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Implications of Imported Used Cooking Oil (UCO) as a Biodiesel Feedstock

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NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and biobased products.

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1 Executive Summary

Biodiesel is a class of transport fuel which includes Hydrogenated Vegetable Oil (HVO) and Fatty Acid Methyl Esters (FAME), produced from either vegetable oils or animal fats. Intended as a replacement for fossil-derived diesel, FAME biodiesel forms a significant component of the total renewable fuels supplied in the UK; between April 2017 and April 2018, nearly half of the 1,600 million litres of renewable fuel supplied in the UK was biodiesel.

The dominant biodiesel feedstock for biodiesel consumed in the UK is Used Cooking Oil (UCO), defined as the purified oils and fats of plant and animal origin that have been used to cook food. Since the BSE crisis European UCO is classified as a waste that is no longer fit for human or animal consumption, placing legal limitations on its collection and disposal; this resulted in it becoming a well-regulated feedstock for biodiesel sold on the market. Its utilisation as a biodiesel feedstock therefore increased significantly within the EU – between 2011 and 2016 there was a 360% increase in its use, rising from 0.68 million tonnes to 2.44 million tonnes in just 5 years driven by supporting renewable fuel policies, particularly in the UK, to incentivise its use.

Although European UCO from a quality perspective is relatively consistent, certain variables such as the characteristics of the base edible oil and the cooking conditions to which it has been subjected – including the number of times the oil has been used and how it has been stored – can directly influence the quality of the resulting waste product. Collation of UCO from different sources can therefore result in heterogenous feedstock streams., impacting the composition of the final product. Standardising the characteristics of UCO is therefore inherently difficult.

In addition to the heterogeneous nature of UCO, it is important that the energy associated with transporting and manufacturing UCO is minimised as much as possible in order to reduce GHG emissions. The GHG reduction delivered by UCO-derived renewable fuels are significant (typically of the order of 80-90% compared to fossil fuel). As the feedstock is classed as a waste in the EU, only the energy used in its transportation and the biofuel conversion process are used to calculate its GHG efficiency.

To meet the growing demand for UCO, sourcing and importing from outside the EU (predominantly Asia) are the only legitimate options for increasing its supply. However, as there are no current globally agreed standards for UCO, suppliers are only required to meet the operator's specifications, resulting in a wide variety of qualities and chemical compositions.

The net imports of UCO and UCO-based FAME biodiesel (UCOME) to the EU and UK have significantly increased since 2014, with a large proportion of this sourced from China, Indonesia and Malaysia. Consequently, in 2018 alone these 3 countries exported more than 500,000 tonnes of UCO into the EU, with around 15% of this delivered to the UK. This reliance is set to continue, with the imports of Chinese UCO into the EU increasing by 5.6% in Q1 of 2019 when compared to Q1 of the previous year.

Due to the reliance on palm within the Chinese, Indonesian and Malaysian food industries, their resulting UCO and UCOME is likely to fundamentally differ to that generated within the EU. Unlike European-grown oilseed rape, palm oil is high in saturated fatty acids – the resulting UCO will therefore have comparable fatty acid contents and chemical properties. This will impact the performance of the produced biofuel; palm oil has a high pour point meaning that, without the addition of cold flow improvers (CFIs), the biodiesel produced from palm UCO will likely gel in colder temperatures, causing engine failure.

Provenance of the UCO is therefore very important as it will make a huge difference to the properties it imparts to the resultant biofuel, especially in the colder winter months in the Northern Hemisphere. UCO sourced from the EU should not be assumed to be the same as that sourced from other parts of the world. For example, Chinese UCO contains a large volume of gutter oil – a crudely produced, 'illegal' cooking oil – which has high levels of rancidification, resulting in a poor-quality feedstock and biofuels that could have hidden problems.

Without a proper understanding of the current volumes of waste oil generated, it is almost impossible to confidently substantiate the GHG savings associated with the feedstock, or if additional wastes and/ or unsustainable virgin materials are being produced and used as a result of the EU's policy support for imported UCO. This is further exacerbated by the possible inclusion of 'non-waste materials' within the UCO waste stream. High-grade waste vegetable oils that are deemed safe for consumption by animals outside of the EU (and are therefore not waste materials) are redirected from animal feed to biofuel production as the EU based fuel suppliers will pay more for a waste-derived biofuel than they would for virgin oil. Consequently, where used cooking oil was being used for animal feed it is now replaced by cheaper virgin oils such a palm, although their replacement within the supply chain – most likely goes unchecked. Indeed, although correlation does not necessarily equate to causation, the available evidence indicates that palm oil imports to China are increasing, in line with their increasing exports of UCO.

If these arguments are connected, then there would be potential for significant indirect land use change (ILUC) implications when imported UCO is used as a feedstock for biodiesel production. Furthermore, if imported UCO is to continue as a double counting feedstock, then confidence in its supply chain should be paramount; the certification process of UCO – specifically when sourced from outside the EU, where it is likely to be used as an animal feed – should be more robust, helping to ensure that the feedstock meets comparable levels of traceability and sustainability. This has recently gained publicity in the Netherlands, with alleged fraudulent activities relating directly to biodiesel production from UCO currently under investigation. Significant volumes of their supplied biodiesel in 2015 and 2016 were incorrectly designated as sustainable, with double-counting credits – that can be traded on the market – claimed as a result.

Undoubtedly, the use of legitimate UCO waste streams in biodiesel production offer an excellent pathway for reducing GHG emissions within the transport sector, however it's important to recognise that their use will not solve other issues like poor local air quality – especially in areas that have prominent issues with congestion.

2 Introduction

The ever-increasing threat of rising global temperatures and the consequences of irreversible climate change has prompted national governments to implement a range of policies to combat these increasingly negative factors. The UK has seen a marked decrease in the GHG emissions associated with electricity generation – due, amongst other actions, to the extensive roll out of low emission, offshore wind turbines – but the story surrounding UK transport emissions is not as promising. Unlike other areas of the UK economy, the transport sector has struggled to reduce its emissions relative to its 1990 baseline; indeed, between 1990 and 2017 the GHG emissions from this sector reduced by less than 1%,[1] as demonstrated by Figure 1.

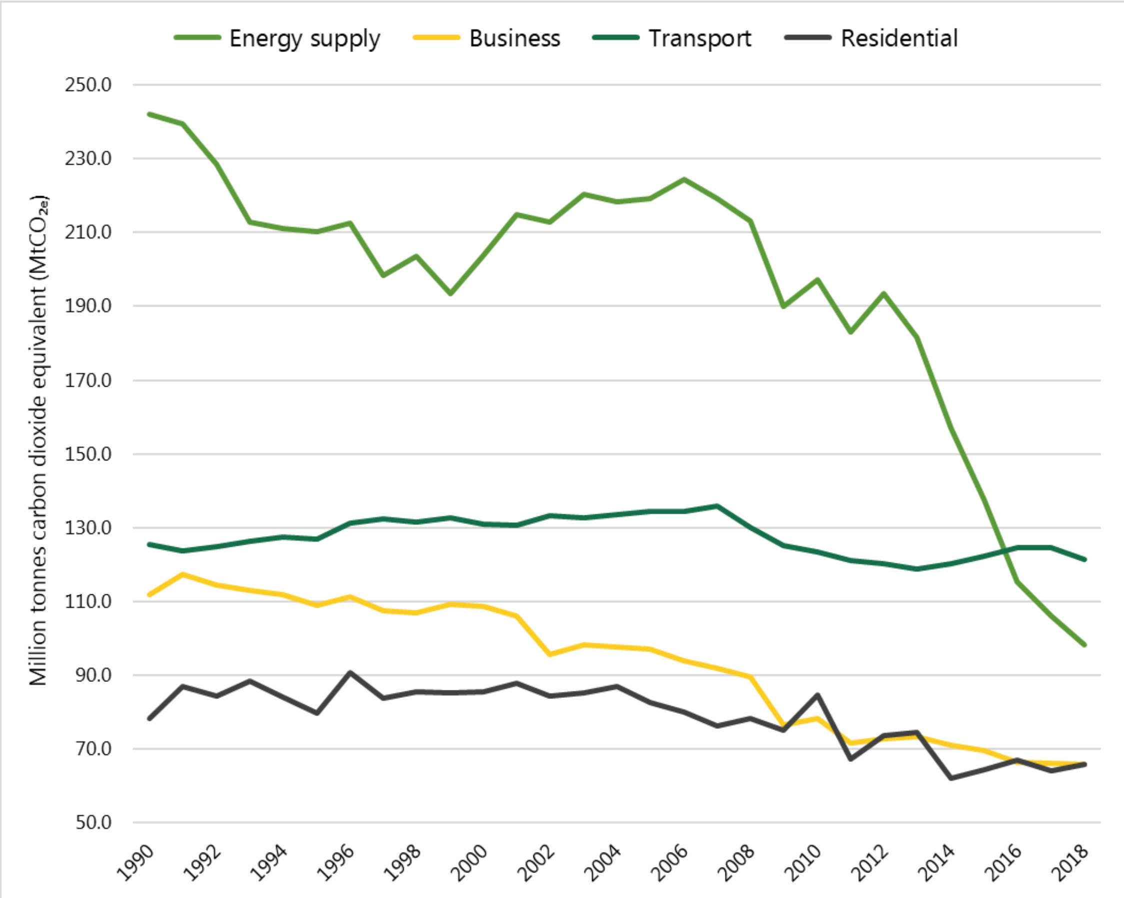

Figure 1 – UK carbon dioxide equivalent (CO_{2e}) emissions by sector, 1990-2018[1]

One of the UK government's main policies for reducing GHG emissions in transport has been via the Renewable Transport Fuel Obligation (RTFO), introduced in 2008.[2] Following the RTFO's launch, transport emissions have reduced by ~7%, due predominantly to the introduction of alternative fuels such as bioethanol and biodiesel.

[1] https://www.gov.uk/government/collections/provisional-uk-greenhouse-gas-emissions-national-statistics
[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/694277/rtfo-guidance-part-1-process-guidance-year-11.pdf

2.1 What is FAME Biodiesel?

Biodiesel is a simplified term, often used in reference to transport fuel produced from long-chained Fatty Acid Methyl Esters (FAME), derived from either vegetable oils or animal fats. Intended as a replacement for fossil-derived diesel, biodiesel is deemed attractive as its use reduces carbon dioxide (CO_2), carbon monoxide (CO) and particulate matter (PM), when compared to its fossil alternative.[3] While unmodified (virgin) vegetable oils can be used as transport fuels they are limited by their poor viscosity, combustion speed and increased tendency to induce fuel injector fouling making virgin oils – particularly their triglyceride component – unsuitable for direct use in transport.

Therefore, FAME production is simply a means to use the energy contained in vegetable oils in the fossil diesel pool. This is achieved by reacting the triglyceride molecule with an alcohol and a catalyst, like a metal hydroxide or an inorganic acid, forming three esters from the fatty acid chains and glycerol. In biodiesel production this is most often achieved using methanol due to its low cost, producing methyl esters of straight-chain fatty acids. Ethanol can be used as an alternative alcohol, resulting in the production of Fatty Acid Ethyl Esters (FAEE), although this type of biodiesel is uncommon.[4]

2.2 Biodiesel Feedstocks

The most established pathways for biodiesel production include edible and non-edible vegetable oils, waste cooking oils and animal fats; more unorthodox feedstocks include algae, microalgae and fungi; however, these tend to have alternative high-value applications in pharma or nutraceuticals. Of the traditional feedstocks, one of the most prevalent are oil-bearing plants and many species exist that could be utilised. The fatty acid composition differs greatly between species, which results in oils with a range of physical and chemical properties; the choice of feedstock is therefore a vital parameter, influencing the composition of the oil and the final quality of the biodiesel product.[5]

Table 1 - Fatty acid composition (wt%) of different oil and fat sources for biodiesel production[6]

Fatty Acid	Soybean	Palm	Rapeseed	Tallow
Myristic (C14:0)	*0.1*	*1.0*	*1.0*	*0.8*
Palmitic (C16:0)	*0.2*	*42.8*	*5.5*	*23.3*
Stearic (C18:0)	*3.7*	*4.5*	*2.2*	*19.4*
Oleic (C18:1)	*22.8*	*40.5*	*55.0*	*42.4*
Linoleic (C18:2)	*53.7*	*10.1*	*24.0*	*10.7*
Linolenic (C18:3)	*8.6*	*0.2*	*8.8*	*0.4*

[3] https://www.tandfonline.com/doi/abs/10.1080/17597269.2017.1336350?journalCode=tbfu20
[4] https://link.springer.com/chapter/10.1007/978-1-84628-995-8_5
[5] https://www.sciencedirect.com/science/article/pii/S0734975010000388

Fundamentally, fatty acids – such as Palmitic (C16:0) or Oleic (C18:1) acid – can differ in two ways; by their carbon chain length and the number of unsaturated bonds. In turn, as demonstrated in Table 1, the fatty acid composition of different feedstocks may vary between each other – for example, palm oil contains a greater weight percentage (wt%) of palmitic acid (a saturated fatty acid, due to its lack of double bonds) when compared to rapeseed oil, which instead has a larger composition of the unsaturated linoleic and linolenic acids.[6]

The fatty acid composition of a feedstock – particularly their distribution between saturated and unsaturated fats – can directly impact the quality, and therefore the suitability, of the biodiesel. Unsaturated fatty acids have significantly lower melting points, crystallising at lower temperatures affording a final fuel that could have detrimental Cloud Point and Cold Filter Plugging Point (CFPP) properties. Producing biodiesel from unsaturated fatty acids will result in a fuel with lower cloud and pour points – it will therefore remain liquid at lower temperatures, making the fuel more suitable for use in locations with colder seasonal temperatures, such as the UK and Scandinavia.[7]

Within the UK there is routine quality testing completed at refineries, terminals and refuelling stations; in 2016 this equated to 1 fuel quality test, comparing the fuel against the EN590 fuel standard, for every 5.3 million litres of supplied diesel. Although there are clearly robust safeguards put in place to avoid issues with fuel quality, there is the potential for these issues to be missed.[8]

2.3 Biodiesel Production in the EU

In 2017, the EU28 had an annual biodiesel production capacity of ~21,000 million litres with a large proportion of this located in Germany, Spain, the Netherlands, France and Italy. The EU's biodiesel generation capacity has reduced since 2011, as demonstrated in Figure 2, with the mothballing of several major plants due to poor market conditions. As a result, in 2017 EU facilities were responsible for producing ~15,000 million litres of biodiesel.[9]

The introduction of anti-dumping measures by the EU in 2013 – aimed at Argentinian and Indonesian biodiesel producers – reduced the fuel suppliers' reliance on cheap imports, helping to protect EU fuel producers. However, these were removed following successful legal challenges, prompting an increased volume of biodiesel imports in 2017. To alleviate pressure, the European Commission came to an agreement with Argentina, imposing anti-subsidy measures on biodiesel imports from the country, while in exchange agreeing to sustainable price commitments and an import limit.[10,11]

[6] https://www.sciencedirect.com/science/article/pii/S0959652619302008
[7] https://biodiesel.org/reports/20050218_gen-358.pdf
[8] https://www.eea.europa.eu/publications/fuel-quality-in-the-eu
[9] http://www.ebb-eu.org/stats.php
[10] https://uk.reuters.com/article/us-eu-biodiesel-analysis/europe-struggles-to-stem-biodiesel-import-flood-idUKKCN1GJ2I9
[11] http://trade.ec.europa.eu/doclib/press/index.cfm?id=1979

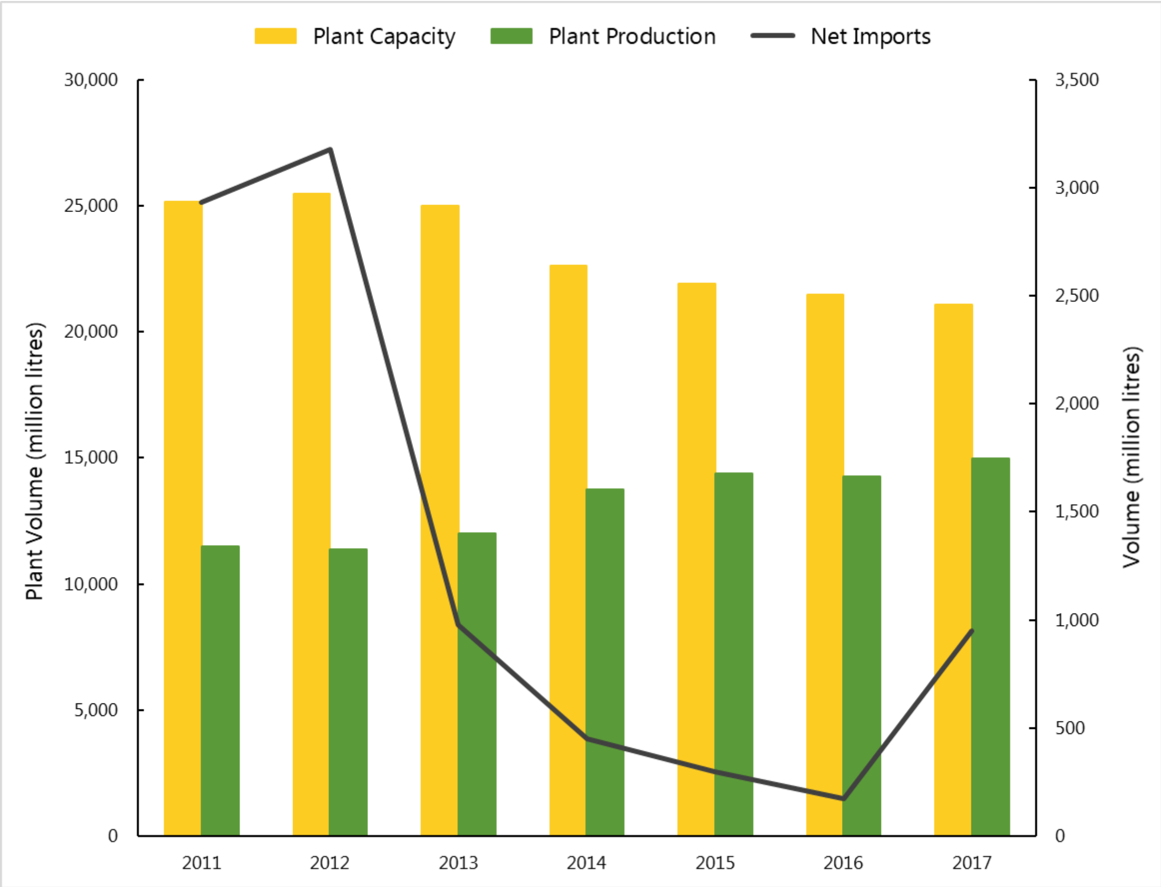

Figure 2 - EU biodiesel production and imports (2011-2017)[12]

In the UK, between the 12 months from April 2017 to April 2018 – more than 1,600 million litres of renewable fuels were supplied, representing 3.1% of the nation's total road and non-road mobile machinery fuel. Of this total, nearly 50% was accounted for by biodiesel with the vast majority produced from used cooking oil (UCO).[13]

3 Used Cooking Oil (UCO)

Used cooking oil (UCO) can be referred to by a variety of different terms – including waste cooking oil, used frying oil, yellow grease etc – however these all refer to the same commodity; purified oils and fats of plant and animal origin that have been used to cook food. UCO is deemed a waste that is no longer fit for human consumption, prompting its inclusion as an acceptable feedstock for 'double counting' towards the biofuel targets set out within the Renewable Energy Directive (RED).[14] In the UK, UCO has been classed as a double counting feedstock since 2011. As a double counting feedstock, suppliers of biofuels produced from UCO will receive double the number of renewable transport fuel certificates (RTFCs) – which are used by the Government to check if suppliers are compliant with the

[12] https://www.fas.usda.gov/data/eu-28-biofuels-annual-0
[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/782482/rtfo-year-10-report-6.pdf
[14] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

regulations. The certificates also have a monetary value, dictated by the principles of supply and demand, and can be openly traded on the market.[15]

The growing supply of UCO – and its consequent exploitation as a 'double counting' feedstock in biodiesel production – can be linked directly to an ever-increasing demand for edible oils. This is apparent in both domestic cooking and industrial food production, with vegetable- and animal-based oils and fats being increasingly used, particularly for frying food. As a waste, the inappropriate disposal of UCO can have major environmental issues – when discharged into the sewerage systems, UCO can impact the operation of wastewater treatment plants.[16]

Within the European Waste Catalogue, UCO is classified as municipal waste, grouped under the edible oils and fats code (20 01 25). UCO sourced from restaurants, catering sites or commercial/household kitchens is defined as catering waste by the UK government and, as such, must be stored and disposed of accordingly. It is a legal requirement in the UK that the UCO produced by catering premises and restaurants is collected by an authorised collector; these are usually specialised waste collection companies that aid the recovery or disposal of the waste oil.[17]

Although domestic catering waste produced within the UK is deemed as low risk, its use in farm animal feed is forbidden. Previously UCO was added to farm animal 'rations' as a cheap and effective way of increasing the calorific value of the feed. However, this practice was halted as a result of high-profile incidents and by halting its use, the spread of diseases, such as swine fever and avian influenza, is thought to have greatly reduced.[18] High-grade filtered oils sourced from food manufacturing industries – such as crisp and chip producers – can be used in farm animal feed, as long as the oil is uncontaminated, having had no contact with meat and animal fats.[19] In general, removing access to the animal feed market for low-grade UCO has created opportunities for alternative pathways for waste oils, predominantly as a biodiesel feedstock.

3.1 Properties of UCO

As highlighted in Table 1, the fatty acid composition of edible-oil feedstocks differs – often significantly – impacting their properties and suitability as a biodiesel feedstock. This is especially important when considering the properties of UCO; the characteristics of the initial edible-oil used for frying will directly influence those of the waste product. Additionally, the cooking conditions employed will also affect the quality of the UCO feedstock; this includes the number of times the oil has been used, the food types fried within the oil and the storage of the oil between uses. During frying there are several chemical processes that take place, resulting in the deterioration of the oil; these include oxidation, hydrolysis and polymerization.[20]

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15 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/740218/rtfo-guidance-feedstocks-including-wastes-and-residues-year-11.pdf
16 https://www.sciencedirect.com/science/article/pii/S1364032115010096
17 https://www.food.gov.uk/business-guidance/food-and-cooking-oil-waste#animal-feed-waste
18 https://www.gov.uk/guidance/how-food-businesses-must-dispose-of-food-and-former-foodstuffs
19 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1017&from=EN
20 https://link.springer.com/article/10.1007/s13197-011-0452-7

The first major consideration of the UCO's properties relates to its saturated fat content. As discussed above, higher concentrations of saturated fatty acids can result in a fuel that has operational issues at lower temperatures. Following the characterisation of fatty acid compositions of edible-oils before and after frying, the saturated fat content has been shown to increase, possibly as a result of the hydrogenation of some of the oils and fats.[21] This is important when considering UCO feedstocks originating from edible-oils that are already high in saturated fat; for example, as shown by the data in Table 1, if palm is used for frying then the saturated fat content of the resulting UCO could be problematic.

Another important consideration of UCO quality is the free fatty acid (FFA) content of the feedstock. FFAs are long carbon chain organic acids that have hydrolysed and become disconnected from the triglyceride backbone s; these are therefore classed as impurities and must be removed before the transesterification process. Refined oil tends to have an FFA content below 0.5 wt% which is ideal for biodiesel production, however in UCO this can range between 0.5 and 15 wt%; without more sophisticated equipment, UCO's with FFA's above 3 wt% can result in increased processing problems, producing soaps which effectively reduce the yield of the target methyl esters.[22,23]

The FFA content of UCO can be greatly influenced by cooking practices, differing significantly between domestic and industrial sources. Increased frying time has been shown to cause degradation of the oil, increasing the FFA content of the UCO. However, the deterioration can be exacerbated further by short batch frying processes; intermittent cooking, involving the heating and reheating of the oil several times, increases the likelihood of oxidation and hydrolysis, impacting the quality when compared to continued frying. This also results in a more viscous and acidic UCO,[24] which again can impact its suitability as a feedstock for biodiesel.

The different sources of UCO – both in the original raw material used and the cooking practices employed – results in a biodiesel feedstock that has the potential to be heterogenous. Standardising these characteristics is therefore inherently difficult and shouldn't be assumed without knowledge of the initial feedstocks. During the last decade a number of published academic review papers (see references 6, 21, 22) have attempted to detail the properties of UCO, however the stated figures – intimating a level of homogeneity – are often based on experimental work that is conducted on a small set of samples. These results have often been repeated within the literature and referenced as definitive, accepted figures for UCO, giving the impression that UCO from one part of the world will be the same as any other. This is unlikely to be the case.

3.2 Used Cooking Oil Methyl Ester (UCOME)

Before it can be used as a feedstock for producing transport fuel, the collected UCO must first be cleaned to remove any impurities and solids that exist as a result of the cooking process. This includes sieving to physically remove solids, degumming to remove phospholipids and de-watering. In addition to this, deacidification is often required, with UCO tending to be more acidic than the original

[21] https://www.sciencedirect.com/science/article/pii/S0960852409006981
[22] http://www.eubia.org/cms/wiki-biomass/biomass-resources/challenges-related-to-biomass/used-cooking-oil-recycling/
[23] https://www.sciencedirect.com/science/article/pii/S1364032112005588
[24] https://www.sciencedirect.com/science/article/pii/S0378382006000762

edible-oil sources. Pre-treatment is particularly important when considering the conversion of UCO into biodiesel; the produced fuel must meet EN 14214 standards in the EU and ASTM D 6751 in the United States.[25]

As stated in the previous section, the concentrations of FFAs in UCO can have a large impact on the transesterification reaction; if FFA's are in excess of 3 wt% then saponification (soap formation) can occur, causing a reduction in biodiesel yield while also increasing the catalyst consumption. In addition to this, the presence of water within the feedstock can lead to hydrolysis which will also affect the efficiency of the conversion process. Consequently, several different mechanical and chemical methods have been developed to reduce the FFA and water content, while also neutralising the UCO.[26]

Once the UCO has been pretreated, the transformation of the waste feedstock into methyl esters is similar to that of virgin oils and fats – resulting in equivalent fuel properties. As with edible-oil feedstocks that are high in saturated fats, any issues with crystallisation at low temperatures requires the addition of cold flow improvers to the produced UCOME to ensure its usability.[27]

3.2.1 UCOME in the EU

There is already a well-established European UCOME market, with UCO – sourced from EU member states – an important feedstock in biodiesel production; there are an estimated 3.5 million tonnes of potential UCO capacity, available within the EU.[28] Between 2011 and 2016, the utilisation of UCO has increased steadily, resulting in a 360% rise in its use, increasing from 680,000 tonnes to 2.44 million tonnes.[29] The prominent users of UCO within the EU28 in addition to the UK are Germany, Italy, the Netherlands and Spain.

Up until 2003, UCO was utilised extensively as a high-fat supplement in animal feeds; however, as previously discussed, the outbreak of BSE – and its capacity to spread to humans via the consumption of prions – helped prompt the banning of UCO as a feed supplement, resulting in its classification as a waste. There are now legal limitations placed on the collection and disposal of UCO as a waste – including European regulations, directives and decisions – that have resulted in it becoming a well-regulated feedstock, attaining certain levels of quality.[30]

In addition to this quality, the traceability and sustainability of the UCO generated in the EU – specifically the oil from where it originates – is well established. Rapeseed is the most prominent oilseed grown in the EU; with nearly 22 million tonnes produced in 2017, rapeseed represents around 63% of the EU's total oilseed production.[31] Around 60% of the rapeseed oil produced in the EU is used to produce transport fuels – namely biodiesel – however, as it is an edible-oil with low saturated fat

[25] https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biofuel_marketplace_biofuel_standards_for_transport_in_the_eu.pdf
[26] https://www.sciencedirect.com/science/article/pii/S096195340300206X
[27] https://www.sciencedirect.com/science/article/pii/S0378382012004614
[28] https://www.greenea.com/wp-content/uploads/2016/09/Greenea-Presentation-July-2016.pdf
[29] https://bioenergyeurope.org/statistical-report-2018/
[30] https://www.epure.org/media/1418/ecofys-2016-low-carbon-biofuels-for-the-uk.pdf
[31] https://www.fediol.eu/data/1536656566Stat%20seeds%202017.pdf

contents and a high smoke point, a proportion of the EU's rapeseed oil is used within the food industry in processes such as frying.[32]

3.2.2 Proposed benefits of UCOME

As UCO is deemed no longer fit for human or animal consumption, the EU legally recognise it as a waste and its disposal is carefully regulated. When considering the UCO produced within the UK, the alternative end-use options, other than biodiesel production, are either incineration or deep landfill which can be costly; as of 1st April 2019, the current standard rate for landfill disposal in the UK is £91.35/tonne.[33] The production of UCOME therefore reduces the amounts of waste sent to landfill – benefitting the UCO generator economically – while also resulting in a feedstock that can be used within the transport sector, reducing its associated GHG emissions.

The default carbon intensity value of biodiesel produced from UCOME is currently defined at 14 gCO_2e/MJ, representing a carbon saving of 83% when used as a replacement to diesel. In comparison, biodiesel from oilseed rape, soy and palm have associated carbon intensity factors of 52, 58 and 68 gCO_2e/MJ, respectively, equating to carbon savings that range from 19-38%.[34] These crop-derived feedstocks for biodiesel do not meet the 50% (latterly 60%) GHG savings threshold required by the RED, therefore – when considering the stated carbon intensity values – UCOME is seen as a preferable alternative fuel for reducing emissions.

The benefits of UCO also extend to the financial commitments of producing and supplying UCOME fuel. In the amended version of the renewable energy directive (RED), the use of double counting biofuels – of which UCO is an eligible feedstock – has been actively promoted by the European Commission, specifically their double counting towards renewable energy targets.[35] As stated above, UCOME supplied in the UK receives double RTFCs for every litre, helping to support and promote its development ahead of other crop-derived fuels.

In addition to its potential for mitigating climate change impacts and achieving an increased revenue, the production of biofuels from waste oil – as a replacement for oil-producing crops – can help to improve food security.[36] Although the use of UCO is widely supported within the EU, particularly that produced by member states, there is a growing demand for it as a resource. This has resulted in the establishment of global UCO markets, although the reductions in feedstock traceability and sustainability – in addition to concerns over quality – has prompted concern over the proposed benefits of imported UCO.

4 Demand for Biodiesel Feedstocks

Although biodiesel feedstock prices tend to differ between one another – a result of varying supply- and demand-based factors – their potential use in transport fuel production has caused them to be linked, with major global events often affecting the individual feedstock prices in a similar manner.

32 http://www.neoda.org.uk/rapeseed-oil
33 https://www.gov.uk/government/publications/rates-and-allowances-landfill-tax/landfill-tax-rates-from-1-april-2013
34 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/694300/rtfo-guidance-part-2-carbon-and-sustainability-year-11.pdf
35 http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/603972/EPRS_BRI(2017)603972_EN.pdf
36 https://www.sciencedirect.com/science/article/pii/S0960852412018627

There are visible correlations of price changes between the three dominant edible-oil based feedstocks used in transport fuel production, as shown in Figure 3, however rapeseed and soybean have traditionally commanded a higher price than palm due primarily to their lower yields and higher agro-chem packages.

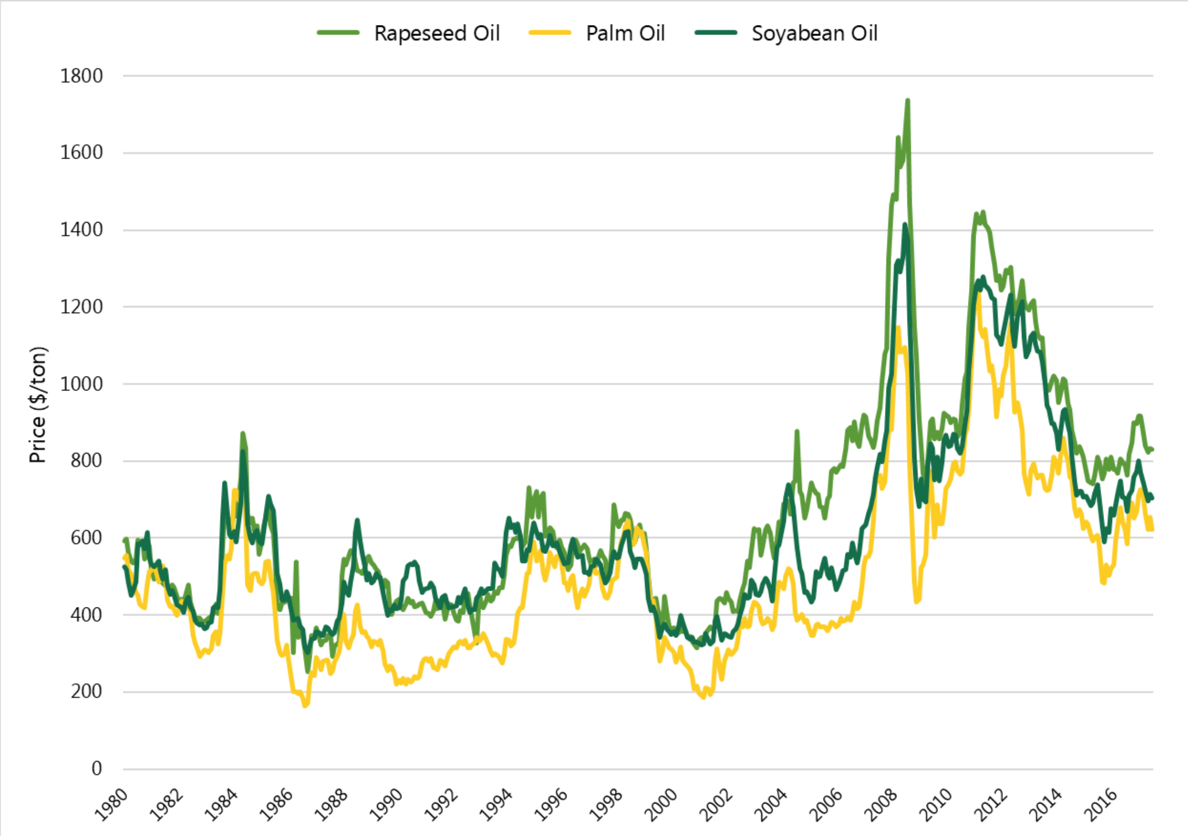

Figure 3 - Global price changes for rapeseed, palm and soybean oil (1980-2017)[37]

UCO has become a competitive commodity for use in biodiesel production, particularly due to its credentials as an eligible feedstock for double counting biofuels. Indeed, at the beginning of May 2019, the market price for UCO was around $620/t, making it a more valuable commodity than crude palm, priced at around $530/t.[38]

4.1 Palm Oil

Palm offers a cheap and versatile feedstock that has applications within several different global markets, however the environmental and ecological impact related to its cultivation has increasingly brought the sustainability and long-term suitability of palm oil use into question. The high yield and low production costs for palm oil – particularly when compared to rapeseed and soybean alternatives – resulted in a major surge in production between 1980 and 2014, increasing output from 4.5 million to 70 million tonnes a year. Market projections indicate that peak palm demand has yet to be reached, with its growth as a commodity expected to continue for several decades.[39] By 2018 the global

[37] https://fred.stlouisfed.org/categories/32217/downloaddata
[38] https://www.argusmedia.com/en/bioenergy/argus-biofuels
[39] https://www.iucn.org/sites/dev/files/iucn_issues_brief_palm_oil_and_biodiversity.pdf

production of palm oil had reached 73 million tonnes, making it the largest source of edible oil; in comparison, during 2018 there was 57 million tonnes of soybean oil and 28 million tonnes of rapeseed oil produced.[40]

Though palm oil is used for many different products, ~75% of its total volume is currently used within the food industry, predominantly as a cheap cooking oil for commercial frying.[41] The large quantities of available palm oil and the cheap production costs has kept its price low, relative to other edible oils. This has resulted in palm becoming the dominate oil used within Africa and Asia, with about half of the world's population dependent upon palm oil as part of their diet.

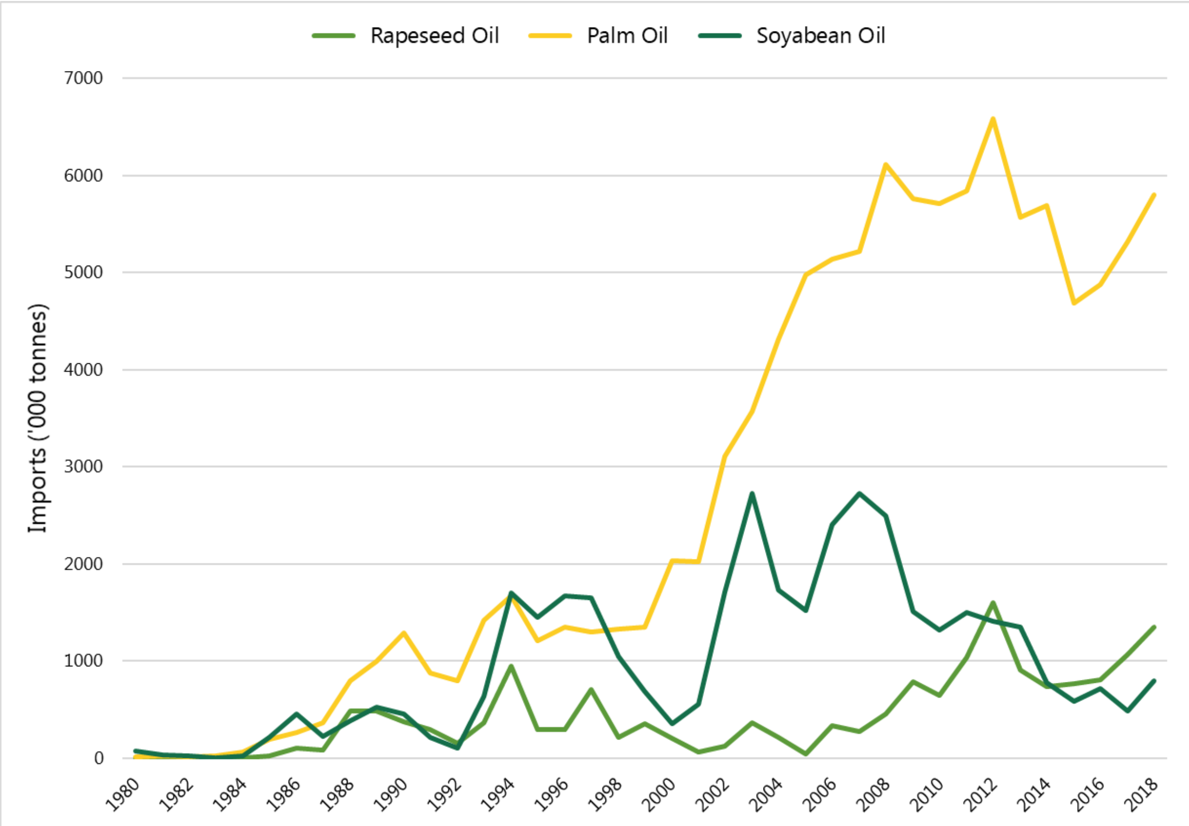

Figure 4 - Imports of rapeseed, palm and soybean oil into China (1980-2018)[40]

This has been particularly evident in China during the last two decades; as demonstrated in Figure 4, since the early 2000s, palm oil has become a staple of Chinese diets dominating the imports of edible-oil feedstocks into China. This has supplemented their extensive consumption of soybean oil, produced predominantly from their processing of imported soybeans.[42]

4.1.1 The Sustainability of Palm Oil

The expansion of palm oil cultivation – specifically in tropical nations such as Indonesia and Malaysia – has had significant environmental, economic and societal impacts. Increasing demand for the

[40] https://www.indexmundi.com/
[41] https://www.sciencedirect.com/referencework/9780122270550/encyclopedia-of-food-sciences-and-nutrition
[42] https://www.ers.usda.gov/webdocs/publications/91333/aes-107.pdf?v=3730.5

commodity has resulted in large-scale deforestation and major instances of natural habitat degradation, with large areas of tropical rainforest replaced by industrial-scale oil palm plantations. It's estimated that between 1990 and 2008 a total forest area of 5.5 million hectares were lost as a direct consequence of increased palm oil cultivation.[43] Further to this, between 2010 and 2015 Indonesia alone lost more than 3 million hectares of forest area due largely to their expanding palm oil industry.[44]

The industry employs nearly 5 million smallholders and labourers in Malaysia and Indonesia, with a further 11 million habitants of the two countries indirectly dependent upon it. Though palm oil cultivation has brought jobs to remote rural areas, it has also created land ownership issues, with local communities losing access to land and resources. As of October 2017, industrial palm oil cultivation accounted for 18.7 million hectares worldwide, however this figure is likely to be significantly larger; smallholder plantations – which are difficult to accurately calculate – account for a large proportion of plantings, making the exact quantification of palm's environmental impact complicated.[45]

There are a number of different environmental and ecological issues associated with deforestation, specific to oil palm plantations; this includes severe biodiversity losses – affecting socially sensitive species, such as the orang-utan – and climate change factors. Palm plantations sequester less carbon above the ground than tropical tree species, absorbing less CO_2 from the atmosphere as a result. Additionally, the drainage of waterlogged peat soils to aid palm growth exposes the peat to oxygen, allowing it to decompose and release the previously sequestered carbon, typically as methane, which is 23 times more potent a greenhouse gas than carbon dioxide.

The sustainability criteria associated with the Renewable Energy Directive (RED) – introduced initially in 2009 – were amended to include iLUC for biofuels and bioliquids in 2015, with the intention of reducing their associated indirect land use change (ILUC) impacts, preparing for the transition towards advanced biofuels, that don't use any food or animal feed in production.[46] iLUC concerns the assessment of the land use change impacts arising from any displaced production as a result of using land to produce biofuels that otherwise would have grown crops for food.[47]

Although an outright ban on palm was not included within the European Commission's 2015 sustainability criteria amendments, by attempting to restrict the conversion of food crops into energy the amended directive actively hinders the use of palm. This has since progressed, with the European Commission in March 2019 indicating that the use of palm for biodiesel production – other than sources which meet specific exemptions – should reduce to zero by 2030.[48]

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[43] http://ec.europa.eu/environment/forests/pdf/1.%20Report%20analysis%20of%20impact.pdf
[44] http://www.europarl.europa.eu/RegData/etudes/ATAG/2018/614706/EPRS_ATA(2018)614706_EN.pdf
[45] https://portals.iucn.org/library/sites/library/files/documents/2018-027-En.pdf
[46] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L1513&from=EN
[47] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria
[48] https://www.transportenvironment.org/press/eu-labels-palm-oil-diesel-unsustainable

4.1.2 Palm Imports to the EU

There are two distinct oils produced from palm; crude palm oil (CPO) – which is used predominantly in biodiesel production and, once refined, for frying food – and palm kernel oil (PKO), the derivatives of which are found within shampoos and detergent products.49 Figure 5 details the supply of palm oil to the EU28 and the UK from their three main exporters; Indonesia, Malaysia and Papa New Guinea. In addition to the net imports of unmodified palm oil and its fractions – falling under the harmonised system commodity code of 1511 – Figure 5 also contains just the CPO component of net imports (given as HS 151110).

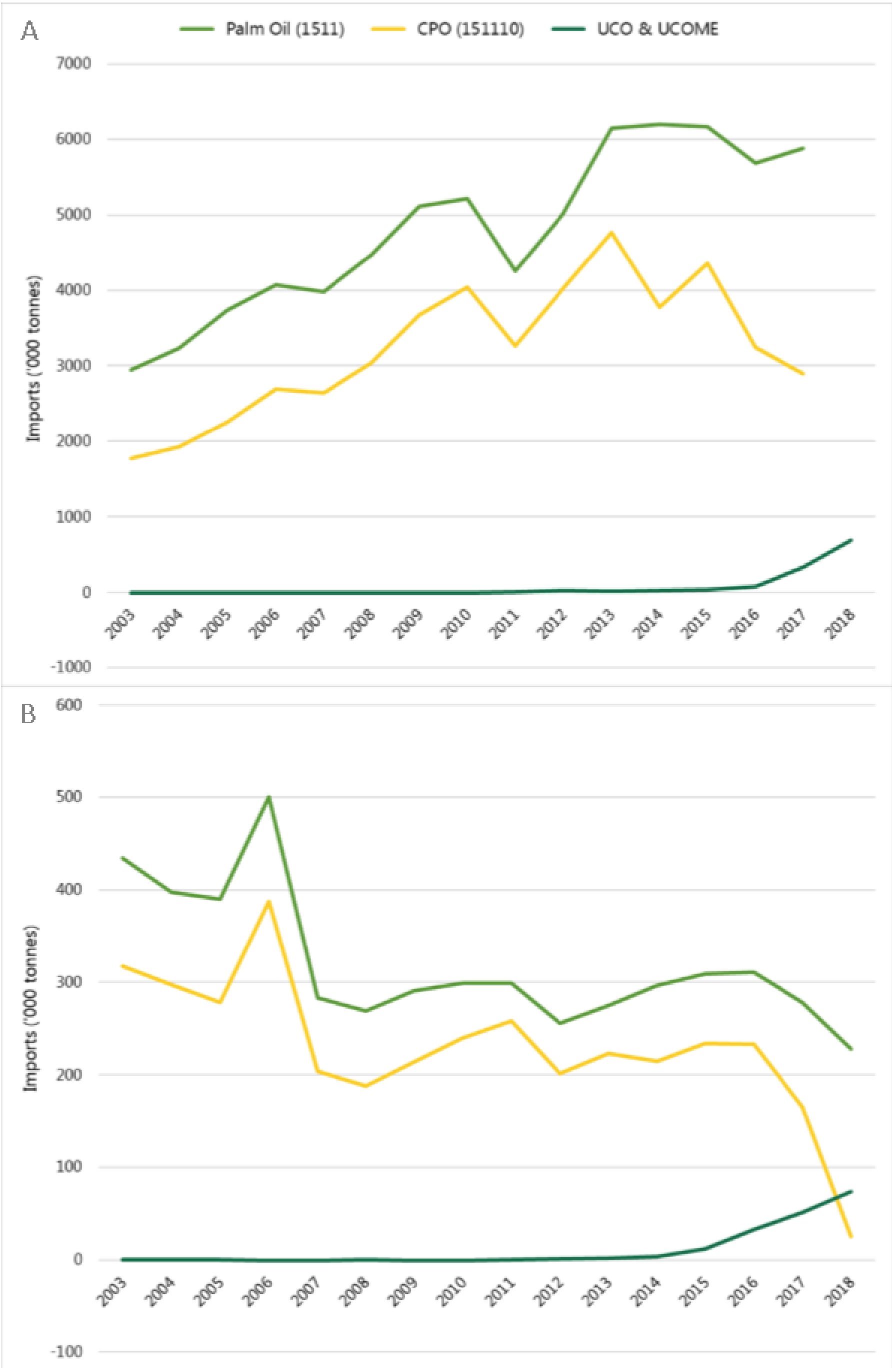

Figure 5 - Net imports of Total Palm Oil, CPO and UCO/UCOME into A) the EU and B) the UK[50]

The EU's demand for palm oil doubled between 2003 and 2013, driven heavily by the development of biofuel policy – particularly the legally binding transport fuel targets, such as those contained within RED. As a result, palm oil established itself as an important component of EU biodiesel and renewable diesel production, attributing to around 20% of the fuel produced.[51] However, as demonstrated by the data in Figure 5, since 2013 – where the associated sustainability issues of palm became increasingly publicised – the net imports of palm oil to the EU have stalled. When focusing on the imported CPO – which is the palm component used directly in biodiesel production – the 2017 imports of CPO were down by nearly 40% from palm's peak in 2013.

The reduction in palm oil imports is especially apparent for the UK, which has seen a significant reduction in CPO and its other imported palm oil fractions since 2016. Indeed, according to HMRC trade data the imports of CPO from Malaysia, Indonesia and Papa New Guinea fell to a low of ~25,000 tonnes – representing just 15% of the volume imported in the previous year.[52] The trade data therefore supports the submission that the EU – including the UK – are beginning to distance themselves from palm and the palm industry.

4.1.3 UCO and UCOME Imports

The reduced reliance on imported palm for biodiesel production has placed an increased demand on alternative feedstocks. In the case of UCO, the EU have an established a well-regulated market for the use of the waste oil produced by member states; reputable companies collect UCO from industrial and commercial food producers, delivering the waste feedstock to biodiesel producers. As a result, 2016 estimates of the UCO market indicated that there was only a small amount of additional supply remaining within the EU.[53]

UCO is classified as a waste in Europe; therefore, it is important that policies which promote its use – specifically as a transport fuel – do not result in the generation of additional waste as this would impact its credentials as a GHG emission reducing mechanism. To meet the growing feedstock demand, global imports from outside of the EU are the only legitimate option for increasing the supply of UCO.

As demonstrated in Figure 5, the net imports of UCO and UCOME to the EU and the UK have shown a significant increase since 2014, continuing to grow during the last 4 years with a large proportion of the imports originating from China, Indonesia and Malaysia. In 2018 these totalled more than 500,000 tonnes of UCO into the EU, with around 75,000 tonnes of this total delivered to the UK. Of the EU's total net imports of UCO in 2018, nearly 100,000 tonnes were sourced from Malaysia; these bulk shipments are however blends of both Malaysian and UCO originating from China.[54]

In the UK, the most common feedstock source of the biodiesel supplied in 2018 – between April and December – is Chinese UCO, totalling 93 million litres, representing 15% of the certified biodiesel and

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[49] http://ec.europa.eu/environment/forests/pdf/palm_oil_study_kh0218208enn_new.pdf
[50] https://trade.ec.europa.eu/tradehelp/statistics
[51] https://www.theicct.org/sites/default/files/publications/Palm_Oil_Briefing_20190130_0.pdf
[52] https://www.uktradeinfo.com/Statistics/Pages/Statistics.aspx
[53] https://www.greenea.com/wp-content/uploads/2016/09/Greenea-Presentation-July-2016.pdf
[54] https://www.iscc-system.org/wp-content/uploads/2018/07/China-Special-Report.pdf

9% of the total certified renewable fuel. Furthermore, Malaysian UCO – which partially consists of blended Chinese UCO – accounted for an additional 36 million litres of the UK's supplied biodiesel. Comparatively, during this same period, the UK's UCO feedstocks were used to produce 76 million litres.[55]

In addition to the increased deliveries of UCO, the EU imported nearly 200,000 tonnes of UCOME in 2018 sourced predominantly from Indonesia. Although biodiesel production from UCO is currently in its infancy in China, their HVO (hydrotreated vegetable oil) biodiesel capacity is increasing; for example, the ISCC EU certified Yangzhou Jianyuan HVO plant[56] has a capacity of 100,000 ton/yr, utilising UCO as its main feedstock. If China establish a significant supply of EU certified biodiesel – using a double counting feedstock – then the imports of Chinese HVO from UCO to the EU may increase significantly.

The trade data (Figure 5) indicates that the EU are replacing their consumption of palm with global imports of UCO and, to a lesser extent, UCOME; this is due to the associated high ILUC impacts of palm cultivation and the well-publicised issues with biodiversity. The continued growth of UCO imports from China and South East Asia strengthens the responsibility for ensuring the validity of the resource and the consequent supply chain of imported UCO feedstocks.

4.2 Implications of Imported UCO

As discussed previously in Section 2, the legislation placed on UCO as a waste – in addition to the increased traceability of the original edible-oils used within the European food industry – has resulted in a biodiesel feedstock that can be confidently assessed for carbon intensity and its estimated reduction in GHG emissions. However, when considering UCO imports from different global locations, the robustness of the supply chain – specifically relating to the confidence in its sustainability – is not as simple to evaluate.

4.2.1 Quality Issues

The consumption of edible vegetable oils in China has grown significantly over the last decade, evidenced by the import data illustrated previously in Figure 4. This has coincided with their increased national demand for fried food, with fast food restaurants – such as MacDonald's and KFC – establishing themselves within China.[57] The domestic consumption of edible oils in China is met mainly by soybean, rapeseed and peanut oil, however in large-scale, commercial food production – frying chips and other snack foods – palm is the preferred cooking oil. As a result, it's estimated that more than 40% of the palm oil consumed in China is used for food production, particularly in catering frying.[58]

In addition to this, most of the edible oil consumed in Indonesia and Malaysia is sourced from domestic palm oil, a result of their dominant palm industries. This is especially prevalent in Indonesia,

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55 https://www.gov.uk/government/statistics/biofuel-statistics-year-11-2018-report-3
56 https://certificates.iscc-system.org/cert-audit/EU-ISCC-Cert-DE129-35234427_audit.pdf
57 https://www.shine.cn/biz/company/1808039850/
58 http://or.nsfc.gov.cn/bitstream/00001903-5/38315/1/1000003623113.pdf

where the use of palm oil in cooking has continued to increase, currently at a rate of ~5%/year. This equated to more than 2 million tonnes of palm oil in 2016 alone.[59]

Palm oil is high in saturated fatty acids, with a pour point of ~23.5°C; therefore – as discussed previously in this paper – any UCO originating from palm would have comparable fatty acid contents and chemical properties. Due to the reliance on palm within their food industries, the UCO sourced from China, Indonesia and Malaysia is likely to fundamentally differ to that generated in the EU as a result of the differing original feedstocks. This could have repercussions, impacting the performance of the produced UCOME; without the addition of cold flow improvers (CFI's), any biodiesel produced from UCO that originates from palm is likely to gel in colder temperatures, causing engines to fail.[60] Though routine quality testing is currently undertaken in Europe, this is by no means definitive; high-profile usability issues with biodiesel fuels could severely impact the public's perception and confidence in them, negatively affecting the broader biofuel sector in general.

An additional quality issue is the rancidification of UCO feedstocks. During the last decade there have been several food safety scandals in China, with the most prominent relating to the supply and use of illegal cooking oil, often referred to as 'gutter oil'. The crudely processed waste oil – sourced predominantly from catering and sewage wastes – is sold for human consumption as a cheap alternative cooking oil. As part of a bid to improve food safety, the Chinese State Council have begun to tackle the mass production of illegal cooking oil,[61] resulting in an increased supply of UCO.

There are currently no global agreed quality standards for UCO, with the supplied feedstock instead required to meet the operators desired specifications – this is normally <1% contaminants and <4% FFAs.[62] UCO that is composed predominantly of gutter oil will contain much higher concentrations of FFAs and contaminants, causing issues in the production of biodiesel; the resulting higher processing costs and reduced yields associated with Chinese UCO may therefore result in an uneconomic process.

4.2.2 Sustainability Issues

The key driver for biodiesel uptake has been its ability to markedly reduce the GHG emissions associated with the transport sector, particularly in helping the transition towards a decarbonised system. Indeed, biofuels that are produced in facilities which began operation after October 2015 are required to comply with a 60% GHG saving threshold, an increase from the previously mandated 50%. Ensuring the sustainability of UCO feedstocks – correctly quantifying their potential for combatting climate change – is therefore imperative, particularly in relation to the obligations of fuel suppliers to reduce GHG emissions as part of the Fuel Quality Directive.[63]

As a waste, UCO is considered a low risk ILUC biofuel feedstock; this differs to those produced from crops grown on arable land, such as palm, which is deemed high risk due to its increased ILUC implications.[64] In the case of gutter oil – and other low-grade waste oil sources that are linked to animal by-products – their validity as wastes is undeniable, falling in line with current EU policy and

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[59] http://palmoilis.mpob.gov.my/publications/OPIEJ/opiejv18n1-said.pdf
[60] https://www.sciencedirect.com/science/article/pii/S2352484715300019
[61] http://english.gov.cn/policies/latest_releases/2017/04/24/content_281475635704771.htm
[62] https://www.london.gov.uk/sites/default/files/the_market_for_biodiesel_production_from_ucos_and_fogs_in_london_-_september_2013.pdf
[63] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L0652
[64] https://www.iscc-system.org/wp-content/uploads/2017/02/Low-iLUC-Feedstock-and-ISCC-Low-iLUC-Approach.pdf

legislation, while their removal from human consumption supply chains will also help improve food safety in China. However, the inclusion of better quality, filtered oils that are not legally mandated as a waste is a more contentious issue.

In China, UCO has historically been an important component of animal feed, acting as a cheap and high energy additive, improving both the energy density and the binding of feed pellets. It has also been used as a supplement in creep feed, helping to support the growth and weight increases of young livestock.[65] This is particularly important within China's growing pork industry; the growth demand for meat protein has resulted in increased demand for cheap animal feed sources. Current Chinese State Council policy forbids the use of UCO – sourced from catering and meat processing facilities – as a supplement for animal feed. Though this policy does not include high grade used vegetable oils, uncontaminated by meat products, these are also beginning to be included as a UCO source.

Their inclusion will result in a better-quality UCO biodiesel feedstock – containing lower levels of contamination and FFAs – but its removal from the animal feed supply chain will need to be replaced. As highlighted previously in Section 4.1.3, since 2015 there has been a sustained increase in the amount of UCO exported from China to the EU. This has coincided with increased imports of edible-oils during the same time period, as evidenced in Figure 4. Both soybean and rapeseed oil imports have shown small increases, however these are small when compared to palm; between 2016 and 2018 palm imports to China grew by 1 million tonnes, representing an increase of more than 20%.

There are complexities relating to Chinese edible oil imports – such as their recent trade dispute with the United States, prompting the need to find alternative sources of soybean oilseeds – however, the available trade data clearly evidences China's increased consumption of palm oil. Although correlation does not constitute causation, this increase should not be ignored; there are clear parallels between increased exports of Chinese UCO and their imports of palm oil, with the growth of both expected to continue throughout 2019.[66]

Consequently, there are concerns over the carbon intensity of UCO sourced from China, Indonesia and Malaysia, due to the potential inclusion of non-wastes within the waste feedstock stream. If their utilisation in EU biofuel production is leading to an increased use of palm oil within animal feed, replacing high grade uncontaminated used oil, then the subsequent ILUC emissions of palm oil should be included in the UCO assessment – or at least be flagged as a potential high ILUC risk fuel.

4.2.3 Traceability Issues

The final, and perhaps most controversial, issue relates to the traceability of the UCO sourced from China. To access the European market, the supplied UCO must meet EU sustainability standards; UCO collecting points (CPs) – which source the waste directly from the points of origin – are audited on the documentation of their supplied materials. Each point of origin must be certified; however, the audit process requires only signed self -declarations as proof. Additionally, only large waste producers –

[65] https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/yellow-grease
[66] https://www.biofuelsdigest.com/bdigest/2019/03/05/malaysian-companies-sign-deals-to-export-1-332-million-tons-of-palm-oil-to-china/

generating more than 120 tonnes/year – are required to provide samples within the CPs auditing framework. [67]

These are relatively soft anti-fraud mechanisms that require a certain level of trust, making them susceptible to exploitation. The motive for this strengthens further when considering the market price of UCO. Figure 6 demonstrates the relationship that exists between UCO and crude palm oil (CPO) commodities, specifically their price changes between 2017 and 2019. Although the costs of Chinese UCO are slightly less than the European UCO used in Figure 6, the data suggests that the two commodities are closely related – likely a result of their suitability as cheap biodiesel feedstocks.

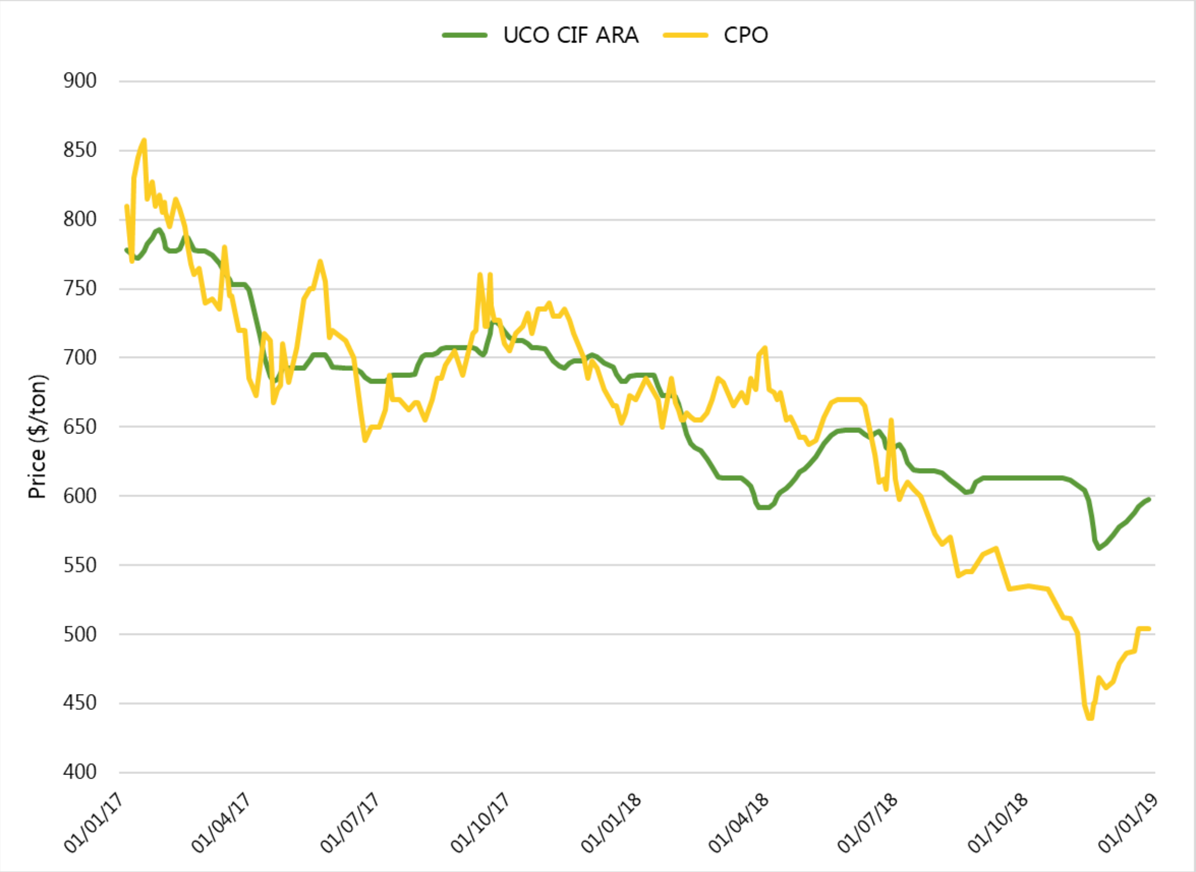

Figure 6 - Price changes of UCO and CPO (2017-2018)[68][69]

As evidenced, during the last 6 months of 2018 the value of UCO was greater than CPO, resulting in increased exports of the commodity from China to the EU. This has continued into 2019, with Chinese UCO accounting for $55.8 million worth of imports in the first quarter alone. The higher value of UCO and a lack of stringent traceability controls on the CPs and points of origin in China could give rise to fraudulent activity.

This potential for fraudulent activities – relating directly to biodiesel production from UCO – has been demonstrated recently within the Netherlands; significant volumes of biodiesel sold there in 2015 and

[67] https://certificates.iscc-system.org/cert-audit/EU-ISCC-Cert-IT206-36_audit.pdf
[68] https://www.rea.co.uk/websites/reaholdingsplc/English/2450/cpo-price.html
[69] https://www.greenea.com/en/market-analysis/

2016 were wrongly designated as sustainable, with double-counting credits claimed as a result.[70] Not only do instances like this raise doubt over the sustainability of certain imported feedstocks, they also – perhaps more importantly – undermine confidence in the entire biofuel sector, which could have much greater repercussions.

5 Conclusions

Reducing the GHG emissions associated with the UK's transport sector has, to date, proved difficult; the instigation of the RTFO has helped turn the tide but the transition towards a truly decarbonised transport sector will require the uptake of more alternative fuels. The potential for additional emissions from certain high-risk crops – as a result of indirect land use change – has prompted the EU to reduce their reliance on certain feedstocks, such as palm, replacing these with other low-risk options.

Utilising wastes which, without the existence of a biofuel market, would end up in landfill is seen as a preferable pathway option ahead of fuel crops. The EU's well-defined legislative framework for wastes has established UCO as a key biodiesel feedstock – one that can be trusted by fuel producers due to its quality, sustainability and traceability. It is important that the promotion of UCO within the EU does not result in the generation of additional waste, therefore the sourcing of alternative global supplies is required. This demand is currently being met by a growing reliance on Chinese UCO imports, however the feedstock quality, traceability and robustness of the supply chain's sustainability may not be as comparable to EU-sourced UCO as initially assumed.

The proper quantification of different UCO sources – in terms of its chemical composition – are first required; the current assumptions that UCO is a homogenous feedstock is flawed, based upon a small sample set of data published a decade ago. Different global sources of UCO are increasingly likely to differ fundamentally, a factor which should be accounted for in its feedstock classification; UCO sourced from the EU should not be assumed to be the same as that sourced from East and South East Asia.

Unlike the EU, estimations of UCO capacity and availability within China, Indonesia and Malaysia are inherently difficult to validate; indeed, without a proper understanding of the current volumes of waste oil generated, it is almost impossible to substantiate the GHG savings associated with the feedstock or if additional wastes are being produced as a result of the EU's policy support for biodiesel production from imported UCO.

This is further exacerbated by the inclusion of possible non-wastes within the UCO waste stream – the redirection of high-grade waste vegetable oils, safe for consumption within animal feed, to biofuel production may result in their replacement with cheaper virgin edible-oils, such as palm. Although correlation does not necessarily equate to causation, the available evidence indicates that palm oil imports to China are increasing, in line with their increased exports of UCO.

If these are indeed connected, then the ILUC implications of using imported UCO as a feedstock for biodiesel could be significant and must be investigated. Furthermore, if imported UCO is to continue

[70] https://www.dutchnews.nl/news/2019/05/dutch-company-embroiled-in-biodiesel-scandal-earning-millions-vk/

as a double counting feedstock then confidence in its supply chain should be paramount; the certification process of UCO – sourced from outside the EU – should be more robust, helping to ensure that the feedstock meets comparable levels of traceability and sustainability.

Legitimate UCO waste streams for biodiesel production offer an excellent pathway for reducing GHG emissions within the transport sector. However, it is important to remember that their use will not solve other issues resulting from the use of diesel fuels, such as poor local air quality, as discussed extensively in our previously published report.[71] While the use of biodiesel has been shown to reduce emissions of particulate matter and nitrous oxide, the use of diesel engines is best suited to long-haul, rural journeys – where a diesel combustion engine is at its most efficient and can combust the fuel properly. In urban stop-start driving environments, such as city centres, then alternative options – such as petrol hybrids fuelled with alcohol blends or full electric vehicles – should instead be pursued.

NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and bio-based products.

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[71] See previous NNFCC paper from April 2019, titled 'Air Pollution and the Role of Diesel Engines in Transport'