European
Commission

Improving the Sustainability of Fatty Acid Methyl Esters (FAME – Biodiesel)

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In collaboration with

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For quality of life

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Abstract

The life cycle based greenhouse gas (GHG) balances of Fatty Acid Methyl Esters (FAME also called "Biodiesel") from various resources have been set in the Renewable Energy Directive (RED). Due to technology and scientific progress there are various options to improve the GHG balances of FAME. This Supporting Action assesses 10 such options:

1) "Biomethanol": Substitution of fossil methanol with biomethanol for the production of FAME;
2) "Bioethanol": Substitution of fossil methanol with bioethanol for the production of FAEE (Fatty Acid Ethyl Esters);
3) "CHP residues": Use of residues and co-products from the production of FAME in a combined heat and power (CHP) facility to provide power and/or heat;
4) "New plant species": Examination of new plants for vegetable oils, that could increase the biomass weight without any detrimental effect on the oil seed;
5) "Bioplastics and biochemicals": Production of bioplastics and biochemicals from the biomass or process residues;
6) "Advanced agriculture": Advanced agricultural practices in terms of N_2O emissions and soil carbon accumulation at resource cultivation;
7) "Organic residues": Use of organic versus mineral fertilizer for feedstock cultivation;
8) "FAME as fuel": Use of FAME in machinery for cultivation, transportation and distribution;
9) "Retrofitting multi feedstock": Retrofitting of single feedstock plants for blending fatty residues, and
10) "Green electricity": Use of renewable electricity produced in a PV plant on site.

The assessment approach started with the GHG standard values of the RED and the corresponding background data documented in BioGrace. For the most relevant FAME production possibilities in Europe, characterized by the

- feedstock (rapeseed, sunflower, palm oil, soybean, used cooking oil, animal fat) and
- FAME production capacity (50 - 200 kt/a),

the technical and economic data of "Best Available Technology in 2015" (BAT 2015) were used as starting point to assess the improvement options. Based on the calculation of GHG emissions (g CO_2-eq/MJ) and production cost (€/t_{FAME}) an overall assessment of the options was made and summarized in "Fact Sheets". The draft final results were reviewed in a stakeholder workshop.

The following results of the assessment were obtained: A significant GHG reduction compared to the RED values in processing is possible, if best available technology (BAT) is applied. The GHG emissions of cultivation compared to RED are higher due to improved data on the correlation between fertilizer input and yields. The assessed GHG improvements options show that the potential to reduce emissions is relatively large in agriculture cultivation, but a relatively low in processing.

The production cost analysis shows that revenues from co-produced animal feed and oil yield per hectare have a strong influence on total production costs, e.g. mainly animal feed from soybeans. The total FAME production cost of BAT are 280 – 1,000 €/t_{FAME}, including revenues from co-products. Cost ranges arise due to different feedstock and capacities. The greenhouse gas analysis of the improvement options results in a GHG reduction potential of 0 - 37 g CO_2-eq/MJ compared to BAT.

The greenhouse gas mitigation costs of improvement options range between -260 and +1,000 €/t CO_2-eq. Options with negative greenhouse gas mitigation costs generate economic benefits compared to the base case.

Feasible short term improvement options (2016) are

- "CHP residues";
- "FAME as fuel";
- "Retrofitting multi feedstock"; and
- "Biochemicals (Pharmaglycerol 99.5+)".

Feasible medium term improvement options (< 2020) are

- "Green electricity from PV plant on site";
- "Biomethanol";
- "Advanced agriculture"; and
- "Organic fertilizer".

Longer term improvement options (> 2020) are

- "New plant species"; and
- "Bioethanol (instead of methanol for FAME production)".

Summing up the assessment one can conclude that the future FAME production has several options to further improve its GHG balance thus contributing substantially to a more sustainable transportation sector.

Executive summary

Goal and scope

The Commission set the following general objective for the Supporting Action:

"The Green House Gas (GHG) balances of Biodiesel from various resources have been set in Annex V of the RED. However due to technology and scientific progress it seems technically feasible that there are several ways to improve the GHG balances of Biodiesel. In this context, this Supporting Action aims at analysing the various options available in improving the GHG balance of Biodiesel from various resources."

Based on this objective the project assessed 10 options to improve the GHG balance of FAME by using the GHG calculation method of the RED. These options are:

1. "Biomethanol": Substitution of fossil methanol with biomethanol for the production of FAME (Fatty Acid Methyl Esters);
2. "Bioethanol": Substitution of fossil methanol with bioethanol for the production of FAEE (Fatty Acid Ethyl Esters);
3. "CHP residues": Use of residues and co-products from the production of FAME in a combined heat and power (CHP) facility to provide power and/or heat;
4. "New plant species": Examination of the species of the plants used for vegetable oils, that could increase the biomass weight without any detrimental effect on the oil seed;
5. "Bioplastics and -chemicals": Production of bioplastics and biochemicals from biomass or process residues;
6. "Advanced agriculture": Advanced agricultural practices in terms of N_2O emissions and soil carbon accumulation at resource cultivation;
7. "Organic residues": Use of organic fertilizer for feedstock cultivation versus mineral fertilizer;
8. "FAME as fuel": Use of FAME in machinery for cultivation, transportation and distribution;
9. "Retrofitting multi feedstock": Retrofitting of single feedstock plants for blending fatty residues, and
10. "Green electricity": Use of renewable electricity produced in a PV plant on site

Approach

The study used the following approach (Figure 1): The starting point of the approach was the GHG standard values as documented in the Directive on the promotion of renewable energy sources (RED, 2009) and the corresponding background data documented in BioGrace GHG calculation tool (BioGrace, 2014). Based on this information, the 14 most relevant FAME production possibilities in Europe were identified, mainly characterized by

- the type of feedstock (rape, sunflower, palm oil, soybean, used cooking oil, animal fat) and
- the FAME production capacity (50 kt/a, 100 kt/a, 200 kt/a).

These "base cases" were described with their technical and economic data based on the "Best Available Technology in 2015" (BAT 2015). Also the different options to improve the GHG balance of FAME were specified in detail. Technical and economic data were collected. All relevant data (GHG standard values, data on base cases and options) were documented in a database. The structure of the database contains all technical and economic data necessary to calculate the GHG emissions according to RED methodology in g CO_2-eq/MJ and cost production cost in €/t_{FAME}. The GHG analysis according to RED methodology and cost analysis for cost indications were done for the base cases and the improvement options. Finally an overall assessment and comparison of the improvement options (SWOT analysis, ranking of options, comparison to base cases) was made and conclusions were drawn. The main results of the assessment on the most promising options to improve the GHG balance of FAME were summarized in compact "Fact Sheets" including key characteristics, facts, figures and recommendations. The draft final results were presented and discussed in a workshop (November 13, 2015 in Vienna/Austria) with selected experts and stakeholders from governmental, industrial, agricultural and scientific institutions to discuss and review the findings. The outcome of this workshop was used to finalize the results.

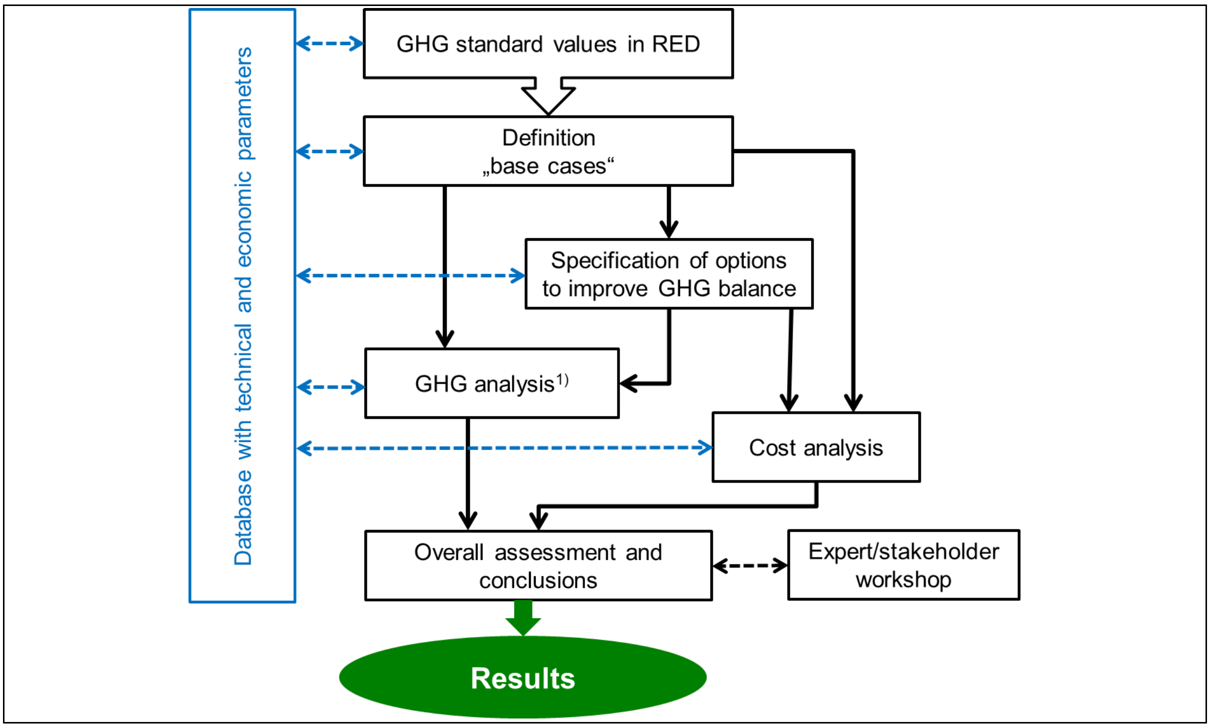

Figure 1: Approach for the assessment of the improvement options

In this approach the following methodologies were applied:

- Life cycle assessment according to RED for GHG calculation;
- Production cost analysis for cost indications;
- Analyses of cost and GHG reduction potential for comparison of the different options;
- SWOT-Analyses (Strengths – Weaknesses – Opportunities – Threats); and
- Stakeholder involvement to review the draft results of assessing the options.

Results

The main results of the assessment are

1. Greenhouse gas emissions;
2. Production costs;
3. Greenhouse gas mitigation costs;
4. SWOT analysis; and
5. Feasibility and realisation time.

Results on base cases, using best available technology

A significant GHG reduction in processing is possible if best available technology (BAT) is used compared to data in BioGrace (Table 1). GHG emissions for cultivation (e_{ec}) are higher due to improved data on the correlation between fertilizer input and yields. Processing emissions (e_p) are lower due to higher process efficiency and lower energy and chemical demand of BAT.

The costs analysis shows that the revenues from co-produced animal feed and the oil yield per hectare have a strong influence on total production costs, e.g. mainly animal feed from soybean. Feedstocks from outside EU (e.g. American soybean, palm oil) have lower costs.
Table 2 shows the calculated FAME production costs for the base cases.

Table 1: Greenhouse gas emissions of base cases using BAT versus BioGrace

Feedstock	**Greenhouse gas emission saving**[2] [%]		**Total GHG emissions E** [g CO_2-eq/MJ_{FAME}]		**Cultivation e_{ec}** [g CO_2-eq/MJ_{FAME}]		**Processing e_p** [g CO_2-eq/MJ_{FAME}]	
	BioGrace	Base case[1]	BioGrace	Base case[1]	BioGrace	Base case[1]	BioGrace	Base case[1]
Rapeseed	38%	43%	52	36	29	36	22	10
Sunflower	48%	49%	44	43	18	31	25	10
Palm oil (with CH_4 capture)	56%	69%	37	26	14	13	18	8
Soybean (American)	32%	52%	57	40	18	13	25	11
Soybean (European)		67%		28		15		11
UCO/Animal fat	75%	88%	21	10	-	-	20	9

[1] FAME production capacity: 100,000 t/year

[2] Compared to fossil reference with 83.8 g CO_2-eq/MJ_{fuel}

Table 2: FAME production costs for the base cases, including revenues from co-products (ranges due to different capacities)

Feedstock	**FAME production costs** [€/t_{FAME}]
Rapeseed	600 - 650
Sunflower	960 - 1,010
Palm oil (with CH_4 capture)	280 - 300
Soybean (American)	490 - 510
Soybean (European)	730 - 750
UCO/Animal fat	630 - 660

Results on improvement options

The GHG analysis of the improvement options indicates a relatively high GHG reduction potential in cultivation and a relatively low GHG reduction potential in processing compared to BAT. Also retrofitting vegetable oil plants for blending fatty residues shows a relatively high GHG reduction potential. Table 3 displays selected results on GHG emission saving of the improvement options and their corresponding base cases. The change in GHG emissions by the improvement options compared to the base cases is presented, as well as FAME production costs and GHG mitigation costs of the improvement options. Some improvement options also have lower productions costs compared to the base cases and therefore also generate economic benefits. The results refer to rapeseed as feedstock with production cost of the base case of 600 – 650 €/t_{FAME}. The improvement option "CHP residues" is also presented for UCO/animal fat with production cost of the base case of 630 – 660 €/t_{FAME}. Figure 2 presents GHG mitigation costs and GHG emission reduction of the improvement options compared to the corresponding base cases. All the improvement options were investigated separately; however, a combination of options is also possible in some cases.

Table 3: Selected results on improvement options, with rapeseed & UCO/animal fat as feedstock

Improvement option	**Greenhouse gas emission saving compared to fossil reference** [%] Option	Base case1)	**Greenhouse gas emissions compared to base case** [g CO_2-eq/MJ] Option	**FAME production costs7)** [€/t_{FAME}] Option	**Greenhouse gas mitigation costs compared to base case5)** [€/t CO_2-eq] Option
Feedstock: rapeseed					
Biomethanol2)	49%	43%	-5	650 - 670	170 - 290
Bioethanol2)	44-46%	44%	0 to -2	680	1,000
CHP residues					
Vegetable oil CHP + steam boile	45%	44%	-0.9	620	not calculated6)
Wood-to-steam boiler	45%	44%	-1	600	-90
Bioplastics and -chemicals					
Pharmaglycerol 99.5%	45%	43%	-2	610	-170
Succinic acid	41%	44%	+2	260	not calculated6)
Advanced agriculture					
Balanced fertilization	47%	43%	-3	590	-260
Nitrification inhibitors	47%	43%	-3	660	360
Crop residue management	67%	43%	-20	610	-20
Reduce tillage	52%	43%	-7	600	-70
Organic fertilizer	55%	43%	-10	620	0
FAME as fuel3)	44-45%	43%	0 to -2	630	90
Retrofitting					
Partial usage of UCO/animal fat	52%	44%	-8	610	-10
Complete modification	88%	43%	-37	610	0
Green electricity from PV plant on site4)	43-44%	43-44%	-0.2	600 - 620	not calculated6)
Feedstock: UCO/animal fat					
CHP residues					
Glycerol CHP+FAME distillation residue steam boiler	88-89%	86%	-1 to -2	630 - 660	0 - 140

1) FAME production capacity correspoding to option

2) Ranges due to different feedstock for biomethanol/bioethanol

3) Ranges due to different FAME uses (use in cultivation or transport & distribution)

4) Ranges due to different production capacities

5) Negative mitigation costs are due to lower FAME production costs compared to base case, e.g. higher revenues from new co-products

6) Not calculated due to small GHG emission reduction (≤ 1 g CO_2-eq/MJ)

7) FAME production costs of base case with rapeseed 600 - 650 €/t_{FAME} and with UCO/animal fat 630 - 660 €/t_{FAME}

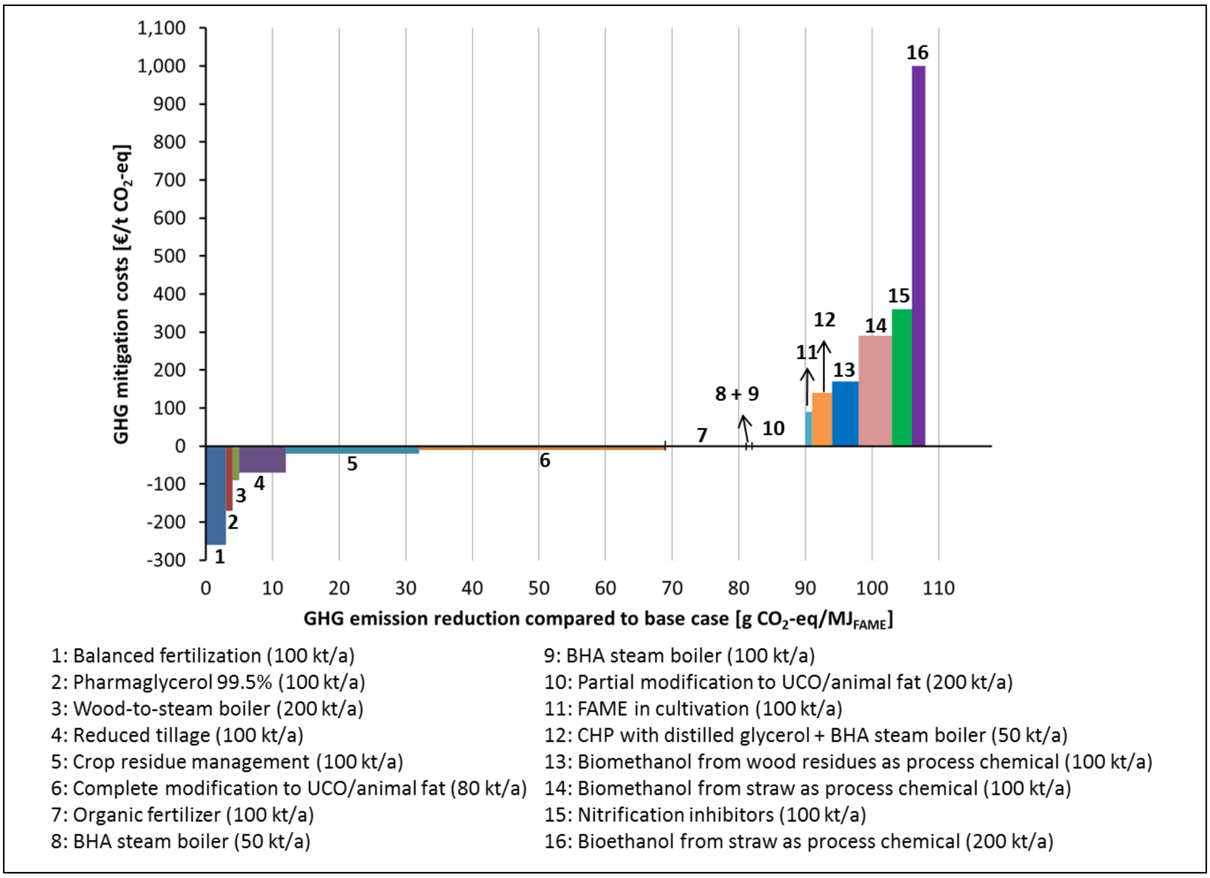

Figure 2: GHG mitigation costs and GHG emission reduction of selected improvement options (improvement options with a GHG reduction > 1 g CO_2-eq/MJ; feedstock of the base case: rapeseed)

SWOT analysis

Selected results of the SWOT analysis influencing the overall assessment on the improvement options are:

- Biomethanol: Due to "economies of scale" biomethanol production at the FAME plant facility is not feasible;
- Bioethanol: Fatty acid ethyl ester (FAEE) are produced instead of fatty acid methyl ester if bioethanol is used. Fuel certification is missing for FAEE according to EN14214;
- CHP residues: All investigated systems for using process residues and renewable fuels to provide process energy are commercially available;
- New plant species: Production chains for new emerging crops are under development. A demonstration and biorefinery approach is needed due to large set of co-products
- Bioplastic and biochemical: The production of succinic acid is already performed on a production scale using a mixture of sugar and glycerol. The production of pharmaglycerol is well established and offers an alternative usage for glycerol;
- Advanced agriculture & organic residues: The current GHG emissions calculation scheme for biofuels does not support the use of advanced agricultural practices and some of the investigated options may be implemented already (e.g. crop residue management). This means that the mitigation potential might be overestimated.
- FAME as fuel: Engines must be adjusted to 100% FAME;

- Retrofitting: Partial and complete modification for blending fatty residues is a commercially viable solution. The implementation depends on the availability of UCO/animal fat;
- Green electricity from PV plant on site: Without storage it is not possible to provide 100% of the electricity needed for FAME processing.

Feasibility and realisation time

The summarized assessment of the improvement options is shown in Figure 3 by qualitatively indicating their feasibility (high – average – low) and realisation time (2016 – 2020 – 2025).

Feasible short term improvement options (2016) are:

- CHP residues;
- FAME as fuel;
- Retrofitting multi feedstock; and
- Biochemicals (Pharmaglycerol 99.5+).

Feasible medium term improvement options (<2020) are:

- Green electricity from PV plant on site;
- Biomethanol;
- Advanced agriculture; and
- Organic fertilizer.

Longer term improvement options (> 2020) are:

- New plant species; and
- Bioethanol (instead of methanol for FAME production).

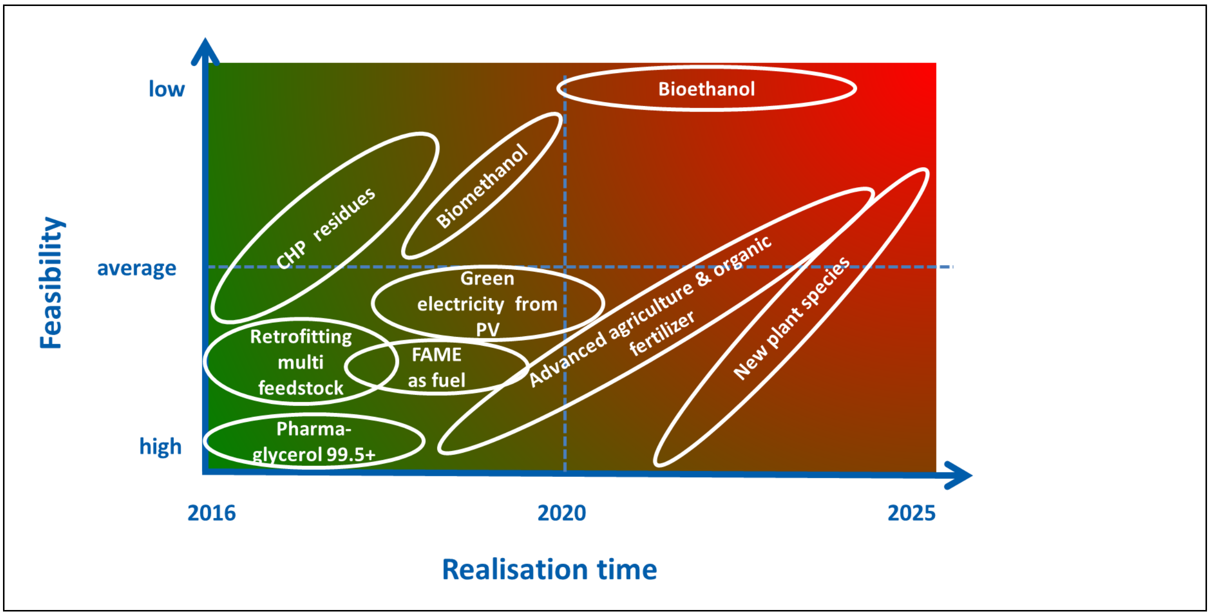

Figure 3: Overall assessment of the improvement options based on feasibility and realisation time

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Technical report

1 Study objectives

First the background and second the goal and scope of the analysis are described.

1.1 Background

The following background information was provided by the Commission:

"The European Union is promoting the use of renewable energy to reach the objective of 20% renewable energy in the energy mix and 10% renewable energy in transport by 2020 as set out by the Renewable Energy Directive (RED, EU 2009/28). Bioenergy contributes at present to more than 60% of all renewables in all three energy sectors. The main alternative to fossil based transport fuels are biofuels, whether liquid or gaseous. Bioenergy is the main RES that can physically replace fossil fuels. The contribution of Bioenergy will remain at least to 50% of all renewables by 2020. The RED has specified sustainability criteria for the use of biofuels in the European Union and the Fuel Quality Directive (EU 2009/30) increased the volumetric limits of ethanol and FAME to 10 vol% and 7 vol% respectively. This has also been addressed by the CEN EN 228 and EN 590 standards for the market. Sustainability issues for power and heat from bioenergy are not specified in the legislation, but the Member States shall follow the bioenergy operations in their countries and report to the Commission. Furthermore the Commission is considering whether to introduce sustainability criteria for power and heat from bioenergy in a future legislation.

Analysis of the submission of the National Renewable Energy Action Plans (NREAPS) indicates that biodiesel will be the predominant biofuel in the EU in the foreseeable future. Furthermore the EU industry has been investing billions of Euros in building large FAME production capacity in several EU Member States."

1.2 Goal and scope

Based on this background the Commission set the following general objective for the tender:

"The Green House Gas (GHG) balances of FAME from various resources have been set in Annex V of the RED. However due to technology and scientific progress it seems technically feasible that there are several ways to improve the GHG balances of FAME. In this context, this Supporting Action aims at analysing the various options available in improving the GHG balance of FAME from various resources."

The various improvement options that were analysed are described in more detail in chapter 2 and ANNEX 1. The options were specified by the tender and the project team. The assessment of every option contains results of analysis of

- Greenhouse gas (GHG) balance;
- Production costs;
- Greenhouse gas mitigation costs; and
- A critical discussion on the relative strengths and weaknesses (SWOT).

Besides the detailed analysis of every option a comparison of the results between the options was developed (chapter 5).

From the detailed results and the comparison conclusions and recommendations were drawn including findings for the development of the RED greenhouse gas calculation methodology.

2 Investigated FAME production systems

The base cases and the improvement options of the investigated FAME production systems are described.

2.1 Base cases

To determine the influence of the improvement options on GHG emissions and cost base cases were defined, representing the reference system for the comparison. Starting point for the definition of the base cases were the GHG standard values as documented in the Directive on the promotion of renewable energy sources (RED) and the corresponding background data documented in BioGrace GHG calculation tool (BioGrace, 2014).

Based on this information the most relevant FAME production possibilities in Europe were identified. Table 4 shows the investigated base cases, which are characterized by

- the type of feedstock (rape, sunflower, palm oil, soybean, used cooking oil, animal fat); and
- the FAME production capacity (50 kt/a, 100 kt/a, 200 kt/a).

For these 14 base cases technical and economic data were collected, representing the "Best Available Technology in 2015" (BAT 2015).

To identify the base cases a naming system was implemented including the type of feedstock and the capacity in a short name, for example:

- "F-Rs-50-BC" (short name) corresponds to a base case (BC) with a FAME (F) production capacity of 50 kt per year using rapeseed (Rs) as feedstock.

Table 4: Investigated base cases with best available technology

Feedstock	Capacity [1,000 t FAME/a]	Short name
Rapeseed	50	F-Rs-50-BC
Rapeseed	100	F-Rs-100-BC
Rapeseed	200	F-Rs-200-BC
Sunflower	50	F-Sf-50-BC
Sunflower	100	F-Sf-100-BC
Sunflower	200	F-Sf-200-BC
American soybean	100	F-Sy(am)-100-BC
American soybean	200	F-Sy(am)-200-BC
European soybean	100	F-Sy(eu)-100-BC
European soybean	200	F-Sy(eu)-200-BC
Palm oil[1)]	100	F-Po(CH4 capt)-100-BC
Palm oil[1)]	200	F-Po(CH4 capt)-200-BC
UCO / animal fat[2)]	50	F-Wo-50-BC
UCO / animal fat[2)]	100	F-Wo-100-BC

[1)] with CH_4 capture at oil mill
[2)] Category 1 & 2 fats

2.2 Improvement options

Within the project 10 options to improve the GHG balance of FAME were investigated.

1. "Biomethanol": Substitution of fossil methanol with biomethanol for the production of FAME (Fatty Acid Methyl Esters);
2. "Bioethanol": Substitution of fossil methanol with bioethanol for the production of FAEE (Fatty Acid Ethyl Esters);
3. "CHP residues": Use of residues and co-products from the production of FAME in a combined heat and power (CHP) facility to provide power and/or heat;
4. "New plant species": Examination of the species of the plants used for vegetable oils, that could increase the biomass weight without any detrimental effect on the oil seed;
5. "Bioplastics and -chemicals": Production of bioplastics and biochemicals from biomass or process residues;
6. "Advanced agriculture": Advanced agricultural practices in terms of N_2O emissions and soil carbon accumulation at resource cultivation;
7. "Organic fertilizer": Use of organic fertilizer for feedstock cultivation versus mineral fertilizer;
8. "FAME as fuel": Use of FAME in machinery for cultivation, transportation and distribution;
9. "Retrofitting multi feedstock": Retrofitting of single feedstock plants for blending fatty residues, and
10. "Green electricity": Use of renewable electricity produced in a PV plant on site

For calculation of the GHG emissions and FAME production costs most of these options needed further specifications. Therefore the sub-options were defined, where needed.

A short overview on the sub-options is given at the end of this section. A detailed description of the investigated sub-options is documented in "ANNEX 1: Fact sheets on improvement options". Table 5 shows which Fact sheet contains the description and results of which sub-options.

Each sub-option was matched with a certain type of feedstock and a FAME production capacity (Table 5). In total 37 different sub-options were investigated:

To identify the improvement option a naming system was implemented including the number of the option, the production capacity and the feedstock:

- "F-Rs-100-Op1a" (short name) corresponds to the Option 1a (Op1a) with a FAME (F) production capacity of 100 kt per year using rapeseed (Rs) as feedstock.

Additionally the options were grouped in five main categories for presenting and comparison in the result section of this technical report:

Categories

1. "Chemicals" (Biomethanol, Bioethanol, Bioplastic & -chemicals);
2. "Energy Supply" (CHP residues, Green electricity);
3. "Cultivation" (New plant species, Advanced agriculture, Organic fertilizer);
4. "FAME as a fuel"; and
5. "Retrofitting".

2.2.1 Overview on sub-options

Some improvement options need further specification for calculation GHG emissions and FAME production costs. Therefore the following sub-options are specified:

Option 1 "Biomethanol"

For the option "Biomethanol" three different raw material options for synthesis gas production are considered:

- Biomethanol from wood residues (1a);
- Biomethanol from straw (1b); and
- Biomethanol from glycerol (1c).

Option 2 "Bioethanol"

For the option "Bioethanol" two different raw materials for the production of bioethanol are considered:

- Bioethanol from wheat (2a); and
- Bioethanol from straw (2b).

Option 3 "CHP residues"

For the option "CHP residues" different possibilities to supply process energy based on renewable sources are investigated:

- CHP with refined vegetable oils + steam boiler with vegetable oils (3b): vegetable oil is used to generate power and heat for the biodiesel production instead of fossil energy sources. Electricity is produced in a diesel engine, steam in a boiler;
- Steam boiler with vegetable oils (3c): vegetable oil is used in a steam boiler to provide heat for the FAME production;
- CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler (3d): glycerol is used to generate electricity for the FAME production with an adapted CHP engine. Heat is produced by co-firing the FAME distillation residue for partly substitution of natural gas;
- Co-incineration of FAME distillation residue (BHA) in steam boiler (3e): Heat for the FAME production is used generated by co-firing the biodiesel distillation residue for partly substitution of fossil fuels; and
- Wood-to-steam boiler (3f): a biomass steam technology is used for heat production for FAME and oil extraction process. Wood chips which are commercially available and customary in trade are used in standard grate furnaces.

The use of harvest residues from cultivation (e.g. rape straw) was originally also investigated (3a), but dismissed because fluidized bed technology is necessary for biofuels rich in sulphur and chlorine, which is not appropriate for the demanded power range (<10 MW) of usual biodiesel production facilities.

Option 4 “Plant species”
Various new plant species are currently developed for cultivation in Europe and beyond. For the option “Plant species” the following examples are analysed:

- Crambe (4a);
- Camelina (4b);
- Jatropha (4c); and
- Guayule (4d).

Option 5 “Bioplastic &-chemicals”
For the Option “Bioplastic &-chemicals” two examples are investigated:

- Pharmaglycerol 99.5% (5a): The refining of crude glycerol to pharmaglycerol (99.5% glycerol) is investigated, which is already implemented in biodiesel production facilities. It is investigated to analyse the influence of current calculations rules from the RED, where crude glycerol is excluded from energy allocation; and
- Succinic acid from straw + glycerol (5c): Conversion (fermentation) of crude aqueous glycerol together with 2nd generation non-food sugars resulting from residues of oil plant materials (straw), after the removal of lignin and hemi-cellulose fractions.

Isobutanol from straw (5b) was originally also investigated. Isobutanol, as a drop-in product for ethanol fermentation processes for food and non-food sugars, was not pursued further, since only two major US-players, GEVO and BUTAMAX, are dominating the market. Due to the classified nature of needed details and several bilateral patent law suits not enough information became available on their latest technology developments for second-generation feedstocks. In particular, the suitability for vegetable oil plant residues, like straw, in comparison to the mostly referred to feedstock wheat straw and corn stover.

Option 6 "Advanced agriculture"

Different advanced agricultural practices in terms of N_2O emissions and soil carbon accumulation at resource cultivation exist. Here the following possibilities are investigated:

- Balanced fertilization (6a): The amount of fertilizer is balanced to the fertilizer demand of the crop to prevent "overfertilization";
- Nitrification inhibitors (6b): Nitrification inhibitors such as dicyandiamide (DCD) can be applied in or together with mineral fertilizer to conserve soil nitrogen and increase the efficiency of nitrogen supply to plants;
- Crop residue management (6d): Crop residue incorporation, where stubble and straw is left on the field ground and incorporated when the field is tilled, enhances carbon flows back to the soil, thereby encouraging carbon sequestration;
- Reduced tillage (6e): Reduced tillage decreases soil heterotrophic respiration and CO_2 emissions while soil carbon stocks are increasing due to higher crop residue incorporation; and
- Return nutrients from palm oil residues as fertilizer (6f): Palm oil residues are returned to the field, which reduces the need for mineral fertilizer and can also sequester carbon in the soil.

The use of catch/cover crops in the rapeseed rotation was originally also investigated (6c), but dismissed because the vast majority of rapeseed in Europe is winter rapeseed, which does not allow for catch/cover crops in the rotation. In summer rapeseed it would be an option, but because of the lower yields summer rapeseed is hardly cultivated.

Option 7 "Organic fertilizer"

Option "Organic fertilizer" investigates the use of organic fertilizer for feedstock cultivation versus mineral fertilizer. No sub-options are specified.

Option 8 "FAME as fuel"

The use of FAME as fuel is investigated for two areas:

- FAME in cultivation (8a): FAME as fuel is used instead of fossil diesel in agricultural machinery in cultivation; and
- FAME in transport + distribution (8b): FAME as fuel is used instead of fossil diesel in transport and distribution processes.

Option 9 "Retrofitting multi feedstock"

For the retrofitting of single feedstock plants for blending fatty residues two possibilities are investigated:

- Partial modification to UCO/animal fat: A retrofit of a continuous sodium methanolate plant for partial usage (20%) of UCO/animal fat is examined; and
- Complete modification to UCO/animal fat: A retrofit of a continuous sodium methanolate plant for 100% use of UCO/animal fat is examined.

Option 10 “Green electricity”

Option “Green electricity” investigates the use of renewable electricity produced in a PV plant on site. The share of electricity covered by PV is estimated to be 30%. The remaining electricity demand is supplied by the grid. No sub-options are specified.

Table 5: Investigated improvement options

#1)	Improvement option	Rapeseed			American soybean	Palm oil (CH4 capt)	New plant species	UCO / animal fat		Short name	Fact sheet title
		50	100	200	100	100	100	50	100		
						CHEMICALS					
1	**Biomethanol**										Biomethanol
1a	Biomethanol from wood residues as process chemical		x							F-Rs-100-Op1a	
1b	Biomethanol from straw as process chemical		x		x				x	F-Rs-100-Op1b F-Sy(am)-100-Op1b F-Wo-100-Op1b	
1c	Biomethanol from glycerol as process chemical		x							F-Rs-100-Op1c	
2	**Bioethanol**										Bioethanol
2a	Bioethanol from wheat as process chemical			x						F-Rs-100-Op2a	
2b	Bioethanol from straw as process chemical			x						F-Rs-100-Op2b	
5	**Bioplastic & -chemicals**										Bioplastic & biochemicals
5a	Pharmaglycerol 99.5+		x						x	F-Rs-100-Op5a F-Wo-100-Op5a	
5c	Succinic acid from straw + glycerol	x		x						F-Rs-50-Op5c F-Rs-200-Op5c	
						ENERGY SUPPLY					
3	**CHP residues**										Vegetable oil & wood chips for process energy supply
3b	CHP with refined vegetable oils+ steam boiler with vegetable oils			x						F-Rs-200-Op3b	
3c	Steam boiler with vegetable oils			x						F-Rs-200-Op3c	
3f	Wood-to-steam boiler			x						F-Rs-200-Op3f	
3d	CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler							x		F-Wo-50-Op3d	Glycerol & FAME distillation residue for process energy supply
3e	Co-incineration of FAME distillation residue (BHA) in steam boiler							x	x	F-Wo-50-Op3e F-Wo-100-Op3e	
10	**Green electricity**		x	x				x	x	F-Rs-100-Op10 F-Rs-200-Op10 F-Wo-50-Op10 F-Wo-100-Op10	Green electricity from PV plant on site
						CULTIVATION					
4	**New plant species**										New plant species
4a	Crambe						x			F-Cr-100-Op4a	
4b	Camelina						x			F-Ca-100-Op4b	
4c	Jatropha						x			F-Ja-100-Op4c	
4d	Guayule						x			F-Gu-100-Op4d	
6	**Advanced agriculture**										
6a	Balanced fertilization		x			x				F-Rs-100-Op6a F-Po(CH4capt)-100-Op6a	Balanced fertilization
6b	Nitrification inhibitors		x							F-Rs-100-Op6b	Nitrification inhibitors
6d	Crop residue management		x							F-Rs-100-Op6d	Crop residue management
6e	Reduced tillage		x							F-Rs-100-Op6e	Reduced tillage
6f	Return nutrients from palm oil residues as fertilizer					x				F-Po(CH4capt)-100-Op6f	Return nutrients from palm oil residues as fertilizer
7	**Organic fertilizer**		x							F-Rs-100-Op7	Organic fertilizer
						FAME AS FUEL					
8	**FAME as fuel**										Use of FAME for cultivation, transport and distribution
8a	FAME in cultivation		x		x					F-Rs-100-Op8a F-Sy(am)-100-Op8a	
8b	FAME in transport + distribution		x		x					F-Rs-100-Op8b F-Sy(am)-100-Op8b	
						RETROFITTING					
9	**Retrofitting**										Retrofitting of single feedstock plants for blending fatty residues
9a	Partial modification to UCO/animal fat			x						F-Rs-200-Op9a	
9b	Complete modification to UCO/animal fat		x1)							F-Wo-80-Op9b	

1) Some sub-options were dismissed after detailed specification, therefore the numbering is not continous.

2) after modification FAME production capacity of 80 kt FAME/a

3 Methodology

The description of the methodology includes the approach of the study, the greenhouse gas calculation according to RED, the production cost analysis, the analysis of the mitigation costs, the SWOT analysis, the Stakeholder involvement and the Fact Sheets.

3.1 Approach

The approach to achieve the study tasks consists of the following eight key elements (Figure 4):

- GHG standard values from RED;
- Definition of "base cases";
- Specification and analyses of options to improve the GHG balance of FAME;
- Database;
- GHG analyses;
- Cost analyses;
- Overall assessment, "Fact Sheet of options" and conclusions; and
- Expert/stakeholder workshop;

The starting point of the approach are the GHG standard values as documented in the Renewable Energy Directive (RED) and the corresponding background data documented in the BioGrace GHG calculation tool (BioGrace, 2014).

Based on this information 14 most relevant FAME production possibilities in Europe mainly characterized by different types of feedstock and the production capacity are be identified. These "base cases" are described by their technical and economic data "Best Available Technology in 2015" (BAT 2015).

The next step of the approach is the specification of the different options to improve the GHG balance compared to the base cases. Technical and economic data are collected.

All collected data (GHG standard values, data on base cases and options) are documented in a database. The structure of the database contains all technical and economic data necessary to calculate the GHG emissions according to RED methodology in g CO_2-eq/MJ and the cost indicators (e.g. production cost in €/t_{FAME}).

GHG analyses according to RED methodology and cost analyses are done for the base cases and the improvement options.

Finally an overall assessment and comparison of the options (e.g. Technology Readiness Level (TRL), SWOT analysis, ranking of options, comparison to base cases) is made and conclusions are drawn. The main results are summarized using compact "Fact Sheets", including key characteristics, facts, figures and recommendations (chapter 3.8).

The draft final results were presented and discussed in a workshop (November 13, 2015 in Vienna/Austria) with selected experts and stakeholders from governmental, industrial, agricultural and scientific institutions to discuss and review the findings. The outcome of this workshop was used to finalize the results.

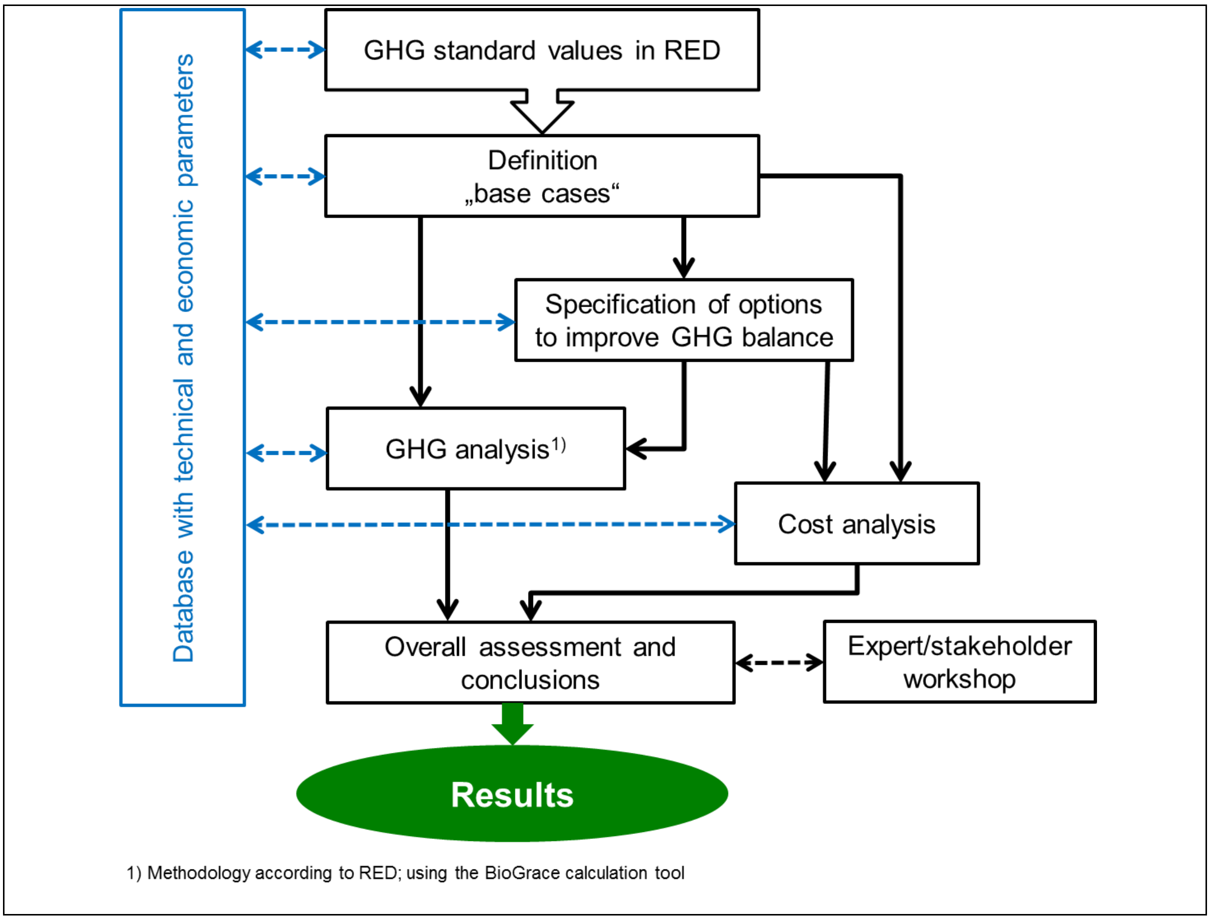

Figure 4: Key elements of the approach used to assess the improvement options

The following different methodologies are used in the presented approach:

1. Life cycle assessment (LCA) according to RED for GHG calculation;
2. Production cost analysis for cost indications;
3. Analysis of cost and GHG reduction potential for comparison of the different options;
4. SWOT analysis for the discussion of strengths and weaknesses; and
5. Stakeholder involvement to review the (draft) results.

These methodologies are described in the next chapters.

3.2 Greenhouse gas calculation according to RED

The greenhouse gas emissions are calculated on the basis of a life cycle analyses (process chain analyses), where all greenhouse gas relevant processes for the supply of transportation services with FAME and diesel are considered (Figure 5).
According to ISO 14,040 “Life Cycle Assessment” a *“Life Cycle analyses is a method to estimate the material and energy flows of a product (e.g. transportation service with FAME) to calculate the environmental effects in the total lifetime of the product - from cradle to grave”* (ISO 14040:2006).

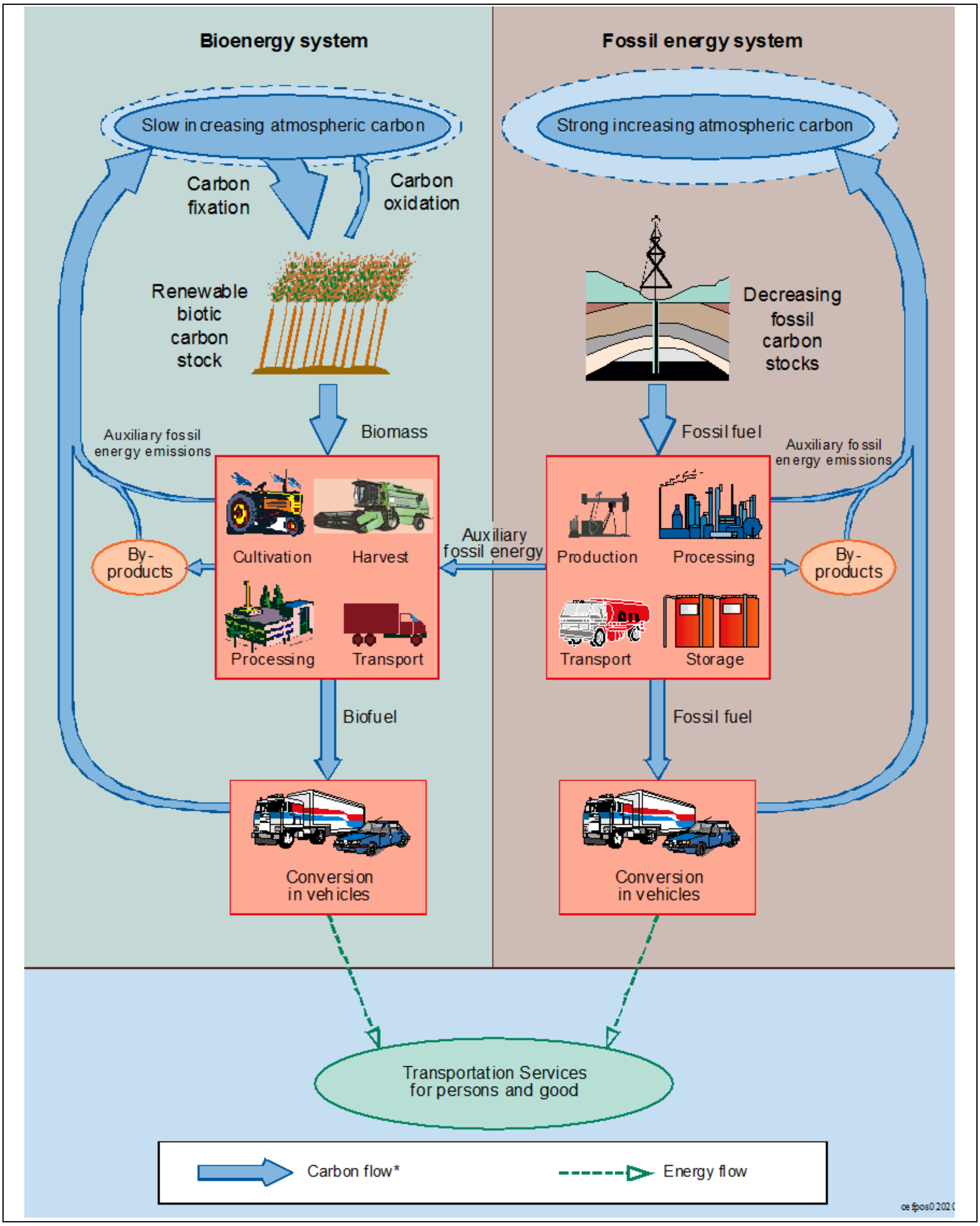

Figure 5: Carbon and energy flows for greenhouse gas emissions of a transportation system with bioenergy (e.g. FAME) in comparison to fossil energy (e.g. diesel) (JUNGMEIER, 2002 based on JUNGMEIER, 1999)

The greenhouse gas emissions from the production and use of FAME are calculated as (EU 2009/28):

$$E_{biofuel} = e_{ec} + e_{l} + e_{p} + e_{td} + e_{u} - e_{sca} - e_{ccs} - e_{ccr} - e_{ee} \; [\text{g } CO_2\text{-eq}/MJ_{biofuel}]$$

$E_{biofuel}$ = total emissions from the use of the biofuel;
e_{ec} = emissions from the extraction or cultivation of raw materials;
e_{l} = annualized emissions from carbon stock changes caused by land-use change;
e_{p} = emissions from processing;
e_{td} = emissions from transport and distribution;
e_{u} = emissions from the fuel in use;
e_{sca} = emission saving from soil carbon accumulation via improved agricultural management;
e_{ccs} = emission saving from carbon capture and geological storage;
e_{ccr} = emission saving from carbon capture and replacement; and
e_{ee} = emission saving from excess electricity from cogeneration.

According to the Directive (RED, EU 2009/28) the greenhouse gas emissions from the manufacture of machinery and equipment are not taken into account.
Annualised emissions from carbon stock changes caused by land-use change (el) are calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule is applied:

$$e_{l} = (C_{SR} - C_{SA}) \times 3{,}664 \times 1/20 \times 1/P - e_{B}{}^{1}$$

where

e_{l} = annualised greenhouse gas emissions from carbon stock change due to land-use change, (measured as mass of CO_2-equivalent per unit biofuel energy);
C_{SR} = the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later;
C_{SA} = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CSA shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;
P = the productivity of the crop (measured as biofuel energy per unit area per year); and
e_{B} = bonus of 29 g CO_2-eq/MJ biofuel if biomass is obtained from restored degraded land under certain conditions[2].

The processes for the calculation of the greenhouse gas emissions of FAME are shown in Figure 6.

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[1] The quotient obtained by dividing the molecular weight of CO_2 (44.010 g/mol) by the molecular weight of carbon (12.011 g/mol) is equal to 3.664.

[2] The bonus of 29 g CO_2-eq/MJ shall be attributed if evidence is provided that the land: (a) was not in use for agriculture or any other activity in January 2008; and (b) falls into one of the following categories: (i) severely degraded land, including such land that was formerly in agricultural use; (ii) heavily contaminated land. The bonus of 29 g CO_2-eq/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

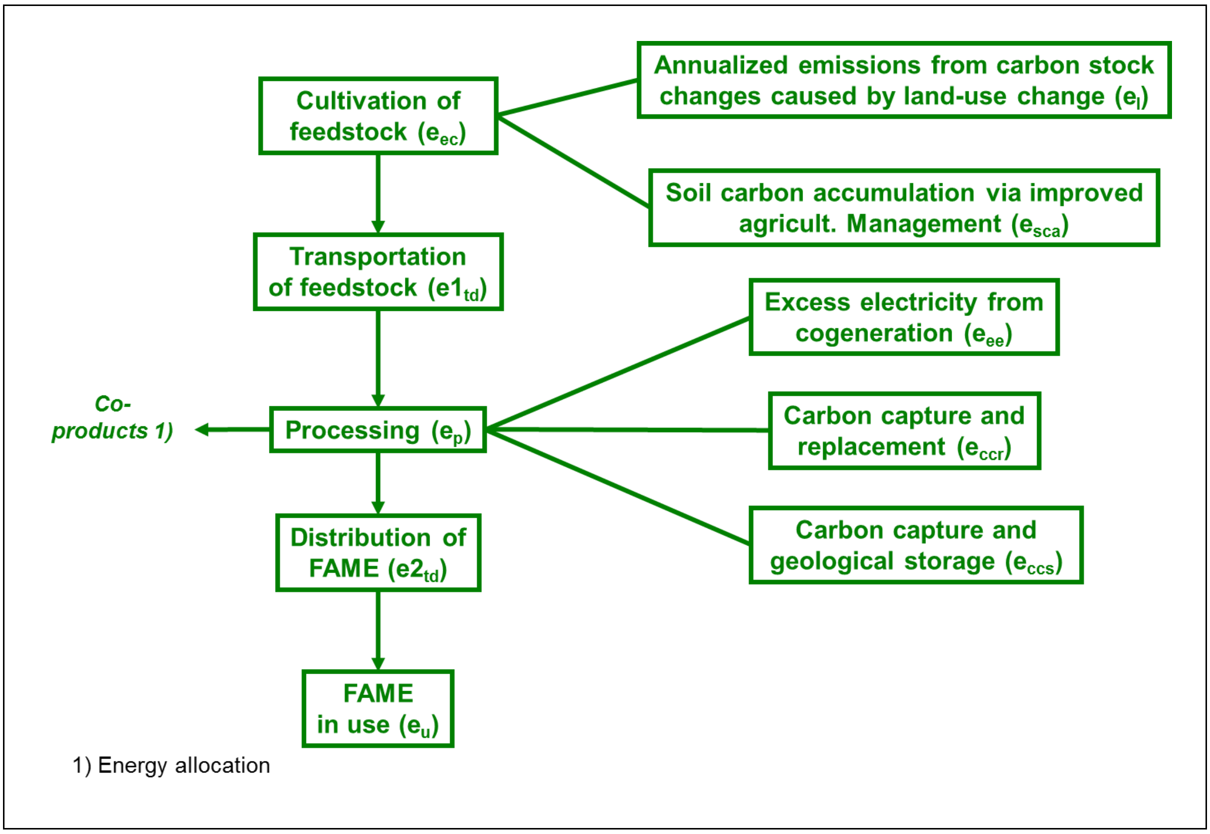

Figure 6: Calculation of greenhouse gas emissions according to the Directive (EU 2009/28) for FAME

The relevant greenhouse gases are

- carbon dioxide (CO_2);
- methane (CH_4); and
- nitrogen oxide (N_2O).

with their CO_2-equivalents[3] of

- 1 kg CO_2 = 1 kg CO_2-eq;
- 1 kg CH_4 = 23 kg CO_2-eq; and
- 1 kg N_2O = 296 kg CO_2-eq.

The greenhouse gas emissions from FAME (E_B) are expressed in terms of grams of CO_2-equivalent per MJ of FAME [g CO_2-eq/MJ] assuming no differences between gasoline and FAME in useful work done by the vehicle (see EU 2009/28).
Shares of the greenhouse gas emissions must be allocated to the co-products. According to the Directive this allocation is based on the energy content of FAME and the co-products ("energy allocation"). According to Annex V – C 18 in the Directive some co-products shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials including wastes, agricultural crop residues and residues from processing, including crude glycerol (glycerol that is not refined). Figure 7 shows the system boundaries of the GHG calculation for crude glycerol and refined glycerol (pharmaglycerol 99.5%).

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[3] According to IPCC, 2007 and IPCC, 2013 the GWP is different, e.g. in IPCC 2013: 1 kg CH_4 = 34 kg CO_2-eq, 1 kg N_2O = 298 kg CO_2-eq (including climate-carbon feedbacks).

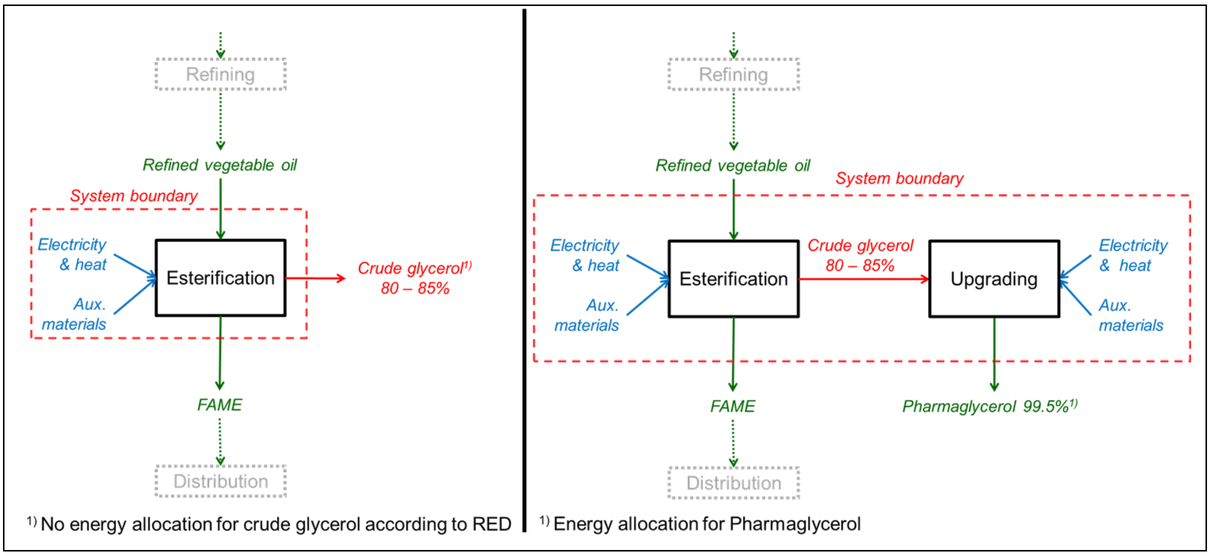


Figure 7: Energy allocation of GHG emissions for crude glycerol and pharmaglycerol according to RED.

The greenhouse gas saving of FAME (E) is given in percentages [%], which are calculated as the difference between the emissions of diesel and FAME ($E_F - E_B$) in relation to the emissions of diesel (E_F):

$$E = (E_F - E_B) / E_F \ [\%]$$

According to the EU-Directive the greenhouse gas savings for biofuels must be the following (EU 2009/28):
The greenhouse gas emission saving from the use of biofuels shall be at least 35 %. With effect from 1 January 2017, the greenhouse gas emission saving from the use of biofuels shall be at least 50 %. From 1 January 2018 that greenhouse gas emission saving shall be at least 60 % for biofuels produced in installations in which production started on or after 1 January 2017.

For the calculation itself, the BioGrace GHG calculation tool (BioGrace, 2014) was used. The calculation tool is approved by the European Commission to verify compliance with the emission saving requirements of the European Union. By using the tool’s option to enter user specific data, the calculation for the base cases and the improvement options was done, based on the collected data. Also the N_2O soil emissions were calculated by the BioGrace tool, based on the default Tier1 emission factor. No fertilizer type specific value was used, as it is not known at EU level which crop receives which fertilizer. Alternatively the NUTS2 specific values could have been used for the EU, but this would have involved too much work as these are not collectively available.

3.3 Production cost analysis

An analysis of the production costs for FAME is made to get a cost indication for the different options to improve the GHG balance. To calculate the production costs for FAME a static investment cost analyses is applied to get an average annual cost [€/a]. The following annual production cost categories are considered, which are documented in the database:

- Capital costs of the investment (using the life time and an interest rate to get the annual capital costs);
- Feedstock costs;

- Energy costs of electricity and heat;
- Costs of auxiliary materials e.g. methanol, bioethanol;
- Personnel costs;
- Maintenance costs;
- Insurance costs; and
- Other costs.

To calculate the annual production costs of FAME the revenues on the market from the co-products (e.g. glycerine, animal feed, bio-chemicals, bio-plastics) are subtracted.

3.4 Analysis on level of accuracy

For correct interpretation of results on GHG emissions and production costs the level of accuracy of results is investigated. Therefore the influence on the GHG emissions is investigated by using ranges for selected parameters, e.g. feedstock yield. The ranges are determined based on expert estimation depending on the uncertainty of the parameter. This analysis on the level of accuracy was performed on the GHG emission and production costs of the base cases with a FAME production capacity of 100,000 t/a. Table 6 shows the parameters, which are considered in the analysis on level of accuracy for the base cases.

Table 6: Selected parameters included in the analysis on level of accuracy and upper and lower ranges of values compared to the average value

Feedstock yield	Palm oil: +/- 10% Other feedstocks: +/-20%
Diesel input	+/-25%
N-fertilizer input (kg N)	+/-25%
Field N_2O-emissions	Soybeans: -30% and +75% Other feedstocks: +/-33%
Methanol input	+10% and -5%
Market price UCO/animal fat	-10% and +20%

3.5 Analysis of mitigation costs

The mitigation costs for the improvement options are calculated in comparison to the GHG emissions and cost of the base cases. The mitigation costs are given in € per Tonne of CO_2-eq saved [€/t CO_2-eq). The mitigation costs are calculated by dividing the difference of the production costs with the difference of the GHG emissions. The mitigation costs are negative, if the FAME production costs of the improvement option are lower than the production costs of the base case. The mitigation costs are zero, if there is no cost difference between the base case and the improvement option. To derive significant results the mitigation costs are only calculated, if the GHG emissions of the improvement options are lower than the base case [> 1 g CO_2-eq/MJ].

3.6 SWOT analysis

A SWOT analysis was applied to analyse and assess the strengths and weaknesses of the different options in addition to improve the GHG balance and cost indicators described above. SWOT stands for analysing:

- Strengths;
- Weaknesses;

- Opportunities; and
- Threats.

A SWOT analysis is a structured assessment method used to evaluate the strengths, weaknesses, opportunities, and threats involved in a project or in a business venture. A SWOT analysis is carried out for the options to improve the GHG balance. The results of the SWOT-analyses of each specific option are presented in a matrix shown in Figure 8.

SWOT analysis aims to identify the key internal and external factors of the different options to improve the GHG balance seen as important to realize these options.

- internal factors – the strengths and weaknesses internal to the FAME production; and
- external factors – the opportunities and threats presented by the environment external to the FAME production.

The matrix will be filled with the following:

- Strengths: characteristics of the options to improve the GHG balance that give it an advantage over others;
- Weaknesses: characteristics that place the options to improve the GHG balance at a disadvantage relative to others;
- Opportunities: elements that the options to improve the GHG balance could exploit to its advantage; and
- Threats: elements in the environment that could cause trouble for the options to improve the GHG balance.

Analysis may view the internal factors as strengths or as weaknesses depending upon their effect on the organization's objectives. What may represent strengths with respect to one objective may be weaknesses (distractions, competition) for another objective.

The external factors may include macroeconomic matters, technological change, legislation, and sociocultural changes, as well as changes in the marketplace or in competitive position.

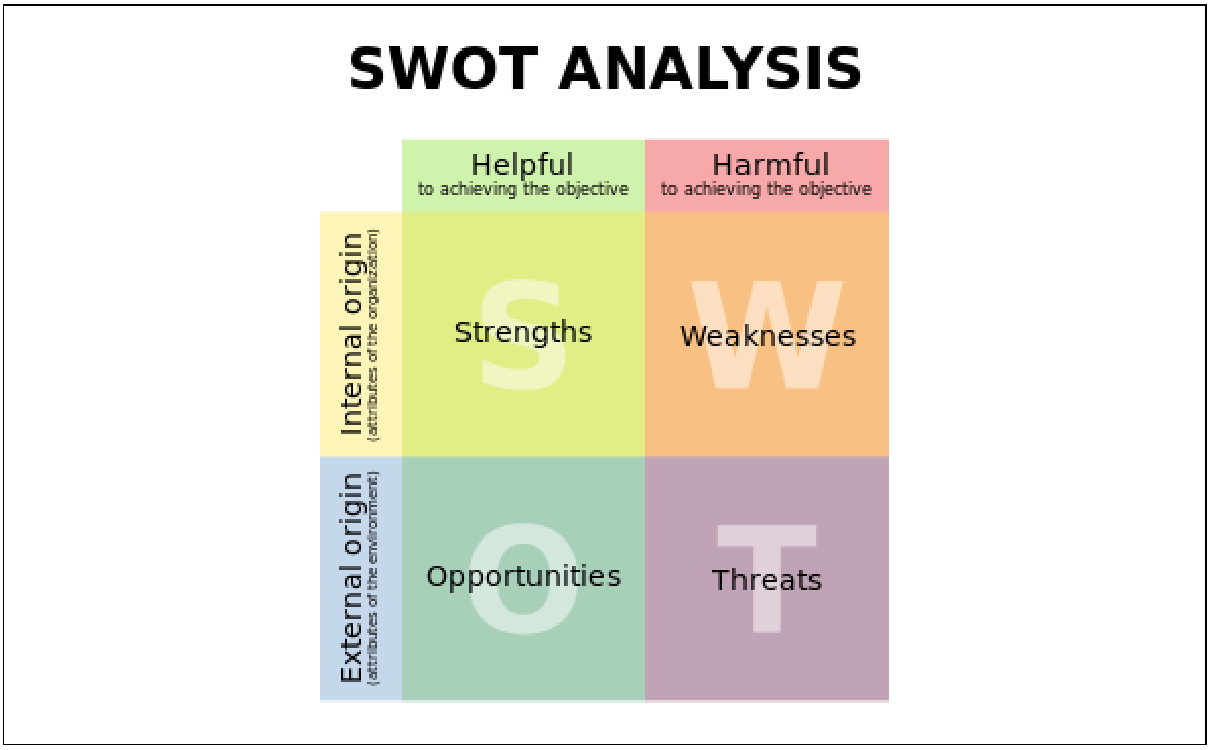


Figure 8: Structure of SWOT analysis (SWOT, 2007)

3.7 Stakeholder involvement

To describe and assess the considered options to improve the GHG balance of FAME and to review the draft results stakeholders were involved. The most relevant stakeholders from governmental, industrial, agricultural and scientific institutions were identified and invited by the consortium and the Commission.

Stakeholders from the following institutions participated in the stakeholder workshop, which took place in Vienna/Austria in November 2015:

- ARGE Biokraft;
- Austrian Chamber of Agriculture;
- Austrian Federal Ministry of Agriculture;
- Forestry, Environment and Water Management;
- IFEU;
- Joint Research Centre JRC;
- Karl Franzens University of Graz;
- Münzer Bioindustrie GmbH;
- NL Enterprise Agency;
- Ministry of Economic Affairs;
- Thünen Institut Braunschweig;
- UFOP;
- Verband der Deutschen Biokraftstoffindustrie e.V. (VDB); and
- European Commission.

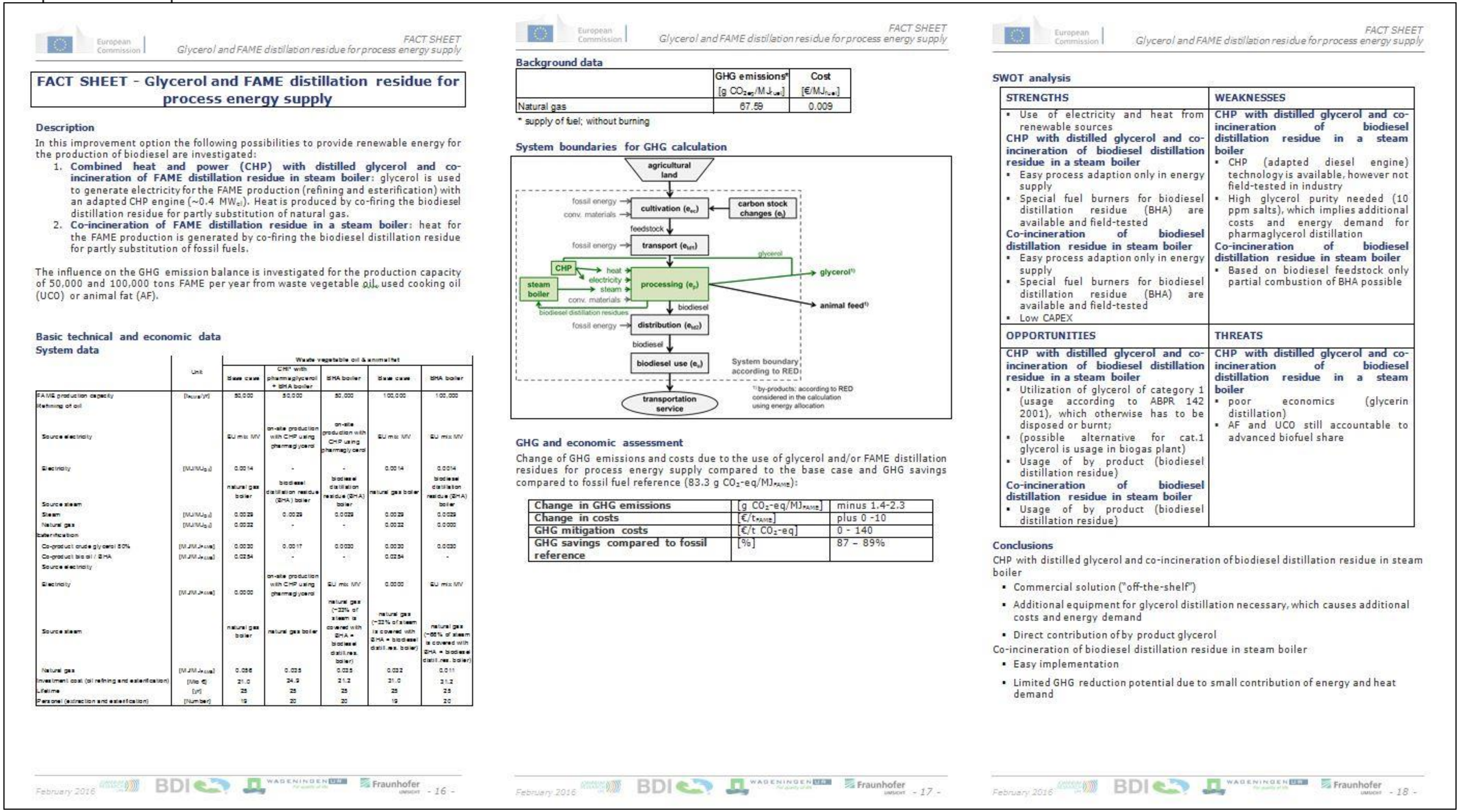
Draft final results were presented and discussed to guarantee high robustness and acceptance of the final results. The main finding of the workshop were documented (see ANNEX 3 "Stakeholder workshop documentation") and used to finalize the results of the assessment.

3.8 Fact sheet

Information on the improvement options and main results are summarized using "Fact sheets" (Figure 9). The "Fact sheets" include

- key characteristics of the improvement option;
- basic technical and economic data;
- system boundaries for GHG calculations;
- results of GHG and economic assessment (changes in GHG emissions, change in costs and GHG reduction costs compared to base case; GHG savings compared to fossil reference) in figures and tables;
- SWOT analysis; and
- conclusions.

Table 5 gives an overview which fact sheet includes which improvement options. Fact sheets can be found in "ANNEX 1: Fact sheets on improvement options."



FACT SHEET - Glycerol and FAME distillation residue for process energy supply

Description

In this improvement option the following possibilities to provide renewable energy for the production of biodiesel are investigated:

1. **Combined heat and power (CHP) with distilled glycerol and co-incineration of FAME distillation residue in steam boiler**: glycerol is used to generate electricity for the FAME production (refining and esterification) with an adapted CHP engine (~0.4 MW_{el}). Heat is produced by co-firing the biodiesel distillation residue for partly substitution of natural gas.
2. **Co-incineration of FAME distillation residue in a steam boiler**: heat for the FAME production is generated by co-firing the biodiesel distillation residue for partly substitution of fossil fuels.

The influence on the GHG emission balance is investigated for the production capacity of 50,000 and 100,000 tons FAME per year from waste vegetable oil, used cooking oil (UCO) or animal fat (AF).

Basic technical and economic data

System data

	Unit	Waste vegetable oil & animal fat				
		Base case	CHP with pharmaglycerol + BHA boiler	BHA boiler	Base case	BHA boiler
FAME production capacity	[t_{FAME}/yr]	50,000	50,000	50,000	100,000	100,000
Refining of oil						
Source electricity		EU mix MV	on-site production with CHP using pharmaglycerol	on-site production with CHP using pharmaglycerol	EU mix MV	EU mix MV
Electricity	[MJ/MJ_{Oil}]	0.0014	-	-	0.0014	0.0014
Source steam		natural gas boiler	biodiesel distillation residue (BHA) boiler	biodiesel distillation residue (BHA) boiler	natural gas boiler	biodiesel distillation residue (BHA) boiler
Steam	[MJ/MJ_{Oil}]	0.0029	0.0029	0.0029	0.0029	0.0029
Natural gas	[MJ/MJ_{Oil}]	0.0022	-	-	0.0022	0.0000
Esterification						
Co-product crude glycerol 80%	[MJ/MJ_{FAME}]	0.0030	0.0017	0.0030	0.0030	0.0030
Co-product bio oil / BHA	[MJ/MJ_{FAME}]	0.0254	-	-	0.0254	-
Source electricity						
Electricity	[MJ/MJ_{FAME}]	0.0000	on-site production with CHP using pharmaglycerol	EU mix MV	0.0000	EU mix MV
Source steam		natural gas boiler	natural gas boiler	natural gas (~33% of steam is covered with BHA = biodiesel distill.res. boiler)	natural gas (~33% of steam is covered with BHA = biodiesel distill.res. boiler)	natural gas (~66% of steam is covered with BHA = biodiesel distill.res. boiler)
Natural gas	[MJ/MJ_{FAME}]	0.056	0.035	0.035	0.032	0.011
Investment cost (oil refining and esterification)	[Mio €]	21.0	24.9	21.2	31.0	31.2
Lifetime	[yr]	25	25	25	25	25
Personel (extraction and esterification)	[Number]	19	20	20	19	20

Background data

	GHG emissions* [g CO_{2eq}/MJ_{fuel}]	Cost [€/MJ_{fuel}]
Natural gas	67.59	0.009

* supply of fuel; without burning

System boundaries for GHG calculation

GHG and economic assessment

Change of GHG emissions and costs due to the use of glycerol and/or FAME distillation residues for process energy supply compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 1.4-2.3
Change in costs	[€/t_{FAME}]	plus 0 -10
GHG mitigation costs	[€/t CO_2-eq]	0 - 140
GHG savings compared to fossil reference	[%]	87 – 89%

SWOT analysis

STRENGTHS	WEAKNESSES
▪ Use of electricity and heat from renewable sources **CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler** ▪ Easy process adaption only in energy supply ▪ Special fuel burners for biodiesel distillation residue (BHA) are available and field-tested **Co-incineration of biodiesel distillation residue in steam boiler** ▪ Easy process adaption only in energy supply ▪ Special fuel burners for biodiesel distillation residue (BHA) are available and field-tested ▪ Low CAPEX	**CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler** ▪ CHP (adapted diesel engine) technology is available, however not field-tested in industry ▪ High glycerol purity needed (10 ppm salts), which implies additional costs and energy demand for pharmaglycerol distillation **Co-incineration of biodiesel distillation residue in steam boiler** ▪ Based on biodiesel feedstock only partial combustion of BHA possible
OPPORTUNITIES	**THREATS**
CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler ▪ Utilization of glycerol of category 1 (usage according to ABPR 142 2001), which otherwise has to be disposed or burnt; ▪ (possible alternative for cat.1 glycerol is usage in biogas plant) ▪ Usage of by product (biodiesel distillation residue) **Co-incineration of biodiesel distillation residue in steam boiler** ▪ Usage of by product (biodiesel distillation residue)	**CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler** ▪ poor economics (glycerin distillation) ▪ AF and UCO still accountable to advanced biofuel share

Conclusions

CHP with distilled glycerol and co-incineration of biodiesel distillation residue in steam boiler

- Commercial solution ("off-the-shelf")
- Additional equipment for glycerol distillation necessary, which causes additional costs and energy demand
- Direct contribution of by product glycerol

Co-incineration of biodiesel distillation residue in steam boiler

- Easy implementation
- Limited GHG reduction potential due to small contribution of energy and heat demand

Figure 9: Example for a "Fact sheet" summarizing information and main results of an investigated improvement option

4 Basic data

The most relevant basic data for cultivation, processing, transport and distribution are described. (This chapter will be finalized by the End of January)

4.1 Cultivation

Some input data for the calculation of the GHG emissions from cultivation are calculated with MITERRA-Europe. MITERRA-Europe is a deterministic environmental assessment model, which calculates greenhouse gas (CO_2, CH_4 and N_2O) emissions, soil organic carbon stock changes and nitrogen emissions (N_2O, NH_3, NO_x and NO_3) on annual basis, using emission and leaching fractions. The model was developed to assess the effects and interactions of policies and measures in agriculture on N losses on a NUTS-2 (Nomenclature of Territorial Units for Statistics) level in the EU-27 (VELTHOF, 2009; LESSCHEN, 2011). Input data consist of activity data (e.g., livestock numbers and crop areas and yield from Eurostat and FAO), spatial environmental data (e.g., soil and climate data) and emission factors (IPCC and GAINS). The model includes measures to simulate carbon sequestration and mitigation of GHG and NH_3 emissions and NO_3 leaching.

The model was applied in the BiomassFutures project to assess the GHG emissions from cultivation of bioenergy crops (ELBERSEN, 2013). In DE WIT, 2014 the model was used to assess the environmental impact for different scenarios of biofuel crops, including scenarios with the application of mitigation measures.

4.1.1 Base case

The most important input data for cultivation is the crop yield and the fertilizer input, especially the nitrogen fertilizer, as that directly affects the soil N_2O emissions. Average crop yield of rapeseed, sunflower and soybean in the EU data have been derived from Eurostat for the period 2011-2014. For soybean in the United States and oil palm average crop yield data were derived from FAOSTAT. For oil palm the average of Indonesia and Malaysia, the two main producing countries, was used.

No crop specific fertilizer statistics exist in Europe, and therefore the average N fertilizer application has to be derived from indirect data sources. We collected several information sources to derive the N fertilizer application, the following sources were included:

- Maximum N application standards at member state level, derived from the national action plans for the Nitrates Directive
- Modelled N fertilizer application from MITERRA-Europe. MITERRA-Europe is a deterministic environmental assessment model, which calculates greenhouse gas emissions, soil organic carbon stock changes and nitrogen emissions on annual basis. The model uses statistical data on NUTS2 level in the EU-27 (Velthof et al., 2009; Lesschen et al., 2011).
- Estimated N demand using N content and crop yields
- Literature sources and some national fertilizer recommendations

Based on these data sources an average N fertilizer application of 168 kg N/ha was assumed to be realistic for the base case of rapeseed. This was based on 80% of the maximum N application values and also in line with fertilizer recommendations and the modelled N application (Table 7).

Table 8 shows the N_2O-emissions of the investigated feedstocks, which were used in the calculation of the GHG emissions for the base cases.

The other input data, e.g. diesel use, pesticide use and seeds, have mostly been taken from BioGrace or updated based on literature.

Table 7: Fertilizer and crop yield values used to derive the nitrogen fertilizer application for the base case

	Rapeseed	**Sunflower**	
Average max N use (ND action plans)	210	83	[kg N/ha]
Modelled N fertilizer input MITERRA	140	69	[kg N/ha]
Modelled N manure input MITERRA	17	8	[kg N/ha]
Crop yield (average 2011-2014)	3,160	1,920	[kg FM/ha]
Crop yield MITERRA (2008)	2,920	1,685	[kg FM/ha]
N demand crop product	102	54	[kg N/ha]
N demand incl. residues	159	84	[kg N/ha]
Biograce value fertilizer N input	137	39	[kg N/ha]
Proposed value (80% max N use)	**168**	**80**	[kg N/ha]

Table 8: N2O-emissions of the investigated feedstocks for the base case

Feedstock	**N_2O-emissions [kg/(ha*a)]**
Rapeseed	4.15
Sunflower	1.19
European soybean	0.73[1]
American soybean	0.68[1]
Palm oi	3.61

[1] Calculated with Biograce, assuming no N leaching (with N leaching the value would be 0.89). Values are much lower compared to previous Biograce value, as that still assumed that N fixation would cause N_2O emission as well, whereas new IPCC guidelines assume only N_2O emissions from the crop residues and not from the N fixation process

4.1.2 Improvement options

Balanced fertilization

For balanced N fertilization at least the amount of N removed with the crop product and crop residues should be replaced. The N removed in the harvested rapeseed is calculated at 102 kg N/ha, and in the crop residues 57 kg N/ha, of which one third is assumed to be removed, i.e. 19 kg N/ha. This means that at least 121 kg N/ha should be replenished. Since some N losses are inevitable, the N fertilizer application should be higher, assuming a 25% loss, which was assumed as overfertilization factor in Velthof et al. (2009), the fertilizer N application under balanced fertilization should be 151 kg N/ha. For phosphate and potassium losses are lower, and based on the nutrient contents the balanced fertilizer application would be about 60 kg P_2O_5/ha and 53 kg K_2O/ha.

Nitrification inhibitors

Based on a review (meta-analysis of 85 data sets) of Akiyama et al. (2010), the use of nitrification inhibitors reduced N_2O emissions on average by 38%. The analysis also indicated that the effectiveness of NI increased with increasing emission of N_2O. Ruser and Schulz (2015) found a realistic mitigation potential of 35%, based on a meta-analysis of 140 data sets. Oenema et al. (2014) assume a total reduction in the N_2O emission factor for fertilizer by 15-20%. Based on these data, a net reduction potential of 20% of the direct N_2O emissions was assumed. N leaching can be reduced, which we estimated at 20% less N leaching (in case N leaching is occurring), which also reduces the indirect N_2O emissions. There might be a possible yield effect (i.e. increase due to more efficient nitrogen use), but literature is not consistent on this aspect, and therefore we have not taken this into account.

4.2 Processing

4.2.1 Base case

Data (yields, energy consumption) for oil extraction of soybean, rape seed, sun flower was collected mainly from information by plant manufactures (e.g. HARBURG-FREUDENBERGER, 2015). Plausibility was checked by comparison with different literature (e.g. KALTSCHMITT, 2009).

Data for palm oil extraction and refining (mass and energy balances/demand) was collected from literature (e.g. ABDULLAH, 2013; FAO; SOMMART, 2011; OLISA, 2014; KERDSUWAN, 2011) and correspondence with manufactures (OLEOCHEMICALS, 2015) for evaluation of investment costs.

Data for the base cases of refining and esterification was collected from BDI (BioEnergy International AG, Austria) own measurements of various state-of-the-art FAME production plants (built by manufacturer BDI in the recent years, approx. 2002-2010). Data were taken from single and multi-feed stock plants of different capacities (between 50.000 to 200.000 tons per year).

4.2.2 Improvement options

Bioethanol

Cost for the ethanol dehydration plant was evaluated with kind support by GEA Wiegand and REKO.

CHP residues

Technical and economic evaluation of CHP option "CHP with straw" and "Wood-to-steam-boiler" was done by inquiry and quotation by boiler manufactures (KOHLBACH, SCHMID ENERGY).

CHP option "CHP with refined vegetable oils + steam boiler with vegetable oils" and "steam boiler with vegetable oils" were evaluated by manufactures inquiries (by BOSCH, ASTEBO -for vegetable oil burner; and LINDENBERG for CHP engines for vegetable oil respectively).

CHP option "CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler" was evaluated with kind support by manufacturer AQUAFUEL.

New plant species

Estimations of investment costs for extraction/refining of new plant species was done with kind support of KOMPTECH (especially for preparation of guayule).

4.3 Transport and distribution

4.3.1 Base case

For rapeseed, sunflower and palm oil the data on transport distances and transport modes provided in BioGrace was used. For American soybean data provided for soybean in BioGrace was used. For transport of feedstock European soybean the transport mode "truck" and the transport distance "150 km" was used. For "transport of FAME to depot" and "transport to filling station" data provided in BioGrace was used.

4.3.2 Improvement options

Transportation modes are not influenced by the investigated improvement options. Therefore the basic data is the same as for the base cases. For the improvement option "FAME in transport and distribution" instead of fossil diesel FAME was used. The amount of fuel, however, was not changed.

4.4 Background data

For the calculation of GHG emissions and the cost analysis cost data and emission factors were used for auxiliary energy, chemicals and other materials (e.g. seeds). For GHG emissions standard values provided in the BioGrace GHG calculation tool (version 4c) were used, if available. If not, information from life cycle inventory databases was used (ecoinvent or GEMIS-Global Emission Model for Integrated Systems). For the cost calculation of palm oil the costs for personal, auxiliary material and auxiliary energy were estimated to be 20% less compared to other feedstocks.

Table 9: Background data on cultivation (Source: GHG emissions: Standard values from BioGrace version 4c; Cost/price/revenues: Estimation of European average)

Description	**GHG emissions**	**Cost/price/revenue**			**Others**	**Note**
	[g CO_2-eq/kg]	[€/kg]	[€/(ha*a)]	[€/h]		
Cultivation						
N-fertiliser (kg N)	5,881	1.24				
N-fertiliser (kg N) including nitrification inhibitars	5,881	1.55				Estimation: plus 25%
CaO-fertiliser (kg CaO)	129	0.15				
K2O-fertiliser (kg K2O)	576	0.81				
P2O5-fertiliser (kg P2O5)	1,011	1.18				
Pesticides	10,971	55				
Machinery	-			15		
Seeds - rapeseed	730	20				
Seeds - soy bean	0	2				
Seeds - sunflower	730	20				
Manure	0	0				
Personal	-			20		
Land cost	-		100			
Insurance	-		25			

Table 10: Background data on auxiliary materials for processing (Source: GHG emissions: Standard values from BioGrace version 4c, if no other source is listed in table; Cost/price/revenues: Estimation of European average, if no other source is listed in table)

Description	**GHG emissions**		**Cost/Price**	**Note**
	[g CO_2-eq/kg]	[g CO_2-eq/MJ]	[€/kg]	
Auxiliary materials processing				
n-Hexane	3,631		0.95	
Methanol (conventional)		100	0.35	Cost: average price for 2015 for Methanex
Biomethanol from wood residues		5	0.67	GHG: RED; cost: estimated production cost, DBFZ
Biomethanol from cereal straw		4	0.90	GHG: same as biomethanol from wood residue; cost: estimated production cost, KIT (<1,000 €/t)
Biomethanol from glycerol		5	0.85	GHG: same as biomethanol from wood residue; purchase cost, commercial
Bioethanol from corn&wheat		13	0.75	GHG: RED; cost: IEA Bioenergy Task 42
Bioethanol from wood&straw		44	0.80	GHG: RED; cost: IEA Bioenergy Task 42
Phosphoric acid (H3PO4)	3,012		0.65	
Sodium methanolate	544		0.65	GHG: Ecoinvent 3.1 (2014)
Fuller's earth	200		0.08	
Hydrochloric acid (HCl)	751		0.12	
Sodium carbonate (Na2CO3)	1,190		0.15	
Sodium hydroxide (NaOH)	469		0.18	
Potassium hydroxide (KOH)	0		1.00	
Potassium sulphate (K2SO4)	1,459		0.11	GHG: Ecoinvent 3.1 (2014)
Sulphuric acid (H2SO4)	208		0.20	
Activated carbon	2,518		0.10	GHG: Ecoinvent 3.1 (2014) - data for carbon black production; no data on activated carbon available;
KE24 (Potassium-Ethylat 24% in EtOH)	1,459		0.90	GHG: assumption - same as K2SO4

Table 11: Background data on cost for feedstock and revenues from co-products

Description	**Price/revenue**
	[€/kg]
Feedstock and co-products	
Co-product refined glycerol (PGL 99.5+)	-0.45
Co-product crude glycerol 85%	-0.23
Co-product crude glycerol 90%	-0.25
Co-product crude glycerol (UCO, animal fat) 80%	-0.22
Co-product crude glycerol (UCO, animal fat) 80%	-0.22
Co-product bio oil / BHA (UCO, animal fat)	-0.17
FFA Phase (acidulation)	0
Glycerin distillation residue	0
Activated carbon loaded	0
Palm kernel (meal and oil)	-0.12
Rapeseed/sunflower meal	-0.24
Soybean meal	-0.32
Wheat straw	0.06
Gums (H2O content: 50%)	0
Waste cooking oil/animal fat (market price)	0.50

Table 12: Background data on fuels, steam production, CH4 and N2O emissions from boilers and CHP and electricity (Source: GHG emissions: Standard values from BioGrace version 4c, if no other source is listed in table; Cost/price/revenues: Estimation of European average, if no other source is listed in table)

Description	GHG emissions	Cost/price/revenue		Note
	[g CO_2-eq/MJ]	[€/kg]	[€/MJ]	
Fuels				
Diesel			0.023	Assumption: 1 €/l
Diesel for soybean truck US			0.012	Cost: 50% of average diesel
HFO for maritime transport	87		0.012	
FAME/Biodiesel			0.026	
Natural gas (4000 km, Russian NG quality)	66			
Natural gas (4000 km, EU Mix qualilty)	68			
Wood chips (for steam)	25	0.08	0.01	BioGrace II (Cultivation + Processing + Transport wood chips from forest residues)
Vegetable oil (for steam)	39	0.50	0.01	Own calculation (Base Case)
Steam				
Steam from natural gas			0.01	0.033 €/kWh natural gas (EUROSTAT, medium size industry - EU 28, 2015) efficiency natural gas burner: 0.9
CH_4 and N_2O emissions				
CH_4 and N_2O emissions from vegetable oil boiler	0.3			GEMIS
CH_4 and N_2O emissions from vegetable oil CHP	1.0			GEMIS
CH_4 and N_2O emissions from wood chip boiler	0.4			BioGrace II
CH_4 and N_2O emissions from glycerol CHP	1.0			Assumption: same as vegetable oil CHP
CH_4 and N_2O emissions from BHA boiler	0.3			Assumption: same as vegetable oil boiler
CH_4 and N_2O emissions from NG boiler	0.4			
CH_4 and N_2O emissions from NG CHP	0			
Electricity				
Electricity EU mix MV	128		0.022	cost: 80 €/MWh
Electricity EU mix LV	129		0.022	cost: 80 €/MWh
Renewable electricity	0		0.024	cost: 88 €/MWh

Table 13: Other cost data

Other cost data		
Personnel costs	[€/(P*a)]	45,000
Life time	[a]	25
Interest rate	[%]	5%
Insurance of investment	[%]	1%
Maintenance of investment	[%]	2%
Other costs truck	[€/(t * km)]	0.0015
Other costs ship	[€/(t * km)]	0.0001
Other costs depot	[€/t]	0.0001
Other costs filling station	[€/t]	0.0010

5 Results

This section gives an overview on the results of the various improvement options on

- greenhouse gas emissions;
- the FAME production costs;
- the greenhouse gas mitigation costs;
- SWOT analysis; as well as
- the feasibility and realization time.

For the presentation of the results in this section the improvement options are grouped in five categories:

1. "Chemicals" (Biomethanol, Bioethanol, Bioplastic & -chemicals);
2. "Energy Supply" (CHP residues, Green electricity);
3. "Cultivation" (New plant species, Advanced agriculture, Organic fertilizer);
4. "FAME as a fuel"; and
5. "Retrofitting".

Specific results for each improvement options are shown in the Fact Sheets in ANNEX 1.

5.1 Greenhouse gas emissions

5.1.1 Base cases

The results on the GHG analysis of the base cases with BAT 2015 compared to RED values with background data from BioGrace (columns with grey background) are shown in Figure 10.

The GHG analysis of the base cases shows that a significant GHG reduction in processing is possible, if BAT 2015 is used, compared to BioGrace. For the bases cases GHG emissions for cultivation (e_{ec}) are higher due to improved data on the correlation between fertilizer input and yields. Processing emissions (e_p) are lower due to higher process efficiency, lower steam demand (50 –90 %) and lower methanol demand (30 – 40 %) for BAT 2015. The FAME production capacity has a low influence on the GHG emission from processing.
In detail the following results were determined for the investigated feedstocks:

- Rapeseed: The base cases with BAT 2015 have with 47.2 – 47.9 g CO_2-eq/MJ_{FAME} lower GHG emissions compared to BioGrace with 51.7 g CO_2-eq/MJ_{FAME}, due to lower emission from processing (BioGrace: 22 g CO_2-eq/MJ_{FAME}; BAT 2015: 10 g CO_2-eq/MJ_{FAME}). The GHG emissions from cultivation of the bases cases are 36 g CO_2-eq/MJ and therefore higher than GHG emissions from cultivation in BioGrace with 29 g CO_2-eq/MJ_{FAME}. This is mainly linked to higher fertilizer input: N-fertilizer plus 30 kg/(ha*a); K_2O-fertilzer + 20 kg/(ha*a); P_2O_5-fertilser+ 46 kg/(ha*a) and higher field N_2O emissions. Fertilizer input was underestimated in default values of the RED, and therefore also in BioGrace. Figure 11 shows the GHG emissions of rapeseed cultivation in more detail.
- Sunflower: The base cases with BAT 2015 have with 42.6 – 43.3 g CO_2-eq/MJ_{FAME} total GHG emissions in the same range as BioGrace with

43 g CO_2-eq/MJ_{FAME}. However GHG emissions for cultivation and processing differ. Emissions from processing are lower for the base case compared to BioGrace. The GHG emissions from cultivation of the base cases are 31 g CO_2-eq/MJ_{FAME} and therefore higher than GHG emissions from cultivation in BioGrace with 18 g CO_2-eq/MJ_{FAME}. This is mainly linked to less yield of 1,920 kg/(ha*a) for the base cases compared to 2,440 kg/(ha*a) in BioGrace, higher N-fertilizer input of plus 41 kg/(ha*a) and higher field N_2O emissions. Fertilizer input was underestimated in default values of the RED, and therefore also in BioGrace.

- Soybean: For soybean two different regions were investigated for the base cases: American and European soybean. Both, American soybean with 40.2 – 39.9 g CO_2-eq/MJ_{FAME} and European soybean with 27.9 – 27.6 g CO_2-eq/MJ_{FAME}, have lower GHG emissions compared to BioGrace with 56.9 g CO_2-eq/MJ_{FAME}. Both regions have lower emissions in cultivation (American 13 g CO_2-eq/MJ_{FAME}; European 15 g CO_2-eq/MJ_{FAME}) and processing (11 g CO_2-eq/MJ_{FAME}) compared to BioGrace (cultivation: 19 g CO_2-eq/MJ_{FAME}; processing: 25 g CO_2-eq/MJ_{FAME}),. Lower emissions from cultivation are mainly linked to lower field N_2O emissions (0.7 kg/(ha*a) for the base cases compared to 2.23 in BioGrace. The IPCC 2006 guidelines state that the process of N fixation does not result in N_2O emissions, and only N_2O emissions from the crop residues should be included, this is different compared to the previous guidelines in which all nitrogen fixed by biological nitrogen fixation had an N_2O emission factor of 1.25 %.
- Palm oil: The base cases with BAT 2015 have with 25.7 and 25.8 g CO_2-eq/MJ_{FAME} lower GHG emissions compared to BioGrace with 36.9 g CO_2-eq/MJ_{FAME}, due to lower emissions in processing (BioGrace: 18 g CO_2-eq/MJ_{FAME}; BAT 2015: 8 g CO_2-eq/MJ_{FAME}). Also a higher yield in palm kernels is assumed in the base cases. Due to energy allocation between palm oil and palm kernels GHG emissions from cultivation are slightly lower compared to BioGrace (BAT 2015: 13 g CO_2-eq/MJ_{FAME}; BioGrace: 14 g CO_2-eq/MJ_{FAME}), although for cultivation a higher fertilizer demand and higher field N_2O emissions are assumed in the base cases.
- UCO/animal fat: The base cases with BAT 2015 have with 10.3 and 12.1 g CO_2-eq/MJ_{FAME} lower GHG emissions compared to BioGrace with 21.3 g CO_2-eq/MJ_{FAME}, due to lower emissions in processing (BioGrace: 20 g CO_2-eq/MJ_{FAME}; BAT 2015: 9-11 g CO_2-eq/MJ_{FAME}). A higher yield in bio oil/FAME distillation residue is reached in the base cases (0.025 MJ/MJ_{FAME} in the base case compared to 0.015 MJ/MJ_{FAME} in BioGrace) compared to BioGrace also leading to a reduction in processing emissions, as more GHG emissions are allocated to the co-product.

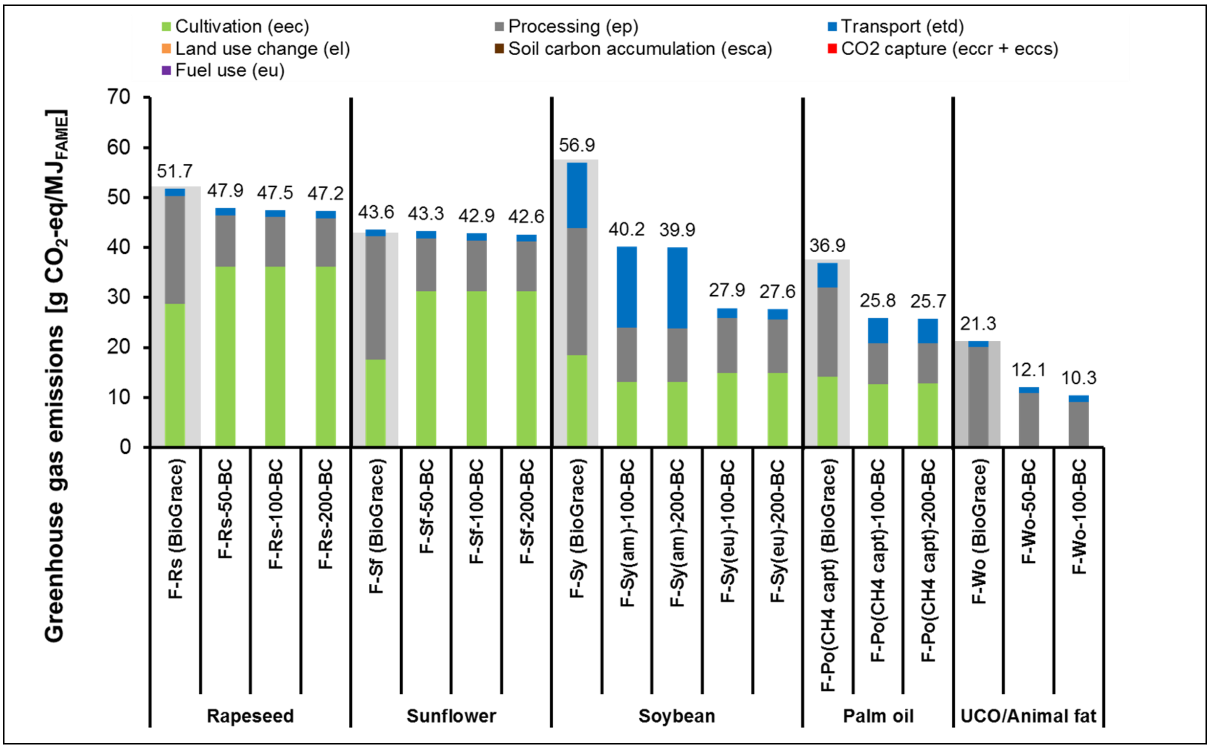


Figure 10: Greenhouse gas emissions of base cases compared to RED values with background data from BioGrace

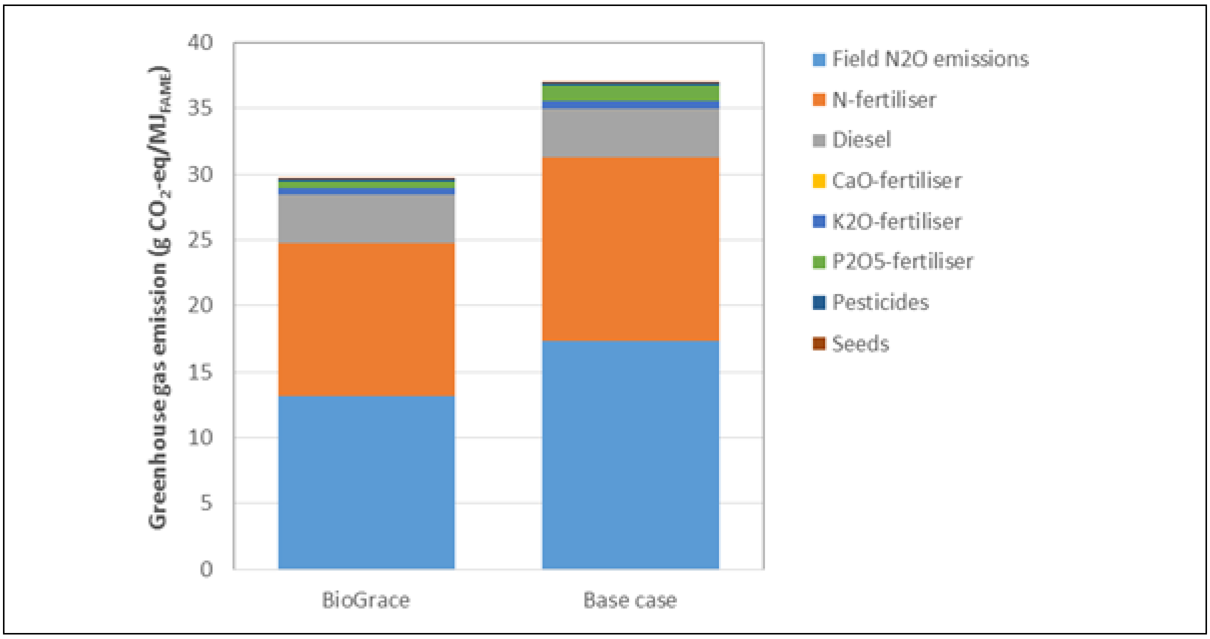


Figure 11: Detailing GHG emissions from cultivation of rapeseed for BioGrace and base case.

In the analysis on level of accuracy the main parameters from cultivation (yield, amount of fertilizer and fuel, as well as field N_2O-emissions) and methanol demand in processing of FAME are varied between an estimated maximum and minimum value. The results on the analysis on level of accuracy of selected base cases (FAME production capacity 100 kt per year) are shown in Figure 12 and Table 14. The uncertainty range for UCO/animal fat is rather low, as the variation of parameter in cultivation has no influence here. For FAME production from cultivated feedstock ranges are higher due to higher uncertainties in data on cultivation and strong influence of these parameters like yield, fertilizer amount and field N_2O-emissions on the total GHG results.

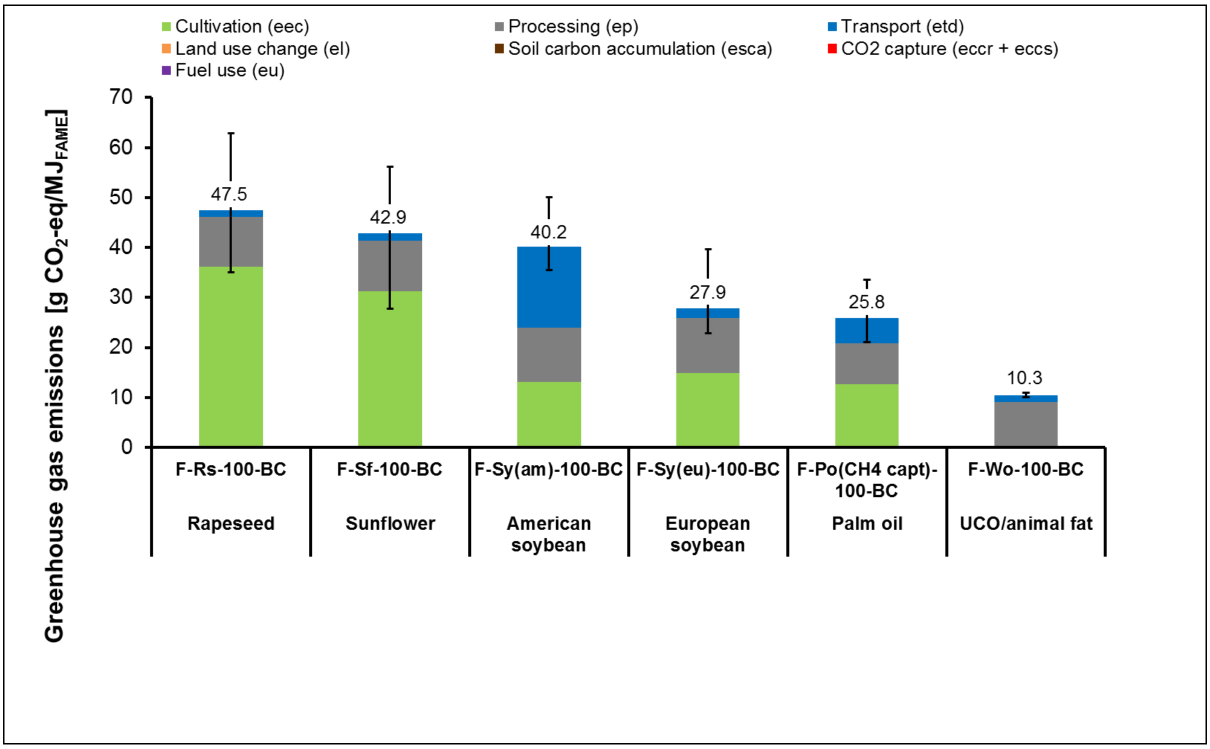


Figure 12: Analysis on level of accuracy of selected base cases (FAME production capacity 100 kt per year)

Table 14: Average value of GHG emissions and possible range for the base cases (FAME production capacity 100 kt per year)

Feedstock	**GHG emissions of FAME production**	
	Average value [g CO_2-eq/MJ_{FAME}]	**Range [g CO_2-eq/MJ_{FAME}]**
Rape seed	47.5	35 - 63
Sunflower	42.9	28 - 56
American soybean	40.2	35 - 50
European soybean	27.9	23 - 40
Palm oil	25.8	21 - 34
UCO/animal fat	10.3	10 - 11

The GHG emission savings of bases cases and of RED values with background data from BioGrace are shown in Figure 13. The following results were determined for the investigated feedstocks:

- Rape seed: the base case with BAT 2015 has with 43 – 44 % a higher GHG saving compared to BioGrace with 38 %;
- Sunflower: the base case with BAT 2015 has with 48 – 49 % a similar GHG saving compared to BioGrace with 48 %;
- Soybean: the base case with BAT 2015 has with 52 % for American and 67 % for European soybean a significant higher GHG saving compared to BioGrace with 32 %;
- Palm oil: the base case with BAT 2015 has with 69 % a significant higher GHG saving compared to BioGrace with 56 %;
- UCO/animal fat: the base case with BAT 2015 has with 86 – 88 % a significant higher GHG saving compared to BioGrace with 75 %.

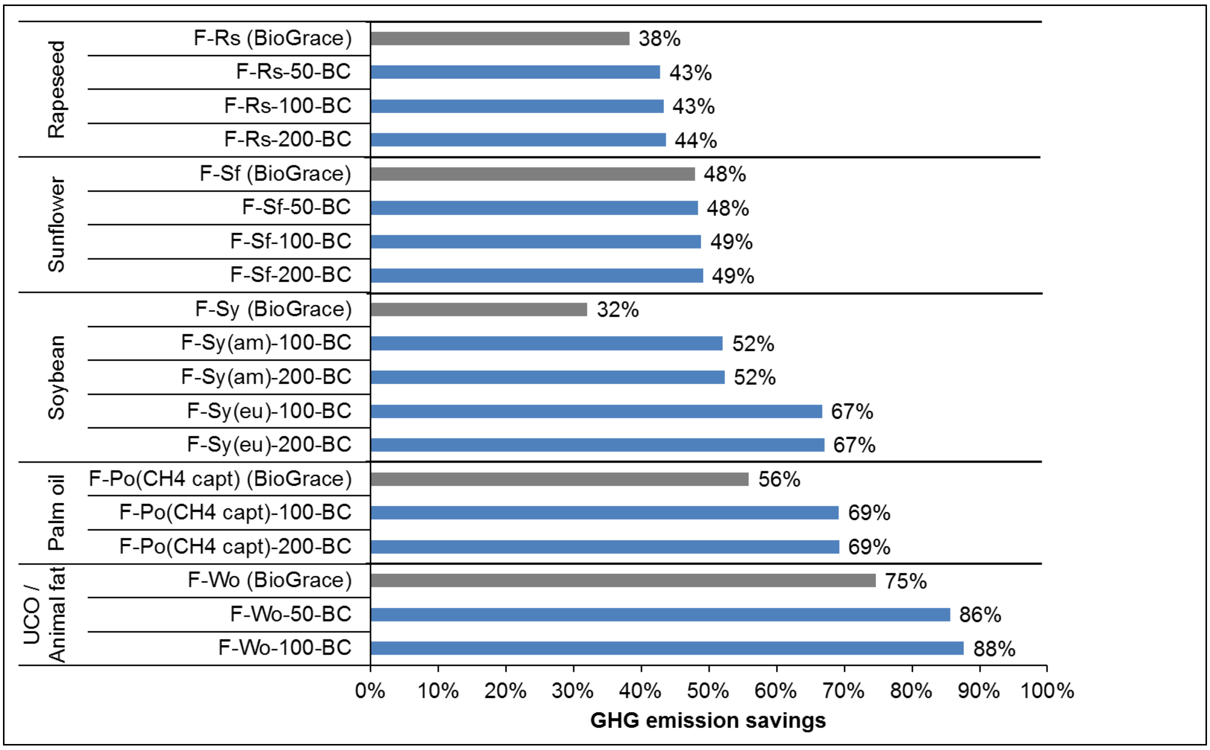


Figure 13: GHG emission savings of base cases and of RED values with background data from BioGrace

5.1.2 Improvement options

Chemicals

The GHG emissions of the improvement options "Biomethanol", "Bioethanol", "Pharmaglycerol 99.5+" and "Succinic acid from straw" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a and 200 kt/a) are shown in Figure 14.

The improvement options with biomethanol have GHG saving of 4.7 g CO_2-eq/MJ_{FAME} compared to the base case, due to lower GHG emissions for biomethanol produced from wood residues or straw (4-5 g CO_2-eq/MJ) than for conventional methanol (100 g CO_2-eq/MJ).

Using bioethanol instead of conventional methanol leads to a GHG saving of 0.4 to 2.0 g CO_2-eq/MJ_{FAEE}[4]. This option was investigated for a FAEE production capacity of 200 kt with GHG emissions of 47.2 g CO_2-eq/MJ_{FAME} for the base case. If bioethanol is produced from wheat (Option "Bioethanol from wheat as process chemical") the GHG emissions result in 46.8 g CO_2-eq/MJ_{FAEE}; if bioethanol is produced from straw (Option "Bioethanol from straw as process chemical) GHG emissions result in 45.2 g CO_2-eq/MJ_{FAEE}.

The GHG emission of option "Pharmaglycerol 99.5+" are with 46.0 g CO_2-eq/MJ lower compared to the base case with 47.5 g CO_2-eq/MJ, which shows that the additional GHG emissions from the energy demand for the production of pharmaglycerol are compensated by the heating value of the pharmagylcerol, which is used for energy allocation between FAME and pharmaglycerol.

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[4] If bioethanol is used instead of methanol fatty acid ethyl ester (FAEE) is produced, with very similar characteristics as fatty acid methyl ester (FAME).

For the "Succinic acid from straw + glycerol" GHG emissions add up to 49.4 g CO_2-eq/MJ_{FAME}. In this case the additional GHG emissions from the energy and material demand for the production of succinic acid are not compensated by the heating value of succinic acid and other co-products (acetic acid, glycerol) which is used for energy allocation between FAME and succinic acid (incl. additional co-products).

The option "Biomethanol from cereal straw as process chemical" was also investigated for the feedstock American soybean and UCO/animal fat. Results on the GHG emissions compared to the corresponding base cases are shown in Figure 15. For American soybean the use of biomethanol from cereal straw leads to GHG emissions of 35.5 g CO_2-eq/MJ_{FAME} compared to the base case for American soybean with 40.2 g CO_2-eq/$MJ_{FAME.}$ For UCO/animal fat the use of biomethanol from cereal straw leads to GHG emissions of 4.8 g CO_2-eq/MJ_{FAME} compared to the base case for UCO/animal fat with 10.3 g CO_2-eq/$MJ_{FAME.}$

Figure 15 also shows the GHG emissions of option "Pharmaglycerol 99.5+" for the feedstock UCO/animal fat. With 11.4 g CO_2-eq/MJ_{FAME} GHG emissions of the option "Pharmaglycerol 99.5+" are approximately 1 g higher compared to the base case. In this case additional GHG emissions from the energy demand for the production of pharmaglycerol are not compensated by the heating value of pharmaglycerol. For UCO/animal fat the influence of energy allocation between FAME and pharmaglycerol is less as there are not GHG emissions from cultivation and feedstock collection, which are allocated.

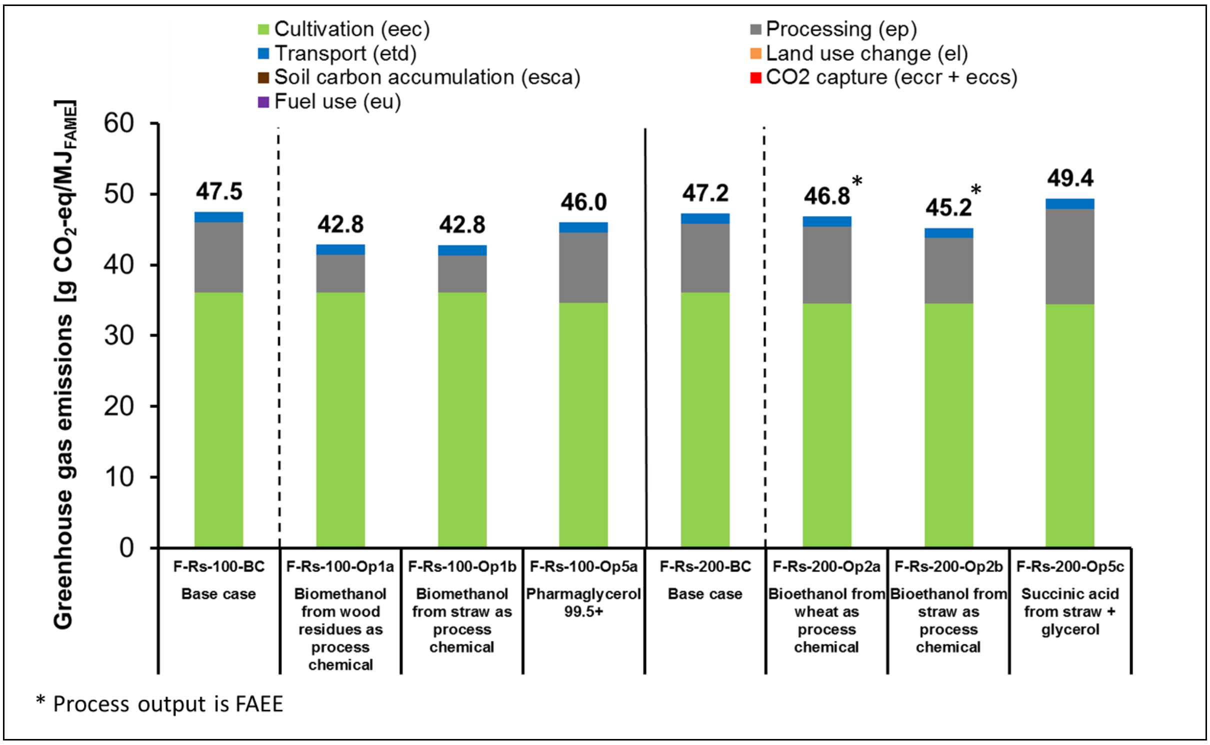


Figure 14: GHG emissions of improvement options "Biomethanol", "Bioethanol", "Pharmaglycerol 99.5+" and "Succinic acid from straw" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a and 200 kt/a)

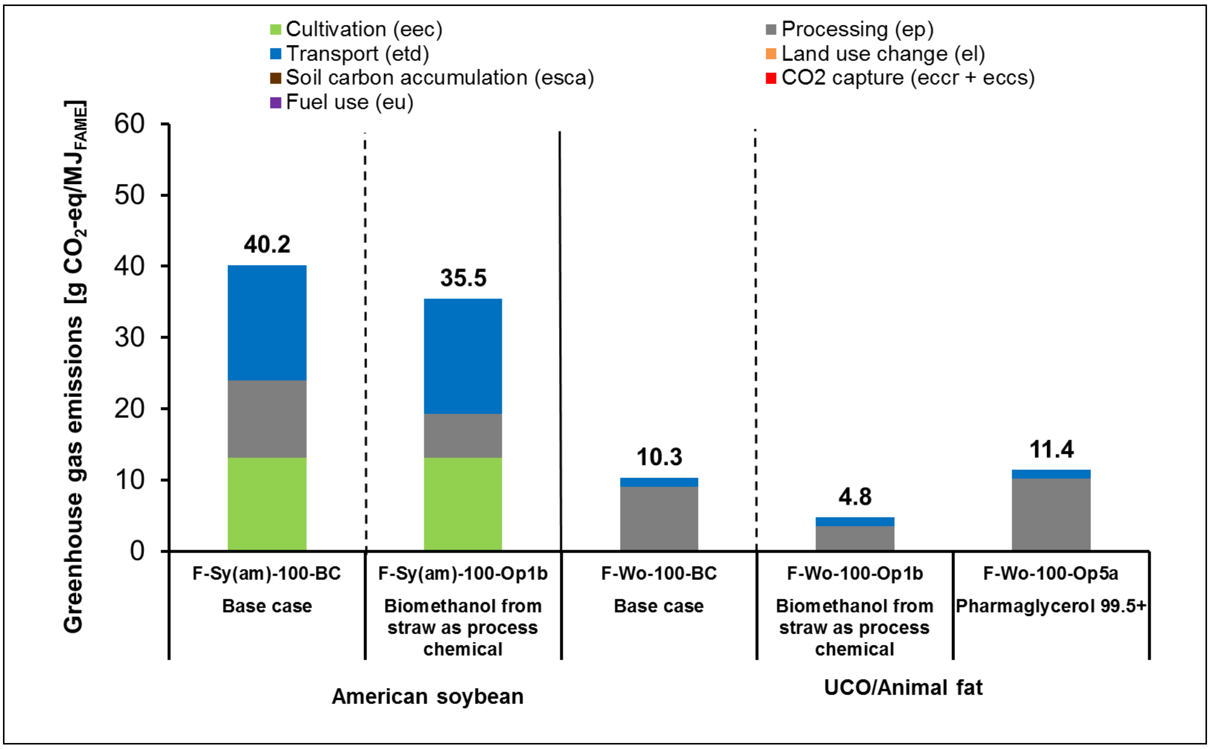


Figure 15: GHG emissions of improvement option "Biomethanol" and "Pharmaglycerol 99.5+" compared to the corresponding base cases (feedstock: American soybean and UCO/animal fat; FAME production capacity: 100 kt/a)

Energy supply

The GHG emissions of improvement option "CHP with refined vegetable oils + steam boiler with vegetable oils", "Steam boiler with vegetable oils", "Wood-to-steam boiler" and "Green electricity" compared to the corresponding base case (feedstock: rapeseed; FAME production capacity: 200 kt/a) are shown in Figure 16. The results in Figure 16 shows that the GHG emissions of

- the Options "CHP with refined vegetable oils+steam boiler with vegetable oils", "Steam boiler with vegetable oils" and "Wood-to-steam boiler" with 45.9 – 46.3 g CO_2-eq/MJ_{FAME} are slightly lower compared to the base case with 47.2 g CO_2-eq/MJ_{FAME}. The differences between the different fuels for the energy supply for FAME processing are low.
- the Option "Green electricity from PV plant on site" are the same as the base case.

The use of renewable energy for the processing of FAME was also investigated for the feedstock UCO/animal fat. Figure 17 shows the GHG emissions of improvement option "CHP with distilled glycerol + co-incineration of FAME distillation residues in steam boiler", "Co-incineration of FAME distillation residues in steam boiler" and "Green electricity" compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 50 kt/a and 100 kt/a). The following results were obtained for UCO/animal fat for the investigated FAME production capacities:

- 50 kt FAME production capacity:
  - GHG emissions of Option "CHP with distilled glycerol + co-incineration of FAME distillation residues in steam boiler" with 9.8 g CO_2-eq/MJ_{FAME} are 2.3 g lower compared to the base case with 12.1 g CO_2-eq/MJ_{FAME};

  - GHG emissions of Option "Co-incineration of FAME distillation residues in steam boiler" with 10.7 g CO_2-eq/MJ_{FAME} are 1.4 g lower compared to the base case with 12.1 g CO_2-eq/MJ_{FAME};
  - GHG emissions of Option "Green electricity" with 11.5 g CO_2-eq/MJ are slightly lower compared to the base case with 12.1 g CO_2-eq/MJ;
- 100 kt FAME production capacity:
  - GHG emissions of Option "Co-incineration of FAME distillation residues in steam boiler" with 8.9 g CO_2-eq/MJ are 1.4 g lower compared to the base case with 10.3 g CO_2-eq/MJ;
  - GHG emissions of Option "Green electricity" with 10.1 g CO_2-eq/MJ are slightly lower compared to the base case with 10.3 g CO_2-eq/MJ.

The option "Green electricity" has a stronger influence on the GHG emissions of FAME plants using UCO/animal fat compared to rapeseed, because the electricity demand for the same FAME production capacity is higher in plants using UCO/animal fat than in plants using rapeseed.

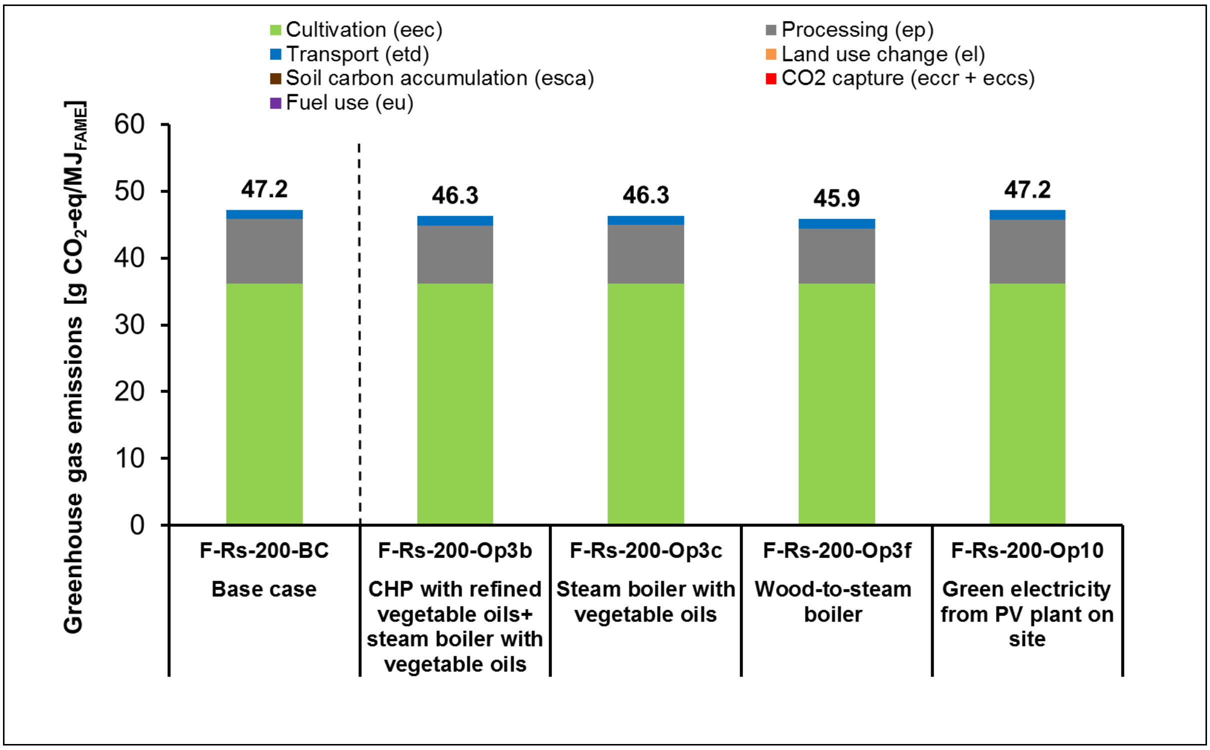


Figure 16: GHG emissions of improvement option "CHP with refined vegetable oils + steam boiler with vegetable oils", "Steam boiler with vegetable oils", "Wood-to-steam boiler" and "Green electricity from PV plant on site" compared to the corresponding base case (feedstock: rapeseed; FAME production capacity: 200 kt/a)

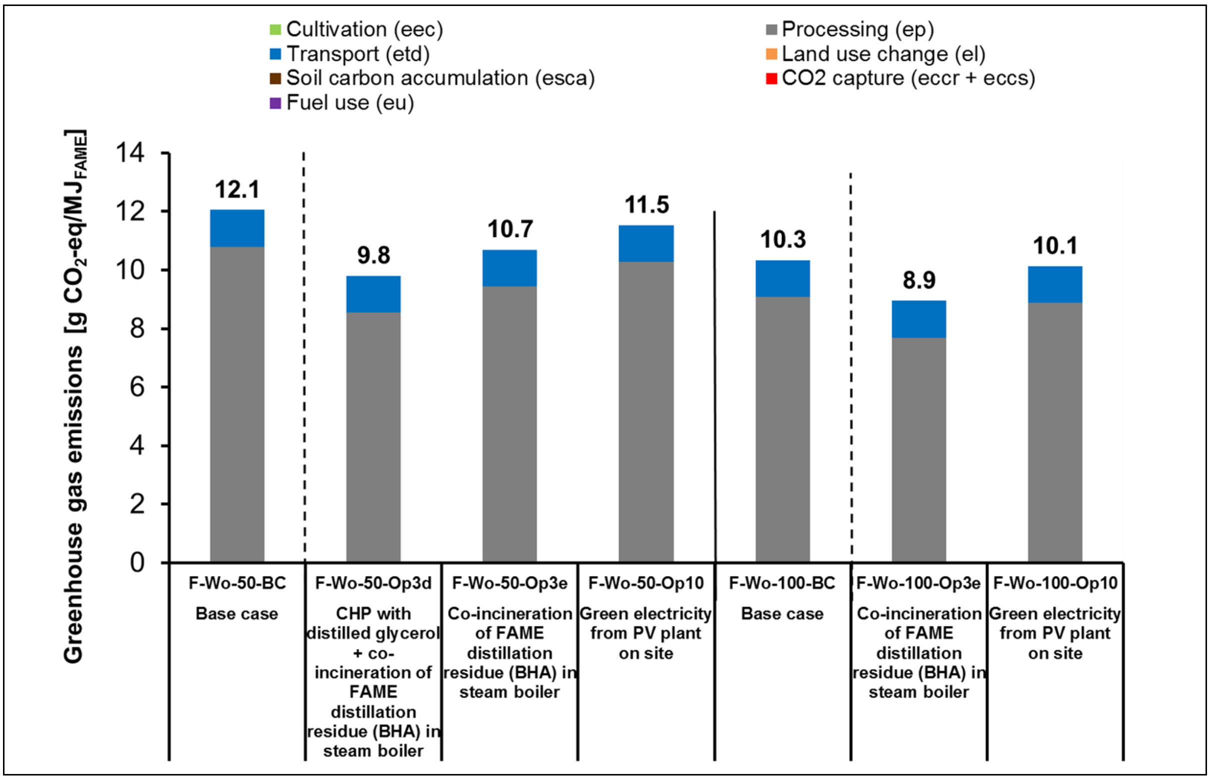


Figure 17: GHG emissions of improvement option "CHP with distilled glycerol + co-incineration of FAME distillation residues (BHA) in steam boiler", "Co-incineration of FAME distillation residues (BHA) in steam boiler" and "Green electricity from PV plant on site" compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 50 kt/a and 100 kt/a)

Cultivation

The GHG emissions of improvement options "Balanced fertilization", "Nitrification inhibitors", "Crop residue management", "Reduced tillage" and "Organic fertilizer" compared to the corresponding base case (feedstock: rapeseed; FAME production capacity: 100 kt/a) are shown in Figure 18. The options "Balanced fertilization" and "Nitrification inhibitors" have GHG emissions of 44.4 g CO_2-eq/MJ_{FAME}. Compared to the base case with 47.5 g CO_2-eq/MJ_{FAME} these options result in a GHG saving of 3.1 g CO_2-eq/MJ_{FAME}.

The difference of the option "Balanced fertilization" to the base case is less fertilizer use:

- N-fertilizer: 151 instead of 168 kg/(ha*a)
- K_2O-fertilizer: 53 instead of 70 kg/(ha*a), and
- P_2O_5-fertilizer: 60 instead of 80 kg/(ha*a) use;

Due to less N-fertilizer use also field N_2O emissions are reduced to 3.83 instead of 4.15 kg/(ha*a).

In the option "Nitrification inhibitors" field N_2O emissions are reduced (3.38 instead of 4.15 kg/(ha*a)), as nitrification inhibitors slow the conversions of N from the relatively immobile ammonium (NH_4) form to the mobile nitrate (NO_3) form.

The option "Crop residue management" shows the highest GHG saving compared to the base case. The total GHG emissions of "Crop residue management" are 26.5 g CO_2-eq/MJ_{FAME}, which leads to a saving of 21 g CO_2-eq/MJ_{FAME}. This significant saving is linked to “emission saving from soil carbon accumulation via improved agricultural management (e_{sca})”, which are subtracted from GHG emissions from cultivation, processing, transport and distribution and fuel use. Crop residue incorporation, where stubble and straw is left on the field ground and incorporated when the field is tilled, enhances carbon flow back to the soil, thereby encouraging carbon sequestration. Resulting soil carbon accumulation in this option was determined with 0.78 t CO_2/(ha*a). However, soil carbon accumulation is not a permanent process. It will stop after a certain time, when the new equilibrium of carbon is reached.

Also the options “Reduced tillage” and “Organic fertilizer‟ show GHG emission savings compared to the base case. “Reduced tillage” reduces the GHG emissions by 7.0 g CO_2-eq/MJ_{FAME} and “Organic fertilizer” by 10.1 g CO_2-eq/MJ_{FAME}. GHG emissions in cultivation are only slightly reduced by these measures (Base case: 36.1 g CO_2-eq/MJ_{FAME}; Reduced tillage: 35.8 g CO_2-eq/MJ_{FAME}; Organic fertilizer: 34.9 g CO_2-eq/MJ_{FAME}). The main GHG saving is linked to soil carbon accumulation (Reduced tillage: 0.28 t CO_2/(ha*a); Organic fertilizer: 0.37 t CO_2/(ha*a) leading to “emissions savings from soil carbon accumulation via improved agricultural management (e_{sca})” of 6.6 g CO_2-eq/MJ_{FAME} for reduced tillage and 8.8 g CO_2-eq/MJ_{FAME} for organic fertilizer, which are subtracted from GHG emissions from cultivation, processing, transport and distribution and fuel use.

For the feedstock palm oil two improvement options were analysed “Balanced fertilization” and “Return nutrients from palm oil residues as fertilizer”. Figure 19 shows the GHG emissions of these options compared to the base case with a FAME production capacity of 100 kt/a. With palm oil as feedstock “Balanced fertilization” leads to GHG emissions of 25.1 g CO_2-eq/MJ_{FAME}, which is slightly lower than the GHG emissions of the base case with 25.8 g CO_2-eq/MJ_{FAME}. Differences in fertilizer use compared to the base case for palm oil are:

- N-fertilizer: 155 instead of 167 kg/(ha*a)
- K_2O-fertilizer: 310 instead of 333 kg/(ha*a), and
- P_2O_5-fertilizer: 131 instead of 144 kg/(ha*a) use;

Field N_2O emissions are reduced slightly (3.54 instead of 3.61 kg/(ha*a)).

To return nutrients from palm oil residues as fertilizers has a higher GHG reduction potential. “Return nutrients from palm oil residues as fertilizer” has GHG emissions of 14.6 g CO_2-eq/MJ_{FAME} compared to the base case with 25.8 g CO_2-eq/MJ_{FAME}, leading to a GHG reduction of 11.2 g CO_2-eq/MJ_{FAME}. Again the saving is mainly linked to carbon accumulation in the soil, being 1.5 t CO_2/(ha*a), compared to the base were it was assumed that palm oil residues are not returned to the field. This leads to “emission saving from soil carbon accumulation via improved agricultural management (e_{sca})” of 10.1 g CO_2-eq/MJ_{FAME}, which is subtracted from GHG emissions from cultivation, processing, transport and distribution and fuel use.

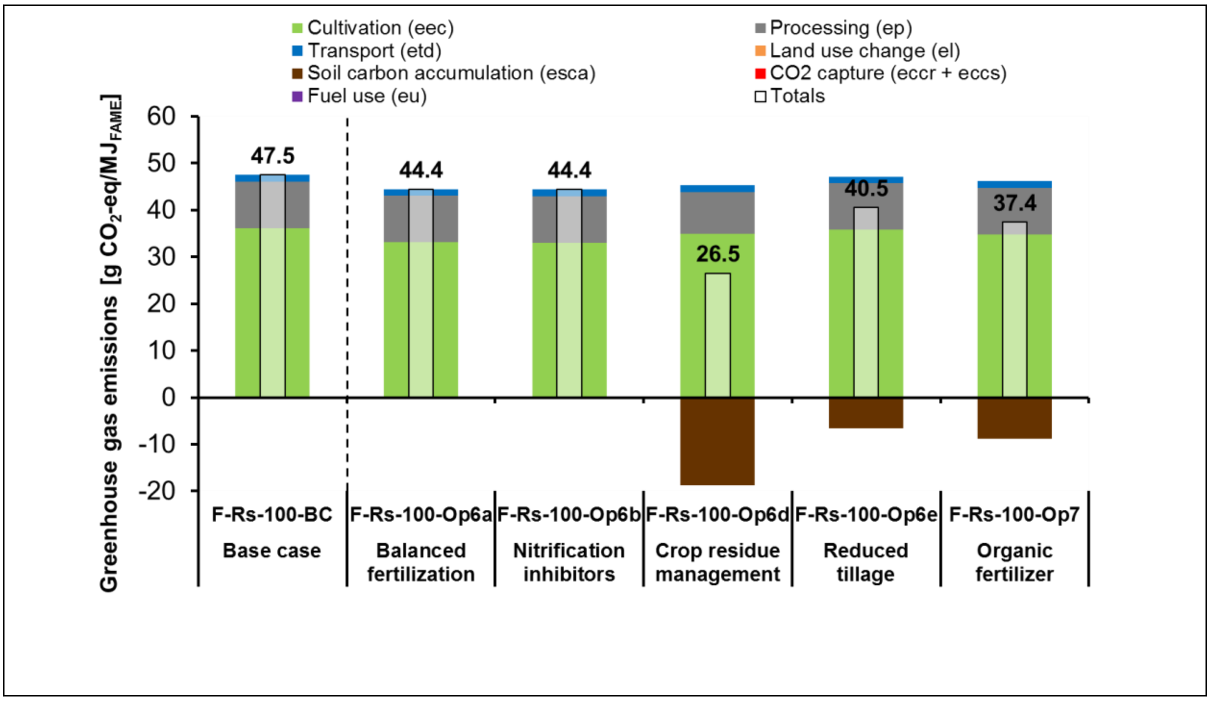


Figure 18: GHG emissions of improvement option "Balanced fertilization", "Nitrification inhibitors", "Crop residue management", "Reduced tillage" and "Organic fertilizer" compared to the corresponding base case (feedstock: rapeseed; FAME production capacity: 100 kt/a)

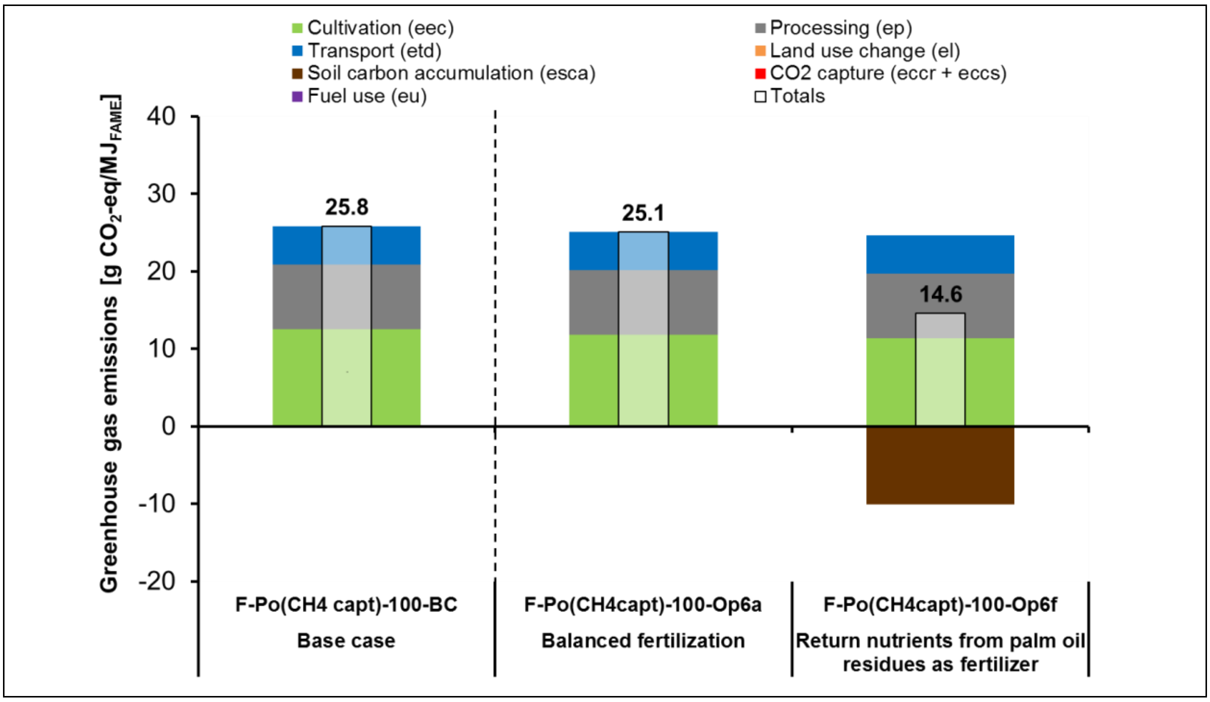


Figure 19: GHG emissions of improvement option "Balanced fertilization" and "Return nutrients from palm oil residues as fertilizer" compared to the corresponding base case (feedstock: palm oil; FAME production capacity: 100 kt/a)

Fame as fuel

The GHG emissions of improvement options "FAME in cultivation" and "FAME in transport + distribution" compared to the corresponding base cases (feedstock: rapeseed and American soybean; FAME production capacity: 100 kt/a) are shown in Figure 20.

The use of FAME in machinery for cultivation processes instead of fossil diesel results in a GHG saving of 1.6 g CO_2-eq/MJ_{FAME} for rapeseed and 2.2 g CO_2-eq/MJ_{FAME} for American soybean. The use of FAME instead in transport and distribution processes of fossil diesel results only results in a low GHG saving compared to the base case. For rapeseed the option "FAME in transport + distribution" has 47.2 g CO_2-eq/MJ_{FAME} compared to the base case with 47.5 g CO_2-eq/MJ_{FAME}. For American soybean the option "FAME in transport + distribution" has 37.8 g CO_2-eq/MJ_{FAME} compared to the base case with 40.2 g CO_2-eq/MJ_{FAME}. The influence is stronger for American soybean as longer transportation distances on land to the harbour are needed compared to rapeseed. However, the major share of GHG emissions of transport and distribution are still generated by the ship transport, where heavy fuel oil is used and no replacement by FAME was considered.

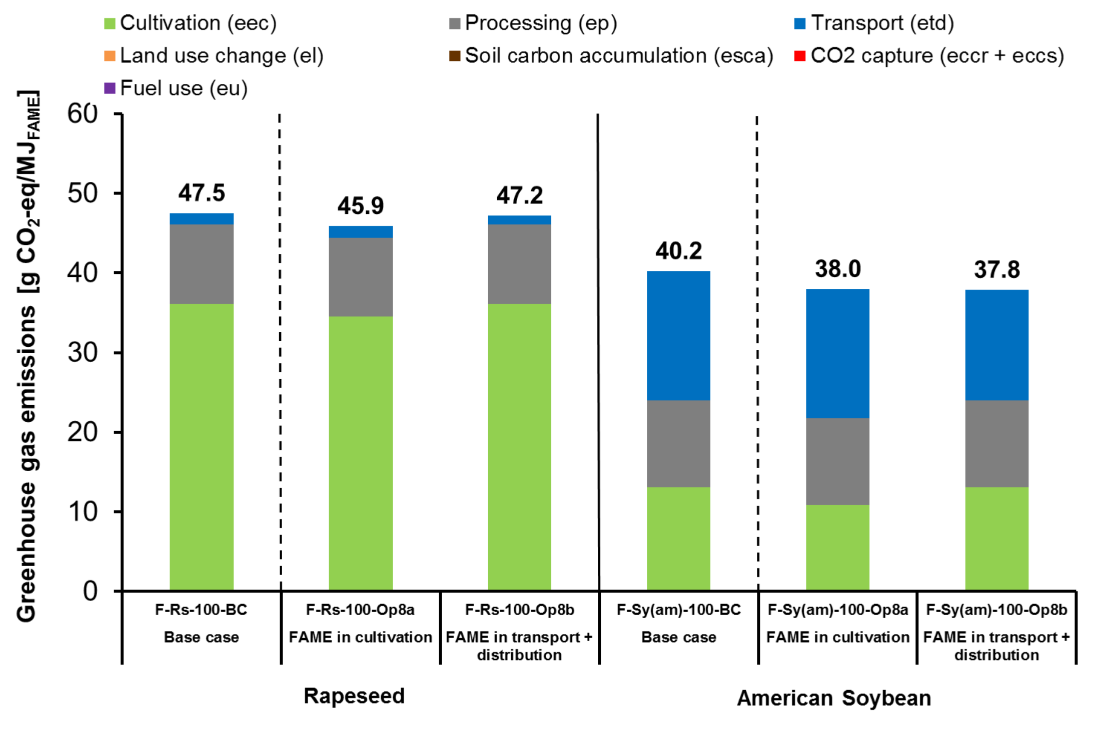
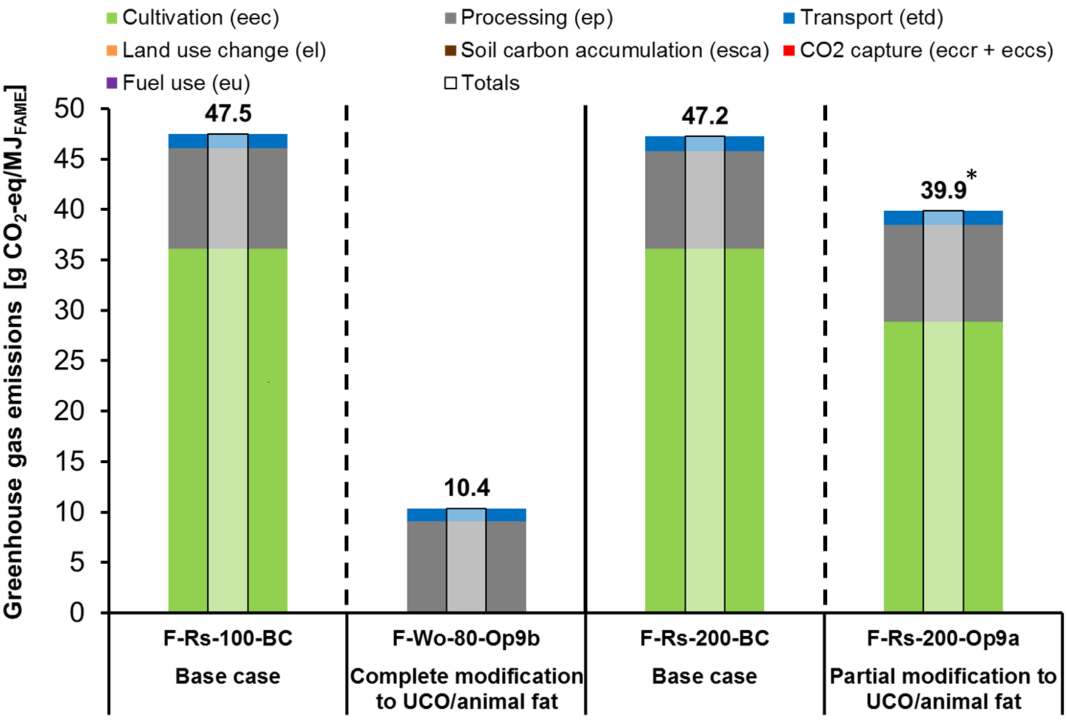


Figure 20: GHG emissions of improvement options "FAME in cultivation" and "FAME in transport + distribution" compared to the corresponding base cases (feedstock: rapeseed and American soybean; FAME production capacity: 100 kt/a)

Retrofitting

Two options are investigated for the modification of existing vegetable oil plants for blending fatty residues: "Complete modification to UCO/animal" and "Partial modification to UCO/animal fat". The results on the GHG emissions for these options compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 80°kt/a, 100 kt/a and 200°kt/a) are shown in Figure 21.
The option "Complete modification to UCO/animal fat" has significantly lower GHG emissions (10.4. g CO_2-eq/MJ_{FAME}) compared to the base case with rapeseed (47.5 g CO_2-eq/MJ_{FAME}), mainly because the GHG emissions for feedstock cultivation of 36 g CO_2-eq/MJ_{FAME} are avoided. However, the production capacity of the plant is reduced from 100 kt to 80 kt FAME per year due to the modification. In the option "Partial modification to UCO/animal fat" the feedstock for the FAME production consists of 80% vegetable oil from rapeseed and 20% UCO/animal fat. Here the GHG emissions are reduced from 47.2 to 39.9 g CO_2-eq/MJ_{FAME}, due to 20% reduced rapeseed cultivation.



* According to the "Communication from the Commission on voluntary schemes and default values in the EU biofuels and bioliquids sustainability scheme (2010/C 160/01)" separate values have to be presented for mixed feedstock streams. Here one value is presented to show the influence of the improvement option.

Figure 21: GHG emissions of improvement options "Retrofitting" compared to the corresponding base case (feedstock: UCO/animal fat; FAME production capacity: 80°kt/a, 100 kt/a and 200°kt/a)

5.2 Production costs

All costs presented in this section are rounded to 10 €/t_{FAME} as this is an indication for a possible cost change.

5.2.1 Base case

The production costs and revenues of co-products for the investigated base cases are shown in Figure 22. For calculating the total FAME production costs (blue columns) the revenues of co-products (grey columns) are subtracted from the production costs (green columns). Production costs include costs for feedstock (costs of cultivation or market price for UCO/animal fat), costs of FAME processing and costs of transport and distribution. The results in Figure 22 show that revenues of co-products have a significant influence on the total costs of FAME. For production of FAME from rapeseed, sunflower and soybean more than 90 % of the revenues are from animal feed, as a co-product from oil extraction. In terms of plant capacity the specific costs in €/t_{FAME} are slightly lower for plants with higher production capacity.

In detail the following results were determined for the investigated feedstocks:

- Rapeseed: Production costs range between 990 and 1,040 €/t_{FAME}, depending on the plant size. Revenues of co-products are 390 €/t_{FAME} leading to total costs of 600 – 650 €/t_{FAME}.
- Sunflower: Production costs range between 1,360 and 1,410 €/t_{FAME}, depending on the plant size. Revenues of co-products are 400 €/t_{FAME} leading to total costs of 960 – 1,010 €/t_{FAME}.
- Soybean: Production costs from American soybean are 2,020 €/t_{FAME} for 100 kt FAME per year and 2,000 €/t_{FAME} for 200 kt FAME per year. Cost for production of FAME from European soybean is higher with 2,260 for 100 kt FAME per year

and 2,240 FAME per year. Revenues of co-products are high with 1,510 €/t_{FAME}. This is explained by the lower oil content compared to rapeseed at the oil extraction and therefore high share of cake used as animal feed from soybeans: at the extraction of 1 ton of oil 4.4 tons of cake are co-produced. This leads to total costs of 490 – 510 €/t_{FAME} for American soybean and 730 – 750 €/t_{FAME} for European soybean.

- Palm oil: Production costs of FAME are 350 – 370 €/t_{FAME}. Revenues from co-products are 70 €/t_{FAME}. This is lower compared to rapeseed, sunflower and soybean as no animal feed is generated with palm oil. Revenues are generated from selling palm kernel and crude glycerol. Subtracting revenues of co-products from production costs lead to total costs of 280 – 300 €/t_{FAME}.
- UCO/animal at: Production costs of FAME are 630 – 660 €/t_{FAME}. Feedstock costs were determined based on average market prices for UCO/animal fat in 2015 of 500 €/t_{oil}. Revenues from co-products are 30 €/$_{FAME}$ and mainly generated from selling crude glycerol. Subtracting revenues of co-products from production costs lead to total costs of 630 – 660 €/t_{FAME}.

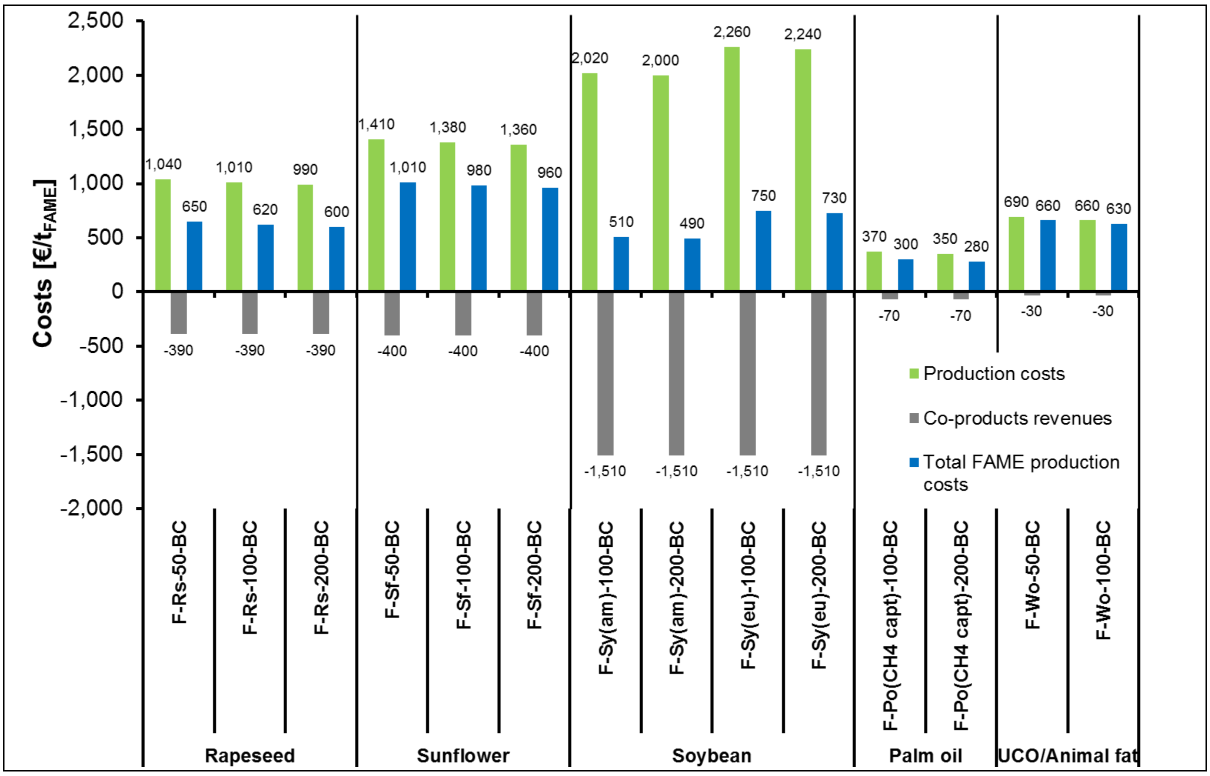
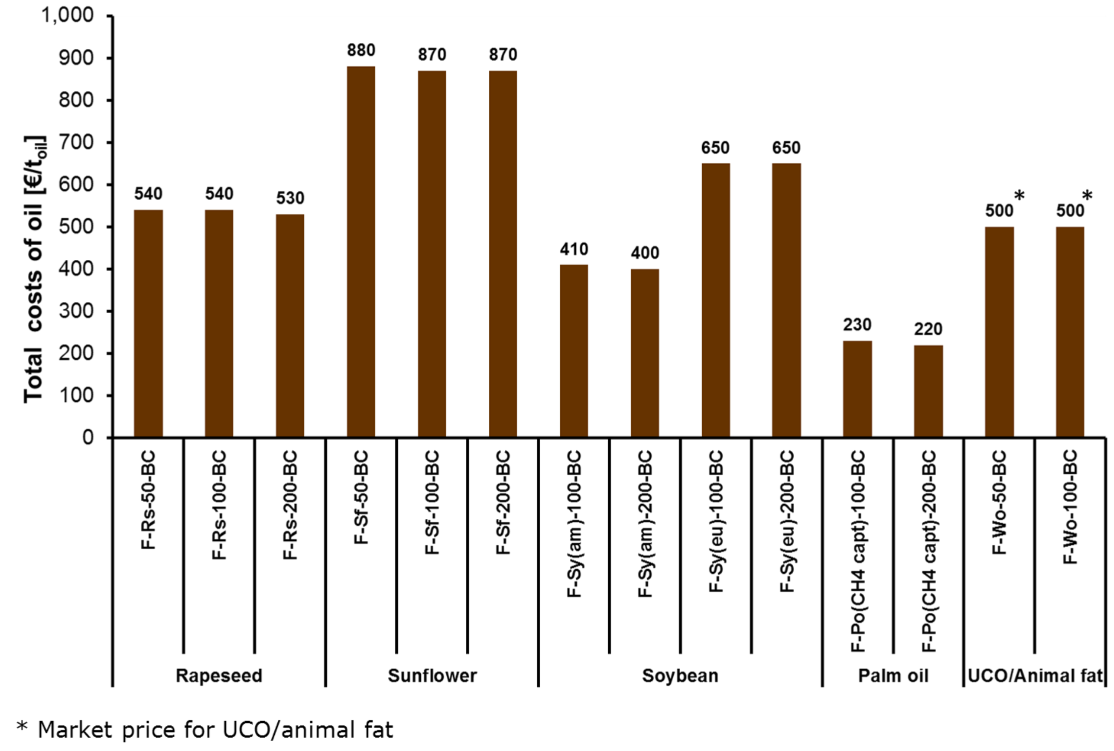


Figure 22: FAME production costs and revenues of co-products for base cases

Figure 23 shows the total costs of oil for the base cases. The total cost of oil include costs of feedstock cultivation, costs of oil extraction and revenues of co-products (cake and palm kernel). In the case of UCO/animal fat the average market price is shown. Costs of rapeseed oil are 530 – 540 €/t_{oil}, of sunflower oil are 870-880 €/t_{oil}, of American soybean oil are 400 – 410 €/t_{oil}, of European soybean oil 650 €/t_{oil}, of palm oil 220 – 230 and of oil from UCO/animal fat 500 €/t_{oil}.



* Market price for UCO/animal fat

Figure 23: Total costs of oil including revenues of co-products for base cases

In the analysis on level of accuracy main parameter from cultivation (yield, amount of fertilizer and fuel) and methanol demand in processing of FAME are varied between an estimated maximum and minimum value. The results on the analysis on level of accuracy of selected base cases with a FAME production capacity 100 kt per year are shown in Figure 24. The uncertainty range for UCO/animal fat is rather low, as the variation of parameter in cultivation has no influence here. For FAME production from cultivated feedstock cost ranges are higher due to higher uncertainties in data on cultivation and strong influence of yield on the production costs.

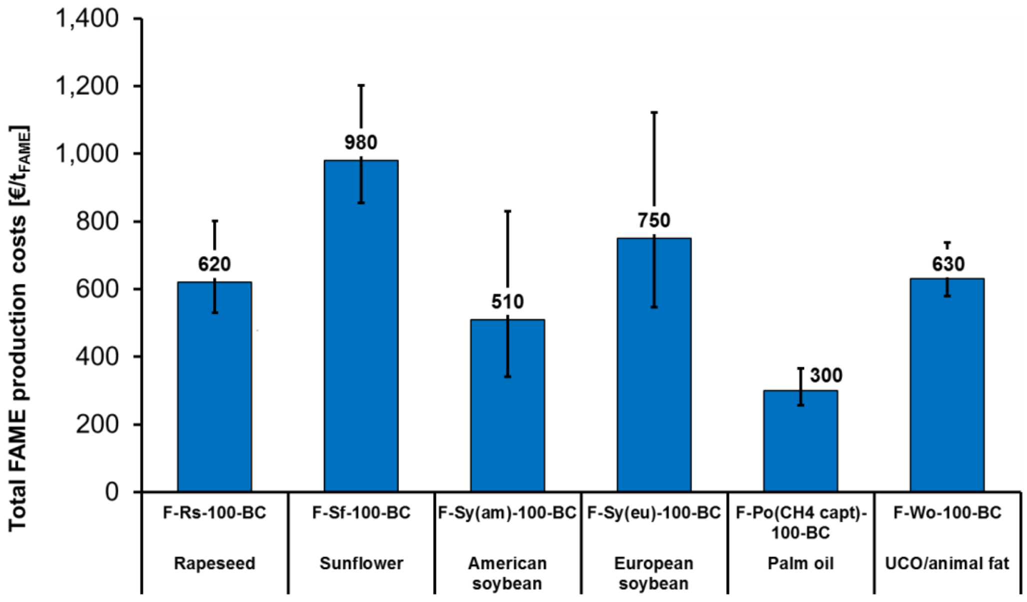


Figure 24: Analysis on level of accuracy of selected base cases (FAME production capacity 100 kt per year)

Table 15: Average value of FAME production costs and possible range for the base cases (FAME production capacity 100 kt per year)

Feedstock	**FAME production cost**	
	Average value [€/t_{FAME}]	**Range [€/t_{FAME}]**
Rape seed	620	530 – 800
Sunflower	980	860 – 1,200
American soybean	510	340 – 830
European soybean	750	550 – 1,120
Palm oil	300	250 – 360
UCO/animal fat	630	580 - 740

5.2.2 Improvement options

Chemicals

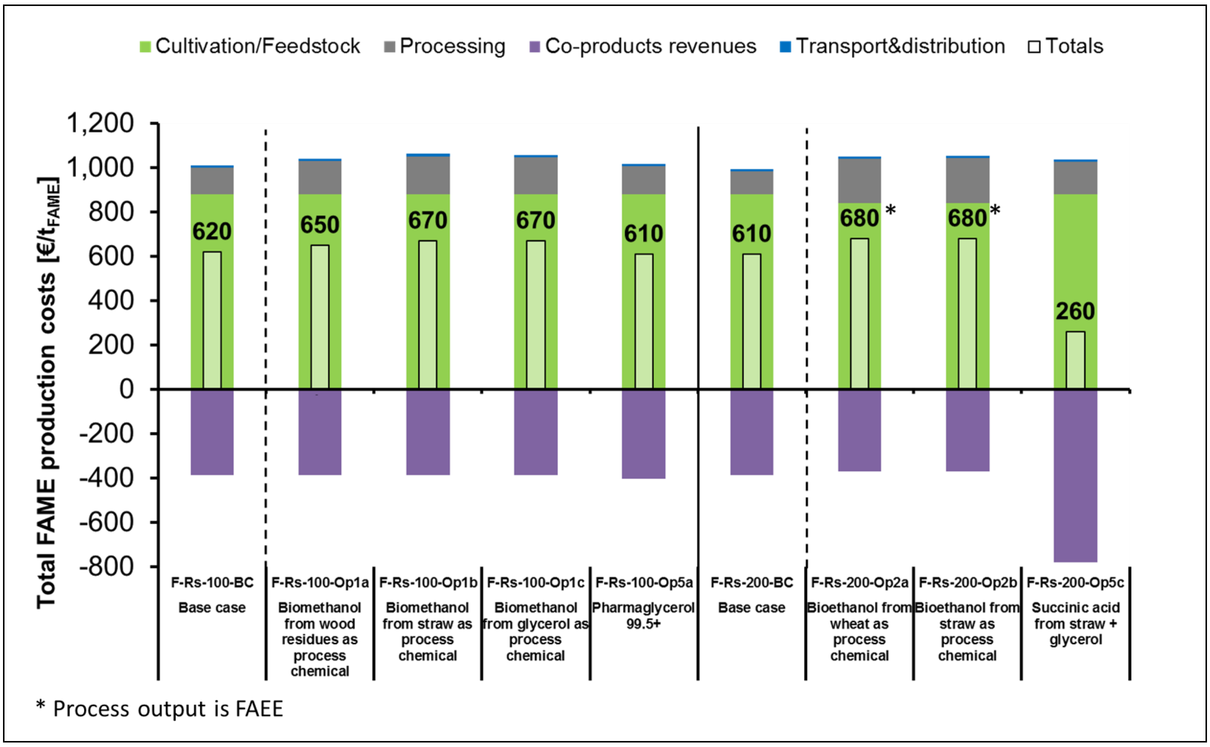
The FAME production costs of the improvement options "Biomethanol", "Bioethanol", "Pharmaglycerol 99.5+" and "Succinic acid from straw" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a and 200 kt/a) are shown in Figure 25.

The improvement options with biomethanol have FAME production costs of 650 €/t_{FAME} using biomethanol produced from wood residues and 670 €/t_{FAME} using biomethanol produced from straw or glycerol. Production costs of the biomethanol options are higher compared to the base due to higher costs for biomethanol than for conventional methanol (900 €/t biomethanol from cereal straw, 850 €/t biomethanol from glycerol and 354 €/t conventional methanol).

Using bioethanol instead of conventional methanol leads to an increase in FAME production costs of 70 €/t_{FAME}. This option was investigated for a fuel production capacity of 200 kt with production costs of 610 €/t_{FAME} for the base case. This significant cost increase is mainly linked to higher costs for chemicals in the esterification step (750 €/t bioethanol from corn and wheat; 800 €/t bioethanol from wood and straw; 900 €/t Potassium-Ethylat 24% in EtOH). Also capital costs for the biofuel production plant are higher for this option. Costs for cultivation of the feedstock are lower compared to the base case, because less feedstock is needed, if bioethanol is used instead of methanol.

The FAME production costs of option "Pharmaglycerol 99.5+" are 610 €/t_{FAME} and are lower than FAME production costs of the base case with 620 €/t_{FAME}. The result show that higher costs the production of pharmaglyerol due to additional capital and energy costs are compensated by the higher market value of pharmaglycerol compared to crude glycerol. For the "Succinic acid from straw + glycerol" the situation is similar: additional costs for the production of succinic acid are more than compensated by high revenues from succinic acid. Total FAME production costs of the option "Succinic acid from straw + glycerol" add up to 260 €/t_{FAME}, which is significant cheaper compared to the base case. The result however is very sensitive to the market value of succinic acid. 5.5 €/kg were used in the calculation being an average value of the spot price in 2012 ranging between 2.7 – 8.2 €/kg.

The option "Biomethanol from cereal straw as process chemical" was also investigated for the feedstock American soybean and UCO/animal fat. Results on the FAME production costs compared to the corresponding base cases are shown in Figure 26. For American soybean the use of biomethanol from cereal straw leads to FAME production costs of 560 €/t_{FAME} compared to the base case for American soybean with 510 €/t_{FAME}. For UCO/animal fat the use of biomethanol from cereal straw leads to FAME production costs of 690 €/t_{FAME} compared to the base case for UCO/animal fat with 630 €/t_{FAME}, whereas the option "Pharmaglycerol 99.5%" again has the same FAME production costs as the base case.



* Process output is FAEE

Figure 25: FAME production costs and revenues of co-products for improvement options "Biomethanol", "Bioethanol", Pharmaglycerol 99.5+" and "Succinic acid from straw" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a and 200 kt/a)

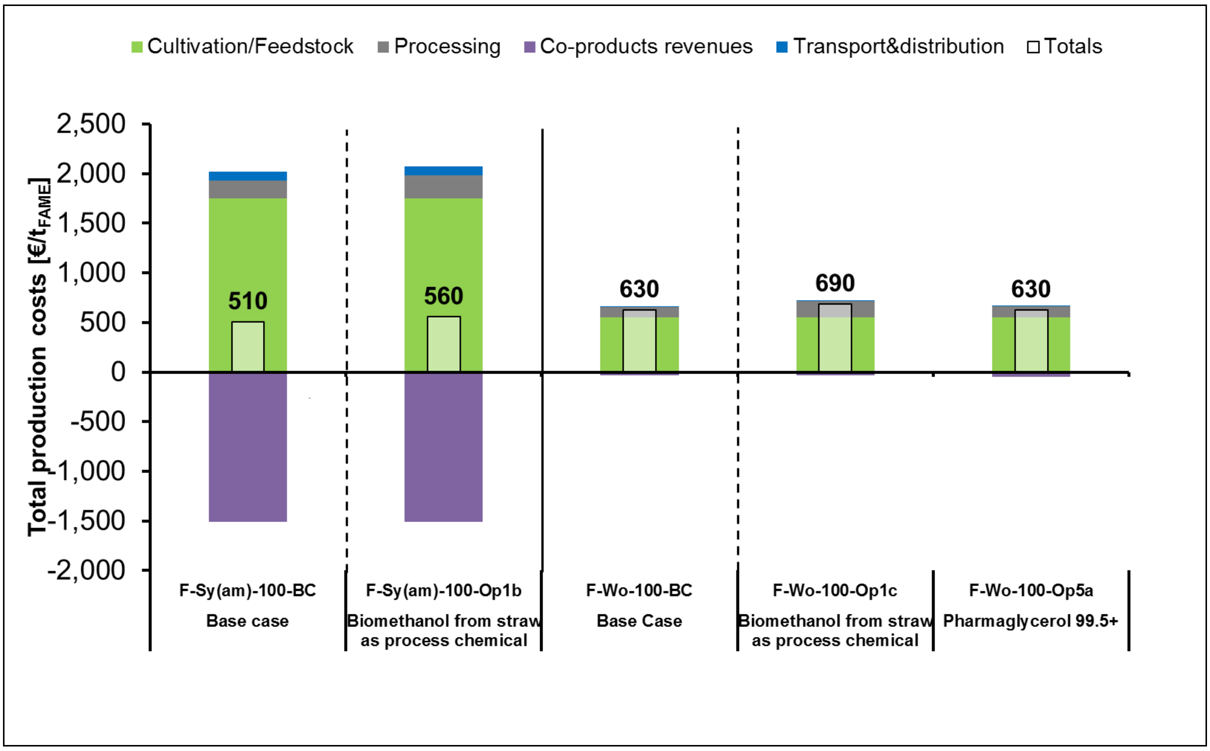


Figure 26: FAME production costs and revenues of co-products for improvement options "Biomethanol" compared to the corresponding base cases (feedstock: American soybean and UCO/animal fat; FAME production capacity: 100 kt/a)

Energy supply

The FAME production costs and revenues of co-products for improvement options "CHP with refined vegetable oils + steam boiler with vegetable oils", "Steam boiler with vegetable oils", "Wood-to-steam boiler" and "Green electricity from PV plant on site" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 200 kt/a) are shown in Figure 27. The supply of process energy has only a small influence on the production costs. Higher capital costs are compensated by lower fuel costs. For the "Wood-to-steam boiler" this leads to a cost decrease of 10 €/t_{FAME} compared to the base case.

The use of renewable energy for the processing of FAME was also investigated for the feedstock UCO/animal fat. Figure 28 shows the FAME production costs of the improvement options "CHP with distilled glycerol + co-incineration of FAME distillation residues (BHA) in steam boiler", "Co-incineration of FAME distillation residues (BHA) in steam boiler" and "Green electricity" compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 50 kt/a and 100 kt/a). For the feedstock UCO/animal fat the improvement options have similar results compared to the base case. "Co-incineration of FAME distillation residues (BHA) in steam boiler" and "Green electricity from PV plant on site" have the same FAME production costs compared to base case of 650 €/t_{FAME} for 50 kt FAME per year and 630 €/t_{FAME} for 100 kt FAME per year. "CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler" has 10 €/t_{FAME} higher FAME production costs compared to base case. Approximately half of the co-product glycerol is used for energy supply, which leads to lower revenues from crude glycerol selling.

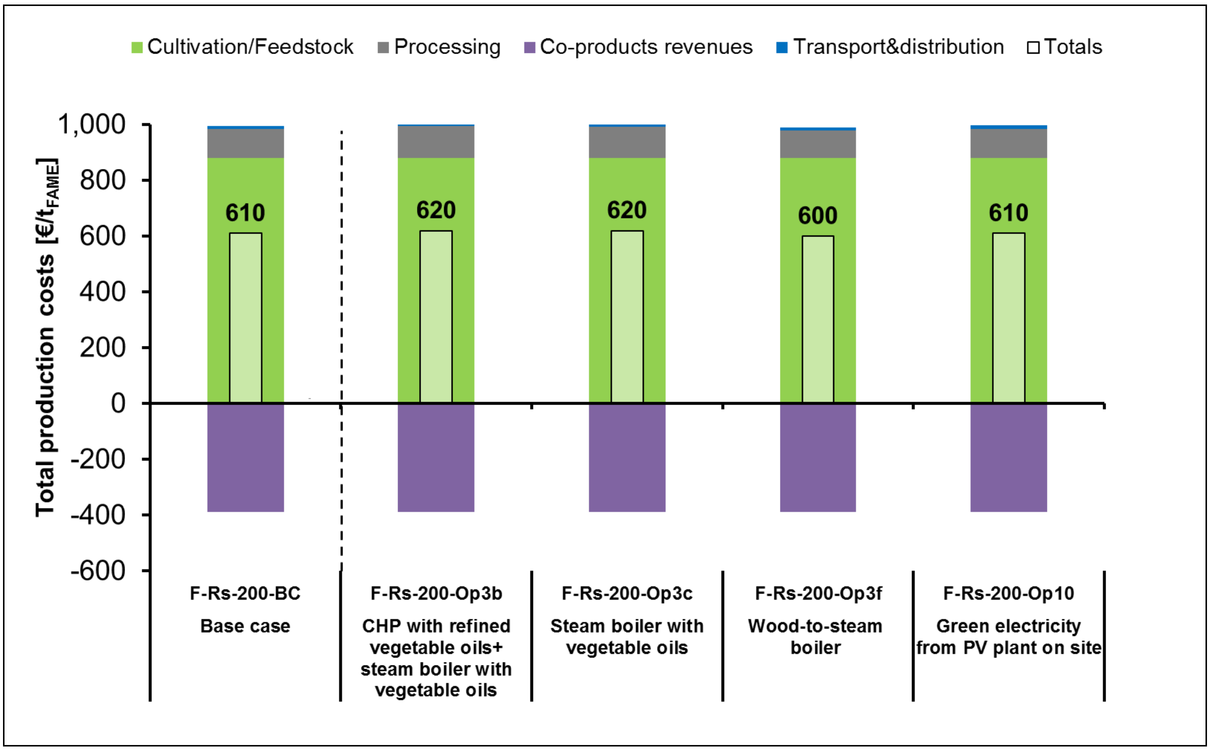


Figure 27: FAME production costs and revenues of co-products for improvement options "CHP with refined vegetable oils + steam boiler with vegetable oils", "Steam boiler with vegetable oils", "Wood-to-steam boiler" and "Green electricity" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 200 kt/a)

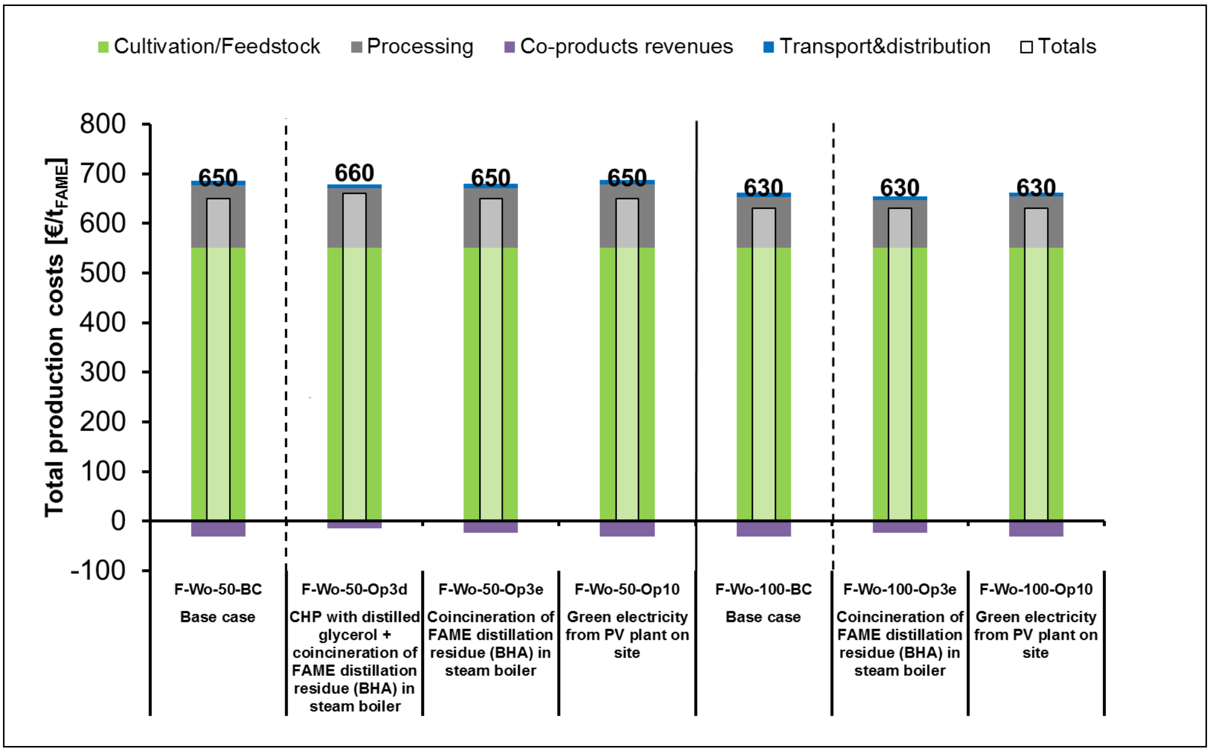


Figure 28: FAME production costs and revenues of co-products for improvement options "CHP with distilled glycerol + co-incineration of FAME distillation residues (BHA) in steam boiler", "Co-incineration of FAME distillation residues (BHA) in steam boiler" and "Green electricity" compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 50 kt/a and 100 kt/a)

Cultivation

The FAME production costs and revenues of co-products for improvement options "Balanced fertilization", "Nitrification inhibitors", "Crop residue management", "Reduced tillage" and "Organic fertilizer" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a) are shown in Figure 29.

The options "Balanced fertilization" has FAME production costs of 590 €/t$_{FAME}$. Compared to the base case with 610 €/t$_{FAME}$ this is a cost decrease of 30 €/t$_{FAME}$. This is linked to avoided costs due to less fertilizer use:

- N-fertilizer: 151 instead of 168 kg/(ha*a)
- K_2O-fertilizer: 53 instead of 70 kg/(ha*a) and
- P_2O_5-fertilizer: 60 instead of 80 kg/(ha*a) use;

For balanced fertilization machinery is needed more often (10.0 compared to 9.4 h/(ha*a) for the base case) and working hours for cultivation are more (11.0 compared to 10.4 h/(ha*a) for the base case. These additional costs however are compensated by the avoided fertilizer costs.

In the option "Nitrification inhibitors" FAME production costs are 40 €/t$_{FAME}$ higher compared to base case due to the estimated 25% higher costs for nitrogen fertilizer including nitrification inhibitors.

The options "Crop residue management" and "Reduced tillage" have 10 €/t$_{FAME}$ lower FAME production costs than the base case due to less costs for nitrogen fertilizer for "Crop residue management" and less fuel costs in the case of "Reduced tillage".

The option "Organic fertilizer" has the same FAME production costs of the base case of 620 €/t_{FAME}.

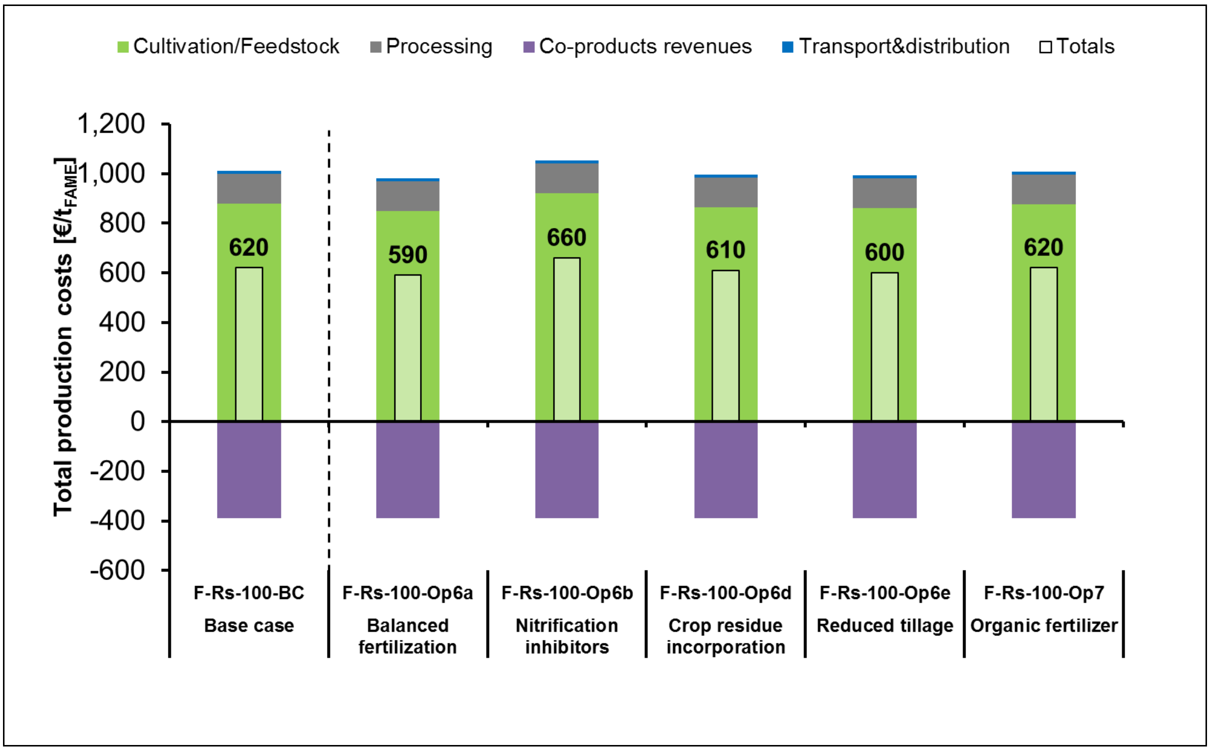


Figure 29: FAME production costs and revenues of co-products for improvement options "Balanced fertilization", "Nitrification inhibitors", "Crop residue management", "Reduced tillage" and "Organic fertilizer" compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a)

For the feedstock palm oil tow improvement options were analysed "Balanced fertilization" and "Return nutrients from palm oil residues as fertilizer". Figure 30 shows the FAME production costs of these options compared to the base case with a FAME production capacity of 100 kt/a.

Using palm oil as feedstock "Balanced fertilization" has higher FAME production costs of 320 €/t_{FAME} compared to the base case with 300 €/t_{FAME}. Pocket fertilizer application instead of broadcasting requires extra labour. Higher costs for personal and machinery operation are not compensated by reduced fertilizer costs.

"Return nutrients from palm oil residues as fertilizer" does not show a cost change compared to the base case.

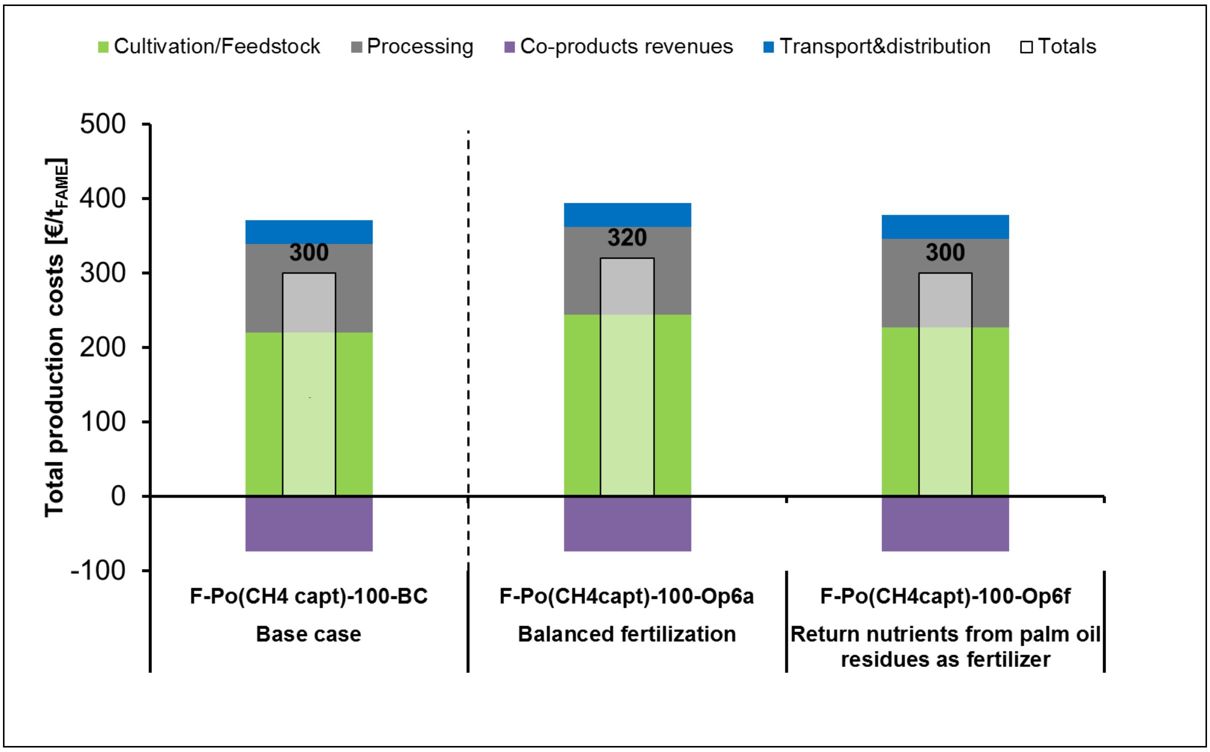


Figure 30: FAME production costs and revenues of co-products for improvement options “Balanced fertilization” and “Return nutrients from palm oil residues as fertilizer” compared to the corresponding base cases (feedstock: palm oil; FAME production capacity: 100 kt/a)

FAME as fuel

The FAME production costs and revenues of co-products for improvement options “FAME in cultivation” and “FAME in transport + distribution” compared to the corresponding base cases (feedstock: Rapeseed, American soybean; FAME production capacity: 100 kt/a) are shown in Figure 31.

The use of FAME in machinery for cultivation processes instead of fossil diesel results in FAME production costs of 630 €/t_{FAME} for rapeseed and of 510 €/t_{FAME} for American soybean. This is an increase up to 10 €/t_{FAME} due to higher costs of FAME (0.026 €/MJ) than fossil diesel (0.023 €/MJ). The use of FAME in transport and distribution processes instead of fossil diesel results an FAME productions costs of 620 €/t_{FAME} for rapeseed and of 550 €/t_{FAME} for American soybean. The influence is stronger for American soybean as longer transportation distances are needed compared to rapeseed.

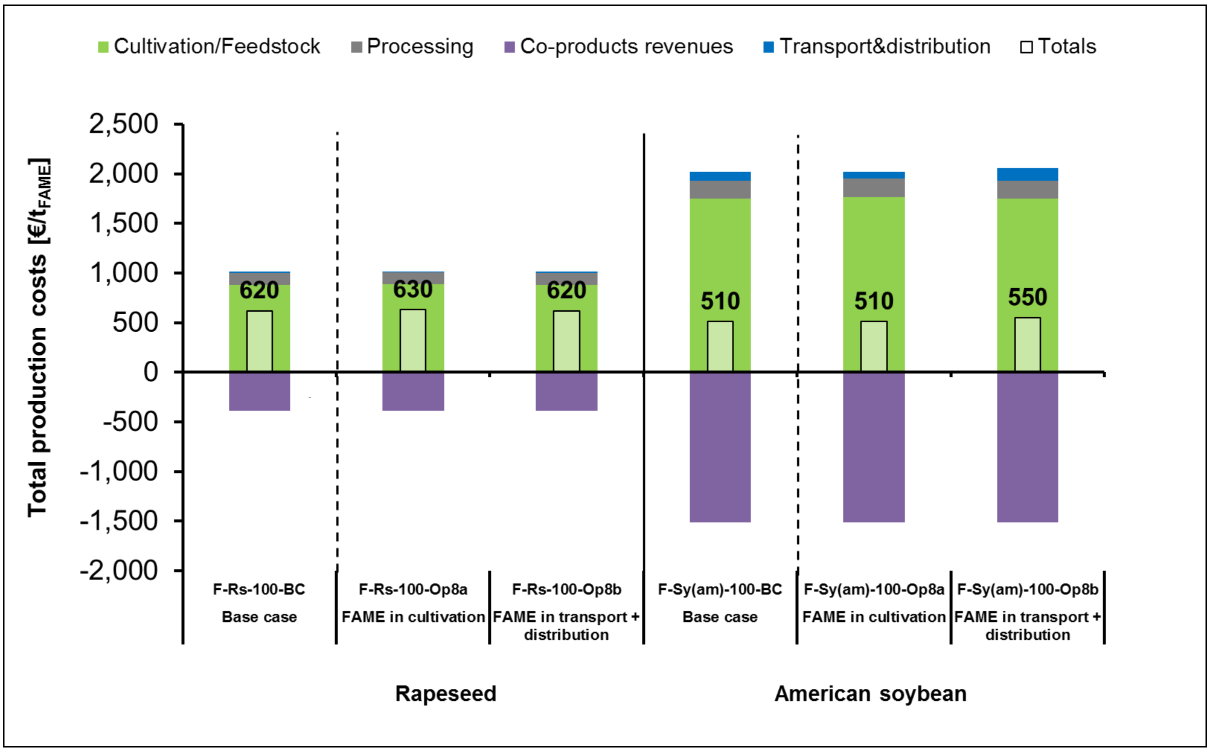


Figure 31: FAME production costs and revenues of co-products for improvement options "FAME in cultivation" and "FAME in transport + distribution" compared to the corresponding base cases (feedstock: Rapeseed, American soybean; FAME production capacity: 100 kt/a)

Retrofitting

The FAME production costs and revenues of co-products for improvement options "Retrofitting" (feedstock: UCO/animal fat; FAME production capacity: 80 kt/a, 100 kt/a and 200 kt/a) are shown in Figure 32.

The FAME production costs of "Complete modification to UCO/animal fat" are with 610 €/t_{FAME} are lower than the FAME production costs of the base case with 620 €/t_{FAME}. However, the cost structure is very different. On the one hand revenues from co-products are 10% of the base case, because no animal feed is produced. On the other hand costs for feedstock are lower, because cost for cultivation and oil extraction of rapeseed are higher (530 €/t_{oil}) than the average market price of UCO/animal fat (500 €/t_{oil}). Also processing has slightly lower costs.

For "Partial modification to UCO/animal fat" the cost analysis results in 610 €/t_{FAME}, which are the same FAME production costs as in the base case. Again there are fewer revenues from animal feed and lower cost from feedstock cultivation and oil extraction. It should be noted that cost data (e.g. market price of UCO/animal fat) may be subject to variation. Therefore both improvement options for retrofitting seem to be in the same FAME production cost range as the base case.

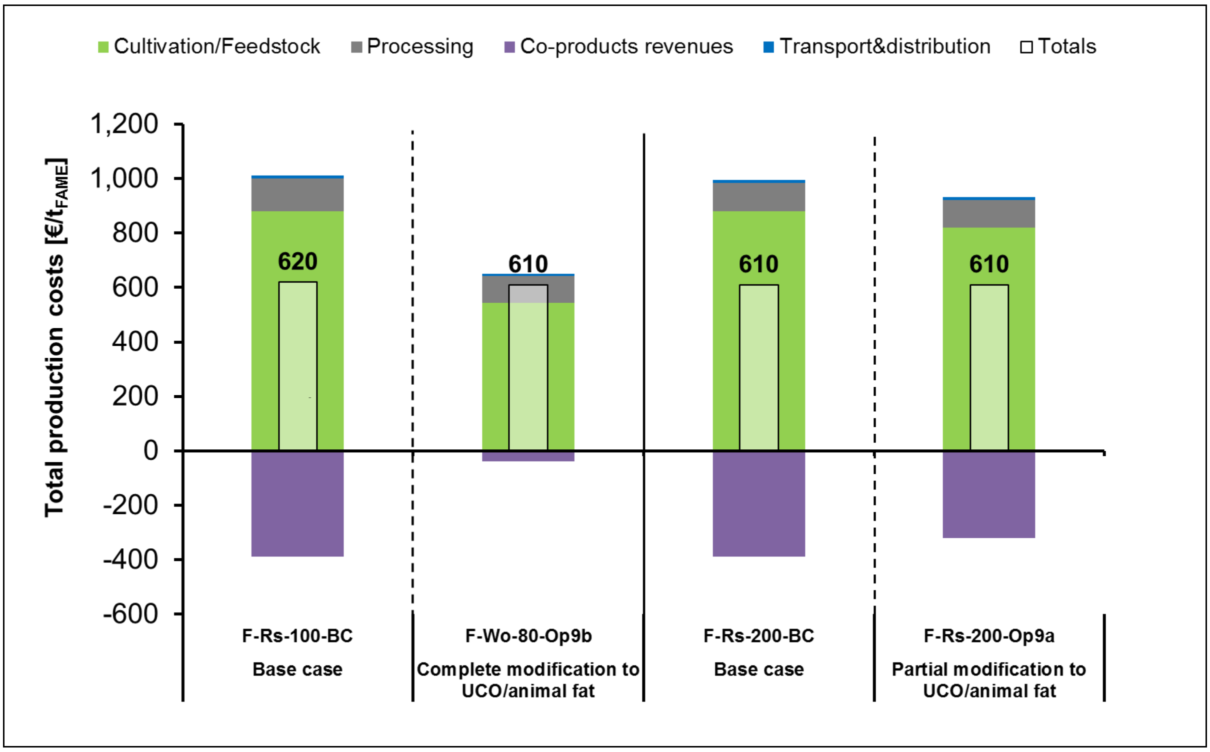


Figure 32: FAME production costs and revenues of co-products for improvement options "Retrofitting" (feedstock: UCO/animal fat; FAME production capacity: 80 kt/a, 100 kt/a and 200 kt/a)

5.3 Greenhouse gas mitigation costs

Greenhouse gas mitigation costs were only calculated for improvement options with a significant GHG reduction higher than 1 g CO_2-eq/MJ_{FAME} compared to the base case. Figure 33 shows the results for options, which were compared to a base case with the feedstock rapeseed.

These options are:

- Partial modification to UCO/animal fat;
- Complete modification to UCO/animal fat;
- FAME as fuel in cultivation;
- Organic fertilizer;
- Reduced tillage;
- Crop residue management;
- Nitrification inhibitors;
- Balanced fertilization;
- Co-incineration of FAME distillation residue (BHA) in steam boiler;
- CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler;
- Wood-to-steam boiler;
- Bioethanol from straw as process chemical;
- Pharmaglycerol 99.5+;
- Biomethanol from straw as process chemical; and
- Biomethanol from wood residues as process chemical.

The greenhouse gas mitigation costs for the improvement options “Reduced tillage”, “Crop residue management” and “Balanced fertilization” are negative, because the FAME production costs of the improvement options are lower compared to the base case. In total the GHG mitigation cost range between minus 260 up to 1,000 €/t CO_2-eq.

The same improvement options are included in Figure 34. Each column represents an improvement option. The options are sorted by greenhouse gas mitigation costs, starting with minus 260 and going up to up to 1,000 €/t CO_2-eq (height of column). The width of the column represents the GHG emissions reduction of the option compared to the corresponding base case. It is possible to combine some of the presented options, for example “Balanced fertilization” and “Wood-to-steam-boiler”, but not all, for example “Balanced fertilization” and “Complete modification to UCO/animal fat”.

The most attractive options are (≤ 140 €/t CO_2-eq):

- Balanced fertilization;
- Pharmaglycerol 99.5+;
- Reduced tillage;
- Wood-to-steam boiler;
- Crop residue management;
- Complete modification to UCO/animal fat;
- Organic fertilizer;
- Co-incineration of FAME distillation residue (BHA) in steam boiler;
- Partial modification to UCO/animal fat;
- FAME as fuel in cultivation;
- CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler; and
- Biomethanol from wood residues as process chemical.

Table 16: Selected results on improvement options, with rapeseed & UCO/animal fat as feedstock

Improvement option	**Greenhouse gas emission saving compared to fossil reference** [%]		**Greenhouse gas emissions compared to base case** [g CO_2-eq/MJ]	**FAME production costs**[7] [€/t_{FAME}]	**Greenhouse gas mitigation costs compared to base case**[5] [€/t CO_2-eq]
	Option	Base case[1]	Option	Option	Option
Feedstock: rapeseed					
Biomethanol[2]	49%	43%	-5	650 - 670	170 - 290
Bioethanol[2]	44-46%	44%	0 to -2	680	1,000
CHP residues					
Vegetable oil CHP + steam boile	45%	44%	-0.9	620	not calculated[6]
Wood-to-steam boiler	45%	44%	-1	600	-90
Bioplastics and -chemicals					
Pharmaglycerol 99.5%	45%	43%	-2	610	-170
Succinic acid	41%	44%	+2	260	not calculated[6]
Advanced agriculture					
Balanced fertilization	47%	43%	-3	590	-260
Nitrification inhibitors	47%	43%	-3	660	360
Crop residue management	67%	43%	-20	610	-20
Reduce tillage	52%	43%	-7	600	-70
Organic fertilizer	55%	43%	-10	620	0
FAME as fuel[3]	44-45%	43%	0 to -2	630	90
Retrofitting					
Partial usage of UCO/animal fat	52%	44%	-8	610	-10
Complete modification	88%	43%	-37	610	0
Green electricity from PV plant on site[4]	43-44%	43-44%	-0.2	600 - 620	not calculated[6]
Feedstock: UCO/animal fat					
CHP residues					
Glycerol CHP+FAME distillation residue steam boiler	88-89%	86%	-1 to -2	630 - 660	0 - 140

[1] FAME production capacity correspoding to option

[2] Ranges due to different feedstock for biomethanol/bioethanol

[3] Ranges due to different FAME uses (use in cultivation or transport & distribution)

[4] Ranges due to different production capacities

[5] Negative mitigation costs are due to lower FAME production costs compared to base case, e.g. higher revenues from new co-products

[6] Not calculated due to small GHG emission reduction (≤ 1 g CO_2-eq/MJ)

[7] FAME production costs of base case with rapeseed 600 - 650 €/t_{FAME} and with UCO/animal fat 630 - 660 €/t_{FAME}

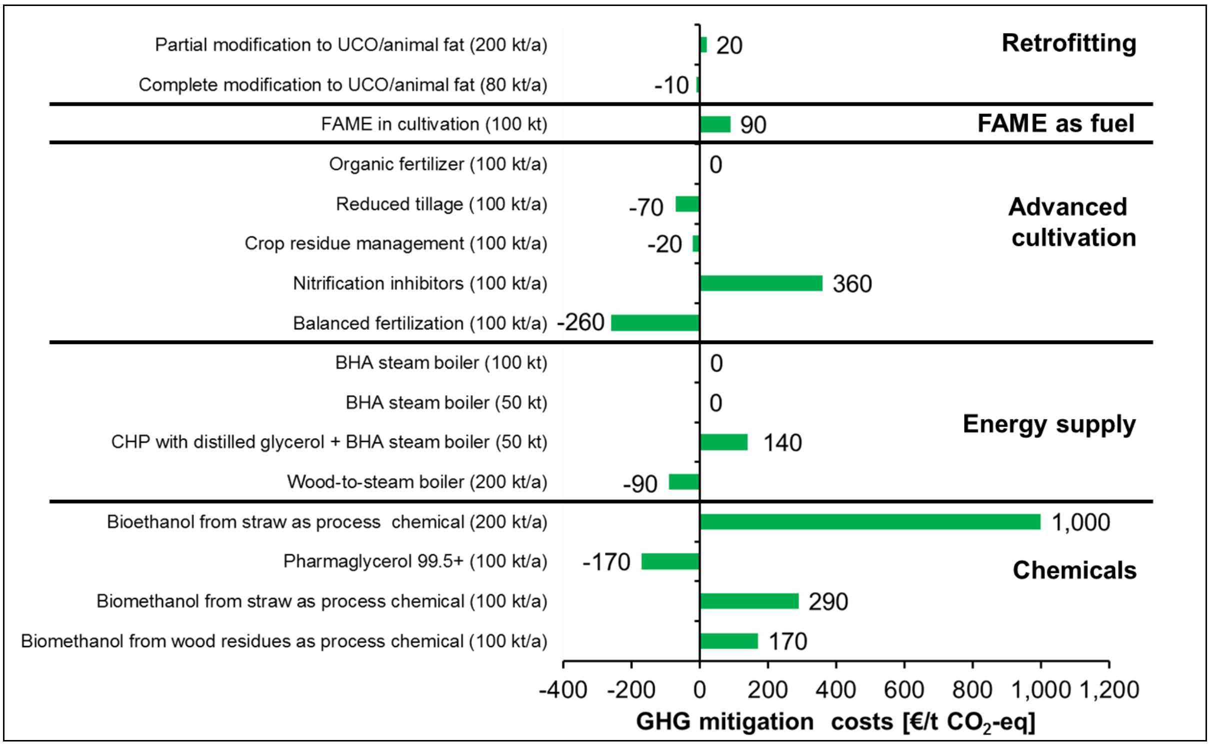


Figure 33: GHG mitigation costs of selected improvement options with a GHG reduction > 1 g CO_2-eq/MJ_{FAME} compared to base case with rapeseed

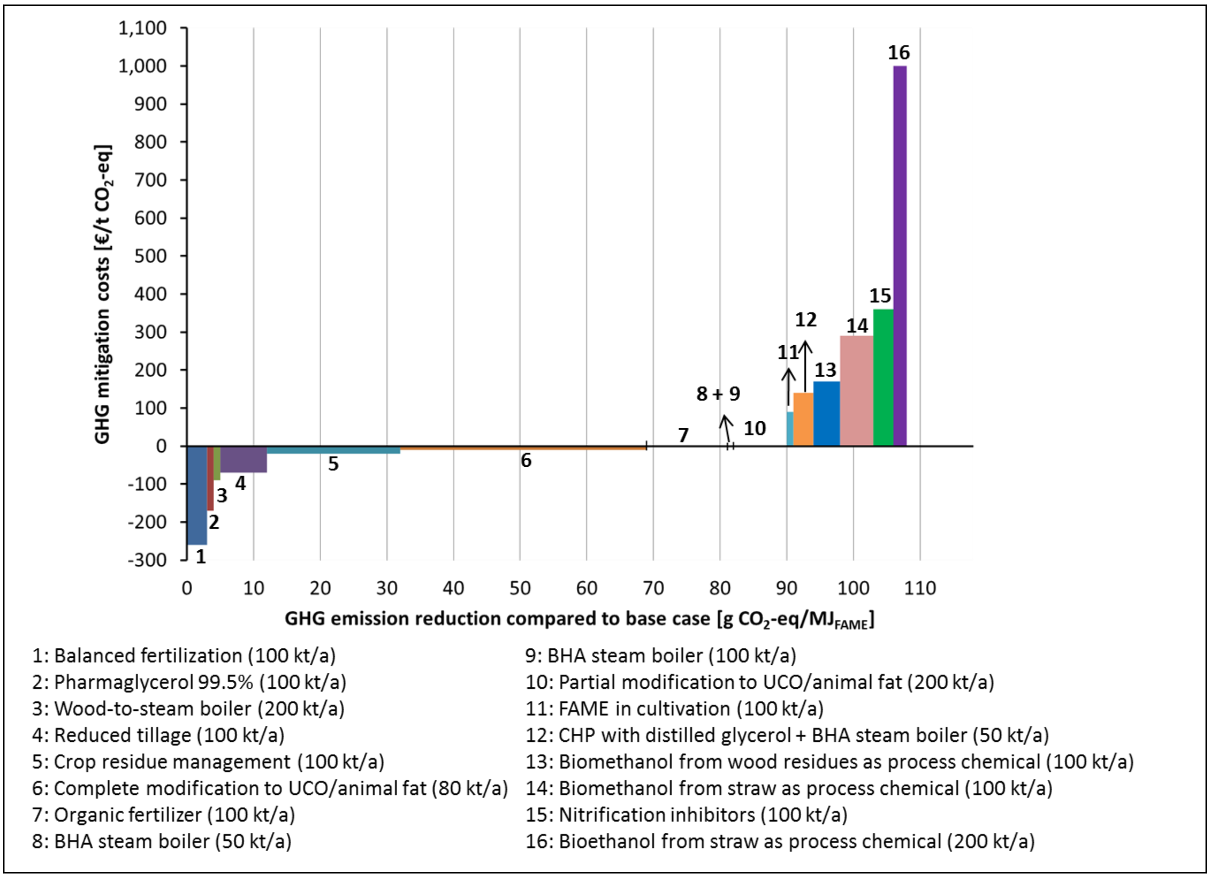


Figure 34: GHG mitigation costs and GHG emissions reduction of selected improvement options with a GHG reduction > 1 g CO_2-eq/MJ_{FAME} compared to base case with rapeseed

5.4 SWOT analysis

The complete SWOT analysis for each improvement option is listed in ANNEX 1 "Fact Sheets". The main aspects addressed in the SWOT analysis are summarized here:

Biomethanol

- Due to economy of scale a biomethanol production at FAME plant facility is not feasible;
- Other feedstocks than rapeseed are more feasible, e.g. cereal straw, forestry residues or, especially in the future, municipal solid waste;
- Currently still relatively small volumes of biomethanol are produced and available on the market.

Bioethanol

- By now technology not applied on industrial and commercial scale today;
- Certification of the product needed. Fatty acid ethyl ester (FAEE), which is produced if ethanol is used instead of methanol, is not included in EN 14214, as this standard only refers to FAME;
- Bioethanol is a transportation fuel itself.

Succinic acid (SA) from glycerol

- Performed already on production scale by Succinity GmbH with a mixture of sugar and glycerol;
- The availability of sufficient "suited" glycerol and the supply chain integration ("biorefinery over the fence") are important success and market entry factors;
- Glycerol as raw material requires a "stable" legislation to allow for demonstration and market penetration.

Pharmaglycerol 99.5+

- Commercial solution;
- Pharmaglycerol offers an alternative usage for glycerol;
- Restrictions due to legislative regulations (animal by-product regulation for glycerol) if animal fat is used as feedstock.

Vegetable oil CHP

- Low level heat cannot be utilized in FAME plant;
- Commercial solution.

Vegetable oil steam boiler

- Vegetable oil feedstock for FAME production: too valuable for heat generation (input 3% of FAME);
- Commercial solution.

Wood-to-steam boiler

- Commercial solution;
- Low fuel costs compared to fossil fuels;
- Solid fuel logistics needed;
- Limited to wood chips, direct usage of residues like straw demand technology, which is not economically for the needed power range.

Distilled glycerol CHP

- Low level heat cannot be utilized in FAME plant;
- Utilization of glycerol of category 1, which otherwise has to be disposed or burnt;
- Commercial solution.

Co-incineration of FAME distillation residue

- Easy process adaption;
- Usage of a process residue;
- Commercial solution.

Green electricity from PV plant on site

- Commercial solution;
- No adaption of FAME process needed;
- Without storage it is not possible to supply the total electricity demand for processing.

Balanced fertilization

- Farm specific assessments have to be made;
- Best practice might require other fertilizer application equipment;
- Risk on crop yield losses if too little fertilizer is applied.

Nitrification inhibitors

- There might be legislative constraints for its use (health and fertilizer regulations);
- Nitrification inhibitors are not under all conditions effective.

Crop residue management

- Uncertainty about current implementation, in some countries this is already current practice;
- Easy to implement in existing farming practices;
- Amount of soil carbon sequestration is uncertain, not permanent and will stop when a new equilibrium is reached.

Return nutrients from palm oil residues as fertilizer

- Uncertainty about potential, in some countries already current practice;
- Amount of soil carbon sequestration is uncertain, not permanent and will stop when a new equilibrium is reached.

Reduced tillage

- Does not fit to all crop rotations and the small seeds make direct seeding in combination with zero tillage not possible;
- Scientific debate on effectiveness of reduced tillage;
- Amount of soil carbon sequestration is uncertain, not permanent and will stop when a new equilibrium is reached.

Organic fertilizer

- Availability of organic fertilizer is limited;
- Uncertainty on the soil carbon sequestration effect and risk on GHG leakage by displacing manure from other crops to rapeseed.

New plant species

- New crops are emerging crops, production chains are under development: demonstration needed;
- New crops can be grown on more marginal land (less water, less fertilizer per kg of biomass and plant);
- New crops not only produce plant oil, but also high proportion of by-products;
- Biorefinery approach more suitable due to large set of co-products.

FAME as fuel

- Adaption for 100% FAME usage in vehicles necessary;
- Commercial solution;
- Year-round usage might not be possible due to low temperatures in Winter, (depending on region).

Partial modification to UCO/animal fat

- Due to separate GHG reduction calculation related to feedstock base, mixed GHG reduction potential cannot be stated;
- Add on system, with no changes to the existing FAME plant;
- Only limited feedstock impurities possible;
- Implementation is a question of feedstock availability and availability of UCO/animal fat is expected to decrease;
- High fluctuations in feedstock price.

Complete modification to UCO/animal fat

- Implementation is a question of feedstock availability and availability of UCO/animal fat is expected to decrease[5];
- High fluctuations in feedstock price;
- Reduced FAME production capacity.

5.5 Feasibility and realization time

The summarized feasibility and realisation of the improvement options are shown in Figure 35 by qualitatively indicating their feasibility (high – average – low) and realisation time (2016 – 2020 – 2025).

Feasible short term improvement options (2016) are:

- CHP residues;
- FAME as fuel;
- Retrofitting multi feedstock; and
- Biochemicals (Pharmaglycerol 99.5+).

Feasible medium term improvement options (~ 2020) are:

- Green electricity from PV plant on site;
- Biomethanol;
- Advanced agriculture; and
- Organic fertilizer.

Longer term improvement options (> 2020) are:

- New plant species; and
- Bioethanol (instead of methanol for FAME production).

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[5] According to European Fat Processors and Renderers Association (EFPRA) the amounts of processed Category 1 & 2 fats did not change significantly in the last 10 years (EFPR, 2015). Based on these data an increase in the processing of Category 1 fats cannot be observed.

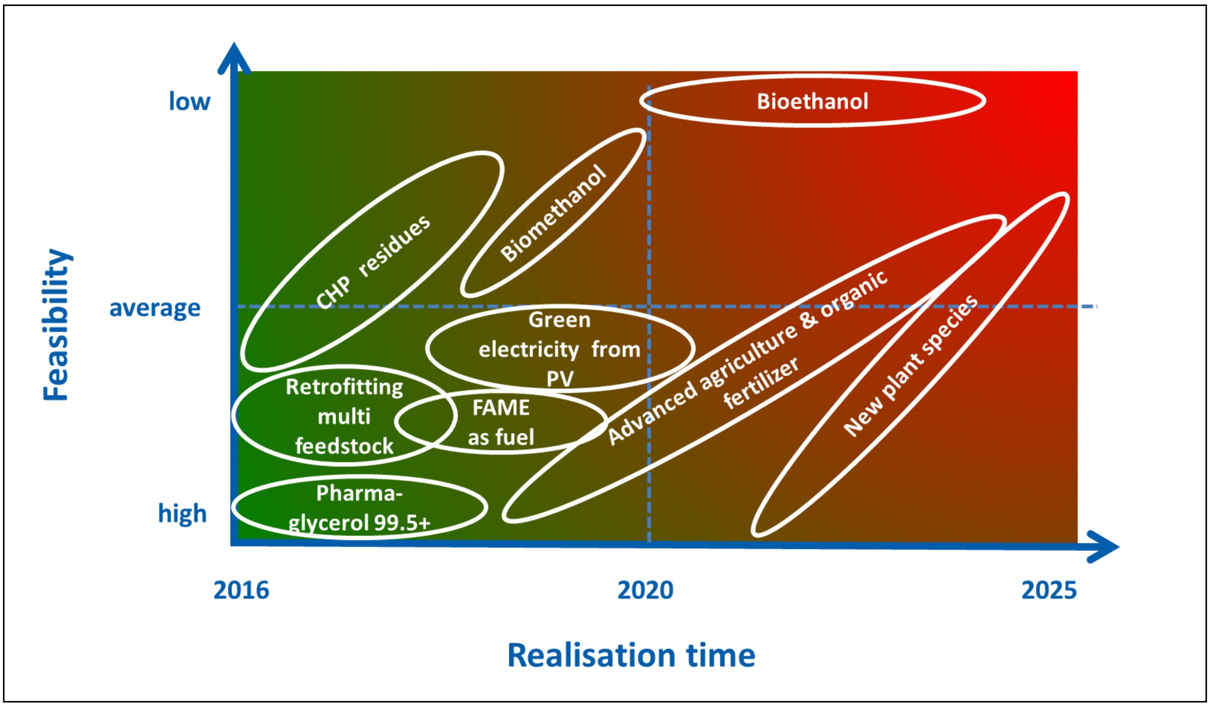

Figure 35: Overall assessment of the improvement options based on feasibility and realisation time

6 Conclusions and recommendations

For the investigated improvement options a GHG analysis, cost analysis and SWOT analysis were performed. Based on these investigations main results and conclusions are summarized on

- State-of-technology;
- GHG emissions;
- FAME production costs;
- Implementation; and
- other aspects.

These are presented in Table 17 to Table 20.

Table 17: Conclusions for the improvement options "Biomethanol", "Bioethanol" and "Bioplastic and biochemical"

	State-of-Technology	**GHG emissions**	**FAME production costs**	**Implementation**	**Others**
Biomethanol	from glycerol: commercially available from forestry: residues and MSW, commercially available but no plant in operation yet from black liquor & straw: small scale demonstration	Medium GHG reduction potential for processing part	High cost for FAME due to biomethanol costs	Due to economy of scale not feasible for onsite biomethanol production	Other feedstock then rape straw are more feasible, e.g. cereal straw, forestry residues or – especially in future – municipal solid waste
Bioethanol	Process steps for esterification and trans-esterification are investigated; esterification in technical scale, trans-esterification in industrial scale available	Small to medium GHG reduction potential for processing part depending on ethanol source	High costs for plant conversion (glycerol line treatment) High costs for biodiesel due to ethanol and catalyst costs	Still development for industrial scale necessary	Certification of the product needed (FAEE not according to EN 14214)
Bioplastic and biochemical					
Succinic acid (SA) from glycerol	Performed already on production scale by Succinity GmbH with a mixture of sugar and glycerol	No GHG reduction potential (results based on estimations of energy and chemical demand, needs to be further investigated with real data from industry in future)	Due to high revenues from SA a significant cost decrease might be possible (results based on cost estimations, needs to be verified with real data from industry in future) Sufficient fermentation quality by-product at affordable cost must be available	The availability of sufficient "suited" glycerol and the supply chain integration ("biorefinery over the fence") are important success and market entry factors Glycerol as raw material requires a "stable" legislation to allow for demonstration and market penetration	The current non-availability of 2nd generation non-food sugars are a window of opportunity for a glycerol / sugar fermentation to SA in Europe and elsewhere
Pharma-glycerol 99.5+	commercial solution, which is already implemented in FAME production plants	Small to medium GHG emission reduction, as crude glycerol is not eligible for energy allocation according to current GHG calculation rules of RED	Cost increase from additional equipment and energy demand compensated by higher revenues from Pharma-glycerol	Implementation proofed in existing FAME production plants	Needed alternative usage for low grade glycerol Glycerol distillation necessary for most fermentation processes

Table 18: Conclusions for the improvement options “CHP residues” and “Green electricity from PV plant on site”

	State-of-Technology	**GHG emissions**	**FAME production costs**	**Implementation**	**Others**
CHP residues					
Vegetable oil CHP	commercially available	Small GHG reduction potential due to small contribution of GHG emissions from electricity and heat demand to total GHG emissions of FAME	None to low cost increase	Low level heat (mainly hot water generated) cannot be utilized in FAME plant	
Vegetable oil steam boiler				No adaption of FAME production process needed	Vegetable oil feedstock for FAME production: too valuable for heat generation (input 3% of FAME)
Wood-to-steam boiler				No adaption of FAME production process needed Solid fuel logistics needed	Limited to wood chips, direct usage of residues like rape straw demands technology, which is not economically for the needed power range
Distilled glycerol CHP				Low level heat (mainly hot water generated) cannot be utilized in biodiesel plant Additional equipment for glycerol distillation necessary, which causes cost and energy demand	Utilization of glycerol of category 1, which otherwise has to be disposed or burnt
Co-incineration of FAME distillation residue				Easy process adaption	Usage of a residue
Green electricity from PV plant on site	commercially available	Very small GHG reduction potential due to small contribution of GHG emission from electricity; only a portion of electricity demand can be provided with PV without storage	None to low cost increase	No adaption of FAME production process needed	On industrial site deposition of dirt and dust on PV panel more likely, lowering the efficiency of PV system

Table 19: Conclusions for the improvement options "Advanced cultivation" and "New plant species"

	State-of-Technology	**GHG emissions**	**FAME production costs**	**Implementation**	**Others**
Advanced cultivation					
Balanced fertilization	Existing practices can be used, for best results precision agriculture techniques should be used	Medium GHG emission reduction potential	Cost decrease for rapeseed; cost increase for palm oil (pocket fertilizer application increases labour costs)	Farm specific assessments have to be made Best practice might require other fertilizer application equipment	Risk on crop yield losses if too little fertilizer is applied
Nitrification inhibitors	Commercially available	Medium GHG emission reduction potential	Cost increase due to higher fertilizer cost	There might be legislative constraints for its use (health and fertilizer regulations)	Nitrification inhibitors are not under all conditions effective
Crop residue management	Existing practice, no new technologies required	High GHG emissions reduction potential, mainly from soil carbon sequestration	Cost decrease due to lower fertilizer cost	Uncertainty about current implementation, in some countries this is already current practice Easy to implement in existing farming practices	Amount of soil carbon sequestration is uncertain, not permanent and will stop when a new equilibrium is reached
Return nutrients from palm oil residues as fertilizer	Existing practice based on additional labour, for automated pocket placement technologies are in development	High GHG emissions reduction potential, mainly from soil carbon sequestration	No significant cost change	Uncertainty about potential, in some countries already current practice	Amount of soil carbon sequestration is uncertain, not permanent and will stop when a new equilibrium is reached
Reduced tillage	Existing practice, requires some other machinery	High GHG emissions reduction potential, mainly from soil carbon sequestration	Cost decrease due to lower fertilizer cost	Does not fit to all crop rotations and the small seeds make direct seeding in combination with zero tillage not possible	Scientific debate on effectiveness of reduced tillage Amount of soil carbon sequestration is uncertain, not permanent and will stop when a new equilibrium is reached
Organic fertilizer	Existing practice	High GHG emissions reduction potential, mainly from soil carbon sequestration	Low to none cost change for manure (other organic fertilizer like compost are expensive)	Availability of organic fertilizer is limited	Uncertainty on the soil carbon sequestration effect and risk on GHG leakage by displacing manure from other crops to rapeseed
New plant species	The new crops crambe, camelina, guayule and jatropha offer new raw material sources for FAME production from cultivation on more marginal land not very suitable for food production: no direct competition with food production systems (also because the crops are not food crops). GHG emissions and FAME production systems were not calculated.				

Table 20: Conclusions for the improvement options "FAME as fuel" and "Retrofitting"

	State-of-Technology	**GHG emissions**	**FAME production costs**	**Implemen-tation**	**Others**
FAME as fuel	Commercial solution	Low GHG emission reduction potential	Cost increase, depending on transport distance	Adaption for 100% FAME usage in vehicles necessary	Year-round usage might not be possible due to low temperatures in Winter, (depending on region)
Retrofitting					
Partial modification to UCO/animal fat	Commercial solution	High GHG emission reduction potential, due to waste based feedstock share compared to 100% vegetable oil plant However, due to separate GHG reduction calculation related to feedstock base, mixed GHG reduction potential cannot be stated	Low to none cost change	Add on system, with no changes to the existing FAME plant Only limited feedstock impurities possible	High fluctuations in feedstock price
Complete modification to UCO/animal fat	Commercial solution	High GHG emissions reduction potential		Implementation a question of feedstock availability. Availability of UCO/animal fat is expected to decrease[6].	High fluctuations in feedstock price Reduced FAME production capacity Limited usage of glycerol (waste based feedstock)

Some of the investigated improvement options addressing cultivation have significant GHG reduction potential and at the same time they show no cost change or reduce costs compared to the base case. These options are:

- "Balanced fertilization" (for rapeseed);
- "Reduced tillage";
- "Crop residue management"; and
- "Organic fertilizer".

In the case of "Reduced tillage", "Crop residue management" and "Organic fertilizer" the high GHG emissions reduction potential is linked to soil carbon sequestration.

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[6] According to European Fat Processors and Renderers Association (EFPRA) the amounts of processed Category 1 & 2 fats did not change significantly in the last 10 years (EFPR, 2015). Based on these data an increase in the processing of Category 1 fats cannot be observed.

However, soil carbon sequestration has a large uncertainty, will reach saturation and is not permanent. It will stop after a certain time (20 – 30 years is a reasonable estimate for the EU average climatic conditions), when the new equilibrium of C is reached. Current agricultural practices are not the same in all regions. These options might be implemented already and hence no improvement in GHG emissions can be gained. Also the current GHG emissions calculation scheme for biofuels does not support the use of advanced agricultural practices of single farmers

As feedstock cultivation contributes significantly to the total GHG emissions of FAME, the modification of a vegetable oil plant for 100 % usage of UCO/animal fat has a very significant GHG emissions reduction potential. This measure is already implemented in the FAME sector. Limiting factors are the availability of fatty residues, high fluctuations in feedstock price, which is strongly influencing the economic performance. As the complete modification is also linked to a high investment, an alternative is partial modification for use of UCO/animal fat. In this case a certain share of vegetable oil is replaced with UCO and animal fat of high quality. Depending on the share of UCO/animal fat a significant GHG emissions reduction can be achieved. However, according to current legislation (Communication of the Commission 2010/c 160/01) separate values have to be presented for mixed feedstock streams.

For improvement options addressing the FAME production process (oil extraction, refining and esterification) three main areas were investigated:

1. Using process residues and renewable fuels to provide process energy: For all investigated options the GHG reduction potential is rather small as GHG emissions from energy supply have a small contribution to the total GHG emissions if best available technology is used. For UCO/animal fat co-incineration of FAME distillation residues seems a promising option in terms of cost, but it leads to a small GHG emission reduction. CHP options turn out to be less interesting due to technical reasons: CHP plants generate mainly hot water with a temperature level, which is too low for most of the heat needed in the processing of FAME. For vegetable oil plants wood-to-steam boilers are a commercially available solution also resulting in a small GHG emission reduction.
2. Replacement of conventional methanol by biomethanol and bioethanol resulted in a medium GHG reduction potential. However, both options showed a significant cost increase for FAME production. If bioethanol is used instead of methanol FAEE (fatty acid ethyl ester) is produced instead of FAME. For FAEE certification is missing according to EN 14214 and therefore it cannot be brought into the market under current regulations.
3. Upgrading of co-products and residues to biochemicals: The upgrading of pharmaglycerol 99.5+ is an option, which is already implemented in FAME production facilities. As crude glycerol is not subject to energy allocation according to the current RED methodology on the calculation of GHG emissions, upgrading to pharmaglycerol 99.5+ shows a small to medium GHG reduction potential. Cost increase from additional equipment and energy demand are compensated by higher revenues from pharmaglycerol compared to crude glycerol. The production of succinic acid from glycerol and straw resulted in an increase in GHG emissions and therefore does not represent in improvement options.

Based on these findings a qualitatively indication on feasibility (high – average – low) and realisation time (2016 – 2020 - 2025 was performed, including stakeholder opinions (Figure 36).

Feasible short term improvement options (2016) are:

- CHP residues
- FAME as fuel
- Retrofitting multi feedstock
- Biochemicals (Pharmaglycerol 99.5+)

Feasible medium term improvement options (~ 2020) are:

- Green electricity from PV plant on site
- Biomethanol
- Advanced agriculture
- Organic fertilizer

Longer term improvement options (> 2020) are:

- New plant species
- Bioethanol (instead of methanol for FAME production)

Summing up the assessment it can be concluded that the future FAME production has several options to further improve its GHG balance thus contributing substantially to a more sustainable transportation sector.

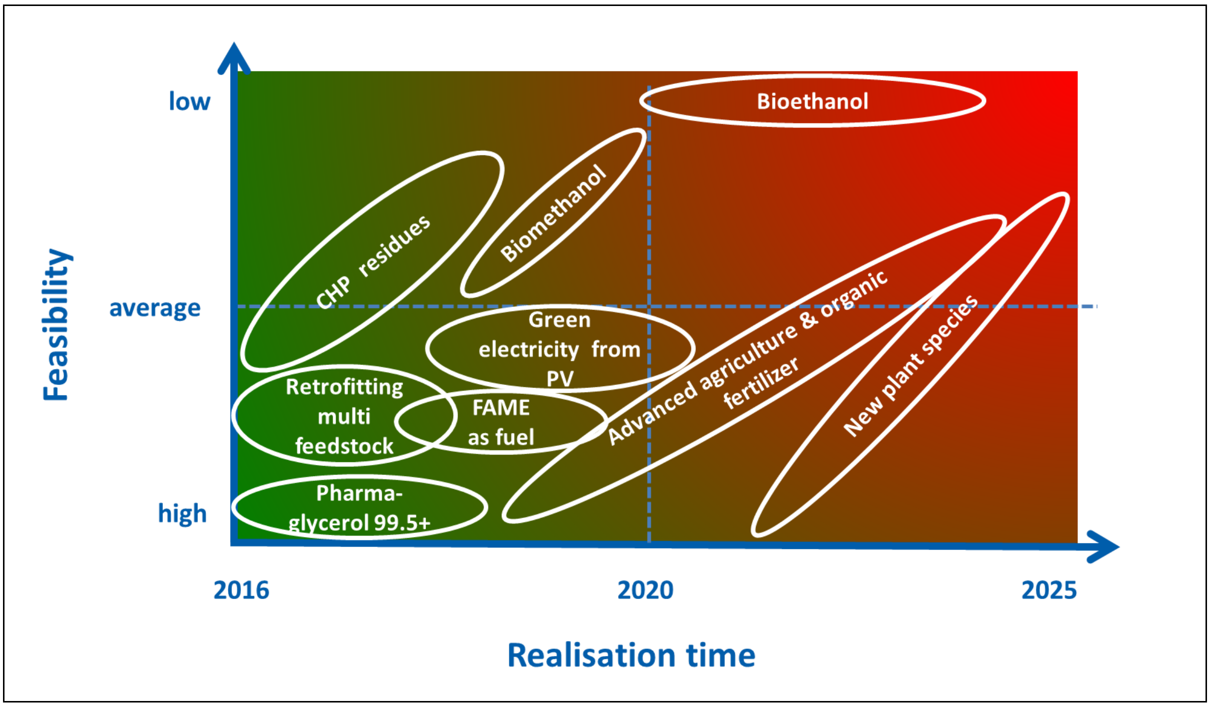

Figure 36: Overall assessment of the improvement options based on feasibility and realisation time

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ANNEX 1: Fact sheets on improvement options

This section provides "Fact sheets" summarizing information and main results on the investigated improvement options. Each "Fact sheet" includes

- key characteristics of the improvement option;
- basic technical and economic data;
- system boundaries for GHG calculations;
- results of GHG and economic assessment (changes in GHG emissions, change in costs and GHG reduction costs compared to base case; GHG savings compared to fossil reference);
- SWOT analysis; and
- conclusions.

The following Fact sheets describe the improvement options and sub-options:

Fact sheet – Biomethanol

- Option: Biomethanol
- Sub-options:
    - Biomethanol from wood residues as process chemical
    - Biomethanol from straw as process chemical
    - Biomethanol from glycerol as process chemical

Fact sheet – Bioethanol

- Option: Bioethanol
- Sub-options:
    - Bioethanol from wheat as process chemical
    - Bioethanol from straw as process chemical

Fact sheet - Vegetable oil and wood chips for process energy supply

- Option: CHP residues
- Sub-options:
    - CHP with refined vegetable oils + steam boiler with vegetable oils
    - Steam boiler with vegetable oils
    - Wood-to-steam boiler

Fact sheet - Glycerol and FAME distillation residue for process energy supply

- Option: CHP residues
- Sub-options:
    - CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler

    - Co-incineration of FAME distillation residue (BHA) in steam boiler

Fact sheet - New plant species

- Option: New plant species
- Sub-options:
    - Crambe
    - Camelina
    - Jatropha
    - Guayule

Fact sheet - Bioplastic and biochemical

- Option: Bioplastic and –chemical
- Sub-options:
    - Pharmaglycerol 99.5%
    - Succinic acid from straw + glycerol

Fact sheet - Balanced fertilization

- Option: Advanced agriculture
- Sub-options: Balanced fertilization

Fact sheet - Nitrification inhibitors

- Option: Advanced agriculture
- Sub-options: Nitrification inhibitors

Fact sheet - Crop residue management

- Option: Advanced agriculture
- Sub-options: Crop residue management

Fact sheet - Reduced tillage

- Option: Advanced agriculture
- Sub-options: Reduced tillage

Fact sheet - Return nutrients from palm oil residues

- Option: Advance agriculture
- Sub-options: Return nutrients from palm oil residues

Fact sheet - Organic fertilizer

- Option: Organic fertilizer

Fact sheet – Use of FAME for cultivation, transport and distribution

- Option: FAME as fuel
- Sub-options:
  - FAME in cultivation
  - FAME in distribution

Fact sheet - Retrofitting single feedstock plants for blending fatty residues

- Option: Retrofitting
- Sub-options:
- Partial modification to UCO/animal fat
- Compete modification to UCO/animal fat

Fact sheet – Green electricity from PV plant on site

- Option: Green electricity

FACT SHEET - Biomethanol

Description

The prevalent process for the production of methanol today is steam reforming of natural gas to get synthesis gas in the first step and subsequent conversion of cleaned and conditioned synthesis gas to methanol. To some extent hard coal and lignite are also used for synthesis gas production resulting in an even higher carbon dioxide footprint for the produced methanol. All options for the production of biomethanol are different options for the production of synthesis gas; the conversion process from synthesis gas to methanol is generally the same for all option. As methanol production severely suffers from thermodynamic constraints, large recycle streams and expensive product make-up processes are part of the plants. Therefore, a strong economy of scale applies to the production process. Also most of synthesis gas production options gain from larger capacities. These limitations lead to the result that there is no viable option to produce the biomethanol onsite a biodiesel plant. All options consider a central methanol plant and a biomethanol distribution to biodiesel plants after production.

The considered raw material options for synthesis gas production are:

- rape straw as residue from biodiesel raw material cultivation (but also cereal straw can be used),
- crude glycerol as by-product from the processing step of FAME,
- additional input materials for gasification are forestry residues, municipal solid waste and black liquor.

Biomethanol from glycerol is commercially available (TRL 9). Plants for biomethanol production from forestry residues and MSW are commercially available, but no plant yet in operation in Europe (TRL 8). Black liquor gasification and straw conversion both are in small scale demonstration (TRL 6-7).

Basic technical and economic data

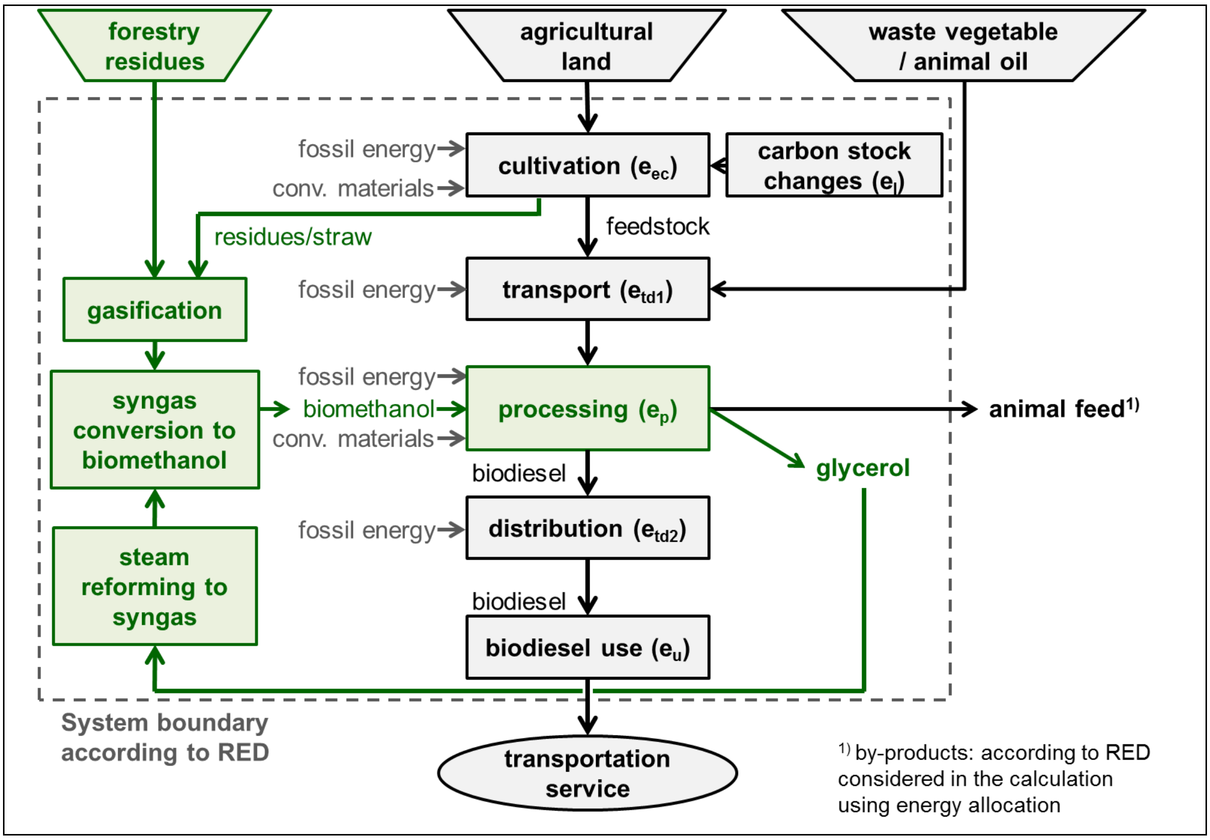
Background data

	GHG emissions [g CO_2-eq/kg]	**Cost** [€/kg]
Methanol (conventional)	1,981[1)]	0.35
Biomethanol from wood residues	100	0.67
Biomethanol from cereal straw	100	0.90

[1)] includes emissions from production and combustion of methanol

[2)] Straw was considered with zero GHG emissions, according to RED

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to biomethanol use for the processing of FAME compared to base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 5 - 6
Change in costs	[€/t_{FAME}]	plus 30 – 50
GHG mitigation costs	[€/t CO_2-eq]	170 - 290
GHG savings compared to fossil reference	[%]	Rapeseed: 49% American soybean: 58%

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ Biomethanol is chemically identical to fossil methanol, therefore no process changes are needed for the biodiesel production ▪ Biomethanol and methanol can be used in changing shares ▪ Biomethanol made from glycerol is already available on the market ▪ Increasing the use of renewable resources to produce FAME	▪ Higher cost of biomethanol compared to fossil methanol ▪ Currently still relatively small volumes of biomethanol are produced and available on the market ▪ Competition with other uses for biomethanol than FAME
OPPORTUNITIES	**THREATS**
▪ New MeOH-production facilities in preparation (wood residues – TKIS, MSW – Enerkem) ▪ New MeOH-production from carbon capture and utilization (e.g. steel mills)	▪ Larger production units might convert directly to olefins or gasoline (MTO/MTG, e.g. bioliq) ▪ Low cost MeOH from shale gas or stranded gas fields

Conclusions

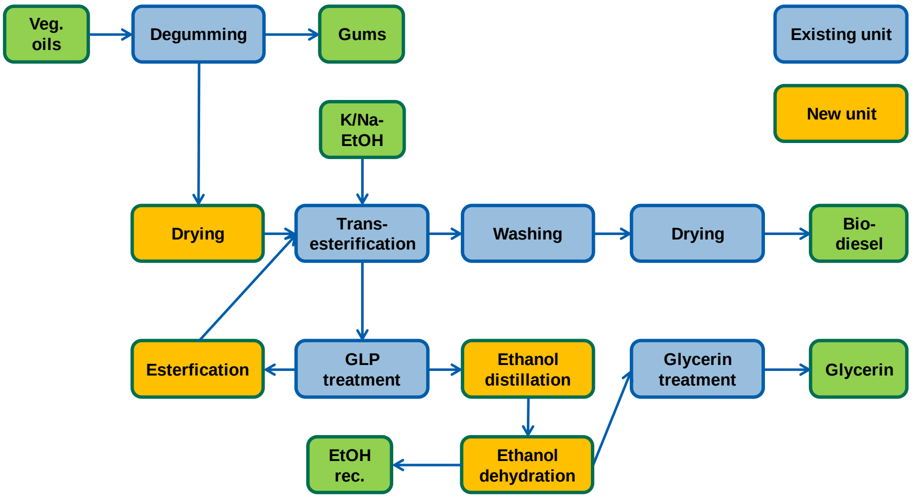
- Technically this is a very easy option, as no alteration to standard processing is needed; can be applied in any share from 0 – 100 %, depending on availability
- MeOH-production from biodiesel residues (glycerol, rape straw, press cake) technically possible in biodiesel plant size, but more efficient and economical in large scale
- MeOH-production from other feedstock (agricultural and forestry residues, MSW) in large scale more likely

FACT SHEET - Bioethanol

Description

In “Option: Bioethanol” fossil methanol is substituted with bioethanol produced from corn and wheat (crop based) and from wood and straw (lingo-cellulosic) for the production of fatty acid ethyl ester (FAEE), which has different characteristics than FAME.

The principle adoption of the biodiesel plant is the same in both cases and shown in the below block diagram:



The influence of bioethanol substitution on the GHG emission balance of FAME is investigated for the production capacity of 200,000 tons FAEE per year from rapeseed.

Basic technical and economic data

System data

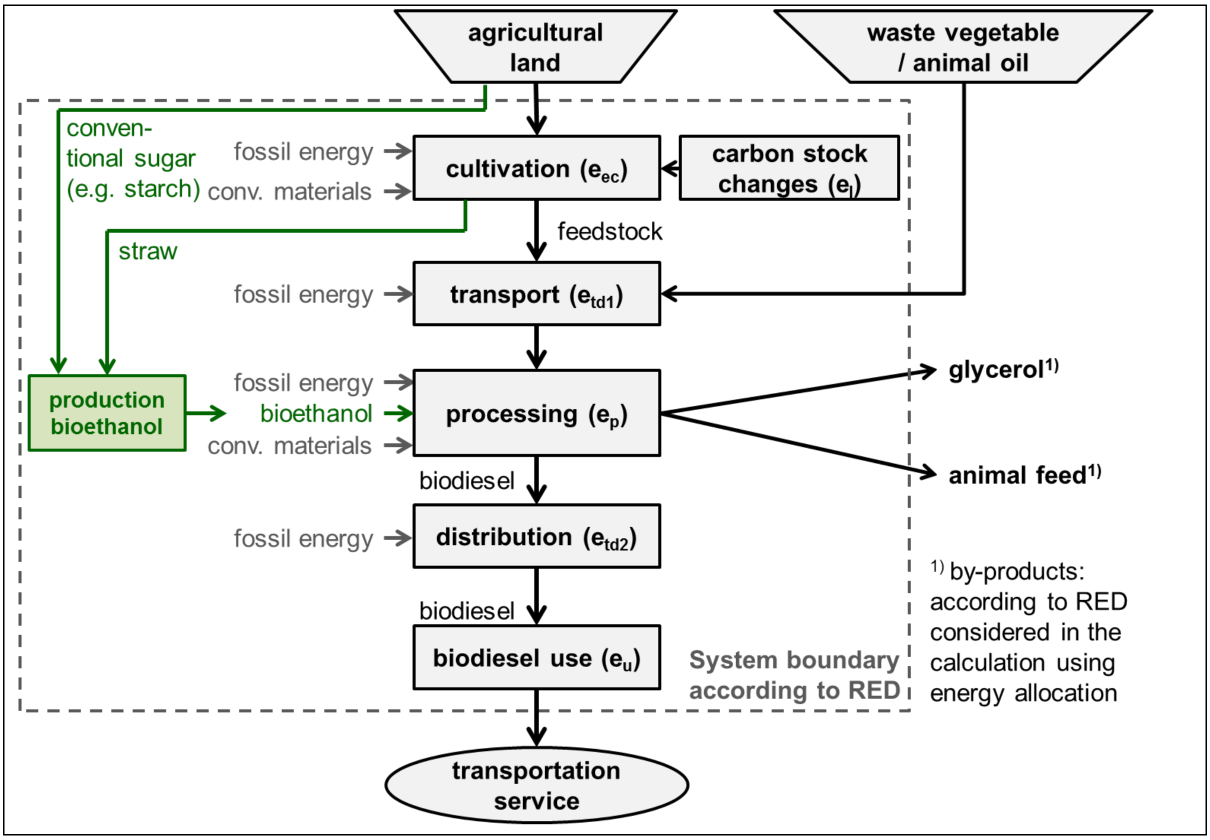
	Unit	Rape seed		
		Base case	**Bioethanol from corn&wheat**	**Bioethanol from wood&straw**
FAME production capacity	[t_{FAME}/yr]	200,000	200,000	200,000
Processing				
Esterification				
Yield FAME/FAEE	[MJ_{FAME}/MJ_{Oil}]	1.003	1.05	1.05
Co-product crude glycerol 85%	[kg/t_{FAME}]	126	-	-
Co-product crude glycerol 90%	[kg/t_{FAME}]	-	109	109
Energy consumption				
Electricity	[MJ/MJ_{FAME}]	0.0013	0.0042	0.0042
Steam (from natural gas boiler)	[MJ/MJ_{FAME}]	0.0137	0.0240	0.0240
Chemicals				
Phosphoric acid (H3PO4)	[kg/MJ_{FAME}]	0.00001	-	-
Sodium methanolate	[kg/MJ_{FAME}]	0.00048	-	-
Hydrochloric acid (HCl)	[kg/MJ_{FAME}]	0.00036	-	-
Methanol	[kg/MJ_{FAME}]	0.00248	-	-
(Bio)-Ethanol	[kg/MJ_{FAME}]	-	0.00195	0.00195
KE24 (Potassium-Ethylat 24% in EtOH)	[kg/MJ_{FAME}]	-	0.00240	0.00240
Investment cost (oil refining and esterification)	[Mio €]	13.0	26.6	26.6
Lifetime	[yr]	25.0	25.0	25.0

Background data

	GHG emissions [g CO_2-eq/MJ]	**Cost** [€/kg]
Methanol	100	0.354
Bioethanol from corn & wheat	44	0.75
Bioethanol from wood & straw$^{1)}$	13	0.80

$^{1)}$ GHG emissions for bioethanol are standard values taken from RED; in the case of Bioethanol from wood & straw, this means that straw was considered with zero GHG emissions

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to the use of bioethanol compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 0.4 – 2.0
Change in costs	[€/t_{FAME}]	plus 70
GHG mitigation costs	[€/t CO_2-eq]	1,000
GHG savings compared to fossil reference	[%]	44 – 46 %

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ Improved GHG emissions (replacement of fossil methanol) ▪ Higher efficiency in conversion of oil to FAEE ▪ Process technology is available	▪ Adaptions of process needed (dehydration of ethanol, feedstock pre-treatment, esterification, glycerol line…) ▪ By now technology not applied on industrial and commercial scale today ▪ Bioethanol per tonne more expensive than methanol ▪ Higher consumption of bioethanol (weight) compared to methanol ▪ Catalyst cost higher (ethanolates instead of methanolate, water free) ▪ High additional investment costs ▪ Higher capital costs
OPPORTUNITIES	**THREATS**
▪ Reduction of fossil methanol part ▪ Ethanol share also in diesel possible ▪ Use of chemical from renewable source ▪ Combustion of FAEE results in no fossil based CO2 compared to FAME with fossil methanol ▪ Development of commercial technology with high share of renewable resources for diesel quality fuel	▪ RED regulation 2020, GHG reduction conventional ethanol ▪ Bioethanol from wheat: GHG emissions for crop based ethanol (expires 2020) ▪ Availability of ethanolates ▪ Commercial availability of lignocellulosic based ethanol insecure ▪ Further ligno-ethanol production improvements/development needed ▪ FAEE is neither included in EN 14214 (European standard for biodiesel) nor in the diesel standard EN 590 ▪ Need of new quality norms/certification for FAEE in fuel market

Conclusions

- Offers small to medium GHG reduction potential for processing part depending on ethanol source
- High costs for plant conversion (glycerol line treatment)
- High costs for biodiesel due to ethanol and catalyst costs
- Still development for industrial scale necessary
- Certification of the product needed (not according to EN 14214)

FACT SHEET - Vegetable oil and wood chips for process energy supply

Description

In this option the following possibilities to provide renewable energy for the production of biodiesel are investigated:

1. **Combined heat and power (CHP) with refined vegetable oils + steam boiler with vegetable oils**: vegetable oil is used to generate power and heat for the biodiesel production instead of fossil energy sources. Electricity is produced in a diesel engine (avg. ~ 0.8 MW_{el}), steam in vegetable oil boilers (sum ~ 11 MW_{th}).
2. **Steam boiler with vegetable oils:** vegetable oil is used in a steam boiler to provide heat for the FAME production (extraction, refining and esterification of oil, sum ~ 11 MW_{th}).
3. **Biomass (wood)-to-steam boiler**: a biomass to steam technology is used for heat production for FAME and oil extraction process. Wood chips which are commercially available and customary in trade are used in standard grate furnaces (2 steam boilers with ~6 MW_{th}).

Note: Rape straw / harvest residues from cultivation was originally also investigated, but dismissed because fluidized bed technology is necessary for biofuels rich in sulphur and chlorine, which is not appropriate for the demanded power range (<10 MW) of usual biodiesel production facilities.

The influence of vegetable oil and wood chips utilization for energy supply on the GHG emission balance and cost of FAME is investigated for the production capacity of 200,000 tons FAME per year from rapeseed.

Basic technical and economic data

System data

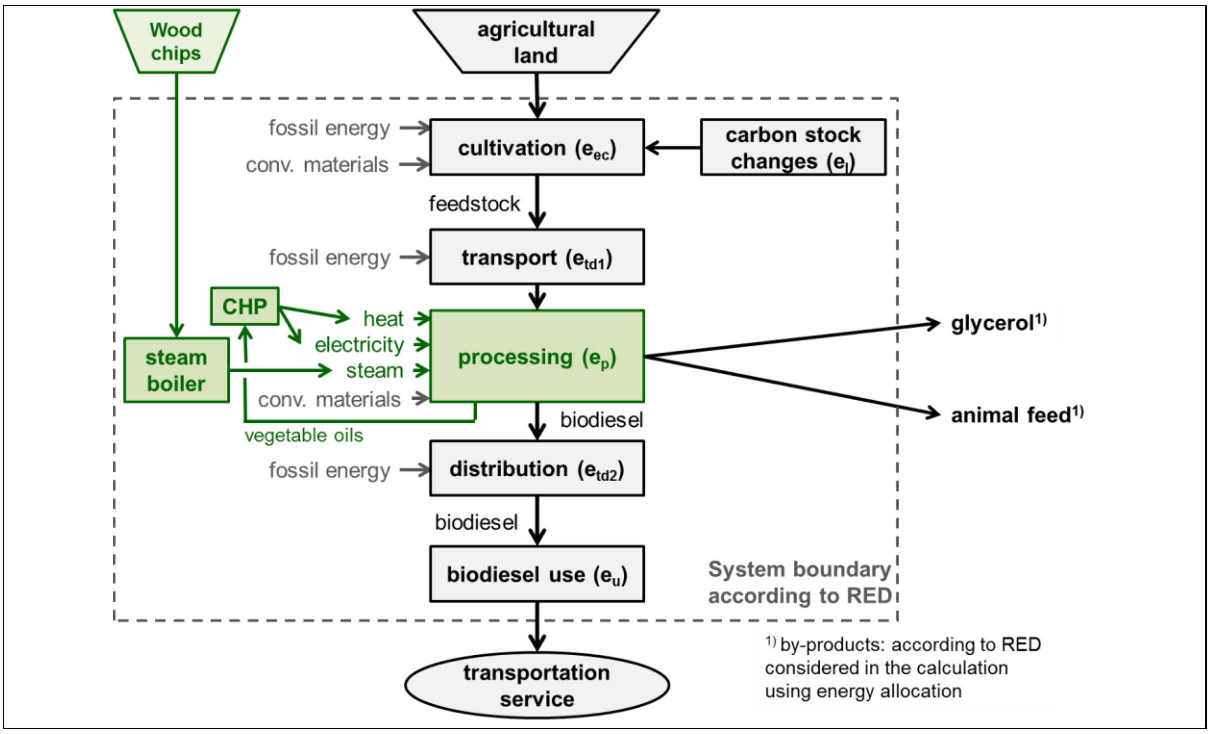
	Unit	Rape seed			
		Base case	**CHP with refined vegetable oils+ steam boiler with vegetable oils**	**Steam boiler with vegetable oils**	**Biomass (wood)-to-steam boiler**
FAME production capacity	[t_{FAME}/yr]	200,000	200,000	200,000	200,000
Extraction of oil					
Electricity	[MJ/MJ_{Oil}]	0.0160	0.0160	0.0160	0.0160
Source steam		natural gas boiler	veg.oil boiler	veg.oil boiler	biomass boiler
Steam	[MJ/MJ_{Oil}]	0.0257	0.0257	0.0257	0.0257
Natural gas	[MJ/MJ_{Oil}]	0.0286	-	-	-
Vegetable Oil	[MJ/MJ_{Oil}]	-	0.0302	0.0302	-
Biomass - wood chips (M40)	[MJ/MJ_{Oil}]	-	-	-	0.0317
Refining of oil					
Source electricity		EU mix MV	on-site production with CHP (engine)	EU mix MV	EU mix MV
Electricity	[MJ/MJ_{Oil}]	0.0011	-	0.0011	0.0011
Vegetable Oil	[MJ/MJ_{Oil}]	-	0.0028	-	-
Source steam		natural gas boiler	veg.oil boiler	veg.oil boiler	biomass boiler
Steam	[MJ/MJ_{Oil}]	0.0025	0.0025	0.0025	0.0025
Natural gas	[MJ/MJ_{Oil}]	0.0028	-	-	-
Vegetable Oil	[MJ/MJ_{Oil}]	-	0.0029	0.0029	-
Biomass - wood chips (M40)	[MJ/MJ_{Oil}]	-	-	-	0.0031
Esterification					
Source electricity		EU mix MV	on-site production with CHP (engine)	EU mix MV	EU mix MV
Electricity	[MJ/MJ_{FAME}]	0.0013	-	0.0013	0.0013
Vegetable Oil	[MJ/MJ_{FAME}]	-	0.0033	-	-
Source steam		natural gas boiler	veg.oil boiler	veg.oil boiler	biomass boiler
Steam	[MJ/MJ_{FAME}]	0.01365	0.0137	0.0137	0.0137
Natural gas	[MJ/MJ_{FAME}]	0.0152	-	-	-
Vegetable Oil	[MJ/MJ_{FAME}]	-	0.0161	0.0161	-
Biomass - wood chips (M40)	[MJ/MJ_{FAME}]	-	-	-	0.0169
Investment cost (oil refining and esterification)	[Mio €]	13	14	13	18
Lifetime	[yr]	25	25	25	25
Personel (extraction and esterification)	[Number]	35	35	35	37

Background data

	GHG emissions*	**Cost**
	[g CO_2-eq/MJ_{fuel}]	[€/MJ_{fuel}]
Natural gas	67.59	0.009
Vegetable oil	44.10	0.014
Biomass - wood chips (M40)	24.70	0.006

* supply of fuel; without burning

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to the use of vegetable oils or wood chips for the process energy supply compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 0.9 – 1.4
Change in costs	[€/t_{FAME}]	minus 10 – plus 10
GHG mitigation costs	[€/t CO_2-eq]	minus 90 1)
GHG savings compared to fossil reference	[%]	45 %

1) For wood-to-steam boiler because only improvement option with a GHG reduction greater minus 1.0 g CO_2-eq/MJ_{FAME} compared to base case

SWOT analysis

STRENGTHS	**WEAKNESSES**
Vegetable oil ▪ No adaptions of process needed, ▪ Technology available (burner, CHP diesel engine for vegetable oil) ▪ Easy to implement ▪ Steam boiler with vegetable oils: Low CAPEX Wood chips ▪ No adaptions of process needed ▪ Technology available for biomass boilers for wood, power range needed is approx. 10 MW (grate furnaces) ▪ This is in contrast to investigated option 3a: straw/residues with high Cl, S-content, where energetic utilization is much more problematic (with regard to corrosion) – and more costly technology is needed (fluidized bed, normally used for higher power range > 20 MW)	Vegetable oil ▪ Vegetable oil is expensive, so far a too valuable resource for heat production (input: 3% of FAME) ▪ CHP with refined vegetable oils: CHP only possible where appropriate heat demand is necessary (esterification) ▪ CHP with refined vegetable oils: Heat from CHP is commonly hot water, only small amounts of steam production possible Wood chips ▪ Insufficient availability of biomass boilers for chemical production plant, => Redundancy needed ▪ Part load behaviour worse than with oil/gas burners, Higher investment costs ▪ Land requirement (construction) higher, ▪ solid fuel logistics, ▪ safety (fire, explosion) issues, (biomass dust deposition in plant,…) ▪ Possible solutions: e.g. 2-3 biomass boiler with half power needed, redundancy veg. oil burner necessary,
OPPORTUNITIES	**THREATS**
Vegetable oil ▪ GHG reduction (replacement of boiler fuel) ▪ (Price increase of mineral / heating oil) ▪ Wood chips ▪ High economic advantage (biomass - wood chips half price of heating oil) -> quick payback of higher investment possible)	Vegetable oil ▪ Price fluctuations of vegetable oil ▪ RED: 2020 limit of 1st gen. biofuel Wood chips ▪ Shortage of wood biomass resources for heating purpose expected for near future, (competition with paper-pulp industry) ▪ Biomass price is expected to rise further ▪ Actual law/regulations (RED directive) gives poor long-term certainty of investment -> amortization of < 3 years is demanded by operating companies (only possible with low investment costs)

Conclusions

All investigated energy generation technologies are commercially available solutions (“off-the-shelf”).

Vegetable oil

- Due to small contribution of energy and heat demand for the process, GHG reduction limited
- High cost for electricity, due to only low level heat (mainly hot water generated) can’t be utilized in biodiesel plant

Wood chips

- Good economics
- Limited to wood chips, direct usage of residues like rape straw would demand technology which is only economically for higher power range
- Limited GHG reduction due to low contribution of energy demand to GHG share

FACT SHEET - Glycerol and FAME distillation residue for process energy supply

Description

In this improvement option the following possibilities to provide renewable energy for the production of biodiesel are investigated:

1. **Combined heat and power (CHP) with distilled glycerol and co-incineration of FAME distillation residue in steam boiler**: glycerol is used to generate electricity for the FAME production (refining and esterification) with an adapted CHP engine (~0.4 MW_{el}). Heat is produced by co-firing the biodiesel distillation residue for partly substitution of natural gas.
2. **Co-incineration of FAME distillation residue in a steam boiler**: heat for the FAME production is generated by co-firing the biodiesel distillation residue for partly substitution of fossil fuels.

The influence on the GHG emission balance is investigated for the production capacity of 50,000 and 100,000 tons FAME per year from waste vegetable oil, used cooking oil (UCO) or animal fat (AF).

Basic technical and economic data

System data

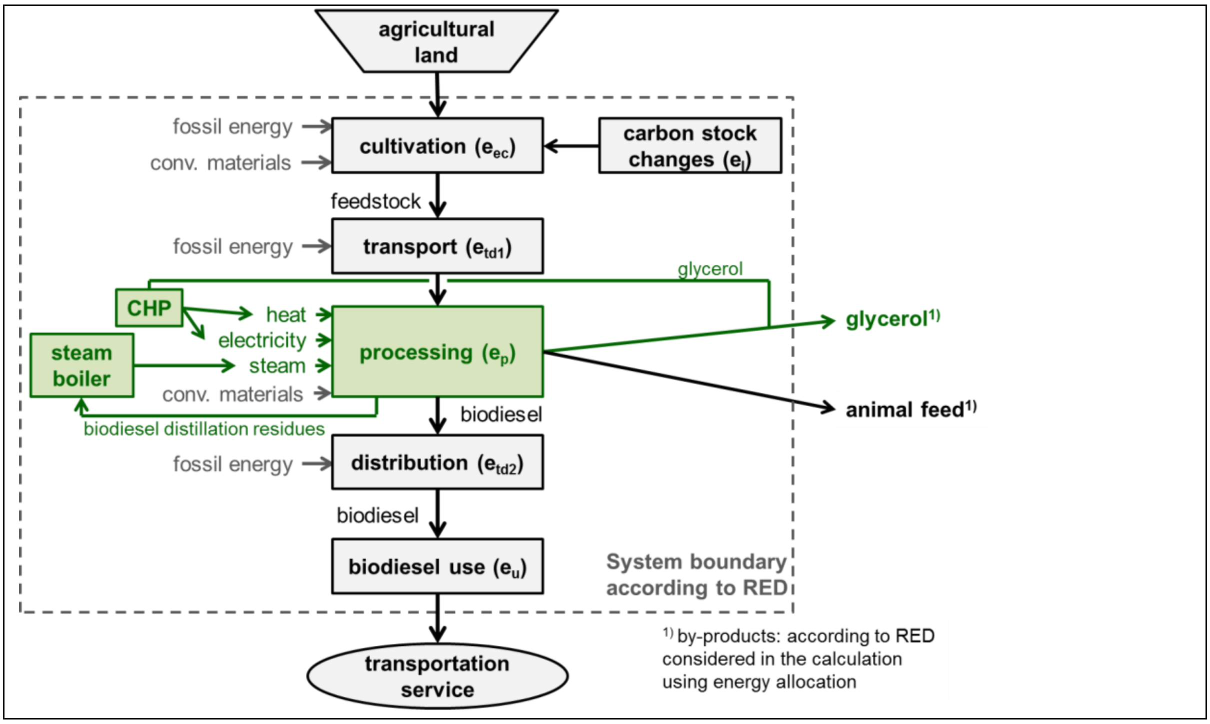
	Unit	Waste vegetable oil & animal fat				
		Base case	**CHP with pharmaglycerol + BHA boiler**	**BHA boiler**	**Base case**	**BHA boiler**
FAME production capacity	[t_{FAME}/yr]	50,000	50,000	50,000	100,000	100,000
Refining of oil						
Source electricity		EU mix MV	on-site production with CHP using pharmaglycerol	on-site production with CHP using pharmaglycerol	EU mix MV	EU mix MV
Electricity	[MJ/MJ_{Oil}]	0.0014	-	-	0.0014	0.0014
Source steam		natural gas boiler	biodiesel distillation residue (BHA) boiler	biodiesel distillation residue (BHA) boiler	natural gas boiler	biodiesel distillation residue (BHA) boiler
Steam	[MJ/MJ_{Oil}]	0.0029	0.0029	0.0029	0.0029	0.0029
Natural gas	[MJ/MJ_{Oil}]	0.0032	-	-	0.0032	0.0000
Esterification						
Co-product crude glycerol 80%	[MJ/MJ_{FAME}]	0.0030	0.0017	0.0030	0.0030	0.0030
Co-product bio oil / BHA	[MJ/MJ_{FAME}]	0.0254	-	-	0.0254	-
Source electricity						
Electricity	[MJ/MJ_{FAME}]	0.0000	on-site production with CHP using pharmaglycerol	EU mix MV	0.0000	EU mix MV
Source steam		natural gas boiler	natural gas boiler	natural gas (~33% of steam is covered with BHA = biodiesel distill.res. boiler)	natural gas (~33% of steam is covered with BHA = biodiesel distill.res. boiler)	natural gas (~66% of steam is covered with BHA = biodiesel distill.res. boiler)
Natural gas	[MJ/MJ_{FAME}]	0.056	0.035	0.035	0.032	0.011
Investment cost (oil refining and esterification)	[Mio €]	21.0	24.9	21.2	31.0	31.2
Lifetime	[yr]	25	25	25	25	25
Personel (extraction and esterification)	[Number]	19	20	20	19	20

Background data

	GHG emissions* [g CO_{2eq}/MJ_{fuel}]	Cost [€/MJ_{fuel}]
Natural gas	67.59	0.009

* supply of fuel; without burning

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to the use of glycerol and/or FAME distillation residues for process energy supply compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 1.4-2.3
Change in costs	[€/t_{FAME}]	plus 0 -10
GHG mitigation costs	[€/t CO_2-eq]	0 - 140
GHG savings compared to fossil reference	[%]	87 – 89%

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ Use of electricity and heat from renewable sources **CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler** ▪ Easy process adaption only in energy supply ▪ Special fuel burners for biodiesel distillation residue (BHA) are available and field-tested **Co-incineration of biodiesel distillation residue in steam boiler** ▪ Easy process adaption only in energy supply ▪ Special fuel burners for biodiesel distillation residue (BHA) are available and field-tested ▪ Low CAPEX	**CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler** ▪ CHP (adapted diesel engine) technology is available, however not field-tested in industry ▪ High glycerol purity needed (10 ppm salts), which implies additional costs and energy demand for pharmaglycerol distillation **Co-incineration of biodiesel distillation residue in steam boiler** ▪ Based on biodiesel feedstock only partial combustion of BHA possible
OPPORTUNITIES	**THREATS**
CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler ▪ Utilization of glycerol of category 1 (usage according to ABPR 142 2001), which otherwise has to be disposed or burnt; ▪ (possible alternative for cat.1 glycerol is usage in biogas plant) ▪ Usage of by product (biodiesel distillation residue) **Co-incineration of biodiesel distillation residue in steam boiler** ▪ Usage of by product (biodiesel distillation residue)	**CHP with distilled glycerol and co-incineration of biodiesel distillation residue in a steam boiler** ▪ poor economics (glycerine distillation) ▪ AF and UCO still accountable to advanced biofuel share

Conclusions

CHP with distilled glycerol and co-incineration of biodiesel distillation residue in steam boiler

- Commercial solution (“off-the-shelf”)
- Additional equipment for glycerol distillation necessary, which causes additional costs and energy demand
- Direct contribution of by product glycerol

Co-incineration of biodiesel distillation residue in steam boiler

- Easy implementation
- Limited GHG reduction potential due to small contribution of energy and heat demand

FACT SHEET - New plant species

Description

Various new plant species are currently being developed for cultivation in Europe and beyond. Examples analysed here are: for cultivation in Europe: 1) crambe (Crambe abyssinica), 2) camelina (Camelina sativa), 3) guayule (Parthenium argentatum) and for cultivation in semi-arid climates: jatropha (Jatropha curcas).

Crambe and camelina are new oil seed crops suitable as spring crops in drier climates of Europe as they require only a short growing season and are therefore suitable for areas with rainfall from 300-500 mm to achieve their maximum yields. The potential seed yield of crambe is 3,000 kg/ha (depending on soil and climate) with 38 % oil. The oil is high in erucic acid (C22:1, 60 %) which has a high value as chemical raw material. The rest product from the oil is a C18 fraction (40 %, with 70 % C18:1 and 30 % C18:2 plus C18:3 fatty acids). This rest product is a new source for producing FAME. Camelina 2,500 kg/ha of seed with 42 % oil which all can be used for FAME (Saturated FA 8%, C18:1 17 %, C20:1 16 %, C18:2 17 % and C18:3 38 %.) Both crops require less nitrogen input (also per unit of FAME production) and therefore can potentially easier reach the required RED criteria for net energy production and net CO2-emission reduction then rapeseed. The seed meal is a valuable feed. The seed hull can be used for electricity production.

Guayule is originally a perennial desert plant that can produce high levels of biomass per hectare with low water demand: 15 ton DM per ha of biomass can be produced with less than 800 mm water. The major products are rubber (10 %), terpenes (5 %), lignocellulose (80 %) and plant oil (5 %), which can become a new source of FAME. It requires also little nitrogen for its cultivation (50 kg/ha per year). Since a high energy output per ha is achieved in the by-products the already relatively low energy input in the cultivation is allocated for over 90 % in the non-oil part and less than 10 % whereas over 50 % of the energy costs of cultivation is allocated to the oil production in oil seed crops. That plus the low nitrogen input might lead to very low energy and CO2-emission cost to the plant oils (and FAME) from guayule.

Jatropha is a perennial crop for semi-arid, (sub-)tropical climates. A new production system with dwarf types of this tree crop has now been developed. It is a combination of a high yield/dwarf trait and a non-toxic jatropha variety, meaning that the press cake can be used as animal feed. These new variety can be grown under wide range of conditions, each with its own productivity. The knowledge on the production functions is available (e.g. JATROPT project). The following yields refer to best technological means: That seed yields on average 2,500 kg/ha of oil. Mechanical harvesting is possible annually yielding 12,200 kg/ha of biomass with 1,800 kg/ha of oil, 1,800 kg/ha of high protein seed meal and 8,600 kg/ha of lignocellulose. The high proportion of energy in by-products results in a relatively low proportion of the cultivation energy and CO2-emission costs to be allocated to the plant oil yielding a high net CO2-emission reduction potential and high net energy production in FAME per kg of FAME.

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ New crops can be grown on more marginal land (less water, less fertilizer per kg of biomass and plant oil) ▪ New crops not only produce plant oil, but also high proportion of by-products (on energy basis) giving less 'burden' on the plant oil and FAME ▪ Processes for new oil crops same as in in existing oil crops	▪ New crops are emerging crops, production chains are under development
OPPORTUNITIES	**THREATS**
▪ Increased demand for the by-products of the new crops (erucamide, nylon, rubber, feed from seed meal) ▪ The oil products are non-edible yielding no direct competition with food production ▪ For FAME, end users prefer products from land not used currently for food	▪ Demand for by-products and FAME need to be in balance ▪ End users need to be convinced about the quality of the FAME and sources are new and therefore not fully tested against specs of end users

Conclusions

- The new crops crambe, camelina, guayule and jatropha offer new raw material sources for FAME production from cultivation on more marginal land not very suitable for food production: no direct competition with food production systems (also because the crops are not food crops)
- Improved net energy production and CO_2-emission might be possible as part of the energy and CO_2-emission costs are borne by the high proportion of by-products (in energy terms as required by the RED-directive).

FACT SHEET - Bioplastic and biochemicals

Description

This fact sheets describes the options "Succinic Acid (SA) from glycerol" and "Pharmaglycerol".

Succinic Acid (SA) from glycerol

The market size for bio-based succinic acid (BBSA) in 2013 was about 0.2 billion EUR, mainly in the sector food, pigments and pharma. The current supply chain is fed by petro-based succinic acid. Succinic acid could also partially replace adipic acid. The potential market size to be served in the future is estimated to be about 7.5 billion EUR consisting of

- Plasticizer (approx. 20%)
- Butanediol (approx. 45%)
- Adipic acid (approx. 35%)
- Plasticizers (approx. 20%)
- Bio Polymers (approx. 1 %)[7]

It is therefore realistic to assume that a major share of the glycerol by-product of the FAME processes could enter into the succinic acid market. Assuming that succinic acid would sell at a price around 5,500 €/t the corresponding global succinic acid market is about 40,000 tons per year.

The option "Succinic Acid (SA) from glycerol" deals with the conversion (fermentation) of crude aqueous glycerol (here without catalyst) together with 2nd generation non-food sugars (C6) resulting from residues of oil plant materials (straw), after the removal of lignin and hemi-cellulose fractions. The processing of sugar could be combined with an Ethanol production site to reach better scale effects. Only the best case, in terms of CO_2-capture and yield of SA, employing a ratio of 5:1 (mass ratio m/m) glycerol to sugar is considered. The data are based on experimental results, publications and patent information. However, other ratios of glycerol and sugar can be processed as well.
CO_2-sink – use of oxygen free CO_2 e.g. from biogas resulting from organic residue processing

- $C_3H_8O_3$ (glycerol) + CO_2 > $C_4H_6O_4$ (SA) + H_2O m/m 0,66 gly/SA 0,31 CO_2/SA
- $6C_6H_{12}O_6$ (glucose)+ $2CO_2$ > $4C_4H_6O_4$ +$2H_2O$ +$2C_2H_5O_2$ (HAc)
  m/m 1,14 glu/SA 0,19 CO2/SA

Currently the main factor impacting cost, next to raw materials, is the "consumable" baker yeast. The fermentation itself generates mainly cell-biomass and some acetic acid (HAc) and unconverted glycerol as residues. Both are converted to biogas. The processing of straw yields a solid lignin fraction, i.e. energy source, and an aqueous hemi-cellulose fraction that is treated to yield biogas.
The influence of this (additional) fermentation on the GHG emission of FAME is investigated for the production capacity of 50,000 and 200,000 tons FAME respectively per year from rapeseed oil and its straw.

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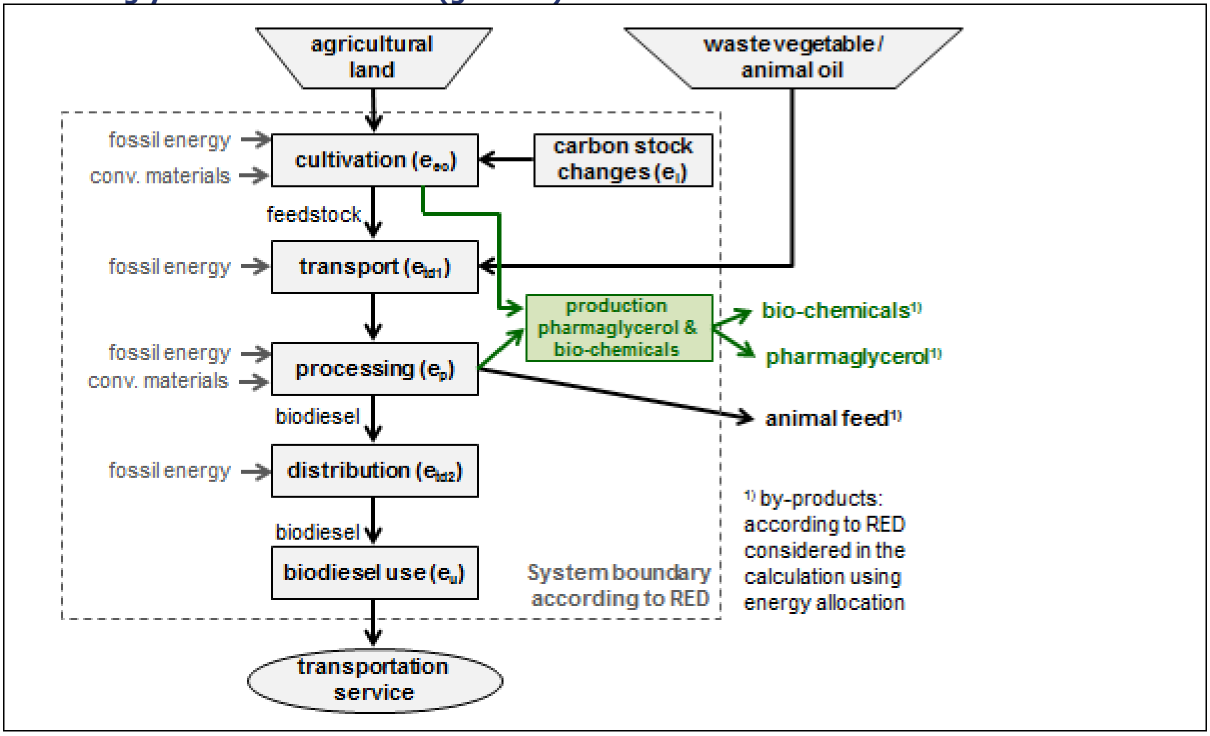
[7] Markus Hummelsberger, Succinity GmbH, "7th International Conference on Bio-based Materials", Cologne, April 9, 2014.

Pharmaglycerol

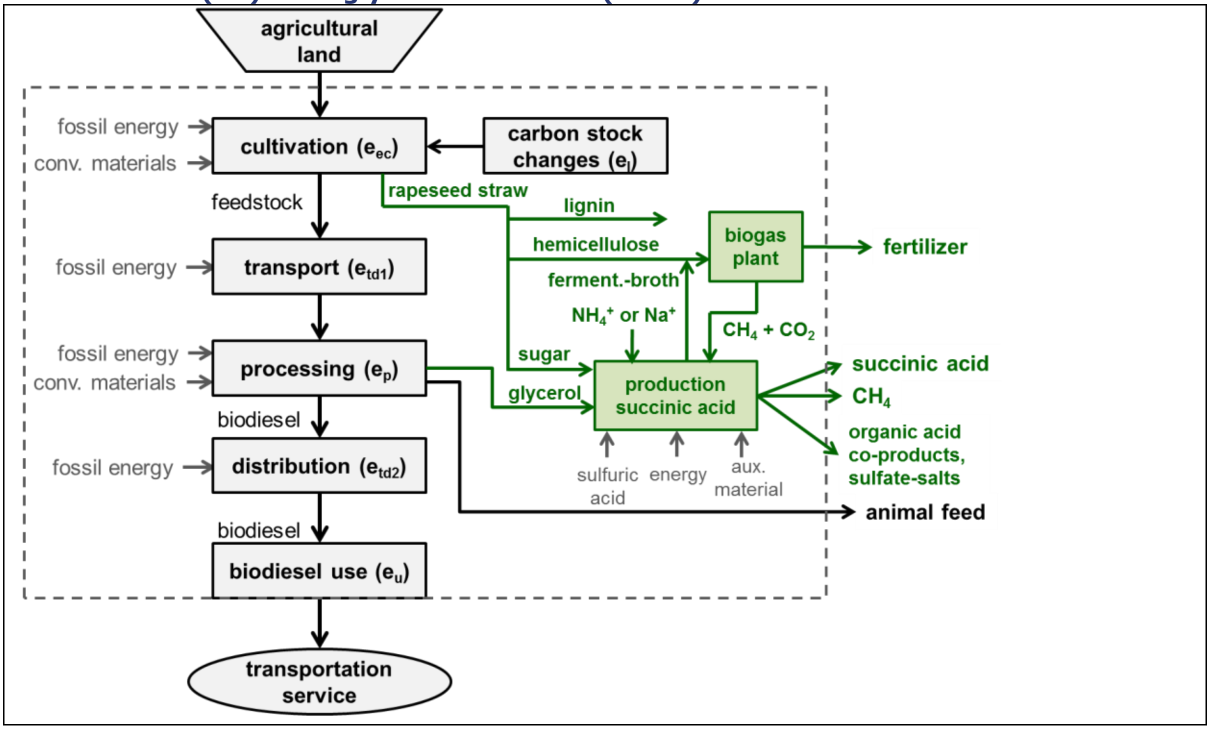
The option "Pharmaglycerol" investigates the refining of crude glycerol to pharmaglycerol (99.5% glycerol). Refining of crude glycerol to pharmaglycerol is a process, which is already installed in biodiesel plants. It is investigated to see the influence on GHG balance by setting different system boundaries.

System boundaries for GHG calculation

Pharmaglycerol & biochemical (general)



Succinic acid (SA) from glycerol and straw (detail)



GHG and economic assessment

Change of GHG emissions and costs due to by-products pharmaglycerol 99.5+ and succinic acid compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

		Pharmaglycerol 99.5+	**Succinic acid**
Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	UCO/animal fat: plus 1 Rapeseed: minus 1.5	plus 2
Change in costs	[€/t_{FAME}]	minus 10 - 0	minus 350
GHG mitigation costs	[€/t CO_2-eq]	Rapeseed: minus 170	1)
GHG savings compared to fossil reference	[%]	Rapeseed: 45% UCO/animal fat: 86%	Rapeseed: 40%

1) Not calculated because GHG reduction smaller than minus 1.0 g CO_2-eq/MJ_{FAME} compared to base case

SWOT analysis

STRENGTHS	**WEAKNESSES**
Succinic Acid (SA) from glycerol ▪ Proven CO_2-Sink; up to -90%1) ▪ Existing market for glycerol ▪ Flexibility in raw materials & costs together with sugar ▪ No green premium required*) ▪ The glycerol-to-SA technology is not only on demonstration scale but on commercial step (SUCCINITY GmbH, www.succinity.com) **Pharmaglycerol** ▪ alternative usage glycerol ▪ independence from strong fluctuating glycerol prices	**Succinic Acid (SA) from glycerol** ▪ Sugar to SA-technology on demonstration level (~90% done) ▪ Economy of scale (FAME) determines glycerol availability and costs **Pharmaglycerol** ▪ glycerol distillation
OPPORTUNITIES	**THREATS**
Succinic Acid (SA) from glycerol ▪ Big players in the SA-market, hence fast learning expected ▪ SA is a prominent example for sustainable chemicals ▪ Down-stream value - Tetrahydrofuran (THF), Butan1,4-Butandiol (BDO) ▪ γ-Butyrolactone (GBL) **Pharmaglycerol** ▪ The production of poly lactic acid2) is expected to increase in the future. This could lead to an increasing demand for upgraded glycerol	**Succinic Acid (SA) from glycerol** ▪ Low sugar commodity price ▪ Stagnation of glycerol supply due to Hydrogenated vegetable oil (HVO) (NESTE Oil) ▪ Dominance of sugar supply chain compared to glycerol ▪ The glycerol market is extremely volatile in terms of availability and pricing **Pharmaglycerol** ▪ usage in case of glycerol based on waste feedstocks (Cat 1) ▪ legislative regulations (animal by product regulation for glycerol)

1) Myriant, 2015

2) Poly lactic acid (PLA) could be used as packaging material. In 2014 approximately 10.2 Mio tonnes of biodiesel were produced in EU 27 (UFOP, 2016). This corresponds to approximately 1 Mio tonnes of glycerol. This glycerol amount could be integrated in PLA production, if the PLA production capacities are increasing accordingly in future.

Conclusions

Succinic Acid (SA) from Glycerol

- Glycerol as raw material requires a “stable” legislation to allow for demonstration and market introduction, ideally 5 years
- The economics and LCA-improvement(s) for an inclusion of glycerol in a SA-process must be significant enough to allow differentiation from competitors
- The current non-availability of 2nd generation non-food sugars are a window of opportunity for a glycerol/sugar fermentation (to SA) in Europe and elsewhere
- The availability of sufficient “suited” glycerol and the supply chain integration (“biorefinery over the fence”) are important success and market entry factors

Pharmaglycerol

- Needed alternative usage for low grade glycerol
- Glycerol distillation necessary for most fermentation processes

FACT SHEET - Balanced fertilization

Description

In “Option: Balanced fertilization” the amount of fertilizer is balanced to the fertilizer demand of the crop to prevent “overfertilization” and related GHG emissions. Balanced application of fertilizers requires the right amount, right timing and placement of the fertilizer. The influence of balanced fertilization on the GHG emission of FAME is investigated for the production of 100,000 tons FAME per year from rapeseed and from palm oil.

Based on a range of data sources (fertilizer recommendations, application standards and model data) the EU average nutrient demand and application were determined for rapeseed. For nitrogen some losses are inevitable and therefore a 25 % overfertilization factor was assumed. The average N application can be reduced from 168 kg N/ha to 151 kg N/ha. Also for P and K the fertilizer amount can be reduced by approximately 25%.

For oil palm data availability on fertilization is much more limited. Based on local data from Indonesia an estimate was made of the nutrient demand. In oil palm on average a reduction in N fertilizer application from 167 to 155 kg N/ha is possible, and also a reduction in K_2O and P_2O_5 fertilizer can be obtained.

Basic technical and economic data

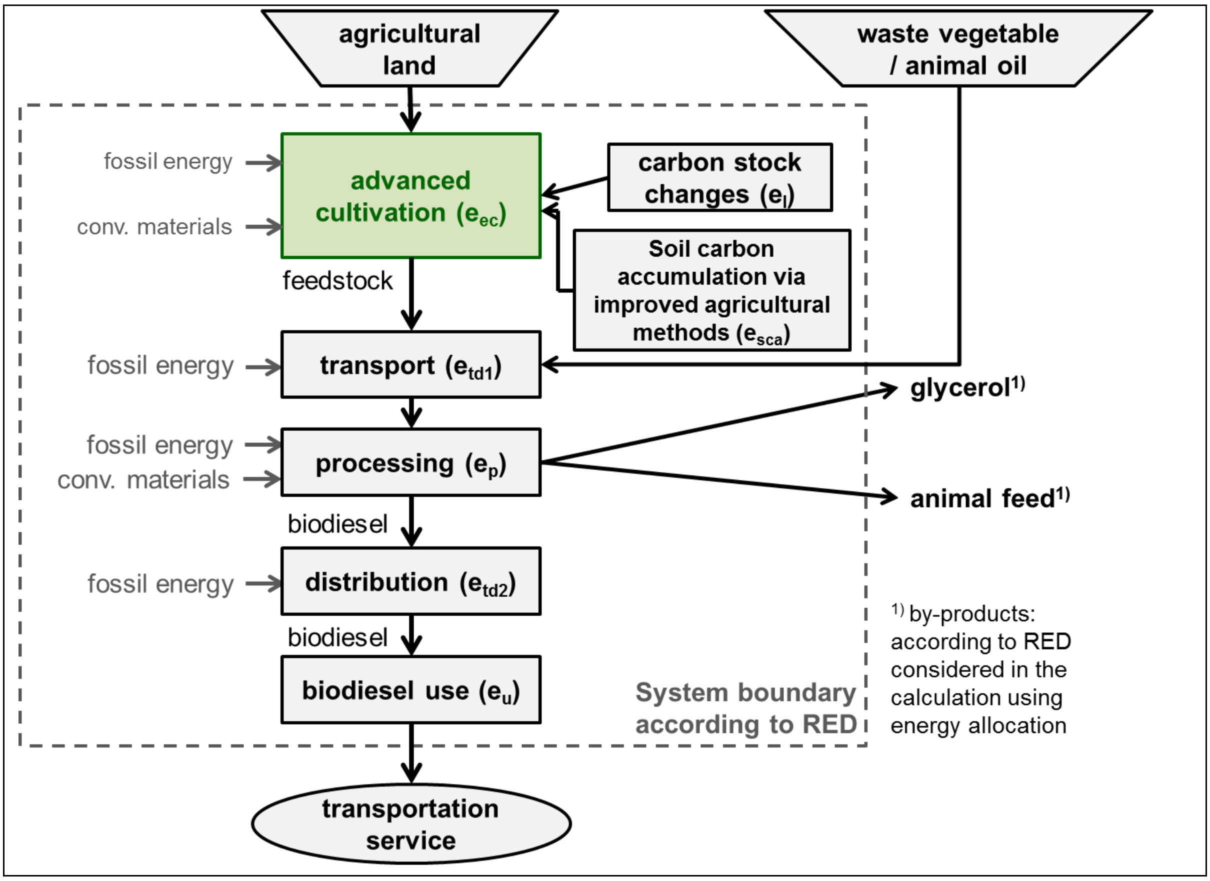
System data

	Unit	Rape seed		Palm oil	
		Base Case	**Balanced fertilization**	**Base Case**	**Balanced fertilization**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000	100,000	100,000
Diesel	[MJ/(ha*yr)]	2,963	2,963	2,065	2,065
N-fertiliser (kg N)	[kg/(ha*yr)]	168	151	167	155
Manure	[kg/(ha*yr)]	-	-	-	-
K_2O-fertiliser (kg K2O)	[kg/(ha*yr)]	70	53	333	300
P_2O_5-fertiliser (kg P2O5)	[kg/(ha*yr)]	80	60	144	110
Field N_2O emissions	[kg/(ha*yr)]	4.1	3.8	3.6	3.4
Resulting soil carbon accumulation	[t CO_2/(ha*a)]	-	-	-	-
Personel	[h/(ha*yr)]	10.4	11.0	20.0	30.0
Machinery	[h/(ha*yr)]	9.4	10.0	10.0	15.0

Background data GHG

	GHG emissions		Cost - Rape seed		Cost - Palm oil	
	[g CO_{2eq}/MJ]	[g CO_{2eq}/kg]	[€/MJ]	[€/kg]	[€/MJ]	[€/kg]
Diesel	87.64	-	0.02	-	0.02	-
Manure	-	0	-	0.001	-	-
N-fertiliser (kg N)	-	5,881	-	1.24	-	0.99
N-fertiliser (kg N) incl. nitrification inhibitars	-	5,881	-	1.55	-	1.24
K_2O-fertiliser (kg K_2O)	-	576	-	0.81	-	0.65
P_2O_5-fertiliser (kg P_2O_5)	-	1,011	-	1.18	-	0.94
			[€/h]		[€/h]	
Personel	-		20		16	
Machinery	-		15		12	

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to balanced fertilization compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

		Balanced fertilization	
		Rape seed	**Palm oil**
Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 3.1	minus 0.8
Change in costs	[€/t_{FAME}]	minus 30	plus 20
GHG mitigation costs	[€/t CO_2-eq]	minus 260	1)
GHG savings compared to fossil reference	[%]	47 %	70 %

1) Not calculated because GHG reduction smaller than minus 1.0 g CO_2-eq/MJ_{FAME} compared to base case

SWOT analysis

STRENGTHS	WEAKNESSES
▪ Both emission reduction and cost savings can be obtained	▪ For implementation farm specific assessments have to be made ▪ EU polices, mainly Nitrates Directive, already reduced part of the potential ▪ In oil pam pocket fertilizer application increases labour cost
OPPORTUNITIES	**THREATS**
▪ Reduction in fertilizer input has also co-benefits for other environmental problems ▪ In intensive oil palm plantations GHG savings might be much larger	▪ Risk on crop yield losses if too little fertilizer is applied ▪ Best practices might require other fertilizer application equipment

Conclusions

- The use of balanced fertilization in EU rapeseed is a cost-effective measure.
- In palm oil cultivation there is potential to reduce the fertilizer input and related GHG emissions, but costs are higher because of pocket application.

FACT SHEET - Nitrification inhibitors

Description

Nitrification inhibitors, such as dicyandiamide (DCD), can be applied in or together with mineral fertilizer to conserve soil nitrogen and increase the efficiency of N supply to plants. These chemicals slow or "inhibit" the conversion of N from the relatively immobile ammonium (NH_4) form to the mobile nitrate (NO_3) form, which results in a reduction of the soil N_2O emissions. However, this option can only be used on ammonium based fertilizers (incl. urea).The influence of nitrification inhibitors on the GHG emission of FAME is investigated for the production of 100,000 tons FAME per year from rapeseed. Based on a literature review an average reduction in soil N_2O emission and N leaching of 20 % was assumed. Cost data is limited available; we estimate that the cost would increase by 25 %, although the range can be large.

Basic technical and economic data

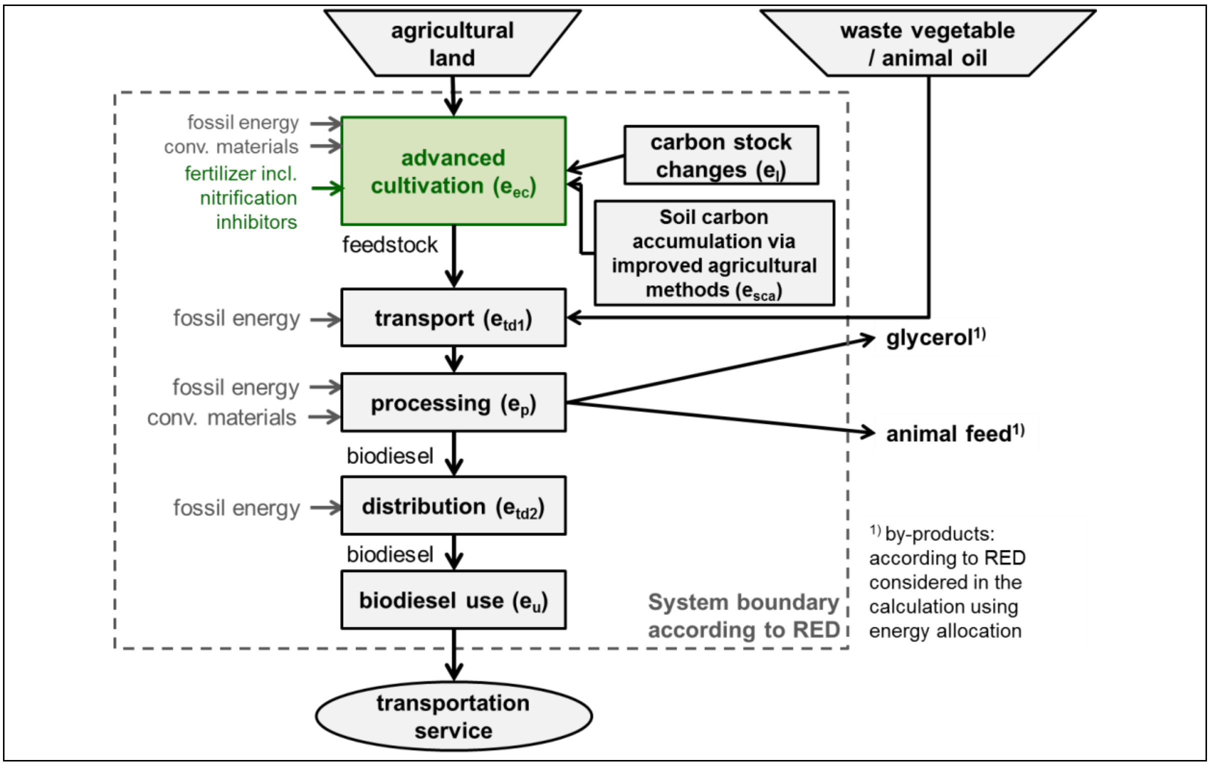
System data

	Unit	Rape seed	
		Base Case	**Nitrification inhibitors**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000
Diesel	[MJ/(ha*yr)]	2,963	2,963
N-fertiliser (kg N)	[kg/(ha*yr)]	168	168
Manure	[kg/(ha*yr)]	-	-
K_2O-fertiliser (kg K2O)	[kg/(ha*yr)]	70	70
P_2O_5-fertiliser (kg P2O5)	[kg/(ha*yr)]	80	80
Field N_2O emissions	[kg/(ha*yr)]	4.1	3.4
Resulting soil carbon accumulation	[t CO_2/(ha*a)]	-	-
Personel	[h/(ha*yr)]	10.4	10.4
Machinery	[h/(ha*yr)]	9.4	9.4

Background data

	GHG emissions		Cost - Rape seed	
	[g CO_{2eq}/MJ]	[g CO_{2eq}/kg]	[€/MJ]	[€/kg]
Diesel	87.64	-	0.02	-
Manure	-	0	-	0.001
N-fertiliser (kg N)	-	5,881	-	1.24
N-fertiliser (kg N) incl. nitrification inhibitars	-	5,881	-	1.55
K_2O-fertiliser (kg K_2O)	-	576	-	0.81
P_2O_5-fertiliser (kg P_2O_5)	-	1,011	-	1.18
			[€/h]	
Personel	-		20	
Machinery	-		15	

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to nitrification inhibitors compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 3.1
Change in costs	[€/t_{FAME}]	plus 40
GHG mitigation costs	[€/t CO_2-eq]	360
GHG savings compared to fossil reference	[%]	47 %

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ Significant emission reduction is possible ▪ No need for new fertilizer application equipment	▪ Nitrification inhibitors are not under all conditions effective ▪ Fertilization costs will increase
OPPORTUNITIES	**THREATS**
▪ There is potential to improve the effectiveness of nitrification inhibitors	▪ Risk on crop yield losses if too little fertilizer is applied ▪ There might be legislative constraints for its use (health and fertilizer regulations)

Conclusions

The use of nitrification inhibitors has emission reduction potential (5-10 %), but it is not a cost-effective option due to the higher fertilizer production costs.

FACT SHEET - Crop residue management

Description

Crop residues incorporation, where stubble and straw is left on the field ground and incorporated when the field is tilled, enhances carbon flows back to the soil, thereby encouraging carbon sequestration. For the base case scenario it was assumed that all harvestable crop residues (i.e. straw) is on average removed, according to BioGrace this was 1420 kg, which is about one third of the total crop residues including roots and stubbles. When this is left on the field this equals an additional C input of 640 kg C/ha, based on a C content of 45%. However, only part of the carbon input can be considered as effective carbon that remains in the soil. This amount is only 213 kg C/ha, based on a humification coefficient of 33%, which equals 780 kg CO_2/ha. In terms of Nitrogen (N) fertilization a slight saving is expected as the N from the crop residues becomes available. This amount is estimated at 19 kg N/ha, but due to N losses, the amount of N fertilizer that effectively can be replaced is lower (15 kg N/ha). The influence of this option on the GHG emission balance of FAME is investigated for the production capacity of 100,000 tons FAME per year from rapeseed.

Basic technical and economic data

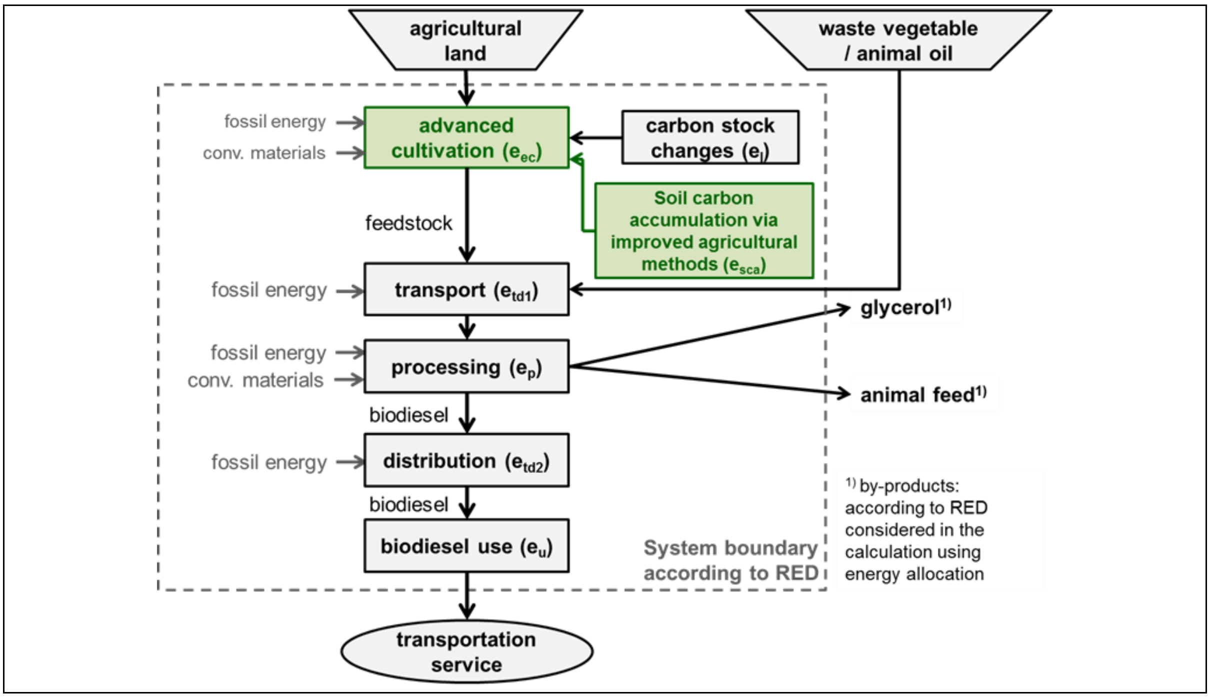
System data

	Unit	Rape seed	
		Base Case	**Crop residue incorporation**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000
Cultivation			
Feedstock	[kg/(ha*yr)]	3,160	3,160
Co-product Straw	[kg/(ha*yr)]	1,420	-
Diesel	[MJ/(ha*yr)]	2,963	2,963
N-fertiliser (kg N)	[kg/(ha*yr)]	168	153
Field N_2O emissions	[kg/(ha*yr)]	4.15	4.14
Resulting soil carbon accumulation	[t CO_2/(ha*yr)]	-	0.8
Personel	[h/(ha*yr)]	10.4	10.4
Machinery	[h/(ha*yr)]	9.4	9.4

Background data

	GHG emissions		Cost - Rape seed	
	[g CO_{2eq}/MJ]	[g CO_{2eq}/kg]	[€/MJ]	[€/kg]
Diesel	87.64	-	0.023	-
N-fertiliser (kg N)	-	5,881	-	1.24
			[€/h]	
Personel	-		20	
Machinery	-		15	

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to crop residue management compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 20
Change in costs	[€/t_{FAME}]	minus 10
GHG mitigation costs	[€/t CO_2-eq]	minus 20
GHG savings compared to fossil reference	[%]	68 %

SWOT analysis

STRENGTHS	WEAKNESSES
▪ High GHG reduction potential, mainly from soil carbon sequestration ▪ Easy to implement in existing farming practices	▪ Uncertainty about current implementation, in some countries this is already current practice ▪ Soil carbon sequestration options have a high uncertainty ▪ Soil carbon sequestration is not permanent and will stop when a new equilibrium is reached
OPPORTUNITIES	**THREATS**
▪ Reduction of fertilizer input and increase in soil carbon have co-benefits for other environmental problems	▪ Risk on pests or diseases ▪ Bio-economy will increase the competition for straw

Conclusions

- This measure has a high GHG mitigation potential, calculated at 46 % (substantial reduction of GHG emissions).
- The soil carbon sequestration potential is uncertain and limited over time.
- The measure is cost-effective but this might change if demand and prices for straw increase.

FACT SHEET - Reduced tillage

Description

Reduced tillage decreases soil heterotrophic respiration and CO_2 emissions while soil carbon stocks are increasing due to higher crop residue incorporation. The influence of this option on the GHG emission balance of FAME is investigated for the production capacity of 100,000 tons FAME per year from rapeseed.

Following the IPCC 2006 guidelines, an average increase in soil organic carbon (SOC) of 6% is estimated. Based on an average SOC stock of 50 t C/ha and a 20 year reference time to reach a new SOC equilibrium, the annual sequestration potential would be 0.55 ton CO_2/ha/year. However, more recent literature challenges the SOC sequestration potential of reduced and zero tillage. Therefore, we used a conservative estimation of 50% of the calculated SOC sequestration potential, i.e. 0.275 t CO_2/ha/year.

Basic technical and economic data

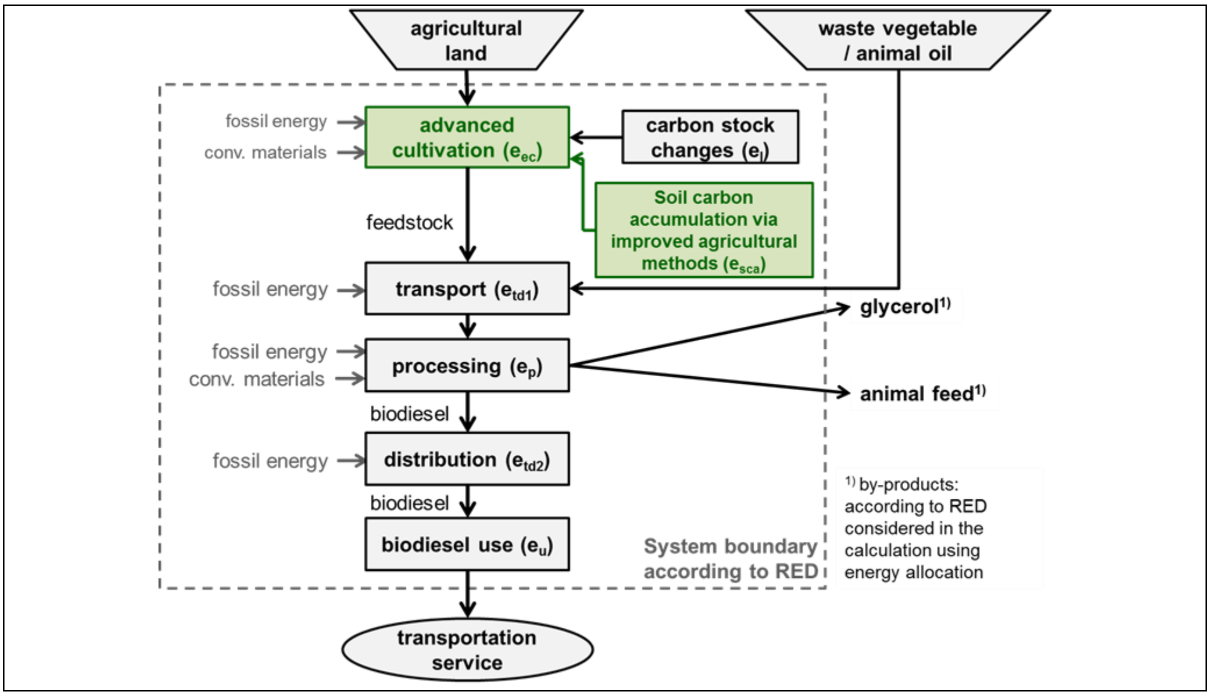
System data

	Unit	Rape seed	
		Base Case	**Reduce tillage**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000
Cultivation			
Feedstock	[kg/(ha*yr)]	3,160	3,160
Co-product Straw	[kg/(ha*yr)]	1,420	1,420
Diesel	[MJ/(ha*yr)]	2,963	2,667
N-fertiliser (kg N)	[kg/(ha*yr)]	168	168
Field N_2O emissions	[kg/(ha*yr)]	4.15	4.15
Resulting soil carbon accumulation	[t CO_2/(ha*yr)]	-	0.3
Personel	[h/(ha*yr)]	10.4	9.9
Machinery	[h/(ha*yr)]	9.4	8.9

Background data

	GHG emissions		Cost - Rape seed	
	[g CO_{2eq}/MJ]	[g CO_{2eq}/kg]	[€/MJ]	[€/kg]
Diesel	87.64	-	0.023	-
N-fertiliser (kg N)	-	5,881	-	1.24
			[€/h]	
Personel	-		20	
Machinery	-		15	

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to reduced tillage compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 7
Change in costs	[€/t_{FAME}]	minus 20
GHG mitigation costs	[€/CO_2-eq]	minus 70
GHG savings compared to fossil reference		52 %

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ Cost effective measure ▪ Decreases fuel use and associated GHG emissions	▪ Scientific debate on the effectiveness of reduced tillage (more a redistribution rather than an increase of soil carbon) ▪ Does not fit to all crop rotations and the small seeds make direct seeding in combination with zero tillage not possible ▪ Soil carbon sequestration is not permanent and will stop when a new equilibrium is reached
OPPORTUNITIES	**THREATS**
▪ Reduced tillage has co-benefits, such as erosion reduction	▪ Risk on a reduction of crop yields during first years

Conclusions

- Reduced tillage is a cost effective measure with significant, but uncertain GHG mitigation potential.

FACT SHEET - Return nutrients from palm oil residues as fertilizer

Description

At the moment, most of palm oil residues remain unused (at least in Indonesia, although in Malaysia it seems that more residues are already returned) and are not returned to the soil. For this option palm oil residues are returned to the field, which reduces the need for mineral fertilizer and can also sequester carbon in the soil. The calculation is based on the return of the empty fruit bunches, which is around 23% of the fresh fruit bunches. In addition, a return of the digestate of palm oil mill effluent and a return of the ash from burned fibre and shells (which are used for energy for the palm oil processing) is assumed. Using the BioEsoil tool (www.bioesoil.org), which was developed by Alterra, we assessed how much residues can be effectively returned to the field, how much fertilizer can be saved and how much carbon can be stored in the soil. The results show that 41 kg of N, 23 kg K_2O and 13 kg P_2O_5 fertilizer can be saved and 1.5 ton CO_2/ha/year can be sequestered in the soil (for 20 years).

The influence of this option on the GHG emission balance of FAME is investigated for the production capacity of 100,000 tons FAME per year from palm oil.

Basic technical and economic data

The following tables show the basic technical and economic data.

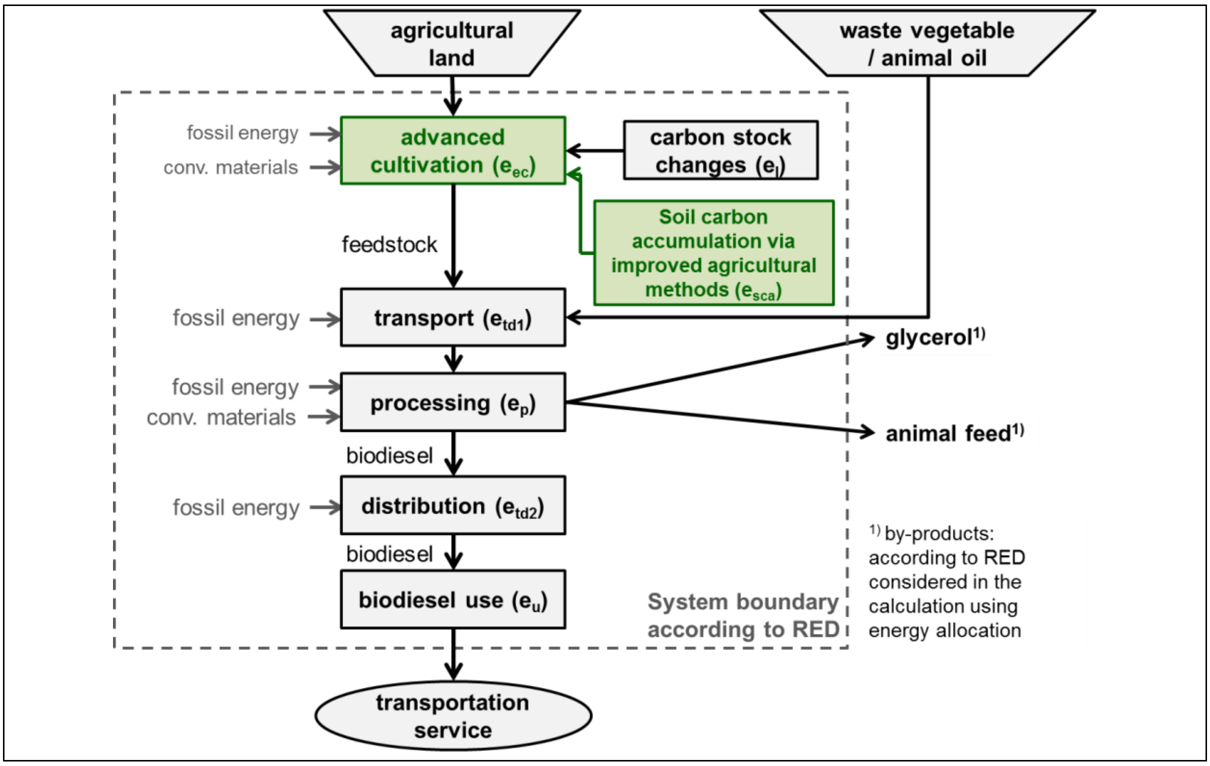
System data

	Unit	Palm oil	
		Base Case	**Return nutrients from palm oil residues as fertilizer**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000
Cultivation			
Feedstock	[kg/(ha*yr)]	19,000	19,000
Co-product Straw	[kg/(ha*yr)]	-	-
Diesel	[MJ/(ha*yr)]	2,065	2,065
N-fertiliser (kg N)	[kg/(ha*yr)]	167	167
Field N_2O emissions	[kg/(ha*yr)]	3.61	3.61
Resulting soil carbon accumulation	[t CO_2/(ha*yr)]	-	1.5
Personel	[h/(ha*yr)]	20.0	25.0
Machinery	[h/(ha*yr)]	10.0	12.5

Background data

	GHG emissions		**Cost - Rape seed**		**Cost - Palm oil**	
	[g CO_{2eq}/MJ]	[g CO_{2eq}/kg]	[€/MJ]	[€/kg]	[€/MJ]	[€/kg]
Diesel	87.64	-	0.023	-	0.019	-
N-fertiliser (kg N)	-	5,881	-	1.24	-	0.99
			[€/h]		[€/h]	
Personel	-		20		16	
Machinery	-		15		12	

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to return nutrients from palm oil residues as fertilizer compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 11.3
Change in costs	[€/t_{FAME}]	0
GHG mitigation costs	[€/t CO_2-eq]	0
GHG savings compared to fossil reference		83 %

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ High soil carbon sequestration potential ▪ Both, GHG emissions reduction and carbon sequestration in the soil	▪ Cost for return of residues are higher than fertilizer savings ▪ Soil carbon sequestration is uncertain and not permanent ▪ Uncertainty about potential, in some countries already current practice
OPPORTUNITIES	**THREATS**
▪ Reduction of fertilizer input and carbon sequestration have also co-benefits for other environmental problems	▪ The empty fruit bunches cannot be used for energy production anymore ▪ The soil carbon sequestration potential will decrease over time (C saturation)

Conclusions

- This measure has a high GHG mitigation potential, calculated at 45 % (substantial reduction of GHG emissions).
- However, the measure will increase the cost for returning the residues to the field.
- The soil carbon sequestration potential is uncertain and limited over time.

FACT SHEET - Organic fertilizer

Description

In “Option: Organic fertilizer” mineral fertilizer is replaced by organic fertilizer, which can reduce GHG emissions from the production of especially mineral nitrogen fertilizer, which is highly energy intensive. Moreover, CO_2 can be sequestered through the addition of carbon to the soil. As the availability of manure is limited in regions where rapeseed is grown, on average only a 20 kg N of mineral fertilizer can be replaced. Based on the average CN ratio of 10, this would equal 200 kg C/ha. With an average humification coefficient of 0.5 this would lead to an effective C input of 100 kg/ha, which is 367 kg CO_2/ha. However, an individual farmer can of course replace much more of his mineral fertilizer. The influence of use of organic fertilizer on the GHG emission of FAME is investigated for the production of 100,000 tons FAME per year from rapeseed.

Basic technical and economic data

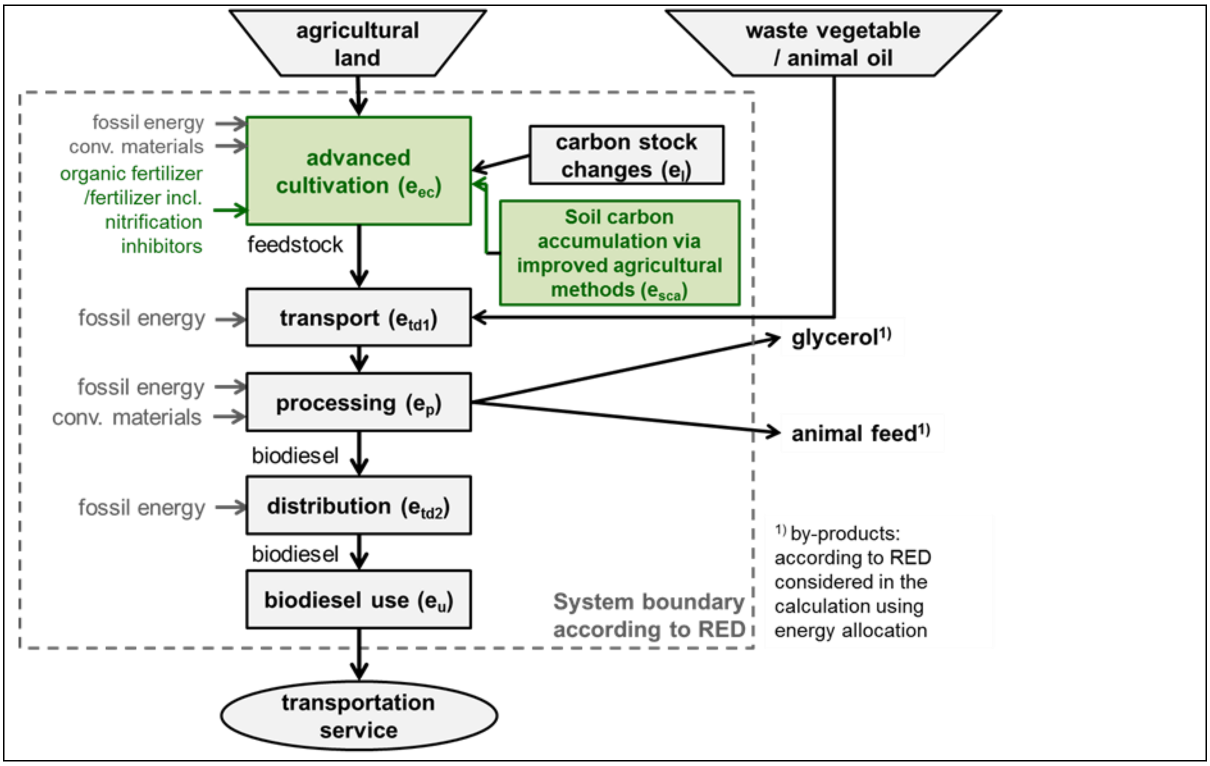
System data

	Unit	Rape seed	
		Base Case	**Organic fertilizer**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000
Diesel	[MJ/(ha*yr)]	2,963	3,111
N-fertiliser (kg N)	[kg/(ha*yr)]	168	148
Manure	[kg/(ha*yr)]	-	20
K_2O-fertiliser (kg K2O)	[kg/(ha*yr)]	70	70
P_2O_5-fertiliser (kg P2O5)	[kg/(ha*yr)]	80	80
Field N_2O emissions	[kg/(ha*yr)]	4.1	4.2
Resulting soil carbon accumulation	[t CO_2/(ha*a)]	-	0.4
Personel	[h/(ha*yr)]	10.4	10.9
Machinery	[h/(ha*yr)]	9.4	9.9

Background data

	GHG emissions		Cost - Rape seed	
	[g CO_{2eq}/MJ]	[g CO_{2eq}/kg]	[€/MJ]	[€/kg]
Diesel	87.64	-	0.02	-
Manure	-	0	-	0.001
N-fertiliser (kg N)	-	5,881	-	1.24
N-fertiliser (kg N) incl. nitrification inhibitars	-	5,881	-	1.55
K_2O-fertiliser (kg K_2O)	-	576	-	0.81
P_2O_5-fertiliser (kg P_2O_5)	-	1,011	-	1.18
			[€/h]	
Personel	-		20	
Machinery	-		15	

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to organic fertilizer compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 10
Change in costs	[€/t_{FAME}]	0
GHG mitigation costs	[€/t CO_2-eq]	0
GHG savings compared to fossil reference	[%]	45 %

SWOT analysis

STRENGTHS	WEAKNESSES
▪ Both CO_2 sequestration in soils and reduction in energy sector	▪ Availability of organic fertilizers is limited ▪ Other organic fertilizers like compost are expensive ▪ What is the current use of the manure? Is it already used for fertilization?
OPPORTUNITIES	**THREATS**
▪ Addition of organic fertilizer has co-benefits for soil quality	▪ High GHG leakage risk, as use of mineral fertilizer might increase at other locations ▪ SOC sequestration potential reduces over time

Conclusions

- The mitigation potential of the option organic fertilizers is significant and is cost-effective.
- However, the potential for implementation is relatively low, due to limited availability of manure and other organic fertilizers.
- The option has uncertainty on the soil carbon sequestration effect and risk on GHG leakage by displacing manure from other crops to rapeseed.

FACT SHEET - Use of FAME for cultivation, transport and distribution

Description

In Option "FAME as fuel" FAME is used as fuel instead of fossil diesel in cultivation, transport and distribution. Two different possibilities were investigated:

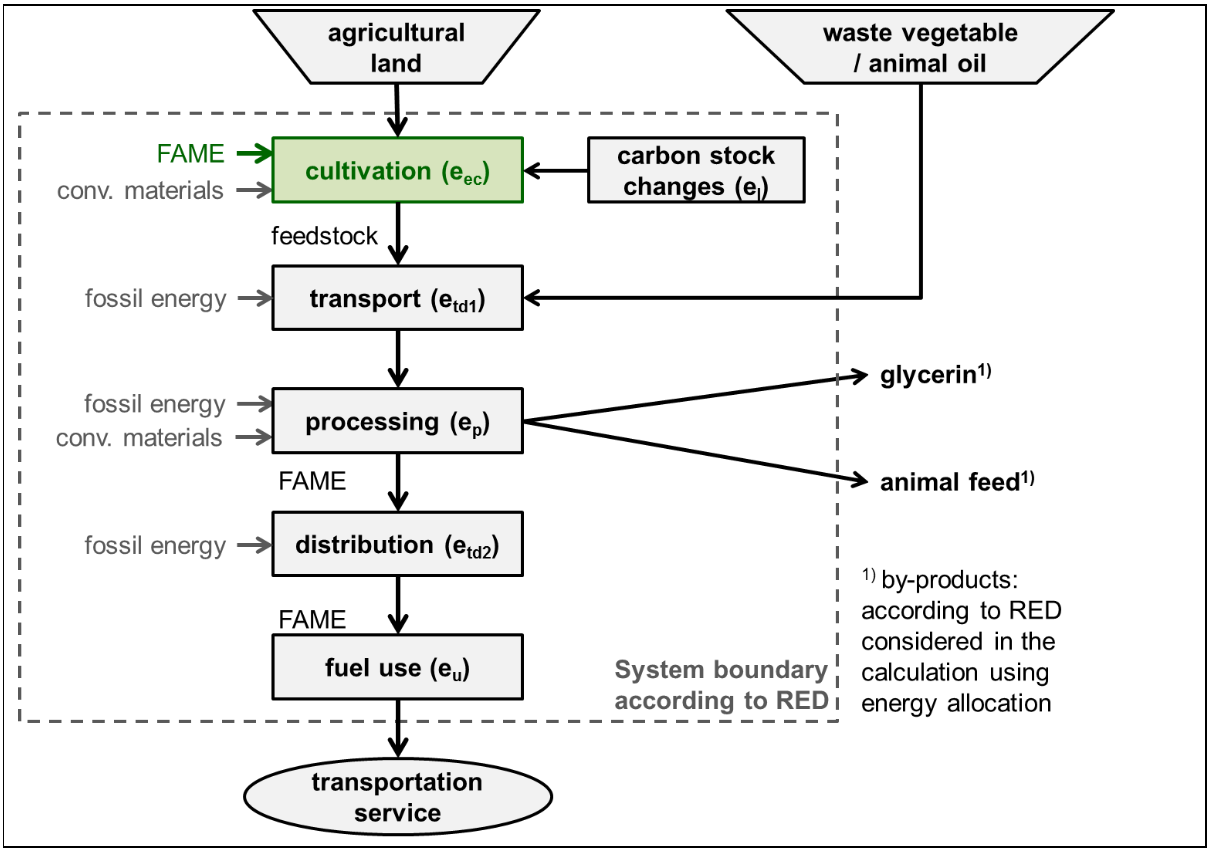
1. FAME in cultivation: FAME as fuel is used instead of fossil diesel in agricultural machinery in cultivation.
2. FAME in transport + distribution: FAME as fuel is used instead of fossil diesel in transport and distribution processes.

Basic technical and economic data

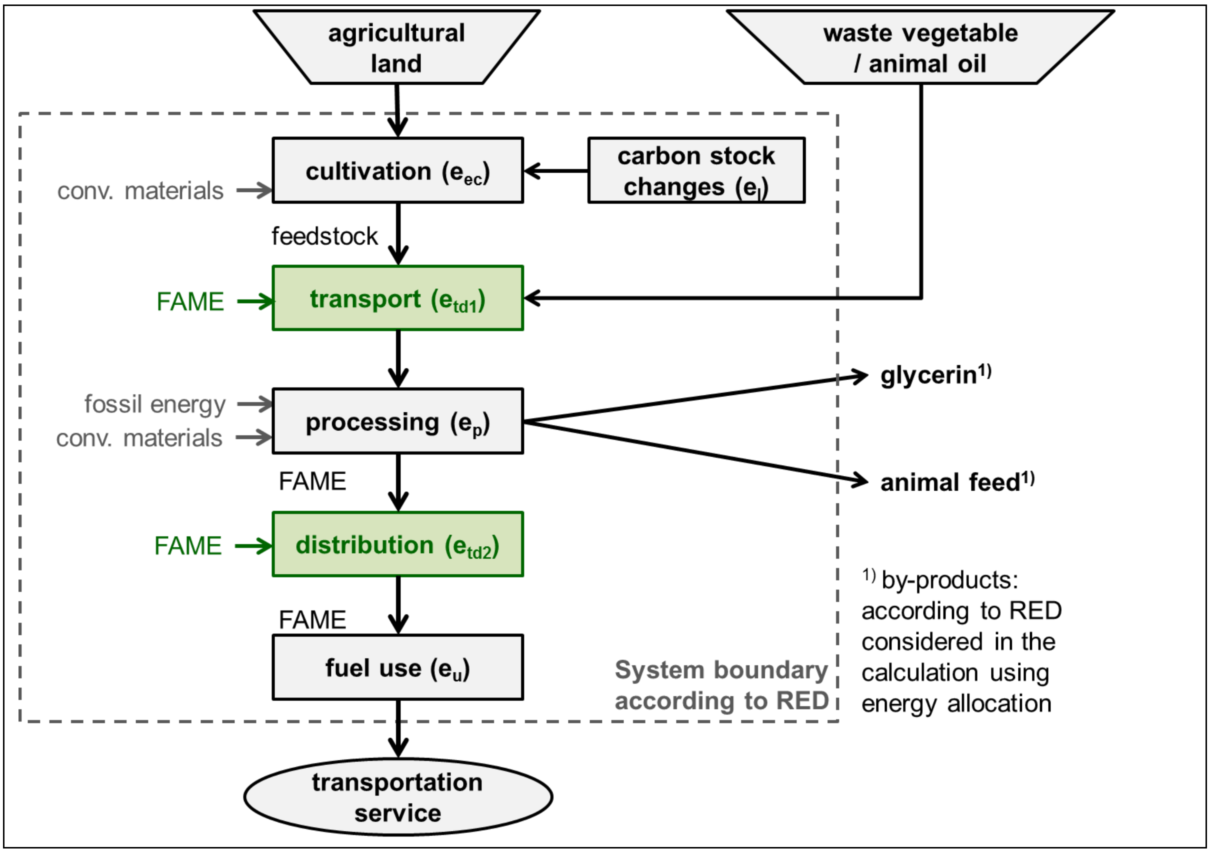
Background data

	GHG emissions [g CO_2-eq/MJ]	Cost [€/MJ]
Fossil diesel	87.64	0.0232
Diesel for soya truck US	87.64	0.0116
FAME from rapeseed	47.50	0.0255
FAME from soybean	40.20	0.0255

System boundaries for GHG calculation



FAME in cultivation



FAME in transport + distribution

GHG and economic assessment

Change of GHG emissions and costs due to use of FAME for cultivation, transport and distribution compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

		Cultivation		Transport and distribution	
		Rape seed	**Soybean American**	**Rape seed**	**Soybean American**
Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 1.6	minus 2.3	minus 0.3	minus 2.4
Change in costs	[€/t_{FAME}]	plus 10	0	plus 10	plus 40
GHG mitigation costs	[€/t CO_2-eq]	90	0	1)	410
GHG savings compared to fossil reference		45 %	55 %	44 %	55 %

1) No GHG mitigation costs calculated because of GHG reduction less than minus 1.0 g CO_2-eq/MJ_{FAME}

SWOT analysis

STRENGTHS	WEAKNESSES
▪ Technology for FAME use in agricultural machinery and transport vehicles available	▪ Adaption for 100% FAME usage in vehicles needed ▪ Year round usage might not be possible due to low temperature in Winter (depending on region)
OPPORTUNITIES	**THREATS**
▪ Usage of product FAME	

Conclusions

- The use of FAME in cultivation offers a small to medium GHG reduction potential.
- The use of FAME in transport offers a small to medium GHG reduction potential depending on the transport distances.
- It is a commercial solution, which has no influence on the FAME production process.

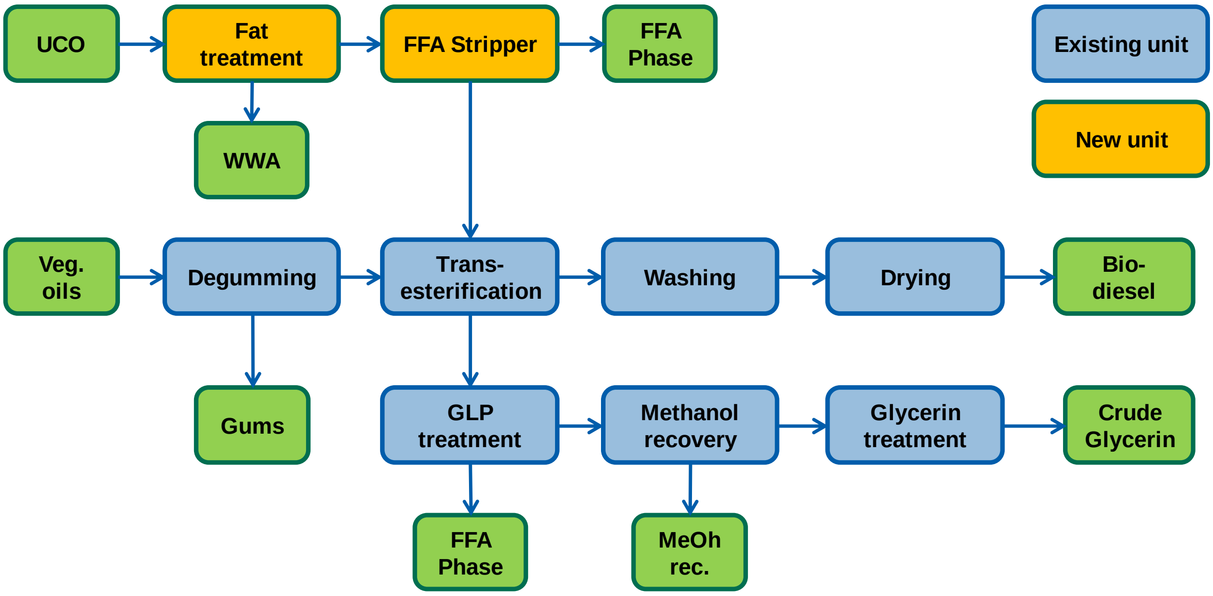
FACT SHEET - Retrofitting of single feedstock plants for blending fatty residues

Description

This fact sheet focuses on the retrofitting of vegetable oil plants for the partial or full use of used cooking oil (UCO) / animal fat (AF) in the plant. For fats category 1 & 2 fats were considered.

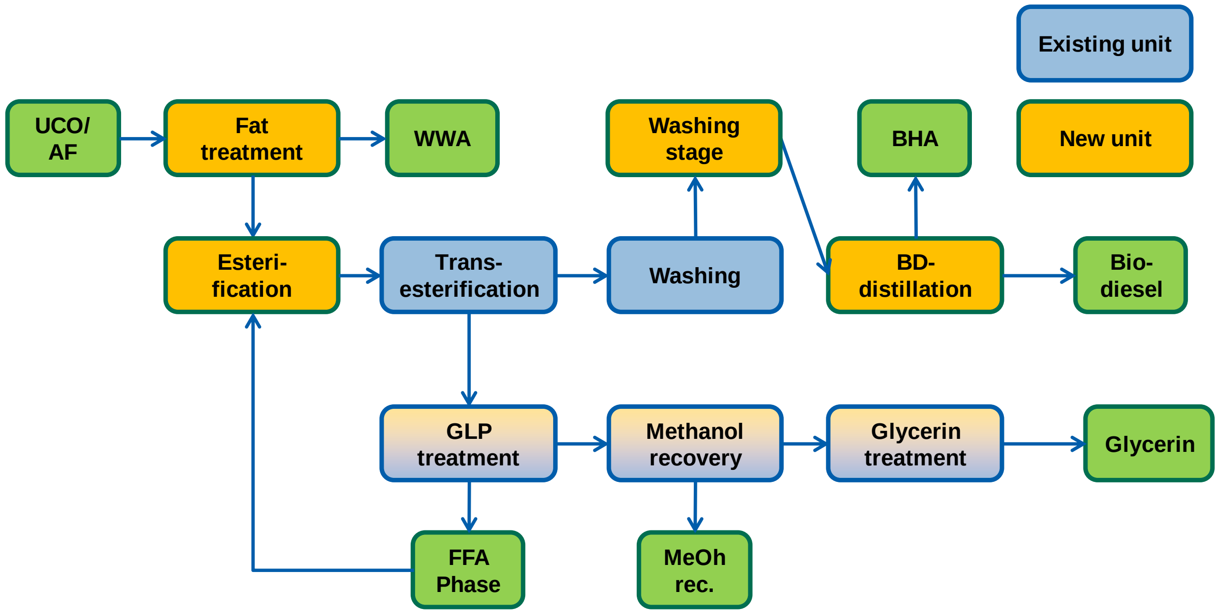
Partial modification of UCO/animal fat

In this option a retrofit of a continuous sodium methanolate plant for a capacity of 200,000 tons FAME per year from rapeseed for a partial usage (20%) of used cooking oil / animal fat is examined.
Changes are necessary with regard to pre-treatment of feedstock by removal of free fatty acids. In the process itself there are only minor modifications necessary.



Complete modification for UCO/animal fat

Here a complete modification of a continuous sodium methanolate plant (capacity is 100,000 tons/year for vegetable oil/rapeseed) for 100% use of used cooking oil / animal fat is examined.
The resulting retrofit plant has an approx. production capacity of 80,000 tons per year of FAME production capacity from UCO/AF (approx. 80% of nominal capacity of the former vegetable oil plant).
Changes are necessary with regard to feedstock pre-treatment, esterification unit (FFA reduction), glycerine phase neutralization, glycerine line treatment, biodiesel distillation. The block diagram below indicates the influenced parts.



Basic technical and economic data

The following table shows basic technical and economic data for the options "Complete modification to UCO/animal fat" and "Partial modification to UCO/animal fat".

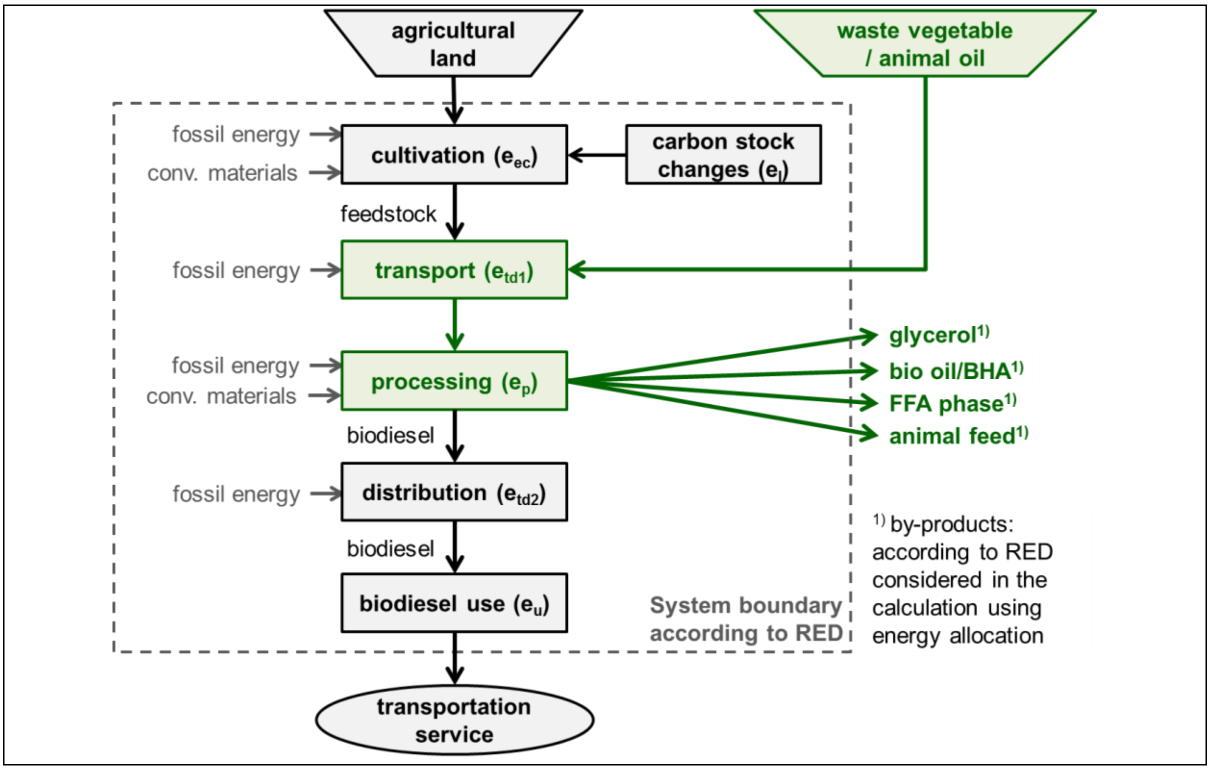
System data

	Unit	Base case	Complete modification to UCO/animal fat	Base Case	Partial modification to UCO/animal fat
FAME production capacity	[t FAME/yr]	100,000	80,000	200,000	200,000
Feedstock		Rapeseed	UCO/animal fat	Rapeseed	80% Rapeseed 20% UCO/animal fat
Extraction of oil					
Yield					
Crude vegetable oil	$[\mathrm{MJ_{Oil}/MJ_{Feedstock}}]$	0.57	-	0.57	0.46
Co-product cake (incl. gums)	$[\mathrm{MJ_{Cake}/MJ_{Feedstock}}]$	0.43	-	0.43	0.35
Refining of oil					
Yield					
Vegetable oil	$[\mathrm{MJ/MJ_{Oil}}]$	0.98	-	0.98	0.96
CPO / UCO, Animal Fat	$[\mathrm{MJ/MJ_{Oil}}]$	-	0.97	-	-
PFAD / FFA Phase	$[\mathrm{MJ/MJ_{Oil}}]$	-	-	-	0.01
Esterification					
Yield					
FAME	$[\mathrm{MJ_{FAME}/MJ_{Oil}}]$	1.00	0.98	1.00	1.00
Co-product crude glycerol 85%	$[\mathrm{kg/t_{FAME}}]$	126	129	126	126
Co-product bio oil / BHA	$[\mathrm{MJ/MJ_{FAME}}]$		0.025		
FFA Phase (acidulation)	$[\mathrm{MJ/MJ_{FAME}}]$	0.005		0.005	0.005
Investment cost - oil extraction	[Mio €/yr]	17.0	0.0	21.3	21.3
Investment cost - oil refining and esterification	[Mio €/yr]	10.0	27.2	13.0	16.8
Lifetime	[yr]	25	25	25	25
Personel (extraction and esterification)	[Number]	34	19	35	42

Background data

	Revenues [€/kg]
Co-product cake	0.240
Co-product crude glycerol 85%	0.234
Co-product bio oil / BHA	0.170
FFA Phase	0.000

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to retrofitting of single feedstock plants for blending fatty residues (partial or complete modification zo UCO/animal fat) compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

		Partial modification to UCO/animal fat	Complete modification to UCO/animal fat
Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 7.4	minus 37.1
Change in costs	[€/t_{FAME}]	0	minus 10
GHG mitigation costs	[€/t CO_2-eq]	0	minus 10
GHG savings compared to fossil reference	[%]	52 %	88 %

SWOT analysis

STRENGTHS	WEAKNESSES
Partial modification of UCO/animal fat ▪ add on system ▪ no changes in the biodiesel plant ▪ manageable conversion costs **Complete modification for UCO/animal fat** ▪ high feedstock flexibility	**Partial modification of UCO/animal fat** ▪ limited UCO feedstock capacity, only high quality animal fat ▪ limited feedstock impurities possible ▪ no FFA conversion ▪ by product FFA phase (stripper and process) **Complete modification for UCO/animal fat** ▪ high retrofit costs ▪ reduced name plate capacity
OPPORTUNITIES	**THREATS**
Partial modification of UCO/animal fat ▪ usage of cheaper feedstocks **Complete modification for UCO/animal fat** ▪ high overall GHG reduction ▪ usage of low cost feedstocks	**Partial modification of UCO/animal fat** ▪ strong changing feedstock prices ▪ feedstock availability[6] **Complete modification for UCO/animal fat** ▪ availability of feedstock[8] ▪ glycerine produced of waste materials ▪ changed/expiring regulations

Conclusions

Partial usage of UCO/animal fat

- Commercial solution ("off-the-shelf")
- Limited usage of glycerol (waste based feedstock)
- UCO/animal fat availability[6]

Complete modification for UCO/animal fat

- Very high GHG reduction potential due to waste based feedstock
- Reduced production capacity and high retrofit costs
- Limited usage of glycerol (waste based feedstock)
- UCO/animal fat availability will be challenging

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[8] According to European Fat Processors and Renderers Association (EFPRA) the amounts of processed Category 1 & 2 fats did not change significantly in the last 10 years (EFPR, 2015). Based on these data an increase in the processing of Category 1 fats cannot be observed.

FACT SHEET - Green electricity from PV plant on site

Description

Option “Green electricity” investigates the use of renewable electricity produced in a PV plant on site. The share of electricity covered by PV is estimated to be 30%. The remaining electricity demand is supplied by the grid.

The influence of green electricity on the GHG emission of FAME is investigated for the production of 100,000 and 200,000 tons FAME per year from rapeseed and for the production of 50,000 and 100,000 tons of FAME per year from waste vegetable oil and animal fat.

Basic technical and economic data

The following table shows the basic technical and economic data for the production of FAME using green electricity.

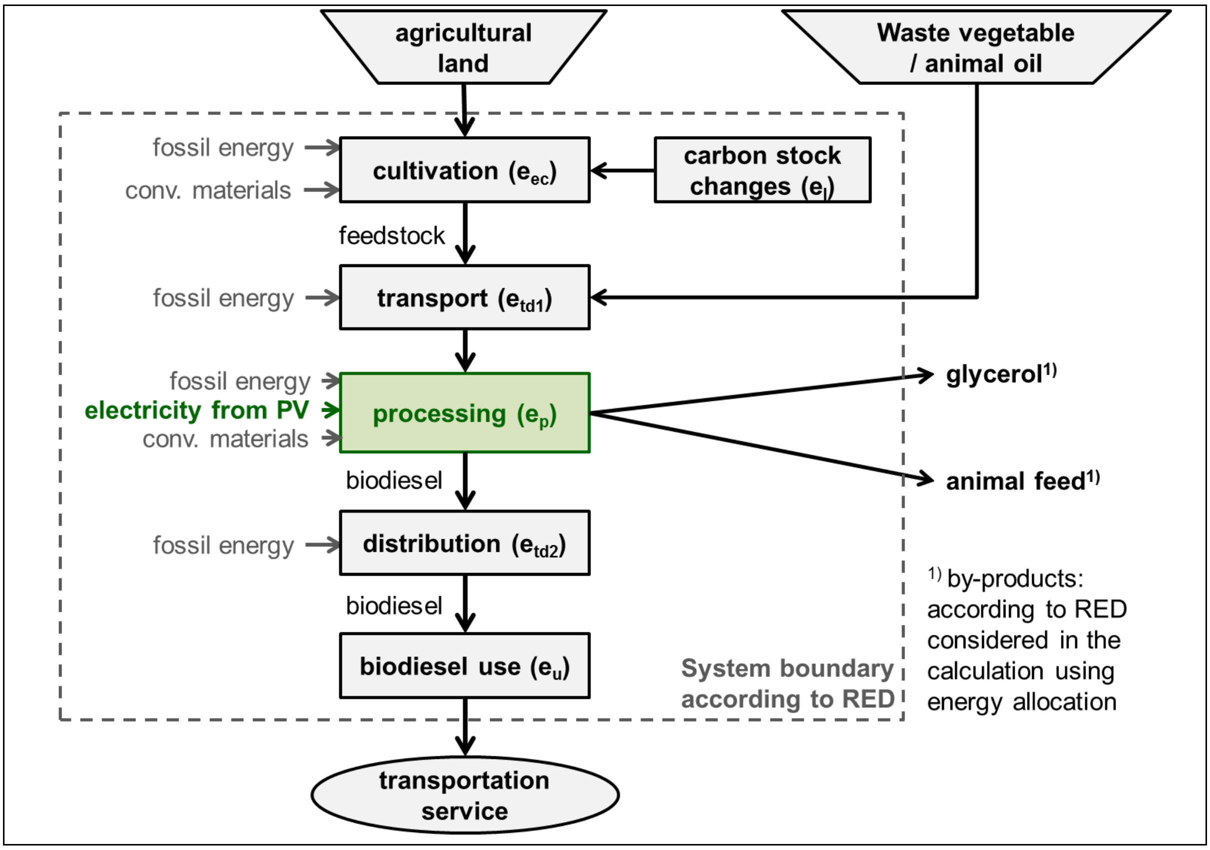
System data

	Unit	Rape seed				Waste vegetable oil / animal fat			
		Base case	**Green electricity**	**Base case**	**Green electricity**	**Base case**	**Green electricity**	**Base case**	**Green electricity**
FAME production capacity	[t_{FAME}/yr]	100,000	100,000	200,000	200,000	50,000	50,000	100,000	100,000
Processing									
Source electricity		EU mix MV	Green electricity mix	EU mix MV	Green electricity mix	EU mix MV	Green electricity mix	EU mix MV	Green electricity
Electricity demand									
Extraction of oil	[MJ/MJ_{Oil}]	0.0160	0.0160	0.0160	0.0160	-	-	-	-
Refining of oil	[MJ/MJ_{Oil}]	0.0011	0.0011	0.0011	0.0011	0.0014	0.0014	0.0014	0.0014
Esterification	[MJ/MJ_{FAME}]	0.0024	0.0024	0.0013	0.0013	0.0045	0.0045	0.0042	0.0042

Background data

	GHG emissions [g CO_{2eq}/MJ]	**Cost** [€/MJ]
EU mix MV	128	0.022
Green Electricity	0	0.024

System boundaries for GHG calculation



GHG and economic assessment

Change of GHG emissions and costs due to use of green electricity from PV plant on site compared to the base case and GHG savings compared to fossil fuel reference (83.3 g CO_2-eq/MJ_{FAME}):

		Rape seed	Waste cooking oil
Change in GHG emissions	[g CO_2-eq/MJ_{FAME}]	minus 0.1	minus 0.2 – 0.5
Change in costs	[€/t_{FAME}]	0 - plus 10	0
GHG mitigation costs	[€/t CO_2-eq]	[1]	[1]
GHG savings compared to fossil reference	[%]	43 - 44 %	86 – 88 %

[1] No GHG mitigation costs calculated because of GHG reduction less than minus 1.0 g CO_2-eq/MJ_{FAME}

SWOT analysis

STRENGTHS	**WEAKNESSES**
▪ No adaptions of FAME production process needed ▪ PV technology commercially available	▪ 100% coverage of electricity demand not possible without storage ▪ Very limited GHG reduction potential due to small contribution of electricity on total GHG emissions of FAME production
OPPORTUNITIES	**THREATS**
▪ Easy to implement	▪ On industrial site deposition of dirt and dust on PV panel more likely, lowering the efficiency of PV system

Conclusion

- The GHG reduction potential is very limited due to the small share of electricity in the total GHG emissions and because PV is not able to cover the total electricity demand for processing.

ANNEX 2: Tables with detailed results on GHG analysis and cost analysis

This section presents tables with the detailed results on GHG analysis and cost analysis. Based on these data the figures in the result section of the technical report were prepared.

Table-A 1: Greenhouse gas emissions of base cases compared to RED values with background data from BioGrace (Part I)

	Rapeseed				Sunflower			
[g CO_2-eq / MJ_{FAME}]	**F-Rs (BioGrace)**	**F-Rs-50-BC**	**F-Rs-100-BC**	**F-Rs-200-BC**	**F-Sf (BioGrace)**	**F-Sf-50-BC**	**F-Sf-100-BC**	**F-Sf-200-BC**
Cultivation (e_{ec})	28.75	36.13	36.13	36.13	17.59	31.26	31.26	31.26
Processing (e_p)	21.56	10.35	9.92	9.67	24.61	10.59	10.16	9.91
Transport (e_{td})	1.43	1.44	1.44	1.44	1.43	1.44	1.44	1.44
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totals	51.75	47.92	47.49	47.24	43.63	43.28	42.86	42.61

Table-A 2: Greenhouse gas emissions of base cases compared to RED values with background data from BioGrace (Part II)

	Soybean				
[g CO_2-eq / MJ_{FAME}]	**F-Sy (BioGrace)**	**F-Sy(am)-100-BC**	**F-Sy(am)-200-BC**	**F-Sy(eu)-100-BC**	**F-Sy(eu)-200-BC**
Cultivation (e_{ec})	18.50	13.07	13.07	14.89	14.89
Processing (e_p)	25.35	10.95	10.70	10.95	10.70
Transport (e_{td})	13.09	16.18	16.18	2.04	2.04
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00
Totals	56.94	40.20	39.95	27.88	27.63

Table-A 3: Greenhouse gas emissions of base cases compared to RED values with background data from BioGrace (Part III)

	Palm oil			**UCO/Animal fat**		
[g CO$_2$-eq / MJ$_{FAME}$]	**F-Po(CH4 capt) (BioGrace)**	**F-Po(CH4 ca**	**F-Po(CH4 capt)-200-BC**	**F-Wo (BioGrace)**	**F-Wo-50-BC**	**F-Wo-100-BC**
Cultivation (e_{ec})	14.19	12.57	12.74	0.00	0.00	0.00
Processing (e_p)	17.76	8.32	8.07	20.01	10.79	9.08
Transport (e_{td})	5.00	4.93	4.93	1.26	1.26	1.26
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00	0.00
CO$_2$ capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00	0.00
Totals	36.95	25.83	25.75	21.27	12.05	10.34

Table-A 4: GHG emission savings of base cases and or FED values with background data from BioGrace

Rapeseed	F-Rs (BioGrace)	38%
	F-Rs-50-BC	43%
	F-Rs-100-BC	43%
	F-Rs-200-BC	44%
Sunflower	F-Sf (BioGrace)	48%
	F-Sf-50-BC	48%
	F-Sf-100-BC	49%
	F-Sf-200-BC	49%
Soybean	F-Sy (BioGrace)	32%
	F-Sy(am)-100-BC	52%
	F-Sy(am)-200-BC	52%
	F-Sy(eu)-100-BC	67%
	F-Sy(eu)-200-BC	67%
Palm oil	F-Po(CH4 capt) (BioGrace)	56%
	F-Po(CH4 capt)-100-BC	69%
	F-Po(CH4 capt)-200-BC	69%
UCO / Animal fat	F-Wo (BioGrace)	75%
	F-Wo-50-BC	86%
	F-Wo-100-BC	88%

Table-A 5: GHG emissions of improvement options “Biomethanol”, “Bioethanol”, “Pharmaglycerol 99.5+” and “Succinic Acid from straw” compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a and 200 kt/a)

	Base case	Biomethanol from wood residues as process chemical	Biomethanol from straw as process chemical	Pharmaglycerol 99.5+	Base case	Bioethanol from wheat as process chemical	Bioethanol from straw as process chemical	Succinic acid from straw + glycerol
[g CO_2-eq / MJ_{FAME}]	**F-Rs-100-BC**	**F-Rs-100-Op1a**	**F-Rs-100-Op1b**	**F-Rs-100-Op5a**	**F-Rs-200-BC**	**F-Rs-200-Op2a**	**F-Rs-200-Op2b**	**F-Rs-200-Op5c**
Cultivation (e_{ec})	36.13	36.13	36.13	34.65	36.13	34.53	34.53	34.48
Processing (e_p)	9.92	5.26	5.21	9.90	9.67	10.87	9.25	13.46
Transport (e_{td})	1.44	1.44	1.44	1.43	1.44	1.43	1.43	1.43
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totals	**47.49**	**42.83**	**42.78**	**45.98**	**47.24**	**46.82**	**45.20**	**49.36**

Table-A 6: GHG emissions of improvement options “Biomethanol” and “Pharmaglycerol 99.5+” compared to the corresponding base cases (feedstock: American soybean and UCO/animal fat; FAME production capacity: 100 kt/a)

	Base case	Biomethanol from straw as process chemical	Base case	Biomethanol from straw as process chemical	Pharmaglycerol 99.5+
[g CO_2-eq / MJ_{FAME}]	**F-Sy(am)-100-BC**	**F-Sy(am)-100-Op1b**	**F-Wo-100-BC**	**F-Wo-100-Op1b**	**F-Wo-100-Op5a**
Cultivation (e_{ec})	13.07	13.07	0.00	0.00	0.00
Processing (e_p)	10.95	6.23	9.08	3.50	10.14
Transport (e_{td})	16.18	16.18	1.26	1.26	1.26
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00
Totals	**40.20**	**35.49**	**10.34**	**4.76**	**11.40**

Table-A 7: GHG emissions of improvement options “CHP with refined vegetable oils+steam boiler with vegetable oils”, “Steam boiler with vegetable oils”, “Wood-to-steam boiler” and “Green electricity from PV on site” compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 200 kt/a)

	Base case	CHP with refined vegetable oils+ steam boiler with vegetable oils	Steam boiler with vegetable oils	Wood-to-steam boiler	Green electricity from PV plant on site
[g CO_2-eq / MJ_{FAME}]	**F-Rs-200-BC**	**F-Rs-200-Op3b**	**F-Rs-200-Op3c**	**F-Rs-200-Op3f**	**F-Rs-200-Op10**
Cultivation (e_{ec})	36.13	36.13	36.13	36.13	36.13
Processing (e_p)	9.67	8.72	8.78	8.29	9.58
Transport (e_{td})	1.44	1.44	1.44	1.44	1.44
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00
Totals	**47.24**	**46.29**	**46.35**	**45.86**	**47.15**

Table-A 8: GHG emissions of improvement options “CHP with distilled glycerol + co-incineration of FAME distillation residue in steam boiler”, “Co-incineration of FAME distillation residues in steam boiler” and “Green electricity from PV plant on site” compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 50 kt/a and 100 kt/a)

	Base case	CHP with distilled glycerol + co-incineration of FAME distillation residue (BHA) in steam boiler	Co-incineration of FAME distillation residue (BHA) in steam boiler	Green electricity from PV plant on site	Base case	Co-incineration of FAME distillation residue (BHA) in steam boiler	Green electricity from PV plant on site
[g CO_2-eq / MJ_{FAME}]	**F-Wo-50-BC**	**F-Wo-50-Op3d**	**F-Wo-50-Op3e**	**F-Wo-50-Op10**	**F-Wo-100-BC**	**F-Wo-100-Op3e**	**F-Wo-100-Op10**
Cultivation/collection (e_{ec})	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Processing (e_p)	10.79	8.54	9.44	10.27	9.08	7.69	8.87
Transport (e_{td})	1.26	1.26	1.26	1.26	1.26	1.26	1.26
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totals	**12.05**	**9.80**	**10.70**	**11.53**	**10.34**	**8.95**	**10.13**

Table-A 9: GHG emissions of improvement options “Balanced fertilization”, “Nitrification inhibitors”, “Crop residue management”, “Reduced tillage” and “Organic fertilizer” compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a)

	Base case	Balanced fertilization	Nitrification inhibitors	Crop residue management	Reduced tillage	Organic fertilizer
[g CO_2-eq / MJ_{FAME}]	**F-Rs-100-BC**	**F-Rs-100-Op6a**	**F-Rs-100-Op6b**	**F-Rs-100-Op6d**	**F-Rs-100-Op6e**	**F-Rs-100-Op7**
Cultivation (e_{ec})	36.13	33.09	33.04	34.91	35.78	34.85
Processing (e_p)	9.92	9.92	9.92	9.92	9.92	9.92
Transport (e_{td})	1.44	1.44	1.44	1.44	1.44	1.44
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	-18.74	-6.61	-8.82
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00	0.00
Totals	**47.49**	**44.45**	**44.40**	**27.53**	**40.53**	**37.39**

Table-A 10: GHG emissions of improvement options “Balanced fertilization”, “Return nutrients from palm oil residues as fertilizer” compared to the corresponding base cases (feedstock: palm oil; FAME production capacity: 100 kt/a)

Palm Oil	Base case	Balanced fertilization	Return nutrients from palm oil residues as fertilizer
[g CO_2-eq / MJ_{FAME}]	**F-Po(CH4 capt)-100-BC**	**F-Po(CH4capt)-100-Op6a**	**F-Po(CH4capt)-100-Op6f**
Cultivation (e_{ec})	12.57	11.81	11.38
Processing (e_p)	8.32	8.32	8.32
Transport (e_{td})	4.93	4.93	4.93
Land use change (e_l)	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	-10.07
CO_2 capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00
Totals	**25.83**	**25.07**	**14.57**

Table-A 11: GHG emissions of improvement options "FAME in cultivation" and "FAME in transport + distribution" compared to the corresponding base cases (feedstock: rapeseed and American soybean; FAME production capacity: 100 kt/a)

	Base case	FAME in cultivation	FAME in transport + distribution	Base case	FAME in cultivation	FAME in transport + distribution
[g CO$_2$-eq / MJ$_{FAME}$]	**F-Rs-100-BC**	**F-Rs-100-Op8a**	**F-Rs-100-Op8b**	**F-Sy(am)-100-BC**	**F-Sy(am)-100-Op8a**	**F-Sy(am)-100-Op8b**
Cultivation (e_{ec})	36.13	34.50	36.13	13.07	10.82	13.07
Processing (e_p)	9.92	9.92	9.92	10.95	10.95	10.95
Transport (e_{td})	1.44	1.44	1.11	16.18	16.18	13.83
Land use change (e_l)	0.00	0.00	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00	0.00	0.00
CO$_2$ capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00	0.00	0.00
Totals	**47.49**	**45.86**	**47.17**	**40.20**	**37.95**	**37.85**

Table-A 12: GHG emissions of improvement options "Retrofitting" compared to the corresponding base cases (feedstock: rapeseed and UCO/animal fat; FAME production capacity: 80 kt, 100 kt/a and 200 kt/a)

	Base case	Complete modification to UCO/animal fat	Base case	Partial modification to UCO/animal fat
[g CO$_2$-eq / MJ$_{FAME}$]	**F-Rs-100-BC**	**F-Wo-80-Op9b**	**F-Rs-200-BC**	**F-Rs-200-Op9a**
Cultivation (e_{ec})	36.13	0.00	36.13	28.91
Processing (e_p)	9.92	9.10	9.67	9.55
Transport (e_{td})	1.44	1.26	1.44	1.40
Land use change (e_l)	0.00	0.00	0.00	0.00
Soil carbon accumulation (e_{sca})	0.00	0.00	0.00	0.00
CO$_2$ capture (e_{ccr} + e_{ccs})	0.00	0.00	0.00	0.00
Fuel use (e_u)	0.00	0.00	0.00	0.00
Totals	**47.49**	**10.37**	**47.24**	**39.86**

Table-A 13: FAME production costs and revenues of co-products for base cases (Part I)

	Rapeseed			**Sunflower**		
[€/tFAME]	F-Rs-50-BC	F-Rs-100-BC	F-Rs-200-BC	F-Sf-50-BC	F-Sf-100-BC	F-Sf-200-BC
Production costs	1,040	1,010	990	1,410	1,380	1,360
Co-products revenues	-390	-390	-390	-400	-400	-400
Total FAME production costs	650	620	600	1,010	980	960

Table-A 14: FAME production costs and revenues of co-products for base cases (Part II)

	Soybean				**Palm oil**		**UCO/Animal fat**	
[€/t_{FAME}]	F-Sy(am)-100-BC	F-Sy(am)-200-BC	F-Sy(eu)-100-BC	F-Sy(eu)-200-BC	F-Po(CH4 capt)-100-BC	F-Po(CH4 capt)-200-BC	F-Wo-50-BC	F-Wo-100-BC
Production costs	2,020	2,000	2,260	2,240	370	350	690	660
Co-products revenues	-1,510	-1,510	-1,510	-1,510	-70	-70	-30	-30
Total FAME production costs	510	490	750	730	300	280	660	630

Table-A 15: Total costs of oil including revenues of co-products for base case (Part I)

	Rapeseed			**Sunflower**		
[€/t_{oil}]	F-Rs-50-BC	F-Rs-100-BC	F-Rs-200-BC	F-Sf-50-BC	F-Sf-100-BC	F-Sf-200-BC
Oil production costs	544	536	531	884	875	869
Oil production costs (rounded)	540	540	530	880	870	870

Table-A 16: Total costs of oil including revenues of co-products for base case (Part I)

	Soybean				**Palm oil**		**UCO/Animal fat**	
[€/t_{oil}]	F-Sy(am)-100-BC	F-Sy(am)-200-BC	F-Sy(eu)-100-BC	F-Sy(eu)-200-BC	F-Po(CH4 capt)-100-BC	F-Po(CH4 capt)-200-BC	F-Wo-50-BC	F-Wo-100-BC
Oil production costs	405	398	654	646	231	223	500	500
Oil production costs (rounded)	410	400	650	650	230	220	500	500

Table-A 17: FAME production costs and revenues of co-products of improvement options “Biomethanol”, “Bioethanol”, “Pharmaglycerol 99.5+” and “Succinic Acid from straw” compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a and 200 kt/a)

	Base case	Biomethanol from wood residues as process chemical	Biomethanol from straw as process chemical	Biomethanol from glycerol as process chemical	Pharmaglycerol 99.5+	Base case	Bioethanol from wheat as process chemical	Bioethanol from straw as process chemical	Succinic acid from straw + glycerol
[€ / t_{FAME}]	**F-Rs-100-BC**	**F-Rs-100-Op1a**	**F-Rs-100-Op1b**	**F-Rs-100-Op1c**	**F-Rs-100-Op5a**	**F-Rs-200-BC**	**F-Rs-200-Op2a**	**F-Rs-200-Op2b**	**F-Rs-200-Op5c**
Cultivation/Feedstock	880	880	880	880	880	880	841	841	880
Processing	120	149	171	166	126	103	197	202	145
Co-products revenues	-388	-388	-388	-388	-403	-388	-369	-369	-779
Transport&distribution	11	11	11	11	11	11	11	11	11
Totals	**623**	**653**	**674**	**669**	**614**	**607**	**680**	**685**	**257**
Totals (rounded)	620	650	670	670	610	610	680	680	260

Table-A 18: FAME production costs and revenues of co-products of improvement options “Biomethanol” and “Pharmaglycerol 99.5+” compared to the corresponding base cases (feedstock: American soybean and UCO/animal fat; FAME production capacity: 100 kt/a)

	Base case	Biomethanol from straw as process chemical	Base Case	Biomethanol from straw as process chemical	Pharmaglycerol 99.5+
[€ / t_{FAME}]	**F-Sy(am)-100-BC**	**F-Sy(am)-100-Op1b**	**F-Wo-100-BC**	**F-Wo-100-Op1c**	**F-Wo-100-Op5a**
Cultivation/Feedstock	1,751	1,751	551	551	551
Processing	179	230	102	163	113
Co-products revenues	-1,510	-1,510	-32	-32	-46
Transport&distribution	91	91	8	8	8
Totals	**511**	**562**	**629**	**691**	**626**
Totals (rounded)	510	560	630	690	630

Table-A 19: FAME production costs and revenues of co-products of improvement options “CHP with refined vegetable oils+steam boiler with vegetable oils”, “Steam boiler with vegetable oils”, “Wood-to-steam boiler” and “Green electricity from PV on site” compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 200 kt/a)

	Base case	CHP with refined vegetable oils+ steam boiler with	Steam boiler with vegetable oils	Wood-to-steam boiler	Green electricity from PV plant on site
[€ / t_{FAME}]	**F-Rs-200-BC**	**F-Rs-200-Op3b**	**F-Rs-200-Op3c**	**F-Rs-200-Op3f**	**F-Rs-200-Op10**
Cultivation/Feedstock	880	880	880	880	880
Processing	103	114	113	99	105
Co-products revenues	-388	-388	-388	-388	-388
Transport&distribution	11	11	11	11	11
Totals	**607**	**618**	**616**	**602**	**608**
Totals (rounded)	610	620	620	600	610

Table-A 20: FAME production costs and revenues of co-products of improvement options “CHP with distilled glycerol + co-incineration of FAME distillation residue in steam boiler”, “Co-incineration of FAME distillation residues in steam boiler” and “Green electricity from PV plant on site” compared to the corresponding base cases (feedstock: UCO/animal fat; FAME production capacity: 50 kt/a and 100 kt/a)

	Base case	CHP with distilled glycerol + coincineration of FAME distillation residue (BHA) in steam boiler	Coincineration of FAME distillation residue (BHA) in steam boiler	Green electricity from PV plant on site	Base case	Coincineration of FAME distillation residue (BHA) in steam boiler	Green electricity from PV plant on site
[€ / t_{FAME}]	**F-Wo-50-BC**	**F-Wo-50-Op3d**	**F-Wo-50-Op3e**	**F-Wo-50-Op10**	**F-Wo-100-BC**	**F-Wo-100-Op3e**	**F-Wo-100-Op10**
Cultivation/Feedstock	551	551	551	551	551	551	551
Processing	126	119	120	127	102	95	103
Co-products revenues	-32	-14	-24	-32	-32	-24	-32
Transport&distribution	8	8	8	8	8	8	8
Totals	653	665	655	655	629	630	631
Totals (rounded)	650	660	650	650	630	630	630

Table-A 21: FAME production costs and revenues of co-products of improvement options “Balanced fertilization”, “Nitrification inhibitors”, “Crop residue management”, “Reduced tillage” and “Organic fertilizer” compared to the corresponding base cases (feedstock: rapeseed; FAME production capacity: 100 kt/a)

	Base case	Balanced fertilization	Nitrification inhibitors	Crop residue incorporation	Reduced tillage	Organic fertilizer
[€ / t_{FAME}]	**F-Rs-100-BC**	**F-Rs-100-Op6a**	**F-Rs-100-Op6b**	**F-Rs-100-Op6d**	**F-Rs-100-Op6e**	**F-Rs-100-Op7**
Cultivation/Feedstock	880	850	921	865	861	877
Processing	120	120	120	120	120	120
Co-products revenues	-388	-388	-388	-388	-388	-388
Transport&distribution	11	11	11	11	11	11
Totals	**623**	**594**	**665**	**609**	**604**	**620**
Totals (rounded)	620	590	660	610	600	620

Table-A 22: FAME production costs and revenues of co-products of improvement options “Balanced fertilization”, “Return nutrients from palm oil residues as fertilizer” compared to the corresponding base cases (feedstock: palm oil; FAME production capacity: 100 kt/a)

	Base case	Balanced fertilization	Return nutrients from palm oil residues as fertilizer
[€ / t_{FAME}]	**F-Po(CH4 capt)-100-BC**	**F-Po(CH4capt)-100-Op6a**	**F-Po(CH4capt)-100-Op6f**
Cultivation/Feedstock	220	244	227
Processing	118	118	118
Co-products revenues	-74	-74	-74
Transport&distribution	32	32	32
Totals	**296**	**320**	**303**
Totals (rounded)	300	320	300

Table-A 23: FAME production costs and revenues of co-products of improvement options “FAME in cultivation” and “FAME in transport + distribution” compared to the corresponding base cases (feedstock: rapeseed and American soybean; FAME production capacity: 100 kt/a)

	Base case	FAME in cultivation	FAME in transport + distribution	Base case	FAME in cultivation	FAME in transport + distribution
[€ / t_{FAME}]	**F-Rs-100-BC**	**F-Rs-100-Op8a**	**F-Rs-100-Op8b**	**F-Sy(am)-100-BC**	**F-Sy(am)-100-Op8a**	**F-Sy(am)-100-Op8b**
Cultivation/Feedstock	880	885	880	1,751	1,762	1,751
Processing	120	120	120	179	192	179
Co-products revenues	-388	-388	-388	-1,510	-1,510	-1,510
Transport&distribution	11	11	12	91	66	127
Totals	**623**	**629**	**624**	**511**	**510**	**547**
Totals (rounded)	620	630	620	510	510	550

Table-A 24: FAME production costs and revenues of co-products of improvement options “Retrofitting” compared to the corresponding base cases (feedstock: rapeseed and UCO/animal fat; FAME production capacity: 80 kt, 100 kt/a and 200 kt/a)

	Base case	Complete modification to UCO/animal fat	Base case	Partial modification to UCO/animal fat
[€ / t_{FAME}]	**F-Rs-100-BC**	**F-Wo-80-Op9b**	**F-Rs-200-BC**	**F-Rs-200-Op9a**
Cultivation/Feedstock	880	544	880	819
Processing	120	98	103	102
Co-products revenues	-388	-38	-388	-320
Transport&distribution	11	8	11	11
Totals	**623**	**612**	**607**	**613**
Totals (rounded)	620	610	610	610

ANNEX 3: Stakeholder workshop documentation

Improving the Sustainability of Fatty Acid Methyl Esters (FAME – Biodiesel)

Stakeholder Workshop - Documentation

Vienna, Austria, November 13, 2015

Participants

Name	**Company/Institution**
Reinhard Thayer	ARGE Biokraft
Alexander Bachler	Austrian Chamber of Agriculture
Heinz Bach	Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management
Martin Ernst	BDI
Peter Haselbacher	BDI
Axel Kraft	Fraunhofer UMSICHT
Tim Schulzke	Fraunhofer UMSICHT
Susanne Köppen	IFEU
Gefried Jungmeier	JOANNEUM RESEARCH
Hannes Schwaiger	JOANNEUM RESEARCH
Johanna Pucker	JOANNEUM RESEARCH
Adrian O'Connell	JRC
Martin Mittelbach	Karl-Franzens-University of Graz
Christian Dyczek	MÜNZER Bioindustrie GmbH
José Muisers	NL Enterprise Agency, Ministry of Economic Affairs
Heinz Stichnothe	Thünen Institut Braunschweig
Dieter Bockey	UFOP - Union zur Förderung von Oel- und Proteinpflanzen e. V.
Wolf-Dietrich Kindt	Verband der Deutschen Biokraftstoffindustrie e. V.
Jan-Peter Lesschen	Wageningen UR, ALTERRA
Robert van Loo	Wageningen UR, Wageningen University

Program of the workshop

November 13, 2015: 9:30 – 16:00: Stakeholder workshop

1) Welcome and presentation on "Renewable Fuels – EU perspective" (European Commission, Rémy Dénos, via video conference)
2) Overview on project & draft results (JOANNEUM RESEARCH, Gerfried Jungmeier)
3) Group work – Session 1

Group 1 - Cultivation	**Group 3 - Chemicals**
Advanced agriculture & organic fertilizer (Wageningen UR ALTERRA, Jan-Peter Lesschen)	Biomethanol (Fraunhofer UMSICHT, Tim Schulzke) Bioethanol (BDI, Martin Ernst) Bioplastic – and biochemical (Fraunhofer UMSICHT, Axel Kraft)

LUNCH BREAK

4) Group work – Session 2

Group 1 - Cultivation	**Group 2 – Energy supply & retrofitting**
Plant species (Wageningen University, Robert van Loo) Advanced agriculture & organic fertilizer (Wageningen UR ALTERRA, Jan-Peter Lesschen)	CHP residues (BDI, Peter Haselbacher) Green electricity (JOANNEUM RESEARCH, Johanna Pucker) Retrofitting to multi feedstock plant (BDI, Martin Ernst)

Summary of main outcomes

The main outcomes of the stakeholder workshop are listed for the discussed options:

Advanced cultivation

Jan-Peter Lesschen presented the following options for advanced cultivation:

- Balanced fertilisation (prevent over-fertilisation),
- nitrification inhibitors (reduce N_2O emissions),
- organic fertilizer (prevent emissions related to production of fertiliser, also add C and get carbon sequestration),
- reduced tillage and
- use of palm oil residues as organic fertilizer.

Comments from the stakeholder discussion:

- In palm the pruning of palm is ignored: less C-storage and N-storage in the calculations than in reality. This could be a 100 kg N that is not taken into account. Heinz Stichnothe will send a publication describing this topic to Jan-Peter Lesschen and Adrian O'Connell.
- The comparison with improved use of palm residue is still valid.
- In Malaysia palm residues are already returned to the soil in reality.
- Incorporation of rapeseed straw: In practice rapeseed straw is incorporated already. In the base case partial removal of straw was taken into account (based on the information provided in BioGrace to explain the RED values).
- Ploughing after rapeseed not necessary in practice. Reality check on ploughing in rapeseed is recommended, as well as a cost check in the base case.
- Technical feasibility for advanced agriculture is there, but the incentives for the farmers are missing. E.g. nitrification inhibitor: no obligation, no criteria to farmers.
- If system becomes more detailed for the cultivation, the farmer has the risk that in a bad year he cannot be above the minimum RED-criterion: not acceptable, too high risks.
- Regional aspects need to be considered.
- Crop rotation needs to be taken into account – wheat as reference in the crop rotation for comparison with rapeseed system
- The impact of crop rotation effects on the GHG-balance of crops for biofuel/energy use. The appropriate consideration of precropping effects and allocation of fertilizer used.
- Nitrification inhibitors: What is there composition?
- Measure and manage soil carbon
- How to implement on farm level?
- Better data for improving the certification scheme vs. how to improve compared to the practical current situations.

New plant species

Robert van Loo presented the selected new plant species (Crambe, Camelina, Guayule and Jatropha)

Comments from the stakeholder discussion:

- Question about quality of seed meal, it could be used for poultry and pigs, but not in too high quantity.
- Discussion about being a food crop, which is not wanted by the industry
- Draft calculation for Jatropha presented by Robert van Loo: There was some doubts on the total oil yield (1800 kg/ha), which is much higher compared to reviews of other studies; *Comment Robert van Loo: is lower than the average measured in the first 2 years after planting (1500 kg oil/ha in year 1 and 2500 kg oil/ha in year 2 and following; this comment is understandable from the point of view of classical planting patterns and old germplasms of jatropha, but this yield is associated with a dwarf genotype at a density of 30,000 plants/ha instead of only 1250 or 2500 plants/ha which take up to 4 years to develop the maximum yield per year).*
- Comparison for new species seems not completely in line with the other crops, e.g. considering lignocellulosic as co-product, while straw in rapeseed is not accounted for. Therefore it was suggested to make two cases, with and without accounting for the co-product.
- Methodology: a) FAME according to RED and b) biorefinery framework
- Estimation of lignocellulosic value is about 400 euro per kg, versus 1200 euro for the oil.
- Results were presented as yield potentials (maximum values), which are likely much lower with lower soil quality and less water availability.
- Would there be a possibility to account for the degraded land GHG bonus (29 g CO2-eq/MJ)? Might be, it is still included in the RED, Commission recently came with a definition of low ILUC risk areas.
- System boundaries are under discussion whether terpenes are a product under the RED definition. In RED raw glycerol is not a product, it should be refined glycerol. Taloil from wood processing is considered as waste/rest product without GHG allocation.
- In Germany there were no good results with Crambe, maybe too far north and better fits to countries as Spain
- Agreement is that realisation time takes long (2025), and feasibility ranges from low to high, depending on the crop and also the region
- Introducing a new crop by farmers is not easy, and might be a barrier, but this is also region specific. This region specific issue should be clear in the final report
- Are new plant species grown only on marginal land? (influence on ILUC)
- Jatropha: toxic/non-toxic?
- Are the investigated plants in crop rotation grown (e.g. crambe)?
- What is the influence on soil carbon from the investigated plants? No change as first approximation, in case of evidence for up, take the up into account.

Biomethanol

- Fossil methanol: GHG emissions in the use phase from burning the fossil carbon are included in the GHG emissions for the supply of methanol in the BioGrace tool (information from Susanne Köppen, IFEU)
- Biomethane from the gas grid is used in methanol production plants

Biobased chemicals - Succinic acid

- Give an overview of all options for use of glycerol – show selection criteria (Comment Axel Kraft: selection done based on any options not being covered by fp7-project GLYFINERY #213506 (03-2008 to 02-2012)
- The energy allocation for use of glycerol in SA is „not fair“
- For GHG-calculation of bio-chemicals a new methodology/procedure may be required
- The use of crude salt containing glycerol needs to be elucidated because it is crucial for cost and CO_2-footprint of glycerol (due to purification footprint and cost)
- What is the lifetime of CO_2 in SA once it is integrated in bio-based chemicals or bio-plastics?
- Technology is (probably) for large enterprises only, due to GMO-modified

- Additional comments via email from SUCCINITY, which could not attend:
  - The glycerol-to-SA is technology is not only on demonstration scale but on commercial step (SUCCINITY GmbH, www.succinity.com)
  - The glycerol market is extremely volatile in terms of availability and pricing
  - The willingness of biodiesel producers to go into long-term contracts with agreed specs/substrate source and applied pricing structures is not always present

Biobased chemicals – pharmaglycerol

- Crude glycerol is a residue according to RED. Energy allocation is only possible for refined glycerol: “*Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials*” (ANNEX V, C. Methodology, 18, 3. Paragraph)

Bioethanol

- High cost and legal problems lead to low chances for realisation
- Not REACH registrated

Process energy supply using glycerol and biodiesel distillation residues

- SWOT: Threats – change to: AF/UCO are not accountable to advanced biofuel share

- Thermal utilization of biodiesel distillation residues is technically proven (state of the art) with compliance of all emission limits. Differences in feedstock (UCO/AF), e.g. sulphur content, have to be considered.

Vegetable oil & wood chips for process energy supply

- Wood chips are a favourable option in combination with other companies, which are producing wood residues and are located nearby (e.g. in industry parks); this is already the case for a biodiesel plant in industry, using excess heat from another company burning their wood residues from their production process
- SWOT: weaknesses – logistics for wood chips:
  - technical this is possible, it means handling an additional and probably new energy carrier for the chemical industry.
  - Storage of wood chips needs additional space. Additional risks like wood dust, additional fire loads can be controlled. Barriers for the use of wood chips seem to be non-technical.
- The change from fuel oil/natural gas to wood chips is economical feasible.
- The use of biomethane might be an additional option to improve the GHG balance. It is not clear if it is allowed according to RED to buy biomethane from a gas supplier (problem of double counting).

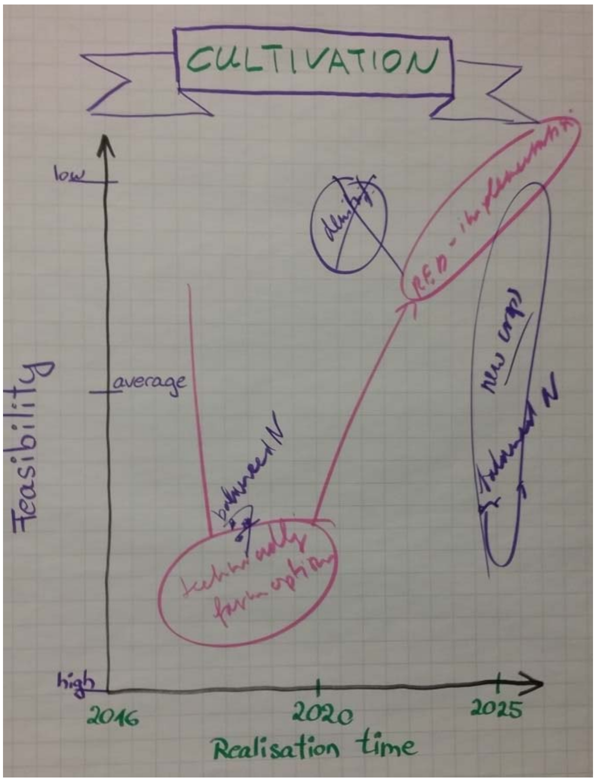
Green electricity

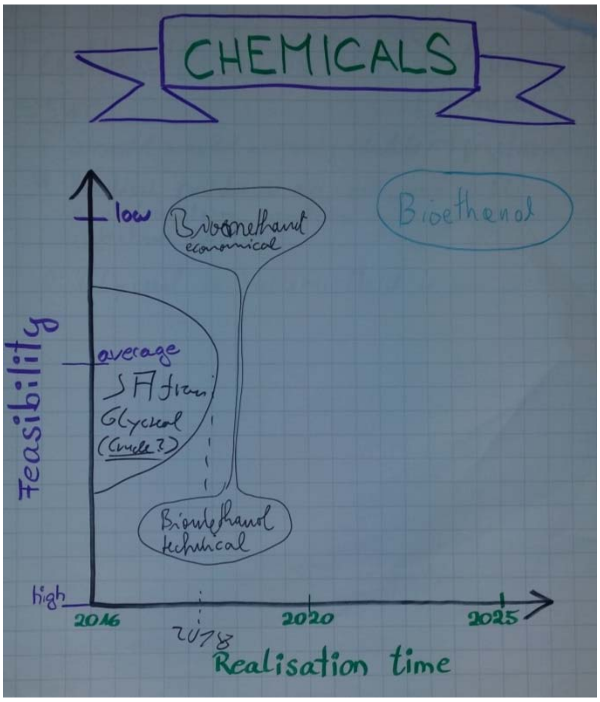
- The use of green electricity supplied by the electricity grid cannot be included in the GHG calculation according to the RED: *“In accounting for the consumption of electricity not produced within the fuel production plant, the greenhouse gas emission intensity of the production and distribution of that electricity shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region. By derogation from this rule, produces may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid”* (ANNEX V, C. Methodology, 11, 2. Paragraph)
- Alternatively the production of electricity from renewable sources directly at the plant location could be investigated (e.g. PV plant mounted on a building of the biodiesel plant).

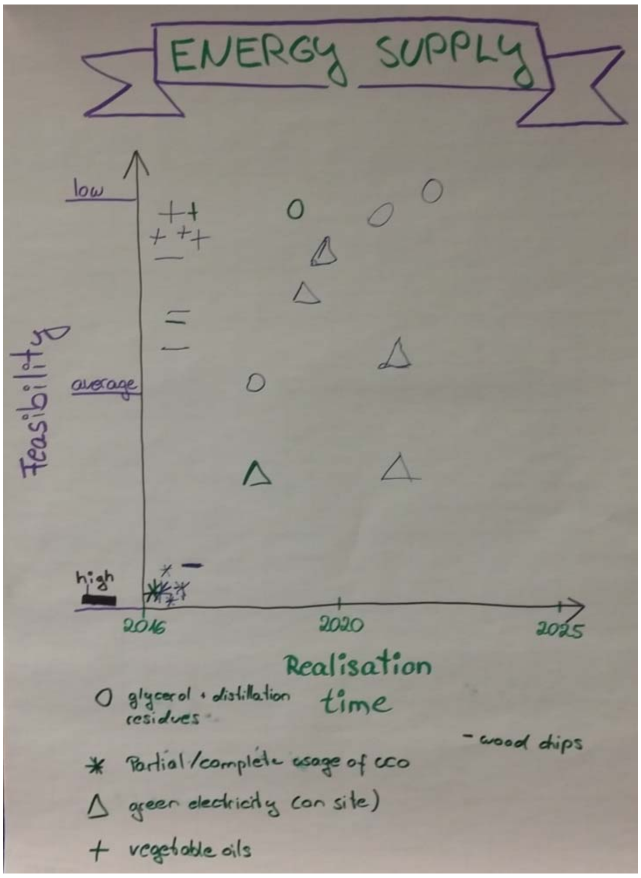
Partial usage of UCO/animal fat & complete modification for UCO/animal fat

- Presenting one value for the GHG emissions with the partial usage of UCO/animal fat is not allowed according to the “Communication from the Commission on voluntary schemes and default values in the EU biofuels and bioliquids sustainability scheme (2010/C 160/01). According to this Communication the GHG emission calculation needs to be done for each feedstock stream separately.

Positioning of options by the participants based on their opinion on feasibility and realisation time of the options







Gerfried Jungmeier presenting the project.

Group work: Advanced agriculture and new plant species.

The Workshop was organised in Cooperation with ARGE Biokraft

We want to thank Marco Münzer and his team of MÜNZER Bioindustrie GmbH for the FAME-Plant visit.