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Comparative Carbon Footprint Assessment of Squid Jig and Bouke Ami (Lift Net) Fishing Fleets at Nizam Zachman Ocean Fishing Port, Jakarta, Indonesia

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***Abstract*—** Squid fishing fleets rank among the leading sources of carbon emissions within the marine fisheries sector. Their fuel use at sea is considerable and differs markedly according to the fishing gear employed. The present study sets out to quantify the carbon footprint of the squid fishing fleet and to contrast Fuel Use Intensity (FUI) and carbon emissions between vessels operating Squid Jig and Bouke Ami (Lift Net) gear at the Nizam Zachman Ocean Fishing Port in Jakarta. A total of 30 fishing vessels were surveyed, comprising 15 Squid Jig and 15 Bouke Ami vessels of 30 to 200 GT, over the April – May 2026 period. Information gathered covered vessel characteristics, fuel use, voyage records, and catch production. FUI was obtained as fuel consumption divided by total catch, whereas the carbon footprint was derived through the IPCC emission factor approach. Findings reveal that the Squid Jig fleet records a lower mean FUI (0.189 kg fuel/kg catch) together with a smaller carbon footprint (0.611 kg CO_2-eq/kg catch) compared to Bouke Ami fleet (0.252 kg fuel/kg catch and 0.813 kg CO_2-eq/kg catch). Within the Squid Jig fleet the footprint falls more steeply as vessels grow larger, by 34.7%, against only 11.7% for the Bouke Ami fleet. Taken together, these results point to the Squid Jig as the more fuel-efficient and environmentally sustainable option, offering a scientific foundation for building low-carbon squid fisheries in Indonesia.

Keywords—Carbon footprint, Fuel Use Intensity, Greenhouse gas emissions, Low-carbon fisheries

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I. INTRODUCTION

Climate change now stands as one of the most pressing global concerns and has drawn earnest attention across many nations, owing to its wide-ranging consequences for the environment, economic systems, and food security [1]. Under the international commitments set out in the Paris Agreement [2], Indonesia has pledged to cut greenhouse gas (GHG) emissions by 31.89% on its own and by as much as 43.20% with international assistance by 2030, a goal stated in its Enhanced Nationally Determined Contribution (ENDC) [3]. Meeting this pledge calls on every development sector, the marine and fisheries fields included, to take an active part in the national climate mitigation agenda.

Reliance on fossil-fuel energy across transportation and production activities is a leading driver of GHG emissions, with carbon dioxide (CO_2) standing out as the principal gas behind global warming. From an economic standpoint, the effect of such emissions is frequently measured through the notion of a carbon footprint, namely the sum of GHG emissions released, whether directly or indirectly, by a given activity or product chain [4]. Such an indicator is being adopted more and more to gauge the sustainability of production systems, the capture fisheries subsector among them [5];[6].

Capture fisheries rank among the principal contributors of carbon emissions along the marine food chain, largely because of the heavy fuel demand of operations at sea. Earlier work has demonstrated that fuel burned by vessels makes up the bulk of GHG emissions in the fisheries production chain, its share surpassing 70% of the total up to the point of landing [7]. Worldwide, the fishing fleet is thought to burn roughly 40 billion liters of fuel each year and to release 179 million metric tons of CO_2-equivalent emissions [8]; [9];[10]. How much is emitted depends on a range of operational factors, such as vessel size, the gear in use, the fishing grounds, trip length, and catch productivity [8];[11]. Mapping and measuring the carbon footprint across different fisheries therefore marks a strategic move toward advancing energy-efficient, low-emission fisheries management [12].

Among Indonesia's many fishery commodities, squid counts as a high-value product and ranks among the

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nation's foremost export goods, with demand still climbing [13]. Squid are harvested with several gear types of differing operational traits, among them squid jigging and boat seine [14]; [15]. Differences in method, lighting needs, vessel size, operating time, and fishing location give rise to marked disparities in fuel use between fishing units [15]. These disparities, in turn, translate into differing carbon emissions across fishing systems [16].

While carbon footprint research within the fisheries sector has progressed markedly [7], [8], [12], studies that specifically examine and compare the environmental performance of squid-fishing fleets by gear type are still scarce in Indonesia. The majority of available work concentrates on the tuna fishery [17], [9], [10], [18] or estimates emissions from longline and line-based gear [19]; [20], without relating it to emission intensity per unit of catch [14]. Because of these gaps, knowledge of the energy efficiency and carbon footprint of the squid fishery stays quite thin, which hampers the design of well-targeted emission-reduction measures.

The Nizam Zachman Jakarta Oceanic Fishing Port (PPSNZJ) ranks among Indonesia's largest squid landing centers and hosts a varied fleet of fishing vessels [15]. Such variety makes PPSNZJ a strongly representative site for studying how energy use, catch productivity, and the carbon footprint of squid fishing interrelate. Earlier research at the port has centered on exhaust emissions from longline vessels [21], which shows that emission assessments here have so far been confined to particular gear types and do not yet fully encompass squid fishing fleets. Data drawn from this site are expected to form a scientific basis for raising the fleet's energy efficiency, encouraging low-emission fisheries, and reinforcing the sector's concrete contribution to national emission-reduction targets [3]; [13].

Against this backdrop, the study was framed to estimate the carbon footprint of the squid fishing fleet at PPSNZJ and to probe how energy performance and emissions differ across gear types. Its outcomes are anticipated to contribute scientifically to shaping emission-mitigation strategies and to enhancing operational efficiency within Indonesia's squid fishing industry.

II. METHOD

A. Research Location and Time

Fieldwork took place between April and May 2026 at PPSNZJ. The subjects comprised a fleet of squid fishing vessels operating Bouke Ami (Lift Net) gear and squid jigs, spanning vessel sizes from 30 to 200 GT.

B. Data Collection

A quantitative approach was adopted, drawing on methods that inventory energy use and carbon emissions tied to squid fishing activities. Primary data came from field observations together with interviews of boat owners, captains, and vessel operations managers. The records gathered covered vessel size (GT), trip duration, fuel consumption, the number of trips, and the volume and composition of the catch.

Secondary data were sourced from port statistics, fleet operational reports, and additional supporting documents held at PPSNZJ. These served to round out the picture of fleet characteristics and fishing activity over the study period.

C. Data Processing

The gathered data were subsequently tabulated and sorted by gear type and vessel size. Size grouping adhered to the classification of Indonesia's capture fisheries fleet, with attention to the 30–50, 50–100, and >100 GT categories. To keep the calculations consistent, all fuel-consumption and catch figures were further converted into kilograms (kg). This step standardized the units underlying the fuel-efficiency and carbon-footprint analysis.

D. Calculation of Fuel Use Intensity (FUI)

Fuel efficiency is assessed through the Fuel Use Intensity (FUI) indicator, defined as fuel used relative to total catch. FUI is computed with the equation below:

$$FUI_{fish} = \frac{\sum FC\ (kg)}{\sum TC\ (kg)} \quad (1)$$

Where:
$\sum$ FC = Fuel consumption per vessel per trip (kg)
$\sum$ TC = Total catch per vessel per trip (kg)

FUI expresses how much fuel is needed to yield a single kilogram of catch, so a smaller FUI signals greater energy efficiency.

E. Carbon Footprint Calculation

Carbon footprint estimates rest on the fuel burned during fishing operations. The computations follow Intergovernmental Panel on Climate Change (IPCC) guidance and apply national emission factors for the energy sector. Carbon emissions are worked out with the following equation:

$$CO_2 emission = \frac{FUI \times NCV \times EF}{10^6} \quad (2)$$

Where:
NCV = Net Calorific Value (MJ/kg)
EF = CO2 Emission Factor (kg CO2/TJ)
10^6 = Conversion from MJ to TJ (1 TJ = 10^6 MJ)

The carbon footprint is reported as kilograms of carbon dioxide equivalent for each kilogram of catch (kg CO_2eq/kg).

F. Data Analysis

The assembled data were examined both descriptively and comparatively to trace the links among vessel size, fuel consumption, catch productivity, FUI values, and carbon footprints. The outcomes then underpinned a comparison of energy performance and carbon emissions across the different squid fishing gear types operating at PPSNZJ.

III. RESULT AND DISCUSSION

A. Characteristics of the Squid Fishing Fleet in PPSNZJ

Understanding the make-up of the squid fishing fleet matters because operational patterns shape energy use and, with it, the carbon footprint. Variation in vessel size, trip frequency, operating time, and fishing area governs the fuel needs and catch productivity of each fishing unit. Characterizing the fleet is thus the opening step in appraising energy efficiency and carbon emissions in squid fishing.

TABLE 1.
CHARACTERISTICS OF THE SQUID FISHING FLEET OBSERVED IN PPSNZJ

Type of Fishing Gear	Vessel Size GT)	Number of Sample Vessels (Units)	Number of Trips perYears	Average Trip Duration (days/trip)	Fishing Operation (WPP)
Squid Jig	30–50	4	2	110	711, 712, 715
	51–100	7	2	123	711, 712, 718
	>100	4	2	138	711, 712, 715, 718
Boat operated lift net	30–50	4	3	118	712, 718
	51–100	8	3	122	711, 712
	>100	3	2	139	711

As Table 1 shows, the surveyed squid-fishing fleet comprises 15 squid jigging vessels and 15 bouke ami vessels, arranged into three size classes: 30–50 GT, 50–100 GT, and above 100 GT. The squid jigging fleet typically makes two trips a year, with an average operating time of 110–138 days per trip. The bouke ami fleet, for its part, undertakes two to three trips annually, each lasting between 118 and 139 days. Such figures place both fleets within medium- to large-scale fisheries marked by comparatively long voyages.

The squid jigging fleet works across WPP 711, 712, 715, and 718, whereas the bouke ami fleet concentrates its effort in WPP 711, 712, and 718. This fairly broad spread of operating grounds reflects differences in fishing areas that may bear on trip length, fuel use, and catch productivity. The observation is in keeping with the study by [7], which noted that Indonesia's squid fishing fleets vary in vessel size, gear, and operating grounds, features that shape the nature of their fishing activity. Analyzing fuel consumption is therefore essential for judging the energy efficiency and carbon footprint of each fleet.

B. Fuel Consumption of the Squid Fishing Fleet

Fuel consumption is among the chief determinants of energy efficiency and the carbon footprint of fishing activity. A number of studies report that fuel combustion during fishing operations is the foremost source of greenhouse gas emissions along the fisheries supply chain, making up 60–90% of the total [13]; [8]. In addition to shaping carbon emissions, fuel use bears directly on operating costs, which makes it a central measure of fishing fleet performance [7].

The fuel consumption of each squid-fishing fleet hinges on vessel size and on the operational traits of the gear deployed. Figures 1 and 2 set out how fuel use varies with vessel size for lift nets and squid jigs.

Figure 1 shows fuel use by the squid fishing fleet rising as vessels grow larger. A 30 GT vessel burns about 11,500 kg of fuel per trip, while a 120 GT vessel uses roughly 25,701 kg. The trend reflects the greater energy that bigger vessels need for propulsion, catch storage, and day-to-day operations at sea. Larger vessels also tend to stay out longer and range farther, which pushes fuel needs higher still [17].

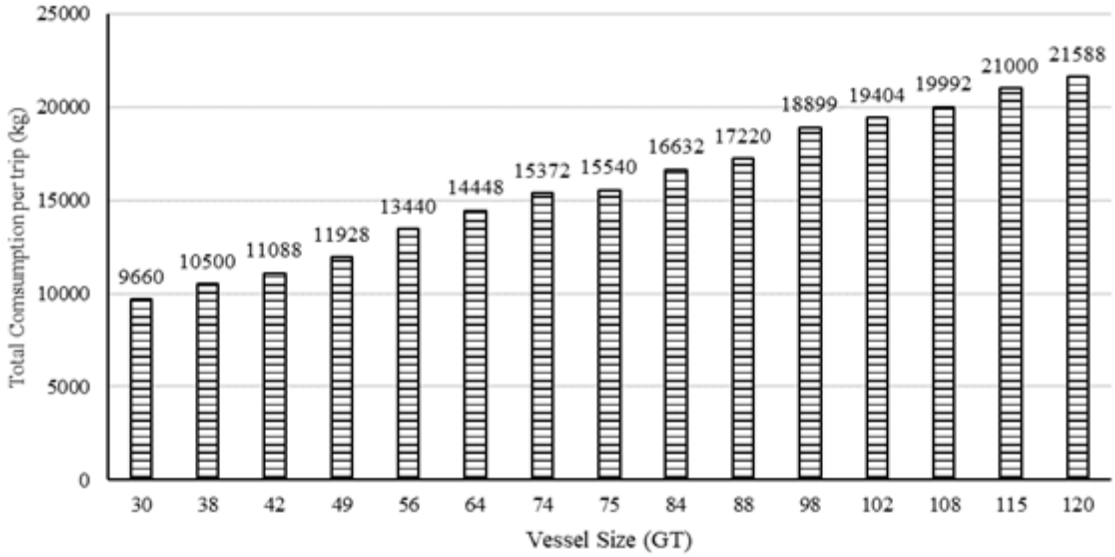


Figure 1. Fuel consumption per trip for the Bouke Ami fleet, by vessel size

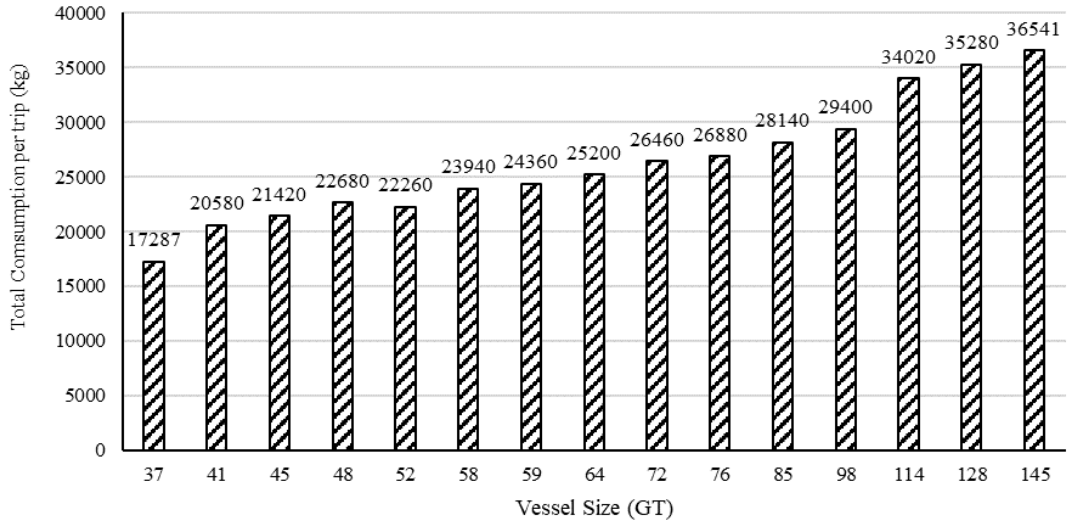


Figure 2. Fuel consumption per trip of the squid fishing fleet by vessel size

A comparable trend appears in the bouke ami fleet (Figure 2), where fuel use climbs from about 23,000 kg per trip for a 37 GT vessel to over 43,500 kg for a 145 GT vessel. Set against the squid jigging fleet, the bouke ami fleet draws more fuel at nearly every vessel size. This gap suggests that gear characteristics, too, help determine the energy demanded during operations.

The heavy fuel use of the Bouke Ami fleet is thought to stem from its reliance on lighting systems, a central element of squid capture. Running these lights for long stretches draws extra power from the vessel's generator, so fuel goes not only to propulsion but also to sustaining the fishing system itself. The somewhat greater trip frequency of parts of the bouke ami fleet further raises energy demand within a single voyage.

On the whole, the bouke ami fleet demands more fuel than the squid jigging fleet. This points to fuel use being governed not by vessel size alone but also by fishing method, the auxiliary equipment aboard, operating time, and fishing area [8]; [6]. Fuel-use levels therefore warrant closer study alongside catch volumes, so that the energy efficiency of each fleet can be established through FUI and carbon-footprint calculations.

A. Catch Composition of Squid Fishing Fleets

Catch productivity is one of the principal yardsticks for judging fishing fleet performance. Beyond signalling how well operations fare, catch volume also anchors he assessment of fuel efficiency via FUI and the estimation of carbon footprints. For this reason, the catch analysis weighs not only how much is produced but also the composition of the catch and vessel operating traits, including trip count and voyage length. Table 2 presents the mean catch composition of the Squid Jig and Bouke Ami (Lift Net) fleets by vessel size class.

Based on Table 2, the squid jig fleet returned larger catches as vessels grew in size. Boats of 30–50 GT landed an average of 46,570 kg per trip, rising to 87,914 kg for the 51–100 GT group and to 134,573 kg for vessels above 100 GT. This gain in output went hand in hand with a lengthening of the mean operating time, from 110 to 138 days per trip. Bigger vessels hold more fuel, offer more storage, and cover greater distances, letting them fish longer and over wider grounds. In every size class squid dominated the catch while non-target species made up only a small share, a sign that this gear is highly selective for the target species.

TABLE 2.
CHARACTERISTICS OF THE SQUID FISHING FLEET OBSERVED IN PPSNZJ

Fishing Gear	Vessel Size (GT)	Fishing Trips (trip/year)	Average Trip Duration (days/trip)	Squid Catch (kg/trip)	Non-target Catch (kg/trip)	Total Catch (kg/trip)
Squid Jig	30–50	2	110	39,699	6,871	46,570
	51–100	2	123	75,874	12,041	87,914
	>100	2	138	117,285	17,288	134,573
Lift Net	30–50	3	118	70,138	16,479	86,617
	51–100	3	122	82,814	15,497	98,311
	>100	2	139	134,423	21,204	155,626

A broadly similar picture emerged for the Bouke Ami (Lift Net) fleet. Mean total catch rose from 86,617 kg/trip in the 30–50 GT group to 98,311 kg/trip in the 51–100 GT group and reached 155,626 kg/trip for vessels above 100 GT. Although operating time varied little between size groups, greater vessel size brings more hold capacity and supports more effective fishing. The lighting system, a hallmark of the Bouke Ami, also draws squid together around the gear and so lifts yields. Differences in output across size classes indicate that catch depends not only on vessel size but also on gear

characteristics, fishing-ground conditions, season, and the abundance of squid resources [8]; [10].

Taken together, both fleets landed catches led by squid as the target species, with non-target species forming only a minor part of the total. Because productivity differed across gear types and size classes, operational efficiency cannot be gauged from fuel use alone; the catch obtained must enter the picture as well. The analysis that follows therefore turns to FUI to characterize each fleet's fuel efficiency before their carbon footprint is estimated.

B. Fuel Use Intensity (FUI)

FUI is a measure used to assess fuel efficiency in fishing operations. It captures the fuel needed to produce one kilogram of catch (kg fuel/kg catch), so a lower value denotes better fuel efficiency at sea. For this reason FUI is widely relied upon as an energy-efficiency indicator and as the starting point for estimating the carbon footprint in capture fisheries [4]; [5]. Figure 3 displays the FUI values of the squid jig and lift net fleets by vessel size.

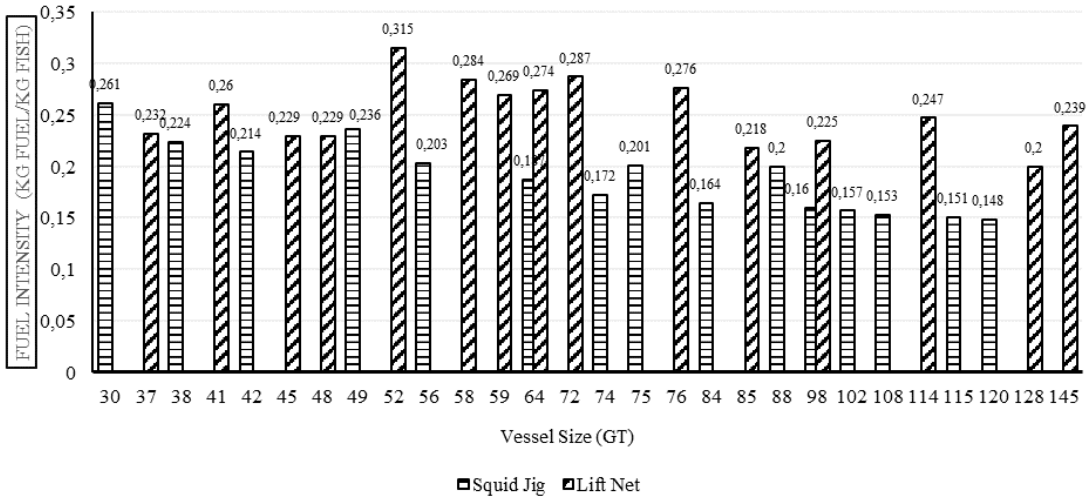


Figure 3. Fuel consumption per trip of the squid fishing fleet by vessel size

Figure 3 reveals a declining FUI for the squid jig fleet as vessel size grows. The value falls from 0.261 kg fuel per kg catch on a 30 GT vessel to 0.148 kg fuel per kg catch on a 120 GT vessel. The pattern implies that, as vessels enlarge, catch rises more than fuel use does, which improves energy efficiency. Bigger vessels usually offer more storage, wider range, and greater operational capacity, raising productivity without a matching rise in fuel consumption.

The Lift Net fleet, by contrast, showed a more erratic pattern, with FUI ranging from 0.200 to 0.315 kg fuel per kg catch. The peak occurred on a 52 GT vessel and the lowest on a 128 GT vessel. Unlike the Squid Jig fleet, larger size in the Bouke Ami fleet does not reliably bring FUI down. Fuel efficiency for this gear thus depends not only on vessel size but also on how operations are run. The light-attraction system used at sea draws power from the vessel's generator and raises fuel use, while differences in fishing location, season, and squid abundance affect catch productivity, together producing the spread in FUI among vessels [8]; [13]. Table 3 summarizes the FUI statistics for the two gear types.

Table 3 shows the Squid Jig fleet averaging an FUI of 0.189 kg fuel per kg catch, below the 0.252 kg fuel per kg catch of the Bouke Ami (Lift Net) fleet. These means indicate that the Squid Jig fleet needs less fuel for each kilogram of catch. Beyond its lower average, the Squid Jig fleet also spans a narrower range, implying that its fuel efficiency holds steadier than that of the Bouke Ami fleet.

To gauge how vessel size bears on fuel efficiency, the FUI values were then sorted by size class, as shown in Table 4. Table 4. Changes in Fuel Use Intensity with Increasing Vessel Size.

TABLE 3.
SUMMARY STATISTIC OF FUI

Fishing Gear	Number of Vessels	Minimum	Maximum	Mean	Standard Deviation
Squid Jig	15	0.148	0.261	0.189	0.035
Bouke Ami (Lift Net)	15	0.200	0.315	0.252	0.031

TABLE 4.
AVERAGE FUI BY VISSEL SIZE CLASS

Fishing Gear	30–50 GT (kg fuel/kg catch)	51–100 GT (kg fuel/kg catch)	>100 GT (kg fuel/kg catch)	Efficiency Improvement (%)	Overall Trend
Squid Jig	0.234	0.184	0.152	35	Decreasing
Lift Net	0.238	0.269	0.229	3.9	Fluctuating

Table 4 indicates that the Squid Jig fleet's FUI fell steadily across every size class, from 0.234 kg fuel per kg catch for vessels of 30–50 GT to 0.184 kg fuel per kg catch in the 51–100 GT group and 0.152 kg fuel per kg catch for vessels above 100 GT. These figures imply that scaling up vessel size can lift fuel efficiency by roughly 35.0%. The Lift Net fleet, however, followed no such downward course. Its FUI rose in the 51–100 GT group before easing again beyond >100 GT, yielding an overall efficiency gain of only about 3.9%. This suggests that a larger vessel does not automatically improve energy efficiency where the gear and operating systems themselves demand a great deal of energy.

On balance, the study finds the squid jig more fuel-efficient than the lift net. The contrast shows that gear type sways FUI more strongly than vessel size on its own. This accords with [4], who hold that energy efficiency in capture fisheries turns on the balance between fuel use and catch productivity. FUI can thus act as a valuable gauge of fleet energy performance and as the basis for computing the operational carbon footprint of each gear type.

C. Carbon Footprin

The carbon footprint gauges the greenhouse gases released while fishing to yield one kilogram of catch. Here it was derived from fuel use with IPCC emission factors and expressed as kilograms of carbon dioxide equivalent per kilogram of catch (kg CO_2-eq/kg catch). The figure captures the emission intensity of fishing operations, so a smaller footprint marks stronger environmental efficiency in a fleet [4]; [14].

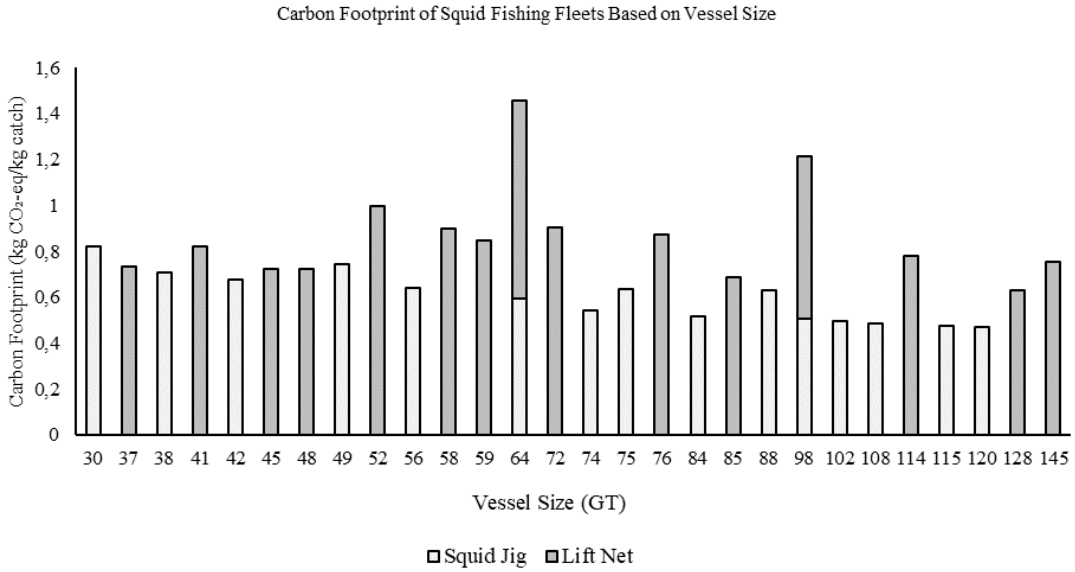


Figure 4. Fuel consumption per trip of the squid fishing fleet by vessel size

As Figure 4 shows, the Squid Jig fleet's carbon footprint spans 0.469 to 0.824 kg CO_2-eq/kg catch, whereas the Bouke Ami (Lift Net) fleet sits higher, at 0.632 to 0.996 kg CO_2-eq/kg catch. By and large, most Squid Jig vessels emit at lower intensity than Bouke Ami vessels of similar size. The Squid Jig fleet also trends toward a falling footprint as vessels enlarge, while in the Bouke Ami fleet this pattern is less steady and continues to fluctuate across vessel sizes.

Within the Squid Jig fleet, the footprint dropped from 0.824 kg CO_2-eq/kg catch on 30 GT vessels to 0.469 kg CO_2-eq/kg catch on 120 GT vessels. The decline shows that added vessel capacity raises catch productivity more than it raises fuel use, lowering carbon emissions per unit of catch. The Bouke Ami (Lift Net) fleet, on the other hand, varies more widely in footprint. Its highest value appeared on a 52 gt vessel at 0.996 kg co_2-eq/kg catch, and its lowest on a 128 gt vessel at 0.632 kg co_2-eq/kg catch. this indicates that larger size has not straightforwardly improved environmental efficiency in the bouke ami fleet, since operational energy demand stays comparatively high. table 5 summarizes the carbon footprint statistics for the two gear types.

table 5 reports the squid jig fleet at a mean carbon footprint of 0.611 kg co_2-eq/kg catch, below the bouke ami (lift net) fleet's 0.813 kg co_2-eq/kg catch. the gap means the squid jig fleet emits less carbon for each kilogram landed. on top of its lower mean, the squid jig fleet's footprint is also more uniform, so environmental efficiency across its vessels is steadier than in the bouke ami fleet.

TABLE 5.
SUMMARY STATISTIC OF CARBON FOOTPRINT

Fishing Gear	Number of Vessels	Minimum	Maximum	Mean	Standar Deviation
Squid Jig	15	0.469	0.824	0.611	0.115
Bouke Ami (Lift net)	15	0.632	0.996	0.813	0.102

To assess how vessel size affects emission intensity, the carbon footprint values were then arranged by size class, as Table 6 presents.

Table 6 shows the squid jig fleet's footprint falling steadily as vessels enlarge, a 34.7% drop in emission intensity from the 30–50 GT group to the >100 GT group. The Bouke Ami (Lift Net) fleet, by comparison, achieved just an 11.7% reduction with no clear pattern, indicating that greater size has not directly bettered its environmental efficiency. This is thought to reflect the fleet's high operational energy demand, especially for light-attraction systems and vessel generators.

TABLE 6.
AVERAGE CARBON FOOTPRINT BY VESSEL SIZE CLASS

Fishing Gear	30-50 GT (kg CO_2-eq/kg catch)	51-100 GT (kg CO_2-eq/kg catch)	>100 GT (kg CO_2-eq/kg catch)	Carbon Footprint Reduction (%)
Squid Jig	15	0.469	0.824	0.611
Bouke Ami (Lift net)	15	0.632	0.996	0.813

These outcomes align with the FUI analysis above, in which the Squid Jig fleet's lower FUI translated into a smaller carbon footprint than the Bouke Ami (Lift Net) fleet. They reinforce Parker et al. [4], who identify fuel consumption as the chief source of greenhouse gas emissions in capture fisheries, and Tyedmers and Parker [5], who argue that raising energy efficiency is the most effective way to shrink the sector's carbon footprint.

All told, the Squid Jig outperforms the Bouke Ami (Lift Net) on environmental grounds, positioning it as a promising alternative gear for advancing low-carbon squid fisheries in Indonesia.

IV. CONCLUSION

This study estimated the carbon footprint of squid fishing fleets and compared their energy and emission performance by gear type at the Nizam Zachman Ocean Fishing Port in Jakarta. Gear type emerged as a strong influence on both fuel efficiency and carbon emissions: the Squid Jig delivered the better environmental record, with a lower mean FUI (0.189 kg fuel/kg catch) and footprint (0.611 kg CO-eq/kg catch) than the Bouke Ami (Lift Net), which averaged an FUI of 0.252 kg fuel/kg catch and a footprint of 0.813 kg CO2-eq/kg catch. Larger vessel size reliably lowered both FUI and footprint in the Squid Jig fleets, whereas this effect was muted in the Bouke Ami fleets given their heavier operational energy needs. The results confirm that fuel-use efficiency is a decisive factor in greenhouse gas emissions from squid fisheries.

The work offers empirical grounds for appraising the environmental performance of squid fishing fleets and underscores how gear choice matters in steering the shift toward low-carbon fisheries. Its findings can serve fisheries managers and policymakers as a scientific reference when devising ways to curb operational emissions in Indonesia's capture fisheries sector. Future studies would benefit from adding variables such as distance to fishing grounds, engine performance, and life cycle assessment, so as to build a fuller account of greenhouse gas emissions along the squid fisheries supply chain.

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