INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Carbon footprint of biodiesel and HVO based on used cooking oil (UCO)

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Abbreviations

aLUC	Attributional land use change
BLE	Bundesanstalt für Landwirtschaft und Ernährung [Federal Office for Agriculture and Food]
CO_2	Carbon dioxide
CO_2Eq.	Carbon dioxide equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPO	Crude palm oil
dLUC	Direct land use change
DUH	Deutsche Umwelthilfe [Environmental Action Germany]
FAME	Fatty acid methyl ester (biodiesel)
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
HVO	Hydrotreated vegetable oil
HVO100	Transport fuel produced 100% from HVO
ICAO	International Civil Aviation Organization
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability & Carbon Certification
LUC	Land use change
LULUCF	Land use, land use change and forestry
MJ	Megajoule
Nabisy	Sustainable biomass systems [Nachhaltige Biomasse Systeme]
PJ	Petajoule
POME	Palm oil mill effluent
RED	EU Renewable energy directive
RED III	RED Directive in the currently valid, new version; Directive (EU) 2018/2001 amended by Directive (EU) 2023/2413
TJ	Terajoule
UBA	German Environment Agency [Umweltbundesamt]
UCO	Used cooking oil
UNFCCC	United Nations Framework Convention on Climate Change

1 Background

Biofuels for diesel engines can be produced from a range of raw materials and also through **different processing technologies**. Currently, these mainly involve two methods: the first is "transesterification", the conventional method for producing biodiesel, resulting in fatty acid methyl ester (**FAME**). The second method is hydrotreatment. This process involves treating the fats and oils with hydrogen, the product of which is referred to as hydrotreated vegetable oil, or **HVO**. Newer technologies for synthetic biodiesel are not yet market-ready. In this brief study, the term biodiesel is used collectively to refer to both FAME and HVO.

Since the end of May 2024, **HVO100,** based on biogenic oils or fats, has been available as a "pure fuel" for general sale in Germany. The number 100 indicates that the HVO used is in an unmixed, pure form. It is worth noting that the term "vegetable" (in hydrotreated vegetable oil) is misleading, as HVO can also be produced from hydrogenated animal fats.. In the general discussion, the focus on HVO100 is primarily on the potential use of **vegetable (or animal) oils and fats** as a raw material.

As these are waste materials that do not have to be produced at great expense and with a high environmental impact, unlike rapeseed or palm oil, the benefits of fuels produced from these materials appear obvious. In particular, these raw materials promise substantial reductions in greenhouse gas emissions.

Distributors obliged to reduce GHG emissions report average savings of 87.16% for HVO compared to fossil diesel. For FAME produced from waste materials, reported reductions in GHG emissions are as high as 88.38%. This can be seen in the latest evaluation and experience report by the Federal Office for Agriculture and Food (BLE) for the year 2023 (BLE 2024). According to the report, a total of 16,700 terajoules (TJ) as HVO and 58,780 TJ as FAME were placed on the market in 2023, each based on waste and residues, and counted towards the legal quotas. This corresponds to 491 million litres of HVO and 1,940 million litres of FAME based exclusively on waste and residues.[1]

As the evaluation reports from previous years show, until 2022 this oil or fat-like waste consisted largely of **used cooking oil** (**UCO** for short). This comes from collections from the food service industry and private households as a raw material for over 30 petajoules of biodiesel including HVO in 2022.

Since then, the spectrum has expanded to include other oil or fat-like waste. In 2022, the contribution of biodiesel or HVO from the palm oil mill effluent – known as **POME**[2] – initially increased to approx. 13,000 TJ. In 2023, the share of biofuels from industrial waste rose to almost 42,000 TJ – appearing from virtually nowhere. These raw materials and POME in particular require critical evaluation for various reasons. The discussion section (Chapter 3.2.2) contains a text box with explanations.

This study focuses on the **raw material UCO**, whose collection is inherently positive, as this resource would otherwise be lost and – at least in Germany or Europe – disposed of via the municipal wastewater system.

[1] The proportion of rapeseed or soybean oil in HVO is far below 1%; under German law, palm oil can no longer be counted towards the GHG reduction quota under RED since 2023.
[2] POME = Palm Oil Mill Effluent

UCO, together with animal fats, is listed under Annex IX Part B of the Renewable Energy Directive (RED III). RED III limits their share to 1.7% of the energy content of fuels and electricity supplied to the transport sector[1], although German law permits a higher level of 1.9%.[2] In relation to the final energy volume used in transport in Germany in 2023, a maximum of 50,000 TJ is therefore eligible. Based on the previous maximum use of 30,000 TJ of biodiesel in 2022, there is still scope to increase the use of biodiesel and HVO from UCO or animal fats.

The key question of this study is whether **the calculation under the rules of RED III[3] assuming the savings mentioned above for HVO and FAME produced from waste materials, truly reflect the actual GHG emission reductions.** The regulatory provisions include the assumption that waste and residues are freely available and that demand and use by other users is not taken into account. However, this neglects the broader picture, given the wide-ranging demand and diverse potential usesof both UCO and animal fats. Due to the funding framework of RED III, which favours the use of biofuels precisely because of the allegedly excellent GHG savings, it can reasonably be assumed that the existing use of these raw materials shifts in favour of fuel production. It should be noted that UCO is fundamentally a scarce resource whose supply is limited. As a waste material, it is not, by definition, deliberately produced – unless by fraudulent means. However, there is still potential for previously uncollected UCO in Germany amounting to 125,000 tonnes or 3,400 TJ per year, equating to a third of the total volume in Germany (Abdalla and Fehrenbach 2020). In 2023, around 15,000 TJ of UCO diesel ended up in German fuel tanks, almost 90% of which was imported.[4] It is unclear how feasible or economical it would be to collect UCO from within Germany, since it is often generated decentrally and has to be collected at great expense. Furthermore, these additional volumes would only cover a fraction of the UCO demand in Germany.

This brief study aims to illustrate how the overall GHG balance of fuel production from UCO is calculated, **taking into account both the lost and possibly even prevented alternative uses**. These include raw material for oleochemical products (surfactants and detergents used in cleaning agents or lubricants, e.g. for hydraulic oils), for reuse as cooking oil after processing or simply for direct energy use as heating fuel.

An important aspect here is that, according to the figures from (BLE 2024), 89% of UCO in Germany is imported, more than half from other continents. The price advantage of using it as fuel is considerably higher than efficient local use. In the countries of origin, the export of UCO means that the demand for vegetable oils must be offset by cheaper fresh oil (often palm oil). This should also be considered in the analysis in this brief study.

2 Method

2.1 Research question

UCO is considered the raw material for the analyses performed in this study. The fuel pathways are transesterification to “conventional” biodiesel (FAME) and hydrotreatment to HVO and use as HVO100.

[1] See Directive (EU) 2018/2001, new version dated 16.07.2024: Article 27 (1) c) iv).
[2] See 38th BImSchV, § 13a.
[3] Calculated according to the rules of RED III in Annex V Part C.
[4] According to written communication from the BLE dated 11.8.2025 provided on request.

The following alternative scenarios are analysed:

1. Transparent calculation of the GHG emissions across the supply chain (including ocean freight) and substitution of fossil diesel fuel, as specified in RED III[1], but including lost alternative use of UCO as heating fuel, which in turn prevents the substitution of fossil heating fuel (fuel comparator).

2. As in scenario 1, but with the approach that UCO collected from Asian countries is replaced by fresh palm oil as the fuel comparator. The contribution to land use change estimated as feasible is included in this scenario.

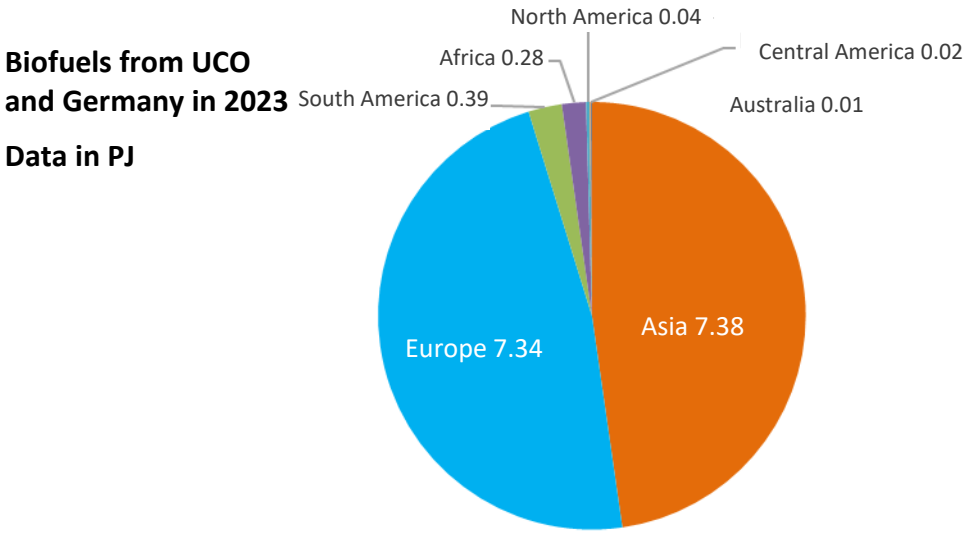
Both scenarios represent holistic and equal-benefit system assessments.

2.2 Data basis

2.2.1 Origin of UCO for biofuels in Germany

Figure 1 shows the shares of the regions of origin for biofuels from UCO placed on the market in Germany in 2023 according to the data from (BLE 2024). It is evident that almost half are imported from Asia. Earlier reports indicate that the main export countries are China, Indonesia and Malaysia. Almost half originate from Europe. This means, specifically, other European countries, since the share from Germany itself is only minimal (around 1,700 TJ,[2] approximately 11% of the UCO used in Germany).

It should be noted that the data from (BLE 2024) do not indicate whether and to what extent the countries of origin differ between UCO used for the production of HVO and UCO used for conventional biodiesel (FAME).



[1] These partial results will largely correspond to the GHG values reported by the BLE.
[2] According to written communication from the BLE dated 11.8.2025 provided on request.

Figure 1: Origin of used cooking oils for the production of biofuels placed on the market in Germany in 2023; data in petajoules (PJ) = 1,000 terajoules (TJ); source: (BLE 2024), illustration ifeu

For the balance sheet, it is therefore assumed that half of the UCO is collected in the East Asian region (assumed radius from the collection point up to shipment 100 km) and transported to Europe by ship over an assumed distance of 11,000 km.

For HVO, delivery is to European ports near HVO plants. The largest HVO production capacities are located in Finland (two plants) and the Netherlands (one plant) as well as an additional plant in Singapore – all belonging to Neste Oil, the largest HVO producer in the world with a 69% share of global capacity.[1] Competitors in Europe include ENI in Italy and TOTAL in France.[2]

It is assumed in this scenario that UCO is delivered to European ports (in this case Rotterdam) and processed in the Netherlands. UCO from European countries is also hydrotreated there to produce HVO. According to a study by (Abdalla and Fehrenbach 2020), the most important European import countries for UCO used in Germany are Poland, Slovakia, Bulgaria, Spain, Romania and Austria. An average transport distance of 1,250 km per tanker truck is assumed. From the production site in the Netherlands, the HVO100 fuel is again distributed by tanker truck to service stations in Germany with an assumed average distance of 450 km.

Since, as noted above, no information is available on the shares of UCO from varying origins used for transesterification to FAME versus HVO production, the same distances are assumed for FAME produced from UCO. The origins shown in Figure 1 can be considered comparable based on the available BLE data for both products.

2.2.2 Data on the process chain

The calculation is based on a calculation tool developed by ifeu, which has been used by the German Environment Agency (UBA) to calculate emission balances for bioenergy sources since 2017 (Fehrenbach et al. 2016). This tool is harmonised with the BioGrace GHG tool (ifeu 2015), previously the only tool recognised by the EU Commission, and the ENZO2 tool recognised by the BLE. The input factors are derived from the data used to calculate the default values in Annex V of the RED.

Table 4 and Table 5 in the Appendix show the structure of the calculation of GHG emissions from FAME and HVO production including all input variables, such as:

- Transportation (including collection)
- Energy required for processing (electricity and steam)
- Use of process chemicals such as methanol, hydrogen, phosphoric acid and caustic soda

These input variables are linked to background data such as:

- Emission of the upstream energy chains of
  - Energy grid
  - Diesel, bunker oil

[1] https://www.neste.com/about-neste/how-we-operate/production
[2] https://www.greenea.com/publication/new-players-join-the-hvo-game/

  - Process steam (based on natural gas firing)
- Emissions for the production of input materials
  - Methanol, hydrogen, phosphoric acid and caustic soda
- Emissions from the transport processes:
  - Tanker truck, seagoing vessel.

2.3 Methodological approach for the comparison

As described, comparisons are made at two different levels. At the first level of comparison, the production of the fuels FAME and HVO from UCO is compared with the direct use of UCO as a heating fuel. At the second level of comparison, the use of UCO for the production of biofuel is assumed to result in the additional production of palm oil to reflect the displacement of UCO from its previous use. Palm oil is adopted because it is the dominant vegetable oil in UCO's main regions of origin in Asia[1] and is also the most economical option[2].

Both considerations assume 1 megajoule (MJ) of UCO. For clarity, an illustration with reference to 1 litre of UCO is also provided. The general values for pure vegetable oil are used for energy content and density in this analysis. The energy density is therefore 34 MJ per litre.[3]

For comparison level 1, the different systems for using UCO are compared. This is illustrated in Figure 2 on the left. The decisive factor is that both usage pathways have different fossil fuel comparators – even though diesel and heating oil[4] do not differ significantly. It could be argued that the heat generated from UCO could also be generated from sources other than heating oil. However, the same also applies to transport fuel, which can, for example, be replaced by electricity. For this analysis, it is therefore important to compare equivalent systems. Each utilisation pathway is evaluated against the corresponding fossil fuel comparator and the GHG emissions are subtracted in the form of a balance. This corresponds to the approach under RED III, where the “saving” of GHG emissions is also determined by deducting the GHG emissions of the fuel comparator from those of the UCO utilisation pathway.[5] The aim here is to determine and evaluate the difference between the balances of the two systems, or the “savings” of each.

Figure 2 shows a diagram for the comparison on the second level on the right. Here, it is assumed that the use of UCO for biofuel means that it is no longer available for its previous uses (e.g. energy but also reprocessing for food preparation). In balance sheet terms, the emissions from UCO-based biofuel production are compared against the additional emissions arising from the production of palm oil to replace the displaced UCO.

With regard to the climate impact of the greenhouse gases CO_2, methane (CH_4) and nitrous oxide (N_2O) included, the values assigned in RED III in Annex V Part C no. 4 are

[1] https://www.mordorintelligence.com/de/industry-reports/asia-pacific-vegetable-oil-market
[2] Prices according to FAO online tool: https://fpma.fao.org/giews/fpmat4/#/dashboard/tool/international
[3] According to RED III Annex III
[4] This refers to light heating oil, also referred to as heating oil EL which stands for “extra light”.
[5] See RED III Annex V Part C, No. 3 a): Saving = (total emissions from the fossil fuel comparator minus total emissions from the biofuel;) divided by the total emissions from the fuel comparator

applied. These refer to a 100-year period, the GWP100, but to an earlier IPCC report (IPCC 2023).[1]

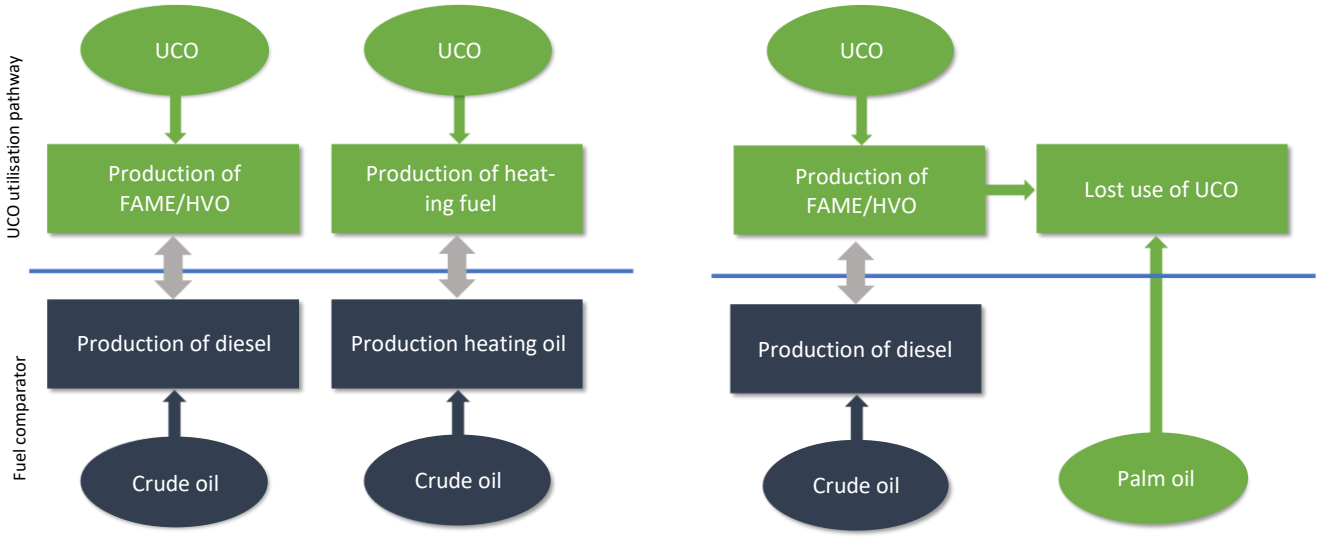


Figure 2: Left side: Comparison level 1: Systems and basis for comparison of FAME/HVO with UCO use as heating fuel, right side: Comparison level 2: Systems and for the consideration of displaced uses (and replacement by palm oil) through the production of FAME/HVO from UCO; illustration: ifeu

3 Results and discussion

3.1 Comparison level 1: FAME and HVO with UCO use as heating fuels

3.1.1 Results

The production of 1 MJ FAME and 1 MJ HVO from UCO generates 18.9 g CO_2Eq. and 15.8 g CO_2Eq. respectively, according to the calculations. This result is composed as shown in Table 1. For HVO, the largest contribution comes from the production of hydrogen for hydrotreatment. With the exception of by-products from mineral oil refineries or heavy oil gasification, hydrogen has so far been produced almost entirely from natural gas through steam reforming. The production of 1 kg of such “grey” hydrogen causes approx. 11 kg CO_2Eq. Emissions could be significantly reduced in the future by using “green” hydrogen. However, its availability currently remains limited.

With FAME, emissions from energy production are higher than for HVO. This is because HVO can make use of waste heat from the process, while FAME relies on natural gas to

[1] In RED III, the factor for methane is set at 25, and at 298 kg CO_2Eq per kg for nitrous oxide. In the 6th Assessment Report of the IPCC, the values for methane are adjusted to 27 and for nitrous oxide to 273 kg CO_2Eq per kg.

provide process heat. In addition, FAME production requires methanol. The specific emissions for 1 MJ FAME are therefore higher than for 1 MJ HVO.

Table 1: Contributions of the individual lifecycle stages to GHG emissions for the production of FAME and HVO from UCO

Section	Procedure	Result in g CO_2Eq/ MJ FAME	Result in g CO_2Eq/ MJ HVO	"Default values" from RED III Annex V	
				FAME	HVO
Collection	Truck	0.2	0.2		
Transportation	Seagoing vessel	1.3	1.4		
Processing	Hydrogen	-	7.8		
	Methanol	7.0	-		
	Other chemicals	0.1	0.1		
	Energy	7.5	3.6		
Distribution	Truck	1.9	1.9		
Service station	Electricity	0.8	0.8		
Sum of processing (e_p)		***14.6***	***11.5***	***13.0***	***14.3***
Sum of Transport & Distribution (e_{td})		***4.3***	***4.4***	***1.9***	***1.7***
Total sum		**18.9**	**15.8**	**14.9**	**16.0**

Calculations by ifeu; RED III – inaccuracies in totals are due to rounding

According to the methodology specified in RED III, the GHG savings are calculated by offsetting emissions against the comparator of 94 g CO_2Eq/MJ for fossil fuels. In fact, the results calculated here for FAME are slightly higher than the default value of 14.9 g CO_2Eq/MJ FAME stated in Annex V of RED III. For HVO, by contrast, the values calculated here are lower than the default value of 16.0 g CO_2Eq/MJ for HVO. The emission value for processing (e_p) documented in the Annex to RED III is higher for HVO and lower for FAME than those calculated here. However, calculated transport-related emissions are higher overall due to their origin in East Asia. Background data for the default values in RED III are not available, so the deviation in processing emissions cannot be further analysed or evaluated. For the purposes of this study, the differences can be considered manageable; in any case, they show that the present study takes a conservative approach in favour of HVO.

The basic assumption of a correct and legal supply chain can be considered conservative. It can be assumed that some of the volumes reported as UCO in FAME and HVO are actually other raw materials, especially fresh palm oil. The issue of fraud is briefly discussed in the text box in Chapter 3.2.2. In principle, where there is fraud, it can be assumed that emissions are significantly higher.

In the following, a series of calculations are carried out for UCO and the products FAME and HVO on the basis of their specific calorific values and yields during conversion. The calorific values are taken from RED III, Annex III, while the yields are calculated based on the process chain data (see Annex).

According to the process data, 0.813 kg of HVO is produced from 1 kg of UCO or 0.958 litres of HVO from 1 litre of UCO. In energy terms, 0.967 MJ of HVO is obtained for 1 MJ UCO input. In the case of FAME, the calorific value of the vegetable oil used also corresponds to that of the produced biodiesel according to the RED III data. However, the process losses here are lower than in hydrotreatment: 1 MJ UCO yields 0.975 MJ FAME.

The results based on 1 MJ UCO for both comparison systems, including the fuel comparator, are presented below (see Table 2). The reference value here is 1 MJ UCO, as different products from UCO are compared here. In Table 1, the reference unit is 1 MJ FAME or 1 MJ HVO instead, as the GHG intensity of these products is to be expressed there.

The production of heating fuel is associated with significantly lower emissions, as it does not involve the complex processes of transesterification or hydrotreatment. The reference process (production of fossil heating oil) also has a slightly lower emission load than diesel, as the quality requirements for diesel (especially sulphur content) are stricter. Instead of 94 g CO_2Eq per MJ of diesel (corresponds to 90.9 g CO_2Eq per MJ of UCO used in HVO and 91.7 g CO_2Eq in FAME), light heating oil only produces 92 g CO_2Eq per MJ (or 89 g CO_2Eq per MJ of UCO used).[1]

[1] The values differ because different volumes of FAME or HVO or heating oil can be produced from 1 MJ UCO, both in kg and in MJ, since diesel and HVO have very different calorific values. The comparison is made at the level of the same volume of UCO.

Table 2: Contributions of the individual life cycle stages to GHG emissions for the production and provision of FAME and HVO from UCO and of heating fuel from UCO and their respective fuel comparators.

Section	Procedure	Production of FAME g CO_2Eq/MJ UCO	Production of HVO g CO_2Eq/MJ UCO	Production of heating oil g CO_2Eq/MJ UCO
Collection	Truck	0.2	0.2	0.2
Transportation	Seagoing vessel	1.3	1.3	1.3
Processing	Hydrogen		7.6	
	Methanol and other chemicals	6.9	0.1	0.1
	Energy	7.3	3.5	0.6
Distribution	Truck	1.9	1.8	1.8
Service station	Electricity	0.8	0.8	0
Total		18.5	**15.3**	**4.0**
Fossil comparative value		91.7	90.9	89.0
Net balance		**-73.2**	**-75.6**	**-84.9**

Ifeu calculations – inaccuracies in totals after the decimal point are due to rounding

The results are shown again as a graph in Figure 3. It also highlights the net results. The highest saving (minus value) is achieved by the heating oil pathway with 84.9 g CO_2Eq/MJ UCO. The net savings from FAME and HVO are lower at 73.2 and 75.6 g CO_2Eq/MJ UCO respectively.

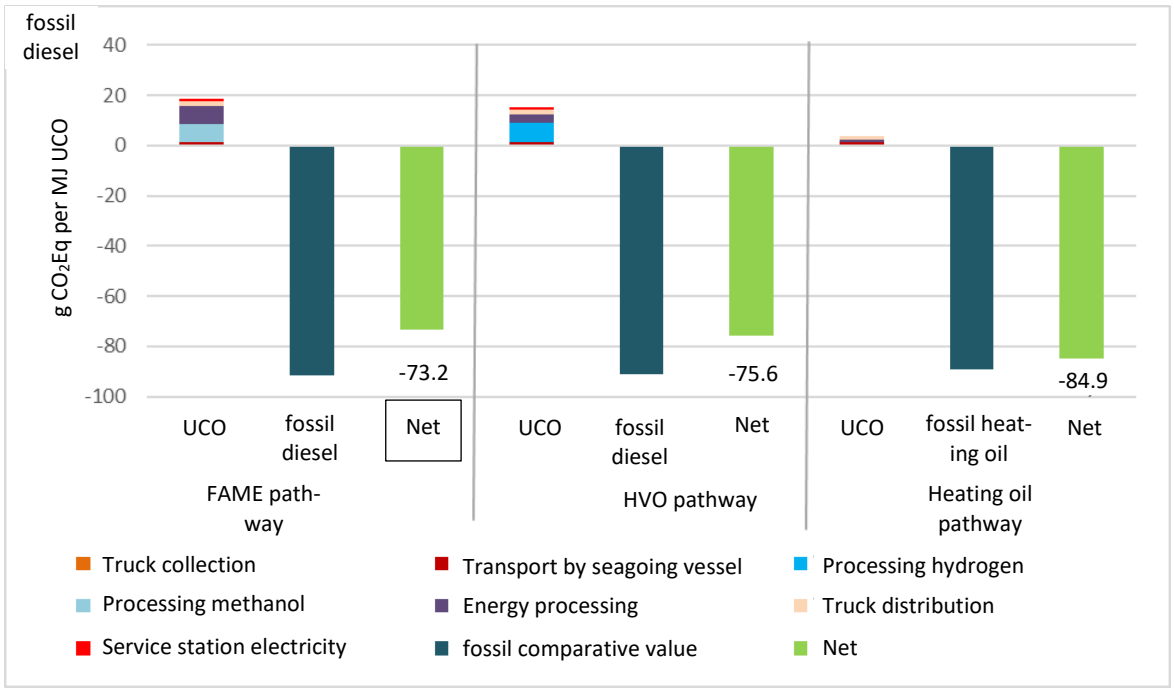


Figure 3: GHG balance of UCO-HVO and UCO-FAME versus UCO use as a heating fuel; calculations and illustration ifeu

3.1.2 Discussion

Firstly, it should be noted that the collection and use of UCO as an energy source or raw material for material use, e.g. for oleochemical products (see Chapter 1 “Background”), enables significant reductions in GHG emissions. This resource should therefore certainly be used.

There are several options. This study compares the option of its use as a heating fuel and as a transport fuel. These are very closely related areas of application; accordingly, the results do not differ significantly. The more complex processing to produce FAME and HVO replaces diesel – a fossil product that is somewhat more complex to produce in the refinery process than the light heating oil of the heating fuel option. Its quality requirements are somewhat lower, as is the production intensity and the associated greenhouse gas emissions. The bottom line is that the savings are higher with the heating fuel option. The difference of significantly more than 10% can be considered quite substantial. In direct comparison with transport fuels, its use as a heating fuel is therefore more effective for climate protection.

The idea that FAME and HVO from UCO would massively reduce GHG emissions would only hold true if there were no alternative uses for UCO or if these were not used. This would therefore only apply to volumes that are not already being used or could not be used elsewhere. However, this is not the case for the volumes on the market. Rather, the situation here is that existing uses as heating fuel are being shifted to for biodiesel production (Kristiana et al. 2022), (van Grinsven et al. 2020). The large volumes imported from Asia in particular were not just the result of newly developed collection systems, but rather reflect an established resources management culture (Stratas Advisors 2024). Conversely, there is a strong incentive to redirect these resources to a subsidised market in the EU.

The opinion that the use of FAME or HVO from UCO leads to a GHG reduction of almost 90% is incorrect from a macroeconomic perspective. Using UCO for transport fuel production does not lead to any reduction in GHG emissions. This can only be justified within the narrowly defined framework of the RED. The savings effect arising purely by replacing fossil diesel comes at the expense of savings through UCO use elsewhere. Compared to the alternative use of UCO as a heating fuel outlined here, it even entails a detrimental impact.

3.2 Comparison level 2: UCO use for biodiesel and replacement by palm oil

Instead of comparing an established alternative use of UCO, this section considers displacement (“leakage”) at the level of raw material. As UCO is withdrawn from the existing market in the assumed scenario, the gap is replaced by an available and cost-effective raw material. This is usually palm oil, which is not limited to the East Asian region, but also applies to the global vegetable oil market. This is because palm oil has had the lowest world market price of all vegetable oils for years.[1] Only since September 2024 has palm oil been more expensive than rapeseed or soybean oil, for example. This is partly due to unfavourable growing conditions in Malaysia.[2] According to Statista, prices for palm oil have once

[1] Prices according to FAO online tool: https://fpma.fao.org/giews/fpmat4/#/dashboard/tool/international
[2] https://openknowledge.fao.org/server/api/core/bitstreams/494e22f9-c748-4634-be2d-d1e6d37eeac8/content;
https://www.ufop.de/files/9817/0738/7445/24_06_W_FAO_Preisindex.pdf

again been significantly lower than for other vegetable oils since spring 2025.[1] In the main East Asian regions of origin of UCO, palm oil is undisputedly the dominant oil crop (van Grinsven et al. 2020).

This only applies to a limited extent to UCO imports from European countries to Germany, as comparable RED III quota obligations for renewable energy or GHG reduction in transport apply in these countries too. If the exported UCO resources are not used there, this means that other raw materials are favoured for fuel production. This could be rapeseed oil, but – depending on legal implementation by 2030 – it could also be palm oil as a cheaper biodiesel feedstock. In any case, the comparison made here is appropriate for the proportion of UCO imported from East and Southeast Asia.

The balance of the production of biodiesel from UCO is therefore compared here with the balance of the alternative raw material palm oil and with the net balance for FAME and HVO.

Is it at all justified that a substitute for UCO exports to Germany must be taken into account in the exporting countries? This would in fact not be the case if the capture and collection were carried out solely to comply with a legal obligation to curb the negative consequences of waste disposal and the producers of UCO had to somehow dispose of it. However, since the availability of UCO in each producing country offers sufficient options for domestic use (whether for energy or material purposes), this utilisation option "is displaced" when UCO is exported. The "potential" use is therefore covered by another raw material source. This procedure is a basic prerequisite for comparative lifecycle assessments to ensure a fair comparison between the systems being assessed.

3.2.1 Results

The calculation is carried out using the same calculation tool as for UCO (see Chapter 2.2.2) and in accordance with the provisions of RED III. Table 6 in the appendix lists the key input variables. In Table 3, only the GHG emissions for the provision of UCO and palm oil are summarised . For UCO, only collection in urban centres is considered here, where transport distances are shorter. However, the results may be an underestimate, as the first stage of the collection process may involve very small vehicles. The emission load in this case may certainly be higher.

According to the calculations carried out here, the cultivation of palm oil accounts for a significant share of emissions, at just under 20 g CO_2Eq per MJ of crude palm oil (CPO). Processing in the oil mill only results in low emissions because biogenic residues from cultivation and production are used as heating fuel. However, these low emissions depend on the capture of palm oil mill effluent (POME) and the prevention of methane release. If this is not the case, emissions increase by 18.4 g CO_2Eq per MJ. It should be noted at this point that the default values in RED III may greatly underestimate the actual GHG emissions from POME pond systems. This is illustrated by satellite-based measurements showing significant methane concentrations around palm oil mills in Indonesia (Valverde et al. 2024).

Another factor that leads to a wide variance in the results for palm oil is the issue of land use change.

There are no clear data for this, but various sources can serve as a reference: firstly, the factors that were originally determined for indirect land use change (iLUC) according to

[1] https://de.statista.com/statistik/daten/studie/1312207/umfrage/preis-von-pflanzlichen-oelen-im-welthandel-art-monate/

RED by (Laborde 2011) and to which RED III in Annex VIII still refers. For palm oil, this is 54 g CO_2Eq per MJ. This value is used for the calculation in Table 3.

Default values for iLUC are also included in the CORSIA Carbon Offsetting and Reduction Scheme for International Aviation introduced by the International Civil Aviation Organization (ICAO) (ICAO 2022). At 39.1 g CO_2Eq per MJ, these values are slightly lower for palm oil than those of RED III. In contrast, the emissions from attributional land use change (aLUC) are higher. See also the info box below.

In total, there is a range of around 25 g CO_2Eq per MJ (without land use change and with prevention of emissions from the POME pond systems) to 94 g CO_2Eq per MJ (with iLUC and POME emissions). The attributional land use change approach was not used here, as this would extend this range significantly upwards. Processing into biodiesel and transportation to Europe are not taken into account either, as the analysis relates solely to crude palm oil.

Info box: Methods for estimating land use changes (LUC)

Depending on the time period and spatial context, land use is always changing. Forests are being cleared for the cultivation of arable crops or pastureland, grassland is being converted to arable land and areas are being sealed for housing, transport or industrial plants. As the production of biomass accounts for by far the largest proportion of the land used by humans, it is also the most significant driver of land use change.

There are various approaches to determining land use change, which differ depending on the context. They can be divided roughly into the following:

- Approaches in the context of national reporting under the UNFCCC that describe the total emissions of an economy
- Approaches to direct land use change (dLUC)
- Approaches to indirect land use change (iLUC)
- Approaches that attempt to mediate between direct and indirect land use change, such as “attributional LUC” (aLUC).

As part of **national reporting**, the annual impact on the national carbon budget arising from changes in land use is calculated using an equilibrium model under the **LULUCF** category. The LULUCF balance reflects the official and realistic total emissions (or sinks) from land use. However, this balance cannot be applied to products and services.

Direct land use change (**dLUC**) refers specifically to the actions of a producer. This approach is needed to demonstrate the sustainability of specific biofuel supplies under RED III. Theoretically, the dLUC would be a suitable tool for accurately determining the actual LUC emissions from products such as rapeseed diesel or palm oil, but not for assessing the lifecycle of products in general. The reason is that when selecting agricultural land for biofuels, the use of land subject to LUC is simply avoided. Biomass from areas with LUC will then go to markets that do not have the verification requirements that apply to biofuels.

Indirect land use change (**iLUC**) is when the manufacture of a product in one location results in the expansion of agricultural land elsewhere. This happens, for example, when existing farmland is displaced for the cultivation of energy crops and elsewhere forests or other areas have to be converted into farmland. Complex models are used to estimate iLUC. These calculate how a sudden or targeted increase in demand – for example due to political specifications – affects the global use of land. One example is the increasing demand for biofuels when quotas for their use are introduced in Europe. The resulting land use changes are then attributed to the biofuels. iLUC is therefore considered a “consequential approach” because it does not consider the properties of the product itself, but

the consequences of political decisions. For example, palm oil can have very different iLUC values depending on its intended use – for example, as biofuels, cosmetics or food.

This is where the attributive land use change (**aLUC**) comes in, which aims to express the LUC of palm oil or rapeseed oil regardless of its use. The basic approach here assumes that land use changes are real and that they are generally documented with data (see national reporting). These actual LUC operations are allocated to the associated processes. This requires an allocation logic, which could, for example, read: in Germany, x% of the area of grassland is converted annually through the production of arable crops. Each agricultural product is then allocated the x% of LUC land conversion from grassland, proportional to the crop land required for that product. This yields a generic emission factor that allocates the actual and measurable LUC in a defined agricultural area to all producers in the agricultural area. See: (Fehrenbach et al. 2016), (Keller et al. 2021). A similar approach has been developed in the Netherlands (Salim et al. 2024).

Table 3: Contributions of each life cycle stage to GHG emissions from UCO versus palm oil fuel comparators.

Section	Procedure	Provision of UCO g CO_2Eq/MJ UCO	Production of palm oil g CO_2Eq/MJ CPO
Land use change	iLUC RED[a)]		54
	iLUC CORSIA		39.1
	aLUC (alternative)		112
Cultivation			19.9
Collection	Truck	0.2	1.2
Processing	Energy		0.4
	Emission from POME pond system		18.4
Total without POME, without LUC		**0.2**	**21.5**
Total with POME, without LUC			**39.9**
Total (with iLUC, without POME) [a)]			**75.5**
Total with iLUC, with POME to $^2/_3$			**87.7**
Total with iLUC, with POME [a)]			**93.9**

Calculations by ifeu.
"without POME" means without methane capture from POME pond systems; "with POME" means with methane capture from POME pond systems;
a) iLUC means the factor from RED III Annex VIII for vegetable oils.

The iLUC factor from RED III Annex VIII for palm oil (54 g CO_2Eq per MJ) is used for land use change in the present analysis.

Including the full emissions from the POME pond system plus the iLUC factors, the GHG load for 1 MJ of palm oil is 93.9 g CO_2Eq. This contrasts with emissions of 0.2 g CO_2Eq for the provision of 1 MJ UCO.

In Malaysia, capture of methane emissions from POME pond systems is already well established. However, Indonesia, a significantly larger producer[1], still lags far behind in terms of this development (Listiningrum et al. 2022), (Mohd Pauzi et al. 2023), (Saad et al. 2021). It is therefore assumed that methane is not captured for at least two thirds of production. However, if, as in Indonesia, hardly any methane emissions from palm oil production are prevented, this results in substantial local sources of emissions.

Using two thirds of the emissions from POME pond systems, the total is 87.7 g CO_2Eq per MJ of palm oil. This value, after deduction of emissions associated with UCO collection (0.2 g CO_2Eq/MJ), is applied as a malus of 87.5 g CO_2Eq/MJ for displacing the use of 1 MJ UCO for biofuels. If we assume a saving of 73.2 g CO_2Eq. for FAME and 75.6 g CO_2Eq. for HVO (see Table 2) after balancing in accordance with RED III (see Chapter 2.2.2), this results in residual emissions of 14.4 g CO_2Eq. per MJ UCO for FAME and 12 g CO_2Eq. per MJ UCO for HVO, taking into account the malus from the additional production of palm oil. In other words: If the provision of palm oil to replace UCO in the countries of origin is taken into account, this does not result in emission reductions compared to fossil diesel, but in emission increases ranging from 12 to 14.4 g CO_2Eq., as shown in Figure 4.

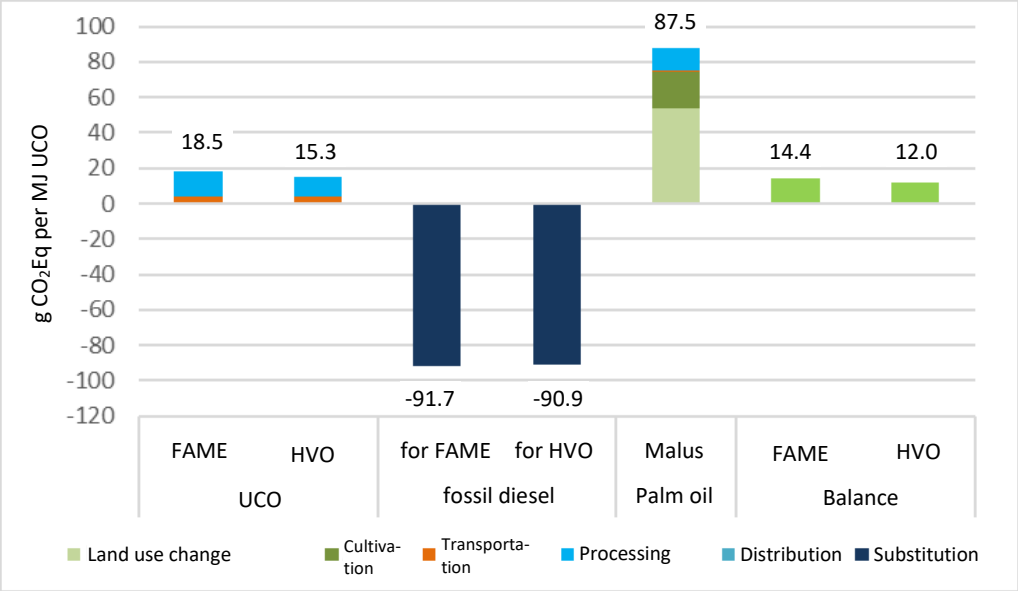


Figure 4: GHG balance of UCO for biofuels with credit for substitution of fossil diesel and the malus for palm oil with the total balance for each; calculation and illustration: ifeu

[1] According to ourworldindata.org, Indonesia produced 49 million tonnes of CPO in 2022, while Malaysia produced 18.5 million tonnes, with both countries together covering 83% of the global market.

3.2.2 Discussion

The preceding Chapter 3.1.2 has already focused on the macroeconomic view. This brief study by no means claims to provide a complete overview of such a framework. It is limited only to the subsystems of this economy that have been identified as essential and the mechanisms that exist within them. One such mechanism is the principle of “leakage”, i.e. the displacement of processes and therefore also of emissions. Similar to the shift from the existing use as a heating fuel to use as a transport fuel described in the previous section, the shift can also occur at a raw material level. If the substance of choice (in this case UCO) can be traded in a new market at a higher price than an alternative (in this case palm oil), UCO will flow into this new market, while the previous user will then switch to the cheaper palm oil.

When put into context as described above, it also becomes clear that the use of UCO for FAME and HVO does not yield a net reduction in greenhouse gas emissions. On the contrary, the use of UCO as a transport fuel results in additional, more climate-damaging production of substitute materials elsewhere. The use for transport fuels leads to additional greenhouse gas emissions. The calculations performed here are given by way of example and the individual assumptions are open to debate. However, the bottom line is, that the benefit according to the savings determined under the RED calculation framework does not reflect real-world emissions.

Info box: on fraud and susceptibility to fraud in the context of UCO

While the volumes of biofuels from UCO (30 PJ) and POME (12.9 PJ) calculated by the BLE in Germany were already high in 2022, the volume of UCO halved in 2023, yet almost 42 PJ of biofuels from industrial waste were added – practically appearing out of nowhere. This new raw material – based on its denomination – appears to be "brown grease", a heavily contaminated grease/oil mixture from separation plants. The advantage of this substance is that it is not classified as RED III Part B (as is the case for UCO and animal fats), but rather as Part A, i.e. as an advanced biofuel for which particularly high quota apply. Like UCO, the majority of this material originated from China. According to the German government[1], there was no verification of origin, i.e. the audits that are required as part of the prescribed certification procedure were not carried out as they were not permitted in China and other countries of origin. According to the ISCC certification system (International Sustainability & Carbon Certification), the sharp rise in imports up to February 2023 indicates that these trade flows may be of dubious or fraudulent origin.[2]

One effect of this massive and largely unchecked "flooding" into the biofuel market in Germany and other EU countries was a sharp decline in prices for biofuels and, above all, for the quota prices for greenhouse gas reduction. The price was € 440 per tonne of CO_2 between May 2022 and January 2023 and then plummeted to around € 220 in April 2023.[3] This has consequences for various market participants, such as electric car drivers with their own charging station or wallbox who have factored in the GHG premium when going elecric[4], as well as any companies that have tailored their business models based on trading quotas or quota-relevant products, such as biodiesel or biogas.

In a statement from November 2023, the DLG outlines how the fraud system works: As of January, palm oil is no longer eligible for the German GHG quota for biodiesel; this has prompted interest in selling palm oil in Europe for biodiesel through alternative routes. Palm oil or HVO from palm oil is sent to China, where it is either hydrotreated (palm oil) or simply re-exported and re-declared as HVO from used cooking oils or as palm oil mill effluent (POME).[5] In this context, the BLE blocked a certified HVO supplier's access to the state database Nabisy[6].[7]

A study on POME by (Transport & Environment 2025) provides information on the volumes actually available. According to the report, the production levels of POME biofuels reported in Europe were almost double the globally available POME – a strong indication of fraud. It should be noted that these oils, whether UCO from East Asia or POME, are all based on palm oil, which is why analytical evidence cannot identify fraud.

[1] The federal government's reply to the parliamentary question put by the CDU/CSU parliamentary group – printed paper 20/7103 – https://dserver.bundestag.de/btd/20/073/2007327.pdf
[2] https://archive.newsletter2go.com/?n2g=ij14sms7-o8am5zg0-t
[3]The federal government's reply to the parliamentary question put by the CDU/CSU parliamentary group – printed paper 20/7103 – https://dserver.bundestag.de/btd/20/073/2007327.pdf
[4] https://www.emobility.energy/thg/der-einfluss-von-brown-grease-auf-die-hohe-der-thg-pramie
[5] https://www.dlg-mitteilungen.de/artikel/biodiesel-hvo-betrug
[6] NaBiSy: Sustainable biomass systems; this is a governmental online system of the Federal Office for Agriculture and Food (BLE) in which sustainability certificates for biomass are issued and submitted.
[7] https://www.ble.de/DE/Themen/Klima-Energie/Nachhaltige-Biomasseherstellung/nachhaltige-biomasseherstellung_node.html

4 Summary

Considerable savings in GHG emissions are reported for the fuel HVO100, which has been approved in Germany since May 2024, as well as for “classic” blended biodiesel from UCO, provided it is produced from waste such as used cooking oil (UCO) and animal fats. The official figures reported by the Federal Office for Agriculture and Food (BLE) indicate savings of around 87 to 88% compared to fossil diesel. These are very substantial savings compared to other biofuels, despite the large proportion of UCO imports from Asia, especially China, with long transport distances.

But do these figures actually reflect real-world circumstances when considering the specific reduction in greenhouse gas emissions? The short study identifies two considerations that show that this is not the case – or at least that the alleged savings do not match the reported levels.

The first aspect relates to the fact that these waste oils and fats would also be used without conversion to fuel. The use of UCO as a transport fuel to replace fossil diesel means it can no longer be used in other sectors to replace fossil raw materials. Use as heating fuel, which is common in Asian countries of origin, was considered. Compared to such use, the production of transport biofuel from UCO for the European market would be associated with lower GHG savings. This means that the net climate benefit of biofuel from UCO is at best zero when considering the lost potential of alternative uses of UCO. In the balance, fuel from UCO therefore does not result in any GHG savings, even when applying the logic of the official calculation method. A different picture could only emerge if additional UCO is collected and not withdrawn from any other sector of use. However, the additional collection potential is very limited.

A comparable result emerges if the second consideration is taken into account: Instead of fossil heating fuel, the export of UCO to the growing European biofuel market can also mean an increased demand for virgin vegetable oil in the countries of origin. The withdrawal of the UCO supply then leads to this gap being filled flexibly by the most cost-effective vegetable oil, which often quite simply means additional palm oil production. If this is treated as a malus for UCO for the production of biofuel to replace fossil diesel, the net savings are reversed, resulting in an overall increase in emissions.

The calculations based on RED methodology showing significant savings therefore do not reflect the actual climate benefit. The use of HVO100 as well as “conventional biodiesel” from UCO does not contribute to climate protection. In view of the predominant origin of UCO from countries where local use competes with the use of fresh palm oil, this practice can even be considered to have adverse effects on climate protection. And that is before even considering the fraud risks.

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Appendix

Table 4: Compilation of key input variables in the calculation tool used for FAME from UCO

Collecting used cooking oil		
Yield		
Used cooking oil	1.00	kg / kg
Collection		
Distance 1 (for 100%) of the UCO	100	km
Means of transport	Truck (40 tonnes) for liquids	
Fuel	Diesel	
Distance 2 (for 50%) of the UCO	11,000	km
Means of transport	Product tanker (22.56 kt), bunker oil	
Fuel	Bunker oil (3.5% S)	

Processing - Transesterification plant		
Biodiesel (FAME)	0.975	kg FAME / kg used cooking oil
By-products		
Glycerine	0.0980	kg / kg Used cooking oil
Organic oil	0.0250	kg / kg Used cooking oil
Input materials		
Phosphoric acid (H_3PO_4)	0.0146	kg / kg FAME
Potassium hydroxide (KOH)	0.0135	kg / kg FAME
Methanol	2.25	kg / kg FAME
Energy		
Power requirement	0.0421	kWh / kg FAME
Steam requirement	3.29	MJ / kg FAME
Natural gas boiler		
Thermal efficiency	90%	%
Natural gas	3.65	MJ / kg FAME
Power requirement (incl. boiler)	0.0603	kWh / kg FAME

Electricity mix	Electricity mix EU low voltage	

Allocation between main and by-product (excess flue gas)		
Total calorific value of products	38.4	MJ
Emissions allocated to FAME	94.5%	%

Transport of FAME to depot & service station		
Transportation		
Distance	100	km
Means of transport	Truck (40 tonnes) for liquids	
Fuel	Diesel	
Depot		
Power requirement	0.00868	kWh / kg FAME
Electricity mix	Electricity mix EU low voltage	
Transportation of hydrotreated oil to the service station		
Transportation		
Distance	150	km
Means of transport	Truck (40 tonnes) for liquids	
Fuel	Diesel	
Service station		
Power requirement	0.0351	kWh / kg FAME
Electricity mix	Electricity mix EU low voltage	

Table 5: Compilation of key input variables in the calculation tool used for HVO from UCO

Collecting used cooking oil		
Yield		
Used cooking oil	1.00	kg / kg
Collection		
Distance 1 (for 100%) of the UCO	100	km
Means of transport	Truck (40 tonnes) for liquids	
Fuel	Diesel	
Distance 2 (for 50%) of the UCO	11,000	km
Means of transport	Product tanker (22.56 kt), bunker oil	
Fuel	Bunker oil (3.5% S)	

Processing - hydrotreatment plant		
Hydrotreated oil (HVO)	0.813	kg HVO / kg used cooking oil
Input materials		
Phosphoric acid (H_3PO_4)	0.00075	kg / kg HVO
Caustic soda (NaOH)	0.00120	kg / kg HVO
Hydrogen (H_2)	3.77	MJ / kg HVO
Energy		
Power requirement	0.200	kWh / kg HVO
Steam requirement	1.17	MJ / kg HVO
Flue gas combined heat and power plant (CHP)		
Electricity and heat production		
Electrical efficiency	54%	%
Thermal efficiency	28%	%
Flue gas from process	2.81	MJ / kg HVO
Heat production	1.52	MJ / kg HVO
Heat for hydrotreatment system	1.17	MJ / kg HVO
Electricity production	0.788	MJ / kg HVO
Electricity for hydrotreatment plant	0.719	MJ / kg HVO
Allocation		
Temperature Heat	150	°C
Allocation factor electricity	0.845	
Allocation factor heat	0.155	

Distribution of emissions		
Fraction of electricity into the hydrotreatment plant	0.770	
Fraction heat into the hydrotreatment plant	0.120	
Emissions from combined heat and power (CHP)		
Flue gas	2.50	MJ / kg HVO
Emissions from flue gas CHP		

Allocation between main and by-product (excess flue gas)		
Total calorific value of products	36.0	MJ
Emissions allocated to HVO	99.3%	%

Transport of hydrotreated oil to depot & service station		
Transportation		
Distance	100	km
Means of transport	Truck (40 tonnes) for liquids	
Fuel	Diesel	
Depot		
Power requirement	0.0103	kWh / kg HVO
Electricity mix	Electricity mix EU low voltage	
Transportation of hydrotreated oil to the service station		
Transportation		
Distance	150	km
Means of transport	Truck (40 tonnes) for liquids	
Fuel	Diesel	
Service station		
Power requirement	0.0416	kWh / kg HVO
Electricity mix	Electricity mix EU low voltage	

Table 6: Compilation of key input variables in the calculation tool used for palm oil

Cultivation		
Yield		
Palm fruit stands (FFB)	19.0	t/ha*a
Water content	34%	%
Fertiliser & Pesticides		
N fertiliser	79.6	kg N / ha*a
P_2O_5 fertiliser	29.6	kg P_2O_5 / ha*a
K_2O fertiliser	151	kg K_2O / ha*a
CaO fertiliser (kg CaCO3)	174	kg $CaCO_3$ / ha*a
Pesticides	53.8	kg / ha*a
Field CO_2 emissions (acidification)	40.2	kg / ha*a
Field N_2O emissions	5.07	kg N_2O/ ha*a
NH_3 emission from N mineral fertiliser	9.66	kg NH_3/ ha*a
Energy		
Diesel	45.0	l / ha*a

Transportation of the FFB		
Distance	50.0	km
Means of transport	Truck (12 tonnes) for FFB transport	
Fuel	Diesel	

Processing - Oil mill		
Palm oil (CPO)	0.200	kg CPO / kg FFB_{Fresh}
By-products		
Extraction meal palm kernels	0.0293	kg / kg FFB_{Fresh}
Water content of extraction meal	0.100	
Palm kernel oil	0.0240	kg / kg FFB_{Fresh}
Energy		
Electricity demand from combined heat and power (CHP)	0.102	kWh / kg CPO
Fiber turbine		
Electrical efficiency	10%	%
Fiber requirement	3.67	MJ / kg CPO

Diesel	0.00459	l / kg CPO
Water requirement	2.25	l / kg CPO
Dealing with POME		
Case: no methane avoidance	5.46	g CH4 / kg CPO

Allocation between main and by-product		
Total calorific value of products	8.76	MJ
Emissions allocated to CPO	84.37%	%