

GUIDANCE DOCUMENT

Technical principles and methodology
for calculating GHG balances of

Biodiesel



GUIDANCE DOCUMENT

Technical principles and methodology for calculating GHG balances of biodiesel

Authors:

Stefan Majer
Arne Gröngröft
Christian Drache

Maria Braune
Kathleen Meisel
Franziska Müller-Langer
Karin Naumann
Katja Oehmichen

The project team would like to thank numerous other colleagues from science and industry for their many helpful tips and comments. We would particularly like to highlight the support of the following people:

Karin Arnold – *Wuppertal Institut für Klima, Umwelt, Energie*
Peter Behm – *GUT Zertifizierungsgesellschaft für Managementsysteme mbH*
BDBE – *Bundesverband der deutschen Bioethanolwirtschaft e.V., Berlin*
Dieter Bockey – *UFOP - Union zur Förderung von Oel- und Proteinpflanzen e.V., Berlin*
Sarah Bossen – *SGS Germany GmbH, Hamburg*
Gerhard Brankatschk – *OVID – Verband der Ölsaatenverarbeitenden Industrie in Deutschland e.V.*
Wolf-Dietrich Kindt – *Verband der Deutschen Biokraftstoffindustrie e. V.*
Susanne Köppen – *IFEU - Institut für Energie- und Umweltforschung Heidelberg GmbH - gemeinnütziges ökologisches Forschungsinstitut, Heidelberg*
Stefan Rauh – *Fachverband Biogas e.V.*
Georg Strükmann – *IPRO Industrieprojekt GmbH*
Iris Waikinat – *REDcert GmbH*

With support from



by decision of the
German Bundestag

Content

Preamble	06
The principles of biodiesel production	07
Oil production	07
Transesterification	10
Biodiesel purification	12
Glycerol purification	13
Typical ranges of the primary input and output flows	14
Oil production	14
Refining process	16
Transesterification	17
Calculating GHG emissions and the GHG saving potential	19
Calculation formulas	19
Calculating GHG emissions	19
Calculating the GHG saving potential	20
Calculation procedure	20
Calculating GHG emissions for each term of the calculation formula	20
Allocating GHG emissions between the biofuel and the co-products	20
Calculating total emissions of the GHG reduction potential	21
Types and sources of data	21

Exemplary calculation for rapeseed-based biodiesel	22
Illustration of an exemplary process chain	22
Cultivation of raw material e'_{ec}	23
Land-use changes e'_1	24
Improved agricultural management statt better agricultural farming practices e'_{sca}	24
Transport e'_{td1}	24
Processing e'_{p1} : oil mill	25
Allocation between rapeseed oil and rapeseed extraction meal	26
Processing e'_{p2} : biodiesel production (including refining)	27
Allocation between biodiesel, pharmaceutical glycerol and free fatty acids	28
Distribution e'_{td2}	30
Total emissions E	31
Calculation of the GHG saving potential	31
Frequently asked questions – FAQ	32
Co-products and allocation	32
Units and conversion steps	34
Combining disaggregated default values and individually calculated GHG emissions	34
Data and key indicators	35
Primary sources of GHG emissions in the biodiesel process chain	36
Special considerations and calculation related questions (incl. N ₂ O, LUC, GHG savings)	37
Balancing	39
Conversion tables	39
Volumes and masses (weight) of biodiesel	39
Density and heating values	39
Conversion of energy units	39
Conversion of energy units	39
References	40

Preamble



© Bahner & Strunz/bahner.de

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

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

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

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

The principles of biodiesel production

Biodiesel is primarily made from vegetable oils. Other raw materials, such as animal fats or used cooking oils (UCO), are also used. Various conversion processes can be used to produce biodiesel depending on the composition of the feedstock. The most widespread process is the transesterification of vegetable oils with methanol to produce fatty acid methyl esters (FAME). High conversion efficiencies can only be achieved for low concentrations of water and free fatty acids (FFA) in the vegetable oil. Thus, in the case of animal fats or used cooking oils, the FFAs need to be separated or esterified beforehand.

In general, we distinguish between production facilities which only conduct transesterification and integrated biodiesel plants (with oil mills) (see Fig. 1). Integrated plants use oilseeds as feedstock and the oil production occurs directly in the biodiesel plant. Plants focussing on the pure transesterification process obtain the oils from external oil mills. In both types, the oils or fats are transesterified and the biodiesel and (often) the resulting by-product, glycerol, is refined.

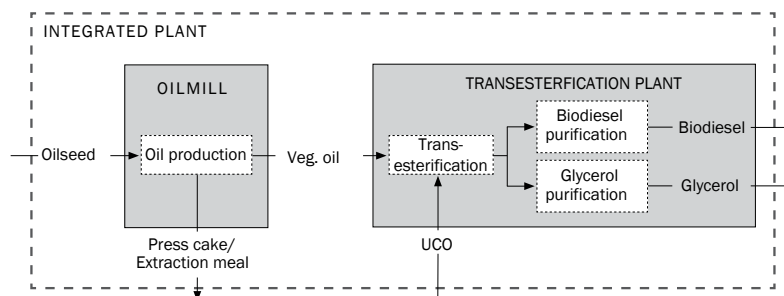
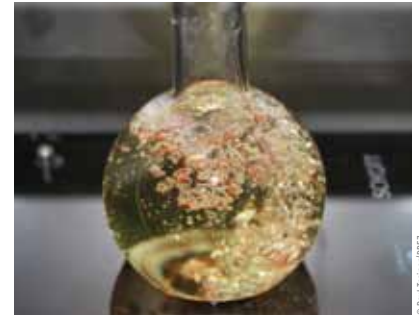


Fig. 1: Biodiesel production in integrated biodiesel plants and pure transesterification plants

Oil production

The aim of oil production is to generate low-impurity vegetable oil from high-yielding oilseeds. The oilseeds are first cleaned, shredded and conditioned before they are pressed. Pressing liberates a major proportion of the oil from the seed. A further extraction process is used to obtain the remaining oil from the press cake. Elements in the press and in extraction oils that interfere with further biodiesel production are later separated during the refining process (Fig. 2).

Pretreatment. The oilseeds can be supplied in different qualities, which is why they may have to be dried and cleaned before actual oil production occurs. The oilseeds are dried using warm air in circulating or continuous flow dryers. Then the dried seeds are separated from foreign matter using air classifiers, sieves, or magnetic separators. In the case of rapeseed, a maximum water content of 9 % and a maximum foreign matter content of 2 % is the typical target. Several raw materials, such as soybeans, sun-

flower seeds and, in rare cases, rapeseed, are partially hulled since the hulls decrease oil yield during pressing and increase the amount of purification needed later on. Normally the seeds are not completely hulled as this would mean there would not be enough fibre in the press residue. Too little fibre can negatively affect the drainage of the press oil and, thus, oil yield. After the optional hulling, the oilseeds are shredded and subjected to thermal conditioning in order to achieve optimal separation in subsequent pressing processes. Steam is used to indirectly heat the shredded seeds to around 80 °C, thus reducing their water content to 3-6 %.

Pressing. Depending on the size of the plant, various processes are used to separate the oil from the oilseed. In small biodiesel plants (typically with a production capacity of up to approx. 30,000 t/a), oil is frequently produced through relatively simple mechanical pressing. In larger plants, higher yields are achieved through an additional extraction process that involves solvents. The oilseeds are pressed using electrically powered screw presses. When only mechanical pressing is used, it is called “final pressing”, and when extraction occurs downstream in the process it is considered “pre-pressing.” Pressing produces press oil (vegetable oil) and a press cake. After the pressing, the press oil has to be prepared for transesterification. In the first step, sediment separators, decanters or filters separate the small seed particles (sediment) from the oil. The sediment can be re-fed into the screw press along with fresh rapeseed. This reduces the amount of oil that is lost. The table below illustrates the typical oil content of various oil plants. This can, in fact, fluctuate. Values presented for the GHG-calculation in a sustainability certification could, for example, be checked for plausibility by measuring the actual oil content or through harvest reports.

Table 1: Typical oil content of various oil fruits used for biodiesel production

Oil fruit ¹	Oil content (%)
Rapeseeds	39
Sunflower seeds	39
Soy beans	21
Oil palms (Asian)	29
Palm kernel (hulled)	50
Palm fruit	23
Coconut	23

¹ in shell unless otherwise indicated

During final pressing, the press cake is de-oiled in one or two pressing sequences until it has an oil content of 6 – 10 %. The remaining oil content in the press cake is higher in the case of pre-pressing, at roughly 20 %. Here a solvent is used to prepare the pressed material for optimum extractability. Oil extraction is carried out in large (integrated) biodiesel plants. This enables a total of up to 98 % of the oil contained in the seed to be extracted. Direct extraction is used in the case of oilseeds with low oil content. In contrast, the oil from seeds with a high oil content (including rapeseed) is primarily produced through a combination of pressing and extraction.

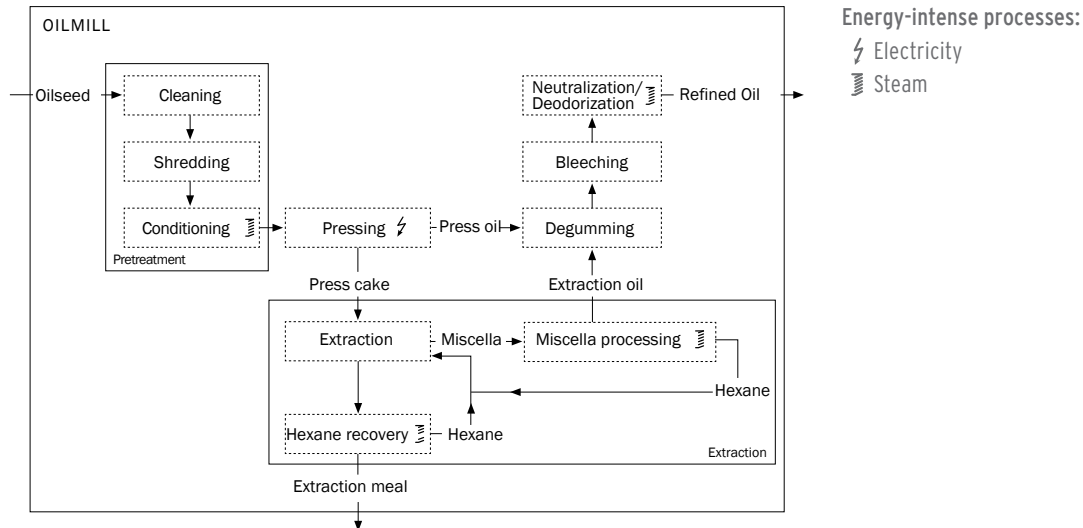


Fig. 2: Oil production in large-scale biodiesel plants through a combination of mechanical pressing and solvent extraction of the oil.

Extraction. N-hexane is primarily used to extract the oil from the press cake. Intermediate products include a mixture containing the extracted oil, the solvent (miscella) and a mostly oil-free, solvent-containing extraction meal. The solvent has to be recovered from both products. To do this, the miscella is filtered. Then the solvent is separated in a steam-heated distillation process. The solvent is collected in a condenser, cooled and returned to the extraction process. In order to recover the solvent from the extraction meal, it is stripped with steam in a desolventizer toaster. This vaporises the solvent which is subsequently separated from the extraction meal along with the steam. The solvent can later be separated from the steam through condensation and be used again in the extraction process. The extraction meal is cooled off and can be used as animal feed.

The refining process. The oil that has been extracted from the press cake contains undesired substances, which is why it needs to be cleaned (refined) before it can be used further. It is degummed, bleached, neutralised and deodorised during the refining process. The refining processes can be distinguished between chemical and physical refining. In the first step of both processes, the gums (phospholipids such as lecithin) are removed from the vegetable oil. Degumming has to be carried out for soybean, rapeseed and sunflower seed oil, while it is not necessary in the case of palm oil. For de-gumming, first water, and subsequently acid (e.g. phosphoric acid), are added to the oil. The gums are then separated from the oil through centrifugation. After degumming, the dyes, soaps, oxidation products and trace metals are removed from the oil with the help of fuller's earth.

During chemical refining, the free fatty acids are neutralised through a saponification reaction with sodium hydroxide. In the case of physical refining, the free fatty acids are separated through distillation. The pre-refined vegetable oil is heated to over 200 °C. At this temperature the oil is deodorised and de-acidified by distillation, remaining dyes, free fatty acids and heavy metals. This means fewer chemicals are required for physical refining than for chemical refining, however physical refining requires more steam.

More steam is needed for oils with a high percentage of free fatty acids as a result of the required neutralisation process.

Depending on the proportion of free fatty acids, partially refined vegetable oils can be used in the transesterification if they have been degummed and neutralised. Even though unrefined vegetable oils that have only undergone a filtering process can be transesterified, they have to be almost completely free of impurities such as water, phosphatides and free fatty acids, since these parameters sensitively impact the biodiesel yield.

Transesterification

Transesterification. In organic chemistry, transesterification is the chemical process in which an organic group of an ester (here triglycerides) is exchanged with an organic group of an alcohol (e.g. methanol). Vegetable oils primarily consist of triglycerides which are esters derived from glycerol and three fatty acids. The latter are long hydrocarbon chains. They have to be separated from the alcohol glycerol so that they can be converted to fatty acid alkyl ester (biodiesel). The transesterification reaction is usually carried out with methanol. The respective reaction is named “methanolysis” and the final products are called fatty acid methyl esters (FAME). Other alcohols, such as ethanol, are only suitable for transesterification under certain rare conditions.

During the transesterification of the oil using methanol, a (bound) fatty acid from the ester compound of a triglyceride is separated and transformed into a fatty acid methyl ester molecule. At the end of the reaction there is an accumulation of three fatty acid methyl ester molecules and a glycerol molecule (Fig. 3).



Fig. 3: Transesterification of vegetable oil to fatty acid methyl ester and an approximate mass balance of the transesterification.

Transesterification is an equilibrium reaction. In order to shift the balance to the side of the fatty acid methyl ester, methanol is used in excess for the transesterification. The transesterification reaction is accelerated by adding a catalyst. Liquid catalysts are most common. Alkaline catalysts are used for high-quality vegetable oils with a low proportion of free fatty acids and water. The most common catalysts are sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium methylate (CH_3NaO) and potassium methylate (CH_3KO).

Transesterifications with heterogeneous catalysts, biocatalysts or with no catalysts at all have not yet been established within the industry.

In the biodiesel plant, vegetable oil is mixed with the catalyst and the methanol in a reactor to start the transesterification. Using homogenous catalysts enables transesterification to be performed under mild reaction conditions and within a short reaction time. The reaction pressure and reaction rate vary according to the type of oil, catalyst and alcohol. For vegetable oils made from oilseeds, the reaction time for the transesterification takes between one and two hours under ambient pressure and at a temperature of approx. 60 °C. At the end of the reaction, the glycerol phase that has settled to the floor of the reactor (due to the difference in density) must be removed from the reactor to prohibit a reversal of the transesterifica-

tion reaction. Separating the glycerol phase from the methyl ester phase can be accelerated by adding glycerol, hexane, water or, depending on the design of the reactor, through centrifuges. Once the methyl ester phase has been separated from the glycerol phase, both material streams have to be purified.

There are two types of transesterification: single-stage and two-stage processes. During single-stage transesterification, all of the reaction materials are mixed in only one reactor. In the two-stage process, merely around 80 % of the catalyst and alcohol is added in the first reactor. After it is mixed and reacts with the plant oil, the glycerol phase is separated and the methyl ester phase is fed into the second reactor where the remaining 20 % of alcohol and catalyst is added. Using two reactors makes better use of the alcohol and reduces the amount of purification required later on.

Various plant designs are suitable for transesterification depending on the scale of production. Batch processes are typically used for productions between 100 t and 10,000 t annually. In this case, all of the process steps are carried out in consecutive batches in one or more vessels. Batch processes allow different process parameters to be taken into consideration and are therefore suitable for feedstocks whose quality widely fluctuates. Due to the long time it takes to load and unload the reaction vessel and the high amount of energy needed to heat and cool a single batch, the batch process is not ideal for large-scale biodiesel production. In this case, it is carried out as part of a continuous process in which a stationary condition is established and reaction materials (educts) are fed in, and products are taken out, on a continuous basis. One requirement for this, however, is consistent feedstock quality.

An additional esterification of free fatty acids (FFA) may be necessary if feedstocks are used that have an FFA content of more than 5 %. Used cooking oil (UCO) and animal fats are particularly affected. The required process steps are illustrated in Fig. 4. The FFAs form soaps when they come into contact with the alkaline catalyst. Due to this reaction, the catalyst is consumed and it becomes more difficult to separate the methyl ester from the glycerol. As a consequence emulsions form when the biodiesel is later washed with water. In order to reduce soap formation, the FFAs are esterified before transesterification. The acids, e.g. sulfuric acid, and methanol, are added to the FFA-rich substrate and react with the FFAs to form methyl ester and water. The water must be continuously removed as it otherwise decreases the biodiesel yield. After esterification, the biodiesel has to be dried since the water forms free fatty acids when it comes into contact with the triglycerides in the oil. Following the esterification, the oil that has been freed of FFAs can be transesterified in another reactor.

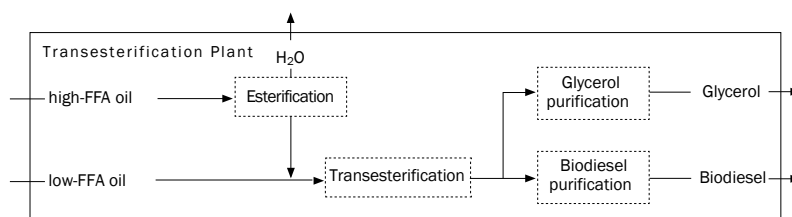


Fig. 4: Biodiesel production based on feedstocks with a high proportion of free fatty acids, here undergoing esterification pretreatment

Biodiesel purification

Methyl ester wash. After transesterification, and once the methyl ester has been separated from the glycerol, impurities are washed out of the biodiesel. Soap that formed during the transesterification can be minimized by refining the oil; however, it cannot be completely prevented. In order to remove the soaps, the biodiesel is first mixed with sulfuric acid (H_2SO_4) or hydrochloric acid (HCl). Since the catalyst used in the transesterification process is alkaline, the soaps are split into salts and free fatty acids. After the acid wash, the biodiesel is washed with water and freed of the salts and the residues from the catalyst and soap. The washing water is removed by gravity settling, sometimes supplemented by centrifuges, and sent to glycerol processing for further treatment.

Drying of methyl ester. After the methyl ester wash, the wet biodiesel is dried in an evaporator. Methanol and water residues evaporate and are thus removed from the biodiesel. The vapour mixture, made of methanol and water is condensed together with the methanol-water mixture from the glycerol evaporation. If (used) cooking oil and animal fats are used in the production of biodiesel, the biodiesel also has to be distilled in order to remove all of the methanol residues. The biodiesel has now been processed to such an extent that it fulfils the quality requirements and can be put into circulation.

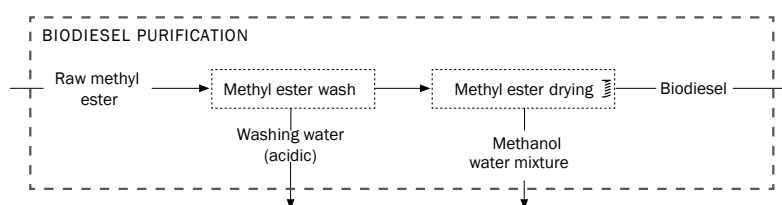


Fig. 5: Sub-steps of methyl ester processing.

Glycerol purification

The glycerol contains water, methanol, free fatty acids and catalyst residues. This raw glycerol has a purity of around 50 %. Due to its high methanol content, it is classified as hazardous waste, which is why plant operators often purify it so that it does not have to be laboriously disposed of. The necessary purification steps depend on the desired glycerol quality.

Glycerol for technical applications. During processing, the glycerol, like the biodiesel, is first mixed with an acid in order to separate the soap contained in it. Then the resulting mixture is stirred and divided into three phases by a decanter centrifuge. The salts precipitate as a solid phase. If KOH is used as a catalyst, sulphuric acid is primarily used and the generated salts can be used as fertilizer (K_2SO_4). The glycerol-water mixture can be separated from the free fatty acids through the difference in density. After the decanting, methanol and water remain in the glycerol phase. Both methanol and water are separated from the glycerol by evaporation in the drying process. Through the drying process the glycerol achieves a purity of around 80 %, which enables it to be marketed for various technical applications.

High purity glycerol. The glycerol can be further upgraded to meet the standards of pharmaceutical applications or cosmetics industry. Due to higher processing costs, this is only applied in large biodiesel plants. The technical glycerol is distilled to remove the remaining 20 % of water. Then, in the deodorising phase, steam is used to remove further impurities and odorous substances under high pressure and high temperature. Finally, the glycerol is treated with activated carbon, filtered and cooled. To meet the requirements of pharmaceutical applications, glycerol has to have a purity of at least 99.7 %. Depending on the design of the plant, an acidic catalyst and methanol are added to the free fatty acids from the decanting process, which is esterified and fed back into the biodiesel process or placed on the market. Free fatty acids are used as a raw material in the manufacturing of soaps or as additives in the feed industry.

Methanol recovery. A methanol-water mixture is generated during the drying process of both biodiesel and glycerol. This is collected and then separated in a steam-heated rectification column. The methanol that is purified in this way is cooled and can then be reintroduced into the cycle.

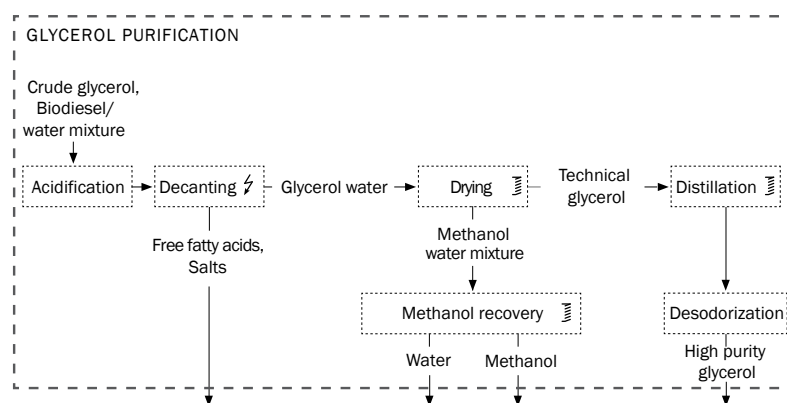


Fig. 6: Sub-steps of glycerol processing.

Typical ranges of the primary input and output flows



© Getty Images

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

Oil production

The majority of the oil from oilseeds is produced through solvent extraction or in combination with upstream mechanical pressing. In contrast to oilseeds, soybeans have a lower oil content and thus require a higher energy and feedstock input per tonne of oil.

The amount of water to be accounted for the production of oil from oilseeds depends on the system boundaries of the oil mills and on the possibilities for recovering water. The system boundary for the oil mill has a great impact insofar as water degumming of the raw oil partly takes place in the oil mills and is therefore not included in the refining stage. Water fed to the boiler to provide steam for conditioning, miscella distillation, benzene removal etc. can partly be recovered; however, water vapour loss does occur and waste water is generated.

Plant/Oil seed	Oil contenc
Soybean	21%
Rapeseed	39%
Sunflowerseed	39%
Peanut	25%
Coconut	23%
Sesame seed	48%
Oil palm (asiatic)	29%
Palm kernel	50%
Palm fruit	23%
Linseed	34%
Safflowerseed	17%

Table 2: Range of mass flows and energy flows in the production of raw plant oil from various oil fruits

		Rapeseed ¹		Sunflower-seed ¹		Soybean ¹		Palm kernel		Palm fruit	
		Menge je t Rohöl									
Input	Unit	min	max	min	max	min	max	min	max	min	max
Oil fruit	kg	2,230	2,600	2,299		5,200	5,300	2,230		5,000	
Water	kg	500		-	-	-	-	400		6,860	
n-Hexane	kg	1	3	2		2	4	-		-	
Electrical energy	MJ	280	490	280		220	1,150	750		360	
Thermal energy	MJ	1,400	1,800	1,300		2,200	5,300	-		8,460	
Output	Unit	min	max	min	max	min	max	min	max	min	max
Press residue	kg	1,200	1,560	1,299		3,850	4,300	1,160		3,370	
Plant oil	kg	1,000									

The ranges illustrated here are based on scientific publications. Details on producing plant oil from various oil fruits can be found in the original literature [2-10]

¹ A combination of mechanical pressing and solvent extraction



© ITZ

Producing oil from the fruits of oil palms is different than producing it from oil seeds. In palm fruits most of the oil is contained in the pulp. Steam is used to sterilize the fruit. Then it is destemmed and cooked using water vapour. In the next step the fruits are pressed and the kernels are removed from the press residue to be processed separately. The juice from the pressing is made up of around one-third oil, which has to be washed, heated and cleansed of impurities. In contrast to other oil fruits, much more water is required here as a result of the water and steam demands. Steam requirements lead to a much higher demand for thermal energy. In contrast to oilseeds, the transportability of palm fruits is very limited so that they have to be processed directly after harvest. As a result, palm oil mills are often located in close proximity to palm oil plantations which are often not connected to the public electricity grid and therefore usually supply their own energy. The press residue of the palm fruit and the shell of the kernel are used as energy carriers.

There are various ways to treat the waste (POME – palm oil mill effluent) produced during palm oil production. The easiest way is to anaerobically treat it by feeding it into open collection sites. The deficit of oxygen leads to methane formation and methane emissions, which have a negative effect on the greenhouse gas balance of the palm oil and consequently the palm oil biodiesel. Aerobic treatment is one alternative. The POME is moved to a collection basin so that it comes into contact with oxygen and methane formation is avoided. Another option is closed anaerobic storage, whereby the resulting methane is captured and used as biogas.

The palm kernels are separately treated from the palm fruit. Quantitatively, they only make up a small proportion of the fruit. While around 60 % of the oil fruit is pulp, the palm kernel makes up only around 5 %. In contrast to the pulp they are easier to transport so that they do not need to be processed on-site. Palm kernel oil is produced through single or double pressing.

Refining process

The energy and material flows for refining the raw plant oil vary only slightly. Depending on the quality of the oil fruit (water and FFA content) there is a light fluctuation in raw oil input per tonne of biodiesel. Unlike seed oils, raw palm oil has a slightly higher FFA content because the more than 1,500 individual fruits on an oil palm fruit bunch ripen unevenly. In order to achieve the largest yield possible, some of the fruits become over-ripe. This increases the amount of free fatty acids which is transferred to the oil.

The material and energy inputs are decisively impacted by quality and by the process steps (full or partial refining). In the case of full refining, the refining process (chemical or physical refining) also impacts the balances. The amount of alkaline catalyst, acid and waste water is higher for chemical refining since a catalyst, rather than a distillation process, is used to separate the free fatty acids. An acid is used to split the soaps, which had been generated during alkaline neutralization, into salts and free fatty acids. During physical refining, the free fatty acids are removed through distillation. In addition, the acidic waste water that is generated has to be neutralised before it can be disposed of. Furthermore, oil losses are slightly higher with chemical refining since a small proportion of the glycerides react to soap when alkaline solutions are used. The soaps also lead to emulsification of parts of the oil. More fatty acids are produced overall than were originally contained in the raw oil as free fatty acids.

The amount of water and waste water can fluctuate considerably depending on the type of water treatment used in the biodiesel plant.

Lecithin is produced during the degumming of raw rapeseed and soybean oil. In the case of rapeseed, this is primarily mixed into the meal. When soybean oil is degummed, however, it is usually separated and marketed separately. It can be used in the food industry as an emulsifier or stabiliser.

Sources of the ranges displayed here and further literature with process data for refining plant oils: [4], [11].

Table 3: Ranges of mass and energy flows for refining of plant oil

Input	Unit	Amount per t of refined oil	
		min.	max.
Raw oil	kg	1,010	1,045
Fuller's earth	kg	5	9
NaOH	kg	2	7
H ₃ PO ₄	kg	-	1
H ₂ SO ₄	kg	-	2
Water	kg	20	700
Electrical energy	MJ	20	130
Thermal energy	MJ	230	350
Free fatty acids	kg	12	

Output	Unit	Amount per t of refined oil	
		min,	max,
Refined oil	kg	1,000	
Fuller's earth	kg	6	14
FFA	kg	10	42
Lecithin	kg	10	25
Waste water	kg	80	700

Transesterification

The amount of **plant oil** required depends less on the type of oil (rapeseed, soybean, sunflower or palm fruits) than on the quality. The higher the proportion of triglycerides, the less plant oil is needed for the same amount of biodiesel in the transesterification process.

The input of **methanol** depends, among other things, on the quality of the oil used. The higher the proportion of triglycerides, the more methyl ester is produced and the more methanol is consumed. However, the recovery of the methanol contained in the glycerol and methyl ester phase after transesterification, which has to be removed through purification steps, has a greater impact. The recovered methanol can be recycled to the transesterification process in varying amounts depending on the design of the biodiesel plant.

The alkaline **catalyst** is consumed at a ratio of 0.5 – 2 % to plant oil. The consumption depends on the amount of soap that is formed from the free fatty acids during the transesterification process. The catalyst residues are converted to salts through the acidification of the biodiesel and glycerol phase and have to be disposed of. In the case of K_2SO_4 , they can be sold as co-products. Low amounts of bases are also required to raise the pH value of the glycerol after acidification.

The choice of **acid** depends, among other things, on the choice of catalyst. In the case of KOH, sulphuric acid is good for the acidification of the biodiesel and glycerol phase. Consumption depends on the amount of catalyst that has to be separated through alkaline hydrolysis with the help of the acid. The esterification of the free fatty acids additionally increases acid consumption.

The amount of **water** required for the biodiesel and glycerol wash depends on the waste water treatment of the biodiesel plant. The same applies to the amount and composition of **waste water**.

Energy input also varies widely. Heat input can be minimized through an efficient heat recovery concept. The required steam is either generated in a boiler in the biodiesel plant using a fuel (i.e. natural gas, heating oil), or it is supplied externally. Particularly in the case of small biodiesel plants, the consumption of electricity can exceed the value listed in the table of value ranges since the process heat is often generated through electricity.

Glycerol accumulates in different amounts, depending on the degree of purification. The higher the purity, from raw glycerol (50 %) up to pharmaceutical grade glycerol (> 99 %), the fewer glycerol accrues.

Sources of the given ranges for the transesterification of vegetable oil to vegetable oil methyl ester [2], [4 - 6], [8], [11 - 16].

Table 4: Ranges of mass and energy flows for the transesterification of vegetable oil to vegetable oil methyl ester

Input	Unit	Amount per t of biodiesel	
		min.	max.
Vegetable oil	kg	995	1,080
Methanol	kg	100	200
Alkaline catalyst	kg	5	20
Acid	kg	10	20
HCL	kg	-	20
H ₂ SO ₄	kg	-	20
H ₃ PO ₄	kg	-	5
Water	kg	20	2,000
Electrical energy	MJ	60	220
Thermal energy	MJ	1,400	2,500

Output	Unit	Amount per t of biodiesel	
		min,	max,
Biodiesel	kg	1,000	
Glycerol	kg	90	200
K ₂ SO ₄	kg	-	40
Waste water	kg	20	2,000

Table 5: Typical lower heating values and densities of various raw materials and auxiliaries in biodiesel production

Material	Lower heating value (MJ/kg)	Density (kg/m ³)
Rapeseed (9 % H ₂ O)	27.0	-
Sunflower seeds (9 % H ₂ O)	27.2	-
Soybeans (13 % H ₂ O)	23.0	-
FFB (fresh fruit bunch) (34 % H ₂ O)	24.0	-
n-Hexane	45.1	-
Palm kernel meal (10 % H ₂ O)	16.0	-
Sunflower extraction meal (10 % H ₂ O)	18.2	-
Soybean extraction meal (11.6 % H ₂ O)	19.1	-
Rapeseed extraction meal (12.8 % H ₂ O)	18.4	-
Plant oil (raw, refined)	37.0	920
Methanol	19.9	793
Glycerol	16.0	1,260
Biodiesel (methyl ester)	37.2	890
Fossil diesel	43.1	832

Calculating GHG emissions and the GHG saving potential

In order to calculate the GHG emissions resulting from the production and use of biodiesel, the GHG emissions and the GHG savings along the entire biodiesel production chain are added together. This is done by adding the GHG emissions produced at every interface along this chain to the GHG emissions of the upstream interfaces. Interfaces can also use disaggregated default values as per Directive 2009/28/EG (RED) instead of individually calculating the GHG emissions [18], [19]. The final interface consolidates the GHG emissions of the individual calculations or the disaggregated default values, and issues the GHG emissions value based on one MJ of biodiesel. The final interface also calculates the GHG reduction potential compared to a defined fossil reference value.

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

Calculation formulas

If an interface along the process chain of biofuel production chooses to calculate individual GHG savings based on actual values, it must do so in accordance with the methods defined in the EU RED [19]. The regulations contain concrete calculation formulas. A biofuel's GHG reduction potential is based on the GHG emissions resulting from biofuel production and use, and on a comparison to a fossil reference value. The section below explains the methodological principles of the two calculation steps.

Calculating GHG emissions

Total emissions are calculated based on the following, generally binding formula (as per Directive 2009/28/EG (RED)). This is based on GHG emissions and GHG emissions savings.

$$E = e_{ec} + e_l + e_p + e_{td} + e_u$$

GHG emissions from:

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

$$- e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$$

GHG emissions savings through:

e_{sca}	Improved agricultural farming practices
e_{ccs}	Capture and geological storage of CO ₂
e_{ccr}	Capture and replacement of CO ₂
e_{ee}	Excess electricity from CHP

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

- In principle there are three ways to provide GHG emission values: by using i) default values (Annex V EU RED), ii) individually calculated values and iii) a combination of disaggregated default values and individually calculated values.

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

- Emission factors represent the “emission backpacks” of the auxiliaries and energy carriers that are used. They contain the GHG emissions from the production and provision (frequently also the use in the case of energy carriers) of an auxiliary or energy carrier. Scientific publications serve as literature sources for emission factors.

- In accordance with RED, GHG emissions for the use of biofuels (e_u) are set to zero.

- e' represents the GHG emissions based on the (intermediate) product of the respective process steps (e.g. CO₂eq/kg rapeseed oil). e stands for the GHG emissions based on the product's energy content (e.g. g CO₂eq/MJ biodiesel).

- A by-product is one of multiple products that stem from the same production process. GHG emissions may only be distributed between the biofuel and co-products. Waste, harvest, processing and production residues are not considered to be co-products. The production of co-products is one of the primary aims of the production processes, i.e. their production is directly desired and the production process is intentionally modified so that they can be produced (EU COM 2010/C 160/02). The allocation (distribution of the GHG emissions) should be done based on the processing step in which the by-product is produced, or at the point where the product experiences no further downstream processing connected to the upstream part of the processing through material or energetic feedback loops (EU COM 2010/C 160/02). If co-products are produced during multiple stages of the biodiesel production chain, multiple allocation factors have to be taken into consideration (see sample calculation). More information can be found in the FAQ section.

Calculating the GHG saving potential

Once the overall emissions have been calculated, the GHG saving potential is obtained from the final interface in the value chain using the formula below:

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

$E_{Fossilfuel}$ = Total emissions of fossil reference fuel
 $E_{Biofuel}$ = Total emissions using the biofuel (e.g. bioethanol)

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

Calculation procedure

The different steps of the calculation procedure to individually calculate GHG emissions and the GHG saving potential are described below.

Calculating GHG emissions for each term of the calculation formula

GHG emissions are calculated for each interface and, based on the amount of processed intermediate products and are passed along to the downstream interface. The same principle applies to each of the terms (or interfaces) e_{ec} , e_p , e_{td} , e_u . In order to determine the GHG emissions of these interfaces, the auxiliaries and energy carriers used in the process chain are multiplied by their emission factors and divided by the amount of intermediate or main product.

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

Special rules apply to calculating the terms e_p , e_{sca} , e_{ccs} , e_{ccr} , e_{ee} , which is explained, in part, in the sample calculation and under frequently asked questions.

Allocating GHG emissions between the biofuel and the co-products

If additional co-products are produced for one interface, the GHG emissions generated up until the production of the main product and the co-product are distributed (allocated) between the biofuel (or its upstream product) and the co-product. The energy content of the original substance (not only the dry substance) of the biofuel and the by-product forms the basis for this allocation. The allocated value is passed on to the downstream interface. The allocated value is obtained as follows:

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

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

with m=mass, H=lower heating value

Calculating total emissions and the GHG saving potential

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 has not yet been used for transport, the final interface determines in which regions the fuel can be transported without falling below the respective GHG saving potential. The final interface also adjusts total emissions of the production and supply chain to the energy content of the fuel (usually per MJ) taking into account the lower heating value of biodiesel.

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. Other information about data sources can be found in the FAQ section.

Table 6: Data sources for the GHG balance

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

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

Exemplary calculation for rapeseed-based biodiesel

Operational data (actual values) are used for this sample calculation. The FAQ section explains what should be considered when disaggregated default values values are used.

A sample calculation of GHG emissions and the GHG emission saving potential is illustrated based on the process chain described below. The sample calculation follows the calculation procedure described in the preceding section. First, the operational data and the corresponding emission factors are listed for every calculation term. Then this data is entered into the calculation formulas. Finally, typical calculation errors are explained.

Illustration of an exemplary process chain

An exemplary process chain for rapeseed-based biodiesel production is described below and each step is explained for calculating the GHG emissions. The process chain illustrated in Fig. 7 consists of the rapeseed cultivation, transport of the rapeseed to the oil mill, the oil mill, the biodiesel plant and the distribution of the biodiesel to the consumption sites. In addition to the GHG emissions released during this process chain, the following also have to be taken into account: the GHG emissions from changes in carbon stocks as a result of land-use changes (in accordance with the basic calculation formula), and theoretically, the GHG emissions savings as part of potential CO₂ capture and geological storage or replacement, as well as the input of excess electricity from cogeneration (please also see the FAQs). The latter factors, however, play no role in the sample calculation for biodiesel illustrated here.

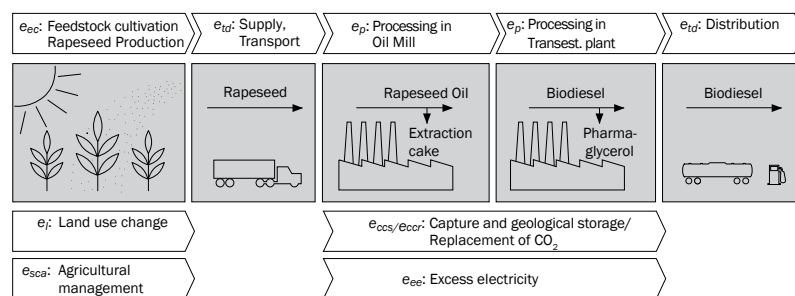


Fig 7: Exemplary rapeseed-based biodiesel production chain

After cultivation and harvest, the rapeseed is transported to the oil mill. At the oil mill, the rapeseed oil and the rapeseed extraction meal (co-product) are produced. In smaller plants extraction often doesn't occur, therefore rapeseed press cakes are produced as by-products.

The extraction meal is usually sold as protein-rich animal feed, which is taken into account in the GHG balance by means of allocation. The vegetable oil that is produced is refined and processed into fuel within the biodiesel plant. During this process, glycerol is produced alongside the biodiesel. After it is processed, the glycerol can be sold to the pharmaceutical industry. The pharmaceutical grade glycerol co-product is also taken into account in the GHG balance through allocation. The biodiesel that is produced is subsequently transported to the different consumption sites.

Cultivation of raw material e'_{ec}

In practice, a disaggregated default value or a NUTS 2 value is usually used for this process stage. For this exemplary calculation, however, the actual GHG emissions are taken into account from the raw material production process. The primary distributor receives, for example, a delivery of rapeseed that originates from an upstream cultivation system. In this case, all of the operational data of the rapeseed production (e.g. data regarding fertiliser input, diesel and electricity production, and harvest yield) have to be taken from operational documents (e.g. field index card). The common values of the emission factors (EF) of these input materials and energies are listed below. These have been taken from the literature and approved databanks.

Table 7: Input data and emission factors for rapeseed production

Input materials and energy	Unit	Value	Unit for EF	Value of EF	Source of EF
Seeds	kg/(ha*a)	6.0	kg CO ₂ -eq./kg	0.73	[Biograce]
N fertiliser	kg/(ha*a)	137.4	kg CO ₂ -eq./kg	5.88/ 6.41/ 7.59	[Biograce]/ [BLE]/[Gemis]
P ₂ O ₅ fertiliser	kg/(ha*a)	33.7	kg CO ₂ -eq./kg	1.01/1.18	[Biograce]/ [BLE]
K ₂ O fertiliser	kg/(ha*a)	49.5	kg CO ₂ -eq./kg	0.58/0.66	[Biograce]/ BLE]
CaO fertiliser	kg/(ha*a)	19.0	kg CO ₂ -eq./kg	0.13/ 0.30	[Biograce]/ BLE]
Plant protection product	kg/(ha*a)	1.2	kg CO ₂ -eq./kg	10.97	[Biograce]
Diesel (agricultural machinery)	l/(ha*a)	82.6	kg CO ₂ -eq./l	3.14/ 2.1	[Biograce]/ BLE
Required electricity (drying)	kWh/(ha*a)	70.3	kg CO ₂ -eq./kWh	0.61/ 0.60/ 0.58	[Biograce]/[BLE]/ [Öko-Institut]
Nitrous oxide emissions from N fertiliser			kg CO ₂ -eq./kg N-Dünger	9.03 ²	[Biograce]

Yield	Unit	Value
Rapeseed yield	kg/(ha*a)	3113

In accordance with the calculation scheme explained above, the quantities of the auxiliaries and the corresponding emission factors are entered into the equation. The following value for e'_{ec} is generated for rapeseed cultivation:

$$e'_{ec} = \frac{\left(6 \frac{\text{kg}}{\text{ha} * \text{a}} * 0.73 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right) + \left(137.4 \frac{\text{kg}}{\text{ha} * \text{a}} * 5.88 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right) + \left(33.7 \frac{\text{kg}}{\text{ha} * \text{a}} * 1.01 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right)}{3.113 \frac{\text{t}}{\text{ha} * \text{a}}} + \frac{\left(49.5 \frac{\text{kg}}{\text{ha} * \text{a}} * 0.58 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right) + \left(19.0 \frac{\text{kg}}{\text{ha} * \text{a}} * 0.13 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right) + \left(1.2 \frac{\text{kg}}{\text{ha} * \text{a}} * 10.97 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right)}{3.1134 \frac{\text{t}}{\text{ha} * \text{a}}} + \frac{\left(82.6 \frac{\text{l}}{\text{ha} * \text{a}} * 3.14 \frac{\text{kg CO}_2\text{eq.}}{\text{l}}\right) + \left(70.3 \frac{\text{kWh}}{\text{ha} * \text{a}} * 0.61 \frac{\text{kg CO}_2\text{eq.}}{\text{kWh}}\right) + \left(137.4 \frac{\text{kg}}{\text{ha} * \text{a}} * 9.03 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}}\right)}{3.113 \frac{\text{t}}{\text{ha} * \text{a}}}$$

The primary distributor forwards the value of 782 kg CO₂eq./t rapeseed on to the oil mill.

■ The values from rapeseed cultivation primarily originate from www.biograce.net [20].

■ In the case of fertiliser data, it should be noted whether the values are based on the entire fertiliser (e.g. combination fertiliser) or only on the nutrients used.

■ N₂O is a greenhouse gas that is released, for example, when nitrogen fertilisers are used in agriculture. There are direct and indirect nitrous oxide emissions. Direct nitrous oxide emissions are generated, for example, through nitrogen inputs from organic and mineral fertilisers and atmospheric N deposition. Indirect nitrous oxide emissions are caused when nitrogen compounds, like nitrate and ammonia, make their way into surrounding natural areas, for instance, as a result of N fertiliser input. Nitrous oxide emissions can be calculated using the GNOC model (Global Nitrous Oxide Calculator) or 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 offers a nitrous oxide calculator in line with the IPCC method at www.biograce.net.

Basic formula:

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

² The emission factor given here for nitrous oxide emissions is not an emission factor in the classical sense. It has to be individually determined for each crop and for the respective type and amount of fertiliser (e.g. synthetic fertiliser, organic fertiliser).

Possible calculation errors

- Nitrous oxide emissions in accordance with IPCC or GNOC methods should not be omitted.
- Some EFs cannot be determined using the trade names of fertilisers. In this case the chemical term for the fertiliser is required.
- It should be noted whether the EF of the fertiliser/pesticide only refers to the active ingredient (e.g. kg N) or to the amount of fertiliser (e.g. calcium ammonium nitrate consists of 76 % NH_4NO_3 and 24 % CaCO_3).
- Unit conversion errors, for instance:
 - The amount of input material and the EF of the input material are based on different units of quantity, e.g. 6 kg of seeds/(ha*a) and EF of 3.54 kg $\text{CO}_2\text{eq/t}$ of 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.

■ In accordance with EU COM 2010/C 160/02, “improved agricultural farming practices” may contain the following practices:

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

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

■ The transport values have been taken from the BLE guidelines for sustainable biomass production. [21]

Land-use changes e'_l

Was the area used for rapeseed production already being cultivated before 1 January 2008?

In this case: Yes. Therefore, the value of e'_l equals zero.

$$e'_l = 0$$

Improved agricultural management e'_{sca}

In this example: No carbon-enriching measures took place.

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

Transport e'_{td1}

The rapeseed is transported from the primary distributor to the oil mill. The following data is provided for this process step:

Table 8: Basic data for the transport process

Input materials and energy	Unit	Value
Volume of the transported rapeseed	kg	24,000.00
Means of transport		Truck (diesel)
Transport distance, loaded (d_{loaded})	km	80.00
Transport distance, empty (d_{empty})	km	20.00
Fuel consumption loaded (K_{loaded})	l/km	0.41
Fuel consumption empty (K_{empty})	l/km	0.24

The emission factor for the diesel fuel that is used is listed as follows:

Table 9: Emission factor for diesel in the transport process

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

The GHG emissions from transport are calculated as follows:

$$e'_{td1} = \frac{(d_{loaded} * K_{loaded} + d_{empty} * K_{empty}) * EF}{transported rapeseed}$$

$$e'_{td1} = \frac{(80 km * 0.41 \frac{l}{km} + 20 km * 0.24 \frac{l}{km}) * 3.14 \frac{kgCO_2eq}{l}}{24 t}$$

$$e'_{td1} = 4.9 \frac{kgCO_2eq.}{t rapeseed}; \text{without allocation}$$

Basic formula:

$$e'_{td1} = \frac{(d_{loaded} * K_{loaded} + d_{empty} * K_{empty}) * EF}{transported rapeseed}$$

Potential calculation errors

- Unit and conversion errors, e.g. diesel consumption and emission factor of diesel have to be uniform and in l or kg.

Processing e'_{p1} : oil mill

An oil mill receives rapeseed and processes this into rapeseed oil and extraction meal. The calculation of the GHG emissions for this interface is based on the following sample operational data. Common values for emission factors of these input materials and energies are also listed below. They have been taken from the literature and from acknowledged databases.

Table 10: Input data and emission factors for rapeseed oil production

Input materials and energy	Unit	Value	Unit for EF	Value of EF	Source EF
Rapeseed	t/a	350,000			
Natural gas for producing steam	GJ/a	225,556	kg CO ₂ -eq./MJ	0.067/0.072/0.070	Biograce/ BLE/Gemis
Electricity demands	MWh/a	4,433.33	kg CO ₂ -eq./ kWh	0.61/ 0.60/ 0.58	Biograce/ BLE/ Öko-Institut
Hexane	kg/a	280,000	kg CO ₂ -eq./kg	3.63	Biograce

Products	Unit				
Rapeseed oil	t/a	150,000			
Rapeseed extraction meal	t/a	197,000			

Inputting this data results in the following values for e'_{p1}

$$e'_{p1} = \frac{\left(225.5 \frac{TJ}{a} * 6700 \frac{kg CO_2eq.}{TJ} \right) + \left(4433 \frac{MWh}{a} * 610 \frac{kg CO_2eq.}{MWh} \right) + \left(280 \frac{t}{a} * 3630 \frac{kg CO_2eq.}{t} \right)}{150,000 \frac{t}{a}}$$

$$e'_{p1} = 125.55 \frac{kg CO_2eq}{t rapeseed oil and 1.31t rapeseed extraction meal}; \text{without allocation}$$

Allocation between rapeseed oil and rapeseed extraction meal

The result e'_{p1} refers to the GHG emissions that result from the overall processes in the oil mills. Since rapeseed extraction meal is produced in the oil mills alongside the rapeseed oil, the GHG emissions that are emitted until the extraction meal is produced are allocated between the two products. The GHG emissions that have been produced up until this point consist of GHG emissions from raw material production, transport and the oil mill.

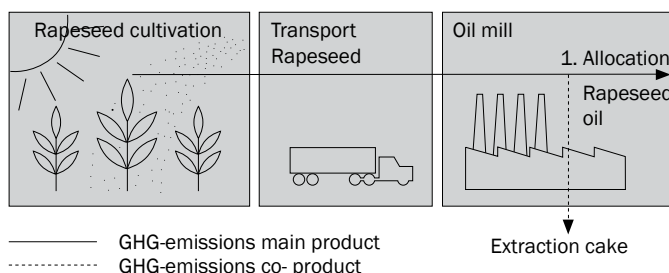


Fig. 8: Allocation between extraction meal and plant oil

GHG values from the raw material production and transport are based on one tonne or one kilogram of rapeseed, and the GHG values from the oil are based on one tonne or one kilogram of vegetable oil, the specific oil content, or oil yield per tonne of rapeseed, is required. This yield and the volumes of vegetable oil and extraction meals needed for the allocation are taken from the operational data. The heating values can be taken from an actual measurement, literature or databases.

Table 11: Heating values for the allocation

Yield	Unit	Value	Source
Oil yield per kg FM rapeseed	kg/kg	0.43	Operational data from the DBFZ databank

Main and co-products	Unit	Lower heating value	Source
Rapeseed oil	MJ/kg	37	BLE
Extraction meal	MJ/kg	15	BLE

The allocated GHG emissions can be calculated as follows:

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

The GHG emission up until extraction meal is produced is determined as follows:

$$\begin{aligned} \text{GHG emissions}_{\text{totalled}} &= e'_{ec} + e'_{td1} + e'_{p1} \\ &= 781.77 \frac{\text{kg } CO_2eq.}{t \text{ rapeseed}} + 4.9 \frac{\text{kg } CO_2eq.}{t \text{ rapeseed}} + 125.55 \frac{\text{kg } CO_2eq.}{t \text{ rapeseed oil}} \end{aligned}$$

In order to add the values together, a common denominator is required, based on one tonne of rapeseed oil. A common denominator is ensured above an oil yield of 0.43 t rapeseed oil per t of rapeseed:

$$781.77 \frac{\text{kg CO}_2\text{eq.}}{\text{t rapeseed}} + 4.9 \frac{\text{kg CO}_2\text{eq.}}{\text{t rapeseed}} = \frac{786.67 \text{ kg CO}_2\text{eq.}}{0.43 \text{ t rapeseed}} = 1,829.47 \frac{\text{kg CO}_2\text{eq.}}{\text{t rapeseed oil}}$$

GHG emissions_{totalled} =

$$1829.47 \frac{\text{kg CO}_2\text{eq.}}{\text{t rapeseed oil}} + 125.55 \frac{\text{kg CO}_2\text{eq.}}{\text{kg rapeseed oil}} = 1955.02 \frac{\text{kg CO}_2\text{eq.}}{\text{t rapeseed}}$$

Until the extraction meal by-product emerges, 1,955 kg CO₂ eq. per t of rapeseed are emitted. These GHG emissions are not yet allocated between the rapeseed extraction meal and the rapeseed oil.

The allocation factor is calculated as follows:

$$AF_{\text{rapeseed oil}} = \frac{m_{\text{main, product}} * H_{\text{lower, main, product}}}{m_{\text{main, product}} * H_{\text{lower, main, product}} + m_{\text{by-product}} * H_{\text{lower, by-product}}}$$

$$AF_{\text{rapeseed oil}} = \frac{150,000 \frac{\text{t}}{\text{a}} * 37 \frac{\text{MJ}}{\text{kg}}}{150,000 \frac{\text{t}}{\text{a}} * 37 \frac{\text{MJ}}{\text{kg}} + 197,000 \frac{\text{t}}{\text{a}} * 15 \frac{\text{MJ}}{\text{kg}}}$$

$$AF_{\text{rapeseed oil}} = 0.65$$

$$e'_{\text{allocated 1}} = 1955.02 \frac{\text{kg CO}_2\text{eq.}}{\text{kg}} * 0.65$$

$$e'_{\text{allocated 1}} = 1275.76 \frac{\text{kg CO}_2\text{eq}}{\text{t rapeseed oil}} \text{ (and } 684.26 \text{ kg CO}_2\text{eq per t extraction meal)}$$

The oil mill therefore passes on a value of 1,276 kg CO₂ eq. per t of rapeseed to the biodiesel plant.

Processing e'_{p2} : biodiesel production (including refining)

The biodiesel plant receives rapeseed oil from the oil mill and uses the following operational data as the basis for calculating its own GHG emissions value. Emission factors for calculating the emissions are also contained in the table below.

Table 12: Input data and emission factors for the biodiesel production

Input materials and energy	Unit	Value	Unit for EF	Value of EF	Source of EF
Rapeseed oil	t/a	210,000			
Natural gas for the provision of process gas	GJ/a	239,760	kg CO ₂ -eq./MJ	0,067/0,072/0,072	Biograce/BLE/Öko-Institut
Electricity	kWh/a	5,000,000	kg CO ₂ -eq./kWh	0,61/0,60/ 0,58	Biograce/BLE/Öko-Institut
Water	kg/a	150,000,000	kg CO ₂ -eq./kg	4,0*10 ⁻⁴	Gemis
Methanol	kg/a	20,000,000	kg CO ₂ -eq./kg.	1,98/1,25	Biograce/BLE
Sodium hydroxide	kg/a	1,300,000	kg CO ₂ -eq./kg	0,47/1,12	Biograce/BLE
Phosphoric acid	kg/a	350,000	kg CO ₂ -eq./kg	3,011	Biograce

Products	Unit	Value			
Biodiesel	t/a	200,000			
Glycerol	t/a	20,000			

Waste	Unit	Value			
Wastewater for treatment	kg/a	120,000,000	kg CO ₂ -eq./kg	2.7 *10 ⁻⁴	Gemis

Inputting this data results in the following values for e' _{p2}

$$\begin{aligned}
 e'_{p2} = & \frac{\left(239,760 \frac{GJ}{a} + 67 \frac{kg \ CO_2eq.}{GJ}\right) + \left(5,000 \frac{MWh}{a} + 610 \frac{kg \ CO_2eq.}{MWh}\right) + \left(150,000 \frac{t}{a} + 0.41 \frac{kg \ CO_2eq.}{kg}\right)}{200,000 \frac{t}{a}} \\
 & + \frac{\left(20,000 \frac{t}{a} * 1980 \frac{kg \ CO_2eq.}{t}\right) + \left(1,300 \frac{t}{a} * 470 \frac{kg \ CO_2eq.}{t}\right) + \left(350 \frac{t}{a} * 3011 \frac{kg \ CO_2eq.}{t}\right)}{200,000 \frac{t}{a}} \\
 & + \frac{(120,000 * 0.27 \frac{kg \ CO_2eq.}{t})}{200,000 \frac{t}{a}} \\
 e'_{p2 \ unallocated} = & 302.36 \frac{kg \ CO_2eq.}{(t \ biodiesel \ and \ 0.1 \ t \ pharmaceutical \ glycerine)}; \text{without allocation}
 \end{aligned}$$

Allocation between biodiesel, pharmaceutical glycerol and free fatty acids

The result of e' _{p2 unallocated} refers to the total GHG emissions released in the biodiesel plant. Since pharmaceutical glycerol is produced alongside biodiesel in the biodiesel plant, the GHG emissions that occur until the by-product is produced are allocated between these products. The GHG emissions produced up until this point are made up of the GHG emissions from the upstream interfaces that have already been added together, and the GHG emissions of this biodiesel plant.

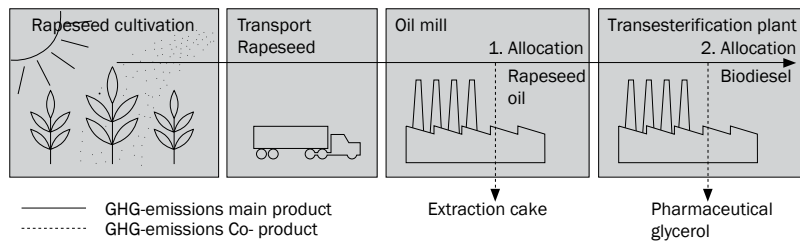


Fig. 9: Allocation of the co-products

Since the GHG values from the upstream interfaces are based on one tonne of rapeseed oil and the GHG values of the biodiesel plant are based on one tonne of biodiesel, the biodiesel yield per tonne of rapeseed oil is required. This yield, the masses of biodiesel and pharmaceutical glycerol necessary for the allocation are taken from the operational data. The heating values can be taken from an actual measurement, literature or databases.

Table 13: Data for the allocation of the co-products

Yield	Unit	Value	Source
Biodiesel yield per kg rapeseed oil	kg/kg	0.95	Operational data from the sample biodiesel plant

Main and co-products	Unit	Lower heating value	Source
Biodiesel	MJ/kg	37.2	BLE
Pharmaceutical glycerol	MJ/kg	16	Biograce

The allocated GHG emissions can be calculated as follows:

$$e'_{p2 \text{ allocated}} = \text{GHG emissions up until the by-product is produced} * \text{Allocation factor}$$

The GHG emissions up until the biodiesel is produced are determined as follows:

$$\begin{aligned} \text{GHG emissions}_{\text{totalled}} &= e'_{\text{allocated 1}} + e'_{p2} \\ &= \text{emissions from rapeseed oil production} + \text{emissions from transesterification} \end{aligned}$$

In order to add together all of the values, a common denominator is required, namely based on one t of biodiesel. A common denominator is ensured above a biodiesel yield of 0.95 kg biodiesel per kg of rapeseed oil

$$= 1275.76 \frac{\text{kg } CO_2 \text{ eq.}}{\text{t rapeseed oil}} = \frac{1275.76 \text{ kg } CO_2 \text{ eq.}}{0.95 \text{ t biodiesel}} = 1342.90 \frac{\text{kg } CO_2 \text{ eq.}}{\text{t biodiesel}}$$

GHG emission_{totalled}

$$= 1342.90 \frac{\text{kg } CO_2 \text{ eq.}}{\text{t biodiesel}} + 302.36 \frac{\text{kg } CO_2 \text{ eq.}}{\text{t biodiesel}} = 1645.26 \frac{\text{kg } CO_2 \text{ eq.}}{\text{t biodiesel}}$$

Until the point that co-products are produced from the biodiesel process, 1,645 kg CO₂ eq. per t of biodiesel are released. These GHG emissions have not yet been allocated between the biodiesel and the co-product pharmaceutical grade glycerol. The allocation factor is calculated as follows:

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

$$AF_{\text{bioethanol}} = \frac{200,000 \frac{\text{t}}{\text{a}} * 37.2 \frac{\text{MJ}}{\text{kg}}}{200,000 \frac{\text{t}}{\text{a}} * 37.2 \frac{\text{MJ}}{\text{kg}} + 20,000 \frac{\text{t}}{\text{a}} * 16 \frac{\text{MJ}}{\text{kg}}}$$

$$AF_{\text{bioethanol}} = 0.96$$

$$e'_{\text{allocated 2}} = 1645.26 \frac{\text{kg } CO_2 \text{ eq.}}{\text{t biodiesel}} * 0.96$$

$$e'_{\text{allocated 2}} = 1579.45 \text{ kg } CO_2 \text{ eq.} / \text{biodiesel}$$

Potential calculation errors

- Dry matter contents (DM), masses and oil content of the raw materials or (intermediate) products have to correspond to one another in the transition between the interfaces. Energetic or material consumption that increases dry matter content has to be listed in the energy and mass balance.
- It is important that the concentrations of the chemicals that are used in the operation correspond to the concentrations of the emission factors that are used.
- It is important that, when allocating all of the heating values, it is based uniformly on the original substance and not only on its percentage of dry matter.
- When allocating, the GHG emissions have to be added together until production of the co-product. If the GHG emissions originate from different interfaces (e.g. primary distributor and oil mill) and are based on different intermediate products (e.g. kg rapeseed and kg rapeseed oil), the GHG emissions cannot simply be added together. They have to be converted through yields to uniform units.
- Unit and conversion calculation errors, e.g. input quantity of the input material 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

Distribution e'_{td2}

The biodiesel is transported from the biodiesel plant to a consumption site. The following data are recorded for this process step:

Table 14: Basic data for biodiesel distribution

Input materials and energy	Unit	Value
Mass of the transported biodiesel (m)	kg	50,000
Means of transport		Tanker, diesel
Distribution distance, loaded (d_{loaded})	km	150
Distribution distance, empty (d_{empty})	km	50
Fuel consumption loaded (K_{loaded})	l/km	0.41
Fuel consumption empty (K_{empty})	l/km	0.24

- The transport values are based on our own assumptions. The fuel consumptions are taken from the BLE.

A common emission factor for the diesel that is used is listed below:

Table 15: Emission factor for diesel in biodiesel distribution

Input materials and energy	Unit	EF	Source
Diesel	kg CO ₂ -eq./l	3.14/3.01	Biograce/TREMOD

The GHG emissions from transport are calculated as follows:

Basic formula:

$$e'_{td2} = \frac{(d_{loaded} * K_{loaded} + d_{empty} * K_{empty}) * EF}{transported\ biodiesel}$$

$$e'_{td2} = \frac{(150\ km * 0.41\ \frac{l}{km} + 50\ km * 0.24\ \frac{l}{km}) * 3.14\ \frac{kg\ CO_2\ eq}{l}}{50,000\ kg}$$

$$e'_{td2} = 4.61\ \frac{kg\ CO_2\ eq.}{t\ biodiesel}$$

Potential calculation errors

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

Total emissions E

The biodiesel plant is the final interface. It has to take into account the GHG emissions from transport, calculate the total emissions, and base these on one MJ biodiesel. Total GHG emissions are calculated from the already totalled and allocated GHG emissions that are linked to biodiesel, and the emissions from the transport of the biodiesel to the consumption sites.

Total emissions per t of biodiesel = $e'_{\text{allocated } 2} + e'_{\text{td}2} =$

$$1579.45 \frac{\text{kg CO}_2\text{eq.}}{\text{t biodiesel}} + 4.61 \frac{\text{kg CO}_2\text{eq.}}{\text{t biodiesel}} = 1584.06 \frac{\text{kg CO}_2\text{eq.}}{\text{t biodiesel}}$$

Taking into account the heating value, the GHG emissions are converted to one MJ of biodiesel:

$$\text{Total emissions per MJ of biodiesel} = \frac{1584.06 \frac{\text{kg CO}_2\text{eq.}}{\text{t biodiesel}}}{37200 \frac{\text{MJ}}{\text{t biodiesel}}} = 0.043 \frac{\text{kg CO}_2\text{eq.}}{\text{MJ biodiesel}}$$

$$\text{Total emissions per MJ of biodiesel} = 42.58 \frac{\text{g CO}_2\text{eq.}}{\text{MJ biodiesel}}$$

Calculation of the GHG emission saving

As the final interface, the biodiesel plant also calculates the GHG saving as follows:

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

$$\text{GHG-reduction} = \left[\frac{83.8 \frac{\text{g CO}_2\text{eq.}}{\text{MJ}} - 42.6 \frac{\text{g CO}_2\text{eq.}}{\text{MJ}}}{83.8 \frac{\text{g CO}_2\text{eq.}}{\text{MJ}}} \right] * 100 = 49.2\%$$

The sample process chain for the production of rapeseed-based biodiesel, as illustrated here, shows that around 50 % of the GHG emissions of the fossil reference value can be saved, when the co-products extraction meal and pharmaceutical glycerol are taken into account.

Frequently asked questions – FAQ

The section below is a collection of frequently asked questions. Some of these questions relate to areas in 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 EU 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 EU RL 2015/1513 [24], [25].

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 RL 2015/1513, not an end product that is meant to be directly produced in a production process [24], [25]. It is not the primary aim of production and the process is not intentionally changed in order to produce it.

Is there a basic rule or a decision-making tool for determining whether it is a co-product so that an allocation of the GHG emissions can occur?

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 [24], [25]. Furthermore, the product must be able to be stored and traded.

In order to place a process output in the category of by-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 raw glycerol. The GHG emissions are only divided between the biofuel (or its pre-product) and the co-product. According to annex V of the EU RED, no GHG emissions can be allocated to waste, harvest residues or production residues [19]. Their life-cycle GHG emissions are zero until the place of their production.

What are the typical co-products of biodiesel production?

Typical co-products of the process chain used to produce rapeseed-based biodiesel include: i) rapeseed press cakes (usually in the case of smaller, de-centralised oil mills) or rapeseed extraction meal (in the cases of larger plants using extraction processes) and ii) pharmaceutical glycerol (if the raw glycerol from the process undergoes transesterification, raw glycerol itself is excluded from allocation) and, in specific cases, free fatty acids at the biodiesel plant stage. However, for fatty acids there must be clear application in the form of excising contractual documents that justify the use of the term by product.

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

The raw glycerol produced as part of the biodiesel production process is explicitly excluded from allocation in Annex V of the EU RED. If raw glycerol is immediately purified into pharmaceutical glycerol, it can be allocated as a by-product. The expenditures from the processing are then to be taken into account in the balance. The term pharmaceutical glycerol, however, is not clearly defined. The concentration of raw glycerol can fluctuate depending on the process and raw material specifications. Usually raw glycerol undergoes a process of methane recovery and then various treatment steps, such as water separation, bleaching or distillation, in order to achieve a pharmaceutical grade.

What happens when a co-product has a negative heating value as a result of a high percentage of water?

According to the EU RED, the energy content of a co-product with a negative energy content is zero for the purpose of the calculation.

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

According to the EU COM 2010/C 160/02, the allocation should take place after the process step in which the by-product is produced, or at the time when the product undergoes no further downstream processing that is connected to the upstream part of the process through material or energetic feedback loops. [24].

Units and conversion steps

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

The Biograce tool (www.biograce.net) and the ENZO2 software offer such supporting information. 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 EU RED and other interfaces along the process chain conduct their own GHG calculations?

According to the legal regulations and system regulations valid at the time this guide was created, individually determined values and partial standard values cannot simply be added together because:

- 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 biodiesel). This means the disaggregated default values of the process steps (raw material production $e_{e'}$, processing e_p , transport and distribution e_{td}) must be converted to a common denominator (e.g. kg or t of the corresponding (intermediate) product). This requires conversion factors (CF). Conversion factors indicate the amount of intermediate product that is required for 1 MJ of end product. These conversion factors are depicted in yields.
- 2) The partial standard value could be based on other AFs than the individually determined GHG value.

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

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

$$e' \left[\frac{\text{kgCO}_2\text{eq}}{\text{kgIntermediate, product}} \right] = \frac{e \left[\frac{\text{kgCO}_2\text{eq}}{\text{MJ}} \right]}{AF \left[\frac{\text{MJ}}{\text{MJ}} \right] * CF \left[\frac{\text{kgIntermediate, product}}{\text{MJ}} \right]}$$

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

According to the Communication “Note on conducting and verifying actual calculations of GHG emissions savings” published in 2015, an adjustment of the partial standard values, e.g. improved efficiencies in the conversion plants, will no longer be possible in the future [27]. Partial standard values (e.g. for cultivation) will then simply be added to the actual values (e.g. for the conversion).

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

Example: a GHG value is determined for biodiesel made from camelina up until biodiesel is produced. Can the disaggregated default value for distribution from the existing default values for biodiesel e.g. based on rapeseed, be extracted and offset against the individually determined value?

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

Data and key indicators

Which emission factors and material densities may be used?

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

When can lump sum emission factors be used and when must actual, individual calculations for additives and energy carriers be performed?

Example: A company uses pellets or wood chips to supply energy to its processes. Can the company use an emission factor from an approved source or does the emission factor have to be generated for the individual value chain?

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

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

According to EU RED the emission factor of the electricity's respective region must be used in cases where grid power is used [19]. In practice, the national or European electricity mix is used depending on the system. In the Communication "Note on conducting and verifying actual calculations of GHG emissions savings", the EU electricity mix will be used in future balancing [27].

If isolated operation is used to generate green electricity, i.e. the plant generating electricity is not connected to the power grid, the emission factor for the average amount of green electricity produced is 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 observed where applicable.

Do infrastructural expenditures, e.g. the construction of the biodiesel plant, have to be considered?

No. According to the EU RED the emissions that are tied to the construction of the plant are not taken into account [19].

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) [24]. The Biograce tool (<http://www.biograce.net>) defines cut-off criteria for small quantities. The system principles of various systems also describe concrete cut-off criteria. 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 emissions balancing.

Primary sources of GHG emissions in the biodiesel process chain**Which processes in the overall biodiesel production chain cause the most GHG emissions?**

For the process chain used in the production of rapeseed-based biodiesel, the highest emissions typically occur during rapeseed production and during the two processing stages. The process of rapeseed production is essentially characterised by emissions from the production (pre-chain emissions depicted by the emission factor) and the use (nitrous oxide emissions) of nitrogen fertilisers, and, to a small degree, from the use of diesel to operate the agricultural machinery.

At the processing stage, processes that supply process energy (provision of heat and electricity) for both rapeseed oil and biodiesel production are typically the main influencing factors. The amount of GHG emissions strongly depends on which energy carrier (natural gas, oil, internally biogenetically produced co-products like biogas) is used to provide heat, and whether the GHG emissions can be partly allocated to the production of co-products.

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

How does one determine the field emissions for the individual calculations of the GHG emissions stemming from raw material production?

The European Commission has approved two methods for determining field emissions: the GNOC Model (Global Nitrous Oxide Calculator) and the IPCC method (Tier 1). The field emissions can be calculated using the GNOC model at <http://gnoc.jrc.ec.europa.eu>. The Biograce Tool provides a nitrous oxide calculator that uses the IPCC method. This can be found at www.biograce.net.

Can NUTS2 values be used as an alternative to the partial standard values for cultivation?

Yes. As of 30 July 2013 NUTS2 values may also be used for GHG emissions in addition to the partial standard values and the previously published estimations for cultivation. The NUTS2 values can be calculated at <http://nuts.redcert.org>.

How does one calculate the GHG emissions resulting from land-use change (LUC) when the area of cultivation was not used as farmland before 1 January 2008?

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

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

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

CS_R Carbon stocks connected to the reference area 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 connected to 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. the IPCC Guidelines) [28]. The values for the conversion factor are taken from the operational data, those for the allocation factor 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 co-products are produced, the emissions are not allocated between the biofuel and the by-product.

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.

When can the bonus, e_B be taken advantage of?

According to the EU RED, a bonus of 29 g CO₂ eq./MJ is conferred when there is proof that the affected area at the time of reference was not used agriculturally or for any other purpose, and falls under the following two categories: i) heavily degraded areas including previous agricultural areas ii) heavily contaminated areas [19]. 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 area if a continuous increase in carbon stocks and a significant decrease in erosion can be assured and the soil contamination. The bonus is only allocated to the biofuel.

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

According to EU COM 2010/C 160/02, “improved agricultural farming practices” may include the following practices [24]:

- Conversion to reduced tillage or zero tillage
- Improved crop rotations and/or cover plants, including management of the harvest residues
- Improved fertiliser or natural fertiliser management
- Use of soil improvers (e.g. compost).

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 there is a reasonable assumption that they have increased. The GHG savings measured during the time period are to be divided by the time period (in years) in order to obtain the annual basis of GHG savings.

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

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

$$e_{ee}' \left[\frac{kg \ CO2eq}{kg \ main \ product} \right] = \frac{excess \ electricity \left[\frac{kWh}{a} \right] - EF_{fuel} \left[\frac{kg \ CO2eq}{kWh} \right]}{Amount_{main \ product} \left[\frac{kg}{a} \right]}$$

According to EU RED, the GHG savings 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 [19]. It is also assumed that the dimensions of the CHP plant producing these excesses correspond to the minimum size needed to produce the heat required for the biofuel.

Balancing

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

The DE and EU system defaults differ in their regulations on balancing. According to Section 16 (2) 2 a) of the Biofuels Sustainability Ordinance, in the DE systems, the GHG saving potentials from different amounts of fuels with different GHG saving potentials can only be balanced when all amounts added to the mixture exhibit the necessary GHG saving potential before being added (currently 35 %, starting 1 January 2017: 50 %) [19].

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

No balancing is possible in EU systems.

Conversion tables

Volumes and masses (weight) of biodiesel

1.000 l biodiesel = 890 kg = 0,89 t
1 t biodiesel = 1.123,59 l = 1,24 m³

Basic formula

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

Density and heating values

	Density kg/l	Heating value MJ/kg	Heating value MJ/l	Heating value kWh/kg	Fuel equivalent l
Biodiesel	0.89	37.20	33.10	10.33	0.86

Conversion of energy units

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

Conversion of energy units

	m ³	l	Barrels	US gal
1 m ³	1	1,000	6.3	-
1 l	0.001	1	0.0063	-
1 barrel	0.159	159	1	-
1 US gal	0.00379	3.79	-	1

References

- [1] BOCKISCH, MICHAEL: *Nahrungsfette und -öle, Handbuch der Lebensmitteltechnologie*. Stuttgart : Verlag Eugen Ulmer, 1993 — ISBN 978-3-8001-5817-1
- [2] BERNESSON, SVEN: *Life cycle assessment of rapeseed oil, rape methyl ester and ethanol as fuels* (Nr. Rapport 2004:01). Uppsala : Swedish University of Agricultural Sciences, 2004
- [3] BERNESSON, S ; NILSSON, D ; HANSSON, P. A: A limited LCA comparing large- and small-scale production of rape methyl ester (RME) under Swedish conditions. In: *Biomass & bioenergy*. Bd. 26 (2004), Nr. 6, S. 545–559
- [4] ESTEBAN, BERNAT ; BAQUERO, GRAU ; PUIG, RITA ; RIBA, JORDI-ROGER ; RIUS, ANTONI: Is it environmentally advantageous to use vegetable oil directly as biofuel instead of converting it to biodiesel? In: *Biomass and Bioenergy* Bd. 35 (2011), Nr. 3, S. 1317–1328
- [5] DUFOUR, JAVIER ; ARSUAGA, JESÚS ; MORENO, JOVITA ; TORREALBA, HELY ; CAMACHO, JAVIER: Comparative life cycle assessment of biodiesel production from cardoon (*Cynara cardunculus*) and rapeseed oil obtained under Spanish conditions. In: *Energy & Fuels* Bd. 27 (2013), Nr. 9, S. 5280–5286
- [6] COCCO, D.: Life-cycle assessment of bioenergy production systems from oilseed rape crops. In: *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* Bd. 225 (2011), Nr. 1, S. 63–73
- [7] SCHMIDT, JANNICK HØJRUP: *Life cycle assessment of rapeseed oil and palm oil*. Aalborg, Aalborg Universitet, Ph.D. thesis, 2007
- [8] RAJAEIFAR, MOHAMMAD ALI ; GHOBADIAN, BARAT ; SAFA, MAJEED ; HEIDARI, MOHAMMAD DAVOUD: Energy life-cycle assessment and CO₂ emissions analysis of soybean-based biodiesel: a case study. In: *Journal of Cleaner Production* Bd. 66 (2014), S. 233–241
- [9] KRAUS, KATJA ; NIKLAS, GUIDO ; TAPPE, MATTHIAS: *Aktuelle Bewertung des Einsatzes von Rapsöl/RME im Vergleich zu Dieselkraftstoff*. Berlin : Umweltbundesamt, 1999
- [10] DREIER, T. ; GEIGER, B. ; SALLER, A.: *Ganzheitliche Prozesskettenanalyse für die Erzeugung und Anwendung von biogenen Kraftstoffen*: TU München und Forschungsstelle für Energiewirtschaft, 1998
- [11] STEPHENSON, A. L. ; DENNIS, J. S. ; SCOTT, S. A.: Improving the sustainability of the production of biodiesel from oilseed rape in the UK. In: *Process Safety and Environmental Protection* Bd. 86 (2008), Nr. 6, S. 427–440
- [12] KALTSCHMITT, M. (Hrsg.): *Energie aus Biomasse*. 2. Aufl. Berlin, Heidelberg : Springer Verlag, 2009
- [13] SKARLIS, STR ; KONDILI, E. ; KALDELLIS, J. K.: Small-scale biodiesel production economics: a case study focus on Crete Island. In: *Journal of cleaner production* Bd. 20 (2012), Nr. 1, S. 20–26
- [14] GASOL, CARLES M. ; SALVIA, JORDI ; SERRA, JOAN ; ANTÓN, ASSUMPCIÓ ; SEVIGNE, EVA ; RIERADEVALL, JOAN ; GABARRELL, XAVIER: A life cycle assessment of biodiesel production from winter rape grown in Southern Europe. In: *Biomass and Bioenergy* Bd. 40 (2012), S. 71–81
- [15] SILALERTRUKSA, THAPAT ; BONNET, SÉBASTIEN ; GHEEWALA, SHABBIR H.: Life cycle costing and externalities of palm oil biodiesel in Thailand. In: *Journal of Cleaner Production* Bd. 28 (2012), S. 225–232
- [16] APOSTOLAKOU, A. A. ; KOOKOS, I. K. ; MARAZIOTI, C. ; ANGELOPOULOS, K. C.: Techno-economic analysis of a biodiesel production process from vegetable oils. In: *Fuel Processing Technology* Bd. 90 (2009), Nr. 7-8, S. 1023–1031
- [17] EDWARDS, R. ; LARIVÉ, J-F. ; RICKEARD, D. ; WEINDORF, WERNER: *WELL-TO-TANK Appendix 1 - Version 4a - Conversion factors and fuel properties*. Luxembourg : Publications Office of the European Union, 2014 — ISBN 978-92-79-33888-5

- [18] EUROPÄISCHES PARLAMENT & EUROPÄISCHER RAT: Richtlinie 2009/28/EG des europäischen Parlaments und des Rates vom 23. April 2009 zur Förderung der Nutzung von Energie aus erneuerbaren Quellen und zur Änderung und anschließenden Aufhebung der Richtlinien 2001/77/EG und 2003/30/EG, 2009
- [19] BOKRAFT-NACHV: Verordnung über Anforderungen an eine nachhaltige Herstellung von Biokraftstoffen (Biokraftstoff-Nachhaltigkeitsverordnung – Biokraft-NachV), 2009
- [20] INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG (IFEU): *Biograce. Harmonized calculations of biofuel greenhouse gas emissions in Europe.* – www.biograce.net
- [21] BUNDESANSTALT FÜR LANDWIRTSCHAFT UND ERNÄHRUNG (BLE): *Leitfaden Nachhaltige Biomasseherstellung.* 1. Aufl. Bonn, 2010
- [22] IINAS INTERNATIONALES INSTITUT FÜR NACHHALTIGKEITSANALYSEN UND -STRATEGIEN ; ÖKO-INSTITUT E. V. INSTITUT FÜR ANGEWANDTE ÖKOLOGIE E.V.: *Gemis*, 2014
- [23] 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
- [24] EUROPÄISCHE KOMMISSION: Mitteilung der Kommission zur praktischen Umsetzung des EU-Nachhaltigkeitskonzepts für Biokraftstoffe und flüssige Biobrennstoffe sowie zu den Berechnungsregeln für Biokraftstoffe (2010/C 160/02) vom 19.6.2010, 2010
- [25] EUROPÄISCHES PARLAMENT & EUROPÄISCHER RAT: *Richtlinie (EU) 2015/1513 des europäischen Parlaments und des Rates vom 9. September 2015 zur Änderung der Richtlinie 98/70/EG über die Qualität von Otto- und Dieselmotoren und zur Änderung der Richtlinie 2009/28/EG zur Förderung der Nutzung von Energie aus erneuerbaren Quellen*, 2015
- [26] JOINT RESEARCH CENTER (JRC): „Update on Data on pathways for RES Directive.XLS“ von der EU Kommission im November 2008 an verschiedene beteiligte Kreise versandte Arbeitsdatei, (2008)
- [27] EUROPÄISCHE KOMMISSION: Note on the conducting and verifying actual calculations of the GHG emission savings, 2015
- [28] 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

Legal notice

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

With support from



by decision of the
German Bundestag

Published by:

DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Torgauer Strasse 116
04347 Leipzig
Tel.: +49 (0)341 2434-112
Fax: +49 (0)341 2434-133
info@dbfz.de
www.dbfz.de

Management:

Prof. Dr. mont. Michael Nelles (Scientific Director)
Daniel Mayer (Administrative Director)

Images: Proof of copyright labelled on the image

Graphic design and typesetting: Steffen Kronberg

Translation: Lorri King

ISBN: 978-3-946629-11-5

© DBFZ, Leipzig 2016

Copyright: All rights reserved. No part of this brochure may be duplicated or distributed without the written consent of the publisher. This prohibition includes commercial duplication by copy, storage in electronic databases, and copying to CD-ROM.





