Used Cooking Oil (UCO) as biofuel feedstock in the EU

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Authors: Anouk van Grinsven, Emiel van den Toorn, Reinier van der Veen, Bettina Kampman

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Further information on this study can be obtained from the contact person Anouk van Grinsven (CE Delft)

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Content

Abbreviations

BSE	Bovine spongiform encephalopathy – mad cow disease
EC	European Commission
EU	European Union
EWABA	European Waste-to-Advanced Biofuel Association
FAME	Fatty Acid Methyl Ester
FAs	Fatty Acids
FTIR	Fourier-transform infrared spectroscopy
HVO	Hydrotreated Vegetable Oil
ICAO	International Civil Aviation Organisation
ILT	Dutch transport authority - Inspectie voor Leefomgeving en Transport
IMO	International Maritime Organisation
ISCC	International Sustainability & Carbon Certification
LIF	Laser-induced fluorescence
NMR	Nuclear Magnetic Resonance
RED	Renewable Energy Directive
PYGCMS	Pyrolysis Gas Chromatography Mass spectrometer
UCO	Used Cooking Oil
UCOME	Used Cooking Oil Methyl Ester – in this report we use the term UCOME for biodiesel based on UCO in general, which could also include HVO

Summary

Introduction to the study

The demand for Used Cooking Oil (UCO) for biodiesel production in the EU is likely to increase significantly, especially in the light of the Renewable Energy Directive II. Besides offering a means to reduce CO_2 emissions in road transport, UCO is also often mentioned as feedstock for renewable fuels for maritime shipping and aviation. Given this likely increase in demand, T&E would like to have more insight into the use, availability and origin of UCO and UCO-based biodiesel, as well as into potential risks and sustainability issues. To this end this study aims to provide a better understanding of:

- developments in demand for UCO;
- developments in the current and potential supply of UCO;
- monitoring and verification issues in relation to possible fraud.

Current UCO/UCOME consumption in EU transport

UCO can be used as feedstock for biodiesel production, which is then called UCOME[1]. UCOME consumption in the EU+UK is currently around 2.85 Mt, which accounts for 19% of total EU biodiesel consumption. However, only ten EU+UK Member States consume significant volumes of UCOME. Germany, Ireland, Hungary, Netherlands, Portugal, UK, Slovenia and Bulgaria have higher shares of UCOME. The latter two started just very recently with consuming UCO-based biodiesel.

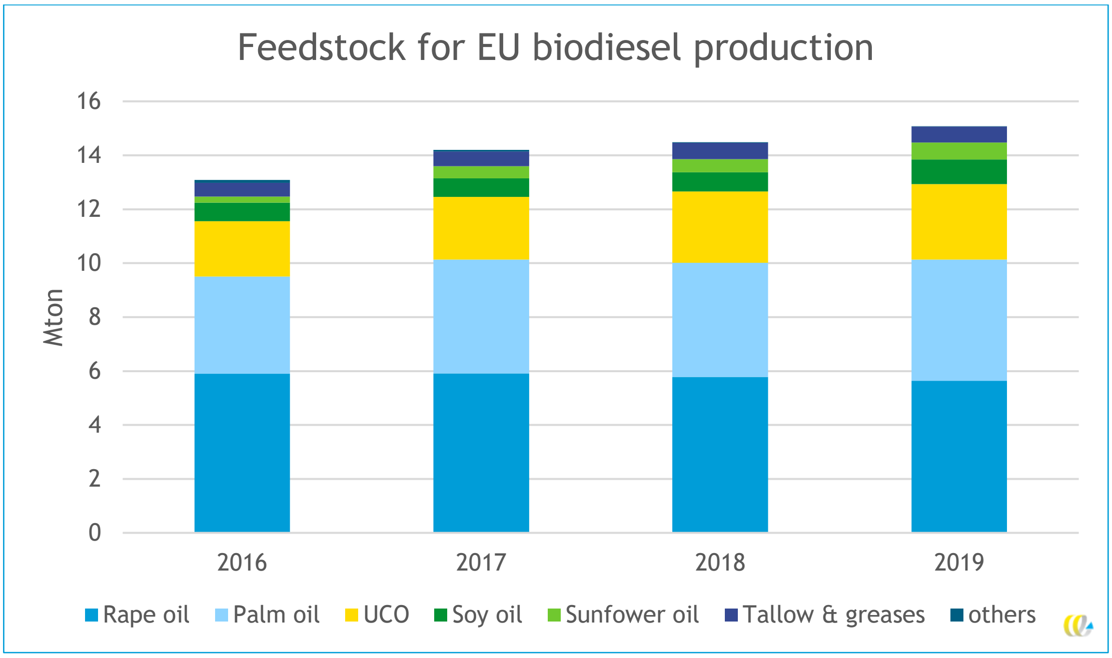
All countries that have a stable and high share of UCOME (NL, DE, HU, IE, PT, UK) have policy incentives for UCOME in place: double counting or, like Germany, another competitive advantage. Several countries have an 80% or higher share of UCOME in biodiesel consumption. Only a few Member States publish information on the origin of UCO for consumption in transport, but overall EU data shows that about half of UCO is being imported, mainly from Asia.

Current use of UCO for biodiesel production in the EU

Biodiesel production in the EU+UK is dominated by only five Member States: Germany, France, Italy, Spain and the Netherlands, and amounted to 2.8 Mton in 2019. 18.5% of the biodiesel produced in the EU is made from UCO, which is similar to the 19% share in consumption, and almost all production in the EU is produced for the European market. Figure 1 presents the development of feedstock for biodiesel produced in the EU.

[1] UCOME (Used Cooking Oil Methyl Ester) is technically only one type of UCO-based biodiesel, but we use the term for all UCO-based biodiesel in this report.

Figure 1 - Feedstock for EU biodiesel production (incl. HVO) (in Mton)



Source: (ISTA Mielke GmbH, 2020).

Since 2014, net imports of UCO to the EU+UK have significantly increased, with China, Indonesia, Malaysia, Russia, the US and Saudi Arabia as the main countries of origin. In 2018 almost half of the UCO used as biodiesel feedstock was imported from outside the EU, this increased to more than half in 2019.

Import data for UCOME are not available, but total biodiesel imports are known: 3.2 Mt net import in 2019. The main countries of origin of biodiesel imports to the EU are Argentina, China, Indonesia and Malaysia (EC, DG TRADE, 2020). The Netherlands, Spain and Belgium are responsible for 97% of the imports (UFOP, 2019). Main export destinations of biodiesel produced in the EU are Norway, Switzerland, US, and Peru. Part of this biodiesel is likely to be UCOME, but whereas statistics on feedstock of biodiesel produced in the EU are available, this is not the case for imported biodiesel.

Supply of UCO

UCO is mainly 'generated' by the food-processing industry, restaurants and other catering companies[2]. Current UCO collection in the EU+UK is estimated at 0.7–1.2 Mton/yr. Another 1.4 Mton/yr is imported.

The total UCO and UCOME potential for the EU+UK, i.e., the sum of the EU UCO supply potential and the import potential from non-EU countries, is 3.1-3.3 Mton/yr, of which 30-50% comes from outside the EU. It will require years to establish collection systems and improve collection rates to reach the global maximum potential. Collection of UCO from industry and restaurants is generally easier and less costly to perform than collection from households, because it becomes available in larger quantities at fewer locations. As a

[2] Organisations with a catering service such as hospitals and schools could also be considered to be part of this sector.

result, UCO collection from the professional sector is currently much more developed and practiced than collection from households.

Supply compared to demand

Table 1 provides an overview of our main conclusions on demand and supply of UCOME. Current EU UCO/UCOME supply and imports add up to a total supply of 2.1-2.6 Mton/year. The highest estimate of supply is somewhat lower than current EU+UK consumption of UCOME, of 2.8 Mton, which illustrates the uncertainty of the data.

Future EU+UK demand estimates show a potential strong increase in UCOME consumption to 6.1 to 6.4 Mton/year in 2030, in a scenario where UCOME achieves a 1.7% share in the transport fuel in all countries in the EU+UK in 2030 (1.7% is the maximum cap set the RED II). This can be seen as a high-demand scenario as long as the 1.7% cap remains in place. About 17-19% of this demand, 1.0-1.1 Mton, would then be used in EU aviation[3], the remainder in the other transport modes. This demand would exceed our estimate of the UCO/UCOME supply potential for the EU of 3.1-3.3 Mton/year significantly. Some literature sources arrive at a much higher potential global supply than we have used (up to 34 Mton/yr), but these did not further specify the underlying assumptions including the extent to which UCO demand for other applications was taken into account.

Table 1 - Demand and supply of UCO/UCOME, for the current situation and the potential in 2030

		Current situation (2019)	Potential for 2030
		Mton/yr	Mton/yr
Demand	EU+UK	2.8	6.1-6.4
	Global	5.12	
	Potential global demand as a transport fuel*		27-37
Supply	EU+UK (excl. imports)	0.7-1.2	1.7
	Imports to EU+UK	1.4	1.4
	Total supply EU+UK	2.1-2.6	3.1-3.3

* Assuming that in 2030 the global share of UCOME in renewable transport fuels equals that of EU (11%-15%).

Apart from this growing demand in the EU, UCO and UCOME demand from other countries and sectors worldwide is also likely to increase. To illustrate this: if the EU share of UCOME in renewable transport fuels is also achieved on a global scale in 2030, 27-37 Mton/yr UCO/UCOME would be needed. The policy developments in aviation and maritime shipping are particularly relevant here, since alternative fuels are expected to play a crucial role in achieving their climate ambitions.

Fraud risks

UCO can be sold at higher prices than virgin oil, since fuel suppliers can count UCO-based biodiesel twice for meeting their renewable energy targets in the countries that use double counting as a policy incentive. In recent years, the market prices of UCO and UCOME were significantly higher than those of virgin oil and virgin oil-based biodiesel (spot market prices of UCOME in North-West Europe were 40 to 65% higher than those of FAME, end of 2019/

[3] Defined as flights departing from the EU and domestic flights in the EU.

beginning of 2020). The double counting mechanism in combination with high market prices incentivises the use of UCOME, but it also creates an incentive for illegal practices: to 'turn virgin oil into UCO', mix virgin oil into UCO or artificially increasing the production of UCO. Research is still ongoing to develop a cheap, quick and accurate measurement method that can detect fraud in the delivery and use of UCO as a feedstock for biodiesel. In the context of this report, such research is especially relevant for the detection of UCO adulteration, i.e. adding virgin oil to UCO. A remaining question is whether the artificial treatment (additional chemical processing) of virgin oil to make it similar to UCO can be detected as well.

A high demand combined with limited supply requires strong rules and regulations, but current rules and regulations lead to a non-transparent certification process of the sustainability of UCO. Weaknesses in the certification process are also applicable to other feedstocks, but due to the higher economic value of UCO and UCOME fraud risks are more linked to this feedstock. Combining this observation with the difficulty to detect adulteration of UCO with virgin oil, it becomes apparent that risks of fraud do exist. Fraud can include:

- mixing of virgin oil and UCO;
- issuing fake proofs of sustainability;
- leaving out deliveries on mass balances, so that the mass balance looks correct on paper;
- issuing certificates twice for the same batch;
- artificial increase of the production of UCO.

Factors that contribute to the likeliness of fraud are a high UCO price, low transparency, low traceability, the opportunity for double bookkeeping and lack of verification procedures.

Improvements to prevent fraud in the future

Several improvements are announced both by the European Commission as well as the market to improve the monitoring and verification practices and to prevent future fraud cases. A large fraud case discovered in 2019 has increased the sense of urgency, and has triggered the certification scheme International Sustainability & Carbon Certification (ISCC) to revise its procedures. This case involved a Dutch company that was suspected to sell biodiesel based on virgin oil as UCOME, which had a higher market value. The European Commission is working on a central database for biofuels, while the initiative Bioledger is developing a blockchain-compliance database in cooperation with the Roundtable on Sustainable Biomaterial (RSB), certification bodies and the waste-based biodiesel sector. Individual Member States are working on improvements at the national level as well. For example, the Spanish regulator has updated the Spanish biofuels framework, obliging producers to provide digitally signed verification of the sources and quality of feedstocks and biofuels production each month, as well as annual reports (Argus, 2020b).

1 Introduction

1.1 Background

With the Renewable Energy Directive II (RED II) the EU aims to stop the growth in biofuels from food and feed crops and phase out biofuels from palm oil due to the high indirect land use change impacts. Instead, the increase in renewable energy in transport should come from advanced (bio)fuels, which may be produced from feedstocks which are listed under Annex IX of the RED II. This includes the use of waste oils and fats, including the use of used cooking oil (UCO) as listed under Annex IX B. Biodiesel production from waste oils and fats is a relatively mature and cheap technology compared to biodiesel production from feedstocks listed under Annex IX A of the RED II. These also require the set-up of new production facilities, while UCO can be processed in current FAME and HVO production facilities[4].

The contribution from Annex IX B feedstocks to the renewable energy target in transport is limited to 1.7% of total energy consumption in transport (RED II Art. 27.1(b)) (although national governments can deviate from this cap if they get permission from the European Commission). Also, biofuels from these feedstocks may be counted twice towards the renewable energy in transport target (Art 27(2(a)). Besides the opportunities of used cooking oil as a biofuel feedstock, there are also concerns about potential drawbacks due to the limited sustainable availability of UCO, and possible fraud. As UCO is becoming more popular, these concerns are becoming increasingly important.

T&E would like to have more insight into the use, availability and origin of UCO as well as into potential risks and sustainability issues related to the increased use of UCO for biofuels and has therefore commissioned this study.

1.2 Objective

The main aim of this study is to provide an overview of the sustainability issues and risks related to the increasing use of UCO. To this end this study aims to provide a better understanding of:
- developments in demand for UCO;
- developments in the current and potential supply of UCO;
- monitoring and verification issues in relation to possible fraud.

1.3 Methodology and scope

This study is based on desktop research and statistical analysis of data sources. Where necessary stakeholders have been contacted.

The scope of this study covers three dimensions: the value chain (from feedstock to application), geography and the time frame. These three elements constitute the framework in which the research questions are assessed.

[4] FAME = Fatty Acid Methyl Esters, HVO = Hydrotreated Vegetable Oil. Both are types of biodiesel.

Feedstocks/production chains

The production process of biofuel from UCO is similar to that of biofuel from virgin (plant) oil, with some simple additional steps. In this study, we will consider UCO (and other animal fats) from the moment they acquire the status of used product until their application in the EU or their potential application elsewhere.

The focus regarding application of UCO will be on feedstock for transport fuel, but other applications that might compete for its use, like animal feed, will be discussed briefly as well.

Within this report we use the term UCOME for UCO-based biodiesel. Although this is technically UCO-based FAME (UCOME is an abbreviation for Used Cooking Oil Methyl Ester), we use it for all UCO-based biodiesel, including both FAME and HVO. Worldwide HVO production (from all feedstocks) is about 11% of total biodiesel production, with almost 3 Mt annual HVO production in the EU. Next to the EU, Singapore is a major consumer of HVO, with 1.8 Mt (UFOP, 2019). Overall, FAME currently dominates biodiesel production and consumption and consequently import and export as well.

Geographical scope

The geographical scope of this report Is focussed on the EU27 plus the UK. At this moment in time most EU data sources still include the United Kingdom. Other countries and parts of the world are considered only where the role of non-EU countries in import and potential future demand is discussed.

Time frame

This study focuses on the current situation (in most instances the most recent data was 2018) and the expected supply and demand in 2030.

1.4 Content of this report

The structure of the report is as follows:
- First of all, Chapter 2 describes the demand for UCO and UCOME in the EU.
- Chapter 3 focusses on the supply of UCO and especially on the collection of UCO within the EU.
- Chapter 4 then compares the outcomes of Chapters 2 and 3, i.e. demand and supply of UCO and UCOME. This chapter also discusses potential displacement effects that can result from increasing demand.
- In Chapter 5 current risks associated with monitoring and verification and a number of fraud cases are described.
- Finally, Chapter 6 provides an overview of the main conclusions.

2 Demand for UCO and UCOME

2.1 Introduction

In the EU, 80% of renewable energy in transport consists of biofuels and almost 90% of this is biodiesel.[5] Biodiesel can be derived from a range of products, including food and feed crops, animal fat and UCO. This section describes the current and estimated future demand of UCO in the transport sector and other sectors.

First, an overview of various applications of UCO is presented in Section 2.2. Secondly, a quantitative overview of current UCOME consumption will be given in Section 2.3. This will be done at global level, EU level and where possible at Member State level. We will describe biodiesel production and the origin of feedstocks for biodiesel production. However, not all Member States have information available on the origin of UCO at the level of final consumption.

After an overview of consumption and production, estimates for future use of UCO and relevant trends are described in Section 2.4, taking into account the new provisions of the RED II and growing demand which can be expected from aviation and maritime shipping.

This chapter ends with a summary of conclusions in Section 2.5.

Concerning the data

Data used in this chapter have several origins, which do not as a rule exactly correspond with each other, mainly due to differences in scope. First, there is the important distinction between production and consumption. Oil World (by ISTA Mielke GmbH), F.O. Licht (as quoted in UFOP annual report) and EU Biofuels Annual give mainly data for production. SHARES (Eurostat) and national reports (mostly) provide data for consumption. We aim to use the more recent data, but had to use some older sources where recent data were not available. Secondly, whereas sources sometimes refer to the same category and year, data does not necessary reflect the exact same values, but show small differences. This might be caused by different information (reporting formats) or calculations, for example due to small differences in conversion rates. Where possible we have tried to align the data sources used to the data sources used in any other publications of T&E on this matter.

2.2 UCO is used for various applications

UCO is a valuable feedstock for various applications. UCO is often referred to as waste, but this depends on the definition of waste. For example, UCO is already being reused as animal feed in some countries.

The focus of this report is the use of UCO in the production of biodiesel. However, due to its fatty acid content, and despite being a waste product, UCO also contains valuable components for other applications while being cheaper than virgin oil. Next to biodiesel,

5 The European Union Member States Main Energy and Climate Indicators

UCO is mainly used for animal feed (outside the EU) and as raw material for several chemical processes.

Animal feed

The nutritious ingredients of UCO make it a possible element of animal feed. However, since UCO in unprocessed form contains harmful components and because it has been in contact with food, very strict safety criteria need to be fulfilled when it relates back to the human food chain. The BSE crisis of the 1990's[6], that was caused by a similar cycle of products, was the direct motive to ban UCO as a component for animal feed in the EU. In many countries outside the EU, such as China and the USA, these safety measures are not in place and is UCO still a common component for animal feed.

Although cheaper than virgin oil and widely used, UCO is not a crucial nor the main component of animal feed. Other by-products from the vegetable oil industry like oil cakes and meals that result from oil pressing and are not contaminated with food products are much more essential. Furthermore, even though by-products are used as animal feed, it mainly consist of primary agricultural products such as corn, sorghum, barley, etc.

Food industry

According to Ecofys (2013a), 90% of UCO that is collected in China is illegally re-used in the food industry. In Indonesia, gutter oil is commonplace as well. It poses direct health risks and is therefore banned in all countries.

Use in the oleochemical industry and heat and energy generation

UCO can also be used for chemical and biological processes. It can for example be processed to obtain pyrolytic oil, as a source of energy to produce hydrogen gas. It can also be chemically transformed to bio lubricants, graces, resins, and biodegradable polymers (Panadare & Rathod, 2015).

Furthermore, UCO can be easily transformed into soap by saponification and it can also be burned directly for energy generation. However, due to the diverse and often low quality of UCO, the chemical industry gives preference to products of higher standards, like animal fats. Also, some food-processing companies use their UCO as a feedstock in their anaerobic digestors (along with other biological waste streams) to produce biogas (Ecofys, 2013a).

In the EU, the oleochemical industry uses 70.000 ton UCO annually. The industry has raised concerns that the increasing demand from the transport sector will result in replacement by palm oil (Ecofys, 2013b).

[6] BSE is commonly known as mad cow disease, see https://en.wikipedia.org/wiki/Bovine_spongiform_encephalopathy

UCOME as dominant application

While different applications are technically possible, biodiesel (i.e. UCOME) is projected to remain the dominant application for UCO (Allied Market Research, 2020). This is mainly due to the fact that conversion to biodiesel is stimulated by policy and hence represents the best economic option.

There is to date no extensive literature on the exact land use and food price effects of the application of UCOME (Delzeit, et al., 2019). We describe potential displacement effects in Section 4.3.

2.3 Current UCOME consumption

Driven by the policy incentives for UCOME, UCO has become an important feedstock for biodiesel. It needs to be purified and can then either be turned into FAME or HVO, following the same production route as virgin oil. At the moment, FAME is by far the largest output, mainly due to lower production costs than HVO. The next paragraphs describe current UCO-based biodiesel consumption worldwide and in the EU.

2.3.1 Worldwide biofuel mandates and UCOME share

In North- and South America, Europe and Asia, policies are aimed at increasing the share of renewable energy in final energy consumption of the transport sector. These often consist of renewable energy or biofuel mandates imposed on fuel suppliers delivering fuels to national markets, and these mandates and renewable energy targets are mostly met by biofuels until now.

Many countries have general biofuel targets, but since UCO is almost exclusively used for biodiesel, we provide in Table 2 an overview of specific biodiesel mandates outside the EU. On average, mandates vary between 2-10% with some higher mandates being applied in Malaysia and Indonesia, where large amounts of palm oil are being produced. One can conclude from this overview that biodiesel use in transport is driven by demand policies in many of the most important transport regions in the world. Note that these mandates reflect the targets, the table does not imply those shares have been realised in practice.

Table 2 – Biodiesel blending mandates around the world (non-EU countries only)

Country	Biodiesel blend	Country	Biodiesel blend
Argentine	10%	Norway	5%
Brazil	10%	Ukraine	2.7%
Canada	4%	Australia	0,5%
Chili	5%	India	5%
Colombia	2-9%	Indonesia	20%
Ecuador	10%	Malaysia	15%
Peru	2%	Philippines	2%
Uruguay	6%	South Korea	2.5%
USA	5%	Taiwan	2%

Source: (Biofuels Digest, 2019).

Table 3 gives an overview of renewable energy mandates for transport for EU Member States.

Table 3 - Renewable energy mandates for diesel in the EU+UK in 2020 (GAIN, 2020b)

Member State	Renewable energy mandate (% of transport fuel*)	Unit	Member State	Renewable energy mandate (% of transport fuel*)	Unit
Austria	6.3	Cal	Italy	9 (all)	Cal
Belgium	9.55	Cal	Latvia		
Bulgaria	1 (second generation)	Vol	Lithuania		
Cyprus			Luxembourg		
Czech Republic	6	Vol	Malta		
Denmark	5.75 (all)	Cal	Netherlands	16.4 (all)	Cal
Estonia			Poland	8.5-9.1 (all)	Cal
Finland	20	Cal	Portugal	10 (all)	Cal
France	8		Romania	6.5	Cal
Germany	6	GHG savings	Slovakia	7.6-8.2 (all)	Cal
Greece	7	Cal	Slovenia	7.5 (all)	Cal
Croatia	7.49	Cal	Spain	8.5 (all)	
Hungary	8.2	Cal	Sweden	19.2	GHG savings
Ireland	11 (all)	Vol	United Kingdom	10.637	Cal

* The scope of the denominator is defined in the RED.
Data is for diesel mandate if a county has a separate renewable energy target for diesel. In other cases, the general target for transport fuel is provided. This is indicated by (all).
Cal = energy content.
Vol = volume based.

Worldwide, UCO is a relatively minor feedstock for biodiesel (FAME/HVO). In 2019, UCOME made up 5.12 Mt of the 45.69 Mt biodiesel produced worldwide (ISTA Mielke GmbH, 2020). The most important feedstocks are various types of virgin oil: palm oil (38.5%, 2019), soy oil (25%, 2019) and rapeseed (14%, 2019, of which 85% EU). UCO accounts for 11% of global biodiesel consumption in 2019, mainly due to the US and EU. UCO is only in the EU — where 40% of global biodiesel is consumed — and in the US a considerable, at least 10% of total, feedstock for biodiesel (UFOP, 2019).

2.3.2 UCOME consumption per EU Member State

Member states enjoy a certain freedom regarding the implementation of the RED and RED II, and hence, there are differences in national regulations regarding biofuels in general and UCOME in particular. For example, not all Member States have chosen to implement the double counting provision for biofuels from waste streams or even have specific mandates.

Table 4 presents an overview of energy consumption in transport, the share of diesel and biodiesel in the total consumption, as well as the share of UCOME (all expressed in energy content), in 2018. In the EU+UK, UCO as feedstock of biodiesel consumed amounts to 19% (around 2.85 Mt). Data for biodiesel consumption is from 2018. The data is based on what Member States report in SHARES (Eurostat, 2020). Note that the amount of UCOME is the physical amount (before double counting).

Table 4 - Energy and biodiesel consumption in the EU+UK (without double counting)

	Energy consumption transport*	Share of diesel in total energy consumption	Share of biodiesel in total energy consumption	UCOME as part of biodiesel	UCOME as part of energy consumption in transport
Unit	TJ	% of TJ	% of TJ	% of TJ	% of TJ
Year	2018	2018	2018	2018	2018
Data source	Eurostat	Shares	Shares	Shares	Shares
EU27+UK	**13,757,434**	**64**	**3.9**	**19**	**0.8**
Belgium	372,790	74	4.1	3	0.1
Bulgaria	141,187	61	4.0	31	1.3
Czech	278,836	66	3.7	0	0
Denmark	185,162	62	3.9	0	0
Germany	2,332,837	60	3.4	41	1.4
Estonia	34,826	64	1.5	0	0
Ireland	171,878	75	3.1	83	2.6
Greece	247,183	43	2.7	9	0.3
Spain	1,362,009	69	4.6	0	0
France	1,897,061	70	5.6	5	0.3
Croatia	89,616	69	1.2	1	0
Italy	1,489,642	61	3.4	11	0.4
Cyprus	28,406	45	1.3	100	1.3
Latvia	46,420	75	2.6	0	0
Lithuania	87,148	78	3.4	0	0
Luxembourg	87,986	79	5.4	1	0.1
Hungary	201,393	62	3.0	65	1.9
Malta	9,662	61	4.2	94	3.9
Netherlands	453,506	54	3.1	83	2.5
Austria	367,618	71	4.1	1	0
Poland	938,458	64	3.3	0	0
Portugal	245,319	71	4.3	64	2.8
Romania	263,925	71	3.2	0	0
Slovenia	82,271	73	3.4	30	1.0
Slovakia	114,888	67	4.8	0	0
Finland	177,582	57	6.6	0	0
Sweden	299,197	44	12.4	1	0.2
United Kingdom	1,750,630	64	2.2	80	1.7

* Energy consumption in transport covers road transport (cars, buses, trucks, etc.), rail transport (trains, metro, trams, etc.), domestic aviation, domestic navigation and pipeline transport.

Diesel is by far the most important fuel used in transport in the EU. An average of 64% of all energy consumed in transport is derived from diesel (see the note under the table for the scope of 'transport' used here). Only Greece, Cyprus and Sweden obtain less than half of all energy in transport from diesel. The highest share of 79% is reached in Luxemburg, where the lower fuel prices have made the country a popular refuelling location for transit road freight.

The table also shows that biodiesel as a share of total energy consumption in transport is in most Member States close to the EU+UK average of 3.9%, with only Sweden having a far higher number. Estonia, Croatia and Cyprus have the lowest share, but also the UK is below average.

The consumption of biodiesel made from UCO gives a much more distinct picture. Although UCOME counts for 19% of total EU biodiesel consumption, only ten Member States consume significant volumes of UCOME. The highest shares of UCOME as part of biodiesel are attained in Cyprus and Malta, the only countries without a 1.7% cap due to their island status, which entails limitations on possibilities to decarbonise. The other countries that are important in terms of relative share of UCOME consumption are Germany, Ireland, Hungary, Netherlands, Portugal, UK, Slovenia and Bulgaria. The latter two started just very recently with consuming UCOME. Considering the shares of UCOME as part of energy consumption in transport, we see that currently the consumption of UCOME is higher than the 1.7% cap in Ireland, Netherlands, Hungary, Malta and Portugal.

It is noteworthy that several countries that introduced double counting have a very low or even absent consumption of UCOME. However, all countries that have a stable and exceptionally high share of UCOME (NL, DE, HU, IE, PT, UK) have double counting (or, like Germany, another competitive advantage[7]) for UCO specifically.

2.3.3 Biodiesel production in the EU+UK

Table 5 gives an overview of how UCO as feedstock for biodiesel production evolved in the EU+UK.

Table 5 - UCO feedstock for biodiesel production in the EU (in million tons)

	2016	2017	2018	2019
UCO (Mton)	2.05	2.33	2.64	2.8
TJ*	75,850	86,210	97,680	103,600

Source: (ISTA Mielke GmbH, 2020).

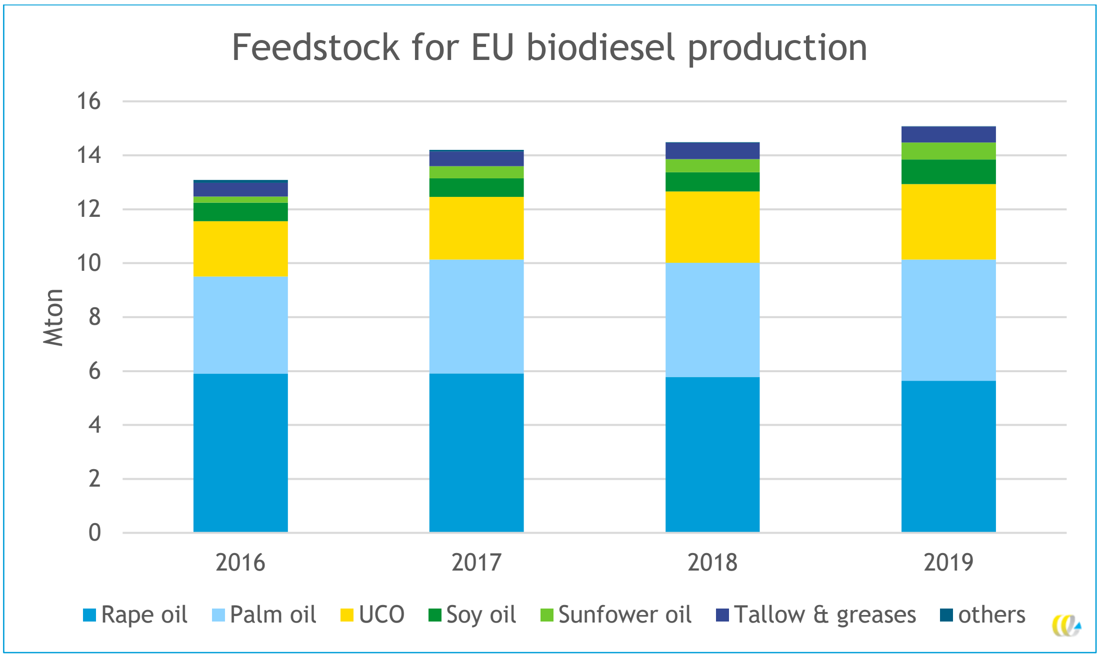
* Lower Heating Value (LHV) of waste cooking oil is 37 MJ/kg (Edwards, et al., 2017).

UCO is the third most used feedstock in the EU+UK for the production of biodiesel, at 18.5% of total feedstock, after rapeseed oil (37%, 2019) and palm oil (30%, 2019).[8] Figure 2 presents the development of feedstock for biodiesel produced in the EU. One can see the steady increase of both UCO and palm oil.

[7] Germany does not have a double counting provision, but rewards fuels that are put on the market according to their GHG-savings laid down in the FQD (which is one of the highest for UCOME).

[8] The EU biofuels annual, produced by the US government gives different data. Palm oil as feedstock is lowered to 2.64 Mt, and therefore superseded by UCO, which is at 2.75 Mt. Rape oil is still ahead but with 5 Mt in 2019. (GAIN, 2019)

Figure 2 - Feedstock for EU+UK biodiesel production (incl. HVO) (in Mton)



Source: (ISTA Mielke GmbH, 2020).

As presented in Figure 2, EU+UK biodiesel production amounted to over 15 Mton in 2019. The growth of biodiesel production in recent years is largely based on the increase of UCO and palm oil as feedstock.

The EU+UK is mainly a consumer market for biodiesel and practically all biodiesel produced is also consumed within the Union. Yet, within the EU, biodiesel is imported and exported and therefore many countries have differences in consumption and production.

Biodiesel production capacity

There are 188 refineries to produce biodiesel in the EU+UK and 14 to produce HVO. The total capacity of biodiesel production amounts to 21,230 million litres (704,206 TJ) and for HVO to 5,000 million litres (163,292 TJ). For both products, there is currently quite a lot of free capacity. Biodiesel refineries are working at a 53% capacity and the HVO refineries at 60% (both 2019). HVO refineries were in previous years running on around 80% capacity[9], biodiesel refineries have never been above 62% (GAIN, 2019).

2.3.4 Biodiesel production per Member State compared to consumption

While biodiesel consumption shares are within the same range throughout the EU+UK, biodiesel production is dominated by only five Member States: Germany, France, Italy, Spain and the Netherlands.

Table 6 lists the main producing countries for both biodiesel and UCOME, together with the consumption data of these countries. This illustrates that the producer countries have all high consumption shares. Second, one can see that the shares of UCO in biodiesel consumed

[9] GAIN (2019) does not give an explanation of the observed decrease in the capacity factor of the HVO refineries.

are for all countries higher than the share in biodiesel produced, with the exception of Spain and France. Thirdly, the last column of the table shows the crucial role of UCO imported from Asia for many of these countries. Also notable is that the Netherlands produces almost five times as much biodiesel as it consumes.

Table 6 - UCO in production and consumption of biodiesel in 2018

	Biodiesel produced (TJ)	% UCO in biodiesel produced	Biodiesel consumed (TJ)	% UCO in biodiesel consumed	% UCO from Asia as part of UCO in biodiesel (consumed)
Source	OW/UFOP/GAIN	OW/UFOP	SHARES	SHARES	National reports
Germany	112,111	27	80,237	41	58*
Netherlands	61,050	7	13,900	83	55
UK	15,540	n/a	37,668	80	32
Ireland, 2019	521	62.5	5,319	83	48
Italy	40,700	7**	50,957	11	
Spain	83,990	6	62,220	0	0
France	71,410	24	107,016	5	30
Portugal	11,470	60	10,575	64	10
Hungary	< 7,400***		6,000	65	
Bulgaria	<14,800***		5,654	31	
Slovenia	0	0	2,762	30	

Source: (Oireachtas, 2018; NORA, 2020; UFOP, 2019; GAIN, 2020a; Eurostat, 2020; ISTA Mielke GmbH, 2020).

* 2017.

** Only nationally collected.

*** Based on maximum capacity.

The LHV of UCO is 37 MJ/kg (Edwards, et al., 2017).

The density of UCO is 0.91 kg/litre (EUBIA, 2020).

Germany

In Germany, 41% of biodiesel consumed is derived from UCO, whereas 27% of the feedstock of biodiesel that is produced in Germany is based on UCO (UFOP, 2019). Germany imported around 0.5 Mton of UCO (18,500 TJ) as biodiesel feedstock in 2018, that is over half of total UCO feedstock (0.86 Mt, 31,820 TJ).

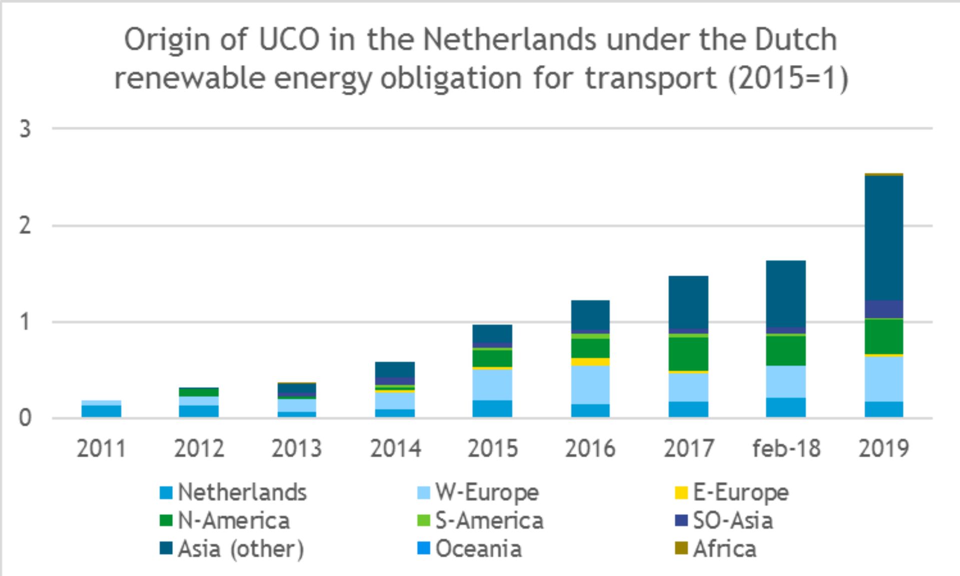
Netherlands

Although the Netherlands is a major biodiesel producer, UCO only has a relatively small share in the feedstock for the biodiesel produced in the country. In contrast, more than 80% of the biodiesel consumed in the Netherlands is UCOME (NEa, 2020). The Netherlands is the biggest net exporter of biodiesel within the EU (based on the difference between production and consumption in Table 6).

Figure 3 shows the origin and growth of UCOME in biofuel consumption relative to index year 2015. The figure demonstrates a steady increase, especially of UCO imported from Asia while supply of UCO from the national market stays stable. Asia is responsible for around half of UCO imported (China, Malaysia, Indonesia, Taiwan, Saudi Arabia). China (35%) and the US (14%) are the two individual most important suppliers of UCO for the Dutch biofuel market.

It should be noted that these data may not be accurate, as the Dutch Human Environment and Transport Inspectorate (part of the Dutch Ministry of Infrastructure and Water Management) recently discovered large-scale fraud with UCOME: biodiesel from other feedstock was sold as UCOME and certificates were falsified[10]. See also Section 5.5.

Figure 3 – Origin and relative growth of UCO in biofuel consumption in the Netherlands, indexed at 2015



Source: (NEa, 2020).
Note: UCO consumption in transport in the Netherlands in 2015 was about 6,800 TJ, or 0.18 Mton (calculation based on Eurostat (2018)).

Ireland

Although Ireland's share of biodiesel is below the EU average, the country has one of the highest shares of UCOME in biodiesel consumed. The country is a minor biodiesel producer (only one facility with a capacity of 34 million litres), and hence is a big importer of UCOME produced in other EU Member States. Almost half of all biodiesel consumed in Ireland is produced from UCO imported from Asia (with UCOME projection in the EU) (NORA, 2020).

Spain

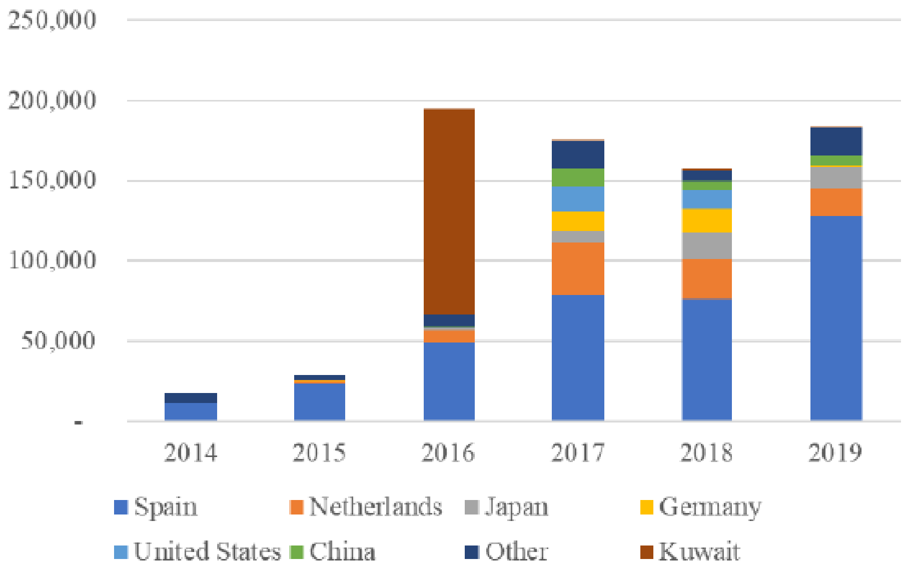
Spain is after Germany the largest producer of biodiesel, but all biodiesel sourced from UCO (at least 180,000 ton) was exported, due to double counting in other countries and lack thereof in Spain (Energías Renovables, 2019). Data on feedstocks used for consumption show that Spain does not consume biodiesel from UCO, but that the country strongly relies on palm oil.

[10] https://www.ilent.nl/actueel/nieuws/2020/11/03/biodiesel (in Dutch).

Portugal

Since 2015, UCOME has increased its share in consumed biodiesel in Portugal to over 60% in 2019. Although the share in imported UCO from Asia is limited (Figure 4), there are probably large imports to Portugal that enter the EU through Spain (GAIN, 2020a).

Figure 4 - UCO import by origin in Portugal in MT (Portugal biofuels policy and market)



Source: (GAIN, 2020a).

2.3.5 Imports and exports

Import and export of biodiesel

In addition to the EU-produced biodiesel, the EU also imports around 3 Mton refined biodiesel. Exports from the EU are relatively small, as is shown in Table 7.

Table 7 - EU+UK imports and exports of biodiesel in Mton

	2017	2018	2019
Total imports	1.17	3.33	3.20
Total exports	0.33	0.57	0.68
Net imports	0.85	2.76	2.52

Source: (EC, DG TRADE, 2020)[11].

The main origin countries of imports to the EU are Argentina, China, Indonesia and Malaysia (EC, DG TRADE, 2020). The Netherlands, Spain and Belgium are responsible for 97% of the imports (UFOP, 2019). Main export destinations of EU-produced biodiesel are Norway,

[11] Biodiesel is defined as "Biodiesel and mixtures thereof, not containing or containing less than 70% by weight of petroleum oils or oils obtained from bituminous minerals" (EC, DG TRADE, 2020).

Switzerland, US and Peru. Whereas statistics on feedstock of EU produced biodiesel are available, this is not the case for imported biodiesel.

Combining information from both tables, we can conclude that biodiesel consumed in the EU was around 17.6 Mton in 2019 (15.08 + 2.52).

UCO imports to the EU

Since 2014, net imports of UCO to the EU have significantly increased, with China, Indonesia, Malaysia, Russia, the US and Saudi Arabia as the main exporters to the EU. Table 8 shows the imports of UCO to the EU over the last three years. It is estimated that the rest of UCO that is consumed (around one third) is collected from recycling points, restaurants and other users in the EU.[12] If these data are compared with feedstock used for production, we can conclude that in 2018 almost half and in 2019 more than half of the UCO used as biodiesel feedstock was imported from outside the EU.

Table 8 - Import of UCO to the EU+UK in Mton

	2015	2016	2017	2018	2019
UCO - 15180095 (Inedible mixtures or preparations of animal or of animal and vegetable fats and oils and their fractions)	0.44	0.76	0.96	1.22	1.41

Source: (EC, DG TRADE, 2020).

2.4 Projected future consumption of UCOME

2.4.1 RED II

In order to address the period after 2020, the Commission adopted the RED recast in 2018 (2018/2001/EU). Member States need to transpose the directive into national regulations by June 2021. In the next paragraphs, we reflect on the potential future consumption of UCO in relation to the RED II.

Targets and caps

The RED II aims to further increase the share of renewable energy in transport by 2030.The Directive aims to stimulate advanced biofuels and limit the growth in biofuels from food and feed crops. To this end, the RED II makes use of a sub target and various caps, which include:

- **A sub target for advanced biofuels** produced from the list of feedstocks given in Annex IXa, which are feedstocks from waste and residues, but also lignocellulosic energy crops. The target is set at at least 0.2% in 2022, at least 1% in 2025 and at least 3.5% in 2030.
- A **cap on the contribution to the targets by biofuels from food and feed crops** set at a Member States' 2020 contribution for these biofuels. The Directive allows a maximum 1% higher contribution, or a 7% contribution in case the 2020 contribution exceeds the 7%.
- A **cap and progressive phase out of the contribution to the targets by high indirect land use change biofuels** (at the moment palm oil is classified as such). The

[12] Cf. NNFCC, (2019).

contribution should not exceed the contribution in a Member State in 2019 (unless certified as low-ILUC risk fuel). The limit will decrease from 2023 to a zero contribution in 2030.
- A **cap on the contribution to the targets by biofuels produced from feedstock listed in Part** B of Annex IX (waste cooking oils (UCO) and animal fats) of 1.7% (except for Malta and Cyprus). Member States are allowed to modify this limit when taking into account feedstock availability and after approval by the Commission (EU, 2018b). The cap has been introduced for various reasons and is linked to limited availability, fraud risks, but also aims to boost the use of Annex IX A feedstocks rather than Annex IX B, which are more mature compared to the less developed Annex IX A production pathways.
- Member States may count fuels from Annex IX (both A and B) at twice their energy content, often referred to as **double counting**. The option to actually implement double counting for the feedstock of Annex IX is up to Member States. This double counting only applies to the renewable energy in transport target, not to the overall renewable energy target of the RED II.

In practice, the RED II ensures that fuel suppliers are obliged by national policies to supply a share of renewable fuels within the fuels they bring on the market and that share increases over time. Biofuels also have to meet sustainability criteria to count towards the target.

National targets

With respect to the level of ambition of the RED II it should also be mentioned that some Member States have higher national targets for decarbonisation of transport and the use of renewable energy in transport, specifically, than the RED II. Examples of those Member States are: France, Germany, the Netherlands, Sweden, Finland, Portugal and Luxembourg. These targets are mostly the outcomes of national policy developments aimed at staying on track to meet national climate targets and the Paris Agreement.

Some Member States also asked for a higher EU climate ambition in line with the Paris Agreement (Finnish Government, 2018). The EU Green Deal includes this higher ambition (55% in 2030). Based on the recently released Climate Target Plan of the European Commission (EC, 2020c), it is likely the RED II transport target and RED II in general will be revised. Without judging to what extent those higher targets will result in sustainable practices, both the EU Green Deal and higher national targets above the level of the RED II are likely to result in a higher demand for UCOME. Of course, to what extent this will be the case depends on specific policy decisions being made.

Implications of the phase-out of high-ILUC palm oil

In March 2019, the EU adopted a delegated act that defines palm oil as a high-ILUC risk and thus unsustainable feedstock. As a result of this definition consumption of biofuels based on palm oil should be frozen at 2019 consumption levels until 2023 and gradually phased out of the targets by 2030. Member States can set more stringent requirements for the phase-out, and some Member States indeed plan to accelerate the phase-out of palm oil. Currently, and especially in relation to the use of UCO, the question is what consequences the phase-out of high-ILUC palm oil will have, in terms of what feedstock will be used to replace it.

The following options for this phase-out can be identified:
- a shift to other food-based feedstocks under the food and feed biofuels cap (capped at 2020 consumption level in each EU country, with a maximum of 7%);

- a shift to low-ILUC certified biofuels (this could also be palm oil);
- a shift to UCO;
- a shift to advanced biofuels produced from feedstocks listed under Annex IX A.
- a shift to other renewable energy sources, such as renewable electricity.

Phasing out of palm oil, which is the cheapest feedstock, might lead to a shift to non-EU soybean oil, since those costs to produce biodiesel are also relatively low (JOANNEUM RESEARCH, et al., 2016). Without specific stimulation (like double counting), UCO might not necessarily be the next best option after palm oil due to its higher prices. Whether or not this will boost consumption of advanced biofuels strongly depends on developments in production facilities, both technologically and in terms of cost. In general advanced biofuels to replace diesel are less developed than advanced biofuels to replace petrol.

Overall, future demand for UCOME in 2030 will strongly depend on the national implementations of the RED II. Besides the RED II, demand for UCOME will also be the result of the decarbonisation of international transport modes, which will be described in the next sections.

2.4.2 Maritime shipping

The International Maritime Organization (IMO)

The IMO has adopted an Initial IMO Strategy on reduction of GHG emissions from ships, which sets the goal to reduce emissions by at least 50% in 2050 compared to 2008, but no specific targets for biodiesel are included. Various options are being discussed to decarbonise maritime shipping (LNG, hydrogen, ammonia, methanol and different biofuels and e-fuels). Until now, biofuels have mainly been used in pilots, so that significant use on a commercial scale is lacking and currently limited to 0.1% of final energy consumption. There is no consensus yet among stakeholders to what extent biofuels are seen as a large-scale decarbonisation option for maritime shipping.

Examples of current initiatives

Various companies have carried out pilots using renewable diesel partly produced from UCO. Since 2013, the ferries of Washington State Ferries have run on biodiesel from soy, animal fats and cooking oils (IEA Bioenergy, 2017). In 2017, fuel supplier GoodFuels started up the GoodShipping Program, which provides renewable fuel to maritime ships. The container ship 'Samskip Endeavor', has run partly on HVO made from UCO in 2018, using the GoodShipping Program (Bioenergy International, 2018). Container ship Mette Maersk has sailed on a fuel blend with 20% biofuel made from UCO in a roundtrip between Rotterdam and Shanghai in 2019, which was reported to be the first time a blend percentage of this level was used in a container vessel on this scale (Bioenergy International, 2019).

FuelEU Maritime Initiative

The 2020 Commission Work Programme included a concrete initiative to accelerate the achievement of low-emission, climate neutral shipping: the FuelEU Maritime initiative. This initiative aims to increase the use of sustainable alternative fuels in European shipping and ports by addressing market barriers and the uncertainty about the market readiness of technical options. The initiative should bring the sector in line with the EU ambition to become climate neutral by 2050 (EC, 2020). With respect to EU policies on maritime shipping, the question is to what extent the Renewable Energy Directive provisions will be followed as well. For example, from a perspective of coherence, it might be unlikely to allow a far larger increase of the use of UCOME in shipping compared to the cap in the RED II, but this still needs to be decided on in the coming years.

2.4.3 Aviation

It is currently cheaper and more profitable to produce road biofuels than aviation biofuels (NNFCC, 2018). This is partly linked to the configurations of refineries, but also to the higher quality and safety levels demanded by aviation. However, from a policy perspective, aviation currently does not have many other options to decarbonise, contrary to maritime and road transport. E-fuels are a decarbonisation option as well, but these are at an early stage of development and are therefore not expected to play a major role in aviation fuel demand before 2030[13].

International Civil Aviation Organization (ICAO)

Sustainable fuels are an important aspect of the aim of the aviation sector to reduce emissions. Sustainable aviation fuels can be obtained from different waste and biomass feedstocks and through different pathways. UCO is prominently mentioned as a sustainable feedstock by ICAO in CORSIA, which is the main global emission reduction/offsetting scheme in aviation. UCO is also the main feedstock currently used, although sustainable fuels only make up 0.05% of all fuels consumed in EU aviation.

ICAO has set the goal to keep net CO_2 emissions stable from 2020 onwards, despite the expected growth until 2050. Alternative fuels play a crucial role in this scenario. Blending is currently restricted to a maximum of 10 to 50% and is commercially not mature (IEA, 2020b).

National initiatives

France and Spain have announced to make blending of biokerosine mandatory from 2025, at 2% in 2025 and at 5% in 2030. In the Netherlands new targets for sustainable aviation fuels adoption at a level of 14% by 2030 are tied to the COVID-19 support package presented to Air France-KLM (IEA, 2020b). The level of ambition has already been part of many discussions before COVID with an active role for the Dutch aviation sector itself.

Examples of market initiatives

In 2015, Hainan Airlines carried 156 passengers from Beijing to Chicago using jet fuel blended with UCO-based sustainable aviation fuel (SAF). The blend contained 15% UCO-based fuel, originating from Zhennan Refining and Chemical, based in eastern China (Quartz, 2017). Since then, several other airline companies have initiated blending low percentages of SAF (partly) made from UCO with fossil aviation fuel, or have plans to do so. In July 2020, San Francisco International Airport announced major airlines will soon be able to use SAF made from waste and residue streams such as UCO. This SAF will be produced by Neste (Energy Live News, 2020). SAF supplier SkyNRG delivers SAF that is produced using UCO as main feedstock. In November 2019, SkyNRG and Shell announced their plan to build a SAF production plant in Delfzijl, the Netherlands, which is due to open in 2022. The

[13] *T&E, 2020, Legislating for aviation alternative fuels* projects that a share for efuels in aviation of 1%-2% would be feasible by 2030, with the possibility to be increased under the right conditions.

feedstocks will be waste and residue materials such as UCO. According to the companies, this will be the first dedicated SAF plant in Europe (SkyNRG, 2019).

ReFuelEU Aviation

As part of the 2050 climate neutrality agenda, the European Commission is currently working on a new legislative initiative called ReFuelEU Aviation, which is expected by the end of 2020 (EC, 2020b). The regulation will aim to boost supply and demand for sustainable aviation fuels in the EU. Without any additional policy intervention, the uptake of SAF is projected to increase only to about 2.8% by 2050, which is insufficient to curb emissions from aviation. The demand for UCO from this sector will partly be determined by the extent to which policy instruments will allow UCO to be applied, as is also in the case for maritime shipping.

2.4.4 Demand projection for 2030

Based on the Impact Assessment of the recently published Climate Target Plan (EC, 2020), the future development of demand for UCO in the EU can be estimated. The Impact Assessment includes EU-wide results for various scenarios, on total energy use in transport and on the share of alternative fuels in transport, see Figure 5 and Figure 6. From these data, we can derive projections for the total transport fuel consumption in 2030. These vary from 318 to 330 Mtoe, where the high value represents the existing 2030 framework scenario (baseline scenario). Demand for liquid biofuels in the EU in 2030 amounts to about 16.8 to 22.9 Mtoe, depending on the scenario, where the lower value corresponds to the baseline scenario.

The assessments do not provide details on the types of biofuels or the transport modes in which where they are used, but we can estimate the implications for EU-wide UCOME demand in 2030 for the case that consumption of UCOME is 1.7% in all countries – i.e. the cap for Annex IX B biofuels is fully met by UCOME, in all countries. This includes fuel demand for intra EU aviation and navigation, and different scenarios reflect different ambition levels of the ReFuel EU aviation and FuelEU maritime initiatives[14]. Total UCOME demand then amounts to 6.1 to 6.4 Mton (5.4 to 5.6 Mtoe), depending on the scenario. We estimate that about 17-19% of this UCOME demand, 1.0-1.1 Mton, would then be used in EU aviation, about 1.2% (80 kton) in inland shipping and the remainder in the other transport modes[15].

Worldwide demand projections for UCOME do not exist, but the World Energy Outlook 2020 projections from the IEA may give some perspective (IEA, 2020c). The IEA projects global total final consumption of renewables in transport to amount to about 220 Mtoe, as shown in Figure 7. The aviation and maritime shipping sectors are included in this total, the WEO2020 forecasts that biofuels demand from these sectors increases to about 34 and 23 Mton/year respectively, in 2030. The share of UCOME is unknown. If we assume (hypothetically) that the UCOME share in global transport fuels will be similar to our assumption of the 2030 renewable mix in the EU, UCOME would have a share of between 11 and 15% of the total alternative fuels in transport. In that scenario, global UCOME consumption would amount to 27 to 37 Mton (24 to 33 Mtoe).

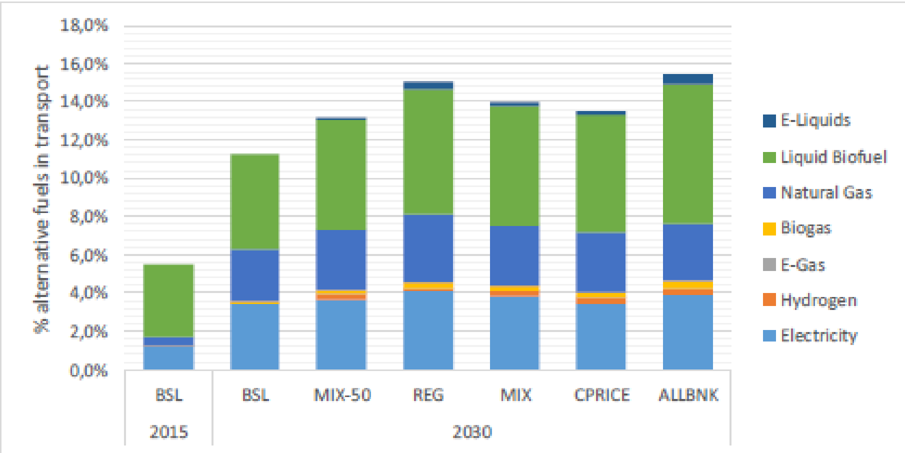
[14] These transport modes are not included in the RED II and are therefore not subject to the same policies, but the data in (EC, 2020) do not allow for a distinction between transport fuel use covered by the RED II and other modes.

[15] This estimate is based on the data in (EC, 2020) and CE Delft analysis. EU aviation is defined here as flights departing from the EU and domestic flights in the EU.

Table 9 - Demand projections for 2030

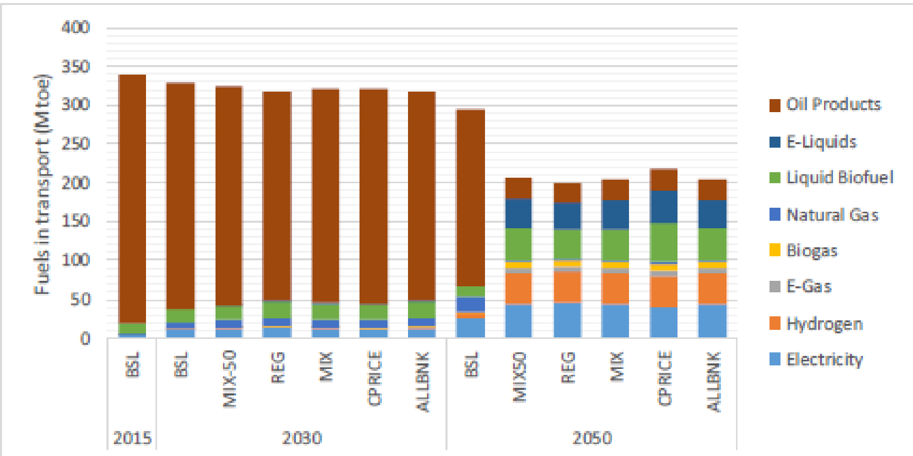
	Transport fuel demand (Mtoe)	Assumption UCOME share of total demand	Assumption UCOME (Mton)
EU	318-303	1.7%	6.1-6.4

Figure 5 - Share of alternative fuels in transport (incl. aviation and maritime navigation) (EC, 2020)



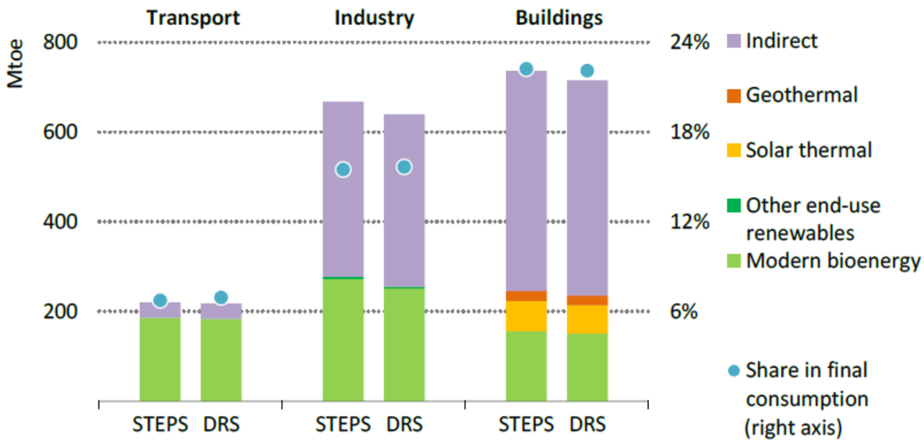
Source: PRIMES model

Figure 6 - Fuels in transport (including aviation and maritime navigation) (EC, 2020)



Source: PRIMES model

Figure 7 - Global total final consumption of renewables by scenario, 2030



Source: (IEA, 2020c).

2.5 Conclusions

Current UCOME consumption

Worldwide biodiesel consumption consists of 5.12 Mt UCOME, which is around 11% of transport fuels. In the EU+UK, UCO as feedstock of biodiesel consumed amounts to 19% (around 2.8 Mt), which represents 56% of worldwide consumption. The share of UCOME in EU biodiesel consumption (19%) is higher than to the worldwide average (11%), but only ten Member States consume significant volumes of UCOME. All countries that have a stable and high share of UCOME (NL, DE, HU, IE, PT, UK) have double counting or, like Germany, another competitive advantage for UCOME. In some of these Member States, for example in the Netherlands and Ireland, UCOME represents over 80% of biodiesel consumption. Some Member States publish information on the origin of the feedstocks and report import shares of about 50% of UCO, mainly from Asia. UCOME consumption in maritime shipping and aviation is negligible.

Biodiesel and UCOME production

Biodiesel production in the EU is dominated by only five Member States: Germany, France, Italy, Spain and the Netherlands. 2.8 Mton, 18.5%, is produced from UCO. The average share in consumption and production are almost the same, which can be explained by the fact that most EU produced biodiesel is produced for the European market. Also the import of UCO shows similarities with the import shares related to UCOME consumption: in 2019 more than half of all UCO was imported.

Other applications of UCO

No indications have been found for significant increase of UCO in other applications. UCOME seems to remain the dominant application of UCO in the coming years, but data are limited. The illegal practice of gutter oil (mixing UCO with virgin oil for human consumption) might reduce when UCOME becomes more attractive from a cost perspective, which might result in a higher demand for virgin oil and thus a displacement effect. Although this is desirable from a health perspective, this might indirectly result in additional indirect land use change impacts.

Future demand from transport

Assuming every Member State applies UCOME at 1.7% of final energy consumption in transport (including in EU aviation and shipping, which are not included in the denominator of the renewable energy in transport target of the RED II), this would amount to a union-wide demand of up to 6.4 Mt of UCOME for 2030, more than double the currently consumed amount.[16] We estimate that 17-19% of this total, 1.0-1.1 Mton, would be used in aviation, about 1.2% (80 kton) in inland shipping and the remainder in the other transport modes.

Worldwide demand projections for UCOME do not exist, but we can create some insight in global demand based on the World Energy Outlook 2020 projections from the IEA: if in 2030 the assumed EU-wide share of UCOME in renewable transport fuel demand would also apply to the global transport fuels demand, global UCOME consumption would amount to 27 to 37 Mton. This includes potential UCOME consumption in maritime shipping and aviation, which strongly depends on the future policies in these sectors, as well as development and choice for other renewable and low carbon fuels. Demand for low and zero carbon fuels might be higher in case other decarbonisation measures do not deliver the potential reduction.

[16] Based on LHV of UCO of 37 MJ/kg, (Edwards, et al., 2017).

3 Supply of UCO

3.1 Introduction

As can be seen in the previous chapter, UCO demand in the European Union (from e.g. biodiesel production plants and biochemical plants) can be met by collection of UCO in the EU, but also by imports of UCO collected in other parts of the world. In addition, biofuels from UCO (UCOME) can be imported to the EU. All three routes are already common practice and need to be taken into account when assessing the potential future supply of UCOME in the EU.

Used cooking oil (UCO) is 'produced' in the food-processing industry, in restaurants and households[17]. To make it available as a feedstock or fuel in other sectors, it needs to be collected. In Section 3.2 we describe the characteristics of UCO collection systems. We then study the supply of UCO from the EU (Section 3.3) the supply of UCO and UCOME from the rest of the world (Section 3.5), and the sum of both (Section 3.6). Conclusions on the supply of UCO for the EU are given in Section 3.7. In the next chapter, we then compare these results with the findings on UCOME demand of the previous chapter.

3.2 Collection of UCO

Sectors of origin

A distinction can be made between two main 'sectors of origin' of UCO: the professional sector and households. The professional sector roughly consists of two main industries in which UCO is 'produced': the food-processing industry, restaurants and other catering companies[18]. Collection of UCO from industry and restaurants is generally easier and less costly to perform than collection from households, because it becomes available in larger quantities at fewer locations. Moreover, households may need to be convinced to bring their UCO to collection points. As a result, UCO collection from the professional sector is currently much more developed and practiced than collection from households. We will elaborate on this in the following sections.

Household collection systems

There are three main types of collection systems for UCO from households (GREENEA, 2016):

a *Decentralised:* UCO is collected door-to-door by the collector. The collector may be a waste company collecting other types of waste at the same time or a dedicated UCO collector.

b *Centralised:* Citizens must bring their UCO to a public collection point, which could be located at supermarkets, schools, parking lots, municipal buildings and squares (Tsoutsos, et al., 2019).The UCO is either poured into a large container at the collection

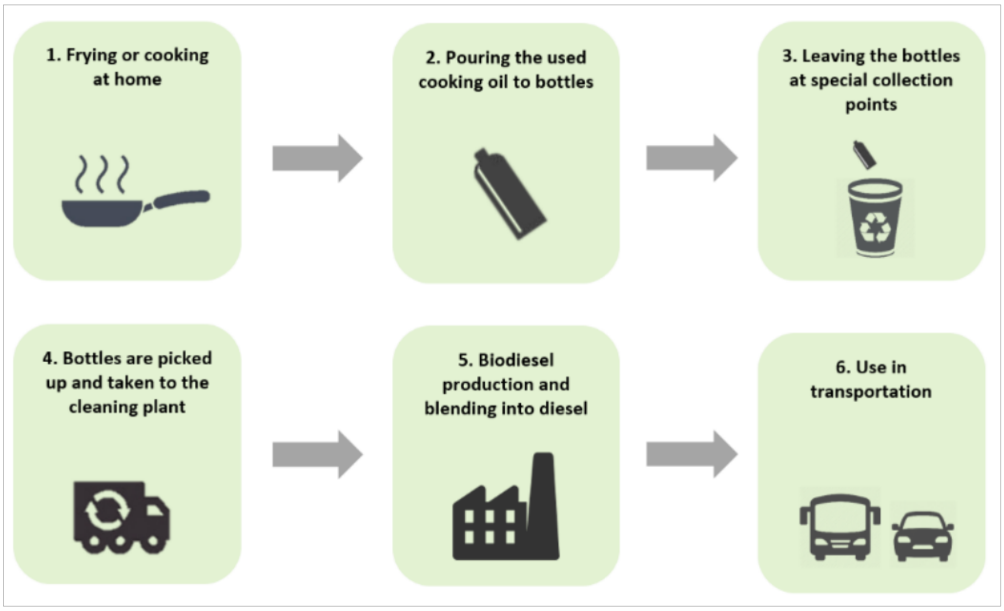
[17] We use the term UCO producers in the report for simplicity, but one can argue that UCO is not 'produced', as it is a waste product from cooking and other production processes.

[18] Organisations with a catering service such as hospitals and schools could also be considered to be part of this sector.

point, or brought and delivered in bottles or containers designed for this purpose. This is by far the most popular type of household collection system because of the lower operating costs compared to decentralised collection (GREENEA, 2016).

c *Combined:* A combination of the above systems.

Figure 8 – Centralised collection system for UCO collection from households



Source: (GREENEA, 2016).

Collection from the professional sector

UCO from food-processing companies and restaurants is typically collected gate-to-gate (decentralised collection).

Collected UCO may go directly to biodiesel producers or other UCO consumers. Alternatively, it can be bought by aggregators, and then filtered and pre-processed (to remove impurities such as water and bits of food), after which it is sold to UCO consumers (Ecofys, 2013a).

Rules and regulations

The adopted rules and regulations on UCO collection can have a large impact on national collection rates. Countries in the EU must transpose the Waste Framework Directive (2009/98/EC) (European Parliament, 2009), which covers the management of waste oils. The Directive requires that Member States adopt waste management plans, but the transposition into national legislation leaves room for specific rules and regulations on UCO collection and recycling.

As a result, the detailed rules on UCO collection vary among EU countries, which means that the existing drivers and barriers for UCO collection vary as well. As an illustration, we briefly describe the rules in a few countries in Table 10.

Table 10 – Overview of the main regulations relevant to UCO collection, in various EU countries

Country	Main regulations
Belgium	In Belgium, sellers and distributors of edible oils are obliged by law to comply with a national UCO recycling program. Quantities of consumed and collected UCO are administered, and (licensed) collectors are paid based on this administration.
France	Since 2012, UCO producers in France are responsible for the collection and recycling of UCO by approved processing and recycling facilities. They must be able to able to prove that they have done this, and thus keep an administration of this. In addition, they must verify that their UCO collector is an approved collector (Oleovia, n.d.).
Italy	Italy has embedded in its national decree on waste management the installation of a dedicated consortium (called CONOE) for the collection and processing of used vegetable oils and animal fats. The consortium is responsible for developing and managing the collection and recycling systems for used oils and fats in the country. It should also promote the distribution of information on UCO collection. Active UCO producers, collectors and recyclers should all be associated with the consortium (Ibanez, et al., 2020).
The Netherlands	The Netherlands does not have any specific regulations on the collection of UCO. Nevertheless, the collection of UCO from companies and central collection points is common practice in the Netherlands, as is sorting and separate disposal of waste streams in general
Spain	The main relevant law for UCO collection and treatment in Spain is the national law 22/2011 on waste (Cortes Generales, 2011), which transposes EU Directive 2009/98/EC (European Parliament, 2009). Regulation 1069/2009 (SANDACH) (EU, 2009b) covers category 3 catering waste. Ibanez et al. (2020) state that collectors and processing companies of UCO must comply to this legislation. Specific regulations on UCO collection appear to be non-existent, however.
United Kingdom	In the UK, UCO must be collected by companies that are registered as a waste carrier by the Environment Agency. The transfer of UCO must be documented and the transfer data should be stored for at least three years (WikipediA, 2019).

Drivers and barriers

In general, the extent to which UCO is collected is determined by profitability and by regulatory obligations. Restaurants can be paid for UCO by collectors, if UCO prices are high enough. This may incentivise restaurants to generate more litres of UCO, however. On the other hand, if restaurants and food-processors need to pay for UCO collection, they might dump it into the environment or sewage, damaging nature and sewage systems.

In the 2013 RecOil project[19], it was estimated that in the EU over 60% of UCO from households is disposed of improperly (Ecofys, 2013a). The main barriers for UCO collection for households were, according to survey results in the 2013 RecOil project, the inaccessibility of collection points and the lack of knowledge of where to dispose the UCO (Ecofys, 2013a). According to GREENEA (2016) governmental support for the realisation of public promotion campaigns is essential. Individuals, individuals must be convinced to bring their UCO to a collection point.

[19] Project website: https://www.recoilproject.eu/.

We compiled the drivers and barriers for UCO collection mentioned in literature in the following table.

Table 11 – Main drivers and barriers for UCO collection

Drivers for UCO collection	Barriers for UCO collection from restaurants	Barriers for UCO collection from households
– Economic value of UCO as a resource – Prevention of environmental damage due to illegal dumping – Prevention of damage to sewage systems, associated costs of cleaning clogged sewage lines and additional processing cost in water treatment plants – A well-designed information campaign	– Operating cost of collection, including logistics costs and administrative costs (related to sustainability requirements) – Uncertain income for collectors, due to fluctuating UCO selling prices and supply volumes at restaurants	– Operating cost of collection – Inaccessible central collection points – Lack of knowledge on the location of collection points – Lack of knowledge on environmental effects of dumping vs. collecting – Financing of repeated public information campaigns

Costs of UCO collection

The only cost estimates of UCO collection in the EU found in literature date back from 2007, from an EC project covering multiple countries (BioDieNet project, 2007).
See Table 12 for the main results.

Table 12 - Cost estimates of UCO collection from BioDieNet project (2007)

Country	Cost of collecting UCO (€/m^3)	Remark
Italy	250	Average estimated cost
Portugal	300	Indication, based on local acknowledgment
Spain	240	For an average route of 250 km
Germany	250	Average estimated cost
Hungary	0	No collection fee is charged. Actual costs of collection are not zero, but are not specified.
Norway	140	
UK	320	22 pence per litre

GREENEA (2016) gives a rough indication of the relative magnitude of different cost components of UCO household collection systems, as shown in Table 13.

Table 13 – Cost components of a UCO household collection system

Cost component	Description	Weight in total cost
Awareness campaign	Providing information about UCO recycling possibilities	Very high
Packaging	Containers in collection points and small containers distributed to people	High
Logistics	Transporting UCO from collection points to the cleaning place	High
HR	Picking up UCO, checking and emptying the bottles	High
Issues	Thefts, damages, contamination with mineral oils	Moderate
Place	Renting place for collection points in supermarkets, etc.	Low

Source: (GREENEA, 2016).

3.3 Current EU supply of UCO

A lot of UCO is collected already, especially in the professional sector in Western Europe. Restaurants form a major source of UCO, followed by food processors and households (Ecofys, 2013a).

In restaurants and catering organisations in Eastern Europe 'quite a big potential of additional UCO that is not yet captured exists' (GREENEA, 2016). In countries such as Romania, Malta and Cyprus, less than 50% of the recyclable UCO from restaurants is collected at the moment (Ecofys, 2019). Furthermore the collection of UCO from households in most European countries was relatively undeveloped by the year 2016.

The 'production' of UCO in the EU varies throughout the year (Delzeit, et al., 2019), following fluctuations in fried food consumption. Below, we describe current UCO supply from the professional sector, households, and the sum of both.

Professional sector

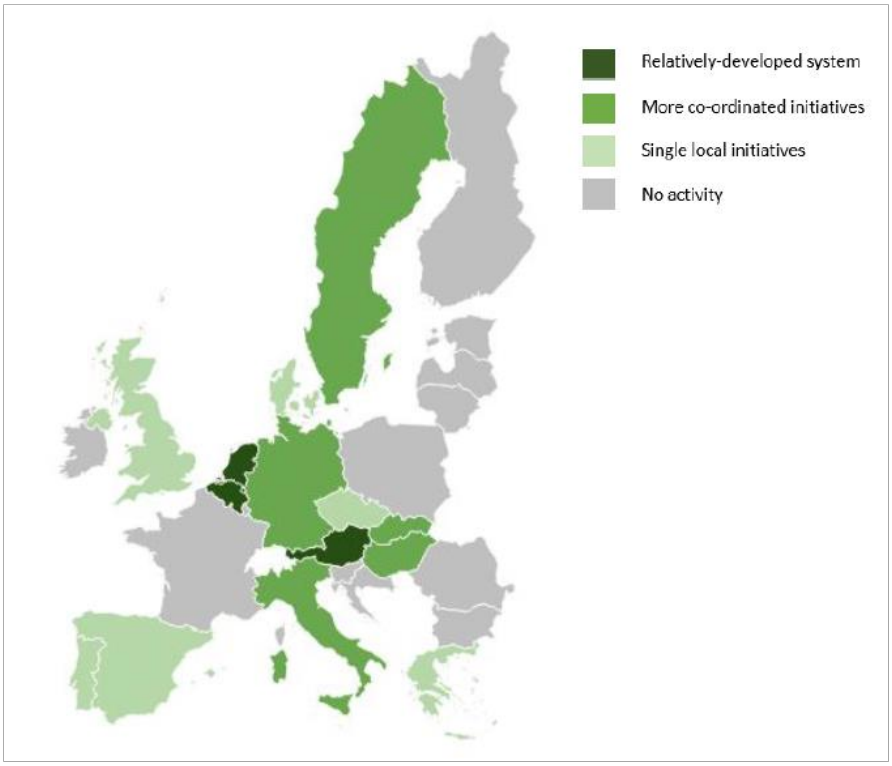
By 2016, 675,000 tonnes of UCO were collected in the EU from the professional sector (GREENEA, 2016).

Households

In most EU countries, household collection systems for UCO are absent or immature. Exceptions are Austria, Belgium and the Netherlands, where national UCO collection systems for UCO from households have been set up. In 2016, Belgium had 700 collection points, the Netherlands had 2,000. Sweden also has an effective collection system, which is organised by local authorities independently from each other. In Italy, Germany and Hungary, household collection systems started in 2016 and local initiatives were initiated in some other EU countries (see Figure 9). In fourteen EU countries, UCO from households is not collected. Less than 50,000 tonnes of UCO per year was collected from households for the whole Europe in the year 2016 (GREENEA, 2016).

Although GREENEA (2016) does not delve into typical UCO collection rates from households in countries with developed collection systems, such rates can be derived from the data provided by the report on UCO volumes collected and estimated UCO resources (which are also presented further below). The resulting collection rates, shown in Table 14, are not up to date, but this list does illustrate the difficulty to convince households to bring their UCO to a collection point.

Figure 9 - Household UCO collection systems across the EU



Source: (GREENEA, 2016).

Table 14 – Share of UCO from households that is collected in various countries (expressed as % of total UCO)

Country	Collection rate	Source
Belgium	45%	(Oliobox, 2020)
Sweden	47%	(GREENEA, 2016)
Austria	34%	(GREENEA, 2016)
Netherlands	41%	(MVO, 2018)
United Kingdom	12%	(GREENEA, 2016)
Italy	4%	(GREENEA, 2016)
Slovakia	4%	(GREENEA, 2016)
Portugal	3%	(GREENEA, 2016)
Czech Republic	3%	(GREENEA, 2016)
Spain	2%	(GREENEA, 2016)
Germany	2%	(GREENEA, 2016)
Hungary	1%	(GREENEA, 2016)
Greece	0%	(GREENEA, 2016)
Denmark	0%	(GREENEA, 2016)

Total supply

The amount of UCO collection in EU Member States in 2015 has been estimated by GREENEA (2016) and is presented in Table 15. For many countries in Eastern Europe, no data could be collected, which is an indication of the absence or immaturity of UCO collection in these countries by 2015. On average, only 5% of the UCO collected came from households.

Table 15 - Collected UCO in the European Union in 2015

Country	Households		Professional sector		Total		% from households
	kton/yr	*PJ/yr*	*kton/yr*	*PJ/yr*	*kton/yr*	*PJ/yr*	
Austria	2.4	0.1	15	0.6	17	0.6	14%
Belgium	8.3	0.3	29	1.1	37	1.4	22%
Bulgaria	-	-	-	-	-	-	-
Croatia	-	-	3	0.1	3	0.1	-
Cyprus	-	-	1	0.0	1	0.0	-
Czech Republic	0.5	0.0	10	0.4	11	0.4	5%
Denmark	0.001	0.0	5	0.2	5	0.2	0%
Estonia	-	-	1.5	0.1	2	0.1	-
Finland	-	-	4	0.1	4	0.1	-
France	-	-	44	1.6	44	1.6	-
Germany	1.2	0.0	140	5.2	141	5.2	1%
Greece	0.014	0.0	22	0.8	22	0.8	0%
Hungary	0.4	0.0	4	0.1	4	0.2	9%
Ireland	-	-	12	0.4	12	0.4	-
Italy	7.0	0.3	59	2.2	66	2.4	11%
Latvia	-	-	2	0.1	2	0.1	-
Lithuania	-	-	3	0.1	3	0.1	-
Luxembourg	-	-	2	0.1	2	0.1	-
Malta	-	-	0.5	0.0	1	0.0	-
Netherlands	3.6	0.1	60	2.2	64	2.4	6%
Poland	-	-	32	1.2	32	1.2	-
Portugal	1.0	0.0	22	0.8	23	0.9	4%
Romania	-	-	19	0.7	19	0.7	-
Slovakia	0.4	0.0	4	0.1	4	0.2	8%
Slovenia	-	-	3	0.1	3	0.1	-
Spain	5.0	0.2	65	2.4	70	2.6	7%
Sweden	1.4	0.1	8	0.3	9	0.3	15%
United Kingdom	5.0	0.2	100	3.7	105	3.9	5%
Total	**36**	**1.3**	**676**	**25**	**712**	**26**	**5.1%**

Source: (GREENEA, 2016).

Table 16 presents all data that were found on current UCO supply on the EU level.

Table 16 – Overview of estimates of current UCO supply in the European Union

Current supply		Source
Mton/yr	*PJ/yr*	
Households		
0.036	1.3	GREENEA (2016)
Professional sector		
0.68	25	GREENEA (2016)
Total		
0.71	26.3	GREENEA (2016)
0.9-1.2	32-43	Panadare and Rathod (2015)
1.2	43.0	2020 article from Argus Media (2020c)

3.4 Supply potential in the EU

Professional sector

As was concluded earlier, most of the UCO from the professional sector in Western Europe is already being collected, but in Eastern Europe a large part of the potential is not yet exploited. Less than 50% of the UCO potential from restaurants is utilised in countries like Romania, Malta and Cyprus (Ecofys, 2019). By 2016, 675,000 tonnes of UCO were collected in the EU from the professional sector. It is estimated that this could potentially grow to 806,000 tonnes within the next ten years, with a large part of the potential growth coming from Eastern Europe (GREENEA, 2016).

Households

It is difficult to estimate the UCO supply potential from households in the EU, because it is hard to obtain data from the various UCO collectors. In some countries, more than sixty collectors are active, and data are often confidential. Therefore, GREENEA (2016) has made an estimation based on information on domestic cooking oil consumption per country. With an assumed recycling potential of UCO from households of 30%[20] for most countries and 40% for Spain, Greece, Belgium and the Netherlands[21]. The total UCO supply potential from EU households was estimated at 854,000 tonnes in 2015, of which 5-6% was actually collected in 2015 (GREENEA, 2016).

For 2030, GREENEA (2016) estimates that without proactive government support the recyclable UCO potential from households will increase to 873,000 tonnes in 2030, but that the actually collected volume would drop from 36,136 tonnes in 2015 to 32,000 tonnes in 2030. With proactive support, the collected volume is estimated to rise to 188,707 tonnes. This would still be only 22% of the potential. This low expected increase may be based on the observation from case studies that it takes time to set up an effective collection scheme in which a significant share of population continues to bring their UCO to collection points.

[20] A large part of the cooking oil that households, restaurants and other companies use cannot be collected because the oil is consumed in the process of cooking and eating. The oil used for deep-frying is collectable.

[21] People consume large amounts of deep-fried food in these countries.

Total EU potential

GREENEA (2016) has estimated the supply potential of UCO in both the professional sector and the domestic sector in the various EU countries, which is shown in Table 17.

Table 17 - Total UCO supply potential in the EU in 2015 estimated by GREENEA (2016)

Country	Household resources		Professional resources		Total		% from households
	kton/yr	*PJ/yr*	*kton/yr*	*PJ/yr*	*kton/yr*	*PJ/yr*	
Austria	7	0.3	18	0.6	25	0.9	28%
Belgium	13	0.5	33	1.2	46	1.7	28%
Bulgaria	27	1.0	8	0.3	35	1.3	77%
Croatia	12	0.4	4	0.1	16	0.6	75%
Cyprus	4	0.1	1	0.0	5	0.2	80%
Czech Republic	16	0.6	13	0.5	29	1.0	55%
Denmark	2	0.1	6	0.2	8	0.3	25%
Estonia	4	0.1	2	0.1	6	0.2	67%
Finland	3	0.1	5	0.2	8	0.3	38%
France	52	1.9	53	1.9	105	3.8	50%
Germany	65	2.3	161	5.8	226	8.1	29%
Greece	20	0.7	26	0.9	46	1.7	43%
Hungary	29	1.0	5	0.2	34	1.2	85%
Ireland	2	0.1	14	0.5	16	0.6	13%
Italy	156	5.6	71	2.6	227	8.2	69%
Latvia	4	0.1	3	0.1	7	0.3	57%
Lithuania	6	0.2	4	0.1	10	0.4	60%
Luxembourg	1	0.0	2	0.1	3	0.1	33%
Malta	2	0.1	1	0.0	3	0.1	67%
Netherlands	12	0.4	69	2.5	81	2.9	15%
Poland	47	1.7	42	1.5	89	3.2	53%
Portugal	30	1.1	26	0.9	56	2.0	54%
Romania	49	1.8	27	1.0	76	2.7	64%
Slovakia	10	0.4	5	0.2	15	0.5	67%
Slovenia	4	0.1	4	0.1	8	0.3	50%
Spain	232	8.4	78	2.8	310	11.2	75%
Sweden	3	0.1	10	0.4	13	0.5	23%
United Kingdom	42	1.5	115	4.1	157	5.7	27%
Total	**854**	**30.7**	**806**	**29.0**	**1,660**	**59.8**	**51%**

Source: (GREENEA, 2016).

We can observe that 51% of the UCO supply potential is estimated to come from households. Given that only about 6% of this potential was utilised in 2016 and most of the UCO from the professional sector in Western Europe is already collected (GREENEA, 2016), most of the potential growth in EU UCO collection lies in the development of effective UCO household collection systems.

Various estimations of the EU potential UCO supply (per sector and/or in total) are presented in Table 18. Of the different sources, only GREENEA (2016) elaborates on the estimation approach. Therefore, the GREENEA estimations might be considered the most reliable.

Table 18 - Overview of estimates of the potential UCO supply in the EU+UK

Estimated potential		Source	Remarks
Mton/yr	*PJ/yr*		
Professional sector			
0.81	30	GREENEA (2016)	
0.97	36	Ecofys (2013a)	EU27
1.8	67	Ecofys (2013a)	Results from BioDieNet project
Households			
0.85	31	GREENEA (2016)	
1.7	64.7	Ecofys (2013a)	Results from BioDieNet project
Total			
1.7	61	GREENEA (2016)	
1.7-2	61-72	Ecofys (2019)	2016 estimate
1.9	70	E4tech and studio Gear Up (2019)	

3.5 Non-EU supply

Current supply

Since 2014, net UCO and UCOME imports to the EU have significantly increased, with China, Indonesia and Malaysia as main exporters. In 2018, the EU imported 200,000 ton of UCOME, mainly from Indonesia. The source of the cooking oil on which the UCO is based in those countries is mainly palm oil. Over the last years, the imports of palm oil-based UCO and UCOME have increased, even though the net imports of palm oil to the EU have stalled since 2013 due to rising sustainability concerns (NNFCC, 2019).

About 54% of the UCO used in the EU for biodiesel production in 2019 was imported from non-EU countries (T&E, 2020b). Important non-EU countries of origin are China (34%), the USA (12%), Malaysia (12%), Indonesia (7%), Saudi Arabia (6%) and Russia (4%). This share varies strongly between countries. For example, in the UK in 2019, 106 million litres of biodiesel were produced from UCO from the UK, whereas 416 million litres were produced from UCO from China (DfT, 2020), which is almost four times higher.[22]

The estimates of current UCO and UCOME import volumes for the EU are presented in Table 19.

Table 19 - Overview of estimates of the current UCO and UCOME import to the EU+UK (Mton/yr)

	2016	2017	2018	2019	Source	Remarks
UCO/UCOME						
	0.64				Ecofys (2019)	UCO-equivalents
UCO						
		0.81			GREENEA (2018)	
		0.96	1.22	1.41	(EC, DG TRADE, 2020)	
UCOME						
			0.2		NNFCC (2019)	Mainly from Indonesia

[22] 106 million litres of biodiesel is equivalent to 0.1 Mton of UCO; 416 million litres to 0.40 Mton of UCO.

Supply potential (non-EU)

Here we describe the supply potential of UCO and UCOME from non-EU+UK countries for the EU+UK. However, it should be kept in mind that the export of UCO/UCOME from non-EU countries to Europe competes with its use in the countries of origin. These countries will sooner or later increase efforts to reduce greenhouse gas emissions in the transport sector and other sectors themselves. For example, a report from the ICCT discusses the potential use of UCO from Indonesia for biodiesel production for the national transport sector, along with the positive effects this could have on economy and environment (ICCT, 2018). As the demand for UCO in non-EU countries increases over time, the supply potential for Europe will decrease (at least, when minimising the risk of displacement effects is used as a basic principle).

Professional sector

In an analysis by Ecofys (2013b) of the supply potential of UCO from the food service industry (restaurants, hotels, catering, etc.) in the USA, China, Indonesia and Argentina combined it was found that at least 1.3 Mton could be collected without negative impacts to other UCO uses, compared to a total supply potential of 4.6 Mton.[23] The shares of the UCO potential that were not yet utilised in 2013, and thus could be exported to Europe without indirect environmental impacts, differ considerably between the countries, as is shown in Table 20. In Indonesia and Argentina, these shares were more than 85%, but the indicated share for China is only 10%, although the produced amount of UCO in China is very large.

Most of the UCO available in China is estimated to be used as 'gutter oil'. Gutter oil is created by processing and blending used cooking oil with fresh cooking oil. It is illegally sold as cooking oil in the food market. There is a large black market for gutter oil, which complicates the gathering of data on UCO availability. Only 0.3 Mton is collected by official collectors (Ecofys, 2013a; 2013b).

This information illustrates that current UCO collection and reuse rates and applications are very country-specific. This will hold not only for UCO from the food service industry, but also for UCO from the food-processing sector and from households.

Table 20 - UCO potential from the food service industry in four countries

Country	Total potential (Mton/yr)	Potential without indirect impacts (Mton/yr)	Percentage without indirect impacts
USA	0.89	0.41	46%
Indonesia	0.65	0.58	90%
Argentina	0.020	0.018	87%
China	3.0	0.30	10%
Total	**4.6**	**1.3**	**29%**

Source: (Ecofys, 2013a)[24].

[23] This suggests that (the collection of) 3.2 Mton of this potential would affect other UCO uses and could therefore create indirect negative environmental effects.

[24] Unfortunately, a more recent estimation of the UCO supply potential from outside the EU has not been found.

Total

The dependency of the UCO supply potential from the professional sector and from households from the rest of the world on country-specific conditions (edible oils consumption, existence of UCO collection systems, rules and regulation on collection, type of alternative uses of UCO, etc.) in combination with a lack of data makes it very difficult to estimate the UCO supply potential from non-EU countries.

GREENEA (2018) estimates that the potential global import of UCOME to the EU is about 0.50 Mton/year, which is equivalent to about 0.54 Mton/year UCO. This is about three times higher than the UCOME import from China in 2017. The actual import of UCO to the EU in 2019 was 1.41 Mton (EC, DG TRADE, 2020), which is higher than the Ecofys (2013a) estimate of the UCO potential from the food service industry in four non-EU countries (see Table 20). It follows that the UCO supply potential from non-EU countries is *at least* 1.4 Mton/year. The literature provides insufficient information to provide a *maximum* supply potential directly, but the highest estimation of global UCO supply potential found in literature is 34 Mton/year (based on an estimation by Ecofys (2019), see Section 3.6).

3.6 Total supply for the EU

Current total supply

In the previous paragraphs, current EU UCO/UCOME supply was estimated at 0.7-1.2 Mton/year[25] and current UCO/UCOME imports at 1.4 Mton/year (2019 figure). This adds up to a global supply of 2.1-2.6 Mton/year (see Table 21).

Table 21 - Overview of estimates of current total supply of UCO/UCOME for the EU

Range (Mton/yr)	Source
2.1-2.6	Sum of estimates for EU and non-EU supply (see previous sections).

Supply potential

We estimate the total supply potential of UCO and UCOME for the EU (EU+UK and import from non-EU countries) at 3.1 to 3.3 Mton/year, by taking the sum of the ranges of EU and non-EU supply potentials from the previous sections. This range can be compared with global supply potential estimates from literature. The results of this comparison are shown in Table 22.

We have not used estimates from literature that are provided without any explanation on the estimation approach, our estimated range of 3.1 to 3.3 Mton/year is based on data and documented research such as the one from GREENEA (2016). Risks of displacement effects are not indicated either. Therefore, we consider this range as more realistic than the much higher estimates from ICAO (2018) and Ecofys (2019). However, it should be noted that the estimation of the import potential was based on the *actual* UCO import to the EU in 2019 of 1.4 Mton. The import *potential* may be higher, although consideration of risks of displacement effects sets a limit on that. Estimates from literature also include UCO supply in non-EU countries that is used outside the EU. Unfortunately, data on UCO consumption in

[25] The value of 0.7 is from 2015 and the value of 1.2 is from 2020.

non-EU countries are missing, which prevented us from calculating the amount that could be exported to the EU.

Table 22 – Comparison of estimates of global UCO and UCOME potential and the found range of the total UCO/UCOME potential for the EU

Mton/yr	PJ/yr	Scope	Source
3.1-3.3	115-122	EU+UK and potential import to the EU	(GREENEA, 2016) (E4tech and studio Gear Up, 2019) (EC, DG TRADE, 2020)
5	200	Global supply potential	Sze Ki Lin et al. (2013)
25	900	Global supply potential	ICAO (2018)
29	1,100	Global supply potential	Ecofys (2019)
34	1,300	Global supply potential	Ecofys (2019)

Note: The UCOME production in the EU is not included, but the UCOME import potential is.

Sze Ki Lin et al. (2013) estimates that the total UCO production worldwide was about 5 million tonnes per year (by the year 2013, more recent data were not found).[26] ICAO (2018) gives an estimation of 25 million tonnes per year, based on older studies. We conclude from the height of these numbers that these are not equal to the collected UCO volumes, but indicate the UCO supply potential.

Ecofys (2019) has estimated the global UCO supply potential to be 29 Mton/year in 2017, rising to 34 Mton/year in 2022. Brown grease and gutter oil are included in these estimations. Brown grease is grease containing free fatty acid levels higher than 15%, which fall under the feedstock category of fats instead of oils. Gutter oil is an illegally produced cooking oil containing both virgin oil and UCO. Therefore, these estimates can be considered too high.

Furthermore, the above estimation also appears to include UCO currently used in other sectors and countries. Based on an analysis of the UCO supply potential in the EU, the USA, China, Indonesia and Argentina, Ecofys (2019) concludes that the EU could make use of about 2 Mton per year of UCO for biofuels at a low risk for indirect land use change (ILUC). This is because UCO collection could still be scaled up significantly worldwide. According to Ecofys (2019) the global potential of waste oils is sufficient to provide feedstock for biofuels for the EU up to the limit in the RED II of 1.7% for renewable energy in transport (road and rail) from Annex IX Part B feedstocks.

Apart from the limitation on the UCO import potential posed by alternative uses[27], quality constraints of UCO recycling and logistics constraints of UCO collection will also reduce the import potential. What is economically feasible depends not only on purification and processing cost and logistics cost, but also on the development of global UCO prices (which are in turn influenced by the biodiesel prices).

[26] Unfortunately, a more recent estimation has not been found.

[27] This is actually a 'soft' restriction, which to a large degree depends on willingness to pay. However, national and international trade policy, or policy aimed at preventing displacement effects, could also contribute to prioritisation of alternative, local uses of UCO.

3.7 Conclusion

The availability of data on UCO collection is limited, especially regarding non-EU countries. For the scarce estimates of the UCO supply potential in and outside the EU it is not always clear if practical (technical and economic) constraints to UCO collection and recycling are considered, or whether the values represent a theoretical potential.

Summarising the collected data, we find that:

- The current UCO production in the EU and current UCO/UCOME imports to the EU add up to a total supply of 2.1-2.6 million tonnes per year. Of this, 0.7-1.2 Mton/yr is from EU+UK UCO supply, the remainder is imported.
- Based on the estimates of the supply potential, we conclude that the global UCO and UCOME potential (i.e., the sum of the EU UCO supply potential and the import potential of UCO and UCOME from non-EU countries) is 3.1 to 3.3 million tonnes per year. 1.4 Mton/yr (30-50% of this total) are potential imports from outside the EU. The remaining 1.7 Mton/yr is the potential UCO supply from the EU+UK.

Hence, the future UCO supply potential is roughly 50% higher than the current UCO supply. This estimation is based on expected developments of cooking oil consumption, UCO collection and competition between alternative uses. It can be considered relevant for the coming decade, although unforeseen developments (such as the corona virus outbreak) can impact the potential.[28] For the global supply, much higher values (up to 34 Mton/yr) were also reported in literature, but the assumptions used and the extent to which UCO demand for other applications is taken into account are not clear.

Little information was found on the collection potential of UCO from households in non-EU countries. As dietary habits, regulations on UCO collection, environmental awareness, and budgets for collection will differ per country, the UCO potential from households is likely to vary from country to country as well. The information suggests that most of the currently imported UCO originates from the professional sector. Furthermore, the current use of UCO in other sectors is largely unknown, complicating the estimation of the potential collection of UCO for EU UCOME production without causing displacement effects that harm the environment.

[28] The estimations from literature have not considered reduced UCO production due to an event like a corona virus outbreak. Therefore, these estimations can be seen as estimations for the coming decade *assuming* that the virus is subdued and economies turn back to their pre-2020 state.

4 Comparison of supply and demand

4.1 Current supply and demand

In Chapter 2 current demand figures have been presented, where EU+UK consumption of UCOME was found to be 2.8 Mton. Worldwide, in 2019, UCOME consumption is 5.12 Mton, 11% of global biodiesel consumption in 2019, mainly due to demand in the US and EU.

In Chapter 3, current EU+UK UCO supply was estimated at 0.7-1.2 Mton/year and current UCO/UCOME imports at 1.4 Mton/year. This adds up to a total supply of 2.1-2.6 Mton/year.

These ranges are due to the uncertainties in the current supply data. Furthermore, current EU+UK supply including imports is lower than current EU+UK demand, which leads us to the conclusion that either the data found in literature are incorrect or demand currently exceeds supply.

Table 23 - Overview of our conclusions on current demand and supply of UCOME

	Mton/yr
Demand EU+UK	2.8
Global demand	5.12
Supply EU+UK (excl. imports)	0.7-1.2
Imports to EU+UK	1.4
Total supply EU+UK	2.1-2.6

4.2 Future supply and demand

Future demand estimates as presented in Section 2.4 show a potential strong increase in UCOME consumption to up to 6.4 Mton in 2030 under the Climate Target Plan – where we assume that UCOME achieves a 1.7% share in all countries in the EU+UK. This can be seen as a high-demand scenario as long as the 1.7% cap remains in place. These figures include EU aviation and shipping, where aviation would be responsible for about 17-19% of the total UCOME consumption (1.0-1.1 Mton).

This demand of 6.1 to 6.4 Mton is much higher than the estimated potential for UCOME from UCO collected in the EU itself, 1.7 Mton/yr. It also exceeds the estimates of UCOME potential supply as depicted in Table 24. It is well within the range of the higher estimates for global potential reported on in the literature, but these data are uncertain. A higher demand for UCO from other parts of the world to decarbonise national transport, aviation or shipping or for other applications can reduce the potential imports of UCO significantly. Furthermore, strong efforts are required to establish collection systems and improve collection rates globally, which also strongly depends on changes in consumer behaviour. On the other hand, future demand could be limited by higher volumes of other low carbon and zero emission fuels, which also requires substantial efforts given the current state of the art of for example advanced fuels form Annex IX A feedstocks and e-fuels.

Table 24 – Overview of our conclusions on potential demand and supply of UCOME in 2030

	Mton/yr
Demand EU+UK	6.1-6.4
Potential global demand as a transport fuel*	27-37
Supply EU+UK (excl. imports)	1.7
Imports to EU+UK	1.4
Total supply EU+UK	3.1-3.3

* Assuming that in 2030 the global share of UCOME in renewable transport fuels equals that of EU (11%-15%).

4.3 Displacement effects

An increasing demand for UCO and/or UCOME from the EU may lead to UCO/UCOME currently used for other applications being diverted to the transport sector within the EU, and, outside the EU, to export to the EU. If this happens, it will result in displacement effects: the other applications are likely to replace UCO with virgin oil. In western Asia, this will probably be palm oil.

In China, a large amount of UCO is currently used as gutter oil. This is illegal and is detrimental to public health in China. The collection and export of this UCO to the EU would thus have a positive effect on public health. However, it will also probably create a high-ILUC risk, as the food sector replaces it with virgin oil (Ecofys, 2013a; 2013b).

According to NNFCC (2019) UCO that is considered safe for consumption by animals in non-EU countries is redirected from the use for animal feed production to biofuel production, because fuel suppliers from the EU are willing to pay more for UCO than for virgin oil. NNFCC (2019) claims that this UCO is replaced by cheaper virgin oils such as palm oil, which happens off the radar (i.e., is not monitored and reported). NNFCC (2019) notes that palm oil imports to China are indeed increasing, although they note that there is not necessarily a causal relation between the two.
Delzeit et al. (2019) mention that UCO is the major feedstock for biofuel production in China, Japan and Korea, and an important feedstock in India and Canada as well. If the UCOME is currently used in non-EU countries, buying up this UCOME may also indirectly lead to displacement effects. In those countries, the reduced supply of UCOME may lead to increased fossil fuel use or an increase of other types of biofuels.

These displacement effects are likely to increase GHG emissions, as they will lead to increase production and use of other, less sustainable alternatives. The extent of this effect is not yet known.

4.4 Conclusion

The comparison of supply and demand estimates that follow from this study, in Table 25, show that future demand is likely to exceed supply already even without taking into account a higher demand for UCOME in other parts of the world. Such a higher demand is realistic given the fact that not only the EU needs to meet the objectives of the Paris Agreement, but other parts of the world do as well. However, many uncertainties exist in relation to future demand and future supply resulting in large ranges for potential supply and demand.

Table 25 - Demand and supply of UCOME, for the current situation and the potential in 2030

	Current situation (2019)	Potential for 2030
	Mton/yr	Mton/yr
Demand EU+UK	2.8	6.1-6.4
Global demand	5.12	
Potential global demand as a transport fuel*		27-37
Supply EU+UK (excl. imports)	0.7-1.2	1.7
Imports to EU+UK	1.4	1.4
Total supply EU+UK	2.1-2.6	3.1-3.3

* Assuming that in 2030 the global share of UCOME in renewable transport fuels equals that of EU (11%-15%).

An increased demand for UCO and/or UCOME from the EU may lead to displacement effects, with potentially negative environmental and climate impacts. The extent of these impacts has not been assessed yet, and will depend on what exactly is displaced and how the different markets respond to these developments.

5 Monitoring and verification

5.1 Introduction

UCO is considered a biofuel feedstock that is regulated by the EU Renewable Energy Directive. In the RED, the sustainability of biomass is monitored through a system of sustainability certification. Deliveries of biomass (i.e., batches of biomass with the same characteristics, such as wood from forests from Latvia) are sustainable if a ‘proof of sustainability’ has been issued for it, which travels along with the biomass through the supply chain from producer to end consumer. In the EU, fuel suppliers can only meet their renewable energy share obligations for transportation by using fuel with a proof of sustainability. This certification system is also used for UCO.

Verification is the process of checking whether the registered sustainable amounts of UCO are correct. To be able to verify, it is important that the origin of the UCO is traceable.

Depending on among others the type of cooking oil and the cooking process, the quality of used cooking oils varies considerably. High-quality UCO (homogeneous substance with low degree of contaminants) is more valuable than low-quality UCO, as purification costs are lower. Thus, it is important to monitor and verify the quality of collected UCO. There is no elaborate certification system for this as there is for sustainability. However, in the sustainability certification system the physical mixing of UCO is also monitored, which affects its quality.

In this chapter, we first briefly describe UCO prices, because this is relevant with respect to fraud. Then, we describe the rules and regulations concerning the monitoring and verification of UCO in Section 5.3. Next, we study the chemical properties of UCO and virgin oils in Section 5.4. This is relevant for both quality and fraud concerns. We then discuss the susceptibility of the sustainability certification system to fraud in Section 5.5, along with a description of some cases of UCO fraud. The implications of fraud risks for the risks of displacement effects is treated in Section 5.6. Based on all this, we present opportunities for improving the monitoring and verification of UCO in Section 5.7. Conclusions on the status of monitoring and verification of UCO are given in Section 5.8.

5.2 UCO prices

UCO can be sold at higher prices than virgin oil, since fuel suppliers can count UCO-based biodiesel (UCOME) twice for meeting their renewable energy shares in the EU countries that use double counting as a policy incentive. In recent years, the market prices of UCO and UCOME were significantly higher than those of virgin oil and virgin oil-based biodiesel (FAME). As shown in Table 26, the spot market prices of UCOME in North-West Europe in late 2019 and the first half of 2020 were 40 to 65% higher than those of FAME.

Table 26 – Comparison of recent market prices of UCOME and FAME

	UCOME price (€/ton)	FAME price (€/ton)	Difference (€/ton)	Source	Remarks
November 2019	1,120	730	390 (+53%)	Argus (2019) [d]	Spot prices, ARA[c] range, 0˚C FAME
April 2020	940	570	370 (+65%)	Argus (2020) [b]	Spot prices, ARA range, 0˚C FAME
July 2020	1,000	710	290 (+41%)	GREENEA (2020) [a]	ARA range

[a] GREENEA (2020); [b] Argus (2020); [c] The ARA region includes Antwerp, Rotterdam, Amsterdam, Dordrecht, Flushing and Ghent; [d] Argus (2019).

The double counting mechanism has been set up with the goal of stimulating production and demand of biofuels from biomass residue streams, which have a lower GHG impact than first generation biofuels. However, it also creates a perverse financial incentive to 'turn virgin oil into UCO'. Also, mixing virgin oil with UCO or artificially increasing the production of UCO would increase the quality of the UCO, further increasing its economic value (Mijnheer, 2019). The higher price of UCO could be considered an underlying weakness of the system, and has in fact led to a number of cases of fraud (see below). Without it, it would not be necessary to install a rigorous monitoring and verification process. The higher the price difference, the more lucrative it becomes to commit fraud.

5.3 Rules and regulations

As discussed in Section 2.4.1 EU biofuels have to meet sustainability criteria to count towards the RED II targets. Biodiesel can be called renewable if it has obtained a 'proof of sustainability'. A proof of sustainability can be issued to deliveries (batches) of biomass feedstock and biofuels by a producer if the following requirements are met (Mijnheer, 2019); (ILT, 2019):
- the renewable origin of the feedstock or the fuel is certified according to one of the certification schemes that have been recognised by the EU (EC, DG Energy, 2020);
- only one proof of sustainability can be issued per delivery (batch) of feedstock or fuel;
- the delivery must have taken place physically;
- a mass balance system is kept, i.e., producers, traders and suppliers make an account of ingoing and outgoing flows of renewable material;
- the issuing producer must be certified by a certification body, which monitors compliance with the procedures.

As the proof of sustainability is passed on between market parties along the biomass/ biofuel supply chain ('chain of custody'), fuel suppliers can deliver proof that they have used the required amount of renewable energy. Fuel suppliers must also prove the use of double counting biofuels such as UCO. This is done by means of the same proofs of delivery, as these also specify the type of feedstocks used to produce a delivery of biofuel and the countries of origin of the feedstocks. However, they do not specify not the location of origin, so the UCO collection points are not indicated.

It is important to note that a proof of sustainability is not needed for biodiesel sold to customers outside the EU, where certification is not mandatory.

The European Commission decides on which biofuel certification schemes ('voluntary schemes') can be used to meet the renewable energy obligations for transport. About fourteen schemes have been recognised by the Commission (EC, DG Energy, 2020).

However, the EU Member States are to a large extent responsible for the monitoring of the implementation of the RED II. This includes the supervision of the certification bodies, which are conducting audits at fuel producers and suppliers under the voluntary schemes (EURACTIV, 2019a). At least once a year, the certification bodies conduct procedural checks based on the mass balance of the producers.

5.4 Chemical properties

The opportunity of committing fraud by mixing (adulteration) of UCO with virgin oil is created by the fact that UCO and virgin oil are similar in composition, making it difficult to detect such fraud. In this paragraph, we discuss the difference in quality and composition between UCO and virgin oil and the possibility to detect adulterated UCO.

UCO quality

The quality of UCO can vary substantially between deliveries (batches). This is one of the reasons why UCO must be cleaned and purified before it can be used as an input for, for example, biodiesel production. There are two main causes of the varying quality of UCO.

First, the original biomass feedstock of the cooking oil defines to a large extent the composition of the end product. UCO that is based on palm oil (which is used a lot in Asia) differs significantly from UCO based on rapeseed oil (which is used a lot in the EU). There is a large difference in fatty acid composition between different types of oil-containing plants, which results in oils with different physical and chemical properties (NNFCC, 2019). Secondly, the quality of the UCO varies as a result of the use of cooking oil for frying food. During the frying process, cooking oil undergoes different chemical processes, which change the physiochemical properties of the substance, including acid value, viscosity, fatty acid profile, calorific value and moisture and carbon content. The exact changes depend to a large extent on cooking times, cooking temperatures and the type of food that is cooked (Panadare & Rathod, 2015).

A list of chemical processes and their effects on UCO composition from Panadare and Rathod (2015) is provided in Table 27. It shows that there are various (concentrations of) molecules in UCO that are absent in virgin cooking oil. Furthermore, UCO was observed to have a higher viscosity and a higher saturation level than virgin oil. These physiochemical differences could serve as a means to physically check whether batches of UCO contain a high share of virgin cooking oil. However, this does not yet mean that lower shares of virgin cooking oil can be easily identified. This topic is discussed below.

Table 27 - Changes in the chemical composition of (used) cooking oil during the frying process

Chemical reaction	Cause	Change in composition
Hydrolysis	Water content in the food interacts with frying oil at high temperature, reaction with atmospheric moisture.	Increase in concentration of total polar molecules, production of free fatty acids, glycerol.
Thermal degradation	Triglyceride degradation at high temperature in absence of oxygen.	Production of alkanes, alkenes, symmetric ketones, oxopropyl esters, CO, CO_2, and dimeric compounds.
Oxidation	Reaction with surrounding atmospheric oxygen.	Hydroperoxide formation, change in content of conjugated dienes and trienes.

Chemical reaction	Cause	Change in composition
Polymerisation	Reactions with unsaturated fatty acyl groups at high temperature.	Formation of polymerised triacylglycerides, including dimers and oligomers.

Source: (Panadare & Rathod, 2015).

Differentiation between UCO and virgin oil

The chemical composition of UCO and virgin oil (based on the same biomass feedstock) are very similar. In a nuclear magnetic resonance (NMR) analysis (a form of spectroscopy), Mannu et al. (2019) found less than 5% of contaminants in UCO, confirming this similarity. However, the virgin oil did not contain any contaminants.

Awogbemi et al. (2019) identified in a Pyrolysis Gas Chromatography Mass Spectrometer (PYGCMS) analysis that vegetable oils mainly contained saturated fatty acids (FAs) and polyunsaturated FAs, whereas UCO mainly contained saturated FAs and monounsaturated FAs. In addition, the pH value of several vegetable oil samples was found to vary between 7.38 and 8.63, compared to a pH value between 5.13 and 6.61 for the UCO samples. Finally, the viscosity of UCO at 40 degrees Celsius was found to be higher than for vegetable oil. A pH meter and a viscometer were used for the respective tests (Awogbemi, et al., 2019).

The above research shows that the difference between UCO and virgin oil can be tested and identified. Some composition/property analysis methods may be too expensive to be used for the identification of UCO vs. virgin oil, but the testing of the pH value can be done in multiple, simple ways. However, the research did not cover mixtures of UCO and virgin oil.

Detection of UCO and virgin oil mixtures

The risk of adulterating UCO with virgin oil is a new problem, related specifically to the renewable energy obligation and the double counting of waste-based biofuels from the RED II. Worldwide, the adulteration of virgin oil with UCO (i.e. gutter oil, the opposite) has been a major concern for many years in many countries including China, India and South Africa, affecting public health. This is why the detection of such adulteration has been scientifically studied. Below we describe several studies, which is summarised in Table 28.

Zhao et al. (2015) have developed a ‘simple and accurate’ method for the detection of UCO in vegetable oils, based on the measurement of cholesterol, β-sitosterol, and campesterol by means of gas chromatography/mass spectrometry. Mixtures of twelve types of vegetable oil and UCO from China were analysed (incl. rice oil, corn oil and peanut oil), with the UCO content varying from 5 to 75%. The method could accurately identify adulterated vegetable oils containing as little as 5% UCO.
Lim et al. (2018) have analysed palm oil adulterated with UCO, using fatty acid composition and Fourier-transform infrared spectroscopy (FTIR) spectral analyses in combination with chemometrics. The UCO content in the adulterated oil samples varied from 1 to 50%. Oil samples were prepared and purchased in Malaysia. The authors conclude that both fatty acid compositions and FTIR spectra are suitable in detecting oil adulteration, although the methods should be further developed to improve their accuracy.
Hao et al. (2019) have studied the effectiveness of laser-induced fluorescence (LIF) spectroscopy in detecting vegetable oil adulteration. Four types of vegetable oil were included in the analysis (rapeseed, olive, peanut and corn), purchased at local supermarkets in China. The UCO content varied from 5 to 50%. The method was found to be fast and accurate, the prediction error being below 2%.

Table 28 - Scientific studies of methods for the detection of adulterated vegetable oils

Study	Vegetable oils	UCO content	Country	Detection method	Result
Zhao et al. (2015)	Twelve types, incl. rice, corn and peanut	5-75%	China	Gas chromatography/mass spectrometry.	Simple and accurate method.
Lim et al. (2018)	Palm oil	1-50%	Malaysia	Fatty acid composition and FTIR spectral analysis.	Suitable methods but need further development.
Hao et al. (2019)	Rapeseed, olive, peanut and corn	5-50%	China	Laser-induced fluorescence spectroscopy.	Fast and accurate method.

Given that all of these scientific studies have tested virgin oil/UCO mixtures with UCO volume shares of up to 75%, the results are valuable for the detectability of UCO adulterated with virgin oil as well.

We cautiously conclude from literature that there are good opportunities for the accurate detection of virgin oil in UCO, because of the existence of multiple physical and chemical differences between virgin vegetable oils and UCO. However, it is still unknown which method is most suitable (cheap, quick and accurate) for the detection of UCO adulteration. Moreover, the literature is about the adulteration of virgin oil with UCO, not about the adulteration of UCO with virgin oil, which is our object of interest. It might be more difficult to detect the latter. A remaining question is whether the artificial treatment (additional chemical processing) of virgin oil to make it similar to UCO can be detected as well. According to a note from the Commission, "it is relatively easy to artificially modify vegetable oil to make it indistinguishable from genuine UCO" (EC, 2014).
Biofuels industry association EWABA's Secretary General, Angel Alvarez Alberdi, told EURACTIV in 2019 that the industry is working on a system to identify the composition of UCO (EURACTIV, 2019b). Thus, it is likely that this research is in progress.

Detection of virgin oil use in production of UCOME

No published research has been found in which the detection of UCO adulterated with virgin oil has been examined. As in the context of the RED II UCO suppliers may have the adverse incentive to mix UCO with virgin oil, research should first look into plausible ways in which virgin oil could be artificially altered to make it look like UCO. Only then can different detection methods be tested on their ability to identify adulterated UCO.

The same holds for the detection of whether virgin oil has been used in the production of biodiesel labelled as UCOME: it is yet unknown if additional *malafide* processing steps can mask the use of virgin oil as a feedstock. The related, preceding research question here is to what extent the biodiesel production process 'erases' the physical and chemical differences between virgin oil and UCO (without additional processing).

Need for further research

In conclusion, based on published studies so far, further research is needed to find out to what degree the fraudulent use of virgin cooking oil in the production of UCO and UCOME can be detected. Although virgin oil and UCO do have different physiochemical properties, it might be possible to process virgin oil artificially to make it look like UCO.

5.5 Fraud

Opportunities for committing fraud arise when market prices of UCO become higher than market prices of virgin cooking oil. When this is the case, suppliers could attempt to make money by selling virgin oil as used cooking oil, or biodiesel based on virgin oil as UCOME. The double counting of UCO-based biofuels in the RED II policy regime, which is meant to incentivise the production of biofuels from biomass residues, increases the likelihood that UCO is worth more than virgin oil. In recent years, this has actually happened, and large cases of fraud has been detected. This is further discussed below.

In a 2016 report, the European Court of Auditors has pointed towards the risk of fraud with double counting biofuels and especially UCO. It concludes that "because of weaknesses in the Commission's recognition procedure and subsequent supervision of voluntary schemes, the EU certification system for the sustainability of biofuels is not fully reliable". As a result, biofuel could be reported as sustainable without a proper verification of sustainability (ECA, 2016).

Ways to commit fraud

A UCO or UCOME producer could commit fraud by mixing virgin oil with UCO, by using virgin oil for biodiesel production instead of UCO, and by issuing fake proofs of sustainability. This is made possible by the fact that is very difficult to detect the difference between UCO and mixtures of UCO and virgin oil mixture. The fraudulent producers can leave out deliveries on their mass balance, so that the mass balance looks correct on paper.

ECA (2016) mentions another way in which a producer could commit fraud on paper: by certifying UCOME twice by different voluntary schemes. The producer could then gain revenue twice from providing the same amount of renewable fuel to the market. This risk of fraud exists for biofuels made from waste and residues, which count double for complying with renewable energy obligations in the transport sector. This risk appears to be relevant for other types of biofuels as well, however. ECA does not elaborate on this, but such fraud may be possible when national authorities verify compliance on the basis of proofs of sustainability.

Another way of committing fraud is to artificially increase the production of UCO, for example by stimulating the disposal of cooking oil at restaurants after much shorter periods of time. This way, producers could try to abuse the system. In other words, if UCO prices are high enough, there is a perverse incentive to produce more waste cooking oils. This type of fraud would require the cooperation of restaurants and other UCO producers.

Signalled fraud

EURACTIV (2019b) quotes a source from the biofuel industry who states that one-third of the UCOME used in the EU biofuels markets is more than likely fraudulent, as it is easy and profitable to mix palm oil with UCO and sell it as UCO.

Already back in 2013, fraud cases with UCO have been reported in the UK. This was about the use and sale of stolen UCO. Criminal activities in which UCO was involved increased due to the fact UCO gained economic value as biofuel feedstock (BBC UK, 2013).[29]

[29] https://www.bbc.com/news/uk-21858841

In 2019, a large case of suspected fraud emerged in the Netherlands. The Dutch transport authority (ILT) made public in 2019 that it had discovered a large-scale fraud case in which biodiesel had illegitimately received a proof of sustainability. A Dutch company, which both collects UCO and produces biodiesel, has been suspected to sell biodiesel based on virgin oil as UCOME, which had a higher market value. The suspected fraud amounted to 31.6% of all biodiesel consumed in the Netherlands in 2015 and 22.6% in 2016 (ILT, 2019).
The investigated company was certified and could therefore issue a proof of sustainability for the UCOME it produced. The company was accused of selling unsustainable biodiesel as UCOME with a fake proof of sustainability (ILT, 2019). This biodiesel was not included in the mass balance of the company, so that this practice could not be detected by looking at the mass balance (Mijnheer, 2020). A criminal investigation has been started against the company. In 2019, the company went bankrupt after it lost its sustainability certification. Furthermore, on November 3rd 2020, the ILT announced that yet again a company is suspected of selling biodiesel with forged proofs of sustainability on a large scale. The books of this company have been confiscated, but no arrests have been made at the time of writing (ILT, 2020). The announcement does not mention the details of the case.

Weaknesses

Examining the literature on the biofuel certification and the Dutch fraud case of 2016, we identified the following weaknesses of the current system (regulations and market conditions):

Low transparency

The sustainable biomass certification system is intransparent, due to the complexity of the system, the high amount of paperwork, and the lack of data exchange. This gives companies more handles to commit fraud on paper. Some concrete example of intransparency:

- The physical properties of biomass feedstocks and biofuels may be altered through blending and splitting, as long as the mass balance of the seller is maintained. As a result, the composition of the physical streams of feedstocks and fuels may not be documented as such. Instead, the overall mass balance, which reflects the balance of in- and outgoing materials on an aggregate level, is described in the administrative documents. This makes it difficult to get an overview of the actual physical streams. This adds to the intransparency of the system, and makes it more prone to acts of fraud (NEa, 2016).
- Operators participate in different voluntary schemes, which makes it harder for auditors (certification bodies) to get an overview of biomass material volumes and transactions (EC, 2014).
- Auditors cannot look into each other's information systems, which makes it possible for operators to get a verification declaration for the same delivery from different auditors (NEa, 2016).
- The series of shipping transactions, where deliveries of feedstocks/fuels are disembarked, mixed, and embarked again makes it difficult to assess what the country of origin of a delivery is. Declarations often show large lists of countries. In addition, contracts are often written in different languages. This complicates the issuing of verification declarations by auditors (NEa, 2016).

Low traceability

Some voluntary schemes do not trace back the origin of the UCO (DfT, 2014; EC, 2014). If the chain of custody of UCO is not beginning at the origin, the collected volumes of UCO cannot be verified. Several voluntary schemes have placed the focus of the auditing process on the UCO collectors, who must document the sources and transactions of UCO in detail. This can help the auditor to verify the origin of the UCO. However, to verify the reported volumes from collectors it may still be necessary to check the books of restaurants and other UCO producers (EC, 2014). However, the number of UCO producers is high and keeping a UCO administration is not the core business of restaurants. Also, auditors are likely to have an incentive to save on auditing costs and limit audits at restaurants.

Opportunity for double bookkeeping

Certification bodies (auditors) have the task to check the books of operators (producers/ suppliers) and verify the volumes and sustainability of traded feedstocks and biofuels based on these feedstocks. The Dutch Emissions Authority has noted in 2016 that the operators themselves present the administration to the auditors, and that a double administration is not easy to detect by the auditors (NEa, 2016).

Lack of verification

The Commission's notes back in 2014 that there were often no detailed descriptions of verification procedures in voluntary scheme documents (EC, 2014), leaving room for scheme organisations and auditors to shape the verification process. Investigations by journalist movement Follow the Money (FTM) confirmed this (Mijnheer, 2019). The content of the UCOME is not checked physically. Auditors (certification bodies) do not rigorously check the mass balance and proofs of delivery of UCO/UCOME producers, they just check if parties have the right documents and work according to the right process. FTM spoke with an auditor, who stated that the yearly checks by certification bodies are often superficial. Leaving out deliveries from the mass balance can go unnoticed (Mijnheer, 2019). Biofuels industry association EWABA appears to agree that the auditing process should be improved: in a presentation from May 2019, the Secretary General of EWABA, Angel Alvarez Alberdi, stressed that the 'auditors objective is to find fraud, not to easily issue certificates', and that all volumes, purchases and sales of biofuels and feedstock should be checked (EWABA, 2019).

National authorities only monitor the companies that deliver biodiesel on the transport market, in order to check if they meet the yearly renewable energy obligations. The Dutch Emissions Authority (NEa) is not authorised to perform monitoring and verification activities upstream in the biofuel supply chain (NEa, 2016).

5.6 Displacement effects

The current system of monitoring and verification of the sustainability of UCO does create risks of displacement effects such as indirect land use change (ILUC), because the points of origin of the UCO can often not be traced back. In addition, auditors do not have to check if the export of UCO leads to the displacement of UCO with virgin oil in other markets. Unfortunately, the diversion of UCO currently used for the production of illegal 'gutter oil' in China and other countries to the production of UCOME is likely to cause displacement effects, despite having a positive effect on public health.

Furthermore, risks of fraud by adulteration of UCO with virgin oil go hand in hand with the risk of adverse environmental impacts due to increased production of virgin oils. This is also true for fraud by artificial increase of UCO production at restaurants.

5.7 Identified improvements

Early Commission guidelines

Back in 2014, the European Commission wrote a note to the voluntary schemes on verification of the chain of custody of biofuels made from waste and processing residues, noticing the non-transparency of the certification procedures and the related risks.
It emphasised three general points (EC, 2014):
- the whole chain of custody (supply chain) should be covered;
- all operators (producers/suppliers of feedstocks and biofuels) should be audited individually, except at the origin of the chain, where group auditing could be considered;
- the frequency and rigor of the auditing process should reflect the level of risk of non-compliance.

Although the Commission does not deem on-site audits at restaurants necessary, it thinks that auditors should have the possibility to conduct such audits. To facilitate the work of the auditors, the voluntary schemes should make sure that operators deliver all the required information to the auditors, including the full mass balance records for a site, previous audit reports and the list of voluntary schemes the operators participate in.

Finally, the Commission stresses that stricter procedures should not create a disproportional administrative burden to operators, as the use of genuine UCO as a sustainable feedstock for biofuels should not be discouraged (EC, 2014).

Proposed measures by International Sustainability & Carbon Certification (ISCC)

The occurrence of the Dutch fraud case has shown that the Commission's concerns were justified. For certification scheme organisation ISCC, who aims to manage a 'leading certification scheme for waste and residues', this case was a trigger for action.[30]
It has withdrawn the ISCC certificate of the company and has put the company on the list of suspended system users. Furthermore, the ISCC has developed a proposal for the strengthening of its certification process, especially regarding waste and residue supply chains, which includes the following measures (ISCC, 2019a; 2019b):
- stricter audit requirements, including double-checks of transactions and feedstock/fuel deliveries and inspections of deliveries;
- a 'whistle-blower' section on its website;
- expansion of the ISCC Integrity Program with more supply chain assessments;
- a training program for system users and auditors;
- a database to support supply chain data exchange and facilitate double-checks of transactions;

[30] About fourteen schemes have been recognised by the Commission (EC, DG Energy, 2020), but it is unclear to what extent each of these are used by UCO/UCOME suppliers, and whether scheme organisations other than ISCC plan to strengthen their certification processes as well.

- requiring operators (suppliers/producers) to report received and supplied amounts of feedstocks and fuels to ISCC on a quarterly basis (which ISCC can share with the auditor);
- risk mapping of the supply chain;
- stricter sanction mechanisms, such as fines and the publication of information on withdrawn certificates;
- communication with other voluntary schemes about risks and sanctions.

Proposed measures regarding the stricter audit requirements include (ISCC, 2019b):
- Auditors (certification bodies) and ISCC are entitled to double-check and verify feedstock/biofuel deliveries received from upstream suppliers and sent to downstream recipients.
- Auditors must verify the existence of a sample of points of origin.
- If the operator (supplier/producer) has multiple storage sites, the auditor should audit the mass balance of each site.
- The physical properties of 'live' deliveries should be checked. Auditors should be trained in identifying common biofuel feedstocks, in particular UCO, palm oil mill effluent (POME), brown grease, virgin palm oil and tallow.
- Guidance by ISCC to auditors on 'typical documents' that should be verified at different operators in the supply chain.

Improvements embedded in RED II

The RED II does already include measures that intend to mitigate the risks of fraud. This includes the creation of a central database with which all biofuels can be traced. In addition, the Commission will introduce detailed certification rules that must be followed up by the voluntary schemes (EURACTIV, 2019a). These rules will be part of an implementing act that is expected to be enforced in 2021.

To create the central database, a blockchain-compliance database called Bioledger is under development. Bioledger is designed in cooperation with the Roundtable on Sustainable Biomaterial (RSB), certification bodies and the waste-based biodiesel sector to support compliance with the chain-of-custody requirements in all of the voluntary schemes. It will replace the paper documents with digital evidence. Only UCO collectors will be allowed to create volumes in the database, taking away opportunities of committing fraud on paper. Suspicious volumes in the database will be flagged, easing the tasks of auditors and regulators. Bioledger is scheduled to go live in 2020 and can then be used voluntarily by operators in the supply chain, but the database is intended to become mandated by the Commission and by national regulators as part of the RED II later on (Argus, 2020a).

Improvements in Member States

Spanish regulator CNMC has updated the national biofuels framework in July 2020 to tackle 'possible fraud risks' related to double-counted biofuels. The new decree will oblige producers to provide digitally signed verification of the sources and quality of feedstocks and biofuels production *each month*, as well as annual reports. The CNMC will cross-check the gathered data (Argus, 2020b).

5.8 Conclusion

Current rules and regulations lead to a non-transparent certification process of the sustainability of UCO and UCOME. Together with the difficulty to detect adulteration of UCO with virgin oil, risks of fraud exist. The case of suspected fraud in the Netherlands testifies to that. However, the RED II does already include measures to improve the monitoring and verification of the sustainability of UCO and UCOME, and voluntary scheme ISCC is taking measures on its own to strengthen the certification process. Furthermore, industry association EWABA is developing a system for detecting adulterated UCO. Recent laboratory studies indicate that it is indeed possible to create an effective detection method. However, such a method should be thoroughly tested, in order to check if it can identify virgin oil that has been processed to make it look like UCO.

The lack of traceability of the origin of UCO and the risks of fraud create risks of displacement effects: if virgin oil is mixed with UCO and more UCO is produced artificially (due the higher economic value of UCO), it will lead to increased virgin oil production, which may cause adverse environmental impacts such as indirect land use change.

6 Conclusions

An overview of our main conclusions on demand and supply of UCOME is shown in Table 29. Current EU+UK UCO and UCOME supply is 2.1-2.6 Mton/year, which consists of UCOME that is produced from UCO that is both collected within the EU+UK (0.7-1.2 Mton/year) and imported (1.4 Mton/year). The highest estimate of supply for the EU+UK (both from EU+UK and non-EU+UK countries) equals current EU demand for UCO/UCOME, 2.8 Mton/year.

Literature sources for the maximum worldwide potential of UCO and UCOME production show a range from 3.1 to 3.3 Mton/yr. Much higher values (up to 34 Mton/yr) are also reported in literature, but the assumptions used and the extent to which UCO demand for other applications is taken into account are not clear. These estimates are given for past years, but because it will require strong efforts to establish collection systems and improve collection rates it probably will take the next decade to reach the global maximum potential.

At the same time UCOME demand in the EU+UK is likely to exceed the maximum potential in the EU+UK (including imports): the RED II could more than double the demand for UCOME, up to 6.1-6.4 Mton/yr in 2030 (in a scenario where all member states reach a 1.7% share of UCOME in transport fuels including aviation and shipping). In this scenario, we expect that about 17-19% of this demand, 1.0-1.1 Mton, would be used in aviation, the remainder in the other transport modes.

If UCOME is also used to contribute to the global ambitions for renewable fuels in transport in 2030, global demand will grow significantly. To illustrate this: to achieve the projected EU share of UCOME in renewable transport fuels on a global scale in 2030 (11-15%), 27-37 Mton/yr UCO/UCOME will be needed. The policy developments in aviation and maritime shipping are particularly relevant here, since alternative fuels are expected to play a crucial role in achieving their climate ambitions. Future demand could be limited by higher volumes of other low carbon and zero emission fuels, but this requires substantial efforts given the current status of for example advanced fuels form Annex IX A feedstocks and e-fuels.

Table 29 - Demand and supply of UCO/UCOME, for the current situation and the potential in 2030

		Current situation (2019)	Potential for 2030
		Mton/yr	Mton/yr
Demand	EU+UK	2.8	6.1-6.4
	Global	5.12	
	Potential global demand as a transport fuel*		27-37
Supply	EU+UK (excl. imports)	0.7-1.2	1.7
	Imports to EU+UK	1.4	1.4
	Total supply EU+UK	2.1-2.6	3.1-3.3

*Assuming that in 2030 the global share of UCOME in renewable transport fuels equals that of EU (11%-15%).

A high demand combined with limited supply requires strong rules and regulations, to prevent undesired displacement effects as well as fraud. The current rules and regulations have led to a non-transparent certification process of the sustainability of UCOME.

This, and the difficulty to detect adulteration of UCO with virgin oil, create risks of fraud. Weaknesses in the certification process are also applicable to other biofuel feedstocks, but due to the higher economic value of UCO fraud risks are more linked to UCO than to other feedstocks.

The European Commission and stakeholders are taking actions to limit these risks:
- the RED II does include measures to improve the monitoring and verification of the sustainability of UCO and UCOME;
- the voluntary scheme ISCC is taking measures on its own to strengthen the certification process;
- industry association EWABA is developing a system for detecting adulterated UCO;
- and the Bioledger project is working on a blockchain-based compliance database.

It has not been studied when these actions could have an effect and to what extent they will be sufficient to limit the risks. Without effective mitigation measures, illegal adulteration of UCO with virgin oil might result in displacement effects and increased GHG emissions. These effects can also occur when selling UCO for UCOME becomes more attractive than gutter oil practices, where UCO is illegally mixed with virgin oil for human consumption. Although desirable from a health perspective, an increase in virgin oil to replace the use of gutter oil in cooking could cause indirect land use change.

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