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Used cooking oil's potential to reduce GHG emissions from Indonesia's fishing fleet

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Summary

Fishing fleets are a considerable contributor to global greenhouse gas (GHG) emissions and their emissions have been increasing as demand for fish products grows. Often the countries that produce the largest volumes of fish rely on old, inefficient vessels and use fuel-intensive fishing practices. Indonesia, the second largest fish producer in the world, is no exception. At the same time, efforts to reduce fishing's climate impact are rarely included in countries' GHG reduction strategies and most fishing vessels are too small to be covered by international maritime regulations.

One way to reduce GHG emissions from fishing fleets is to use more sustainable fuels with lower carbon intensity. Indeed, Indonesia has opportunities to maximize its bioenergy potential by adding new feedstocks for biodiesel production, and this study explores the potential of using used cooking oil (UCO) biodiesel, an advanced biofuel, in the Indonesian fishing fleet and the associated benefits. We also estimate the fuel consumption and GHG emissions benefits of banning the use of trawlers.

Using 2019 fish catch data and fuel intensity values found for Asia, our mid-range estimate is 5,000 ML of fossil diesel used by the Indonesian fishing fleet when including the use of trawls, and that is equivalent to 174,000 TJ of energy demand. If supplied at its full potential, we estimated that UCO biodiesel could replace 16% of this energy demand. Replacing fish trawling with less fuel-intensive practices was estimated to decrease fuel consumption by 32% and thus increase UCO's potential to cover total demand from the fishing fleet to 24%.

Our life-cycle, well-to-wake (WTW) carbon intensity estimate for biodiesel produced from UCO in Indonesia is 21.7 gCO_2/MJ, more than four times lower than that of fossil diesel or gasoline. At the estimated 5,000 ML of fuel demand for the fishing fleet, blending UCO biodiesel could cut WTW CO_2e emissions by 11% compared to fossil diesel, and those emissions savings go up to 43% in a scenario where trawls are replaced with more sustainable fishing gears including surrounding nets, hooks and lines, and pots and traps for crustaceans.

As a few businesses have already demonstrated, there is demand for UCO biodiesel among small-scale fisheries in Indonesia. At the same time, achieving full-scale UCO collection and implementation in Indonesia is likely to require strong policy support

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from the government, including by adding UCO biodiesel to the national biofuel mandate and a subsidies program. There are important co-benefits from sustainable fishing fuels and fishing methods. Maintaining a strong and wide-ranging trawls ban nationally and advancing more sustainable fishing practices would improve energy efficiency and maximize the positive effect of UCO biodiesel blending. Additionally, collecting more data on Indonesian fishing fleet fuel consumption and efficiency in the future would enhance our understanding of this and support strategies for continued improvement.

Introduction and background

Indonesia has the largest fishing fleet in the world and ranks second largest in terms of fishing production by volume (California Environmental Associates [CEA], 2018; Organisation for Economic Co-operation and Development [OECD], 2021). Fishing is 2.65% of the national gross domestic product and, importantly, is a source of national food security and employment. Indonesia is the eighth most fish-dependent nation in the world and the fishing sector employs approximately 6 million people.

Around 7.5 million tonnes (Mt) of fish was landed in capture fisheries in Indonesia in 2019, the most recent year for which this data was readily found, and that was a 54% increase by volume from 2005 (Central Bureau of Statistics Republic of Indonesia, 2020b). Most fisheries in Indonesia are artisanal and belong to individual households. Industrial fisheries are estimated to own less than 1% of the total fishing vessels (Central Bureau of Statistics Republic of Indonesia, 2018). The overall technological performance of small-scale fisheries in Indonesia is rather poor due to their use of old, inefficient vessels and this leads to relatively high fuel use per tonne of fish landed in Indonesia (Organisation for Economic Co-operation and Development, 2021; Parker & Tyedmers, 2015). Indonesia's fishing fleet also has one of the largest overall greenhouse gas (GHG) emissions footprints in the world, second only to China, and fuel consumption is the primary source of GHG emissions from fishing (Parker et al., 2018).

In 1981, Indonesia adopted its first nationwide ban on the use of all *cantrang* trawlers (Bailey, 1997). The intention of the ban was to stop the environmental damage caused by trawling such as significant bycatch, overfishing, and ocean floor destruction (Bailey, 1997; Costa et al., 2008), but trawling is also the most carbon-intensive fishing practice in the world. Replacing trawls with less fuel-intensive fishing gears such as surrounding nets and fishing lines considerably decreases fishing vessels' fuel consumption and GHG emissions (Parker & Tyedmers, 2015). Although the ban was extended to all types of trawls and seine nets in 2015 (California Environmental Associates, 2018), the rules were subsequently gradually eased because of strong resistance from industrial fisheries, and in 2020, the ban was removed with few exceptions (Gokkon, 2020). However, less than a year later, in June 2021, the ban was reinstated on the most common types of bottom and mid-water trawlers in Indonesian national waters (Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, 2021).

Fishing vessels in Indonesia are running predominantly on diesel that is supposed to be blended with 30% palm biodiesel, as required by the national biofuel blending mandate (Appendix A). However, even though the blending mandate was applied to the transportation sector beginning in 2015, in 2018, biodiesel represented only 12% of the diesel consumption in the transportation sector of Indonesia (Zhou et al., 2021). While estimates showed the percentage rose to close to 30% in 2020, as transport demand that year was reduced by the COVID-19 pandemic, it is expected that in the coming years, the percentage achieved could be lower.

Diesel is 83% of fuel consumption in the Indonesian fishing fleet; the remaining 17% is mostly gasoline, and there is a small fraction, 0.2%, of kerosene (Central Bureau of Statistics Republic of Indonesia, 2018; Kurniawati, 2019). In addition to the national biofuel mandate, a program run by the Indonesian government promotes the conversion of diesel to liquefied petroleum gas (LPG). The program distributes LPG converter kits for smaller fishing vessels and guarantees the availability of LPG supply. The goal is to reduce operational costs for fishermen and diversify transportation fuels (Kurniawati, 2019). LPG also has a lower carbon content than diesel and can help to reduce GHG emissions from fishing vessels (California Air Resources Board, 2022). However, this program has limitations: It applies only to fishing vessels less than 5 gross tonnage (GT), and some evidence found the number of kits distributed has been relatively limited, as only 25,000 kits were distributed by 2018 (Ministry of Energy and Mineral Resources, 2019).

Diversification of biofuel feedstocks can help to meet the national blending targets while contributing to climate goals. Although Indonesia's biodiesel program currently only focuses on a single feedstock, palm, many other alternative feedstocks and production pathways are available (Kristiana & Baldino, 2021). Used cooking oil (UCO) has the potential to be an alternative feedstock and with a lower price than diesel and be available in volumes large enough to meaningfully contribute to the mix of transport fuels (Zhou et al., 2021). UCO biodiesel can be directly blended with diesel and does not require any modifications when used in marine engines. Additionally, UCO biodiesel has considerably lower carbon content than fossil diesel: 21.7 gCO_2e/MJ versus the 95 gCO_2e/MJ from fossil diesel, both estimated based on 100-year global warming potential (GWP; Council of the European Union, 2015).

Producing biodiesel from UCO is also a new market opportunity. Several Indonesian private companies, including Yayasan Lengis Hijau, GenOil, and Artha Metro Oil, and some multinational corporations, such as Cargill, Adaro, Aqua, and Unilever, are already in the business of producing and selling it (Indonesian Palm Oil Association, 2021). Moreover, GenOil is one of the few companies that produce and deliver UCO biodiesel specifically to small-scale fisheries. The company collects UCO from sources including hotels, restaurants, and households and guarantees that its UCO-based biodiesel is safe for engines. Currently, GenOil produces around 1,300 L biodiesel per day and its retail price is lower than the retail biodiesel price (BPDP Sawit, 2018; IDN Financials, 2020).

This study analyzes the emissions reduction benefits of using UCO-based biofuel in the fishing fleet in Indonesia. We also estimate the fuel use and GHG emissions benefits that come from banning the use of trawlers and show how the potential of UCO biodiesel is increased when paired with more sustainable fishing practices. The analysis is based on published data on fishing production and the fuel use intensity of the most common fishing gears, both of which are used to estimate the fuel demand of the fishing fleet.

Characteristics of the fishing fleet in Indonesia

The exact number of fishing vessels in Indonesia is not known. Most fishing boats belong to household businesses (California Environmental Associates, 2018) and almost the entire fleet is made up of smaller vessels less than 24 m in length, 88% of which are less than 10 GT (Southeast Asian Fisheries Development Center [SEAFDEC], 2019). Only vessels larger than 30 GT are required to carry vessel monitoring system (VMS) transmitters.

The national statistics catalogue of fishing establishments in Indonesia includes an annual census of only larger fishing establishments and, according to the most recent publicly available data found, in 2020, there were 1,133 fishing boats recorded (Central Bureau of Statistics Republic of Indonesia, 2020a). When smaller fisheries are included, the fishing fleet size is estimated to be significantly larger: According to Indonesia's Ministry of Marine Affairs and Fisheries (2019), Indonesia has 936,249 sea-going fishing vessels. However, even this larger number does not reflect the actual fishing fleet size, because fishing boats smaller than 10 GT are not required to hold a fishing license and therefore are not recorded in any database. Although the Indonesian government has offered free registration for smaller fishing boats since the 2010s, the number of registered fishing vessels less than 7 GT was 33,052 in 2019 (Ministry of Transportation of the Republic of Indonesia, 2019). Given that SEAFDEC (2019) stated that 88% of all fishing vessels in Indonesia are less than 10 GT, the number of vessels in both databases is likely to be significantly underestimated. However, even without accounting for the smallest vessels, Indonesia has the largest fishing fleet size of all ASEAN countries (Southeast Asian Fisheries Development Center, 2019).

Fuel use intensity of different fishing gears

Instead of reporting fuel consumption per trip, it is standard practice in the fishing sector to use a fuel use intensity (FUI) value unique to specific fishing gears and/or harvested fish types.[1] This is a common indicator of a fishing vessel's energy efficiency and it has been applied in multiple studies (e.g., Damalas et al., 2016; Driscoll & Tyedmers, 2010; Parker et al., 2018). Use of FUI values is especially common when studying countries with a large fishing sector where the fishing fleet size is uncertain, a vessel monitoring system is not compulsory, and the energy efficiency of fishing vessels is not well-documented (Parker & Tyedmers, 2015).

FUI values can vary significantly depending on the fish species targeted and the gears used, and even similar fishing gears can have different performance depending on a variety of factors, including geographic region, overall technological development of the vessel, size of the vessel, fishing trip patterns, and the technical skills of the vessel's crew (Basurko et al., 2013). It has been found that target fish group, type of fishing gear, and geographic region have the strongest effects on FUI variability (Parker & Tyedmers, 2015). Figure 1 displays a range of the FUI values for the most common fishing gears from different geographic regions of the world, as estimated in published research (full details are in Appendix B). Surrounding nets have the least variability (23 to 358 L/t), and trawls, hooks, and lines can vary up to three orders of magnitude.

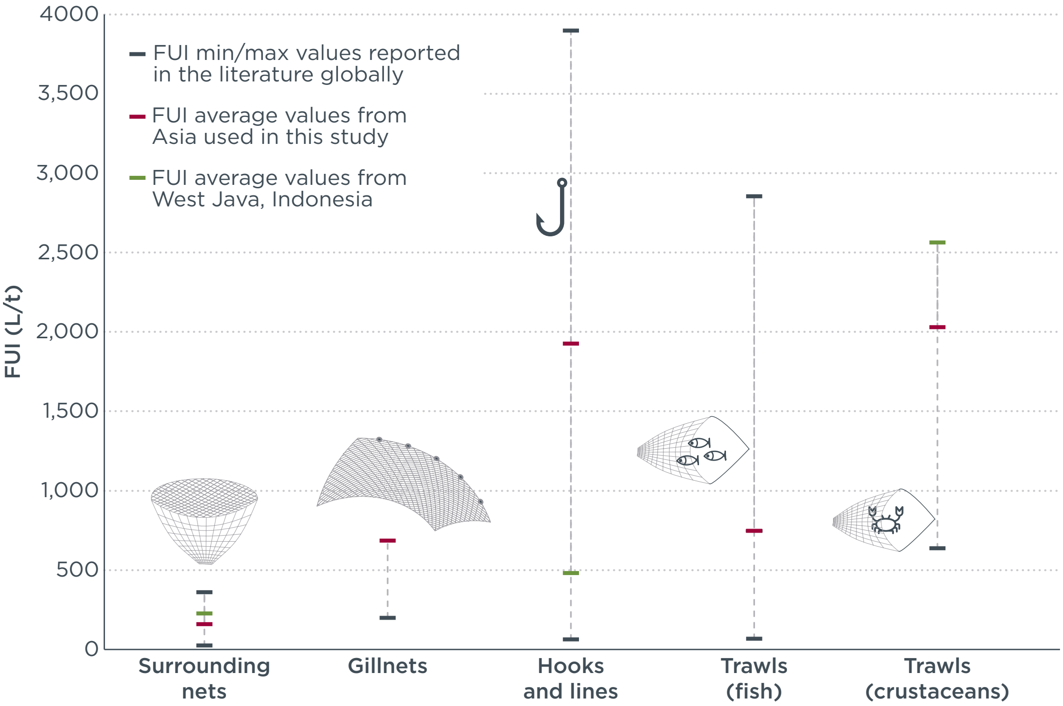

Figure 1. Fuel use intensity (FUI) values reported for different fishing gears. Average FUI values

1 FUI is the amount of fuel spent on a tonne of fish landing (L/t).

reported for West Java Province in Indonesia are from (Kurniawati et al., 2017) and average FUI values from Asia are from Parker & Tyedmers (2015).

Similar to fishing fleet size, region-specific FUI values for Indonesia are scarce in the literature and we found few data from Indonesia's fisheries statistical report. Only one study reporting FUI values specifically for Indonesia was found, Kurniawati et al. (2017), and because it was based on regional surveys in a single province, West Java, it cannot be extrapolated to the whole country. In this analysis, we therefore applied average FUI values for fishing gears and target fish species typical in Asian countries from Parker and Tyedmers (2015) and these are listed in Table 1. They cover five classes of fishing gears: hooks and lines, gillnets, surrounding nets, pelagic trawls, and bottom trawls. Each gear targets a specific fish group landed in Asia. The range of values ($FUI_{min-max}$) is reported where multiple measurements were available.

Table 1. Fuel use intensity (FUI) values for the fishing gear and fish type combinations used in this analysis.

Fishing gear	Fish type	FUI_{av} (L/t)	$FUI_{min-max}$ (L/t)
Pelagic trawls	Crustaceans	2,028	
Hooks and lines	Large pelagic fish	1,925	106 – 4,985
Bottom trawls	Small pelagic fish	922	
Bottom trawls	Finfish	766	766 – 874
Gillnets	Large pelagic fish	683	
Bottom trawls	Flatfish	549	
Surrounding nets	Finfish	162	
Surrounding nets	Large pelagic fish	156	149 – 162
Surrounding nets	Small pelagic fish	152	142 – 162

Source: Parker and Tyedmers (2015).

When compared to the average FUI values for Asia from Parker and Tyedmers (2015), FUI values from Kurniawati et al. (2017) for West Java Province were generally higher. The FUI of trawling for crustaceans was found to be 2,560 L/t in West Java and 2,028 L/t in Asia; using surrounding nets to catch pelagic fish ranged from 180–270 L/t in West Java and 152–156 L/t in Asia. The only exception is hooks and lines—480 L/t for West Java versus 1,925 L/t for Asia—and that can be explained by the prevalence of passive hand liners in West Java.

Estimating fuel demand

To estimate fuel consumption from the Indonesian fishing fleet, we used the latest marine fisheries production data per fish type that we found for Indonesia. That data was for 2019 and is from the United Nations' Food and Agriculture Organization (FAO; 2019). Figure 2 shows the workflow used in this study. There are more than 90 species in Indonesia's fishing market and the biggest share are pelagic marine fish such as tuna. In Indonesia in 2019, 3.8 Mt of pelagic fish were landed and that was 59% of the total; 2.1 Mt of demersal fish were landed, 33% of the total, and crustaceans were 0.5 Mt or 8% (Food and Agriculture Organization of the United Nations, 2019).[2]

2 According to FAO (2019), 1.0 Mt of the marine fish in Indonesia were "not elsewhere included" (NEI). For the purpose of this study, assumed that NEI marine fish were equally distributed between two general fish categories, demersal and pelagic fish.

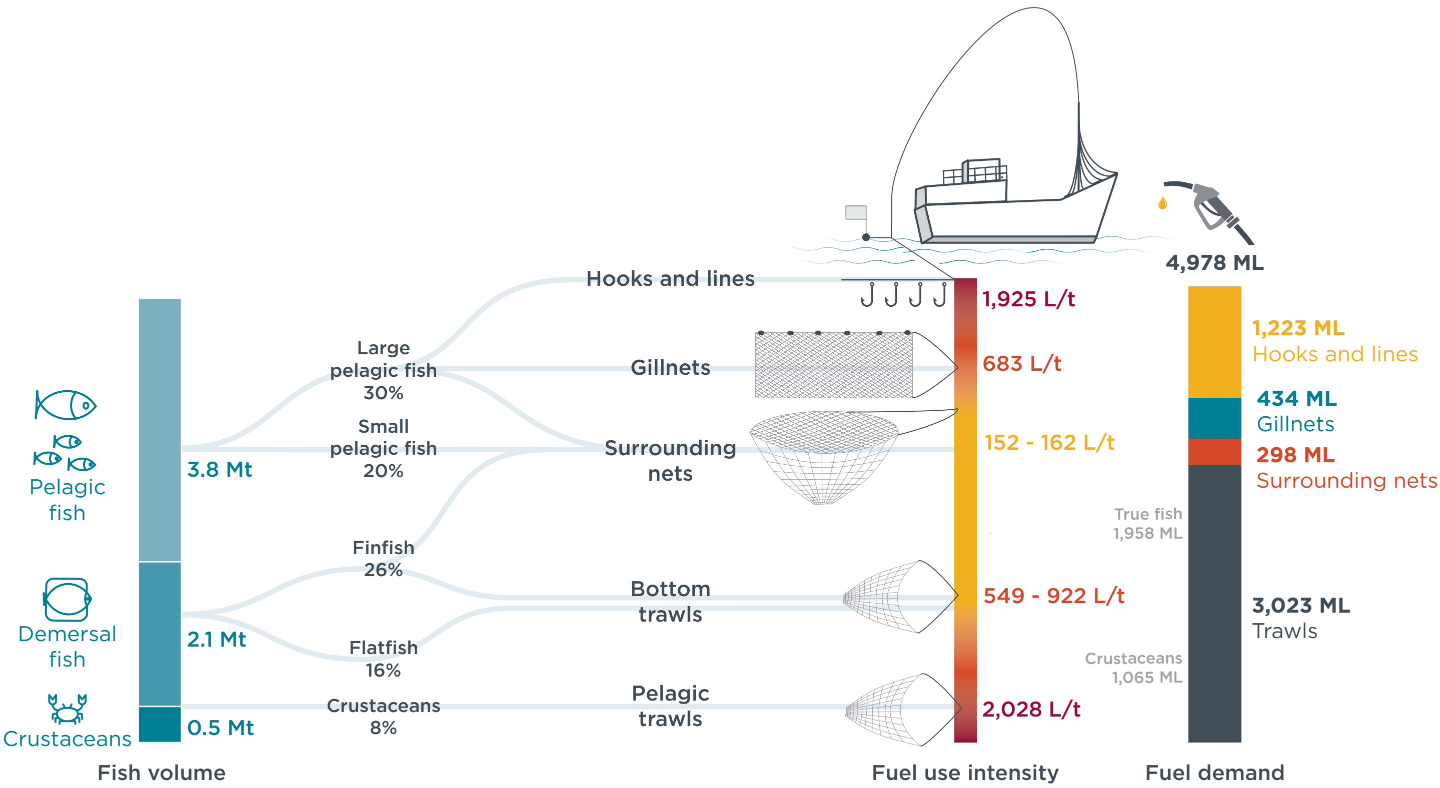

Figure 2. Production volume, fuel use intensity, and fuel consumption of the fishing gears and fish types in Indonesia

We identified which gears would be used for the target fish group by referring to the fishing gear technical characteristics and fish species biology (see Appendix C for definitions of all gear and fish types). For instance, Parker and Tyedmers (2015) reported different FUI values for finfish caught with surrounding nets and bottom trawls. *Finfish* is a general term used in fisheries to aggregate a group of so-called *true fish*, which are everything that is not *shellfish*. Hence, *finfish* includes both pelagic and demersal fish species. Because surrounding nets are used for pelagic fishing and bottom trawls are used for demersal fish, the volumes of finfish were equally distributed between these two gear types.

Pelagic fish can be captured using several fishing gears—there are six fish/gear combinations in total—and the FUIs of these gears have a large spread of values, 152 – 1,925 L/t. Given this, we also performed a sensitivity analysis. Our default scenario assumed that all pelagic fish species can be equally captured with all suitable gears listed in Table 1. The worst- and best-case scenarios assumed that up to 50% of all demersal fish can be caught using the most- and least- energy intensive gears, hooks and lines and surrounding nets, respectively.

Total fuel consumption

After allocating all fish production volume to fishing gear, we calculated total fuel consumption by multiplying the corresponding FUI values and fish production volume. The result was that nearly 5,000 ML of fuel are estimated to be needed for the 6.4 Mt of marine fish that records show was landed in Indonesia in 2019, assuming unrestricted use of trawls. The fuel demand estimate could be as low as 4,200 ML and could be as high as 6,900 ML for the aforementioned best- and worst-case scenarios, respectively. This range shows that the model is sensitive to the allocation of fishing gears and that using the 5,000 ML estimate is conservative.

Assuming that 83% of the fuel is diesel and 17% is gasoline, that fuel demand volume is equal to 118,615 TJ. According to the Central Bureau of Statistics Republic of Indonesia (2018), only 75.3 ML are used by industrial fishing enterprises. That implies that 98.5% of the fish landings are from small artisanal fisheries.

Fuel consumption benefits of a trawling ban

Even though the primary purpose of the trawling ban is not to decrease fuel consumption, it does have that effect because trawling is more fuel intensive than other practices. For example, even though crustaceans represent only 8% of the fish production volume in Indonesia, our scenario estimated that trawling for crustaceans accounted for 21%, 1,065 ML of total fishery fuel consumption. In contrast, surrounding nets are suitable for a variety of fish species that are 30% of the total fishing volume and they consume only 6%, 298 ML, of the total fuel volume.

Crustaceans can be fished using pots and traps. Pots and traps are more energy-efficient than trawling, especially when they are used in large numbers per vessel and left for long hours in one fishing area (Parker et al., 2017). Although a few studies stated that pots and traps are used in Indonesia, their regional FUI values were not found (Irhamsyah et al., 2017; Slack-Smith, 2001) and the average value for Asia was not reported in Parker & Tyedmers (2015). In our scenario that is meant to isolate the impacts of banning trawling, we assumed that fish trawling gears were replaced with gillnets, surrounding nets, and hooks and lines, with corresponding FUI values from Parker and Tyedmers (2015); for pots and traps, we applied the average FUI value for Europe, 834 L/t. The actual FUI values for pots and traps might be higher in Indonesia than in Europe, but the efficiency of fishing gears can change over time due to improvements in technology and national policies (Stevens, 2021). For instance, Western Europe's energy efficiency for fishing gears has gradually improved as a result of increasing technological maturity; meanwhile, other countries have remained at the same performance level (Parker & Tyedmers, 2015).

As illustrated in Figure 3, our results show that replacing fish trawling with gillnets, surrounding nets, and hooks and lines and replacing crustaceans trawling with pots and traps generates a 32% reduction in fuel consumption, from 5,000 ML to 3,400 ML.

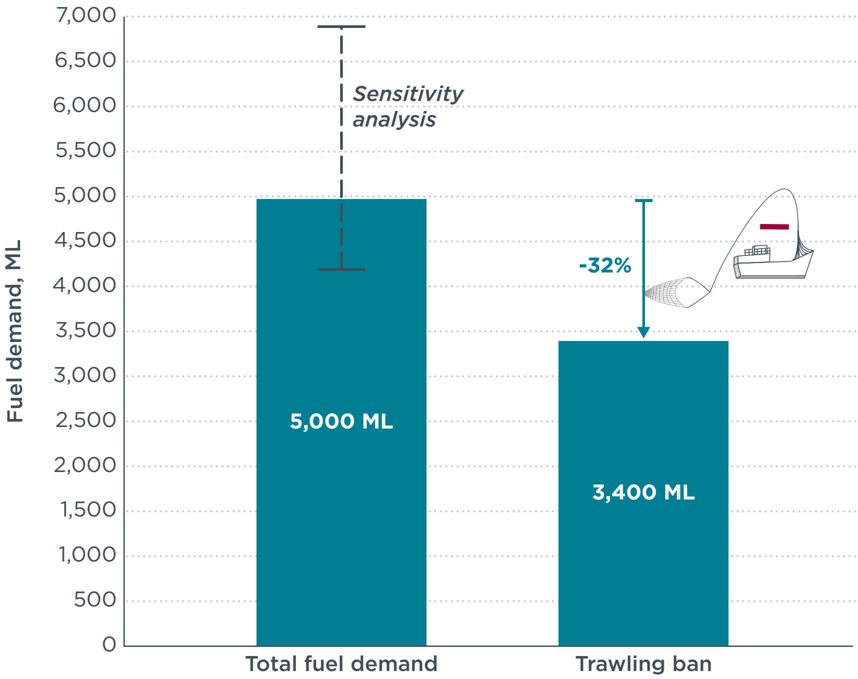

Figure 3. Total fuel demand of the fishing fleet in Indonesia estimated for 2019 marine fish landing of 6.4 Mt.

Potential supply of UCO

Kristiana et al. (2022) estimated that between 182 and 266 kt of UCO is collected annually in Indonesia from urban households, restaurants, and the food processing industry. As shown in Figure 4, food processing is the major source, 43%–49%, and is followed by urban restaurants, 36%–38%, and then households, 14%–19%. Nearly 220 kt, or 83% of collected UCO, was exported by Indonesia in 2020; it was sent mainly to Europe and elsewhere in Asia as feedstock for biofuel and partly to be used by the oleochemical industry (van Grinsven et al., 2020).

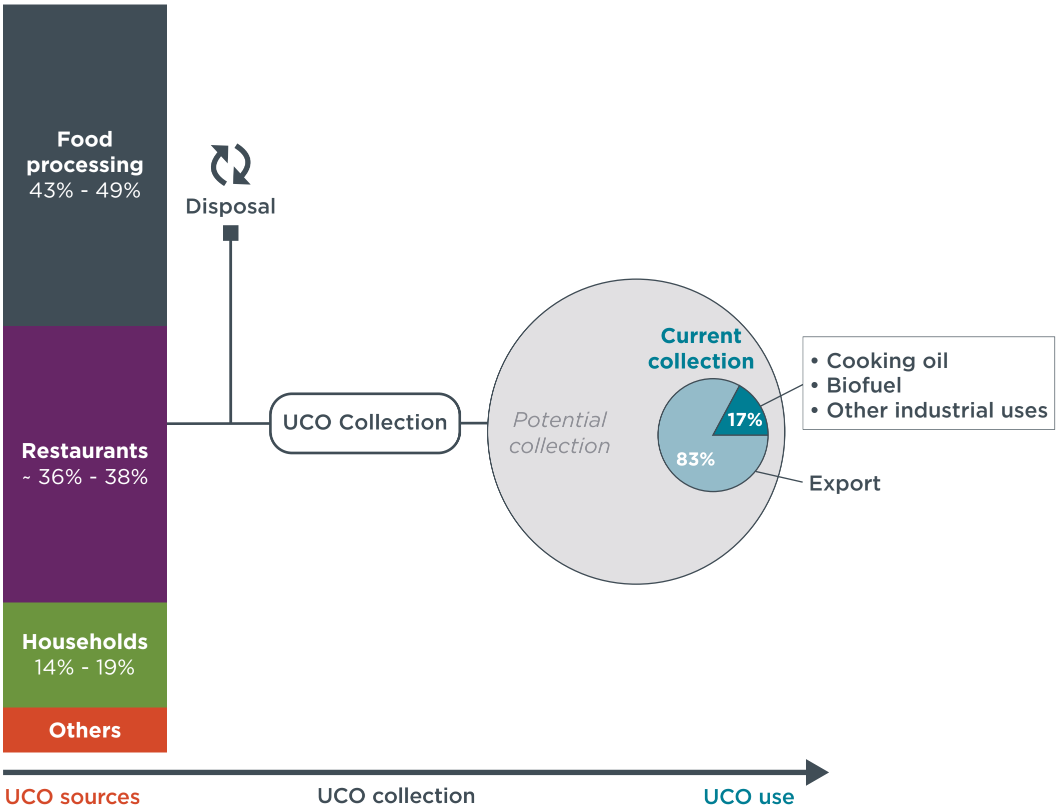

Figure 4. Current UCO supply chain in Indonesia. Source: Kristiana et al. (2022).

There is much more UCO in Indonesia than what is currently collected. Current low collection rates are mainly explained by the absence of a well-organized and centralized distribution system. As a result, most UCO is disposed of in drainpipes or as part of municipal waste collection (Kharina et al., 2018). However, if UCO were added to the government subsidies program as an approved biofuel feedstock, the same distribution channels used for palm oil could be utilized for UCO.

The analysis done by Kristiana et al. (2022) showed that UCO supply in Indonesia could reach more than 786 ML per year, which is equivalent to 732 ML of biodiesel per year (Table 2 and Figure 5). Most of the feedstock would come from restaurants, 46% or 365 ML per year, and that was followed by households, 36% or 280 ML per year, and food processing, 18% or 141 ML per year. Table 2 summarizes the UCO and UCO biodiesel potential supply from the sources considered in Kristiana et al. (2022).

Table 2. Estimates of potential UCO supply from households, restaurants, and food processing plants in Indonesia.

Feedstock source (percentage assumed collected)	Potential supply					
	(tonnes/year)[a]		(ML/year)[b]		(TJ/year)[c]	
	UCO	UCO biodiesel	UCO	UCO biodiesel	UCO	UCO biodiesel
Households (50%)	255,069	232,112	280	261	9,438	8,685
Restaurants (100%)	332,316	302,408	365	340	12,296	11,315
Food processing plants (100%)	128,195	116,658	141	131	4,743	4,365
Total	**715,580**	**651,178**	**786**	**732**	**26,476**	**24,364**

[a] As reported in Kristiana et al. (2022)

[b] Density (kg/L): UCO = 0.91 kg/L, from the European Biomass Industry Association (2021); UCO biodiesel (FAME) = 0.89 kg/L, from Argonne National Laboratory (2020)

[c] Energy density (MJ/kg): UCO = 37.0 MJ/kg, from van Grinsven et al. (2020); UCO biodiesel (FAME) = 37.5 MJ/kg, from Argonne National Laboratory (2020)

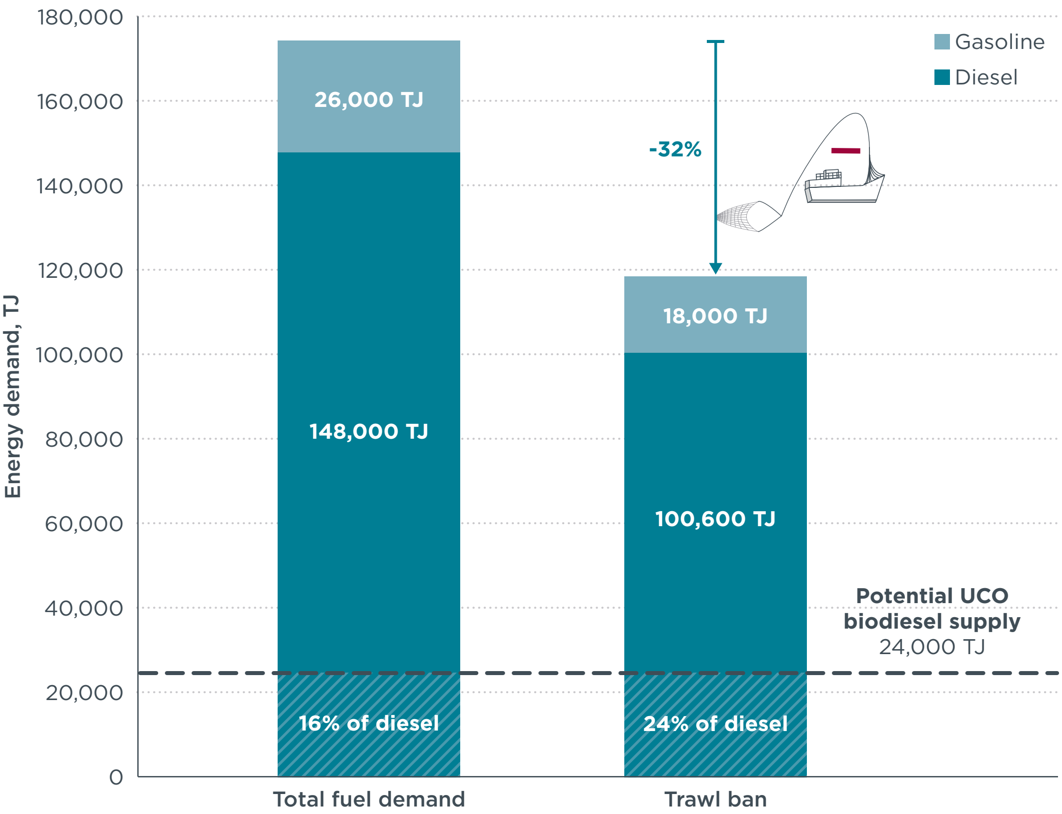

Figure 5. Energy demand of the fishing fleet in Indonesia and UCO biodiesel potential supply

Well-to-wake CO_2e emissions

Well-to-wake (WTW) CO_2e emissions can be divided into two phases: the fuel production stage (well-to-tank, or WTT) and the combustion in the engine (tank-to-wake, or TTW). For estimating WTW CO_2e emissions from UCO biodiesel (FAME) in Indonesia, we used the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by the U.S. Argonne National Laboratory (2020).[3] The GREET tool examines energy use and emissions from different transportation modes, including fuel production pathways and their use in on-road vehicles, aircraft, and marine vessels. For this study, we adjusted the GREET default

3 Fatty Acids Methyl Esters (FAME) are esters of fatty acids whose physical properties are similar to those of fossil-based diesel (ETIP Bioenergy, 2022).

electricity mix, which is the U.S. average, to reflect the Indonesian power sector. The sources used to power the electricity grid in Indonesia are presented in Table 3.

Table 3. Indonesia electricity mix.

	Indonesia electricity mix	Default GREET electricity mix (U.S. average)
Coal	59.1%	38.7%
Natural gas	20.8%	27.6%
Residual oil	4.2%	1.2%
Biomass	3.6%	1.6%
Nuclear	0.0%	19.5%
Others[a]	12.3%	11.4%

Source: International Energy Agency (2021)

[a] Other electricity sources include hydroelectric, geothermal, wind, and solar photovoltaic power.

Our life-cycle assessment (LCA) for UCO biodiesel was composed of the following steps: raw UCO collection and transportation, UCO conversion to biodiesel (FAME), and biodiesel distribution. It was conducted using the energy allocation method and the functional units g/MJ. The results are reported in terms of CO_2e using the GWP100 values from the IPCC's Fourth Assessment Report (Forster et al., 2007).

Previous studies found a wide range of emissions from UCO's collection stage and that they can represent between 6% and 71% of the total GHG emissions (Caldeira et al., 2016; Dufour & Iribarren, 2012; Peiró et al., 2010; Souza et al., 2012). Because actual distances from where UCO is collected to production centers in Indonesia are unknown, we estimated a minimum of 0.8 mi and a maximum of 44 mi based on the distance between current UCO suppliers' locations and the Indonesian coastline, as detailed in Go4World (2021). As the Go4World dataset is based on voluntary reporting and therefore limited, we also applied the default GREET value of 100 mi. We found that total WTW emissions are not sensitive to changes in the distances between UCO collection and production centers in this range and that it was less than 2% of the variation.

Figure 6 shows the results of the LCA for UCO-based biodiesel production in Indonesia. WTW emissions for diesel and gasoline are also included for comparison and those shown are a global average (Council of the European Union, 2015). Still, Indonesia might have slightly higher actual emissions from fossil fuels, given the country's crude oil and refining practices (Jing et al., 2020). The LCA shows that WTW emissions from Indonesian UCO biodiesel are 21.7 gCO_2e/MJ. This number is higher than the default GREET case of 19 gCO_2e/MJ mainly because of the significant amount of coal-based electricity in Indonesia (Table 3). The biodiesel conversion stage is responsible for the highest share of the life-cycle emissions, 56%, and that is followed by raw UCO transportation, 7%, and UCO-biodiesel distribution, 7%. Overall, these results indicate that UCO biodiesel in Indonesia reduces up to 77% of GHG emissions compared to fossil fuels.

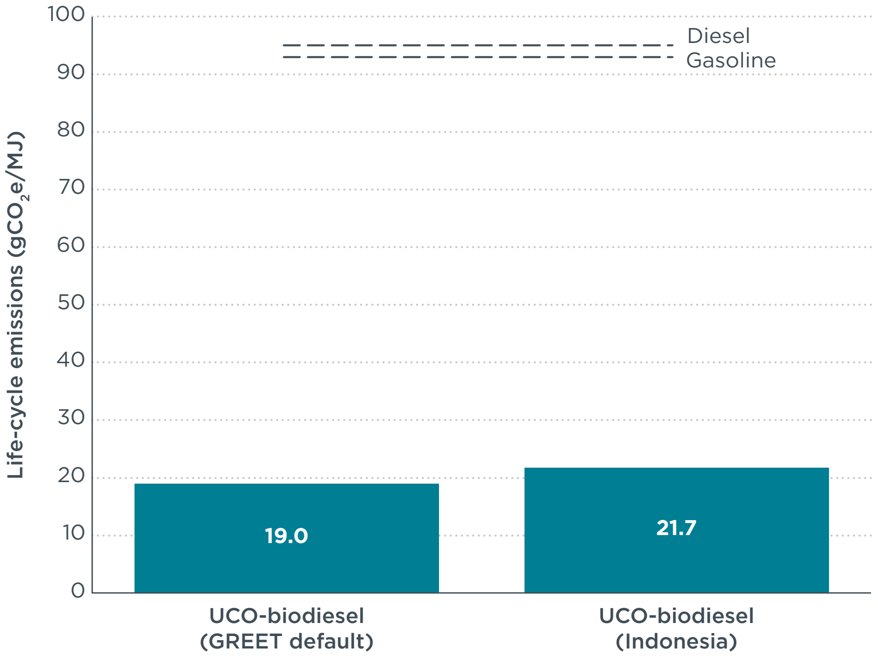

Figure 6. WTW CO_2e emissions results for UCO-based biofuel in Indonesia using GWP100.

Table 4 lists all estimates of fuel consumption, energy use, and CO_2e100 emissions. We used the UCO emissions factors from the LCA and considered that 83% of fishing sector fuel demand is met with diesel and 17% of the demand is met with gasoline, in accordance with official records from the Central Bureau of Statistics Republic of Indonesia (2018). For the UCO-biodiesel scenario, we assumed that fossil diesel was blended with the potential UCO biodiesel production, so a 16% blend. The WTW emission factors were adjusted according to the fuel mix. For the trawls ban scenario, we estimated total CO_2e emissions from fossil fuels and from the potential UCO blend of 24%. Modeling the trawls ban scenario is important because there is scant research that attempts to quantify the GHG emissions savings from this strategy. We used the best data available to us, but collecting more data for different ship types and fishing gears in the future would allow us to improve our understanding of the benefits.

Table 4. Fuel and energy use consumption and corresponding CO_2e100 emissions from the Indonesian fishing fleet

		Scenario			
	Fuel type	**2019 demand met with 100% fossil fuels**	**2019 demand with trawl ban, met with 100% fossil fuels**	**2019 demand met with 16% UCO and 84% fossil fuels**	**2019 demand with trawl ban, met with 24% UCO and 76% fossil fuels**
Fuel consumption (ML)	**Diesel**	4,132	2,810	3,451	2,129
	Gasoline	846	576	846	576
	UCO	0	0	732	732
	Total	**4,978**	**3,386**	**5,029**	**3,437**
Fuel consumption (TJ)[a]	**Diesel**	147,916	100,600	123,552	76,236
	Gasoline	26,488	18,015	26,488	18,015
	UCO	0	0	24,364	24,364
	Total	**174,404**	**118,615**	**174,404**	**118,615**
WTW CO_2e100 (Mt)[b]	**Diesel**	14.1	9.6	11.7	7.2
	Gasoline	2.5	1.7	2.5	1.7
	UCO	0.0	0.0	0.5	0.5
	Total	**16.5**	**11.2**	**14.7**	**9.4**

[a] Assumes the following energy contents: diesel at 35.8 MJ/L; gasoline at 31.3 MJ/L; and UCO at 33.3 MJ/L.

[b] Assumes the following WTW emissions factors: diesel at 95 gCO_2e100/MJ; gasoline at 93 gCO_2e100/MJ; and UCO at 21.7 gCO_2e100/MJ.

The estimated WTW CO_2e emissions from the fishing fleet fueled only with fossil fuel is 16.5 Mt (also illustrated in Figure 7). Blending UCO can contribute up to 11% of emissions reduction and result in 14.7 Mt of emissions. Just replacing trawling with less carbon-intensive fishing practices leads to a 32% reduction and combining the two strategies has the potential to increase GHG savings to 43%.

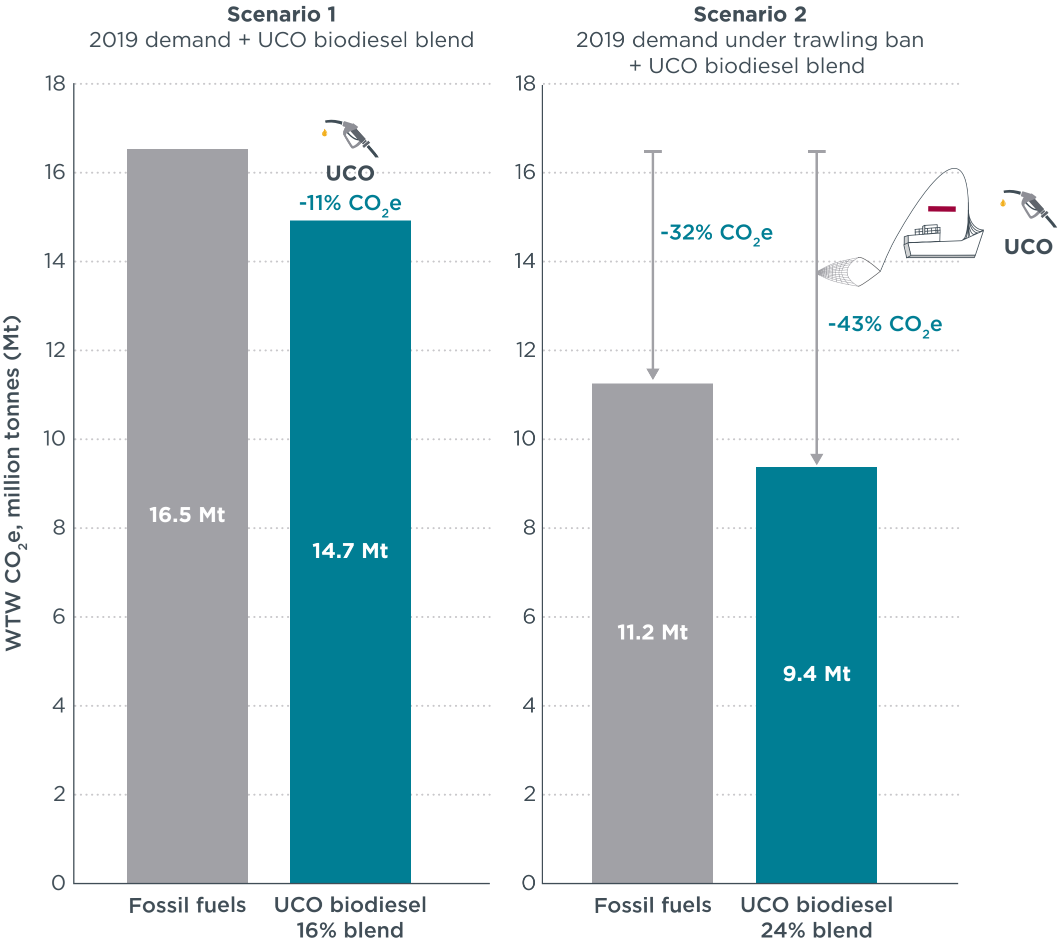

Figure 7. Estimated WTW CO_2e100 emissions from the Indonesian fishing fleet.

Discussion

The nearly 5,000 ML of fuel that we have estimated is needed to support Indonesia's marine fisheries at least at the level of 2019 fish production, without a trawling ban, is about 13% of total global fishery fuel consumption, which is about 40,000 ML annually. Replacing trawls with the fishing gears commonly used in Asia was estimated to save up to 32% of the fishing fuel and increase UCO biodiesel blending capacity to 24%, but this not a ceiling. The fuel consumption of fishing vessels can be reduced even further through technology optimization of fishing gear, improving marine navigation, and diversifying the target fish species (Kurniawati et al., 2017). Moreover, the positive climate impacts of the trawl ban can combine with other environmental and social benefits. Such benefits were documented after trawling was banned in Indonesia in the 1980s, including the demersal fishing stock recovery and reduction of unemployment rates in artisanal fisheries (Bailey, 1997).

The precise magnitude of a trawl ban's positive impact on fuel consumption depends on the fishing gear replacements used and the fishing practices adopted instead of the trawls. Our sensitivity analysis showed that even without a trawl ban, the fleet fuel consumption can go as low as 4,200 ML and as high as 6,900 ML for the same fish landed volume, depending on the fishing methods applied. For a clearer understanding of how much alternate fishing methods can improve GHG footprint, a systematic inventory of vessel-based fuel consumption from artisanal fisheries by fishing gear and fish type is needed. Using this data, local FUI values specific for Indonesia need to be recorded. Even though Indonesia and many other ASEAN countries are heavily dependent on the fishing sector, they have few FUI records in the International Fisheries and Energy Use database compared to other regions; there are 866 records from Europe but only 224 records from Asia (Parker & Tyedmers, 2015).

We found that a trawl ban and UCO biodiesel blending can together result in annual WTW CO_2e emissions savings of 7.1 Mt or 43% compared to fossil diesel. Including UCO in biofuel programs has multiple environmental and social co-benefits such as avoiding disposal of UCO in landfills and preventing groundwater and waterways pollution. Additionally, diverting UCO from reuse as cooking oil can decrease the risks of neurological and heart diseases that have been linked to the practice (Kharina al., 2018; Sudaryadi et al., 2021).

Despite the many benefits of UCO biofuel, current UCO collection rates in Indonesia do not reach even half of the country's estimated potential. However, ICCT has estimated that if UCO were collected from urban households in Indonesia at 50% capacity and from restaurants and food processing at 100% capacity, it could grow from 266 kt to 716 kt per year (Kristiana et al., 2022). Current UCO biodiesel production is also stunted by limited infrastructure and lack of standardized quality control, both of which cause instabilities in feedstock and biodiesel quality (Orjuela & Clark, 2020). This issue could be addressed by upgrading processes and quality control at small-scale UCO biodiesel production facilities.

Another reason for low UCO utilization rates is the absence of policy incentives from the government. The National Energy Plan of Indonesia does not include UCO as a feedstock for biodiesel production and the 30% blending mandate in transportation is attempted by promoting solely palm biodiesel (Sudaryadi et al., 2021). Adding UCO feedstock to the blending mandate could help close any gap between the 30% blending mandate and the actual blending percentage and would contribute to diversifying the transport fuel market in Indonesia.

UCO biodiesel is currently produced in Indonesia in moderate quantities by small-to-medium scale companies, and some of this UCO biodiesel ends up in the engines of fishing vessels. Because UCO biodiesel is not produced in large centers and is often manufactured locally, close to its consumers, it is more accessible for use in artisanal fishing. UCO biodiesel is also attractive to artisanal fisheries because it is a drop-in fuel and does not require any specific modifications of an engine, unlike the national conversion to LPG program (Kurniawati, 2019). GenOil, aware of the regular interruptions in fuel supply and the scarcity of fuel available along the Indonesian coastline, helped address this by delivering UCO biodiesel directly to fishers in the areas where they could not go to sea because of fuel supply interruptions, and the UCO biodiesel was sold at a lower price than diesel (BPDP Sawit, 2018; Netral News, 2021). GenOil demonstrated how site-based UCO biofuel production could increase the energy security of Indonesian small fisheries experiencing frequent fuel delivery disruptions. Enhanced energy security for small fisheries would also help increase catch volumes in distant fishing areas.

Conclusion and policy recommendations

The growing global demand for fish is putting more and more pressure on fisheries, including those in Indonesia, already one of the largest fish exporters in the world. The Indonesian fishing fleet consists mainly of small-scale artisanal fisheries and our analysis found that their fuel consumption without a trawl ban could range from

4,200 ML to 6,900 ML per year, depending on which fishing practices are used; the mid-range estimate is 5,000 ML. We also calculated that the existing fishing fleet in Indonesia, at the level of 2019 demand and operating on diesel and gasoline, would emit 16.5 Mt of CO_2e without a trawl ban. That is equivalent to 9% of emissions from Indonesia's entire agriculture sector.

This GHG footprint can be reduced by diversifying marine fuel, and one way to do that is to make more significant volumes of UCO biodiesel available to small-scale fisheries. Maintaining a strong, comprehensive trawling ban and upgrading the fishing gears that are used instead of trawls would also reduce GHG emissions. Although the GHG benefits of these improvements are less often discussed, this is a win-win strategy. When taking these measures into account, we estimated that UCO biodiesel has the capacity to replace 24% of the entire fishing fleet's fuel demand and reduce life-cycle CO_2e emissions by 43%. This strategy would also bring numerous public health and environmental co-benefits. As such, we recommend pursuing the following policy incentives:

Incorporate UCO into the National Energy Plan of Indonesia as an approved feedstock for biodiesel production and add it to the national biodiesel mandate to make it eligible for subsidies. This would increase both UCO collection and biodiesel production because it would lower the retail price for UCO biodiesel. Adding UCO to the national biodiesel mandate would also include UCO in the national biodiesel standards (SNI), which serve as a safeguard for feedstock and production quality and as safety standards. Additionally, local governments could support regional businesses that produce and deliver sustainable UCO biodiesel to small fisheries on demand. Local governments could also issue regulations regarding UCO collection and, similar to how it currently works for palm oil, appoint companies like GenOil to produce UCO biodiesel and distribute it to local fishers. Such regulations would boost UCO collection and increase supply, which is currently based only on market demand; this, in turn, would increase fuel supply to smaller fisheries in remote areas and improve their energy security.

Include small-scale fisheries in the annual inventories produced by Indonesia's Central Bureau of Statistics. Current inventories include only large-scale industrial fisheries, which consume only a tiny share of the total fuel used by the Indonesian fishing fleet. The lack of reliable data from fisheries of all sizes is an obstacle to developing an adequate plan for decarbonizing the sector.

Maintain and strengthen the nationwide trawl ban and establish a goal-oriented program to improve existing fishing practices. Keeping a trawl ban in place can reduce Indonesian fishing fleet fuel consumption by 32%. This number can go even higher through improvements in technological optimization, marine navigation, and aquaculture practices. Reducing fuel consumption would cut operational costs and lower the fishing fleet's overall carbon intensity.

References

Argonne National Laboratory. (2020). *The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model (GREET)* (Version 2020). https://greet.es.anl.gov/index.php

Bailey, C. (1997). Lessons from Indonesia's 1980 trawler ban. *Marine Policy*, *21*(3), 225–235. https://doi.org/10.1016/S0308-597X(97)00003-1

Basurko, O. C., Gabiña, G., & Uriondo, Z. (2013). Energy performance of fishing vessels and potential savings. *Journal of Cleaner Production*, *54*, 30–40. https://doi.org/10.1016/j.jclepro.2013.05.024

BPDP Sawit. (2018, October 29). *Instead of disposing, convert waste cooking oil into biodiesel*. https://www.bpdp.or.id/en/Instead-of-Disposing-Convert-Waste-Cooking-Oil-into-Biodiesel

Caldeira, C., Queiróz, J., Noshadravan, A., & Freire, F. (2016). Incorporating uncertainty in the life cycle assessment of biodiesel from waste cooking oil addressing different collection systems. *Resources, Conservation and Recycling*, *112*, 83–92. https://doi.org/10.1016/j.resconrec.2016.05.005

California Air Resources Board. (2022). *LCFS pathway certified carbon intensities*. https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

California Environmental Associates. (2018). *Trends in marine resources and fisheries management in Indonesia*. https://www.ceaconsulting.com/wp-content/uploads/Indonesia-Report-2018_Executive-Summary-compressed.pdf

Cashion, T., Tyedmers, P., & Parker, R. (2017). Global reduction fisheries and their products in the context of sustainable limits. *Fish and Fisheries*, *18*, 1026–1037. https://doi.org/10.1111/faf.12222

Central Bureau of Statistics Republic of Indonesia. (2018). *Statistics of fishery establishment 2018* (05220.1901). https://www.bps.go.id/publication/2019/10/22/498c1b0d46851ccd4d1c1d32/statistik-perusahaan-perikanan-2018.html

Central Bureau of Statistics Republic of Indonesia. (2020a). *Statistics of fishery establishment 2020* (05220.1901). https://www.bps.go.id/publication/2021/11/29/19818990830fa979adb29e8b/statistik-perusahaan-perikanan-2020.html

Central Bureau of Statistics Republic of Indonesia. (2020b). *Statistics of marine and coastal resources 2020*. Sub-directorate of Environmental Statistics. https://www.bps.go.id/publication/2020/11/27/643ef35d3f0ddd761b85d074/statistik-sumber-daya-laut-dan-pesisir-2020.html

Cokkon, B. (2020, December 17). *Indonesia allows use of destructive seine and trawl nets in its waters again*. Mongabay Environmental News. https://news.mongabay.com/2020/12/indonesia-allows-use-of-destructive-seine-and-trawl-nets-in-its-waters-again/

Costa, M., Erzini, K., & Borges, T. (2008). Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve). *Scientia Marina*, *72*, 801–814. https://doi.org/10.3989/scimar.2008.72n4801

Council of the European Union. (2015). Council Directive (EU) 2015/652 of 20 April 2015 laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels. *Official Journal of the European Union, L107*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0652&from=DE

Damalas, D., Maravelias, C. D., & Kapantagakis, A. (2016). *Energy performance, fuel intensity and carbon footprint of the Greek fishing fleet*. 11th Panhellenic Symposium on Oceanography and Fisheries, Mytilene, Lesvos island, Greece, Mytilene. https://cloudfs.hcmr.gr/index.php/s/Id8RsUEpBatAQan

Driscoll, J., & Tyedmers, P. (2010). Fuel use and greenhouse gas emission implications of fisheries management: The case of the new england atlantic herring fishery. *Marine Policy*, *34*(3), 353–359. https://doi.org/10.1016/j.marpol.2009.08.005

Dufour, J., & Iribarren, D. (2012). Life cycle assessment of biodiesel production from free fatty acid-rich wastes. *Renewable Energy*, *38*(1), 155–162. https://doi.org/10.1016/j.renene.2011.07.016

ETIP Bioenergy. (2022). *Fatty acid methyl esters (FAME) fact sheet*. https://www.etipbioenergy.eu/fact-sheets/fatty-acid-methyl-esters-fame-fact-sheet

European Biomass Industry Association. (2021). *Used cooking oil*. https://www.eubia.org/cms/wiki-biomass/biomass-resources/challenges-related-to-biomass/used-cooking-oil-recycling

Food and Agriculture Organization of the United Nations. (2001). *Fisheries. FAO term portal. Food and Agriculture Organization of the United Nations*. https://www.fao.org/faoterm/collection/fisheries/en

Food and Agriculture Organization of the United Nations. (2019). *Fisheries and aquaculture. Fishery and aquaculture country profiles. Indonesia*. https://www.fao.org/fishery/en/facp/idn?lang=en

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., Haywood, J., Lean, J., Lowe, D. C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M., & Van Dorland, R. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 129–234). https://doi.org/10.1103/PhysRevB.77.220407

Go4World. (2021). *Indonesian used oil suppliers and manufacturers*. https://www.go4worldbusiness.com/suppliers/indonesia/used-oil.html

He, P., Chopin, F., Suuronen, P., Ferro, R. S. T., & Lansley, J. (2021). *Classification and illustrated definition of fishing gears*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cb4966en

Horton, T., Kroh, A., Ahyong, S., Bailly, N., Bieler, R., Boyko, C. B., Brandão, S. N., Gofas, S., Hooper, J. N. A., Hernandez, F., Mees, J., Molodtsova, T. N., Paulay, G., Bouirig, K., Decock, W., Dekeyzer, S., Vandepitte, L., Vanhoorne, B., Adlard, R., … Zhao, Z. (2022). *World register of marine species (WoRMS)*. WoRMS Editorial Board. https://www.marinespecies.org

IDN Financials. (2020, July 9). *Indonesian government raises the price of biodiesel*. https://www.idnfinancials.com/news/35073/indonesian-government-raises-price-biodiesel#:~:text=JAKARTA.,biodiesel%20used%20for%20B30%20fuel.

Indonesian Palm Oil Association. (2021). *Incredible Palm Oil! It's UCO used to produce biodiesel*. https://gapki.id/en/news/19762/incredible-palm-oil-its-uco-used-to-produce-biodiesel

International Energy Agency. (2021). *Country profile—Indonesia*. https://www.iea.org/countries/indonesia

Irhamsyah, Ahmadi, & Rusmilyansari. (2017). Fish and fishing gears of the Bangkau Swamp, Indonesia. *Journal of Fisheries*, *5*(2), 489–496. http://eprints.ulm.ac.id/5105/1/2.%20Bdfish.%20Fish%20and%20Fishing%20Gears%20489-496.pdf

Jing, L., El-Houjeiri, H. M., Monfort, J.-C., Brandt, A. R., Masnadi, M. S., & Gordon, D. (2020). Carbon intensity of global crude oil refining and mitigation potential. *Nature Climate Change*, *10*(6), 526–532. https://doi.org/10.1038/s41558-020-0775-3

Kasim, K., Nugroho, D., Muawanah, U., Triharyuni, S., & Samusamu, A. S. (2021). Does *cantrang* trawl fishing become more efficient after the partial trawl ban? A case study of technical efficiency of *cantrang* fishery in the Java Sea – Indonesia. *E3S Web of Conferences*, *322*, 03005. https://doi.org/10.1051/e3sconf/202132203005

Kharina, A., Searle, S., Rachmadini, D., Kurniawan, A., & Prionggo, A. (2018). *Potential economic, health, and greenhouse gas benefits of incorporating used cooking oil into Indonesia's biodiesel*. International Council on Clean Transportation. https://theicct.org/publication/potential-economic-health-and-greenhouse-gas-benefits-of-incorporating-used-cooking-oil-into-indonesias-biodiesel/

Kristiana, T., & Baldino, C. (2021). *Potential biofuel production pathways in Indonesia: Overview of processes, feedstocks, and types of fuel*. International Council on Clean Transportation. https://theicct.org/publication/potential-biofuel-production-pathways-in-indonesia-overview-of-processes-feedstocks-and-types-of-fuel/

Kristiana, T., Baldino, C., & Searle, S. (2022). *An estimate of current collection and potential collection of used cooking oil from major Asian exporting countries*. International Council on Clean Transportation. https://theicct.org/publication/asia-fuels-waste-oil-estimates-feb22/

Kurniawati, V. R. (2019). *Sustainable development of fishing operations: A case study focusing on small vessels in Palabuhanratu, Indonesia* [Doctoral dissertation, Newcastle University]. https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.799650

Kurniawati, V. R., Birmingham, R. W., & Murphy, A. J. (2017). *Energy consumption of small scale fishing vessel operations in Indonesia: A case study in Palabuhanratu, Indonesia*. MARENER, Malmo, Sweden. https://commons.wmu.se/cgi/viewcontent.cgi?article=1059&context=marener_conference

Levinton, J. (2021). *Glossary of marine biology*. Stony Brook University. https://you.stonybrook.edu/marinebio/glossary/

McKuin, B., Watson, J. T., Stohs, S., & Campbell, J. E. (2021). Rethinking sustainability in seafood. *Elementa: Science of the Anthropocene*, *9*(1), 00081. https://doi.org/10.1525/elementa.2019.00081

Ministry of Energy and Mineral Resources of the Republic of Indonesia. (2015). *Regulation No.12/2015*.

Ministry of Energy and Mineral Resources of the Republic of Indonesia. (2019, November 25). *Govt distributes 705 converter kits to fishermen in South Sulawesi and East Kalimantan* [Press release]. https://www.esdm.go.id/en/media-center/news-archives/govt-distributes-705-converter-kits-to-fishermen-in-south-sulawesi-and-east-kalimantan

Ministry of Marine Affairs and Fisheries of the Republic of Indonesia. (2019). *Statistic KKP database*. https://statistik.kkp.go.id/home.php?m=kapal&i=5#panel-footer

Ministry of Marine Affairs and Fisheries of the Republic of Indonesia. (2021). *Penempatan alat penangkapan ikan dan alat bantu penangkapan ikan di wilayah pengelolaan perikanan negara Republik Indonesia dan laut lepas serta penataan andon penangkapan ikan*. https://jdih.kkp.go.id/peraturan/f06f4-permen-kp-18-tahun-2021.pdf

Ministry of Transportation of the Republic of Indonesia. (2019, February 22). *As of February, 33 thousand fishing vessels have been certified*. http://dephub.go.id/post/read/per-februari,-33-ribu-lebih-kapal-nelayan-telah-disertifikasi

Netral News. (2021, April 17). *Magic of used cooking oil to become biodiesel, this boy makes Rp 200 million a month: Okezone economy*. https://netral.news/en/magic-of-used-cooking-oil-to-become-biodiesel-this-boy-makes-rp-200-million-a-month-okezone-economy.html

Organisation for Economic Co-operation and Development. (2021). *Fishing fleet*. https://stats.oecd.org/Index.aspx?DataSetCode=FISH_FLEET

Orjuela, A., & Clark, J. (2020). Green chemicals from used cooking oils; Trends, challenges and opportunities. *Current Opinion in Green and Sustainable Chemistry*, *26*, 100369. https://doi.org/10.1016/j.cogsc.2020.100369

Parker, R. W. R., Blanchard, J. L., Gardner, C., Green, B. S., Hartmann, K., Tyedmers, P. H., & Watson, R. A. (2018). Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, *8*(4), 333–337. https://doi.org/10.1038/s41558-018-0117-x

Parker, R. W. R., Gardner, C., Green, B. S., Hartmann, K., & Watson, R. A. (2017). Drivers of fuel use in rock lobster fisheries. *ICES Journal of Marine Science*, *74*(6), 1681–1689. https://doi.org/10.1093/icesjms/fsx024

Parker, R. W. R., & Tyedmers, P. H. (2015). Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish & Fisheries*, *16*(4), 684–696. https://doi.org/10.1111/faf.12087

Peiró, L. T., Lombardi, L., Villalba Méndez, G., & Gabarell i Durani, X. (2010). Life cycle assessment (LCA) and exergetic life cycle assessment (ELCA) of the production of biodiesel from used cooking oil (UCO). *Energy*, *35*(2), 889–893. https://doi.org/10.1016/j.energy.2009.07.013

Slack-Smith, R. J. (2001). *Fishing with traps and pots*. Food and Agriculture Organization of the United Nations. https://www.fao.org/publications/card/es/c/3ca9bd38-1db7-5a31-b532-4e6a02a46980/

Southeast Asian Fisheries Development Center. (2019). *Report of the regional meeting on the regional fishing vessel record (RFVR) for 24 meters in length and over as a management tool toward combating IUU fishing in ASEAN* (TD/RP/2014). http://repository.seafdec.org/handle/20.500.12066/5506

Souza, D. de P., Mendonça, F. M., Nunes, K. R. A., & Valle, R. (2012). Environmental and socioeconomic analysis of producing biodiesel from used cooking oil in Rio de Janeiro. *Journal of Industrial Ecology*, *16*(4), 655–664. https://doi.org/10.1111/j.1530-9290.2012.00517.x

Stevens, B. G. (2021). The ups and downs of traps: Environmental impacts, entanglement, mitigation, and the future of trap fishing for crustaceans and fish. *ICES Journal of Marine Science*, *78*(2), 584–596. https://doi.org/10.1093/icesjms/fsaa135

Sudaryadi, Tony, K., Ricky, A., Tipung, H., Fariz, P., Mutmainah, S., & Annisa Sekar, S. (2021). *Used cooking oil (UCO) collection model for biodiesel feedstock in Indonesia*. Traction Energy Asia. https://tractionenergy.asia/

van Grinsven, A., Toorn, E. van den, Veen, R. van der, & Kampman, B. (2020). *Used cooking oil (UCO) as biofuel feedstock in the EU*. CE Delft. https://www.transportenvironment.org/wp-content/uploads/2021/07/CE_Delft__200247_UCO_as_biofuel_feedstock_in_EU_FINAL%20-%20v5_0.pdf

Zhou, Y., Searle, S., & Kristiana, T. (2021). *Opportunities for waste fats and oils as feedstocks for biodiesel and renewable diesel in Indonesia*. International Council on Clean Transportation. https://theicct.org/publication/opportunities-for-waste-fats-and-oils-as-feedstocks-for-biodiesel-and-renewable-diesel-in-indonesia/

Appendix A. Indonesia's biofuel mandates

The table below details past and future biofuel mandates in Indonesia (Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2015).

Table A1. Biofuel blending mandates in Indonesia by sector.

Sectors	April 2015	January 2016	January 2020	January 2025
	Biodiesel			
Microbusinesses, fisheries, agriculture, transportation, and public services	15%	20%	30%	30%
Transportation (non-public services)	15%	20%	30%	30%
Industry and commercial	15%	20%	30%	30%
Electricity	25%	30%	30%	30%
	Bioethanol			
Microbusinesses, fisheries, agriculture, transportation, and public services	1%	2%	5%	20%
Transportation (non-public services)	2%	5%	10%	20%
Industry and commercial	2%	5%	10%	20%
Electricity	—	—	—	—

Appendix B. Fuel use intensity values

The table below contains details of fuel use intensity (FUI) values that we found reported for different geographical regions. The highlighted cells are the FUI values used in this study.

Table B1. FUI values found in the literature

Fishing gear	Other names	Species	FUI (L/tonne)	Region	Source
Surrounding nets	Purse seine, lift net	Pelagic fish	23	Atlantic	Driscoll and Tyedmers (2010)
			23 – 109	Norway	Cashion et al. (2017)
			29 – 37; 293 – 358	Continental United States	Cashion et al. (2017); McKuin et al. (2021)
			180 – 270	Indonesia, West Java Province	Kurniawati et al. (2017)
			152 – 162	Asia	Parker and Tyedmers (2015)
Gillnets	Entangling nets	Pelagic fish	677	Basque	Basurko et al. (2013)
			199 – 686	North America	Parker and Tyedmers (2015)
			602	Europe	Parker and Tyedmers (2015)
			683	Asia	Parker and Tyedmers (2015)
Hooks and lines	Trolling, poles and lines, longlines, hand lines	Pelagic fish	60 – 1,136	Basque	Basurko et al. (2013)
			849 – 3,896	American Samoa	McKuin et al. (2021)
			573	North Pacific	McKuin et al. (2021)
			1,023 – 2,246	Hawaii	McKuin et al. (2021)
			480	Indonesia, West Java Province	Kurniawati et al. (2017)
			1,925	Asia	Parker and Tyedmers (2015)
Trawls	Bottom trawls, otter trawls	Demersal fish, pelagic fish	1,646	Basque	Basurko et al. (2013)
			431 – 1,084	North America	Parker and Tyedmers (2015)
			83 – 2,851	Europe	Parker and Tyedmers (2015)
			549 – 922	Asia	Parker and Tyedmers (2015)
	Pelagic trawls, beam trawls	Demersal fish, pelagic fish	111 – 371	Norway	Cashion et al. (2017)
			168 – 1,444	Europe	Parker and Tyedmers (2015)
			66 – 101	North America	Parker and Tyedmers (2015)
		Crustaceans	634	Europe	Parker and Tyedmers (2015)
			2,560	Indonesia, West Java Province	Kurniawati et al. (2017)
			2,028	Asia	Parker and Tyedmers (2015)

Appendix C. Glossary

Gear		Source
Surrounding nets	A long piece of net framed by ropes that is constructed mostly from rectangular sections of netting and catches fish by surrounding a school of fish	He et al. (2021)
Purse seine	A wall of netting that is designed to encircle a school of pelagic fish near the surface with a purse line to close the bottom of the net	
Lift net	A piece of netting mounted onto a frame that is lowered into the water to allow fish to enter the area above the net and is then lifted or hauled upward to collect the fish accumulated there	
Gillnets and entangling nets	Long rectangular walls of netting that catch fish by gilling, wedging, snagging, entangling, or entrapping them in pockets	
Hooks and lines	Gears catch fish by the mouth with baited hooks, or by penetrating their flesh (impaling, ripping, or tearing) with unbaited hooks when they pass within the range of movement of the hook	
Trolling	Line with one or more baited hooks (or lures) towed behind a boat	Kasim et al. (2021)
Poles and lines	Carried out with one or more baited (natural or artificial) hooks attached to a single line and fish must take the bait to be captured	
Longlines	Type of hook-and-line gear where hooks are connected to branch lines which are then attached to a long horizontal mainline at certain intervals	
Hand lines	Carried out with one or more baited (natural or artificial) hooks attached to a single line and fish must take the bait to be captured	
Trawling (pelagic and demersal)	A cone-shaped body of netting, usually with one cod end, towed behind one or two boats to catch fish through herding and sieving	
Bottom trawls	A cone-shaped net towed on the seabed and designed to catch fish living on or near the seabed	
Otter trawls	One cone-shaped trawl towed on the seabed by one boat, with its horizontal spread maintained by a pair of otter (door-like) boards	
Beam trawls	A trawl where the horizontal spread is maintained by a rigid beam across the net mouth	
Pots and traps	Set on the bottom with bait, a single pot or in a fleet of many pots, and connected by a rope to a marker on the surface	
***cantrang* trawls**	A special type of modified Danish seine that targets demersal fish and squid in the Java Sea, Indonesia	
Fish groups		
Pelagic fish	Fish that spend most of their life swimming in the water column with little contact with or dependency on the bottom	Horton et al. (2022); Levinton (2021); FAO (2001)
Demersal fish	Fish living in close relation with the bottom and that depend on it	
Flatfish	Demersal fish not bilaterally symmetrical, with one eye migrating to the other side of the cranium	
Finfish	Used to describe the biological group of fishes, sometimes called *true fishes*	
Shellfish	Includes both mollusks, such as clams, and crustaceans, such as lobsters	
Crustaceans	A type of animal that has several pairs of legs and a body made up of sections that are covered in a hard outer shell	