to a vinasse concentrate (approx. 65 % DM). Furthermore, less steam is needed in the sugar factory when during the campaign raw juice is processed into ethanol, because the multi-stage evaporation process to turn it into thick juice is not required. However, steam requirements in an ethanol plant increase since the vinasse has a low dry matter content and the evaporation process is, accordingly, more elaborate.

Water is used primarily to wash the sugar beet and to adjust the concentration of the sugar juices. During the washing process, process water, as well as small amounts of fresh water is used. After the washing process the water used to wash the beet is purified and re-introduced into the washing cycle.

Nutrients for fermenting the sugar juices are seldom bought and are often only used in small amounts since the molasses serves as a source of nutrients.

Not all of the bioethanol plants use acids and bases to adjust pH values. Frequently the pH value regulates itself due to microbiological milieu conditions. The amount of acids and bases used depends on their concentration (diluted/undiluted) and on their strength. It is expected that higher quantities of weak acids (e.g. nitric acid) than strong acids (e.g. sulphuric or phosphoric acid) are added. Often acids are also used in conjunction with hot water to clean the fermenter (CIP – cleaning in place).

The amount of accrued vinasse at the end of the production process depends heavily on the dry matter content of the vinasse. Some of the fresh vinasse can also be re-used in the fermentation process to dilute the sugar juices.

Table 3: Ranges of the input and output flows in a sugar beet-based bioethanol process (including upstream sugar factory)

Input/output	Unit	Amount per t of ethanol (99.9 wt.%)	
		From	To
Input			
Input raw material			
Sugar beet	t	12.5	15.5
Auxiliaries and process energy			
Process steam	MJ	11,500	15,000
Electricity	kWh	300	500
Water	t	3.3	5.9
Coke	t	0.017	0.023
Limestone	t	0.29	0.62
Yeasts	kg	1.8	8.6
Nutrients (optional)	kg	0.18	6.8
Acids (optional)	kg	2.7	
Output			
Products and co-products			
Ethanol	t	1	
Thin vinasse (DM: 10 %)	t	10	
Vinasse (DM: 65 %)	t	0.8	1.2
Beet pulp (fresh)	t	26	
Beet pulp (pellets)	t	0.7	1.8
Carbon dioxide	t	0.95	1.1
Carbonatation lime	t	0.29	0.57
Fusel oils (optional)	kg	45	
Residual and waste materials			
Waste water	t	8.7	13.4

The figures quoted here are sample values based on scientific publications [2], [6], [13] - [18].

During mechanical vapour recompression, steam is compressed using a mechanical compressor (heat pump principle). This achieves a higher level of pressure and temperature. The compressed steam can subsequently be used for heating. This considerably lowers the amount of fresh steam required but has an additional demand of electricity.

Bioethanol from grains

Around 30 % of the process steam is used in the distillation, rectification and dehydration processes to process the alcoholic mash into ethanol; 27 % is used to evaporate stillage, and 37 % is used to dry stillage. In contrast, the maceration only requires 6 % of the process steam [19]. The amount of process steam required by each plant can vary greatly depending on the process and raw material used. For example, if the accrued stillage is marketed as fresh animal feed rather than processed into DDGS, process steam requirements decrease significantly.

The single largest electricity consumers are usually the mills for grinding the grain. Electricity is also used to stir the mash in the fermenters and to pelletize bran or DDGS. Sometimes electrically powered mechanical vapour recompression is used instead of steam heating in the distillation, rectification and vaporisation of stillage. This replaces process steam at the production site, however it raises electricity consumption. In addition to large electricity consumers, there are also many smaller electricity consumers at the production site which consume relevant amounts of electricity.

Water is primarily used to produce a mash with the grain flour. Yeast cultivation and, where applicable, washing-out of gluten are other process steps that require water. Water is also used to clean the plant. Water recycling concepts can vary heavily from plant to plant. The need for water depends on whether process water flows (e.g. luter water from the rectification process or thin stillage from DDGS processing) can be recycled and used in the process for e.g. maceration, or whether they leave the plant as waste water. In addition to the water used in the process (process water), water is used additionally at different stages of the process for cooling (cooling water).

The amount of yeasts used depends on whether the yeasts are cultivated and propagated by the plant operator on site, or whether it is bought from external yeast producers in form of dry or liquid yeast. It is also possible to separate the yeasts from the alcoholic mash after fermentation and to re-use them, which considerably lowers the amount of fresh yeasts required.

The use of nutrients can vary according to the raw material and plant. It should be noted that yeasts require a source of nitrogen to grow. This is added in the form of urea, diammonium phosphate or ammoniac water. Various minerals and trace elements are also essential for yeast propagation, such as phosphor, magnesium, potassium and calcium.

Data on the enzymes used in the saccharification and liquidification processes for processing grain are taken from information provided by enzyme manufacturers (DELTAZYM® GA L-E5, OPTIMALT BBA and Fuelzyme®). The manufacturers, however, recommend adjusting the dosage to the operating conditions of the respective plant. This means wider ranges are also possible.

Table 4: Ranges of the input and output streams in a grain-based bioethanol process

Input/Output	Unit	Amount per t of ethanol (99.9 wt.%)	
		From	To
Input			
Input raw material			
Grain	t	3.3	3.6
Auxiliaries and process energy			
Process steam	MJ	6,200	11,000
Electricity	kWh	350	700
Water	t	1.5	5.0
Yeasts	kg	2	10
Nutrients (optional)			
Urea	kg	6.5	
Diammonium phosphate	kg	29	
Ammonia water	kg	2.5	
Ammonia	kg	3.9	
Enzymes			
Alpha-amylase	kg	0.2	0.9
Glucoamylase	kg	1.2	4.2
Acids (optional)	kg	7	42
Bases (optional)	kg	5	45
Output			
Products and co-products			
Ethanol	t	1	
Thin stillage (DM: 10 %)	t	7.5	10
DDGS (DM: 91 %)	t	0.55	1.2
Carbon dioxide	t	0.95	0.96
Gluten (optional)	t	0.14	0.22
Bran (optional)	t	0.12	0.87
Germ oil (optional)	t	0.04	0.09
Residual and waste materials			
Waste water	t	1	7.7

The figures shown here are sample values based on scientific publications [2], [6], [13], [18], [20], [21].

Calculation of the GHG emissions and the GHG emission saving

Interfaces are accredited enterprises along the biofuel production chain. They are divided into primary distributors (e.g. dealers and cooperatives that receive the biomass), sugar and starch factories, and other enterprises that process the liquid or gaseous biomass to the required level of quality for end use (e.g. bioethanol production plants). The interface that processes the biofuel to the required level of quality for end use (e.g. bioethanol plant) is called the final interface.

In principle there are three different ways of providing GHG emission values. Using:

- default values (Annex V RED),
- individually calculated values and
- a combination of disaggregated default values and individually calculated values

In order to calculate the GHG emissions resulting from the production and use of bioethanol, the GHG emissions and the GHG emission savings along the entire bioethanol process chain are added together. Each interface of this chain calculates the GHG emissions that it emits and adds this value to the GHG emissions from upstream interfaces. In addition to calculating the GHG emissions individually, the interface also has the possibility of using disaggregated default values as per EU Directive 2009/28/EC (RED) [22]. The final interface adds up the GHG emissions from the individually calculated values or the disaggregated default values, and issues the GHG emissions value based on one MJ of bioethanol. The final interface also calculates the GHG emission saving compared to a defined fossil reference value.

The principles for calculating the GHG emissions and the GHG emission saving are explained below and are demonstrated using a sample process chain.

Calculation formulas

If an interface along the process chain of biofuel production decides to calculate individual GHG emissions based on actual values, it must do so in accordance with the methods defined in the RED [22]. The set of regulations contains concrete calculation formulas. A biofuel's GHG emission saving is the result of the GHG emissions from biofuel production and use and a comparison of these GHG emissions to the 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 RED Annex V). The formula consists of the GHG emissions and the GHG emission savings from the biofuel production chain.

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

E = Total emissions from the production and use of the biofuel

GHG emissions from:

e_{ec} = Extraction/cultivation of raw materials
 e_l = Land-use change
 e_p = Processing
 e_{td} = Transport and distribution
 e_u = Use

GHG emissions savings through:

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

Formula (1)

Calculating the GHG emission saving

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

$$\text{GHG emission saving} = \left[\frac{E_{\text{fossil fuel}} - E_{\text{biofuel}}}{E_{\text{fossil fuel}}} \right] * 100$$

Formula (2)

$E_{\text{fossil fuel}}$ = total emissions from the fossil reference fuel
 E_{biofuel} = total emissions from the biofuel (e.g. bioethanol)

The value of the fossil reference fuel is defined by the RED as being 83.8 g CO₂eq/MJ.

Calculation procedure

The different steps to individually calculate GHG emissions and the GHG emission saving are illustrated below.

Calculating the GHG emissions for each term of the calculation formula

Every interface of the process chain calculates the GHG emissions accrued up to its enterprise relating to the amount of the processed (intermediate) product and passes this value on to the next downstream interface. The same calculation principle applies to the terms e_{ec} , e_p , e_{td} . In order to determine the GHG emissions for these terms, all of the materials and energy used in the process chain are multiplied by the respective emission factors (EF) and divided by the amount of intermediate product or product.

$$e'_{ec,ptd} = \frac{\sum (\text{Quantity of material input (MI)} * \text{Emission factor of the material (EF)})}{\text{Yield or quantity of the (intermediate) product}}$$

The FAQ section explains what should be considered when disaggregated default values are combined with individual calculations.

Emission factors represent “emission backpacks” of auxiliaries, energy carriers and products. They reveal the environmental impacts (e.g. GHG emissions) associated to the production and use of materials, energies or products. Scientific publications and acknowledged databases serve as sources for emission factors.

Formula (3)

As per RED, GHG emissions for the use of biofuels (e_u) are set to zero. Special rules apply for calculating the terms e_p , e_{sca} , e_{ccs} , e_{ccr} , e_{ee} . This is explained in more detail in the example calculation and in the FAQ section.

Allocating GHG emissions between the biofuel and the co-products

If co-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 co-product. The energy content of the original substance (not only the dry matter) of the biofuel and the co-products forms the basis for this allocation. The allocated value is passed on to the downstream interface and is calculated as follows:

The term e' represents the GHG emissions based on the (intermediate) product of the respective process step (e.g. g CO₂-eq./kg of thick juice from sugar beet). The term e stands for the GHG emissions based on the product's energy content (e.g. g CO₂eq./MJ of bioethanol).

More detailed information on declaring co-products and on allocation can be found in the FAQ section. If co-products are produced at multiple stages of the bioethanol production chain, multiple allocation factors have to be taken into consideration (see the section on example calculation). Once the EU Communication “Note on conducting and verifying actual calculations of GHG emission savings” goes into effect on 31/12/2016, the energy content of the biofuel/intermediate products/co-products will have to be based on the dry matter [23].

Formula (4)

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

Formula (5)

$$AF = \frac{m_{\text{main product}} * LHV_{\text{main product}}}{m_{\text{main product}} * LHV_{\text{main product}} + m_{\text{co-product}} * LHV_{\text{co-product}}}$$

 m = mass LHV = lower heating value

Calculation of the total GHG emissions and the GHG emission saving

The final interface calculates the sum of the GHG emissions. If the GHG emissions from the transport processes are not given, or the disaggregated default value for transport has not yet been used, the final interface determines in which regions the fuel can be transported without falling below the respective GHG emission saving. 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 bioethanol. It also calculates the GHG emission saving according to Formula (2).

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 the table below. Further explanations on data sources are found in the FAQ section.

Table 5: Types and sources for data required for the GHG balance

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

For values taken from literature sources or databases, the respective sources must be indicated (author, title, (journal, volume) year).

Example calculation

The steps for calculating the GHG emissions in relation to one MJ of bioethanol and for determining the GHG emission saving are exemplarily illustrated for a sugar beet-based bioethanol production (see Figure 8). The example calculation follows the calculation procedure described above. First the operating data and the corresponding emission factors are listed for every calculation term, then this data is entered into the calculation formulas. Afterwards typical calculation errors are highlighted.

Operational data is used for this example calculation. The FAQ section explains what should be considered when disaggregated default values are used.

Illustration of a sample process chain

The sample process chain shown in Figure 8 consists of the sugar beet cultivation, transport of the sugar beet to the sugar factory, the sugar factory, the bioethanol plant and the distribution of the bioethanol to the consumption sites. In addition to the GHG emissions released during this process chain, GHG emission savings from improved agricultural management, carbon capture and geological storage or replacement and excess electricity from the cogeneration of heat and electricity also have to be considered in accordance with Formula (1).

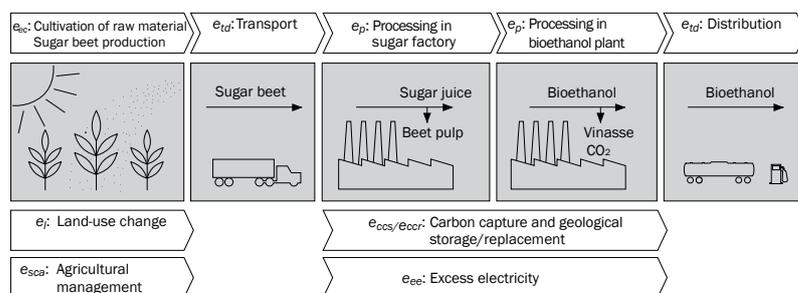


Figure 8: Example of a bioethanol production chain based on sugar beet

After they have been cultivated and harvested, the sugar beet is transported to the sugar factory. In the sugar factory, sugar juice is produced from the sugar beet in multiple process steps. This juice is then used as the basis for bioethanol production. The accrued beet pulp is processed into dried beet pulp by drying and pelletizing it. In our example the dried beet pulp is considered as co-product, i.e. the GHG emissions that are released up until this point are allocated between the sugar juice and the beet pulp. The sugar juice is fed into the bioethanol plant where it is fermented into bioethanol. In addition to bioethanol, the fermentation process also produces vinasse, which is vaporised into the co-product vinasse concentrate. CO_2 is also released during fermentation. In this example calculation it is assumed that a partial flow of this is liquefied under pressure to replace fossil CO_2 in the drinks industry.

This CO₂ is not considered as a co-product in the GHG balance. Instead it is credited to bioethanol production as the GHG emission savings e_{ccr} . The process steam required in the sugar factory and in the bioethanol plant is made available through natural gas firing. The ethanol is then transported to the different consumption sites.

Cultivation of raw materials e'_{ec}

In practice, a disaggregated default value or a NUTS 2 value is used for this process step. However, in this example calculation, actual GHG emissions from the cultivation of raw materials are considered at this stage. For instance, the primary distributor receives a delivery of sugar beet that originates from the following cultivation. In this case, the data on the input materials and quantities has to be taken from operating data.

Table 6: Input materials and quantities from sugar beet cultivation

Input materials and energy	Unit	Value
Seeds	kg/(ha*a)	6.0
N fertiliser	kg N/(ha*a)	119.7
P ₂ O ₅ fertiliser	kg/(ha*a)	59.7
K ₂ O fertiliser	kg/(ha*a)	134.9
CaO fertiliser	kg/(ha*a)	400.0
Pesticides	kg/(ha*a)	1.3
Diesel (agricultural machines)	l/(ha*a)	175.9

The values from sugar beet cultivation have been taken from [24].

Yield	Unit	Value
Sugar beet yield	t/(ha *a)	68.86

Common emission factors of these input materials and energies are listed below. They have been taken from the literature and acknowledged databases.

Table 7: Emission factors of the materials and energy used in cultivation of raw materials

Input materials and energy	Unit	EF	Sources
Seeds	kg CO ₂ -eq./kg	3.54	[24]
N fertiliser	kg CO ₂ -eq./kg	5.88 / 6.41 / 7.59	[24] - [26]
P ₂ O ₅ fertiliser	kg CO ₂ -eq./kg	1.01 / 1.18	[24], [25]
K ₂ O fertiliser	kg CO ₂ -eq./kg	0.58 / 0.66	[24], [25]
CaO fertiliser	kg CO ₂ -eq./kg	0.13 / 0.30	[24], [25]
N ₂ O field emissions	kg CO ₂ -eq./kg N fertiliser	8.08 ³	[24]
Pesticides	kg CO ₂ -eq./kg	10.97	[24]
Diesel	kg CO ₂ -eq./l	3.14 / 2.1	[24], [25]

N₂O is a greenhouse gas that is emitted, for example, when fertiliser containing nitrogen is 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. How to calculate nitrous oxide emissions is described in the FAQ section.

³ The emission factor for nitrous oxide emissions stated here is not an emission factor in the traditional sense. It has to be individually determined for every crop and for the respective amount and type of fertiliser (e.g. synthetic fertiliser, organic fertiliser).

Entering the input quantities and emission factors into Formula (3) results in the following value for e'_{ec} for sugar beet cultivation:

$$e'_{ec} = \frac{6 \frac{kg}{ha \cdot a} * 3.54 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 119.7 \frac{kg}{ha \cdot a} * 5.88 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 59.7 \frac{kg}{ha \cdot a} * 1.01 \frac{kg \text{ CO}_2 \text{ eq.}}{kg}}{68.86 \frac{t}{ha \cdot a}}$$

$$+ \frac{134.9 \frac{kg}{ha \cdot a} * 0.58 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 400 \frac{kg}{ha \cdot a} * 0.13 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 119.7 \frac{kg}{ha \cdot a} * 8.08 \frac{kg \text{ CO}_2 \text{ eq.}}{kg}}{68.86 \frac{t}{ha \cdot a}}$$

$$+ \frac{1.3 \frac{kg}{ha \cdot a} * 10.97 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 175.9 \frac{l}{ha \cdot a} * 3.14 \frac{kg \text{ CO}_2 \text{ eq.}}{l}}{68.86 \frac{t}{ha \cdot a}}$$

$$e'_{ec} = 35.57 \frac{kg \text{ CO}_2 \text{ eq.}}{t \text{ sugar beet}}; \text{ without allocation}$$

Basic formula:

$$e' = \frac{\sum MI * EF}{\text{Yield or quantity}}$$

The primary distributor passes on a value of 35.57 kg CO₂ eq. per t of sugar beet to the sugar factory.

Potential calculation errors

- The direct and indirect nitrous oxide emissions, calculated using the IPCC or GNOG 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 % NH₄NO₃ and 24 % CaCO₃). The amount of N in the fertiliser can be determined via stoichiometry.
- 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. 6 kg seeds/(ha*a) and an EF of 3.54 kg CO₂ eq./t seeds;
 - 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

Was the land used for sugar beet production already being cultivated before 1 January 2008?

In this example: Yes. Thus the value for the term e'_l equals zero.

$$e'_l = 0$$

Improved agricultural management e'_{sca}

Were improved agricultural management measures used?

In this example: No carbon-enriching measures were taken.

$$e'_{sca} = 0$$

Improved agricultural management measures are more precisely defined in the FAQ section.

The transport values have been taken from [25].

Transport e'_{td1}

The sugar beet is transported from the primary distributor to the sugar factory. This example uses the following data for this process step:

Table 8: Input materials and quantities for transport e'_{td1}

Input materials and energy	Unit	Value
Mass of the transported beet (m)	t	24
Means of transport		tanker (diesel)
Transport distance, loaded (d_{loaded})	km	80
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

A common emission factor for the diesel fuel used here is listed in Table 9:

Table 9: Emission factor of the materials and energy used for transport

Input materials and energy	Unit	EF	Source
Diesel	kg CO ₂ -eq./l	3.14 / 3.01	[24], [27]

The GHG emissions from transport are calculated as follows:

Formula (6)

$$e'_{td} = \frac{(d_{loaded} * f_{loaded} + d_{empty} * f_{empty}) * \text{Emission factor of the fuel}}{\text{transported quantity}}$$

Entering the input quantities and emission factors into Formula (6) results in the following value for transport e'_{td1} :

$$e'_{td1} = \frac{(80 \text{ km} * 0.41 \frac{\text{l}}{\text{km}} + 20 \text{ km} * 0.24 \frac{\text{l}}{\text{km}}) * 3.14 \frac{\text{kg CO}_2\text{eq.}}{\text{l}}}{24 \text{ t}}$$

$$e'_{td1} = 4.92 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar beet}}; \text{ without allocation}$$

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} : sugar factory

Sugar beet is delivered to a sugar factory. GHG emissions are calculated for this interface based on the following sample operating data.

Table 10: Input materials and quantities in the sugar factory

Input materials and energy	Unit	Value
Sugar beet	kg/a	1,189,256,000
Natural gas	MJ/a	442,377,866
Electricity	kWh/a	17,856,000
Limestone	kg/a	54,985,000
Process water	kg/a	507,018,000
Wastewater treatment	kg/a	763,269,000

Products	Unit	Value
Sugar juice	t/a	752,747
Dried beet pulp	t/a	70,650

The common values of the emission factors for these input materials and energies are listed below. These have been taken from the literature and acknowledged databases.

Table 11: Emission factors for the materials and energy used in the sugar factory

Input materials and energy	Unit	EF	Sources
Natural gas	kg CO ₂ eq./MJ	0.067 / 0.072 / 0.070	[24] - [26]
Electricity	kg CO ₂ -eq./kWh	0.61 / 0.60 / 0.58	[24] - [26]
Limestone	kg CO ₂ -eq./kg	9.72*10 ⁻³	[26]
Process water	kg CO ₂ -eq./kg	4.0*10 ⁻⁴	[26]
Wastewater treatment	kg CO ₂ -eq./kg	2.7 *10 ⁻⁴	[26]

Entering the input quantities and emission factors into Formula (3) results in the following value for e'_{p1} :

$$e'_{p1} = \frac{442,377,866 \frac{MJ}{a} * 0.067 \frac{kg \text{ CO}_2 \text{ eq.}}{MJ} + 17,856,000 \frac{kWh}{a} * 0.61 \frac{kg \text{ CO}_2 \text{ eq.}}{kWh} + 54,985,000 \frac{kg}{a} * 0.00972 \frac{kg \text{ CO}_2 \text{ eq.}}{kg}}{752,747 \frac{t}{a}} + \frac{507,018,000 \frac{kg}{a} * 0.0004 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 763,269,000 \frac{kg}{a} * 0.00027 \frac{kg \text{ CO}_2 \text{ eq.}}{kg}}{752,747 \frac{t}{a}}$$

$$e'_{p1, \text{ unallocated}} = 55.10 \frac{kg \text{ CO}_2 \text{ eq.}}{t \text{ sugar juice and } 0.09 t \text{ dried beet pulp}}; \text{ without allocation}$$

It is assumed that a partial flow of sugar juice from the sugar factory is used as a basis for the bioethanol production process. The main flow is used in the production of household sugar. The mass and energy flows of the sugar factory listed here only pertain to the production of sugar juice that is ultimately used in the bioethanol plant.

Basic formula:

$$e' = \frac{\sum MI * EF}{\text{Yield or quantity}}$$

The terms e'_i and e'_{sca} are exempt from allocation. They are only attributed to the biofuel (see the FAQ section).

Allocation between sugar juice and beet pulp

The result $e'_{p1, unallocated}$ refers to the GHG emissions resulting from the overall processes in the sugar factory. Since, in addition to sugar juice, beet pulp is also produced in the sugar factory, the GHG emissions that are emitted until the point when beet pulp emerges are allocated between these two products. The GHG emissions emitted up to this point consist of GHG emissions from cultivation of sugar beet, transport and those from the sugar factory (see Figure 9).

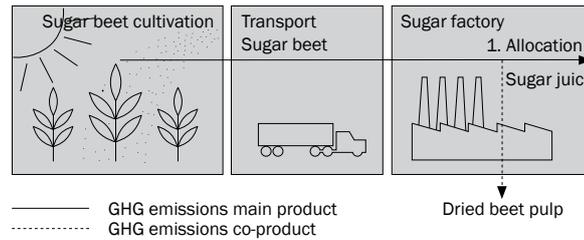


Figure 9: Allocation between sugar juice and dried beet pulp

Since the GHG values from cultivation of sugar beet and transport are based on one tonne of sugar beet, and the GHG values from the sugar factory are based on one tonne of sugar juice, a sugar juice yield per tonne of sugar beet is required. This yield and the sugar juice and dried beet pulp masses needed for the allocation are taken from the operating data. The heating values can be taken from actual measurements, from the literature or from databases.

Table 12: Sugar juice yield and heating values of the main products and co-products

Yield	Unit	Value	Source
Sugar juice yield per t of sugar beet	t/t	0.63	Operating data from an example plant

Main and co-products	Unit	Lower heating value	Source
Sugar juice	MJ/kg	18.0	Operating data from an example plant
Dried beet pulp	MJ/kg	12.7	Operating data from an example plant

The allocated GHG emissions are calculated as follows:

$$e'_{\text{allocated } 1} = \text{GHG emissions up until the co-product is produced} * \text{Allokation factor (AF)}$$

The GHG emissions emitted until beet pulp emerges are determined as follows:

$$\begin{aligned} \text{GHG emissions}_{\text{totalled}} &= e'_{ec} + e'_{td1} + e'_{p1} \\ &= 35.57 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar beet}} + 4.92 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar beet}} + 55.10 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}} \end{aligned}$$

In order to add the values together, a common denominator is required, based on one tonne of sugar juice. A common denominator is ensured using a sugar juice yield of 0.63 t sugar juice per tonne of sugar beet:

$$35.57 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar beet}} + 4.92 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar beet}} = \frac{40.94 \text{ kg CO}_2\text{eq.}}{0.63 \text{ t sugar juice}} = 104.37 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}}$$

$$\text{GHG emissions}_{\text{totalled}} = 104.37 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}} + 55.10 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}} = 159.47 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}}$$

Until the point when beet pulp is produced, 159.47 kg CO₂ eq. per tonne of sugar juice is emitted. These GHG emissions have not yet been allocated between the dried beet pulp and the sugar juice. The allocation factor is calculated according to Formula (5):

$$AF_{\text{sugar juice}} = \frac{752,747 \frac{\text{t}}{\text{a}} * 18,000 \frac{\text{MJ}}{\text{t}}}{752,747 \frac{\text{t}}{\text{a}} * 18,000 \frac{\text{MJ}}{\text{t}} + 70,650 \frac{\text{t}}{\text{a}} * 12,700 \frac{\text{MJ}}{\text{t}}}$$

$$AF_{\text{sugar juice}} = 0.94$$

$$e'_{\text{allocated 1}} = 159.47 \frac{\text{kg CO}_2\text{eq.}}{\text{t}} * 0.94$$

$$e'_{\text{allocated 1}} = 149.56 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}} \text{ (and } 105.53 \frac{\text{kg CO}_2\text{eq.}}{\text{t dried beet pulp}})$$

Basic formula:

$$AF = \frac{m_{\text{MP}} * H_{\text{MP}}}{m_{\text{MP}} * H_{\text{MP}} + m_{\text{CP}} * H_{\text{CP}}}$$

MP = Main product

CP = Co-product

Thus the sugar factory passes on a value of 149.56 kg CO₂ eq. per tonne of sugar juice to the bioethanol plant.

Processing e'_{p2}: bioethanol production

The bioethanol plant receives the sugar juice from the sugar factory and uses the following operating data as the basis for calculating its own GHG emission value.

Table 13: Input materials and quantities for bioethanol production

Input materials and energy	Unit	Value
Sugar juice	kg/a	752,747,000
Natural gas	MJ/a	902,927,200
Electricity	kWh/a	10,092,120
Nitric acid (65 %)	kg/a	238,000
Sodium hydroxide (50 %)	kg/a	246,000
Dry yeast	kg/a	156,000
Urea	kg/a	604,000
Process water	kg/a	226,770,000
Wastewater treatment	kg/a	350,000,000

Products	Unit	Value
Bioethanol	t/a	88,830
Vinasse concentrate	t/a	69,568
Liquid CO ₂	t/a	36,346

The values from the bioethanol plant have been taken from [2].

The common values of the emission factors of these input materials and energies are listed below. They have been taken from the literature and acknowledged databases.

Table 14: Emission factors for the materials and energy used in the bioethanol plant

Input materials and energy	Unit	EF	Source
Natural gas	kg CO ₂ -eq./MJ	0.067 / 0.072 / 0.072	[24] - [26]
Electricity	kg CO ₂ -eq./kWh	0.61 / 0.60 / 0.58	[24] - [26]
Nitric acid (65 %)	kg CO ₂ -eq./kg	1.89	[26]
Sodium hydroxide (50 %)	kg CO ₂ -eq./kg	0.47 / 1.12	[24], [25]
Dry yeast	kg CO ₂ -eq./kg	3.2	[28]
Urea	kg CO ₂ -eq./kg	0.81	[26]
Process water	kg CO ₂ -eq./kg	4.0*10 ⁻⁴	[26]
Wastewater treatment	kg CO ₂ -eq./kg	2.7 *10 ⁻⁴	[26]

Entering the input quantities and emission factors into Formula (3) results in the following value for e'_{p2} :

Basic formula:

$$e' = \frac{\sum MI * EF}{\text{Yield or quantity}}$$

$$e'_{p2} = \frac{902,927,200 \frac{MJ}{a} * 0.067 \frac{kg \text{ CO}_2 \text{ eq.}}{MJ} + 10,092,120 \frac{kWh}{a} * 0.61 \frac{kg \text{ CO}_2 \text{ eq.}}{kWh} + 238,000 \frac{kg}{a} * 1.89 \frac{kg \text{ CO}_2 \text{ eq.}}{kg}}{88,830 \frac{t}{a}} + \frac{246,000 \frac{kg}{a} * 0.47 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 156,000 \frac{kg}{a} * 3.2 \frac{kg \text{ CO}_2 \text{ eq.}}{kg} + 604,000 \frac{kg}{a} * 0.81 \frac{kg \text{ CO}_2 \text{ eq.}}{kg}}{88,830 \frac{t}{a}} + \frac{226,770,000 \frac{kg}{a} * 0.0004 \frac{kg \text{ CO}_2 \text{ eq.}}{t} + 350,000,000 \frac{kg}{a} * 0.00027 \frac{kg \text{ CO}_2 \text{ eq.}}{t}}{88,830 \frac{t}{a}}$$

$$e'_{p2 \text{ unallocated}} = 769.91 \frac{kg \text{ CO}_2 \text{ eq.}}{(t \text{ bioethanol and } 0.78 t \text{ vinasse concentrate and } 0.41 t \text{ liquid CO}_2)}; \text{ without allocation}$$

Production of excess electricity e'_{ee}

Is excess electricity produced in the sugar factory and/or the bioethanol plant?

In this example: No.

$$e'_{ee} = 0$$

Allocation between bioethanol and vinasse concentrate

The result $e'_{p2, \text{ unallocated}}$ refers to the total GHG emissions released from the bioethanol plant. Since, in addition to bioethanol, vinasse concentrate is also produced as a co-product, the GHG emissions are allocated between both products until the point when the vinasse concentrate is produced. As illustrated in Figure 10, the GHG emissions emitted until this point consist of the GHG emissions from the upstream interfaces that have already been added together and the GHG emissions from the bioethanol plant.

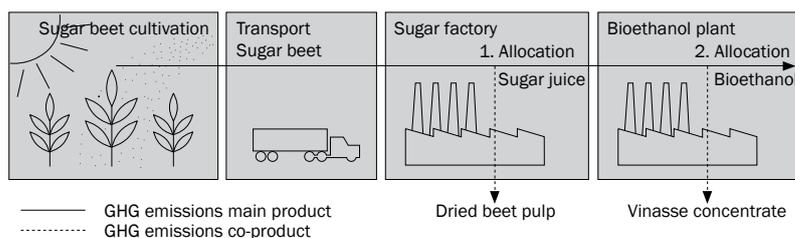


Figure 10: Allocation between bioethanol and vinasse concentrate

Since the GHG values from the upstream interfaces are based on one tonne of sugar juice, and the GHG values from the bioethanol plant are based on one tonne of bioethanol, a bioethanol yield per tonne of sugar juice is required. This yield and the bioethanol and vinasse concentrate masses needed for the allocation are taken from the operating data. The heating values can be taken from actual measurements, from the literature or from databases.

Table 15: Bioethanol yield and heating values of the main products and co-products

Yield	Unit	Value	Source
Bioethanol yield per t sugar juice	t/t	0.12	Operating data from a sample plant

Main and co-products	Unit	Lower heating value	Source
Bioethanol	MJ/kg	27	[22]
Vinasse concentrate	MJ/kg	15	Operating data from a sample plant

The allocated GHG emissions are calculated as follows:

$$e'_{\text{allocated } 2} = \text{GHG emissions up until the co-product is produced} * \text{Allocation factor (AF)}$$

The GHG emissions emitted until the vinasse concentrate is produced are determined as follows:

$$\begin{aligned} \text{GHG emissions}_{\text{totalled}} &= e'_{\text{allocated } 1} + e'_{\text{p2 unallocated}} \\ &= 149.56 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}} + 769.91 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} \end{aligned}$$

In order to add the values together, a common denominator is required, based on one tonne of bioethanol. A common denominator is ensured using a bioethanol yield of 0.12 t bioethanol per tonne of sugar juice:

$$\begin{aligned} 149.56 \frac{\text{kg CO}_2\text{eq.}}{\text{t sugar juice}} &= \frac{149.56 \text{ kg CO}_2\text{eq.}}{0.12 \text{ t bioethanol}} = 1,246.37 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} \\ \text{GHG emissions}_{\text{totalled}} &= 1,246.37 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} + 769.91 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} = 2,016.28 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} \end{aligned}$$

Basic formula:

$$AF = \frac{m_{MP} * H_{MP}}{m_{MP} * H_{MP} + m_{CP} * H_{CP}}$$

MP = Main product
 CP = Co-product

Until the point when vinasse concentrate is produced, 2,016.28 kg CO₂ eq. per tonne of bioethanol is emitted. These GHG emissions have not yet been allocated between the bioethanol and the vinasse concentrate. The allocation factor is calculated according to Formula (5):

$$AF_{\text{bioethanol}} = \frac{88,830 \frac{t}{a} * 27,000 \frac{MJ}{t}}{88,830 \frac{t}{a} * 27,000 \frac{MJ}{t} + 69,568 \frac{t}{a} * 15,000 \frac{MJ}{t}}$$

$$AF_{\text{bioethanol}} = 0.7$$

$$e'_{\text{allocated 2}} = 2,016.28 \frac{kg \text{ CO}_2 \text{ eq.}}{t \text{ bioethanol}} * 0.7$$

$$e'_{\text{allocated 2}} = 1,404.99 \frac{kg \text{ CO}_2 \text{ eq.}}{t \text{ bioethanol}} \text{ (and } 780.55 \frac{kg \text{ CO}_2 \text{ eq.}}{t \text{ vinasse concentrate}})$$

What has to additionally be noted when e_{ccr}' is crediting is explained in further detail in the FAQ section.

Carbon capture and replacement e_{ccr}'

It is assumed in the example calculation that the CO₂ from the bioethanol plant, which has been liquefied under pressure, is used in the drinks industry to replace fossil CO₂. This CO₂ is not considered as a co-product in the GHG balance. Instead the GHG emissions avoided through the replacement of the fossil CO₂ are credited to the bioethanol. However, the energy and material expenditures for capturing and liquefying the CO₂ under pressure have to be considered within this credit. As a prerequisite for recognising this GHG savings, the CO₂ must be verifiably used for commercial products or services and must replace fossil CO₂ in these situations. The data needed to calculate the term e_{ccr}' are summarised in Table 16.

Table 16: Operating data for calculating e_{ccr}'

Input materials and energy	Unit	Value
Electricity	kWh/a	7,649,284

Products	Unit	Value
Bioethanol	t/a	88,830
Liquid CO ₂	kg/a	36,346,000

The emission factor of electricity can be taken from Table 11.

The value for the term e_{ccr}' is calculated as follows:

Formula (7)

$$e'_{ccr} = \frac{\text{Quantity of captured CO}_2 - \sum(\text{Amount of material input} * \text{Emission factor of the material})}{\text{Quantity of biofuel}}$$

When the values are entered into the formula, the following value for the term e_{ccr}' is produced.

$$e'_{ccr} = \frac{36,346,000 \text{ kg CO}_2 - (7,649,284 \text{ kWh} * 0.61 \frac{kg \text{ CO}_2 \text{ eq.}}{kWh})}{88,830 \text{ t bioethanol}} = 356.64 \frac{kg \text{ CO}_2 \text{ eq.}}{t \text{ bioethanol}}$$

Potential calculation errors

- Dry matter content and sugar concentrations of the raw material or (intermediate) products have to correspond to one another when passed on from one interface to the next. Energy or material expenditures that increase dry matter content or sugar concentrations have to be listed in the energy and mass balance.
- It should be ensured that the concentrations of the chemicals actually used in the operations correspond to the concentrations of the emission factors used. For example: a bioethanol plant uses a sodium hydroxide 50% solution. The EF used in the GHG balance is based on a sodium hydroxide 45% solution. The corresponding input amount of the chemical can be determined using the rule of three.
- Care should be taken that, during allocation, all heating values are uniformly based on the original substance and not only on its dry matter content.
- For the allocation, the GHG emissions have to be added up until the co-product appears. If the GHG emissions originate from various interfaces (e.g. primary distributor and sugar factory) and are based on different intermediate products (e.g. kg sugar beet and kg sugar juice) the GHG emissions cannot simply be added together. They must then be converted using yields (e.g. sugar juice yield and bioethanol yield) to uniform units.
- Unit and conversion errors, e.g. input amounts of the input quantities and EF of the input material are based on different units of quantity, e.g. 6.7 GJ of process heat/a and EF of 0.07 kg CO₂ eq./MJ of process heat.

Transport e'_{td2}

The bioethanol is transported from the bioethanol plant to a consumption site. The following data is recorded for the transport:

Table 17: Input materials and quantities for transport e'_{td2}

Input materials and energy	Unit	Value
Mass of the transported bioethanol (m)	t	50
Means of transport		Road tanker, diesel
Distribution distance, loaded (d_{loaded})	km	150
Distribution distance, empty (d_{empty})	km	50
Fuel consumption loaded (f_{loaded})	l/km	0.41
Fuel consumption empty (f_{empty})	l/km	0.24

The transport values are taken from our own assumptions. The fuel consumptions have been taken from [25].

A common emission factor can be taken from Table 9.

The GHG emissions from transport are calculated using Formula (6):

$$e'_{td2} = \frac{(150 \text{ km} * 0.41 \frac{\text{l}}{\text{km}} + 50 \text{ km} * 0.24 \frac{\text{l}}{\text{km}}) * 3.14 \frac{\text{kg CO}_2 \text{ eq.}}{\text{l}}}{50 \text{ t}}$$

$$e'_{td2} = 4.62 \frac{\text{kg CO}_2 \text{ eq.}}{\text{t bioethanol}}$$

Basic formula:

$$e'_{td} = \frac{(d_{loaded} * f_{loaded} + d_{empty} * f_{empty}) * \text{EF fuel}}{\text{transported quantity}}$$

Potential calculation errors

- Unit and conversion errors, e.g. the diesel consumption and emission factor of diesel have to be uniformly based on l or kg.

Total emissions E

The bioethanol plant is the final interface. It must calculate the total emissions and base these on one MJ of bioethanol. Total GHG emissions are calculated from the already totalled and allocated GHG emissions assigned to the bioethanol, the GHG savings e_{ccr} , and the GHG emissions from the transport of the bioethanol to the consumption sites.

$$\begin{aligned} \text{Total emissions } E \text{ per } t \text{ of bioethanol} &= e'_{\text{allocated } 2} - e'_{\text{ccr}} + e'_{\text{td2}} \\ &= 1,404.99 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} - 356.64 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} + 4.62 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} \\ &= 1,052.97 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}} \end{aligned}$$

Taking into consideration the heating value, the GHG emissions are converted to one MJ of bioethanol:

$$\begin{aligned} \text{Total emissions } E \text{ per } MJ \text{ of bioethanol} &= \frac{1,052.97 \frac{\text{kg CO}_2\text{eq.}}{\text{t bioethanol}}}{27,000 \frac{\text{MJ}}{\text{t bioethanol}}} = 0.039 \frac{\text{kg CO}_2\text{eq.}}{\text{MJ bioethanol}} \\ E &= 39 \frac{\text{g CO}_2\text{eq.}}{\text{MJ bioethanol}} \end{aligned}$$

Total emissions do not include the GHG emissions from energy expenditures in the depot and at the filling station. These can be taken from the Biograce tool, for instance [24].

Calculation of the GHG emission saving

As the final interface, the bioethanol plant also calculates the GHG emission saving using Formula (2):

Basic formula:

$$\text{GHG emission saving} = \left[\frac{E_{\text{fossil}} - E_{\text{bio}}}{E_{\text{fossil}}} \right] * 100$$

$$\begin{aligned} \text{GHG emission saving} &= \frac{83.8 \frac{\text{g CO}_2\text{eq.}}{\text{MJ}} - 39.0 \frac{\text{g CO}_2\text{eq.}}{\text{MJ}}}{83.8 \frac{\text{g CO}_2\text{eq.}}{\text{MJ}}} \\ &= 53.5 \% \end{aligned}$$

This reveals a GHG emission saving of around 54 % compared to the fossil reference value when bioethanol is produced from sugar beet, taking into consideration the co-products dried beet pulp and vinasse concentrate and the GHG savings from the carbon capture and replacement.

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 or guidance available. In those cases where no official communications from the certification systems exist, the answers to these questions reflect the views of the authors. Fundamentally, the regulations that have been established as part of a specific certification system are to be 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 definitions of the terms. However, these terms are partially defined in European Commission Communication No. 2010/C 160/02 and in the EU Directive 2015/1513 [29], [30].

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 [29], [30].

Is there a basic rule or a decision-making tool for determining whether it is a co-product and, thus, whether the GHG emissions can be allocated?

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 [29], [30]. 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. A number of specific materials are explicitly left out of these current policies and may not be defined as co-products. This includes straw and bagasse.

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. Their life-cycle GHG emissions are zero until the place of their production [22].

What are the typical co-products of bioethanol production?

If bioethanol is produced using plants that contain starch, typical co-products include gluten, bran, germ oil and DDGS depending on the grain that is used. When raw materials containing sugar are used (e.g. sugar beet, sugar cane), typical co-products are beet pulp, carbonatation lime/filter cake and vinasse.

Do raw juice, thin juice, thick juice and molasses count as sugar factory residues or waste?

There are no clear stipulations on this. According to the requirements of co-products in 2010/C 160/02, raw juice, thin juice and thick juice are intermediate products of sugar production. They are produced for the purpose of production [29]. They are not considered to be production residues of the sugar factory that go into the bioethanol production process with zero GHG emissions. For molasses, the question of whether it meets the requirements of a co-product has to be clarified on a case-by-case basis (see question 2). The extent to which sugar juices are used in the production of household sugar and/or bioethanol, plays a role in the distribution of the sugar factory's GHG emissions.

What happens when a co-product has a negative heating value due to its high water content?

In accordance with Annex V, No. 18 of the RED, co-products with a negative energy content take on the value of zero when the energy content of co-products is calculated [22]. This means no allocation can occur between the main product and this co-product.

After the Commission's communication "Note on conducting and verifying actual calculations of GHG emission savings" is implemented on 31/12/2016, the energy contents of the biofuel/intermediate product/co-product have to be based on dry matter content during allocation [23]. This avoids the issue of products having negative heating values.

At what stage of the process chain should the allocation be applied?

According to the EU COM 2010/C 160/02, the allocation should be applied 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 [29].

Units and conversion steps

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

The use of various accompanying information found in the Biograce Tool (www.biograce.net) or the ENZO2 software is recommended. The section "Conversion tables" provides additional assistance.

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 disaggregated default 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 bioethanol). This means the disaggregated default values of the process steps (cultivation of raw materials e_{ec} , processing $e_p - e_{ee}$, transport and distribution e_{td}) must be converted to kilograms of their corresponding (intermediate) product. This requires conversion factors (CF). Conversion factors indicate the amount of intermediate product that is required for one MJ of end product. These conversion factors are depicted in yields.
- 2) The disaggregated default value can be based on other allocation factors (AFs) than the individually determined GHG value.

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

$$e' \left[\frac{\text{kg CO}_2\text{eq.}}{\text{kg intermediate product}} \right] = \frac{e \left[\frac{\text{kg CO}_2\text{eq.}}{\text{MJ}} \right]}{AF \left[\frac{\text{MJ}}{\text{MJ}} \right] * CF \left[\frac{\text{kg intermediate product}}{\text{MJ}} \right]}$$

The allocation factors AF and the conversion factors CF, which the disaggregated default values are based on, have been taken from [31].

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

According to the Communication "Note on conducting and verifying actual calculations of GHG emissions savings" published in 2015, an adjustment of the disaggregated default values, e.g. improved efficiencies in the conversion plants, will no longer be possible in the future [23]. Disaggregated default values (e.g. for cultivation) will then simply be added to the actual values (e.g. for the conversion) by the final interface once the notice has been implemented on 31/12/2016.

In the case that they are separate enterprises, do the sugar factory and the bioethanol plant have to individually calculate their GHG emissions or can they both use the disaggregated default value?

There is a disaggregated default value used for processing in bioethanol plants that directly receive and process the sugar beet. A separate sugar factory is not considered. It is, therefore, impossible for only one of the two interfaces to individually determine its GHG emission value. Either both the sugar factory and the bioethanol plant calculate their GHG emissions individually, or they both use the disaggregated default value for the processing.

The same holds true for the GHG emissions from multiple transports. Either the GHG emissions are individually calculated for all transports, or the disaggregated default value is used for all. If the final interface has no information on GHG emissions from transport, it determines in which regions the fuel can be transported without exceeding the respective GHG emission saving.

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

Example: a GHG value is individually determined for bioethanol made from triticale up until the bioethanol is produced. Can the disaggregated default value for transport and distribution be taken from the existing default values for bioethanol made from e.g. sugar beet 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 disaggregated default values exist. In this concrete example, this means that, since there are no disaggregated default values available for distribution, no disaggregated default value 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 acknowledged 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 determined for its own product, this EF must be published in the literature or in acknowledged databases. In addition, prescribed values from the system principles of the certification system must be observed, where available.

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

Emission factors can be used when they represent processes and raw materials that resemble the processes that are to be reproduced.

If, for example, a company uses pellets to supply energy to its processes, an acknowledged emission factor for wood pellets can be used if the supply processes resemble those for wood pellets.

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 [22]. 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 [23].

If green electricity is generated in isolated operation, 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 heating values can be used?

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 infrastructural expenditures, e.g. the construction of the bioethanol 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 [22].

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) [29]. The Biograce tool (<http://www.biograce.net>) defines cut-off criteria for small quantities [24]. 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 bioethanol process chain

Which processes in the overall bioethanol production chain cause the most GHG emissions?

In bioethanol production based on grain and sugar beet, most of the GHG emissions are released during the processing stage (from the raw material to the bioethanol). The GHG emissions tied to the provision of the process heat make up the largest portion of this. This level of GHG emissions mainly depends on which energy carrier (e.g. natural gas, oil, internally biogenically produced co-products like biogas) is used to provide heat, and whether the GHG emissions can be allocated across the production of the co-products.

A large proportion of the GHG emissions are also released during the cultivation of raw materials. The diesel consumption for agricultural machinery and fertiliser input are the primary drivers of GHG emissions in this context.

Special considerations and questions relating to GHG calculation (incl. N₂O, LUC, GHG savings)

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 acknowledged 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.

Can NUTS2 values also be used as an alternative to disaggregated default values for cultivation?

Yes. As of 30/7/2013, NUTS2 values can also be used for the GHG emissions in addition to the disaggregated default values for cultivation and the previously published estimated values for cultivation. The NUTS2 values can be determined at <http://nuts.redcert.org>.

How are the GHG emissions from land-use changes (LUC) 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:

$$e_i' \left[\frac{kg \text{ CO}_2 \text{ eq.}}{kg \text{ harvest yield}} \right] = \frac{CS_R \left[\frac{kg \text{ C}}{ha} \right] - CS_A \left[\frac{kg \text{ C}}{ha} \right]}{\text{harvest yield}_{\text{main product}} \left[\frac{kg}{ha * a} \right] * 20[a]} * 3.664 - \frac{e_B}{AF * CF}$$

e_i' 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 CO₂ 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. IPCC) [32]. 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 CO₂ eq./MJ is conferred when there is a 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 or ii) heavily contaminated areas [22]. The bonus of 29 g CO₂ 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.

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

According to EU COM 2010/C 160/02, "improved agricultural management" may include the following practices [29]:

- 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).

GHG emission 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 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 e_{ccr} is limited to the GHG emissions avoided through the capture of the biogenic CO_2 [22]. 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 e_{ccr} . 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 e_p , 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 accounted?

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

$$e'_{ee} \left[\frac{kg \text{ CO}_2 \text{ eq.}}{kg \text{ main product}} \right] = \frac{\text{excess electricity} \left[\frac{kWh}{a} \right] * EF_{\text{fuel}} \left[\frac{kg \text{ CO}_2 \text{ eq.}}{kWh} \right]}{\text{quantity}_{\text{main product}} \left[\frac{kg}{a} \right]}$$

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 [22]. 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 produced in a 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. No balancing is possible in EU systems.

Conversion tables

Converting volumes and mass (weight)

$$\rho = \frac{m}{V}$$

ρ	density
m	mass
V	volume

Example

1.000 l ethanol \cong 794 kg = 0.79 t

1 t ethanol \cong 1,259.4 l = 1.26 m³

Converting content of fresh matter. dry matter and water

$$DM = \frac{m_d}{m_d + m_w} \times 100\% = \frac{m_d}{m_{tot}} \times 100\%$$

$$W = \frac{m_w}{m_w + m_d} \times 100\% = \frac{m_w}{m_{tot}} \times 100\%$$

$$FM = DM + W = 1 = 100\% \cong m_{tot}$$

DM	dry matter content	Indices:	
FM	fresh matter content	d	dry
W	water content	w	water
m	mass	tot	total

Converting per cent by weight and per cent by volume

$$w_i = \frac{m_1}{m_1 + m_2} = \frac{m_1}{m_{tot}} = \frac{\varphi_1 \times \rho_2}{(\varphi_1 \times \rho_2 + \varphi_2 \times \rho_1)}$$

$$\varphi_i = \frac{V_1}{V_1 + V_2} = \frac{V_1}{V_{tot}} = \frac{w_1 \times \rho_2}{(w_1 \times \rho_2 + w_2 \times \rho_1)}$$

w	per cent by weight	Indices:	
φ	per cent by volume	1	dissolved components (e.g. ethanol)
m	mass		
V	volume	2	solvent (e.g. water)
ρ	density	tot	total

Density and heating values

	Density kg/l	Heating value MJ/kg	Heating value MJ/l	Heating value kWh/kg	Fuel equivalent l
Bioethanol	0.79	26.7	21.06	7.416	0.65

Converting 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

Converting units of measurement

	m ³	l	barrel	US gal
1 m ³	1	1.000	6.3	264.172
1 l	0.001	1	0.0063	0.264172
1 barrel	0.159	159	1	42
1 US gal	0.00378541	3.78541	0.0238	1

Bibliography

- [1] KALTSCHMITT, MARTIN; HARTMANN, HANS; HOFBAUER, H.: *Energie aus Biomasse: Grundlagen, Techniken und Verfahren. 2.*, 2nd revised and extended edition Heidelberg; New York : Springer, 2009 — ISBN 978-3-540-85094-6
- [2] BRAUNE, MARIA; GRASEMANN, ELIAS; GRÖNGRÖFT, ARNE; KLEMM, MARCEL; OEHMICHEN, KATJA; ZECH, KONSTANTIN: *Die Biokraftstoffproduktion in Deutschland – Stand der Technik und Optimierungsansätze* (DBFZ-Report No. 22). Leipzig, 2015
- [3] SCHMITZ, NORBERT: *Bioethanol in Deutschland*. 1st Ed.; Landwirtschaftsverlag, 2003 — ISBN 3-7843-3217-X
- [4] SCHIWECK, HUBERT; CLARKE, MARGARET; POLLACH, GÜNTER: *Sugar*. Ullmann's Encyclopedia of Industrial Chemistry. Weinheim, Germany : Wiley-VCH Verlag GmbH & Co. KGaA, 2012 — ISBN 3-527-30673-0
- [5] OBERFORSTER, MICHAEL; FELDER, HANS; KINASTBERGER, ALEXANDRA: *Einfluss variierender Protein- und Stärkegehalte auf die Ethanolausbeute bei Getreide und Mais*. 64. ALVA Conference. St. Virgil, 2009, pp. 180–182
- [6] IGELSPACHER, ROMAN: *Methode zur integrierten Bewertung von Prozessketten am Beispiel der Ethanolherzeugung aus Biomasse*. 1st Ed. München: Energie & Management, 2006 — ISBN 978-3-933283-43-6
- [7] KHATIWADA, DILIP; LEDUC, SYLVAIN; SILVEIRA, SEMIDA; MCCALLUM, IAN: *Optimizing ethanol and bioelectricity production in sugarcane biorefineries in Brazil*. Renewable Energy 2016; Vol. 85: pp. 371–386
- [8] MORAES, BRUNA S.; JUNQUEIRA, TASSIA L.; PAVANELLO, LUCAS G.; CAVALETT, OTÁVIO; MANTELATTO, PAULO E.; BONOMI, ANTONIO; ZAIAT, MARCELO: *Anaerobic digestion of vinasse from sugarcane biorefineries in Brazil from energy, environmental, and economic perspectives: Profit or expense?* Applied Energy 2014; Vol. 113: pp. 825–835
- [9] LINO, K. N. V.; DHAVALA, PRABHA; GOSWAMI, ANANDAJIT; MAITHEL, SAMEER; RAJU, K. V.: *Liquid biofuels in South Asia: resources and technologies*. Asian Biotechnology and Development Review 2006; 8 (2): 31–49
- [10] LORA, E. E. S.; ZAMPIERI, M.; NOGUEIRA, L. A. H.; LEAL, M. R. L. V.; COBAS, V. M.: *Thermodynamic limits for the production of ethanol and electricity from sugarcane*. Sugar Industry 2006; 131 (11): 759–765
- [11] QUINTERO, J. A.; MONTOYA, M. I.; SÁNCHEZ, O. J.; GIRALDO, O. H.; CARDONA, C. A.: *Fuel ethanol production from sugarcane and corn: Comparative analysis for a Colombian case*. Energy 2008; 33: 385–399
- [12] MACEDO, I. C.; SEABRA, J. E. A.; SILVA, J. E. A. R.: *Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020*. Biomass and Bioenergy 2008; 32: 582–595
- [13] MORTIMER, N. D.; ELSAYED, M. A.; HORNE, R. E.: *Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet* (No. 23/1). Sheffield Hallam University: School of Environment and Development, 2004
- [14] HEMPELMANN, REINHOLD: *Innovative flexible sugar/bioethanol production: the point of view of an equipment supplier*. Sugar Industry 2007; 132 (9): 698–703
- [15] AHRING, GÜNTHER: *Combined Sugar and Ethanol Production from Beet - Technical Issues*. Vortrag auf: International Conference on World Perspectives for Sugar Crops as Food and Energy Suppliers, Luxor, 2009
- [16] SEEMANN, FRANK; BOELCKE, CHRISTIAN: *Design and construction of the bioethanol plant at Klein Wanzleben*. Sugar Industry 2008; 133 (2): 69–77
- [17] SCHULZ, M.; HEBECKER, D.: *Thermodynamische Analyse und Bewertung der Bioethanolherstellung*. Chemie Ingenieur Technik 2005; 77 (6): 792–798

- [18] KEIL, MARTEN; KUNZ, MARKWART; VESELKA, MARCO: *Europäisches Bioethanol aus Getreide und Zuckerrüben – eine ökologische und ökonomische Analyse (3th part)*. Sugar Industry 2009; 134 (2): 114–130
- [19] LEHR, MARKUS: *Special Downstream Processing Solutions - the basis for successful production of first and second generation bioethanol*. XIX. International Symposium on Alcohol Fuels, Verona, 2011
- [20] MURPHY, JERRY D.; POWER, NIAMH M.: *How can we improve the energy balance of ethanol production from wheat?* Fuel 2008; 87 (10–11): 1799–1806
- [21] ARIFEEN, N.; KOOKOS, I.K.; WANG, R.; KOUTINAS, A.A.; WEBB, C.: *Development of novel wheat biorefining: Effect of gluten extraction from wheat on bioethanol production*. Biochemical Engineering Journal 2009; 43 (2): 113–121
- [22] 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
- [23] EUROPEAN COMMISSION: *Note on the conducting and verifying actual calculations of the GHG emission savings*, 2015
- [24] INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG (IFEU): *Biograce. Harmonized calculations of biofuel greenhouse gas emissions in Europe*. – www.biograce.net
- [25] BUNDESANSTALT FÜR LANDWIRTSCHAFT UND ERNÄHRUNG (BLE): *Leitfaden Nachhaltige Biomasseherstellung*. 1st Ed.; Bonn, 2010
- [26] IINAS INTERNATIONALES INSTITUT FÜR NACHHALTIGKEITSANALYSEN UND -STRATEGIEN ; ÖKO-INSTITUT E. V. INSTITUT FÜR ANGEWANDTE ÖKOLOGIE E.V.; Gemis, 2014
- [27] KNÖRR, W.: *Aktualisierung "Daten-und Rechenmodell: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2030" (TREM0D)*. Heidelberg : ifeu-Institut für Energie-und Umweltforschung GmbH, 2012
- [28] PRICEWATERHOUSECOOPER: *Carbon footprint of yeast produced in the European Union*. Paris, France : COFALEC, 2012
- [29] 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
- [30] 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
- [31] JOINT RESEARCH CENTER (JRC): *"Update on Data on pathways for RES Directive.XLS"* EU Commission working Excel spreadsheet, 2008
- [32] 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

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