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Approaches for optimising the greenhouse gas balance of biodiesel produced from rapeseed

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INHALTSVERZEICHNIS

LIST OF ABBREVIATIONS USED

eq.	equivalent
CO_2	carbon dioxide
DBFZ	German Biomass Research Centre Deutsches Biomasse Forschungszentrum
EC	European Community
EU	European Union
GJ	Gigajoule
g	Gramme
IFEU	Institute for Energy and Environmental Research Heidelberg Institut für Energie- und Umweltforschung Heidelberg GmbH
JRC	Joint Research Centre
kg	Kilogramme
kWh	kilowatt hour
MJ	Megajoule
N	Nitrogen
RED	Renewable Energy Directive
t	tonne
GHG	greenhouse gas
UFOP	Union for the Promotion of Oil and Protein Plants Union zur Förderung von Oel- und Proteinpflanzen e.V.
BioKraft-NachV	Biofuel Sustainability Ordinance

SUMMARY

With the enactment of the EU Directive on the promotion of the use of energy from renewable sources (RES-D) and its enactment under German federal law in the form of the Biofuel Sustainability Ordinance (BioKraft-NachV), a number of binding sustainability criteria for the production and use of biofuels have been introduced. Amongst other criteria, the EU Directive as well as the German Ordinance includes specifications with regard to the reduction of greenhouse gases (GHG) by means of biofuel use. Meeting these reduction targets will in future be a mandatory condition for the recognition of a fuel as part of the national biofuel quota. It is specified, that when the Biofuel Sustainability Ordinance comes into force biofuels will initially have to demonstrate a reduction in GHG emissions of at least 35% in comparison to fossil fuels. In two subsequent stages this reduction target is to be raised to 50% (in the year 2017) and 60% (in the year 2018 for new installations starting their production from 2017). /1/, /2/

This required reduction in GHG emissions can, according to the ordinance specifications, be demonstrated by own calculations of the biofuel producer, the use of so-called default values, or by means of a combination of default values and own calculations. However, a look at the default values which are contained in Appendix V of the directive indicates that the sole application of the standard values will for most biofuels not be sufficient to achieve compliance with the subsequent GHG reduction targets of 50% and 60%. (cf. Fig. 1)

The default values are intended to represent a conservative average of GHG emissions from the production and use of the biofuel options which are displayed in Appendix V of the directive. However, this raises the question of the data basis on which the default values were calculated and what reduction in GHG emissions could theoretically be achieved with a process chain optimised in terms of its GHG account. This question is analysed by this study on the basis of the process chain for the production of biodiesel from rapeseed. For this purpose the background data for the calculation of the default values for biodiesel from rapeseed is analysed in a first step, together with a transparent explanation of the basic calculation process for determining the GHG emissions of a biofuel within the context of the EU directive. The next stage identifies the parameters of the individual stages of the process chain which make the most significant contribution to the overall GHG emissions of the Biodiesel process chain. Where possible these influence parameters are varied, in order to estimate, within the framework of a sensitivity analysis, the possible optimisation potential of the individual process stage. In the last step of the calculations the results of the individual process stages as well as the sensitivity analyses which have been implemented are compared for purposes of determining the resulting potential for cutting GHG emissions.

At the process level of biomass (rapeseed) production the main influencing factor on the overall results is the production and use of industrial (synthetic) nitrate fertilisers. The amount of GHG emissions resulting from the biomass conversion stages (production of rapeseed oil and biodiesel) is mainly influenced by the use of process heat and power and the process chemical methanol.

By varying the use of industrial (synthetic) nitrate fertilisers and the fuel used in the agricultural production process (from diesel to biodiesel) it is possible to reduce the level of GHG emissions originally calculated (represented by the default values for the agricultural production of rapeseed) from 29 to approx. 21 kg CO_2 Eq./GJ biodiesel. The sample calculations which have been carried out also show that GHG emissions at the two conversion levels are heavily dependent on the input required to generate the process heat. In the course of a sensitivity analysis the energy source for the process heat production was varied for the purpose of establishing the potential for improvement if an alternative, biogenic energy source is used. The result was that the emissions from the rapeseed oil production process were reduced from approx. 3 to approx. 1.5 kg CO_2 Eq./GJ biodiesel and from the biodiesel production process (refining + transesterification) from approx. 11 to approx. 6.4 kg CO_2 Eq./GJ biodiesel.

In the calculations for the transesterification process the potential for reducing GHG by using biomethanol as a process chemical was also investigated. However, this approach only led to a very slight reduction in GHG emissions.

In addition to the auxiliary and the power sources used for process energy supplies, the process input data in the various stages of rapeseed oil production and biodiesel production was varied. For this purpose the consumption data relating to both process stages (rapeseed oil production and biodiesel production) was adjusted to the level of facilities operating on the latest technology.

With GHG emission levels of approx. 28 kg CO_2 Eq./GJ biodiesel, the maximum theoretical optimisation potential for the sample process chain which was analysed represented an improvement of approx. 46 % compared to the corresponding default value. Furthermore, this result represent a GHG mitigation potential of approx. 67 % compared to the fossil reference value of 83.8 kg CO_2 Eq./GJ which is defined by the RES-D. It must be pointed out that the optimisation options which are analysed in this study are focused solely on a potential improvement of reducing the emission of GHG. Combining these calculations and approaches with an analysis of economic feasibility was not part of the scope of the study.

1 INTRODUCTION

1.1 Background and objective

The achievement of demanding, politically defined climate protection objectives requires, in addition to a general improvement in energy efficiency, intensive and effective use of the available potentials in the field of renewable energies. The frequently expressed political wish for greater use of these energy sources is reflected in a range of prescribed targets at the domestic and European level (for example in RES-D 2009/28/EC) /1/. Bioenergy is seen as one of these highly promising energy sources, but bioenergy and in particular fuels produced from biomass are currently the focus of heated political and social controversy. This debate is strongly focused on the environmental performance and the sustainability of a large scale bioenergy use. In this context, the environmental assessment of bioenergy and especially biofuels is becoming more and more relevant also in the framework of binding sustainability targets.

In connection with the implementation of a decarbonisation strategy at the European level it is to be expected that first those biofuels and other bioenergy options which show a relatively high potential for cutting GHG emissions (compared to their fossil reference) will be promoted by subsidies ahead of other biofuels and bioenergy options.

For the producers of biofuels it will, for the purpose of identifying and exploiting possible environmental optimisation potentials, be of decisive importance to know the main influencing factors to the GHG balance of there fuel. Since a competition between biofuels based on there GHG balance is expected to emerge in the future, this can help to increase the competitiveness of producers and an additional contribution can be made to the achievement of domestic and European fuel quotas and climate protection targets.

The aim of this study is to conduct a stepwise analysis of the saving potentials on GHG emissions for a representative process chain for the production of biodiesel by using a calculation methodology in line with the RES-D. Using the results of this analysis the main influencing factors for the principal stages in the process chain (i.e. biomass production, biomass transport, biomass conversion, biodiesel distribution) are then identified and described in summary form. /1/

As a final step possible optimisation potentials for improving the GHG account will be identified. This will be done in the form of sensitivity analyses, in which the main influencing factors which have been identified are looked at more closely on the basis of their input parameters. To the extent possible, these parameters will be appropriate substituted by alternatives offering a better GHG account. For auxiliary materials which cannot be simply substituted it also needs to be estimated to what extent their GHG account could be improved by various optimisation measures. These sensitivity calculations will be the basis to estimate the theoretical GHG mitigation potential of a fully optimized production chain for Biodiesel from domestically produced rapeseed.

1.2 Method for achiving the aim of the study

On the basis of the objective which has been described above the work on this study is divided into the following sections:

- definition of a representative process chain for the production of biodiesel from rapeseed, analysis of the RES-D rapeseed biodiesel background data;
- calculation of the resulting GHG mitigation potential of the defined biodiesel production process chain in accordance with the calculation procedure specified by the RES-D;
- Sensitivity calculations, identification and variation of the main influencing factors, estimation of the existing optimisation potential.

These three sub-stages are described below in the individual chapters of the study.

2 DEFINITION OF THE PROCESS CHAIN

Background and motivation for this study are formed by the current political framework conditions for biofuels including the introduction of binding specifications on the reduction of GHG emissions through the use of biofuels. The RES-D and the BioKraft-NachV are setting binding GHG mitigation targets for biofuels in comparison to the fossil reference. After implementation of the RES-D biofuels will initially need to demonstrate a reduction in GHG emissions of at least 35% compared to fossil fuel. During subsequent stages these savings targets are increased to 50% (in the year 2017) and to 60% (in the year 2018 for new installations from 2017). Compliance with these mandatory requirements has to be demonstrated by biofuel producers as a precondition for the inclusion of the fuel in the national biofuel quota. The RES-D and the BioKraft-NachV contain concrete specifications for the calculation of this GHG mitigation value /1/. In addition to the calculation methodology, both directives contain a number of aggregate and disaggregate default values for a range of biofuel options. These default values can be applied by the producers of biofuels in determining the relevant GHG mitigation potential of their fuel if they are unwilling or unable to make their own calculations. In accordance with the RES-D and the the German ordinance (BioKraft-NachV), the following three possibilities are accepted for determining the GHG mitigation potential of a biofuel process chain:

1. calculation of the GHG mitigation potential in accordance with the specified calculation method,
2. use of the aggregated default value for the biofuel path which is being analysed,
3. a combination of the producer's own calculations for individual elements of the process chain (e.g. biomass production) with the disaggregate default values for the rest of the process chain.

Since biofuel producers are free to always use the specific default value, in accordance with the existing regulation framework the application of this default value always represents the 'worst possible' GHG reduction value for a biofuel.

On the basis of this observation the objective of the first work package of this study is to identify and explain the background process chain that was used to calculate the default value for biodiesel from rapeseed. Furthermore, the background information of this process chain including flows of materials and energy will be displayed in detail. Fig. 1 shows an extract from the default values for different biofuels as specified in Annex V of the RES-D.

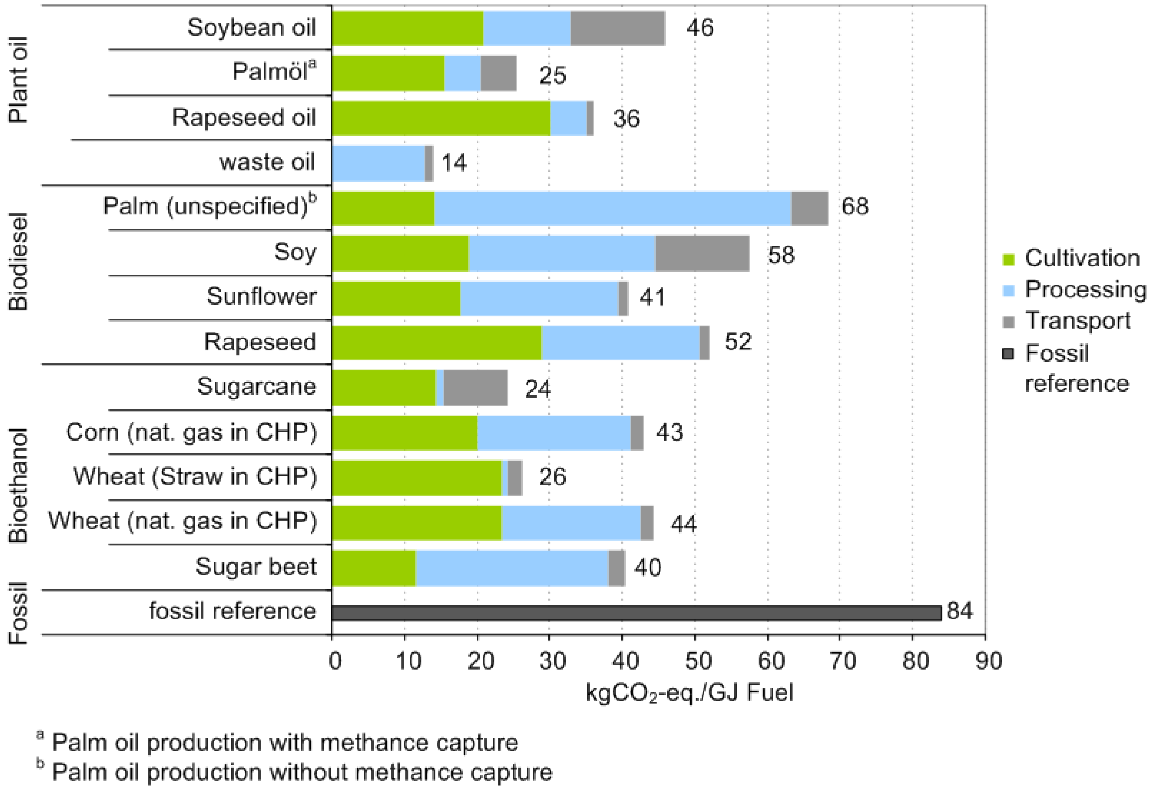


Fig. 1 selected default values taken from the RES-D /1/

With 52 kg CO_2 Eq./GJ biofuel the default value for biodiesel from rapeseed represents a GHG mitigation potential of approx. 38% compared to the fossil reference value of approx. 84 kg CO_2 Eq.. The aggregated default value for rapeseed biodiesel is formed by so called disaggregated default values which represent the process stages of (biomass) cultivation (approx. 29 kg CO_2 Eq./GJ fuel), (biomass) processing (approx. 22 kg CO_2 Eq./GJ fuel) and transport processes (approx. 1 kg CO_2 Eq./GJ fuel).

Another important factor fort he calcluation of GHG emissions from Biofuels are the system boundaries considered fort he calcuation. The methodology defined in the RES-D describes these system boundaries as "Well-to-Whell". This means that all process steps from the production of the biofuel feedstock, transport processes as well as the biofuel production process and biofuel distribution have to be included in the calculations. Fig. 2 provides am example of a "Well-to-Whell" biofuel process chain.

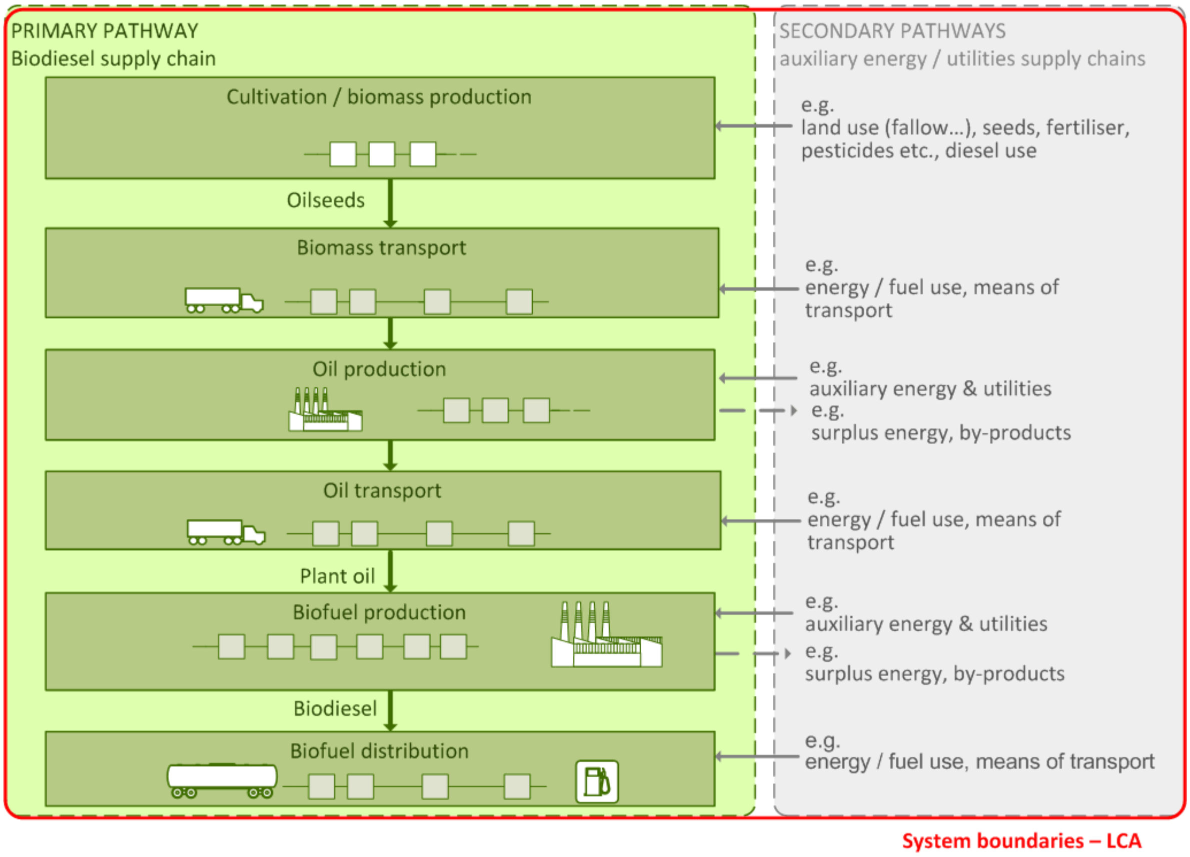
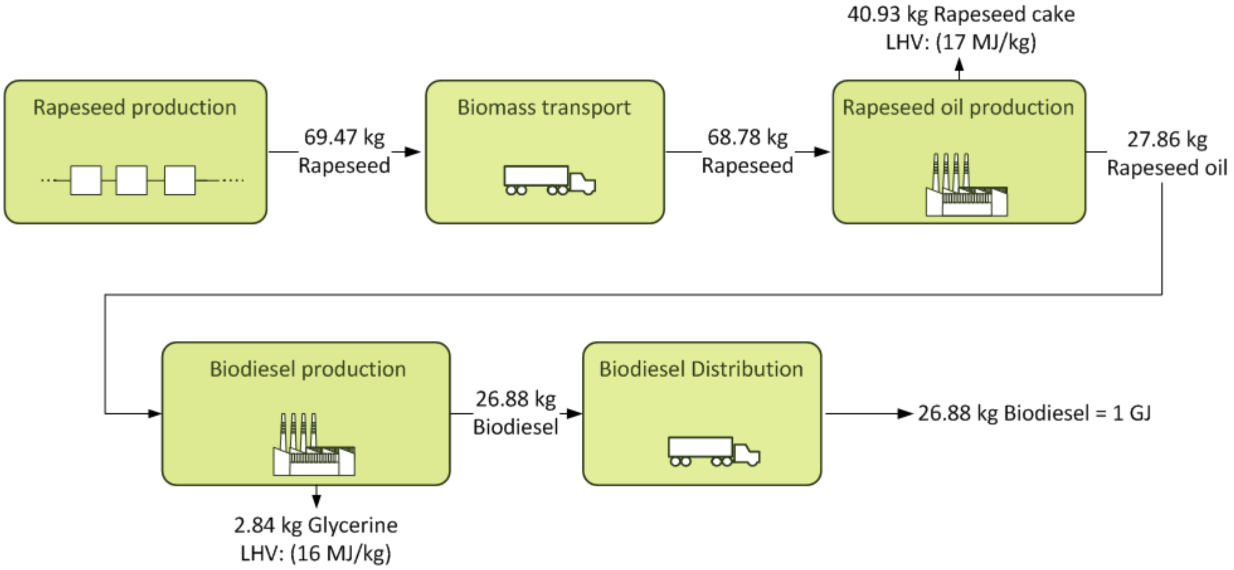


Fig. 2 An example for system boundaries for GHG analysis in line with RES-D calculation methodology

In the next step, background system and calculation of the default value for biodiesel from rapeseed are analyzed below in order to show the basic method for calculating the GHG account on the one hand, and on the other to provide a database for further stages of the study, i.e. the identification of possible optimisation potentials. For the most part this the data for this calculation is derived from the documents JRC 1 (/3/) and JRC 2 (/4/). These documents contain the basic assumptions background information and data that have been used in order to calculate the RES-D default values.

On the basis of these documents it is possible first to determine the mass flow behind the “default value process chain” for rapeseed biodiesel. This mass flow, including information according to produced by-products which need to be taken into account in the calculation, is shown in Fig. 3. The mass flow which is shown (including by-products) refers to 1 GJ of produced biodiesel. According to JRC 1 a lower heating value of 37.2 MJ/kg is assumed for the produced biodiesel.



© DBFZ 2009 based on JRC und EU RES-D default values

Fig. 3 Material flow for the production of 1 GJ rapeseed methyl ester as per /3/ and /4/

On the basis of this mass flow and the information derived from it (mass and calorific value) about produced by-products (rapeseed meal and glycerine) it is possible to conduct a reverse calculation in order to calculate “unallocated” GHG emission results for each step of the process chain. These values are needed to explain the GHG calculation methodology for each process step and to understand the influence of the individual parameter to the overall result. This reverse calculation is necessary since the aggregated and disaggregated default values contained in the directive represent allocated results. In this context 'allocated values' mean that the by-products which are produced in the individual stages of the process chain have already been included in the calculation. At the level of rape oil production, for example, this means that the emissions which have arisen up to this process and the emissions arising from the process itself (in this example these are emissions from rapeseed production, biomass transport and rapeseed oil production) are allocated to the two products which result from the oil production process (rapeseed oil and rapeseed cake). In accordance with the requirements of the RES-D this allocation is implemented on the basis of the lower heating values for these products.

In order to “recalculate” this allocation it first needs to be understood that the default values which are shown in Fig. 1 have been derived on the basis of so-called typical values. These typical values also appear in Appendix V of the RES-D. The typical values represent the results of the commissions GHG calculations for the presented biofuel options. Since the commissions wanted the default values to represent a conservative average of the GHG emissions from different biofuel pathways, typical values and default values differ at the processing level (biomass conversion). This difference represents an extra “charge” of an approx. 40% increase on the calculated typical value.

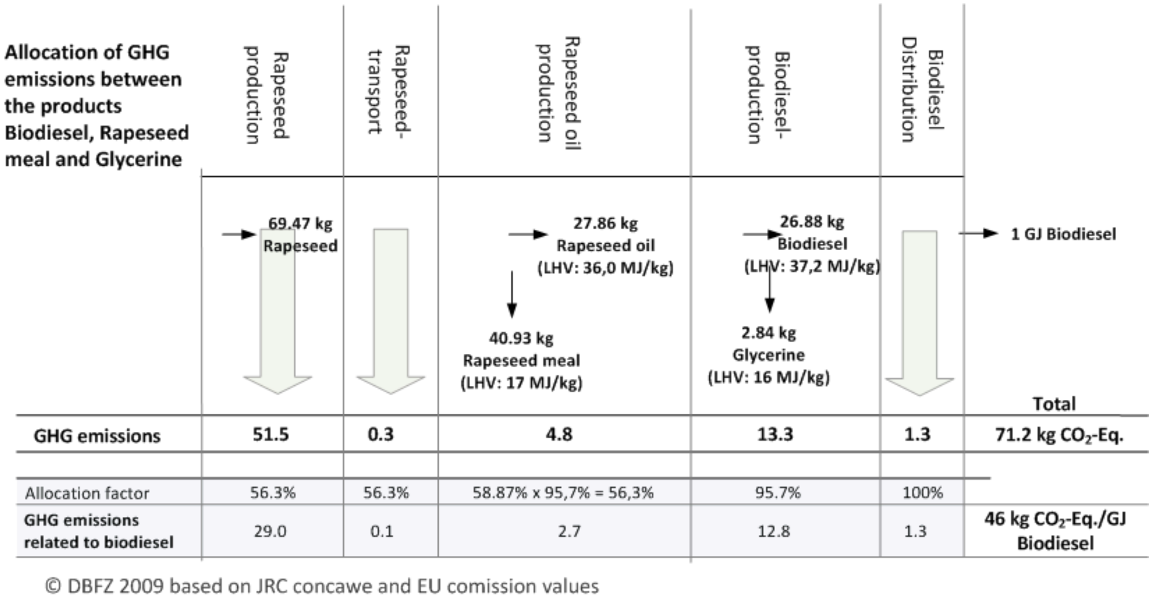
The numerical values of the disaggregated typical and default values for biodiesel from rapeseed are shown in Table 1.

Table. 1 Disaggregate default values for rapeseed methyl ester as per /1/

	Typical GHG emissions (gCO_2-Eq./MJ)	Default GHG emissions (gCO_2-Eq./MJ)
Cultivation	29	29
Processing	16	22
Transport	1	1

With the information available from the mass flow and the lower heating values of all products from the biodiesel product system it is now possible to recalculate the “unallocated” disaggregated typical values (s Fig. 2 and JRC 1) In addition, JRC 1 contains information which makes it possible to break down these disaggregate typical values further in terms of smaller elements in the process chain. For example, it contains typical values for the biomass transport and the two conversion stages.

The reverse calculation for the allocation approach and the calculation of non-allocated typical emission values for the individual elements of the process chain for the production of rapeseed biodiesel are displayed in Fig. 4. Here the lower row shows the typical emission values for biodiesel from rape taken from the RES-D and JRC 1.



	Rapeseed production	Rapeseed-transport	Rapeseed oil production	Biodiesel-production	Biodiesel Distribution	Total
GHG emissions	**51.5**	**0.3**	**4.8**	**13.3**	**1.3**	**71.2 kg CO_2-Eq.**
Allocation factor	56.3%	56.3%	58.87% x 95,7% = 56,3%	95.7%	100%	
GHG emissions related to biodiesel	29.0	0.1	2.7	12.8	1.3	**46 kg CO_2-Eq./GJ Biodiesel**

© DBFZ 2009 based on JRC concawe and EU comission values

Fig. 4 Calculating the allocation for the typical GHG emission value for biodiesel (German Biomass Research Centre (DBFZ); based on /3/ and /4/)

The row labelled 'allocation factors' indicates the factor with which the GHG emissions from the individual process (shown in the GHG emissions row) are allocated to the product biodiesel. This allocation factor is formed based on the lower heating values of the products produced in a process. In the case of the shown product system for the production of rapeseed biodiesel the products rapeseed oil, rapeseed meal as well as rapeseed methyl ester and glycerine are considered.

With the information from the two lower rows it is possible to calculate the emission values without allocation for the individual elements in the process chain, given in the upper row (GHG emissions). With the help of this value together with the assumptions and input parameters for the individual elements in the process chain contained in JRC 1, it is now possible to reproduce the calculations for the partial results for the processes of biomass cultivation, rapeseed oil production, biodiesel production and transport.

3 CALCULATION OF THE GHG MITIGATION POTENTIAL FOR THE SELECTED PROCESS CHAIN

In the next subchapters of this study we first look in detail at the process chain for the production of biodiesel from rapeseed which forms the basis for the calculation of the RES-D default value. The input parameters and assumptions for the individual elements of the process chain are outlined and on this basis the GHG emission value for the individual stage is calculated. After that possible optimisation options for each process stage are discussed and their possible influence on the results is assessed.

3.1 Calculation of GHG emissions for the rapeseed cultivation process

The following information about input parameters and assumptions can be obtained from JRC 1 for calculating the GHG emissions value of rapeseed production.

Table 2 Background data for calculating the disaggregate default value for rape cultivation /3

	Unit	Amount
Yield	t pro ha*a	3,1
Diesel use	kg pro ha*a	69,2
N-Fertiliser	kg pro ha*a	137,4
CaO-Fertiliser	kg pro ha*a	19,0
K_2O-Fertliser	kg pro ha*a	49,5
P_2O_5-Fertiliser	kg pro ha*a	33,7
Plant protecting agents	kg pro ha*a	1,2
Seed	kg pro ha*a	6
Electricity demand drying	kWh per t Rapeseed	22,6
Diesel for drying	MJ per t Rapeseed	4,8

Looking at these values, especially the rather the low input of nitrate fertilisers (for German circumstances) and secondly the relatively low rapeseed yield are noted. Literature values (e.g. KTBL 2008 /8/, IFEU 2007 /9/) and experiences for the rapeseed production in Germany would lead to the expectation of both higher fertilisation levels and higher yields.

The publications named above which are used to identify the input data and assumptions behind the RES-D default value do not indicate the emission factors with which the emissions resulting from the application of the input materials were calculated. In consequence emission factors from the literature, from the DBFZ project database and the Ecoinvent 2.0 database [/5/] were applied. The emission factors used are summarised in the following table.

Table 3 Emission factors for calculating the disaggregate default value for rapeseed cultivation [/5/], [/6/]

	Unit	Emission factor	Source
Diesel use	kg CO_2-Eq. per kg	3,8	IFEU Institut
N-Fertiliser	kg CO_2-Eq. per kg	7,0	DBFZ Database
CaO-Fertiliser	kg CO_2-Eq. per kg	0,3	DBFZ Database
K_2O-Fertliser	kg CO_2-Eq. per kg	0,5	DBFZ Database
P_2O_5-Fertiliser	kg CO_2-Eq. per kg	1,3	IFEU Institute
Plant protecting agents	kg CO_2-Eq. per kg	9,5	DBFZ Database
Seed	kg CO_2-Eq. per kg	1,9	Ecoinvent Database
Electricity demand drying	kg CO_2-Eq. per kWh	0,46	Ecoinvent Database
Diesel for drying	kg CO_2-Eq. per kg	3,8	IFEU Institute

For the calculating of the GHG emissions resulting from the process of rape production, the input parameters shown in Table 2 as well as the corresponding emission factors from Table 3 have been used. The resulting emissions for the cultivation process are shown in Fig. 5.

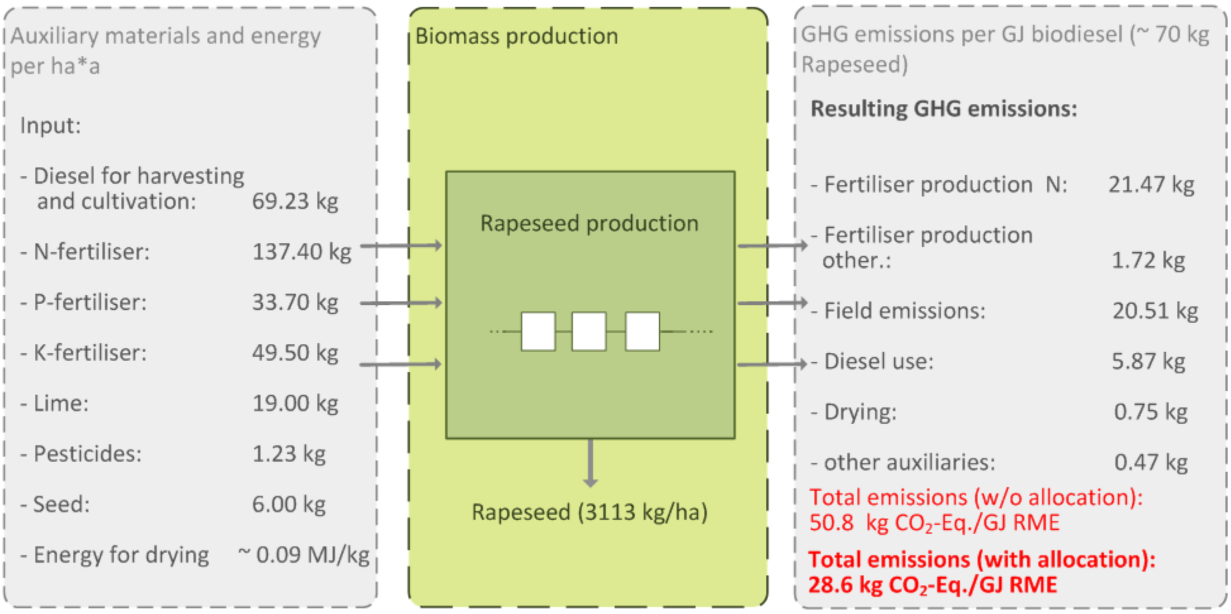


Fig. 5 Results of the GHG calculation for the rapeseed production process

The emissions resulting from the application of the input materials shown on the left-hand side are displayed on the right-hand side of the diagram.

Summing up the emissions resulting from the input of the individual parameters, the overall emissions from the rapeseed production process account for 50.8 kg CO_2 Eq./GJ biodiesel. In accordance with the method displayed in Fig. 4 this value has to be allocated between the main product of the process chain (biodiesel) and the by-products of the chain (rape meal, glycerine). According to this approach, the final emission value for the process of cultivating rapeseed for the biodiesel production is 28.6 kg CO_2 Eq./GJ biodiesel.

The data clearly shows the major influence which the use of nitrate fertiliser has on the overall emissions created by the cultivation process. Emissions are generated on the one hand by the production of the fertiliser and on the other by field emissions (mainly N2O) from the application of the fertiliser. The level of nitrous oxide emissions was calculated on the basis of IPCC 2006 (/10/), which indicates that 1% of the nitrate fertiliser is converted to N2O. For purposes of comparison these emissions were then calculated in terms of CO_2 Eq. using a characterisation factor of 296. It must be pointed out here that, depending on the particular crop, varying conversion rates are used for converting nitrate into nitrous oxide for the calculation of the default values contained in RES-D. According to JRC 1 the range here varies between 1% for maize via approx. 1.4% for rapeseed to approx. 1.8% for sugar beet cultivation /10/. The document does not provide any further details about the basis for this variance in nitrous oxide accounting in relation to the various crops.

3.1.1 Possibilities for reducing greenhouse gas emissions from rapeseed cultivation

Within the context of this study optimisation possibilities for the process of rapeseed cultivation are only to be looked at on the basis of the prescribed input parameters. This means that the optimisation of cultivation methods, varying the amount of fertilisers or varying the yield levels are not included in these investigations. Instead, possible savings on GHG are considered on the basis of the following two approaches:

- varying the fuel used in agricultural production
- varying the industrial (synthetic) nitrate fertilisers used.

The results shown in Fig. 6 demonstrate that the use of fossil diesel in the investigated rapeseed production process is responsible for approx. 12% of the overall emissions generated by this process. If biodiesel were to be used in this process instead of fossil fuel the emissions generated by fuel use of approx. 5.87 kg CO_2 Eq./GJ biodiesel could be reduced to approx. 3.44 kg CO_2 Eq./GJ biodiesel. For calculating the relevant GHG emissions resulting from the use of biodiesel, the default value for biodiesel from rape was used as the emission factor (this represents 52 kg CO_2 Eq./GJ compared to the emission factor for fossil diesel of 88.79 kg CO_2 Eq./GJ).

The production of industrial nitrate fertilisers is responsible for approx. 42% of the overall emissions generated by the rapeseed cultivation process. In addition the nitrous oxide emissions generated by the use of this volume of nitrates are responsible for approx. 40% of the overall emissions. If we look at the emissions arising from the production of industrial nitrate fertilisers it becomes clear that the level of these emissions varies considerably between different types of industrial nitrate fertiliser.

In the calculations which were made initially an emission factor from the DBFZ database of approx. 7 kg CO_2 Eq./kg N was used. This value represents an average for the different nitrate fertiliser used in Germany. In the literature, however, we find the spectrum ranging from approx. 2.7 kg CO_2 Eq./kg N (value for one kg N from ammonium sulphate in accordance with /5/) to approx. 15.9 N kg CO_2 Eq./kg N (value for one kg N from potassium nitrate in accordance with /5/). This range shows the considerable influence which the choice of fertiliser has on the results of the GHG account for the rapeseed cultivation. In order to establish the extent of possible GHG savings by the selection of an alternative nitrate fertiliser in the rapeseed cultivation process the use of urea as a fertiliser was applied as an alternative to the basic calculation. This option has the effect of reducing the emissions generated by nitrate production from approx. 21.47 kg CO_2 Eq./GJ biodiesel to approx. 10.17 kg CO_2 Eq./GJ biodiesel. Fig. 6 shows the results of the two options which have been discussed in graphic form, together with the overall result produced by combining them.

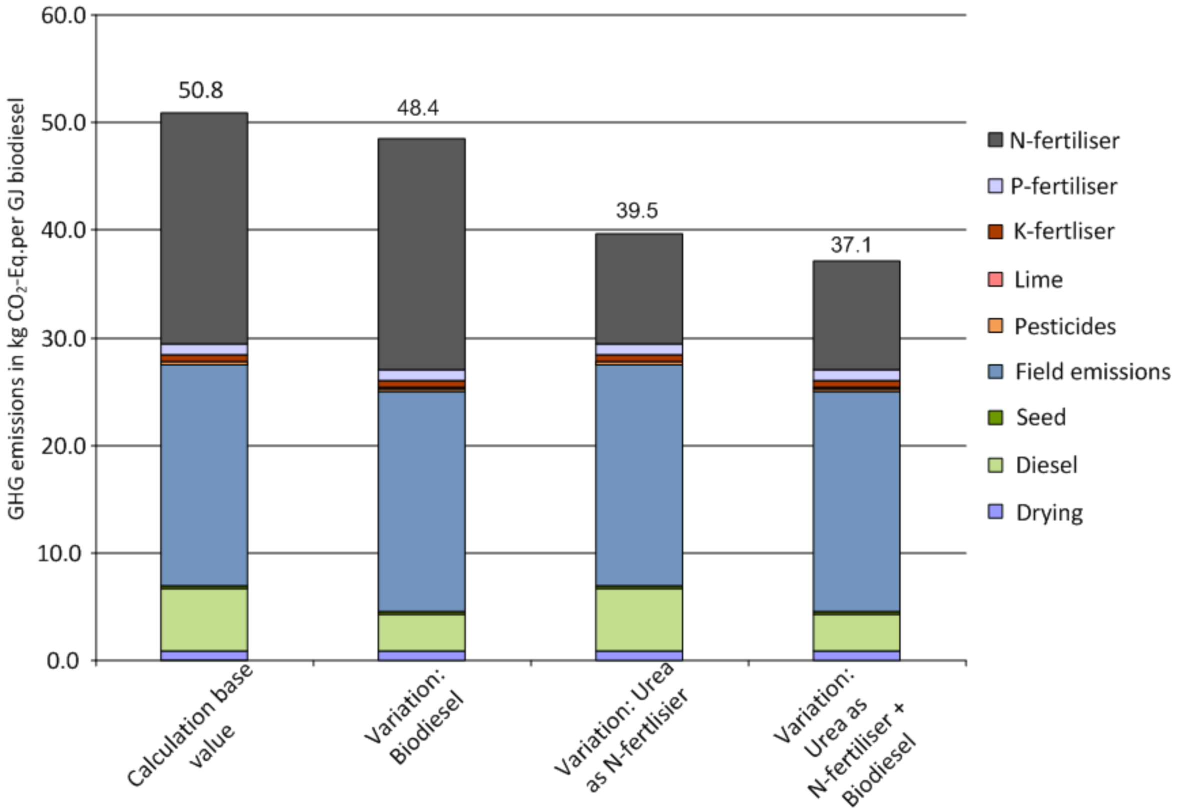


Fig. 6 Overall results of the GHG account for the rape cultivation process

Changing the fuel which is used from fossil diesel to biodiesel and using other sources of nitrates provides considerable potential for GHG reduction on the default value for the rape cultivation process. By varying these two parameters in the sample calculation, the emissions value was reduced by approx. 27 % from 50.8 kg CO_2 Eq./GJ biodiesel to approx. 37.1 kg CO_2 Eq./GJ biodiesel.

3.2 Calculation of the GHG emissions from the production of rapeseed oil

In the next step the GHG emissions generated by the production of rapeseed oil production for the investigated rapeseed biodiesel process chain are calculated. The calculation is implemented on a similar basis to that which was applied to the cultivation process. First the available information on input parameters and assumptions for the process of oil production are derived from JRC 1 and JRC 2. These parameters are shown in Table 4.

Table 4 Background data for the calculation of the disaggregate default value for the rapeseed oil production process /3/

	Unit	Amount
Electricity:	kWh per t Rapeseed	37,2
Natural gas:	MJ per t Rapeseed	644,4
Hexane:	kg per t Rapeseed	1,0
Rapeseed oil	kg per t Rapeseed	405,0
Rapeseed cake	kg per t Rapeseed	595,0

Similarly to the calculation which was made for the cultivation process, the input parameters for this stage of the process (show in Table 4) are also related to the relevant emission factors. These are displayed in Table 3. The resulting emissions for the process are displayed in Fig. 7.

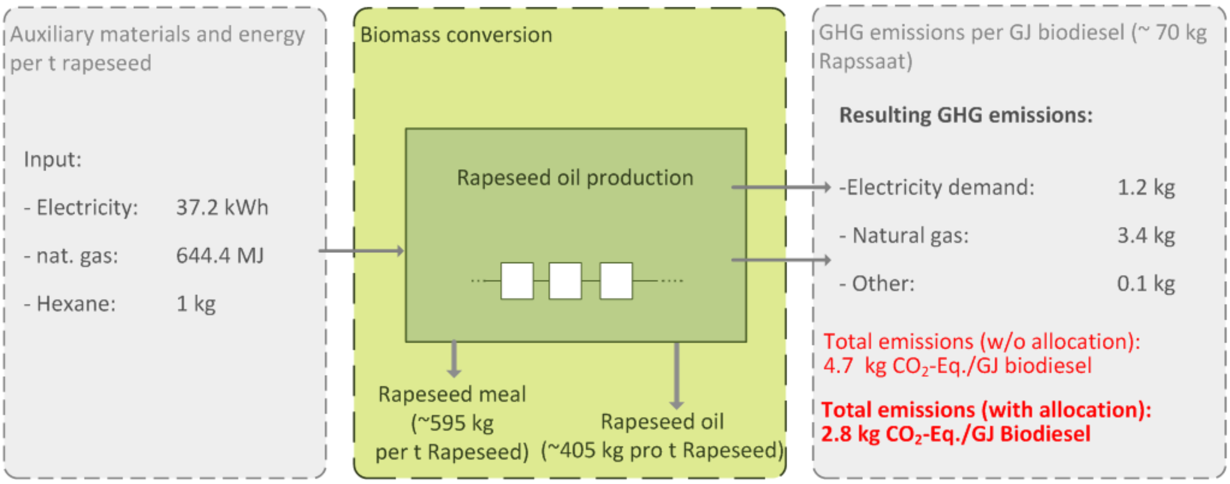


Abb. 7 Results of the GHG account for the rape oil production process

In this diagram, too, the process inputs are shown on the left-hand side, emissions which result from the application of these materials and energies are shown on the right-hand side. When added together the individual emissions provide an overall emission of 4.7 kg CO_2 Eq./GJ biodiesel. This overall result is again allocated between the product biodiesel and corresponding by-products. In accordance with the methodology shown in Fig. 4 this value is allocated between the main product of the process chain (biodiesel) and the by-products rapeseed cake and glycerine. After this allocation, the remaining emission value for the rapeseed oil production process is 2.8 kg CO_2 Eq./GJ biodiesel.

The relatively low emissions of this process (compared to the rapeseed cultivation process) are caused mainly by the demand for heat/steam and the related use of natural gas. Apart from the use of natural gas the electricity demand of the oil mill is responsible for the second-highest component of the overall emissions. The emissions resulting from the application of hexane at the oil mill play a minor role in the context of the overall emissions for the process.

3.2.1 Options for reducing the GHG emissions generated by rapeseed oil production

Similarly to the approach described in Section 3.1.1, the parameters with the biggest influence on the result for the rapeseed oil production process will be varied, followed by a display of the effects of these variations. For the rapeseed oil production process the following parameters were taken into consideration:

- varying the emission factor for the electricity supply by switching from the European electricity mix to the German electricity mix,
- varying the emission factor for the generation of steam,
- varying the basic consumption data in line with the consumption of an oil mill operating to the latest technological standards.

For the calculation of the RES-D default value for the rapeseed oil production process an emission factor for electricity consumption which represents the emissions generated by average electricity production in Europe is used. At approx. 460 g CO_2 Eq. per kWh this emission factor is considerably lower than the emission factor for German electricity, which according to /6/ is approx. 633 g CO_2 Eq. per kWh. If this parameter is varied the result of the GHG emissions calculated on the basis of the assumed electricity consumption of approx. 37.2 kWh per tonne of rapeseed (as input to the mill) and 95.2 kWh per tonne of biodiesel increases from approx. 1.2 kg CO_2 Eq. per GJ biodiesel (which corresponds to a quantity of approx. 70 kg) to approx. 1.6 kg CO_2 Eq. per GJ biodiesel.

At approx. 3.4 kg CO_2 Eq. per GJ biodiesel the generation of steam represents the biggest source of emissions in the oil production process. However, the emissions related to the provision of steam can be reduced by changing the energy source for generating this steam. The calculation of the default value for rapeseed biodiesel was based on steam generated by natural gas /3/. For the calculation of the emissions resulting from this use of natural gas an emission factor of approx. 0.078 kg CO_2 Eq. per MJ natural gas was applied. In order to assess the extent to which these emissions could be reduced by the application of steam provided by a biogenic source of energy, a sensitivity calculation was implemented for the generation of heat by a combined heat and power plant running on biogas. The emission factor for the emissions resulting from this source of heating were estimated at 0.019 kg CO_2 Eq. per MJ in accordance with [Ecoinvent 2.0]. By changing the energy source the emissions created by the generation of heat can be reduced from the original approx. 3.4 kg CO_2 Eq. per GJ biodiesel to approx. 0.8 kg CO_2 Eq. per GJ biodiesel.

As a last step, the consumption data on which the calculation is based were varied and replaced by the consumption data for a mill operating to the latest technological standards. The relevant consumption values are taken from information provided by a manufacturer /7/. The original consumption values and those applied in this sensitivity calculation are shown in Table 5.

Table. 5 Comparison of the consumption values of the oil mills applied in the original calculation /3/ and a facility operating to the latest technological standards /7/

	Unit	Consumption data Default-value per t Rapeseed	Consumption data „state of technology" per t Rapeseed
Electricity:	kWh per t Rapeseed	37,2	31,9
Natural gas:	MJ per t Rapeseed	644,4	387,9
Hexane:	kg per t Rapeseed	1,0	1

The main difference in the consumption data lies in the amount of heat demand, which in the case of the oil mill with the latest technology is much lower than the basic value. The results of these sensitivity calculations and the result of the prior variations in parameter are summarised in Fig. 8.

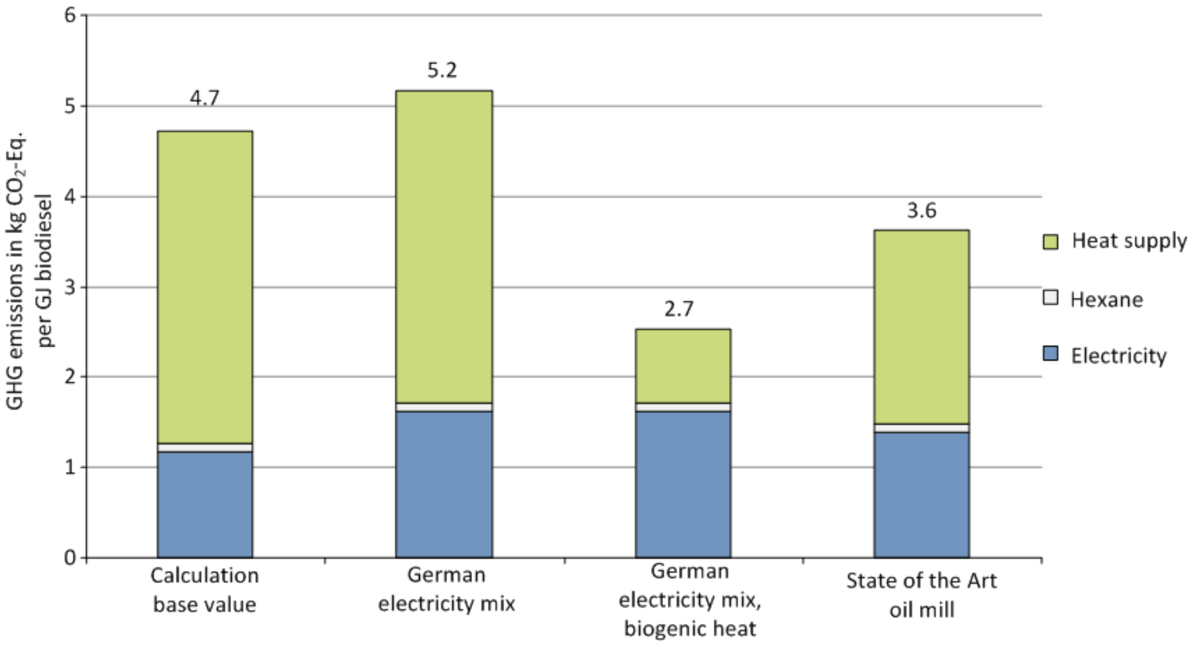


Fig. 8 Overall results of the GHG account for the rapeseed oil production process

The results of the parameter variations which were implemented are in part very different from the base value for the production of rapeseed oil which was calculated on the basis of the background data for the RES-D default value. The results once more show the major influence which is exerted on emission levels in the rapeseed oil production process by the generation of the required heat. By switching the energy source for the heating process from natural gas to biogas it proved possible to reduce the overall emissions for the rape oil production process from approx. 4.7 kg CO_2 Eq. per GJ biodiesel to 2.7 kg CO_2 Eq. per GJ biodiesel. The accounting process for an oil mill operating with the latest technology which was implemented as part of a sensitivity calculation also shows considerably lower GHG emission values at approx. 3.6 kg CO_2 Eq. per GJ biodiesel in comparison to the basic value. The reason for this is the mill's significantly lower demand for process heat (cf. Table 5).

The result of the sensitivity calculation clearly shows the optimisation potential of using an alternative energy source for the generation of heat in the rapeseed oil production stage.

3.3 Calculating greenhouse gas emissions for the production of biodiesel stage

After the calculations for the process stages of rapeseed cultivation and rapeseed oil production, the GHG emissions from the biodiesel production stage will be calculated as a next step. The method of calculation will be the same as that used for the previous process stages. For the calculations relating to this stage the calculations for refining the crude rapeseed oil and the subsequent transesterification process are summarised. For this purpose the information about input parameters and basic assumptions was initially extracted from the JRC 1 and JRC 2 documents for both sub-processes. These parameters are shown in Table 6.

Table 6 Background data for calculating the disaggregate default value for the biodiesel production process [/3/]

	Unit	Amount
Electricity:	kWh per t biodiesel	44,9
Natural gas:	MJ per t biodiesel	2940
H_3PO_4:	kg per t biodiesel	2
HCl:	kg per t biodiesel	20
Methanol:	kg per t biodiesel	109
NaOH:	kg per t biodiesel	7
Na_2CO_3:	kg per t biodiesel	2,5
Kaoline:	kg per t biodiesel	6
Glycerine:	kg per t biodiesel	105,7

In order to determine the emissions resulting from the biodiesel production process, the consumption values shown in Table 6 have to be related to the relevant emission factors. The JRC 1 and JRC 2 documents do not indicate the emission factors with which the emissions resulting from the application of the input materials were calculated. In consequence emission factors from the literature and from the DBFZ database and the Ecoinvent 2.0 database [/5/] were applied. The emission factors used are summarised in Table 7 below.

Tab. 7 Emission values for calculating the disaggregate default value for biodiesel production [/5/], [/6/]

	Unit	Emission factor	Source
Electricity Mix EU:	kg CO_2-Eq. per kWh	0,46	DBFZ Database
Electricity Mix Germany:	kg CO_2-Eq. per kWh	0,63	BLE guidance document
Heat production based on natural gas:	kg CO_2-Eq. per MJ	0,078	DBFZ Database
H_3PO_4:	kg CO_2-Eq. per kg	1,44	DBFZ Database
HCl:	kg CO_2-Eq. per kg	0,35	BLE guidance document
Methanol:	kg CO_2-Eq. per kg	1,25	BLE guidance document
NaOH:	kg CO_2-Eq. per kg	1,12	BLE guidance document
Na_2CO_3:	kg CO_2-Eq. per kg	0,4	DBFZ Database
Kaoline:	kg CO_2-Eq. per kg	0,2	Ecoinvent Datenbank

On the basis of the indicated emission factors and consumption data, the GHG emissions are calculated below for the sub-processes of refining and transesterification. The overall emissions calculated on this basis for the biodiesel production process (refining + transesterification) are shown in Fig. 9 below.

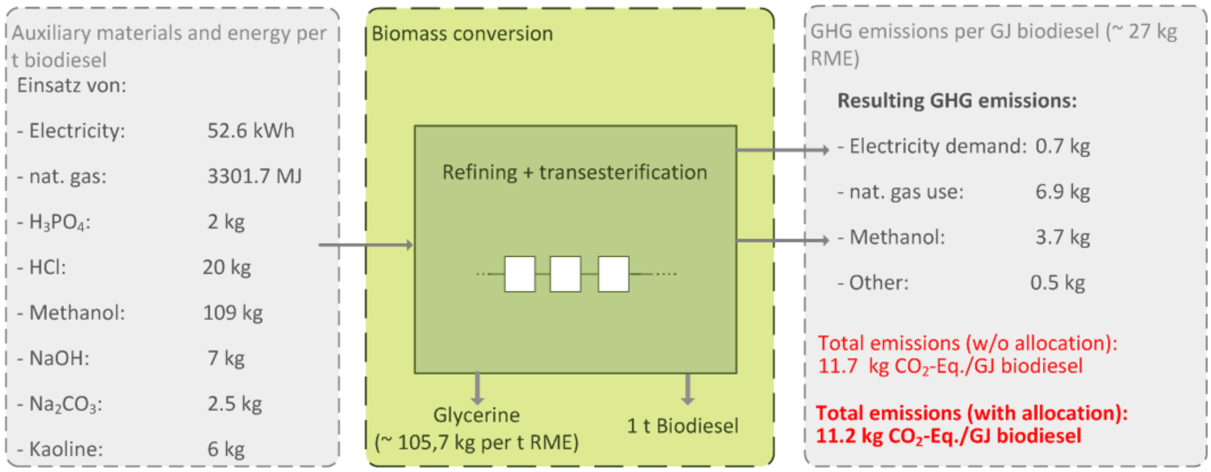


Fig. 9 Results of the GHG account for the biodiesel production process

Similarly to Figs. 5 and 7 the right-hand side of Fig. 9 shows the emissions which are produced on the basis of the application of the input materials shown on the left-hand side. Adding up these individual emissions gives a total emission of 11.7 kg CO_2 Eq./GJ biodiesel.

In line with the methodology described in Fig. 4 this value is allocated between the main product of the process chain (biodiesel) and the by-product of this process (glycerine). After the allocation the emission value for the biodiesel production process amounts to 11.2 kg CO_2 Eq./GJ biodiesel.

The diagram shows clearly that in the biodiesel production stage the generation of heat accounts for the major part (approx. 59%) of the overall emissions which are generated. At approx. 32 % the provision of the methanol which is required for the transesterification process also accounts for a considerable part of the overall emissions generated by the biodiesel production process.

3.3.1 Possibilities for reducing greenhouse gas emissions in the production of biodiesel n

For the biodiesel production process, i.e. in concrete terms for the sub-process of transesterification, a number of options which may be suited to reduce the emissions generated by the transesterification process are discussed below. The following options and their specific impact on the GHG emissions generated by the transesterification process are looked at:

- changing the methanol which is used from conventional methanol to methanol produced on the basis of biogenic raw materials,
- varying the emission factor for the generation of steam,
- comparing the basic consumption data with a sample account for a biodiesel facility operating with the latest technology.

In accounting for the GHG emissions from the biodiesel production process in Germany the emission factor for the German electricity mix is used in the calculation. However, the EU default value is based on an emission factor derived from the European electricity mix. Accordingly the effect of varying this emission factor on the overall results will be looked at first. At approx. 460 g CO_2 Eq. per kWh the emission factor for the European electricity mix is much lower than the emission factor for German electricity, which according to /6/ is approx. 633 g CO_2 Eq. per kWh. By varying the emission factor the results for the calculated GHG emissions on the assumed electricity consumption can be increased from approx. 0.7 kg CO_2 Eq. per GJ biodiesel to approx. 0.9 kg CO_2 Eq. per GJ biodiesel.

In addition to the generation of steam, the biggest influence on GHG emissions generated by the production of biodiesel is the production of the methanol which is required for the transesterification process. The calculation of the emissions resulting from the use of methanol applies an emission factor taken from the guidelines published by the Federal Department of Agriculture and Food (BLE). What is noticeable here is that at approx. 1.25 kg CO_2 Eq. per kg methanol this emission value is considerably higher than the emission factors which are found in the literature (e.g.: 0.77 kg CO_2 Eq. per kg methanol in /5/). In order to analyse the emission factor for methanol more closely and then assess how the emission factor for methanol production could be changed by an alternative form of production on the basis of biogenic raw materials, the DBFZ carried out, parallel to this study, a short environmental evaluation of various methanol production paths (cf. /11/). This evaluation established GHG emissions of approx. 560 g CO_2 Eq. per kg biomethanol for a biomethanol path on the basis of synthetic gas from forestry logging waste. This path was the most environmentally favourable of the various sources which were analysed./11/

If the GHG account for the transesterification processes is now based on the use of this biomethanol and if the emission factor in the accounting process is adapted accordingly, the emissions from the use of methanol could be reduced from approx. 3.7 kg CO_2 Eq. per GJ biodiesel to approx. 1.6 kg CO_2 Eq. per GJ biodiesel. If the emission factors for electricity from the German electricity mix and the use of biomethanol are both taken into account, the GHG account results in emissions of approx. 9.9 kg CO_2 Eq. per GJ biodiesel, compared to approx. 12 kg CO_2 Eq. per biodiesel where the calculation is made on the basis of conventional methanol.

As a third option for reducing GHG emissions from the biodiesel process, the generation of heat in the account is based on biogas, similarly to the procedure used in the rapeseed oil production process. For this purpose the relevant emission factor for the generation of heat from natural gas (approx. 0.078 kg CO_2 Eq. per MJ natural gas) is replaced in the calculation by an emission factor for heat generation on the basis of biogas (approx. 0.019 kg CO_2 Eq. per MJ). Both emission factors are taken from the Ecoinvent [5] database. In combination with the emission factor for the German electricity mix the use of this biogenic heat generation source results in overall emissions of approx. 6.7 kg CO_2 Eq. per GJ biodiesel.

In the final stage of the calculations for the biodiesel process the consumption data on which the default values are based were, similarly to the analysis at the rapeseed oil production stage, varied and replaced by the consumption data for a biodiesel facility operating with the latest technology. In this case, however, only the consumption values for electricity and heat were varied. The corresponding consumption values are taken from DBFZ data. In order to display the differences in the consumption values once more, the original consumption values and those used within the context of the sensitivity analysis are contrasted in Table 8.

Tab. 8 *Comparison of the consumption values for the biodiesel plant included in the original account in accordance with /3/ and a facility using the latest technology (DBFZ data)*

	Unit	Consumption data Default-value per t Rapeseed	Consumption data „state of technology“ per t Rapeseed
Electricity:	kWh per t Biodiesel	52,6	46,4
Natural gas:	MJ per t Biodiesel	3.301,7	1705,7
H_3PO_4:	kg per t Biodiesel	2	2
HCl:	kg per t Biodiesel	20	20
Methanol:	kg per t Biodiesel	109	109
NaOH:	kg per t Biodiesel	2,5	2,5
Kaoline:	kg per t Biodiesel	6	6
Hexane:	kg per t Biodiesel	1,0	1,0

The consumption data once more differs mainly in terms of demand for process heat, which in the case of a facility operating with the latest technology are much lower than the base value.

The results of the sensitivity calculations are displayed in Fig. 10 below, together with the results of the prior parameter variations and a combination of varying the emission factor for the German electricity mix, biogenic heat generation and the use of biomethanol.

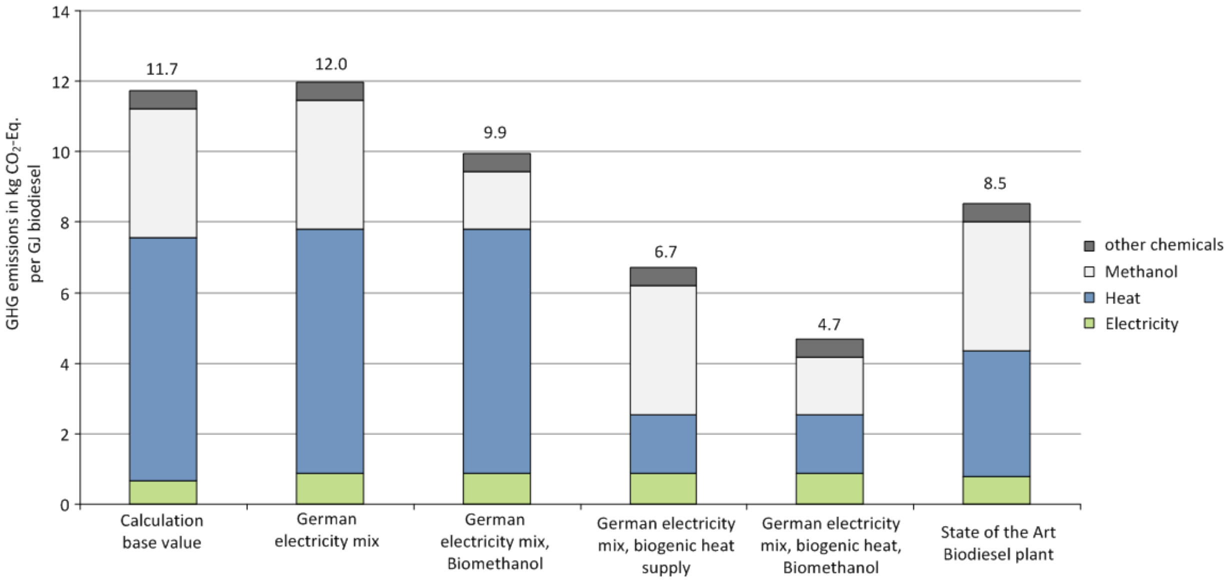


Fig. 10 Overall results of the GHG account for the biodiesel production process

The results of the parameter variations indicate considerable potential for reducing GHG at the biodiesel production stage. For example, modification of the energy consumption values in biodiesel production leads to a cut in emissions of approx. 28% on the base value. In the scenario providing the highest reduction in GHG it proved possible to cut overall emissions from approx. 11.7 kg CO_2 Eq. per GJ biodiesel for the base value to approx. 4.7 kg CO_2 Eq. per GJ biodiesel. This represents a reduction of approx. 60 % on the base value.

3.4 Calculating the greenhouse gas emissions generated by the transport processes

As a final stage the individual transport processes which form the basis for the corresponding default value in the EU directive will be investigated. As the overall default value for all transport processes is very low at 1 kg CO_2 Eq. per GJ biodiesel, no detailed optimisation options will be discussed for this stage of the process chain. However, an estimate was made of the extent to which the emissions in the individual transport stages could be lowered by the use of biodiesel as transport fuel. For this estimate an emission factor based on the default value for biodiesel from rape (52 kg CO_2 Eq. per GJ biodiesel) was used.

In drawing up the account for the disaggregate default value of the transport operations the processes shown in Table 9 were analysed in combination. The emissions resulting from the specific transport process together with the extent of possible GHG savings by the use of biodiesel are also shown in the table. The filling operations describe the input involved in filling the vehicles with fuel.

Table 9 GHG emissions for the individual transport processes in the rapeseed methyl ester process chain according to /3/

Prozess	Transport-distance	Base value (w/o allocation) in kg CO_2-Eq/GJ Biodisel	Variation: Use of Biodiesel
Biomassetransport	50 km	0,31	0,19
Distribution	150 km	0,82	0,51
Aufwendungen Tankstelle	-	0,44	-

The processes which are grouped under the collective term of 'transport operations' are responsible for GHG emissions amounting to 1.57 kg CO_2 Eq./GJ rapeseed methyl ester (without allocation). Through the use of biodiesel as process fuel these emissions can be reduced to approx. 1.14 kg CO_2 Eq./GJ biodiesel. However, as the default value for transport operations amounts to 1 kg CO_2 Eq. after allocation, when rounded off the minor savings provided by the use of biodiesel are hardly relevant.

3.5 Summarising the results of the calculations

In order to analyse more precisely the overall potential for GHG savings within the process chain and the influence of the suggested parameter variations, the results of the individual partial stages of the process chain for the production of biodiesel on the basis of rapeseed are collated. The results of the calculation together with the GHG reductions within the process chain and the parameter variations are displayed in Fig. 11 below.

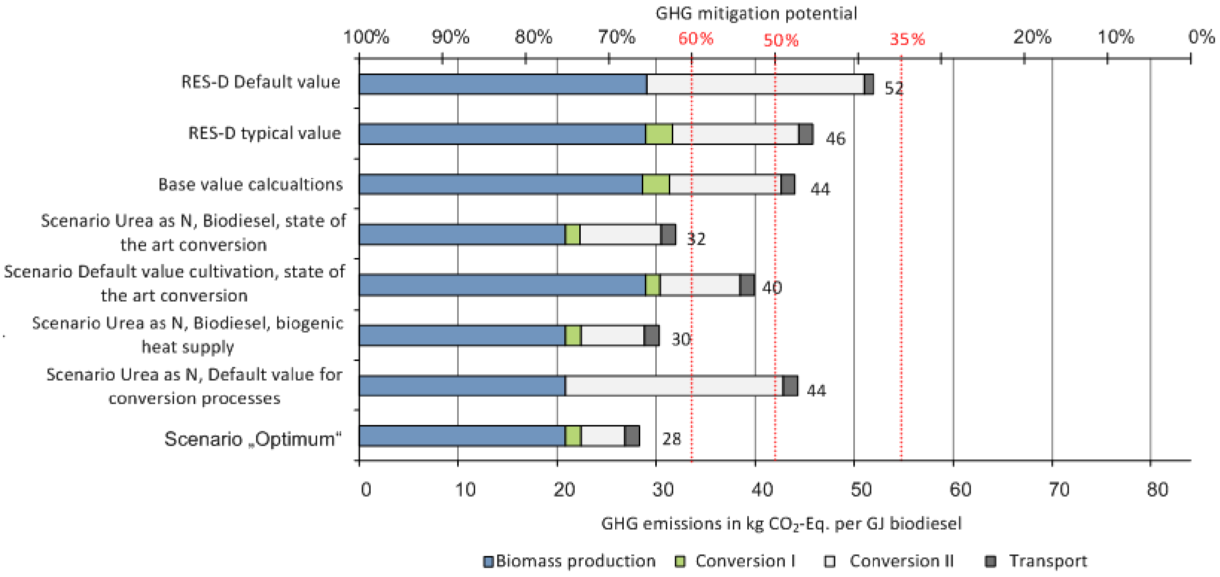


Fig. 11 Overall results of the GHG account for the entire rapeseed biodiesel process chain

The illustration first shows (arranged from top to bottom) the default value once more, together with the so-called 'typical emissions value' for biodiesel from rapeseed contained in RES-D.

Below these two values we see the base value which has been reproduced and represents the basis for our calculations. This value forms the basis for all variations and all options for the possible optimisation of the overall results which are displayed in the bars below this value. Directly below the base value we see the results of a calculation in which the various optimisation options for the rapeseed cultivation stage (varying the nitrate fertiliser, use of biodiesel as fuel) are combined with a calculation for the conversion stage on the basis of consumption data relating to the use of the latest technology. At approx. 32 kg CO_2 Eq./GJ biodiesel the result of this calculation indicates a potential for GHG reductions of approx. 62 %. Below this value there is an analysis in which the same approach at the conversion stage (calculating the GHG emissions on the basis of consumption values for the latest technology) is combined with the default value for the rapeseed cultivation stage. This option takes into account the fact that, in accordance with the specifications of the RES-D, individual reductions in GHG can also be calculated on the basis of a combination of disaggregate default values (e.g. for rapeseed cultivation) with actual calculations for the individual elements in the process chain. At approx. 40 kg CO_2 Eq./GJ biodiesel the result of this approach provides a reduction in GHG of approx. 52 % compared to the fossil reference value contained in the EU directive.

In the next analysis (referred to as "Scenario urea as N; biodiesel; biogenic heat") the optimisation approach for the rapeseed production stage which has already been discussed was combined with an analysis in which the heat demand for the two conversion stages (i.e. oil mill and production of biodiesel) was supplied on the basis of biogenic energy resources. In calculating the default value (and the base value) the generation of the necessary heat accounted in each case for the largest proportion of the emissions for both conversion stages. This approach therefore offers significant potential for savings on GHG. Overall the combination of these two parameter variations (alternative nitrate fertilisers and fuel during cultivation + alternative generation of heat for both conversion stages) provides an overall emission of 44 kg CO_2 Eq./GJ rapeseed methyl ester, which means a reduction in GHG of approx. 47 %.

Finally, the last bar shows the most promising optimisation approach for the individual elements in the process chain in combination. In addition to the options for the rapeseed cultivation stage, which have already been discussed (alternative nitrate fertiliser and fuel), an alternative heat source is assumed for both conversion stages. In addition, the use of biomethanol was analysed in the accounting of GHG emissions arising from the process of transesterification and the resulting GHG savings were included in the account. Overall the combination of these optimisation options results in a total emission of 28 kg CO_2 Eq./GJ biodiesel, which represents a reduction in GHG of 67% on the fossil reference value.

4 CONCLUSIONS AND DERIVATION OF RECOMMENDATIONS FOR ACTION

The aim of this study was in the first instance to analyse the calculation of the default value for biodiesel from rapeseed as contained in RES-D and, on the basis of this analysis, to identify possible ways of optimising the account. The calculation of the default value and the display of the assumptions on which this value is based (e.g. What assumptions were made with regard to fertiliser requirements at the rape cultivation stage? On what consumption data was the rapeseed oil production account based, etc.) was possible with the assumptions and information published in the JRC 1 and JRC 2 documents. With the aid of secondary literature, the DBFZ database and the Ecoinvent database it was then possible to reproduce the individual part calculations for the so-called disaggregate default values. For this purpose, the background values identified (from JRC 1 and JRC 2) were, at each stage of the process chain, collated with corresponding emission factors (e.g. from Ecoinvent).

In the cultivation process the production and use (field emissions) of industrial nitrate fertilisers proved to be the main influencing parameters for the overall results, while at the biomass conversion stages it was the use of heat, electricity and methanol which exerted the main influence on the process.

Varying the industrial nitrate fertilisers and the fuel used for the agricultural production indicated considerable improvement potential, in which it was possible to reduce the overall emissions from rapeseed cultivation from 29 to approx. 21 kg CO_2 Eq./GJ biodiesel. At this stage it must be pointed out that the optimisation results which were calculated do not represent a hard and fast figure but merely serve to illustrate the extent of the existing potential.

The GHG emissions of the two conversion stages are dominated primarily by the input required to generate the process heat. In the course of a sensitivity calculation the possible improvement in the results by the use of an alternative, biogenic source of energy was analysed. This analysis indicated that the emissions from the rapeseed oil production process could be reduced from approx. 3 to approx. 1.5 kg CO_2 Eq./GJ biodiesel and from the biodiesel production process (refining + transesterification) from approx. 11 to approx. 6.4 kg CO_2 Eq./GJ biodiesel. The calculation of both values also includes the GHG emissions resulting from the use of electricity from the German electricity mix, which indicates a relatively high emission factor compared to the European electricity mix. For the transesterification stage, the GHG savings potential derived from the use of biomethanol was also included. This option shows a relatively moderate improvement in the results from approx. 11 kg CO_2 Eq./GJ biodiesel as the base value to approx. 9.5 kg CO_2 Eq./GJ biodiesel.

With GHG emission levels of approx. 28 kg CO_2 Eq./GJ biodiesel, the maximum theoretical optimisation potential which was identified by the sensitivity analyses represent an improvement of approx. 46 % on the default value for rapeseed biodiesel and approx. 67 % on the reference fossil fuel value of 83.8 kg CO_2 Eq./GJ which is defined by the RES-D.

The optimisation options which are analysed in this study are focused on a potential improvement in the GHG account. Combining these calculations with an analysis of economic feasibility was not part of the scope of the study. The possibilities for optimising the GHG account which have been identified now need to be brought into line with economic realities in order to make a closer analysis of the viability of the individual options and their impact on fuel production costs. In addition, the optimisation options which have been suggested for the rapeseed cultivation stage will need to be refined on the basis of field trials. This study clearly shows the influence of the use of industrial fertilisers and the wide variations in the emission factors related to individual nitrate fertilisers. As a result this study could provide an initial basis for the modification of fertiliser use strategies with the aim of developing GHG- optimised rapeseed cultivation.

ABBILDUNGSVERZEICHNIS

TABELLENVERZEICHNIS

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