WORKING PAPER 2022-13

FEBRUARY 2022

An estimate of current collection and potential collection of used cooking oil from major Asian exporting countries

Authors: Tenny Kristiana, Chelsea Baldino, and Stephanie Searle
Keywords: used cooking oil (UCO), Renewable Energy Directive (RED II), Annex 9, ReFuelEU Aviation, FuelEU Maritime, California Low Carbon Fuel Standard, HEFA, HVO, biodiesel, waste oils cap

Summary

Used cooking oil (UCO) is a low-carbon feedstock for biofuel that is both technologically mature and commercially available. It is ideal for meeting existing biofuel mandates in Europe and the United States, and Asian countries have been increasing exports of UCO to these regions. In the European Union (EU), the Renewable Energy Directive (RED II) incentivizes the use of UCO biofuel to meet renewable energy targets in transport, and proposals to incentivize the use of renewable fuels in the aviation and marine sectors, ReFuelEU Aviation and FuelEU Maritime, are likely to stimulate additional demand for UCO in Europe. At the same time, the demand for UCO for biofuel within Asia is increasing, as well.

This study estimates how much UCO is likely to be available from the six countries in Asia that currently export the most UCO to Europe and the United States: China, India, Indonesia, Japan, Malaysia, and the Republic of Korea. Based on a literature review of restaurant, household, and food processing UCO production in each country, we estimate how much UCO could potentially be collected and how much UCO is currently collected. For restaurants and households, we base our estimates on urban areas because we assume collection in rural areas would be too difficult. For food processing, we use nationwide data. We also compare our current collection estimates to imports, exports, and current use in biofuel production. Domestic use of UCO could also include the illicit gutter oil market, where waste oil is collected from sources such as restaurant fryers and sewer drains for re-use; however, this is not quantified in this study due to lack of data.

Table 1 is a summary of our estimates in the six countries, including ranges for current collection. The estimates of collection potential assume 100% collection from urban restaurants, 50% from urban households, and 100% from food processing nationwide,

Acknowledgments: This work was generously supported by the David and Lucile Packard Foundation. Thanks to Adrian O'Connell and Yuanrong Zhou for their reviews.

www.theicct.org

communications@theicct.org

twitter @theicct

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

based on the idea that collection from businesses like restaurants and food processing plants is easier than from households, especially in large amounts. We also list both estimates of currently collected UCO and 2019 imports, and compare that with 2019 exports and UCO already used in biofuel. The difference between these categories is shown in the final column. Note that, due the assumptions made about current collection, uses, trade, and lack of data on gutter oil, this work may underestimate or overestimate any surplus or deficit identified in the final column of the table.

Table 1. Summary of estimates of UCO potential, UCO collection, import-export, and biofuel use, in kilotonnes per year.

Country	Estimated potential collection	Estimated current collection	Current collection share of potential	Total of estimated current collection + 2019 imports	Total of 2019 exports + estimated current biofuel use	Net of totals
China	5,131	3,086–4,097	60%–80%	3,128–4,139	1,655	1,473–2,484
India	1,697	224–326	13%–19%	273–375	74	199–301
Indonesia	715	182–266	25%–37%	191–275	149	42–126
Japan	331	70–122	21%–37%	79–131	106	(27)–25
Malaysia	158	48–71	30%–45%	256–279	321	(65)–(42)
Republic of Korea	116	88–107	76%–92%	150–169	168	(18)–1

As shown in the final column, China and India might have a UCO surplus, and in Malaysia it might be the opposite, that it exports more UCO than it currently collects. However, any UCO surpluses, particularly in China, India, and Indonesia, might not exist because the UCO could be used in the gutter oil market. Studies suggest that gutter oil is a problem in these three countries, even as their governments try to address it through things like a biofuel program or adjusting the market price of cooking oil to increase legal UCO collection.

Our study highlights how there is some room in these UCO-exporting countries for policymakers to incentivize increased UCO collection, either for use domestically, such as in biofuel, or for export. We further estimate that the European Union could demand around 3,500 kilotonnes of UCO imports in 2030 if a proposed revision to RED II goes into effect. FuelEU Maritime and ReFuelEU Aviation would further incentivize additional UCO-based fuels beyond the incentives in RED II. In 2035, for example, the ReFuelEU 15% SAF mandate (outside the 5% submandate) could incentivize demand for 5,600 kilotonnes of UCO imports. These are a sizeable amount when compared to our total estimate for current collection in these six countries, which is between 3,700 and 5,000 kilotonnes. We therefore suggest the European Union include 1.7% caps on waste oils in amendments to both ReFuelEU Aviation and FuelEU Maritime, to align with the 1.7% cap on waste oils in RED II. Such caps are reflective of a desire to stimulate other kinds of renewable fuels in addition to those derived from waste oils like UCO, and their implementation would support the development of nascent technologies needed to achieve long-term decarbonization of transport.

Introduction

Used cooking oil (UCO) is an excellent low-carbon feedstock for meeting biofuel mandates. It can be used to produce biodiesel, hydroprocessed vegetable oils (HVO), also known as drop-in renewable diesel, and hydroprocessed esters and fatty acids (HEFA), a kind of jet fuel (Kristiana & Baldino, 2021). Because these fuel pathways are technologically mature and commercially available, there is strong demand for UCO as a feedstock, especially as many other low-carbon fuel pathways are currently less technologically and commercially mature.

A lot of the UCO imported by the European Union comes from Asia and the United States, and 68% of total UCO imports in 2019 were from these regions (UN Comtrade, n.d.). Already most of the growing UCO biodiesel production in China is driven by demand for UCO biodiesel in the European Union, and the demand stems from policy incentives under the Renewable Energy Directive or RED (Greenea, 2021). The RED II incentivizes the use of waste oils like UCO to help meet a renewable energy target for transport in 2030, though their contribution is limited to 1.7% of road and rail energy (European Commission, 2021). Proposed changes to RED II and new regulations, however, would also incentivize and mandate renewable fuel in the marine and aviation sectors in the European Union. A proposed revision to the RED means more waste oil would qualify toward this directive, because it would apply to *all* transport energy, including the fuel used in the marine and aviation sectors, and thus a greater volume of transport fuels is under the directive, even though the cap remains at 1.7%. Additionally, two new regulations have been proposed, FuelEU Maritime and ReFuelEU Aviation, and these would incentivize additional UCO-based fuels (European Commission, 2021) beyond the incentives in RED II. Meanwhile, demand for UCO for biofuel production within Asian countries that produce significant amounts of it is also on the rise, and there are policy incentives in the United States. One U.S. example is California's Low Carbon Fuel Standard (LCFS), which is designed to decrease the carbon intensity of transportation fuels (California Air Resources Board, 2020); UCO is an attractive option to help meet this standard.

Given the demand for UCO, this study assesses exports from the six countries in Asia that currently export the most UCO to the European Union and United States—China, India, Indonesia, Japan, Malaysia, and the Republic of Korea. We estimate UCO collection from urban households, urban restaurants, and food processing. This study includes total estimated UCO potential together with an estimate of the total amount of fuel that could be produced from it, the current collection rate, import and export data, and consideration of UCO's domestic uses, including for biofuel or re-use as cooking oil, which is called gutter oil. Gutter oil is a term that describes illicit cooking oil recycled from waste oil collected from sources such as restaurant fryers, sewer drains, grease traps, and slaughterhouse waste that is then resold as cooking oil in grocery stores. Gutter oil is reported to be an issue in some Asian countries, but at present, the available data about it is very limited.

Analysis of collection and potential by country

Our estimates of UCO collection potential are based on literature reviews of restaurant, household, and food processing UCO production in each country. For restaurants and households, we focused on urban areas, under the assumption that collection in rural areas is too difficult. This same assumption was made in several previous studies (Kabir, 2014; Kumar et al., 2020; Liu et al., 2018; Yano et al., 2015). For food processing, we focused on nationwide collection and potential; because food processing locations produce so much UCO, we assumed it is economically advantageous to collect from all of them, even in rural areas. We assume that chips and instant noodle companies generate the most UCO in the food processing industry, and thus estimated UCO generation from only these two kinds of food processors.

For the potential (not current) collection in each country, we assumed 100% from urban restaurants, 50% from urban households, and 100% from food processing. After obtaining the estimates of total potential collection for each country, we converted them into biodiesel and renewable diesel potential using biofuel conversion yields from Argonne National Laboratory's GREET model. These are 0.91 kg biodiesel/FAME per kg UCO and 0.85 kg renewable diesel per kg UCO.

To estimate current collection from urban restaurants and households, we applied percentages found in the literature. We then assumed that countries with the highest collection from urban households and restaurants collect 70%–90% of UCO from food processors, and that countries with a relatively lower amount of restaurant and household collection achieve 40%–50% collection from food processors. Where information was not found in the literature, we made assumptions based on data that was available, for example from other countries.

China

Potential collection methodology

For urban restaurant collection potential, we used Spottle et al. (2013), which contains results from a survey in several cities for UCO generation from traditional restaurants and fast-food restaurants; results were presented per unit from each kind of restaurant, per year. We applied these yearly restaurant UCO rates to the number of urban restaurants from a study by Textor (2020). We assumed all fast-food restaurants are located in urban areas and calculated the number of fast-food restaurants by combining data from YumChina (2020) and Burger King (n.d.). To find the total number of traditional restaurants, we subtracted the total number of fast-food restaurants from the total number of restaurants from Textor (2020). To estimate how many of the traditional restaurants are in urban areas, we applied China's urbanization percentage of 60%, based on the urban population share for 2018 that we found in data from the National Bureau of Statistics of China.

No reliable China-specific data was found for collection from residences, so we used a study done in Korea (Cho et al., 2015). The study found the average household consumes 6.6 liters of cooking oil per year and 10% of this becomes UCO. We therefore used the estimate of 0.6 liters of UCO per household to calculate the collection potential from households in China's urban areas. To determine the number of urban households in China, we divided the total population by the average household size of three people and then applied an urbanization rate (National Bureau of Statistics of China, 2018).

No China-specific data on food processing was located, so we used data from Indonesia and applied it to China. We used an estimate of UCO generation for a small-to-medium size potato chip factory from Spottle et al. (2013) and scaled it to large chip factories based on the amount of chips produced. To understand the number of chips generated per factory, we found the average for small-to-medium size and large producers in Adiyoga et al. (1999). We then multiplied the estimates of UCO generation per factory by the number of small-to-medium and large chips factories in Indonesia. We used data from Spottle et al. (2013) on the number of small-to-medium size chip factories in Indonesia and companies' websites and news articles to estimate the number of large chip factories (Amenan, 2019; Garudafood, 2022; Manufakturindo.com, n.d.). The total UCO generation was then divided by total population in Indonesia and we found 0.29 kg/year UCO per capita generation. We retrieved the Chinese population from the National Bureau of Statistics of China (2018) and applied 0.29 kg/year UCO per capita to China's population to find total UCO generation in China from chips manufacturing.

For instant noodle UCO production, we found that Indofood has 16 instant noodle factories producing 15 billion packs per year in Indonesia, and each factory generates 3,750 tonnes per year UCO (Jumiati, 2009; Kippuw, 2019). From this we calculated that 4 g of UCO is produced per pack. Indofood dominates the instant noodle market with a share of around 70% (Kingwell et al., 2019) of sales. To calculate total UCO generation from the instant noodle industry in China, we applied World Instant Noodles Association (WINA; 2021) data on China instant noodle consumption, assuming that the amount of instant noodles consumed is a conservative estimate of the amount produced, to find total UCO generation from instant noodles. Lastly, we combined UCO generation from

chips manufacturing and instant noodle manufacturing to determine total UCO potential for food processing.

Current collection methodology

The literature on UCO collection in China focuses mostly on restaurant collection, and we assume there is no household collection currently because of the small amount of UCO generated per household. In other words, we think it is unlikely that households would bother to donate or sell their UCO when only producing 0.6 liters per year. For restaurants, a study by Liu et al. (2018) found that around 50% of restaurants provided their UCO to an authorized collector and a recent study by Goh et al. (2020) that focused on Beijing found a 76% collection rate. We assumed, therefore, that UCO collection from restaurants in China falls between those numbers, and calculated a range of current collection between 60% and 80% for both authorized and unauthorized collectors. For food processing, due to the high collection rates from restaurants, we assumed that between 70% and 90% is currently collected.

Results – Potential collection

Total theoretical UCO potential from restaurants in urban areas is estimated to be 4,500 kilotonnes annually, and the household sector could generate 84 kilotonnes. We estimate that UCO from food processing could reach as high as 600 kilotonnes per year. The total annual UCO potential of 5,100 kilotonnes could produce 4,700 kilotonnes of biodiesel or 4,400 kilotonnes of renewable diesel.

Results – Current collection

We assumed China does not collect any UCO from households. From restaurants, we estimate China collects between 2,700 and 3,600 kilotonnes of UCO each year, and collection from food processing ranges from 400 to 500 kilotonnes. Thus, in total, we estimate that China collects between 3,100 and 4,100 kilotonnes annually.

India

Potential collection methodology

To calculate the potential amount of UCO that could be collected from restaurants, we used an IMRB International (2016) study which conducted surveys in New Delhi of UCO generation from large and small-to-medium size restaurants. Smergers (n.d) had the data on the total number of small-to-medium and large restaurants in the country. We then applied the 2018 urbanization rate from the United Nations, 34%, to the country's total number of restaurants to estimate the number of urban restaurants.

For households, IMRB International's (2016) data on cooking oil consumption per month shows 3.5 to 5 liters in India, 5% of which we assumed becomes UCO. We took the average of cooking oil consumption, 4.25 liters per month, and applied 5%, and that is 2.55 liters per household per year. We used that to find the collection potential from households in urban areas. There is no data on total households, so we applied a household size of 4.6 people for India from United Nations (2019) to India's total population in 2018, based on Statista data (O'Neill, 2021a), and multiplied it by the urban population percentage to get the number of urban households. Similar to China, we applied Indonesia's ratio, the 0.29 kg/year UCO per capita generation for chips to India's total population based on (O'Neill, 2021a) and 4 g of UCO per pack to total instant noodle consumed in India based on WINA (2021) data. The total from chips and instant noodles is the total UCO potential from food processing in India (as in all other countries).

Current collection methodology

No data on household UCO collection in India was found, so we conservatively assume little is collected, about 1% or less. For restaurants, Kumar et al. (2020) found 10% UCO is collected in the city of Bengaluru, and thus we assumed a 5%–10% collection rate for all

urban restaurants in India. For food processing, given the relatively low collection from households and restaurants, we assumed 40%–50% is collected.

Results – Potential collection

Total UCO potential from restaurants in urban areas is estimated to be 1,200 kilotonnes per year and from urban households, we estimate India generates around 117 kilotonnes of UCO. UCO from food processing is around 400 kilotonnes annually. The total annual UCO potential in India is thus around 1,700 kilotonnes and it is equivalent to 1,500 kilotonnes of biodiesel or 1,400 kilotonnes of renewable diesel.

Results – Current collection

Despite its relatively high potential, our estimates suggest India collects little UCO today. From urban households, we estimate between 0 and 2 kilotonnes per year. Estimated collection from urban restaurants ranges from 58 to 116 kilotonnes annually, and from food processing, it is around 166 – 208 kilotonnes. Our calculation thus shows India's current collection ranges from 224 to 326 kilotonnes per year.

Indonesia

Potential collection methodology

Starting with urban restaurants, we first used the restaurant total from Indonesia's Central Bureau of Statistics from 2016 and 2018. However, as we found no data on how many of those restaurants are located in urban areas, we applied Indonesia's urbanization rate from Central Bureau of Statistics (2020), 57%, to get the total number of urban restaurants. We applied an average of UCO generation from medium and large restaurants in the city of Jakarta to all medium-to-large restaurants (Spottle et al., 2013). For small restaurants, we used Sudaryadi et al. (2021) and Hanisah et al. (2013) and took average numbers of UCO generation from small and micro restaurants. For households, we used Sudaryadi et al.'s (2021) study of Greater Jakarta's household UCO generation, and estimated 1.18 liters per month. We took the Central Bureau of Statistics' (2020) 57% urbanization rate, the latest year for which that rate was available, and applied it to Indonesia's total population, also from Central Bureau of Statistics (2021), to find the number of urban households. For the food processing industry, as explained above for China, we applied the 0.29 kg/year UCO per capita generation for chips to the total population in Indonesia from the Central Bureau of Statistics (2021) and 4 g UCO per pack for instant noodles and retrieved Indonesia's instant noodle consumption data from WINA (2021).

Current collection methodology

For households, Sudaryadi et al. (2021) conducted a survey in Greater Jakarta and estimated that current UCO collection is about 9%–10%. Based on this, we assumed that for Indonesia nationally, the household collection range is between 5% and 10%. For the restaurant sector, we also based our assumption on Sudaryadi et al. (2021), which in their survey found around 20% of restaurants stated their UCO is collected and re-used as cooking oil. We therefore applied a 20%–30% current collection range for urban restaurants. For food processing, we applied a collection rate of 70%–90%.

Results – Potential collection

Indonesia's UCO potential from urban restaurants is estimated to be around 332 kilotonnes per year. A large amount also could be generated from its urban households, where Indonesia could collect at least 255 kilotonnes annually, and UCO potential from food processing is estimated to be 128 kilotonnes per year. Together these make Indonesia's yearly UCO potential around 715 kilotonnes, which is equivalent to 651 kilotonnes of biodiesel or 608 kilotonnes of renewable diesel.

Results – Current collection

Our estimation for urban household collection is between 26 and 51 kilotonnes per year, and for collection from urban restaurants, we estimate it falls between 66 and 100 kilotonnes. Collection from food processing is estimated at around 90 to 115 kilotonnes. In total, we estimate that Indonesia collects between 182 and 266 kilotonnes annually.

Japan

Potential collection methodology

For urban restaurants, we found a study by The Environment Bureau of the City of Kyoto (n.d.) which estimated UCO potential from restaurants. We divided that by the total population in Kyoto (Statistical Handbook of Japan, 2009) and got 2.03 kg of UCO generation per capita per year. Although the Environment Bureau study used 2006 data and the population statistics are from 2009, we found no significant change in Kyoto's population and thus assumed this per capita UCO generation applies to the present day. We multiplied this value by Japan's urban population (World Bank, 2021) to estimate Japan's urban restaurant UCO potential. For households, similar to the method we applied to restaurants, we retrieved a total UCO potential from the Environment Bureau of the City of Kyoto (n.d.) and divided by total households in Kyoto (Statistical Handbook of Japan, 2009). That result was 2.34 liters per household UCO generation and we applied that to urban areas in Japan. We did not have data on the number of households, so we used the United Nations (2019) household size, 2.3. For the food processing sector, we applied Indonesia's ratio of 0.29 kg per year UCO per capita generation for chips and 4 g of UCO per pack for instant noodles, and retrieved instant noodle data from WINA (2021).

Current collection methodology

Yano et al. (2015) reported the current collection from households and restaurants in Kyoto. To get the current collection percentage for both, we compared the number from Yano et al. (2015) to total potential from the Environment Bureau of the City of Kyoto (n.d.). For households the percentage is 13%, and we assumed that urban areas in Japan achieve less than half the current collection rate of Kyoto, around 3%–5%. This assumption is based on a literature review regarding UCO collection in Japan which suggested Kyoto was a role model and because the 13% collection rate in Kyoto is higher than other studies, including one from Niigata City (Fujita et al., 2015). For restaurants, our calculation found a 37% collection rate and we applied the percentage range from 20% to 40% for all urban restaurants in Japan. For food processing, based on the household and restaurant percentage trend, we applied the low collection rate, 40%–50%.

Results – Potential collection

We estimate Japan could collect 217 kilotonnes of UCO per year from its urban restaurants. UCO potential from urban households is estimated to generate only a quarter of this potential, around 54 kilotonnes annually, and collecting UCO from food processing would add another 60 kilotonnes. Total UCO potential thus reaches 331 kilotonnes per year, and this is equivalent to 301 kilotonnes of biodiesel or 281 kilotonnes of renewable diesel.

Results – Current collection

Our current collection estimate for households in urban areas falls between 3 and 5 kilotonnes per year. Urban restaurants collect between 43 and 87 kilotonnes annually, and food processing generates between 24 and 30 kilotonnes of UCO. The total UCO collection from three sectors is 70 – 122 kilotonnes per year.

Malaysia

Potential collection methodology

Starting with the restaurant sector, there are limited studies on UCO potential, especially for medium-to-large restaurants. Given this, we divided our estimate of total potential production from Indonesian restaurants by Indonesia's urban population to find the UCO generation per capita in Indonesia of 2.16 kg per year. We then applied that per capita number to Malaysia's urban population to find UCO production from urban restaurants in Malaysia (O'Neill, 2021b). We expect the UCO generation per capita in Malaysia and Indonesia to be similar because the two countries share a similar cooking culture. For households, we applied a Malaysian household generation rate of 2.34 kg per month from Kabir, Yacob and Radam (2014) and multiplied it by the number of total urban households from the Department of Statistics Malaysia (2020). To find food processing UCO potential, we applied Indonesia's 0.29 kg per year UCO per capita generation for chips to the total population of Malaysia (Department of Statistics Malaysia, 2020) and 4 g UCO per pack for instant noodles and multiplied it by Malaysia's total instant noodle consumption based on data from WINA (2021).

Current collection methodology

We base our calculation on Kabir (2014), which found a 30% collection participation rate in one city in Malaysia, and we assume this applies to restaurants where collection is easier. Kabir et al. (2014) found that 12% of households recycle UCO in Malaysia. For both sectors, we assume the collection rate in Malaysia has increased since 2014, due to the establishment of startup companies that produce biodiesel from UCO and export it, and because of a rigorous campaign to collect UCO. Thus, we assume higher percentages for current collection: 30%–40% for urban restaurants and 12%–20% for urban households. We apply a 70%–90% collection rate for the food processing sector.

Results – Potential collection

We estimate that maximum UCO potential from urban restaurants in Malaysia is around 54 kilotonnes UCO per year. An additional 88 kilotonnes annually could come from urban household collection, and from food processing, a maximum collection would add an estimated 16 kilotonnes. The total UCO potential in Malaysia from those three sectors is therefore around 158 kilotonnes per year. This potential could generate 144 kilotonnes of biodiesel or 134 kilotonnes of renewable diesel.

Results – Current collection

Our current collection estimation for households in Malaysia is between 21 and 35 kilotonnes UCO annually. Meanwhile, for restaurants, we estimate the current UCO collected each year is between 16 and 22 kilotonnes. For food processing, we estimate between 11 and 14 kilotonnes of UCO annually and that means in total, Malaysia collects between 48 and 71 kilotonnes UCO.

Republic of Korea

Potential collection methodology

Limited data on UCO collection from urban restaurants in Korea was found. Furthermore, based on a U.S. Department of Agriculture report (2018), vegetable oil and animal fats are used sparingly in Korean cuisine, and restaurants serving Korean cuisine are about 52% of all dining establishments in the country. We applied our Japanese restaurant rate of 2.03 kg UCO per capita per year, considering the cooking culture of Korea uses less oil, like Japan. We determined urban population by applying an urbanization rate we retrieved from Statista (O'Neill, 2021c), 81%, to total population in Korea from Statistics Korea (2019). Multiplying our estimate for Japan's per-capita UCO production by Korea's urban population gives us the estimate of urban restaurant potential in Korea. For households, we used Cho et al.'s (2015) study on Korea's household UCO generation. The

total number of households data is taken from Statistics Korea (2019), and we applied O'Neill's (2021c) urbanization rate to find the total number of households in urban areas. For food processing, we applied Indonesia's ratio of 0.29 kg per year UCO per capita generation for chips, multiplied it by total population in Korea (Statistics Korea, 2019), and used 4 g UCO per pack for instant noodles and Korea's instant noodle consumption data from WINA (2021).

Current collection methodology

According to Cho et al. (2015), the household collection rate in Korea is quite low. Additionally, KEEI (2011) related that a survey in Korea found that household collection was only around 18%, while for restaurants and food service collection, it reaches 79%–98%. We applied these rates to the total potential to calculate for urban households and restaurants, but we increased the percentage for households because the KEEI study is 10 years old and UCO collection increased with Korea's Renewable Fuel Standard, which went into effect in 2012 (Shin et al., 2018). For households, we used a range from 20% to 25% and for restaurants, we applied a range of 80% to 95%. With a high collection rate from restaurants, we assumed the food processing collection rate in Korea falls between 70% and 90%.

Results – Potential collection

Urban restaurants in Korea are estimated to generate as many as 78 kilotonnes of UCO annually, and with collection from urban households, an additional 7 kilotonnes could be collected. The food processing industry is estimated to increase the potential by 31 kilotonnes per year. Total Korean UCO potential could reach 116 kilotonnes, which is equivalent to 106 kilotonnes of biodiesel or 99 kilotonnes of renewable diesel.

Results – Current collection

From urban households, we estimate Korea collects around 3 – 4 kilotonnes of UCO annually. Urban restaurant collection is estimated to fall between 63 and 75 kilotonnes per year, and collection from food processing is around 22 – 28 kilotonnes. In total, from the three sectors, Korea collects an estimated 88 – 107 kilotonnes UCO annually.

Potential and current collection summary

Table 2 presents a summary of UCO potential from urban households, urban restaurants, and food processing in each country. Among the six countries, China is estimated to have by far the greatest potential for UCO, followed by India. We find China and India have the highest UCO potential from restaurants, and Indonesia and India have the highest potential from households. For food processing, China and India, again, share the highest estimated potential. It is understandable that China and India rank at the top because they have the biggest population compared to other countries, respectively almost 1.4 billion (National Bureau of Statistics of China, 2018) and 1.35 billion (O'Neill, 2021a).

Table 2. Estimates of UCO collection potential from urban households, urban restaurants, and food processing in kilotonnes per year.

Country	Household, 50%	Restaurant, 100%	Food processing, 100%	Total potential	Fuels potential	
					FAME	Renewable diesel
China	84	4,461	586	5,131	4,669	4,361
India	117	1,164	416	1,697	1,544	1,442
Indonesia	255	332	128	715	651	608
Japan	54	217	60	331	301	281
Malaysia	88	54	16	158	144	134
Rep. of Korea	7	78	31	116	106	99

Table 3 summarizes the estimated current collection from the three sectors and the total collection for each country. China ranks first with total collection between 3,100 and 4,100 kilotonnes of UCO per year and India, despite its low collection rate, is estimated to collect the second largest amount, from 224 to 326 kilotonnes of UCO.

Table 3. Estimates of current collection from urban households, urban restaurants, and food processing.

Country	Household rate	Volume (kt)	Restaurant rate	Volume (kt)	Food processing rate	Volume (kt)	Total collection (kt)
China	0	0	60%–80%	2,676–3,569	70%–90%	410–528	3,086–4,097
India	0%–1%	0–2	5%–10%	58–116	40%–50%	166–208	224–326
Indonesia	5%–10%	26–51	20%–30%	66–100	70%–90%	90–115	182–266
Japan	3%–5%	3–5	20%–40%	43–87	40%–50%	24–30	70–122
Malaysia	12%–20%	21–35	30%–40%	16–22	70%–90%	11–14	48–71
Rep. of Korea	20%–25%	3–4	80%–95%	63–75	70%–90%	22–28	88–107

Alternative uses and trade of UCO

Besides export for use in biofuel, there are alternative uses for UCO, including within countries. Studies show that most UCO is used in biofuel or is re-used as cooking oil, known as gutter oil. Gutter oil plagues several countries, and as discussed below, a few of the countries we focus on in this study have policies in place to minimize it. But there is very little data available on the quantity of UCO that becomes gutter oil.

At the same time, UCO is extensively traded, both inside and outside of Asia. Besides exports to the European Union and United States, China and Indonesia export UCO to Malaysia, and Indonesia, China, and Japan all export to the Republic of South Korea (UN Comtrade, n.d.). Meanwhile, Japan also imports UCO from Malaysia, and China and Indonesia export to India (UN Comtrade, n.d.). This intra-Asia trade is reflective of existing demand that is affecting incentives for both UCO collection and exports from the six countries we consider in this study.

We obtained information on imports and exports from UN Comtrade data from 2019, and this data is self-reported by all countries in the database. We do not use 2020 Comtrade data due to the COVID-19 pandemic. UN Comtrade groups UCO with "animal or vegetable fats and oils and their fractions" under HS Code 151800. While this code is not limited to UCO, and includes all waste oils such as animal fats, we expect UCO to make up the majority of this category. It is important to note that when the European Union, for example, reports its imports, there is sometimes not a match when those numbers are compared to the numbers reported by the exporting countries.

For biofuel use, we obtained data from various sources, including USDA (2020a; 2020b; 2020d) for China, India, and Japan, Korea Bioenergy Association (2021) and Shin et al. (2018) for Korea, and various newspaper articles for Indonesia (Megawati, 2018; Ramli, 2020; Rusdianto, 2019). For Malaysia, there is a lack of data. Still, as crude palm oil is the primary feedstock for the biodiesel program in Malaysia, we assume that a limited amount, if any, UCO is used in biofuel for the domestic market. Besides for domestic use, UCO biodiesel is also being exported from China, Japan, and Indonesia (Artha Metro Oil, n.d.; USDA, 2020a; USDA, 2020d). However, the UCO biodiesel is under the same HS Code category as biodiesel from other feedstocks, for example palm biodiesel in Indonesia, so it is difficult to track the precise amount of export of UCO biodiesel only.

Table 4 is a summary of our estimates of UCO currently collected and of imports, exports, and biofuel uses. Recall that any potential gutter oil is not included in the table

because of a lack of data. We compare the sum of estimated total collection and imports and to biofuel uses and exports; the difference is reported in the final column.

Table 4. Summary of estimated current collection of UCO, plus imports, exports, and biofuel use, in kilotonnes per year.

Country	Estimated current collection	Imports in 2019 (from Comtrade)	Total collection + imports	Exports in 2019 (from Comtrade)	Biofuel use (various sources)	Total export + Biofuel use	Net of totals
China	3,086–4,097	42	3,128–4,139	737	918	1,655	1,473–2,484
India	224–326	49	273–375	9	65	74	199–301
Indonesia	182–266	9	191–275	148	0.66	149	42–126
Japan	70–122	9	79–131	84	22	106	(27)–25
Malaysia	48–71	208	256–279	321	no data	321	(65)–(42)
Republic of Korea	88–107	62	150–169	7	161	168	(18)–1

Gutter oil

UCO re-used as cooking oil is also known as gutter oil. There is scant data available about the gutter oil market, and this can affect estimates of both current collection of and current use of UCO. It is also possible that some of the UCO going to gutter oil is illegally collected and therefore not considered in the studies upon which we based our estimates of current collection. Several studies have estimated how much UCO becomes gutter oil in China, India, and Indonesia, and some articles suggest there is no domestic use of gutter oil in Malaysia. For Japan and the Republic of Korea, no sources estimating gutter oil were found. More information about gutter oil in each country is included in the following section.

Re-using UCO as cooking oil has several impacts on human health. A previous ICCT study, Kharina et al. (2018), explained that UCO contains toxic substances that could be linked to several diseases, including stroke, heart disease, hypertension, and other cardiovascular risks. A researcher from Indonesia's Fiscal Policy Agency (Badan Keuangan Fiskal) linked several health problems in Indonesia to the re-use of UCO as cooking oil (Haryanto, 2018). As is detailed further below, some countries, including China and India, seek to address gutter oil by issuing regulations on UCO collection and requiring its use for biofuel production. Not only does use in biofuel instead of re-use as cooking oil reduce the negative human health impacts, but it also has environmental benefits. Displacing fossil fuels with UCO biofuel reduces carbon emissions and can strengthen energy security. -

Discussion

Here we discuss each country's UCO potential, challenges, and policies.

China

One university study estimated there are around 6,580 kilotonnes of gutter oil in China, while another found 2,000 – 3,000 kilotonnes of gutter oil (Spottle et al., 2013). In another study, PRIMA Markets (2018) estimated that current UCO and gutter oil collection in China reaches around 3,000 kilotonnes per year, based on interviews with collectors. A professor from the South China Academy of Agriculture and Food calculated total edible oil consumption annually and subtracted Chinese domestic edible oil production and imports; results showed that around 4,000 – 5,000 kilotonnes are unaccounted for, and the author argued this is likely met with waste oil (Meng & Yang, 2012). Meanwhile, others estimated that around 2,000 – 3,000 kilotonnes of waste oil are re-used in cooking every year (Meng & Yang, 2012). A USDA report (2020a) said that in 2018, China produced about 10,000 kilotonnes of gutter oil. Thus, our literature review

suggests that gutter oil in China is somewhere between 2,000 and 10,000 kilotonnes annually. This large range in estimates is because there is no one method to measure waste oil in China (Meng & Yang, 2012). As the findings in these studies are greater than or equal to the surplus from our estimates in Table 4, it is possible that none of that surplus UCO is available for other uses.

The Chinese government tries to reduce gutter oil with a UCO collection program that appoints legal collectors to collect UCO and use UCO for their biofuel program. There are already 33 pilot projects (Liu et al., 2018). The government also offers financial incentives to reduce UCO recycling as cooking oil. Further, UCO is not only used for biodiesel in China but also to produce jet fuel. For example, Sinopec and Boeing have partnered with Hainan Airlines to produce UCO-derived jet fuel (USDA, 2020a). While domestic biofuel production using UCO is increasing in China, government support is limited only to tax breaks (USDA, 2020a). Unlike ethanol, there is no biodiesel program or mandate at the national level. Shanghai has a 5% biodiesel blending mandate, however.

India

In our estimation, India, which has a total population close to China, only has one-third of China's UCO collection potential. This is because we focused on urban UCO potential for both restaurants and households and India's urbanization rate is only 34% (United Nations, 2018), far below China's 60% urbanization rate. Although India's urbanization rate is low, its UCO potential is still high compared to other countries. At the same time, we estimate that India currently collects less than 20% of its potential. The Food Safety and Standards Authority of India (FSSAI; n.d.) estimated that 1,200 kilotonnes of UCO from household and commercial activities becomes gutter oil. Thus, it is unclear if the approximately 200–300 kilotonnes surplus shown in the final column in Table 4 is available for other uses.

India is likely to increase its UCO collection in the future, especially with a new program called Repurpose Used Cooking Oil (RUCO), which tries to curb the amount of UCO that becomes gutter oil and instead encourage its use as a feedstock for biodiesel. The Ministry of Petroleum and Natural Gas predicted that India could collect 1.4 billion liters, equivalent to 1,300 kilotonnes UCO (USDA, 2020b). Under the National Policy on Biofuels 2018, the government set a target of 5% biodiesel blending by 2030, with UCO is listed as a feedstock, and to date, there are 39 biodiesel manufacturers enlisted under the RUCO program (FSSAI, n.d.). Food business operators in India whose consumption of edible oil for frying is more than 50 liters per day are also required to maintain purchase records and need to dispose of the UCO via an agency under FSSAI authority (FSSAI, n.d.).

Indonesia

Our estimates show that currently Indonesia collects less than 40% of its UCO potential. Our estimated range of 182 – 266 kilotonnes collected is lower than several studies, such as a fairly recent one that placed collection at 2,700 kilotonnes per year (TNP2K and Traction Energy, 2020). In general, there is disagreement in the literature about Indonesian cooking oil consumption. For example, TNP2K and Traction Energy report that 13,000 kilotonnes cooking oil are consumed, while GIMNI (2020) data shows the total sale of vegetable oil in Indonesia was 7,420 kilotonnes in 2019. GIMNI's estimate is similar to data from USDA (2020c), which stated that 7,000 kilotonnes of oilseeds went to domestic food use in 2020.

Unlike most of the other countries, data concerning biofuel use of UCO in Indonesia is difficult to obtain. Production is done by small-to-medium scale companies, and it has not become part of the national biofuel program. The small-to-medium biofuel

producers mostly either focus on a limited domestic market, such as GenOil, which produces UCO biodiesel for the fishing community in Makassar, or on export, such as Artha Metro Oil in East Java (Syam et al., 2018; Artha Metro Oil, n.d.).

Indonesian UCO exports continue to increase, from only 17 kilotonnes in 2012 to 148 kilotonnes in 2019 (UN Comtrade, n.d.). Almost one-third of the total UCO exported by Indonesia in 2019 went to the European Union. At the start of the COVID-19 pandemic, UCO collection in Malaysia dropped, but Indonesia experienced an opposite trend (Parmar, 2021c). UN Comtrade (n.d.) data shows that Indonesia's exports jumped from 148 kilotonnes in 2019 to 220 kilotonnes in 2020. In 2021, China and Malaysia's UCO exports rebounded and Indonesia continued to increase exports (Moffitt, 2021; Parmar, 2021d). From January to September, Indonesia exported 256 kilotonnes of UCO (Parmar, 2021a). This 2021 export number is close to our estimate of current collection, so the surplus of UCO shown by our estimates could go to export or to gutter oil, as we did not include 2021 in our estimate of exports. At the same time, there is a discussion that palm oil is blended with UCO and exported as UCO to avoid some of the high taxes the government puts on palm oil product exports (GIMNI & Majalah Sawit Indonesia, 2021).

News articles (e.g., Hermansyah, 2016) have suggested that UCO is re-used as gutter oil in Indonesia. Fujita et al. (2015) and Sudaryadi et al. (2021) estimated that in Indonesia, 10%–15% of UCO from households and 5%–6% of UCO from small and micro restaurants becomes gutter oil; these studies were based on surveys in different cities, namely Jakarta, Depok, and Bogor. Survey respondents said that UCO was given to others, like maids, for use as cooking oil. By comparing the results of these studies with our estimates, we see the amount of gutter oil in Indonesia could potentially fall between 77 and 108 kilotonnes per year. This gutter oil estimation is much lower than a vegetable oil industry projection, which is approximately 1,100 kilotonnes, or around 18%–22% of total cooking oil consumption (GIMNI, 2021).

The Indonesian government has tried to address gutter oil via a regulated cooking oil price that was supposed to go into effect on January 1, 2020, but it was not implemented due to COVID-19 (BPDP, 2019; Pratama, 2021). Unlike China and India, the Indonesian government has not supported UCO in its biofuel program, which is well-developed compared to the other countries in this study. However, even though UCO is absent from the national biofuel program, there are local government regulations supporting the use of UCO in biodiesel. For example. Bogor city previously ran a UCO program from 2008 to 2015, and the regional transport company collaborated with the Bogor City Environmental Management Agency to collect the UCO from various sectors and convert it into biodiesel for use in public buses (Kharina et al, 2018).

Japan

We estimated that Japan currently collects around 20%–40% of its total potential from urban households, urban restaurants, and food processing. Japan could likely increase its collection from urban restaurants and households up to 60%–80% because we estimate that neighboring countries have achieved a similar level. Comparing Japan's estimated current collection and imports to its domestic use and exports shows that Japan exports UCO more than uses it domestically. The export share is around two-thirds of current collection. No research on gutter oil in Japan was found.

The biodiesel market in Japan is limited and there are no financial incentives from the government and no national biodiesel program. Nonetheless, several municipalities have programs that focus on biodiesel from UCO, and one is Kyoto. Since 2017, UCO is the only feedstock used to produce biodiesel in Japan. Around 15 million liters of UCO biodiesel are consumed in Japan and around 9 million liters are exported, mainly to Europe (USDA, 2020d). Japan is considering not only using UCO for biodiesel but also using it to produce bio-jet fuel. A New Energy and Industrial Technology Development

Organization project plans to use domestic UCO as a sustainable aviation fuel (SAF) feedstock, which they aim to supply by 2025. This likely means either that the domestic UCO supply will be allocated for the project or that collection will increase under the project (JGC Holdings Corporation, 2021).

Malaysia

Malaysia has the smallest population compared to other five countries. However, Malaysia's UCO potential in our calculation is higher than the Republic of Korea's and is one-fifth of Indonesia's UCO potential, even though Malaysia's population is nine times smaller than Indonesia's. Besides the urbanization rate, which is 77% compared to Indonesia's 57%, another reason for the relatively high UCO production rate is cooking habits. A survey in Malaysia found that almost 50% of households discharge UCO after only two times use (Kabir et al., 2014). In Indonesia, around 65% are using it three times and the rest, 35%, are using it more than three times or until there is none left (Sudaryadi et al., 2021). We assume these cooking habits affect the amount of leftover UCO. No reference to gutter oil being consumed domestically in Malaysia was found. An article in *The Straits Times* (Zengkun, 2014) suggested that UCO collected illegally in Singapore is sometimes exported to Malaysia, where it is mixed with crude palm oil and exported to other countries, mostly developing countries.

Malaysia's Cooking Oil Stabilization Scheme (COSS) is a subsidy program that aims to alleviate the cost burden of cooking oil and it began during high crude palm oil prices in 2006 and 2007 (Ministry of Domestic Trade and Consumer Affairs Malaysia, 2021; C4Center, 2015). The objective of the subsidy is to prevent consumers from purchasing illicit gutter oil and it is given to cooking oil packed in a 1 kg polybag and offered to consumers at an affordable price (Ministry of Domestic Trade and Consumer Affairs Malaysia, 2021). The Malaysian Palm Oil Board (MPOB) assures that the product meets the prescribed quality and is not from recycled cooking oil (FreeMalaysiaToday, 2021b). In 2021 alone, the Malaysian government allocated RM 600 million for the subsidy (Ministry of Domestic Trade and Consumer Affairs, 2021). MPOB (2008) stated that the subsidy scheme is funded by a levy collected from oil palm plantations, estate companies, and their owners.

The COSS is also probably one of the reasons why Malaysian households consume more cooking oil than other countries in the region like Indonesia. In Malaysia, under the COSS, Malaysians only pay RM 2.50 per kg, or equivalent to IDR 8,500 per kg. In Indonesia, meanwhile, people pay around IDR 17,000 per kg (Catriana, 2021). Additionally, the Malaysian government has another policy which sets a ceiling price for its 2, 3, and 5 kg cooking oil to make the price affordable (FreeMalaysiaToday, 2021a).

With respect to the estimates of current collection, despite Malaysia having a relatively strong collection rate of 30%–40% of its UCO potential from urban households and restaurants and food processing, it also imports high amounts of UCO. In 2019, Malaysia imported three times more UCO than it collected domestically. This could be due to increasing UCO biodiesel production by companies such as FatHopes Energy, Vance, or Mewah (Parmar, 2021b). These increases in UCO biodiesel production are not likely to be linked to Malaysia's domestic biodiesel program. Currently, Malaysia mandates a 10% biodiesel blend (B10). B20 was supposed to be implemented in mid-2020, but due to COVID-19, the government decided to postpone the program (USDA, 2020e). Almost all biodiesel producers in Malaysia use crude palm oil as a feedstock for the national biodiesel program and we assume the UCO biodiesel is mostly exported.

Another reason that Malaysia imports a large amount of UCO is because it is a hub for UCO and serves as a consolidation area for UCO from surrounding countries including China, Singapore, and Indonesia (Greenea, 2021). Along with Greenea, Pearmar (2021b) also noted several UCO traders have set up bulking capabilities in Malaysia's major ports,

such as Port Klang and Pasir Gudang. Thus, Malaysia is a hub for small imports from the region and then larger shipments are exported to Europe. In 2019, half of Malaysia's UCO export went to the European Union and the United Kingdom.

Republic of Korea

Based on our literature review, UCO collection from restaurants in Korea is quite high. Household collection is only around 20%, though, so Korea could increase its collection from the residential sector. Like Japan, it is unclear whether gutter oil is a factor in Korea.

UCO for domestic use in Korea, specifically biofuel, is expected to increase if the government increases the biodiesel blending ratio under its Renewable Fuel Standard (RFS) program. Started as pilot program in 2002, the Korean RFS adopted a 0.5% (B0.5) biodiesel blending for transport in 2006. Since 2010, biodiesel producers have replaced palm oil with UCO and palm fatty acid distillate (PFAD). In 2012, the RFS program became a regulatory policy with a 2% blending ratio. In 2015, the RFS was introduced in Korea's Intended Nationally Determined Contribution plan under the Paris Agreement. In 2018, the blending ratio was increased to 3%. In 2015 alone, the UCO share of biodiesel feedstock reached 35% (Shin, Kim, Zepernick, & Kang, 2018).

Conclusion and EU policy implications

The amount of UCO available from any country is going to be limited, and part of what this study shows is that the availability of UCO from these six Asian countries is influenced by a variety of factors. At the same time, demand for UCO, particularly from the European Union, is expected to increase as a result of changes in climate legislation and new proposals. To understand how much the European Union might demand, we can subtract the current contribution of domestically available waste in the European Union, that is UCO and animal fats, and then estimate how much UCO could be demanded for import to meet the proposed revision to the RED II in 2030 and the ReFuelEU aviation proposal in 2035, since the 15% SAF ambition (outside the 5% submandate) in this year is much higher than the 4.3% SAF mandate (outside the 0.7% PtL submandate) in 2030 (European Commission, 2021c). Assuming UCO is used to produce solely HVO, which has fewer limitations for use as a road transport fuel compared to biodiesel, the European Union could demand around 3,500 kilotonnes of UCO in 2030. In 2035, the ReFuelEU SAF mandate could incentivize demand for 5,600 kilotonnes of UCO, based on the European Commission's projection of aviation energy demand (European Commission, 2021b). These are a sizeable amount of the UCO that we estimate is currently collected in the six countries of this study, which is in the range of 3,700 to 5,000 kilotonnes. It also does not include further demand which could occur due to the implementation of the FuelEU Maritime and ReFuelEU Aviation regulations.

In RED II, the contribution of waste oils including UCO is currently limited, but under the proposed revision, the definition of transport energy would include the marine and aviation sectors and thus the volume of fuel qualifying toward the directive would increase, even though the cap remains at 1.7%. Additionally, the proposed ReFuelEU Aviation regulation requires SAF blending beginning in 2025 and it will further incentive the production of fuels using waste oils, especially because the contribution of waste oils is not capped. HEFA fuel is the only commercially mature jet fuel pathway and can only be produced with waste oils under ReFuelEU Aviation; it is likely that the entirety of an SAF mandate, outside of a sub-mandate for another kind of SAF, power-to-liquids, would be met with waste oils like UCO (Searle, 2021b). Similarly, the proposed FuelEU Maritime regulation requires reductions in the greenhouse gas intensity of fuels used in the marine sector beginning in 2025, and here the contribution of waste oils is also not capped (Searle, 2021a). Similar to HEFA, HVO will be one of the lowest-cost fuel options to meet the regulation, and UCO will be an attractive low-carbon feedstock.

Thus, we suggest policymakers include caps in amendments to both ReFuelEU Aviation and FuelEU Maritime, to align with RED II. Doing so would support the development of nascent technologies needed to achieve long-term decarbonization of these two sectors (O'Malley, Pavlenko, & Searle, 2021).

Note that, due to the various assumptions that went into our estimates of current collection, uses, and trade, it is possible that any surplus or deficit identified from the six countries analyzed is the result of an overestimate or an underestimate. Additionally, for many countries it is not possible to understand the extent to which UCO is being used as gutter oil, if at all. In any case, given that various policies around the world—including in Europe, the United States, and inside Asia—are stimulating demand for waste oils, it is important to consider whether there is enough of this feedstock to meet a growing demand, or if supply is more likely to remain relatively limited. Policies that include a cap, like the 1.7% cap in the RED in the European Union, are reflective of a desire to stimulate other kinds of renewable fuels in addition to those derived from waste oils like UCO. The analysis here also suggests that in UCO-exporting countries, there is some room for policymakers to provide incentives that would increase UCO collection, either for use domestically in biofuel or for export.

References

Adiyoga, W., Suherman, R., Asgar, A., & Irfansyah. (1999). *The potato system in West Java, Indonesia: Production, marketing, processing, and consumer references for potato products*. Retrieved from International Potato Center, https://www.researchgate.net/publication/242455263_The_Potato_System_in_West_Java_Indonesia_Production_Marketing_Processing_and_Consumer_Preferences_for_Potato_Products

Amenan, A. (2019, December 22). Siantar Top berencana bangun dua pabrik baru. *Berita Satu*. https://www.beritasatu.com/ekonomi/591922/siantar-top-berencana-bangun-dua-pabrik-baru

Artha Metro Oil. (n.d.) *Tentang kami*. http://arthametrooil.co.id/about.html

BPDP. (2019, October 6). 1 January 2019, Cooking oil must be packaged. Retrieved from https://www.bpdp.or.id/en/1-January-2020-Cooking-Oils-Must-be-Packaged

Burger King. (n.d.). *Burger King China About us*. https://www.bkchina.cn/trained/index.html

California Air Resources Board. (2020). *Low Carbon Fuel Standard*. https://ww2.arb.ca.gov/sites/default/files/2020-09/basics-notes.pdf

Catriana, E. (2021, November 3). Awal November, harga minyak goreng terus naik. *Kompas.com*. https://money.kompas.com/read/2021/11/03/124949126/awal-november-harga-minyak-goreng-terus-naik

Central Bureau of Statistics Republic of Indonesia. (2016). *Results of accommodation and food service activities establishments data collection*. Retrieved from https://www.bps.go.id/publication/2018/12/31/98c47af6da1bec4377dc4c07/hasil-pendataan-usaha-perusahaan-penyediaan-akomodasi-dan-penyediaan-makan-minum-sensus-ekonomi-2016-lanjutan-indonesia.html

Central Bureau of Statistics Republic of Indonesia. (2018). *Food and beverage service activities statistics*. Retrieved from https://www.bps.go.id/publication/2020/05/19/46f4771e281557c89c35f732/statistik-penyediaan-makanan-dan-minuman-2018.html

Central Bureau of Statistics Republic of Indonesia. (2020). *Statistical yearbook of Indonesia 2020*. Retrieved from https://www.bps.go.id/publication/2020/04/29/e9011b3155d45d70823c141f/statistik-indonesia-2020.html

Central Bureau of Statistics Republic of Indonesia. (2021). *Hasil sensus penduduk 2020 Indonesia*. Retrieved from https://sensus.bps.go.id/berita_resmi/detail/sp2020/74/hasil-sensus-penduduk-2020-indonesia

Cho, S., Kim, J., Park, H., & Heo, E. (2015). Incentives for waste cooking oil collection in South Korea: A contingent valuation approach. *Resources, Conservation and Recycling*, *99*, 63–71. https://doi.org/10.1016/j.resconrec.2015.04.003

C4Center. (2015). *Management of cooking oil stabilisation scheme*. https://c4center.org/kleptocrazy/management-of-cooking-oil-stabilisation-scheme/

Department of Statistics Malaysia. (2021). *Latest statistics 2020*. https://www.mycensus.gov.my/#latest-statistics-2020

Environment Bureau City of Kyoto. (n.d.). *Usage of recycled cooking oil as an alternative fuel for transportation*. Retrieved from https://kitakyushu.iges.or.jp/docs/network_meetings/kin4/ppt/13.Minami.pdf

European Biomass Industry Association. (n.d.). *Used cooking oil*. http://www.eubia.org/cms/wiki-biomass/biomass-resources/challenges-related-to-biomass/used-cooking-oil-recycling/

European Commission. (2021a). Directive of The European Parliament and of The Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

European Commission. (2021b). Regulation of The European Parliament and of The Council on ensuring a level playing field for sustainable air transport. https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf

Food Safety and Standards Authority of India. (n.d.). *Repurpose used cooking oil*. https://fssai.gov.in/ruco/index.php

Free Malaysia Today. (2021a, July 27). Govt sets ceiling price for bottled cooking oil. Retrieved from https://www.freemalaysiatoday.com/category/nation/2021/07/27/govt-sets-ceiling-price-for-bottled-cooking-oil/?__cf_chl_jschl_tk__=WjIruVaLYx6Q8n9zjoNnvMJfpIU9XT7orlXIHer5t78-1637004527-0-gaNycGzNDn0

Free Malaysia Today. (2021b, June 19). Only quality cooking oil in polybags, not recycled, says MPOB. Retrieved from https://www.freemalaysiatoday.com/category/nation/2021/06/19/only-quality-cooking-oil-in-polybags-not-recycled-says-mpob/?__cf_chl_jschl_tk__=pmd_QQEpAb4ZlUmhTe87UO9dPl_Vcn_xyboF018Ke_PLDv4-1632905411-0-gqNtZGzNAnujcnBszQml

Fujita, H., Iijima, W., Nakano, K., Prayitno, J., Tsubaki, H., & Kitagawa G. (2015). A comparative study of waste cooking oil recycling programs in Bogor and Niigata cities and GHG emission reduction by recycling. *International Conference on Circuits and System (CAS 2015)*. https://doi.org/10.2991/cas-15.2015.41

Gabungan Industri Minyak Nabati Indonesia (GIMNI). (2020, April 18). *Dampak Covid-19, konsumsi minyak goreng turun* [Press release]. https://gimni.org/dampak-covid-19-konsumsi-minyak-goreng-turun-2/

Gabungan Industri Minyak Nabati Indonesia (GIMNI). (2021, June 17). *Punya potensi untuk biodiesel, minyak jelantah justru kerap dioplos di dalam negeri* [Press release]. https://gimni.org/punya-potensi-untuk-biodiesel-minyak-jelantah-justru-kerap-dioplos-di-dalam-negeri/

Gabungan Industri Minyak Nabati Indonesia (GIMNI) & Majalah Sawit Indonesia. (2021, June 23). *Webinar kupas tuntas regulasi minyak jelantah dari aspek tata niaga dan kesehatan, 23 June 2021* [Webinar]. https://gimni.org/kupas-tuntas-regulasi-minyak-jelantah-dari-aspek-tata-niaga-dan-kesehatan/

Garudafood. (2022). Profil perusahaan. Retrieved from https://garudafood.com/cfind/source/files/tentang-garudafoood/company-profile.pdf

Ghani, M.R.A. (2007, May 22). Price stabilization scheme for cooking oil re-introduced. *BERNAMA*. Retrieved from https://bepi.mpob.gov.my/news/detail.php?id=4057

Goh, B.H.H., Chong, C., Ge, Y., Ong, H., Ng, J., ..., Jozsa, V. (2020). Progress in utilization of waste cooking oil for sustainable biodiesel and biojet fuel production. *Energy Conversion and Management*, *223*, 113296. https://doi.org/10.1016/j.enconman.2020.113296

Greenea. (2021). *Greenea horizon 2030: The year 2021 which investments will see the light in the biofuel industry?* Retrieved from http://www.greenea.com/wp-content/uploads/2021/01/Greenea-Horizon-2030-Which-investments-will-see-the-light-in-the-biofuel-industry-1.pdf

Hanisah, K., Kumar, S., and Yang, T. (2013). The management of waste cooking oil: A preliminary survey. *Health & the Environment Journal, 4*(1), 76–81. https://www.researchgate.net/publication/320823701_The_Management_of_Waste_Cooking_Oil_A_Preliminary_Survey

Haryanto, J.T. (2018). Studi pemanfaatan limbah minyak jelantah di daerah. The Ary Suta Center, 14, 187–212. http://lib.ui.ac.id/detail?id=20495887&lokasi=lokal

Hermansyah, A. (2016, March 21). Illegal UCO cartels hinder biofuel program: observers. *The Jakarta Post*. https://www.thejakartapost.com/news/2016/03/12/illegal-uco-cartels-hinder-biofuel-program-observers.html

IMRB International. (2016). *Exploring current practices regarding disposal and usage of used cooking oil (UCO)*. Retrieved from https://www.muenzer.in/files/cto_layout/img/company/Study%20on%20Current%20Practices%20Regarding%20Disposal%20and%20Usage%20of%20Used%20Cooking%20Oil%20(UCO).pdf

JGC Holdings Corporation. (2021, August 2). *Establishment of a supply chain model for bio-jet fuel production from domestic used cooking oil: Selected as a NEDO (New Energy and Industrial Technology Development Organization) project* [Press release]. https://www.jgc.com/en/news/assets/pdf/20210802e.pdf

Jumiati, Tri. (2009). Laporan magang di PT. Indofood Sukses Makmur Tbk Semarang-Jawa Tengan: Pengendalian mutu mi instan. Universitas Sebelas Maret Surakarta. Retrieved from https://core.ac.uk/download/pdf/16507081.pdf

Kabir, I. (2014). *Household willingness to accept collection and recycling of waste cooking oil for biodiesel input in Petaling District, Selangor, Malaysia* (Master's thesis). University Putra Malaysia. Retrieved from https://core.ac.uk/reader/237297493

Kabir, I., Yacob, M., & Radam, A. (2014). Households' awareness, attitudes and practices regarding waste cooking oil recycling in Petaling, Malaysia. *IOSR Journal of Environmental Science, Toxicology and Food Technology, 8*(10), 45–51. https://www.iosrjournals.org/iosr-jestft/papers/vol8-issue10/Version-3/I081034551.pdf

Kharina, A., Searle, S., Rachmadini, D., Kurniawan, A.A., & Prionggo, A. (2018). *The potential economic, health and greenhouse gas benefits of incorporating used cooking oil into Indonesia's biodiesel*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/UCO_Biodiesel_Indonesia_20180919.pdf

Kippuw, Lucia. (2019). Optimasi biodiesel dari 'Blothong' (limbah pabrik mie instant) ditinjau dari konsentrasi katalis (NaOH) dan waktu pemanasan. Tugas Akhir Universitas Kristen Satya Wacana. Retrieved from https://repository.uksw.edu/bitstream/123456789/20240/2/T1_652012701_Full%20text.pdf

Korea Bioenergy Association. (2021). *Biodiesel*. http://www.kbea.or.kr/front/site/business/bio-diesel.php

Kristiana, T. & Baldino, C. (2021). *Potential biofuel production pathways in Indonesia: Overview of processes, feedstocks, and types of fuel*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Potential-biofuel-pathways-indonesia-EN-apr2021.pdf

Kumar, H., Jayram, S., Prajanya, G., & Nagarjun, M. (2020, February). Assessing the availability of used cooking oil (UCO) in Bengaluru City. In Deka, P.C., Gumtapure, V., Jena, D., Sharma, A., & Rinwa, M. (Editors), *International conference on recent advances on renewable energy 2020*, https://www.kscst.org.in/research_articles_files/Assessing%20the%20availability%20of%20used%20cooking%20oil%20(UCO)%20in%20Bengaluru%20city.pdf

Liu, T., Liu, Y., Wu, S., Xue, J., ..., Kang, J. (2018). Restaurants' behaviour, awareness, and willingness to submit waste cooking oil for biofuel production in Beijing. *Journal of Cleaner Production*, *204*, 636–642. https://doi.org/10.1016/j.jclepro.2018.09.056.

Liu, Y., Liu T., Agyeiwaa, A., & Li, Y. (2018). A SWOT analysis of biodiesel production from waste cooking oil. *IOP Conference Series: Earth and Environmental Science*, *170*, 022136. https://iopscience.iop.org/article/10.1088/1755-1315/170/2/022136/meta

Malaysia Palm Oil Board. (2008, May 8). Govt to review cooking oil subsidy scheme. Retrieved from https://bepi.mpob.gov.my/news/detail.php?id=4991

Manufakturindo.com (n.d.). *PT.URC Indonesia*.

https://en.manufakturindo.com/company/detail/pt-urc-indonesia-bekasi.html

Megawati, S. (2018, 1 August). Kumpulkan dari 1.300 rumah, hanya mampu kirim 7000 liter jelantah. *Radar Jogja*. Retrieved from https://radarjogja.jawapos.com/boks/2018/08/01/kumpulkan-dari-1-300-rumah-hanya-mampu-kirim-7000-liter-jelantah/

Meng, Li & Yang, Xie. (2012). Waste Oil "Revolution" (in Chinese). Retrieved on August 10, 2021 from http://roll.sohu.com/20121117/n357847522.shtml

Ministry of Domestic Trade and Consumer Affairs Malaysia. (2021, June 8). *The government is concerned about the cost of living of the people* [Press release]. https://www.kpdnhep.gov.my/en/media-kpdnhep/berita-kpdnhep/berita-terkini/2021/982-the-government-is-concerned-about-the-cost-of-living-of-the-people.html#:~:text=COSS%20is%20a%20cooking%20oil,50%20per%20packet

Moffitt, L. (2021, October 19). Malaysian biodiesel, UCO trade rebounds in August. *Argus Media*. Retrieved from https://www.argusmedia.com/en/news/2264891-malaysian-biodiesel-uco-trade-rebounds-in-august

National Bureau of Statistics of China. (2019). *China statistical yearbook 2019*. Retrieved from http://www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm

O'Malley, J., Pavlenko, N., & Searle, S. (2021). *Estimating sustainable aviation feedstock availability to meet growing European Union demand*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Sustainable-aviation-fuel-feedstock-eu-mar2021.pdf

O'Neill, A. (2021a). *India: Estimated total population from 2016 to 2026*. Retrieved from Statista, https://www.statista.com/statistics/263766/total-population-of-india/

O'Neill, A. (2021b). *Malaysia: Urbanization from 2010 to 2020*. Retrieved from Statista, https://www.statista.com/statistics/455880/urbanization-in-malaysia/

O'Neill, A. (2021c). *South Korea: Urbanization from 2010 to 2020*. Retrieved from Statista, https://www.statista.com/statistics/455905/urbanization-in-south-korea/

Parmar, A. (2021a, November 9). Indonesia mulls hoarding UCO to hit emissions goals. *Argus Media*. Retrieved from https://www.argusmedia.com/en/news/2271894-indonesia-mulls-hoarding-uco-to-hit-emissions-goals

Parmar, A. (2021b, March 16). Malaysia becoming net UCO importer. *Argus Media*. Retrieved from https://www.argusmedia.com/en/news/2196263-malaysia-becoming-net-uco-importer

Parmar, A. (2021c, May 11). Malaysia's Covid lockdown squeezes UCO supplies. *Argus Media*. Retrieved from https://www.argusmedia.com/en/news/2213693-malaysias-covid-lockdown-squeezes-uco-supplies

Parmar, A. (2021d, October 22). Delays send China's September UCO sales to record high. *Argus Media*. Retrieved from https://www.argusmedia.com/en/news/2266213-delays-send-chinas-september-uco-sales-to-record-high

Pratama, A.M. (2021, December 10). Pemerintah cabut larangan penjualan minyak goreng curah. *Kompas.com*. Retrieved from https://money.kompas.com/read/2021/12/10/182246726/pemerintah-cabut-larangan-penjualan-minyak-goreng-curah?page=all

PRIMA Markets. (2018). *Shanghai update: Chinese waste boom spurs trade and traceability investment*. Retrieved from https://www.iscc-system.org/wp-content/uploads/2018/07/China-Special-Report.pdf

Ramli, R. (2020, December 7). Daur ulang minyak jelantah jadi biodiesel, kelompok masyarakat ini raup omzet Rp 2 juta per hari. *Kompas.com*. Retrieved from, https://money.kompas.com/read/2020/12/07/125446126/daur-ulang-minyak-jelantah-jadi-biodiesel-kelompok-masyarakat-ini-raup-omzet?page=all

Rusdianto, E. (2019, August-September). Mengubah minyak jelantah menjadi biodiesel di Makassar. Retrieved from Bakti News, https://baktinews.bakti.or.id/artikel/mengubah-minyak-jelantah-menjadi-biodiesel-di-makassar

Searle, S. (2021a). *Alternative transport fuels elements of the European Union's "Fit for 55" package*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/alternative-fuels-fit-for-55-eu-sept21

Searle, S. (2021b). *Public comments on proposed ReFuel EU regulation*. Retrieved from the International Council on Clean Transportation, https://theicct.org/news/refuel-eu-sustainable-air-transport-dec21

Shin, J., Kim, G., Zepernick, J., & Kang, K. (2018). A Comparative study on the RFS Program of Korea with the US and UK. *Sustainability* 2018, *10*(12), 4618. https://doi.org/10.3390/su10124618

Smergers. (n.d.). *Indian Restaurant Industry: What's on your menu?*. https://www.smergers.com/industry-watch/indian-restaurant-industry/

Spottle, M., Alberici, S., Toop, G., Peter, D., Gamba, L., ..., Bellefleur, D. (2013). Low ILUC potential of wastes and residues for biofuels: Straw, forestry residues, UCO, corn cobs. Ecofys. Retrieved from https://www.tweedekamer.nl/downloads/document?id=dce7deab-bf15-41b3-9cf3-b97ed6d45c5e&title=Low%20ILUC%20potential%20of%20wastes%20and%20residues%20for%20biofuels.%20Straw%2C%20forestry%20residues%2C%20UCO%2C%20corn%20cobs.pdf

Statistics Bureau Ministry of Internal Affairs and Communication Japan. (2009). *Statistical Handbook of Japan 2009*. Retrieved from https://www.stat.go.jp/english/data/handbook/pdf/2009all.pdf

Statistics Bureau Ministry of Internal Affairs and Communication Japan. (2020). *Statistical Handbook of Japan 2020*. Retrieved from https://www.stat.go.jp/english/data/handbook/pdf/2020all.pdf#page=23

Statistics Korea. (2020). *Population and households in 2019*. http://kostat.go.kr/portal/eng/pressReleases/8/1/index.board

Sudaryadi, Amukti, R., Panghegar, F., Sari, A., Septiani, M., & Kristiantono, T. (2021). *Used cooking oil (UCO) collection model for biodiesel feedstock in Indonesia*. Traction Energy Asia.

Suriyani, L. (2016, September 2). Cerita menarik pengolahan jelantah jadi biodiesel di Bali. *Mongabay*. Retrieved from https://www.mongabay.co.id/2016/09/02/cerita-menarik-pengolahan-jelantah-jadi-biodiesel-di-bali/

Syam, M., Putra, A., Amaliyah, A., & Hayat, A. (2018). Pemanfaatan limbah minyak goreng sebagai bahan baku biodiesel di Makassar. *TEPAT jurnal teknlologi terapan untuk pengabdian masyarakat, 1*(2), 155–161. https://doi.org/10.25042/jurnal_tepat.v1i2.49

Textor, C. (2020). *Number of outlets in the foodservice market of China in 2017 and forecasts for 2022, by subsector*. Retrieved from Statista, https://www.statista.com/statistics/429864/chinese-foodservice-market-outlets-by-subsector/

Tim Nasional Percepatan Penanggulangan Kemiskinan (TNP2K) & Traction Energy Asia. (2020). *Pemanfaatan minyak jelantah untuk produksi biodiesel dan pengentasan kemiskinan di Indonesia*. Retrieved from https://tractionenergy.asia/wp-content/uploads/2021/03/Paparan-Pemanfaatan-Minyak-Jelantah-Untuk-Produksi-Biodiesel-dan-Pengentasan-Kemiskinan-di-Indonesia.pdf

United Nations. (2018). *Population country profile*. Retrieved from https://population.un.org/wup/Country-Profiles/

United Nations. (2019). *Population household*. Retrieved from https://www.un.org/development/desa/pd/data/household-size-and-composition

United Nations. (n.d.). *UN Comtrade database*. Retrieved from https://comtrade.un.org/data

U.S. Department of Agriculture. (2018). *Korea edible oils market brief-palm and soy oils lead the way*. Retrieved from https://kr.usembassy.gov/wp-content/uploads/sites/75/KS-1801-Edible-Oils-Market-Brief_1-17-2018-1.pdf

U.S. Department of Agriculture. (2020a). *China biofuels annual report 2020*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Beijing_China%20-%20Peoples%20Republic%20of_07-27-2020

U.S. Department of Agriculture. (2020b). *India biofuels annual report 2020*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_New%20Delhi_India_07-06-2020

U.S. Department of Agriculture. (2020c). *Indonesia oilseeds and products annual report 2020*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds%20and%20Products%20Annual_Jakarta_Indonesia_03-15-2020

U.S. Department of Agriculture. (2020d). *Japan biofuels annual report 2020*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Tokyo_Japan_10-28-2020

U.S. Department of Agriculture. (2020e). *Malaysia biofuels annual report 2020*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Kuala%20Lumpur_Malaysia_10-26-2020

World Instant Noodles Association. (2021). *Global demand for instant noodles: Demand rankings*. https://instantnoodles.org/en/noodles/demand/table/

World Bank. (2021). *Urban* population-Japan. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=JP

Yano, J., Aoki, T., Nakamura, K., Yamada, K., & Sakai, S. (2015). Life cycle assessment of hydrogenated biodiesel production from waste cooking oil using the catalytic cracking and hydrogenation method. *Waste management*, 38, 409–423. https://doi.org/10.1016/j.wasman.2015.01.014

YumChina. (2020). *Annual report 2020*. Retrieved from https://ir.yumchina.com/static-files/b4636991-66a8-4048-878e-519fe5bea623

Zengkun, F. (2014, March 6). 'Gutter oil' not sent to hawkers, says NEA. *The Straits Times*. Retrieved from https://www.straitstimes.com/singapore/gutter-oil-not-sent-to-hawkers-says-nea