Energy consumption of traditional fishing vessels in Palabuhanratu, Indonesia

[1]Vita R. Kurniawati, [2]Richard W. Birmingham, [2]Alan J. Murphy, [1]Dwi P. Yuwandana, [1]Prihatin I. Wahyuningrum, [1]Eko S. Wiyono, [1]Yopi Novita, [1]Budhi H. Iskandar, [3]Eren Uyan

[1] Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Bogor, Indonesia; [2] School of Engineering Newcastle University, Newcastle upon Tyne, United Kingdom; [3] Altinova Vocational School, Yalova University, Turkey. Corresponding author: V. R. Kurniawati, vitarumanti@apps.ipb.ac.id

Abstract. Indonesian fisheries, which are predominantly artisanal, have provided 54% of the animal protein intake to the country's population, accounted for 2% of the employment absorption and increased the fisher's prosperity index by 8.7% from 2014 to 2020. However, their operations have a significant environmental impact, including the fish resource depletion and intensive energy use. Sustainably managing these fishing operations is an essential yet complex task given the requirements to proportionally account for fish resources, fishing technology and fisheries organisations**.** This paper focuses on the energy intensity of these operations which is particularly important given its correlation with operational costs, productivity and environmental impact. Data was collected from fieldwork in Palabuhanratu, one of the fishing regions in Indonesia which has an artisanal fishing fleet counting hundreds of vessels and is typical of many fishing regions in Indonesia and other developing nations. A comparative study was conducted on the four principal types of vessels operated in Palabuhanratu Bay, pelagic Danish seiners, hand liners, trammel netters and lift net fishing units. Statistics published by the fishing port were used to conclude that trammel netters, which are targetting demersal species, are the most energy intensive and that, in general, the artisanal fisheries in Palabuhanratu are less energy efficient compared to those in developed countries. Analysis of internal and external factors of fishing operations showed that the socioeconomic characteristic of this fishery determined the management measures taken to improve the energy efficiency.
Key Words: fishing operation, fuel consumption, small-scale fisheries.

Introduction. Regarding the seafood production system comprising the fish catching process, preservation, processing and distribution, a considerable amount of energy is consumed; with the most significant element used in the catching process being the fuel (Hospido et al 2006; Thrane 2004b; Ziegler et al 2003). Approximately 1.2% of global fuel consumption was associated with fishing operations (Tyedmers et al 2005). Annually, Japanese fishing vessels consume 3.22 million kilolitres fuel year^{-1} and emit 8.37 million tons CO_2, which ranked marine fisheries industry in the third place in CO_2 contribution per ¥1 million production volume (Hasegawa 2008; Nansai & Moriguchi 2010; Furuya et al 2011). In Indonesia, fishing operations are responsible for 3.09% of national fuel consumption (BPH Migas 2017; Pertamina 2016). Furthermore, despite the broad variation in costs, fuel also represents the principal cost component in relation to fishing (Davie et al 2015; Sumaila et al 2008). Consequently, fuel efficiency should have significant impacts on the return on investment both from the energy and economic points of view.

Roughly 81% of the global fishing fleet is composed of small motorised boats which are typically operated in coastal areas (FAO 2022). Some boats are equipped with deck machinery and work with fish aggregating or fish finding devices; however, most are man-powered using limited supporting technology. In the case of these less sophisticated operations, they have to deal with a higher level of uncertainty. In fact, this traditional practice is the typical nature of fishing operations in developing nations, which play an essential role in human activities and attitudes. In Indonesia, for example, approximately

89% of fishing vessels are less than 10 gross registered tons (GT) and perform local in-shore artisanal fishing. However, Indonesian fisheries have provided 54% of the animal protein intake for the nation's people, absorb approximately 2% of the locally available employment pool, and increased the fisher's prosperity index by 8.7% from 2014 to 2020 (Centre for Data Statistics and Information 2021). The index represents the fishers' capability in fulfilling basic needs by using their income from fishing.

The intensive energy use, uncertain productivity levels and economic importance justify this research with a specific focus on energy use in small-scale fishing vessel operations. The aim of the study was to assess the energy consumed by typical traditional fishing vessels and to formulate feasible strategies to improve the energy efficiency of these fishing practices.

Material and Method

Port and fleet selection. A case study was conducted in Palabuhanratu, Indonesia, which is situated in the western part of Java Island adjacent to the Indian Ocean (Figure 1). The region was selected as the research site due to data availability, the variety of fishing fleets conducting different types of operations, and it being one of the major fishing bases in Indonesia. At least 600 vessels ranging from 2 GT to 200 GT are based in Palabuhanratu, of which about 63% of the fleet performs artisanal fishing using boats of less than 10 GT. The fishing fleet consists of various vessels including long liners, troll liners, gill netters, purse seiners, pelagic Danish seiners, hand liners, trammel netters, and lift net fishing units. The first four fleets incorporate fishing vessels which mainly perform commercial fishing in distant-waters using vessels larger than 10 GT. Therefore, this study focuses on the remaining vessels which represent small-scale operations; specifically, pelagic Danish seiner (PD vessel), hand liner (HL vessel), trammel netter (TN vessel) and lift net fishing unit (LF vessel). These fishing vessels operate daily in the shallow water along Palabuhanratu bay (up to Binuangeun or Ug Genteng) as depicted in Figure 1.

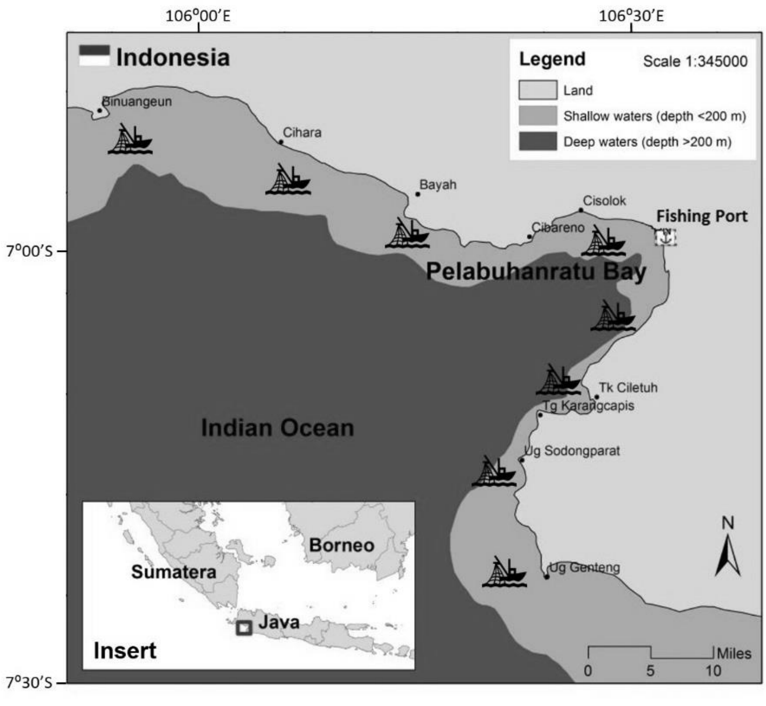

Figure 1. Palabuhanratu bay.

Data collection. The approach to data collection was two-fold including statistical data and qualitative data. Statistical data was mainly obtained from fisheries reports published by the Palabuhanratu fishing port and by the Ministry of Fisheries and Marine Affairs Indonesia, from 2009-2019. Qualitative data were gathered from significant stakeholders associated in the fisheries through in-depth interviews. In 2021, the first fieldwork, twenty-seven respondents including owners, skippers, fishers, and government representatives were interviewed to gather information about the fishing practices. They were chosen using a purposive sampling method, through a selection based on the types of fishing vessels they operate, and on their roles in the fishing port and government agencies. Further fieldwork was conducted in 2022 to investigate the potential measures for improving the fishing efficiency.

Energy consumption analysis. Energy inputs in a fishing operation can be classified as direct or indirect. According to Tyedmers (2004), direct inputs, which account for 70 to 90% of the total inputs, are commonly associated with the energy that is consumed to propel vessels, to operate the fishing gear and to preserve the fish on board. The remaining 30 to 10% are indirect inputs which relate to the construction and maintenance of the vessels and the fishing gear, as well as to the provision of fishing supplies and fishing labour. This research focuses on the direct inputs derived from the fuel that is consumed during the fishing operations. Indirect energy is assessed separately, which is not included in this paper.

Fuel Use Intensity (FUI) which refers to the fuel consumption per kg fish catch is the typical indicator of energy consumption in fishing activities (Basurko et al 2013; Parker et al 2015a; Parker & Tyedmers 2015; Parker et al 2015b; Schau et al 2009). Furthermore, considering fish is a protein source, edible protein Energy Return on Investment (ep-EROI), which represents the ratio of energy yielded and energy used to obtain it, is also applied to indicate energy consumption (Tyedmers 2004; Vázquez-Rowe et al 2014). Both indicators are discussed in this paper.

Fuel use intensity was calculated based on the total catch and total revenue, using the following equations (Tyedmers 2004; Vázquez-Rowe et al 2014). Subsequently, FUI from four studied vessels was compared to investigate the most efficient types of fishing operations.

$$FUI_{kg} = \frac{\sum_{i=1}^{n} F_i}{\sum_{i=1}^{n} Q_i}$$

$$FUI_{\$} = \frac{\sum_{i=1}^{n} F_i}{\sum_{i=1}^{n} R_i}$$

Where:
FUI_{kg} and $FUI_{\$}$ - the intensity per kg of catch and per USD of revenue;
F_i, Q_i, and R_i - the total fuel used (L), catch landed (kg) and revenue ($) during the considered periods.

The original revenue data is given in Indonesian Rupiah (Rp), but for calculation purposes it has been converted to US Dollar ($) using a fixed currency rate (Table 1). Furthermore, energy return was calculated by dividing energy yield with energy input from total fuel used during the given periods, as seen in the following equation (Tyedmers 2004; Vázquez-Rowe et al 2014). Energy yield is quantified from the multiplication of an edible portion of fish landed, its protein content and total catch.

$$ep - EROI = \frac{\sum_{i=1}^{n} Q_i \times C \times P \times c_p}{\sum_{i=1}^{n} F_i \times \rho \times c_f}$$

Where:
ep - EROI is the energy return;
C - the edible portion per kg fish landed (%);
P - the protein content per kg edible portion (%).

The portion for both C and P were defined based on FAO (1989). The amount of protein yield and fuel consumption were transformed into joule (J) using the calorific values (c_p and c_f), as described in Table 1.

Table 1

Conversion factors

Parameter	*Conversion factor*	*Sources*
Protein calorific value (c_p)	17,866 kJ kg^{-1}	FAO (2003b)
Petrol density (ρ)	0.747 kg L^{-1}	Directorate General of Oil and Gas (2013a)
Diesel density (ρ)	0.837 kg L^{-1}	Directorate General of Oil and Gas (2013b)
Petrol calorific value (c_f)	44,000 kJ kg^{-1}	Demirel (2012)
Diesel calorific value (c_f)	43,200 kJ kg^{-1}	Demirel (2012)

Formulation of improvement strategies. The formulation of potential strategies to improve the energy efficiency in small-scale fishing vessel operations was approached by analysing relevant influencing factors. According to Hindle (2008), external and internal factors influencing a particular industry can be analysed by identifying its strengths, weaknesses, opportunities and threats (SWOT); therefore this was applied in this study. A SWOT analysis was conducted based on qualitative data gathered from interviews. Subsequently, it is used as guidance to formulate potential improvement strategies rationally. Through a focus group discussion, stakeholders were involved in the formulation process by way of validation and refinement of the proposed action plans.

Results

Characteristics of studied vessels. Before describing the results, a general characteristic of the selected fishing vessel operations is presented in order to provide the background information about the existing practice. Therefore, the following paragraphs explain the four types of investigated vessels. All the vessels perform one-day trips, either day fishing (approximately from 5 am to 6 pm) or night fishing (roughly from 4 pm to 6 am). Operations are mostly conducted at fishing grounds along the coast up to 74 km from the port as indicated in Figure 1. Both PD and LF vessels are targeting small pelagic species, which live near the water surface and migrate in large schools. On the other hand, HL and LF vessels catch demersal fish, which live lonely, near the seabed. Key characteristics of each vessel are presented in Table 2.

Pelagic Danish seiner. Pelagic Danish seine (PD) fishing uses a net resembling a trawl which is operated by encircling the water column in order to surround the fish (FAO 2003a). It is called pelagic because it operates near the water's surface; thus, targeting small pelagic fish. Following the classification system suggested by Fyson (1985), the principal operation of a PD vessel can be classified as an encircling method. Therefore, the vessels are required to produce good manoeuvrability rather than high towing power. These vessels are typically wooden hulls with the length, breadth and depth dimensions being approximately 12, 2.5 and 1.8 m, respectively, and powered by 40 HP marine outboard engines. The net is operated manually by 10-15 people.

Hand liner. Hand line (HL) fishing uses a monofilament fishing line consisting of branch lines which are arranged vertically or horizontally. Typically, one vessel is crewed by 1 to 2 fishers. When the gear is being operated, the vessel is anchored, and the propulsive engine is deactivated. All HL vessels in Palabuhanratu are fibreglass hulled vessels with lengths varying between 7-9 m, and the registered tonnage is approximately 2 GT. Outriggers are attached to improve their stability. Additionally, these vessels are typically powered either with two 5 HP multipurpose engines or a single 15 HP marine outboard engine. In the past, HL vessels in Palabuhanratu were wooden hulled vessels; however, the technical adaptation of the fibre-reinforced plastic in 2008 has successfully transformed the fleet.

Trammel netter. A trammel net (TN) consists of three layers of nylon net vertically immersed or drifted in the water column (FAO 2001). The TN vessel is typically a 4 GT wooden-hulled vessel, roughly 9 m in length, powered by a 24 HP inboard engine and generally crewed by 2 to 4 persons including the skipper. The primary target of TN fishing is demersal fish and crustaceans, especially prawns, which are active during daytime and live in shallow waters on the soft muddy or sandy seabed. The gear is originally passive fishing gear, however, in Palabuhanratu it is operated both in active and passive method depending on the season. During the local rainy season, the TN vessel performs an active operation by towing the net for 30–60 minutes; in contrast, during the dry season, the net is soaked for a minimum of 12 hours. The fishing grounds of TN vessels can be up to 74 km from the fishing port.

Lift net fishing unit. Unlike other vessels which are equipped with fishing gear, an LF vessel consists of an LF ferry and 8 to 10 LF platforms which are anchored at sea and operated by immersing the net horizontally under the floating bamboo platform. The ferry is crewed by 1 or 2 persons, and it is used to shuttle fishers to their platforms. The ferry is a wooden-hulled boat, typically 14 m in length powered by a 100 HP marinised diesel engine with a tonnage of approximately 5 GT. Such a large engine is required as the ferry on occasion is used to tow the platforms to new locations.

Table 2

Key characteristics of studied vessels

Characteristics	*PD vessel*	*HL vessel*	*TN vessel*	*LF vessel*
GT	*5*	*2*	*4*	*5*
Power	Outboard 40 HP	Outboard 10–15 HP	Inboard 22 HP	Inboard 100 HP Generator 3.2 HP
Fuel	Petrol	Petrol	Diesel	Diesel (ferry) Petrol (platform)
Fishing gear	Pelagic Danish seine (1 gear)	Hand line (1-2 gear)	Trammel net (1-2 gear)	Lift net (8–10 platforms)
Operation profile	Daytime Active	Night time (primarily) Passive	Daytime Active (primarily)	Night time Passive
Crew	10–15	1–2	2–4	1–2 by ferry 1–2 by platform
Main target species	Bullet tuna, ponyfish, and moonfish	Hairtail	Prawns, Lobster	Anchovies, and small shrimp
Fleet size*	73	244	31	25 with 217 platforms
Fishers*	759	492	60	267

* Source: PPN Palabuhanratu (2020).

The LF platform itself is roughly 9x9 m, and the working deck is approximately 2 m above the sea. They are typically distributed within 9.3 km of the fishing port and are regularly moved depending on the fish abundance, current directions and wind directions. The primary fish target in the lift net fishery are anchovies and small shrimp which are attracted by light. Therefore, the fishing operation is performed at night and employs lamps to attract fish. Around 3 pm each day, ferries shuttle the fishers out to their platforms; then, the next morning, ferries will take them and their catch back to the port, at around 6 am. The number of fishers working in each platform is 1 to 2 persons.

Fishing seasons, catch production and fuel use. Fish migration and weather changes affect the fishing pattern throughout the year (Brönmark et al 2008; Eveson et al 2015; Nontji 2005). In this study, fishing patterns were mapped based on the interview with respondents. Table 3 shows that the most productive season lasts for only three or four months, followed by three to eight months of moderate and low seasons. The rainy season occurs from December to March, which is the low season for all types of vessels, except for TN vessels which become least productive during the dry season.

Table 3

Fishing seasons for studied vessels

Vessels	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
PD vessel	Low	Low	Low	Mod	Mod	Mod	Peak	Peak	Peak	Mod	Mod	Low
HL vessel	Low	Low	Mod	Peak	Peak	Mod	Low	Mod	Mod	Peak	Peak	Low
TN vessel	Peak	Peak	Mod	Mod	Low	Low	Low	Mod	Mod	Mod	Peak	Peak
LF vessel	Low	Low	Low	Mod	Mod	Mod	Mod	Peak	Peak	Peak	Mod	Low

Furthermore, each fishing vessel target principal species, with a seasonal abundance. However, operations are conducted regardless of the fish seasons; hence, the species caught by each vessel extends beyond their main target, as shown in Figure 2. Considering its variability, therefore, FUI and ep-EROI in this study were calculated based on total landed catches per fishing vessel rather than on a per species basis.

The port's statistics are collected based on the daily reports from the fishing vessels; however, as not all vessels regularly report, the number recorded in the report might be less than the actual number. Subsequently, catch production data are grouped according to the vessel types and recorded on a trip basis regardless of the vessel's identity. Since each vessel performs multiple trips, information about the number of fishing vessels contributing to the catch production is not provided. Table 4 displays the total catch production and fuel use from each studied fishing fleet from 2009 to 2015. The table shows that by quantity, the largest fish production was landed by the LF vessels which constituted 49%, followed by the PD vessels which were responsible for 41%. In contrast, the HL vessels, which were the most significant fleet by number, only supplied 9%, whilst TN vessels landed roughly 1%. From the monetary value, it can be seen that the LF and PD vessels contributed with the highest value, of 37% each, whilst HL and TN vessels were responsible for 22% and 3% respectively. The two latter vessels show a more significant proportion in value than in quantity, which indicates that they landed more valuable catches than their counterparts.

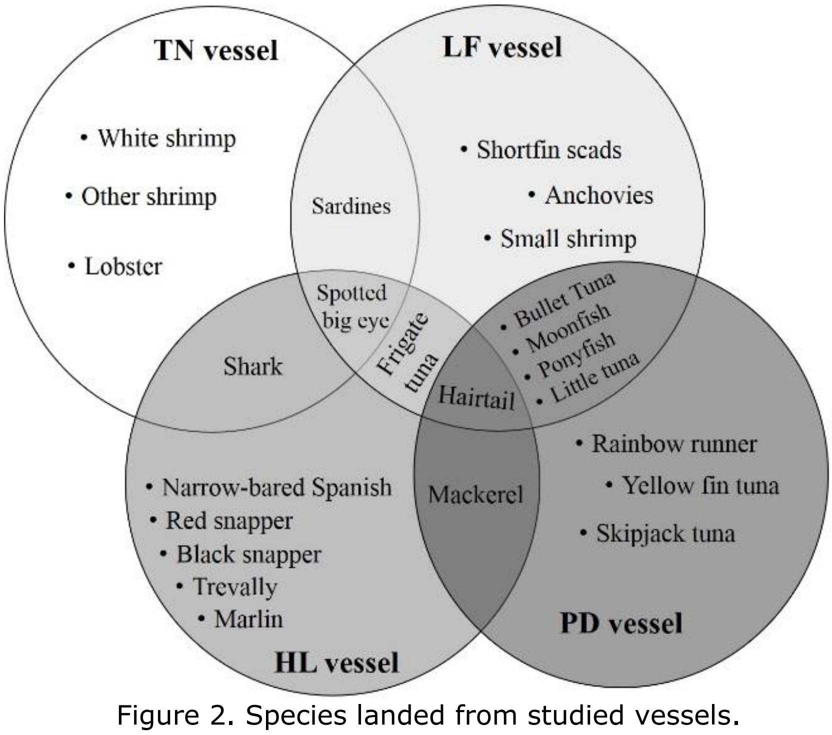

Figure 2. Species landed from studied vessels.

Table 4
Total catch quantity, monetary value and fuel use for the entire studied fishing fleets from 2009 to 2020

Fishing vessels	Catch		Value		Fuel burned (thousand litres)	
	Tonne	Percentage	Thousand ($)	Percentage	Diesel	Petrol
PD vessels	2824	41%	1205	37%		732
HL vessels	637	9%	720	22%		284
TN vessels	45	1%	92	3%	80	
LF vessels	3392	49%	1284	37%	236	353
Total	6898		3301		316	1369

Catch and monetary value have been rounded from the precise data.

Energy consumption

Fuel use intensity. The two types of fuel that are commonly used in Palabuhanratu are diesel and petrol. Diesel fuel is used in both the LF ferry and TN vessel, whilst petrol is used in the PD and HL vessels. Petrol is also used on the LF platform for generating electricity. For a typical day trip, the amount of diesel fuel brought by an LF ferry ranges from 20–40 L, depending on the number of platforms and their distribution, whilst a TN vessel usually brings about 20–30 L. Conversely, PD vessel, HL vessel and LF platform carry about 90–120 L, 5–10 L and 7–10 L of petrol respectively. When the season changes, the amount of fuel brought by each fishing vessel will be slightly adjusted, however on average, it remains within those ranges. In this study, fuel consumption was calculated based on the fuel provision reported by vessels from 2009 to 2019, as shown in Table 3.

The FUI calculation, as presented in Figure 3, reveals that TN vessels are the most energy-intensive fishing operation in terms of catch and revenue.

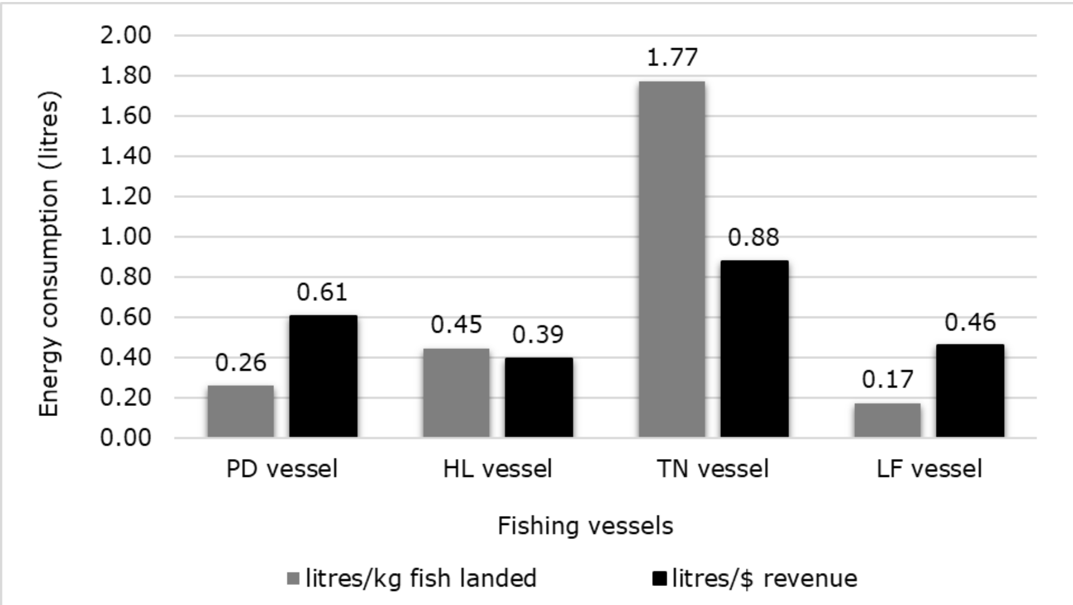

Figure 3. Fuel use intensity of studied vessels.

At least 1.77 L of fuel were consumed to land a 1 kg catch. This is approximately four times higher than HL vessels and even ten times higher than LF vessels. Its inefficiency is due to a relatively low catch production, which on average was only 15 kg (trip vessel)$^{-1}$, whilst fuel use made up 25 L (trip vessel)$^{-1}$. Furthermore, there is also the significantly different proportion of main catch and bycatch. The main catch of TN vessels is shrimp which accounted for only 40–50% of the total catch; however, considering that shrimp is one of the most valuable catches in the region, it contributes up to 80% of the total revenue. The remaining catch is bycatch which is relatively large in quantity, yet very low in value. The small quantity of valuable catch from TN vessels determined their energy-intensity to remain high.

Regarding the catch volume, it can be observed that LF vessels, which shared the largest catch production, is the most efficient fishing operation which only spends 0.17 L kg^{-1}. However, in terms of economic value, HL vessels show the best performance by spending 0.39 L of fuel to produce 1 USD revenue. This implies that the LF vessel consumed a small amount of fuel to catch inexpensive fish, whilst a reasonable amount of energy was consumed by HL vessel to catch valuable species.

Fuel intensity is a function of catch and fuel consumption. Whilst catch rate is highly unpredictable; fuel consumption is dependent on the type of fishing vessel, the engine, fishing gear, fish target and the fishing ground (Basurko et al 2013; Gulbrandsen 2012). Therefore, FUI is a unique value attached to a particular fishery, which usually shows a wide variation even within similar fishing practices. Table 5 indicates the FUI result from studied vessels, with a comparison of the results from earlier studies which have the greatest similarity.

Table 5

FUI of studied vessels and published studies

Fishing vessels	*Studied vessels*	*Comparable published studies*		
	FUI (L kg^{-1})	*Fishing vessels*	*FUI (L kg^{-1})*	*Region*
PD vessel	0.26	Danish seiner	0.42[a]	Denmark
			0.32[e]	Australia
			0.13[b]	Norway
		Operating surrounding nets	0.15[d]	Asia
HL vessel	0.45	Operating hook	0.15[b]	Norway
		Hand liner	0.06[c]	Spain
TN vessel	1.77	Bottom trawler	1.61[e]	Australia
		Shrimp trawler	1.22[b]	Norway
		Bottom gillnetter	0.19[b]	Norway
LF vessel	0.17	NA	NA	

[a)] Thrane (2004a); [b)] Schau et al (2009); [c)] Basurko et al (2013); [d)] Parker and Tyedmers (2015); [e)] Parker et al (2015a).

The table shows that FUI of other Danish seiners ranges from 0.11 to 0.42, where the performance of PD vessel in Palabuhanratu lies in between. Danish seine nets are commonly operated near the seabed with the principal target being demersal species (FAO 2003a), as are all of the published results presented in the table. However, in Indonesia, Danish seine nets are also operated near the surface and therefore are called pelagic Danish seine nets. The operation method is generally the same as the original net, yet its design has been modified in order to catch pelagic fish effectively, likewise the ones operated in Palabuhanratu. Considering the fact that most of the pelagic fishing is more productive than demersal fishing, it is plausible that pelagic Danish seining show a better performance than some fishing practices presented in the table. Nevertheless, a sample calculation for Danish seining in Norway and general surrounding net fishing practice in Asia demonstrated higher efficiency than the result obtained from this study.

In HL fishing, the efficiency of similar fishing practices shows better performance. Furthermore, both comparable studies are considered as the most efficient fishing in their respective studies given that they perform multi-gear operations which only operate HL gear seasonally depending on the targeted fish.

No published research concerning TN was found; therefore, FUI comparisons were approached through the bottom trawl and shrimp trawl for an active operation, whilst for the passive operation, the FUI for the bottom gillnet is provided. However, due to data limitations, the FUI of TN vessels was calculated based on annual catch and fuel consumption, regardless of the type of operations. Additionally, interviews with fishers revealed that the net was passively deployed only during the low season, which lasts for about three months. Passive operation consumes less fuel, yet it produces low or even no catch, which might result in high FUI. Therefore, the comparison shows that the TN vessel displays a lower energy performance than other vessel types. Unfortunately, no studies investigating on LF vessel or similar can be used as a comparison.

Generally, it can be noted that the FUI for HL and TN vessels are relatively high. The fact that those vessels are small traditional vessels confirms that energy use in artisanal fishing is not necessarily less intense than that found on larger scale fisheries with more advanced technology. Furthermore, pelagic fishing reveals better energy performance than demersal fishing, which is also shown through a comparison of FUI from global fisheries (Parker & Tyedmers 2015).

In 2000, the energy intensity of the global fisheries was 0.62 L of fuel kg^{-1} fish landed (Tyedmers et al 2005), and in 2013 it increased to 0.64 L of fuel kg^{-1} fish landed (Parker & Tyedmers 2015). The increase was primarily caused by the intensification of fishing capacity and technical advancements in a fishing method which is not aligned with the fish stock recruitment. Similarly, the energy performance of fishing operations in Palabuhanratu is also threatened by the fact that fishing productivity is declining, as confirmed by most fishers who state that fishing is becoming less productive in terms of catch; therefore, they go further away from the port and spend more fuel.

Energy return. The energy yielded from edible protein is used to calculate energy return in fishing operations. This research only focuses on direct input from fuels; therefore, using the defined conversion factor, the energy input released by fuel was calculated and expressed in gigajoule (GJ), as presented in Table 6. Subsequently, the energy outcome is calculated based on the edible portion and protein content of the landed catch. According to Figure 2, the composition of catches landed by each vessel widely varies, leading to a different proportion of edible protein. Therefore, for the purpose of this study, only the main catch was taken into consideration. The protein content in the consumable portion for certain species has been assumed based on selected values published by the Torry Research Station, Aberdeen, the UK (FAO 1989). The edible protein return for different fishing fleets is also presented in Table 6.

According to the ep-EROI value, it can be clearly seen that pelagic fishing conducted by PD and LF vessels in Palabuhanratu produce the highest return compared to HL and TN vessels which are targeting demersal species. A similar pattern was shown in (Tyedmers 2001, 2004; Vázquez-Rowe et al 2014), where the highest edible return belongs to small pelagic fishing, followed by demersal fishing and crustaceans. Furthermore, the average value of ep-EROI produced by global capture fisheries is 0.08, which is considerably higher than other animal protein sources (Tyedmers et al 2005). With that in mind, it can be said that most of the seafood products from this study are generally valuable protein resources.

Despite the fact that fishing produces high-protein food with a higher energy return than other animal protein production system, there is still need to improve the energy efficiency due to its association with fossil fuel consumption and marine resource utilisation. The concern in relation to inefficiency in fishing has led to several studies on how to reduce fuel consumption for fishing, such as onboard monitoring systems, service speed management, repainting and engine load reduction (Basurko et al 2013; Latorre 2001). However, in the context of small-scale fishing vessels operating in Indonesia, the reduction of energy consumption in these fisheries will be highly challenging due to the requirement to consider complex socioeconomic aspects. From the fishers' point of view, reducing fuel consumption through investment in the aforementioned technical advancement is not a priority, due to the requirement to fulfil their economic needs and their reluctance to change fishing habits. In order to address that problem, a SWOT analysis was therefore conducted to identify the internal and external factors influencing fishing activities in Palabuhanratu, particularly in association with energy use. Accordingly, potential improvement can be proposed.

Table 6

Energy return on investment

Fishing vessels	*Energy input (GJ)*	*Edible portion**	*Protein content**	*Energy yield (GJ)*	*Ep-EROI*
PD vessels	23,636	58%	22%	6,437	0.27
HL vessels	9,151	59%	20%	1,342	0.15
TN vessels	2,592	57%	20%	92	0.04
LF vessels	19,010	61%	19%	7,024	0.37

* estimated based on FAO (1989).

SWOT analysis and improvement strategies

Internal and external factors of fishing operations. Identification of internal and external factors of the system is a key to the formulation of effective management measures (Gürel 2017), likewise in the fishing operation system. Internal factors refer to the existing strengths and weaknesses attached to the system, whilst external factors correlate with opportunities and challenges faced by the system. In this study, internal and external factors affecting the fishing operations conducted by traditional fishers were identified using a SWOT analysis. Data was collected during the first fieldwork by interviewing fishers and local government officers, in addition to analysing government reports.

Strengths

Fishing activity in Palabuhanratu drives the coastal economy in West Java province. Approximately 600 fishing vessels are based in this fishing port, and at least 4800 people are conducting fisheries-related business, including fishing, boat building, fish marketing and fish processing. Furthermore, fishing activities have been supported by adequate facilities such as a spacious quay, fish market, ice plant and fuel station which make it easier to prepare fishing operations. Fish from this area is known for its good quality due to being landed daily and being caught from little-polluted fishing grounds (Astuti 2016). An additional strength is that due to the close proximity of local universities the fishers are familiar with research activities, and welcome being involved. As a result, they are more open to technical developments.

Weaknesses

Fishing operations are speculative with uncertain outcomes, especially when operated in traditional ways, as in Palabuhanratu. Without fish finders or fish aggregating devices, the fishers rely on their instinct and experience when hunting the fish. Fishers are familiar with the fishing grounds along the coastline, within Palabuhanratu bay; nevertheless, they do not want to fish further offshore because of concerns related to safety and comfort. During the rough season, most fishers break from fishing and remain unemployed because they have limited working skills apart from fishing. Furthermore, due to the difficult financial situation, fishers refrain from spending additional costs on technical applications, especially when their profitability is unproven.

Opportunities

Considering the location and capacity, Palabuhanratu fishing port has the potential for the development of offshore fishing. Its facilities have been designed to serve larger fishing vessels between 30 to 60 GT. Furthermore, as one of the major fishing ports in West Java, the region is also popular as a research site for various fishery related studies focusing on technical, social and economic aspect. Another opportunity is a number of tourist destinations in Palabuhanratu which have numerous weekend visitors, has open a potential market for seafood products and sea-based activities such as recreational fishing. Accordingly, the government has also set fisheries and tourism as the principal focus of development regarding spatial planning. Although this will create a new challenge in how to manage the fisheries and tourism in harmony, the successful relationship between these two sectors could potentially support the development of the coastal economy by way of additional income and market opportunity (Pariat 2013).

Threats

The greatest challenge confronting fishers is the increasing fuel price. Small-scale fisheries use subsidised fuel. Moreover, decreasing subsidies from 2009 to 2015 raised the fuel price by 23.53% for petrol and 26.67% for diesel. The depletion of the fish stock is also an additional problem for fishers to deal with. The fishers reveal that hunting fish around the bay is becoming more difficult, which requires further exploration. This is confirmed by the statistic reports, which in general show that there was a decreasing trend in the catch quantity per trip between 2009 and 2015.

Strategies for improvement. Following the identification process, strategies for improvement have been formulated by considering the internal and external factors, as summarised in Table 7. There are six strategies which are classified into four groups as described below. Each of them was discussed with respondents to investigate the potential for implementation. Their opinion and insight about the proposed strategies were gathered through a focus group discussion, which was conducted in the second fieldwork.

Strengths-Opportunities strategy: using strengths to make the best use of opportunities

Strategy 1: Encourage more research on technical advancements to increase fishing efficiency. Numerous fisheries research projects have been conducted in Palabuhanratu; however, only a few are focusing on applicable technical improvements, specifically ones designed to reduce energy consumption. Fishers, local government and local universities or research institutions might begin to collaborate by defining a research strategy with goals related to sustainable development, including fish stock preservation, environmental protection and fisher's quality of life. This means that the research strategy should be driven by fishers' needs.

Strategy 2: Strengthening the existing market and developing the variety of seafood products. The most common seafood products from Palabuhanratu are fresh fish, salted fish, boiled fish and fish balls, which are popular amongst local tourists. Strengthening the existing market and developing a variety of seafood products such as fish snack and fish flour might have two benefits. Firstly, it improves the energy yield, through the more edible portion, and secondly, it elevates the fish demand which might increase the fish price. However, further energy consumption has to be investigated to identify the total energy use and the output, including the fish processing stages.

Strengths-Threats strategy: using strengths to deal with threats

Strategy 3: Fuel substitution. In Indonesia, fuel substitution using liquid petroleum gas (LPG) is now established in various sectors, including fishing. Portable LPG cylinders with a capacity of 3 kg have been extensively used throughout the nation since 2007, as part of the implementation of a national kerosene conversion programme. Subsequently, in 2012, the development of converter kits broadened the opportunity for implementation on fishing vessels; however, the available converter is limited to small petrol-fuelled engines. The LPG conversion programme has been gradually implemented, and in 2016 it was introduced in Palabuhanratu. Considering the capacity of the converter kit, HL vessels with outboard engines of less than 15 HP are the only eligible fishing vessels for conversion. Despite safety issues, fishers are pleased with the conversion programme, as it is estimated that the conversion will reduce the energy consumption and operational cost of hand line fishing by up to 70% and 50%, respectively. When this study was conducted, LPG has not been used regularly due to the limited gas supply; therefore an actual FUI calculation was not performed. Furthermore, it should be noted that this study has concluded that the FUI of HL vessels remains reasonable and thus, this substitution will further improve its energy performance. Unfortunately, the solution for other more inefficient fishing vessels continues to be a long way from realisation given that the technology is not yet available.

Weaknesses-Opportunities strategy: countering the weaknesses by means of exploiting opportunities

Strategy 4: Encourage fishers to work in larger scale fishing. Palabuhanratu Bay is facing the Indian Ocean, specifically fishing zone 572 and 573 where the total potential yield is roughly 2.4 million ton year^{-1} (Ministry of Marine Affairs and Fisheries 2017). Offshore fishing will increase fishing capacity in Indonesian EEZ as well as fuel consumption. Therefore, the development of productive operations using large nets and targeting pelagic fish, such as purse seine and gillnet, is expected to maintain energy efficiency at a reasonable level. Parker and Tyedmers (2015) and Schau et al (2009) confirmed that both fishing methods performed with better efficiency than other operation types in general. However, the fact that fishers are comfortable with daily trips discourages them from fishing outside the bay. Safety considerations are a further burden since not all fishers are skilful and robust workers. They prefer to stay close to the family even though this means a small income.

In Palabuhanratu, there is a vocational high school which concentrates on fisheries and maritime education. However, most of the graduates, especially those majoring in fishing, prefer to work with foreign fishing vessels based in Japan or Korea because they offer higher salaries, job security and health and safety insurance, which are not provided by most national fleets. In this area, progress is being made by the government through the release of Indonesian Law No. 7 of 2016 related to the Protection and Empowerment of fishers, fish farmers, and salt farmers, which is expected to improve job security as well as health and safety insurance. However, the standard salary for Indonesian fleets remains lower than on foreign vessels. Therefore, further improvement both from the government and fishing companies is still vital to encourage young professional fishers to work for the national fleet.

Weaknesses-Threats Strategy: countering weaknesses and threats

Strategy 5: Low-cost technical applications to reduce fuel cost. Financial situation restricts the implementation of technical advancement; therefore, low-cost technology is preferred, not only for production but also for maintenance. Practically, the skippers will do their best to save fuel and optimise the engine's lifetime for economic reasons. They are aware that managing the speed according to operational modes, such as when steaming and setting the nets, will reduce fuel bills. Furthermore, periodic maintenance is also performed to keep the engine working as long as possible.

Strategy 6: Implementing open and closed fishing seasons. In order to avoid energy inefficiency, especially during low season, fishers should be encouraged to reduce their fishing efforts and do other land-based jobs. However, limited skills prevent them from securing other jobs easily, and thus economic needs drive them to keep conducting fishing operations as long as it is still profitable. Hence, educating the fishers concerning the importance of energy efficiency and additional skills training could support the fishers to be involved in promoting the open and closed fishing programmes.

Discussion. In Indonesia, most small-scale fisheries practice artisanal fishing conducted in the coastal waters and aimed at supplying the local markets. These fisheries have to deal with uncertainty in the catch size, and this is due to their limited technology and variation in the productivity of confined fishing grounds. Even though they use less fuel and rely on manual equipment, the energy performance in traditional fishing practices is not necessarily better than that found in advanced ones. Energy intensity in fishing operations is highly dependent on the operational modes, catch volume and fish selling price. In fact, the fishing operation within the bay has been less productive since 2013; therefore, efficiency can be achieved if the operation method uses a low amount of energy per kg catch, whilst at the same time capturing valuable fish.

This research reveals a significant difference between small pelagic fishing (PD and LF vessels), demersal fishing (HL and TN vessels). Pelagic fishing is the most efficient both regarding FUI or ep-EROI because pelagic fish typically migrate in schools; hence, the quantity per trip will be considerably different to operations targeting groundfish or crustaceans. However, regarding value per kg, the price of small pelagic fish is lower than its counterparts.

Potential improvements could focus on increasing energy efficiency by means of lowering the energy consumption and optimising the benefit from fish production both as income and food sources. However, factors related to economic priority and fisher's fishing habits limit the possible alternatives. At the practical level, the fishers have already implemented the concept of saving energy, even though it is not optimal. Development of a fuel monitoring system that is applicable for small-scale fishing vessel might be a potential measure to help fishers control their energy use. Hence, further research is required to investigate the possibility.

Table 7

Strategies formulation based on SWOT analysis

	Strengths (S)	*Weaknesses (W)*
	S1. Fishing activities are supported by various fisheries-related business and adequate facilities S2. Good quality fish S3. The fishers are open to technical improvements in fishing operations S4. The fishers are welcome to be involved in research activities	W1. Fishing operations face high uncertainty W2. The fishers resist fishing further and longer than regular one-day trips W3. Fishers have limited non-fishing skills W4. Fishers refrain from spending additional costs on technical applications
Opportunities (O)	*S–O Strategies*	*W–O Strategies*
O1. Open sea fishing O2. Various fisheries research activities O3. Tourism industry development	Strategy 1: S3, S4 and O2 Encouraging more research on technical advancements to increase fishing efficiency Strategy 2: S1, S2, and O3 Strengthening the existing market and developing the variety of seafood products	Strategy 4: W2 and O1 Encouraging fishers to work on larger vessels and further offshore fishing operations
Threats (T)	*S–T Strategies*	*W–T Strategies*
T1. Fuel price is increasing T2. A gradual decrease in fishing productivity in the last six years	Strategy 3: S3 and T1 Fuel substitution	Strategy 5: W4 and T1 Low-cost technical applications to reduce fuel bills Strategy 6: W1, W3, and T2 Implementing of open and closed fishing

According to the aforementioned strategies, most of them could be applied only if there were policy changes or if supporting policies were introduced, which implies that government action is crucial for improving the fisher's quality of life, in addition to the quality of the environment. To conclude, the support and cooperation of the fishers themselves with respect to any proposed action is key to successfully promote energy efficient fishing.

Conclusions. This study suggests that trammel netters, which are targetting demersal species, are the most energy intensive operation amongst the studied vessels. In general, compared to other fuel consumption in similar yet advanced operations in developed countries, the fuel consumption of traditional fishing vessels in Palabuhanratu is relatively high. Furthermore, according to analysis of internal and external factors of fishing operations, the socioeconomic characteristic of the traditional fishery is a key factor in determining the management measures to promote energy efficient fishing practices.

Acknowledgements. The authors would like to thank to: 1) Directorate General of Higher Education (DIKTI); 2) Indonesian Endowment Fund for Education (LPDP); 3) Institute for Research and Community Services IPB University for funding this research under the scheme of Young Lecturer Research Grant; and 4) Palabuhanratu fishers who help us with valuable inputs to this paper.

Conflict of interest. The authors declare no conflict of interest.

References

Astuti K. D., 2016 [Fish quality from Palabuhanratu bay is better than fish from Jakarta bay]. Pikiran Rakyat, Bandung, https://www.pikiran-rakyat.com/jawa-barat/pr-01257335/kualitas-ikan-palabuhanratu-lebih-baik-dari-ikan-teluk-jakarta-371017 [In Indonesian].
Basurko O. C., Gabiña G., Uriondo Z., 2013 Energy performance of fishing vessels and potential savings. Journal of Cleaner Production 54:30-40.
Brönmark C., Skov C., Brodersen J., Nilsson P. A., Hansson L. A., 2008 Seasonal migration determined by a trade-off between predator avoidance and growth. PLos ONE 3(4):e1957.
Davie S., Minto C., Officer R., Lordan C., Jackson E., 2015 Modelling fuel consumption of fishing vessels for predictive use. ICES Journal of Marine Science 72(2):709-719.
Demirel Y., 2012 Energy and energy types, green energy and technology. Springer-Verlag, London, pp. 27-70.
Eveson J. P., Hobday A. J., Hartog J. R., Spillman C. M., Rough K. M., 2015 Seasonal forecasting of tuna habitat in the Great Australian Bight. Fisheries Research 170:39-49.
Furuya A., Fukami M., Ellingsen H., Kagaya S., 2011 A survey on energy consumption in fisheries, and measures to reduce CO_2 emissions. 51st Congress of the European Regional Science Association "New Challenges for European Regions and Urban Areas in a Globalised World", Barcelona, Spain, European Regional Science Association (ERSA), Louvain-la-Neuve, 20 p.
Fyson J. F., 1985 Design of small fishing vessels. Fishing News Books, Farnham, 320 p.
Gulbrandsen O., 2012 Fuel savings for small fishing vessels - A manual. FAO, Rome, 57 p.
Gürel E., 2017 SWOT analysis: a theoretical review. The Journal of International Social Research 10(51):994-1006.
Hasegawa K., 2008 Annual fuel oil consumptions of Japanese fishing vessels. Technical report of National Research Institute of Fisheries Engineering 30:9-15.
Hindle T., 2008 Guide to management ideas and gurus. The Economist in association with Profile Books LTD, London, pp. 181-182.
Hospido A., Vazquez M. E., Cuevas A., Feijoo G., Moreira M. T., 2006 Environmental assessment of canned tuna manufacture with a life-cycle perspective. Resources, Conservation and Recycling 47(1):56-72.
Latorre R., 2001 Reducing fishing vessel fuel consumption and NOx emissions. Ocean Engineering 28(6):723-733.
Nansai K., Moriguchi Y., 2010 Embodied energy and emission intensity data for Japan using input-output tables (3EID): For 2005 IO table (Beta+version). National Institute for Environmental Studies, Ibaraki, Japan, http://www.cger.nies.go.jp/publications/report/d031/index.html.
Nontji A., 2005 [Nusantara sea]. Djambatan, Jakarta, 372 p. [In Indonesian].
Pariat M., 2013 Linking fisheries to the tourism economy. Farnet Magazine. European Commision, Brussel, 31 p.
Parker R. W. R., Hartmann K., Green B. S., Gardner C., Watson R. A., 2015a Environmental and economic dimensions of fuel use in Australian fisheries. Journal of Cleaner Production 87:78-86.
Parker R. W. R., Tyedmers P. H., 2015 Fuel consumption of global fishing fleets: current understanding and knowledge gaps. Fish and Fisheries 16(4):684-696.
Parker R. W. R., Vázquez-Rowe I., Tyedmers P. H., 2015b Fuel performance and carbon footprint of the global purse seine tuna fleet. Journal of Cleaner Production 103:517-524.
Pertamina, 2016 [Policy of fuel station construction to fulfil fisher's need for fuel]. Ministry of Marine Affairs and Fisheries, Jakarta, 38 p. [In Indonesian].
Schau E. M., Ellingsen H., Endal A., Aanondsen S. A., 2009 Energy consumption in the Norwegian fisheries. Journal of Cleaner Production 17(3):325-334.

Sumaila U. R., Teh L., Watson R., Tyedmers P., Pauly D., 2008 Fuel price increase, subsidies, overcapacity, and resource sustainability. ICES Journal of Marine Science 65 (6):832-840.
Thrane M., 2004a Energy consumption in the Danish fishery: Identification of key factors. Journal Industrial Ecology 8:223-239.
Thrane M., 2004b Environmental impacts from Danish fish products: hot spots and environmental policies, Institut for Samfundsudvikling og Planlægning. Aalborg Universitet, Aalborg, Denmark, 510 p.
Tyedmers P., 2001 Energy consumed by North Atlantic fisheries. In: Fisheries impacts on north atlantic ecosystems: Catch, effort and national/regional datasets. Zeller D., Watson R., Pauly D. (eds), pp. 12-34, Fisheries Centre Research.
Tyedmers P., 2004 Fisheries and energy use. In: Encyclopedia of energy. Cleveland C. J. (ed), pp. 683-693, Elsevier, New York.
Tyedmers P. H., Watson R., Pauly D., 2005 Fueling global fishing fleets. Ambio 34(8):635-638.
Vázquez-Rowe I., Villanueva-Rey P., Moreira M. T., Feijoo G., 2014 Edible protein energy return on investment ratio (ep-EROI) for Spanish seafood products. Ambio 43(3):381-394.
Ziegler F., Nilsson P., Mattsson B., Walther Y., 2003 Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts. The International Journal of Life Cycle Assessment 8:39-47.
*** BPH Migas, 2017 [Annual national fuel consumption]. BPH Migas Jakarta. [In Indonesian].
*** Centre for Data Statistics and Information, 2021 [Marine and fisheries in figures 2020]. Ministry of Marine Affairs and Fisheries Republic of Indonesia, Jakarta, 212 p. [In Indonesian].
*** Directorate General of Oil and Gas, 2013a [Standard and specification of petrol fuel type 88 for national market]. Ministry of Energy and Mineral Resources Republic of Indonesia, Jakarta. [In Indonesian].
*** Directorate General of Oil and Gas, 2013b [Standard and specification of diesel fuel type 48 for national market]. Ministry of Energy and Mineral Resources Republic of Indonesia, Jakarta. [In Indonesian].
*** FAO, 1989 Yield and nutritional value of the commercially more important fish species. FAO Fisheries Technical Paper. No. 309. FAO, Rome, 187 p.
*** FAO, 2001 Fishing gear types: Trammel nets, technology fact sheets. FAO Fisheries and Aquaculture Department, Rome.
*** FAO, 2003a Fishing techniques: Danish seining, technology fact sheets. FAO Fisheries and Aquaculture Department, Rome.
*** FAO, 2003b Food energy: Methods of analysis and conversion factors. FAO Food and Nutrition Paper. FAO, Rome, 93 p.
*** FAO, 2022 FAO yearbook 2020: Fisheries and aquaculture statistic. FAO Fisheries and Aquaculture Department, Rome, pp. 63-65.
*** Ministry of Marine Affairs and Fisheries, 2017 [Estimation of potential yield, total allowable catch, and status of fisheries resource in indonesian fishing areas]. Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia. [In Indonesian].
*** PPN Palabuhanratu, 2020 [Capture fisheries statistics of 2020]. Pelabuhan Perikanan Nusantara Palabuhanratu, Palabuhanratu, Indonesia. [In Indonesian].

Received: 30 November 2022. Accepted: 21 March 2023. Published online: 06 April 2023.
Authors:
Vita Rumanti Kurniawati, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Gedung FPIK-IPB, Lt 3 Wing 4, Jl. Agatis Kampus IPB Dramaga, 16680 Bogor, Indonesia, e-mail: vitarumanti@apps.ipb.ac.id
Richard Walter Birmingham, The Marine, Offshore and Subsea Technology (MOST) Research Group, School of Engineering, Armstrong Building, Newcastle University, NE1 7RU Newcastle upon Tyne, United Kingdom, e-mail: r.w.birmingham@ncl.ac.uk
Alan John Murphy, The Marine, Offshore and Subsea Technology (MOST) Research Group, School of Engineering, Armstrong Building, Newcastle University, NE1 7RU Newcastle upon Tyne, United Kingdom, e-mail: a.j.murphy@ncl.ac.uk
Dwi Putra Yuwandana, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Gedung FPIK-IPB, Lt 3 Wing 4, Jl. Agatis Kampus IPB Dramaga, 16680 Bogor, Indonesia, e-mail: dwiputra@apps.ipb.ac.id
Prihatin Ika Wahyuningrum, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Gedung FPIK-IPB, Lt 3 Wing 4, Jl. Agatis Kampus IPB Dramaga, 16680 Bogor, Indonesia, e-mail: piwahyuningrum@apps.ipb.ac.id
Eko Sri Wiyono, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Gedung FPIK-IPB, Lt 3 Wing 4, Jl. Agatis Kampus IPB Dramaga, 16680 Bogor, Indonesia, e-mail: eko-psp@apps.ipb.ac.id
Yopi Novita, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Gedung FPIK-IPB, Lt 3 Wing 4, Jl. Agatis Kampus IPB Dramaga, 16680 Bogor, Indonesia, e-mail: yopi_novita@apps.ipb.ac.id
Budhi Hascaryo Iskandar, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Gedung FPIK-IPB, Lt 3 Wing 4, Jl. Agatis Kampus IPB Dramaga, 16680 Bogor, Indonesia, e-mail: budhihascaryo@apps.ipb.ac.id
Eren Uyan, Altinova Vocational School, Yalova University, Cumhuriyet Mah. Atatürk Bulvarı 8. Sok. No:4, 77700 Altınova/Yalova, Turkey, e-mail: eren.uyan@yalova.edu.tr

How to cite this article:
Kurniawati V. R., Birmingham R. W., Murphy A. J., Yuwandana D. P., Wahyuningrum P. I., Wiyono E. S., Novita Y., Iskandar B. H., Uyan E., 2023 Energy consumption of traditional fishing vessels in Palabuhanratu, Indonesia. AACL Bioflux 16(2):929-944.