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Energy Efficiency of Liquefied Petroleum Gas and Gasoline (Pertalite) in Small-Scale Handline Fishing Operations at Barrang Caddi Island, Indonesia

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Abstract

Fuel is the dominant operating cost and source of greenhouse gas emissions in small-scale capture fisheries, yet empirical comparisons of alternative fuels in artisanal fleets remain scarce. This study compared the energy efficiency and fuel-based catch productivity of liquefied petroleum gas (LPG) and gasoline (Pertalite, RON 90) in handline fishing operations at Barrang Caddi Island, Makassar, Indonesia. A single small-scale vessel powered by a 10 HP (360 cc) engine was monitored over 25 fishing trips with each fuel. Fuel consumption, distance travelled, and catch weight were recorded per trip, and fuel use per nautical mile, energy use per nautical mile, and catch per unit of fuel and per unit of energy were calculated. Because the data were not normally distributed, the two fuels were compared using the Mann–Whitney U test. Mean fuel consumption was 0.546 ± 0.174 L nmi^{-1} for Pertalite and 0.213 ± 0.008 kg nmi^{-1} for LPG. After conversion to a common energy basis, LPG required 9.80 ± 0.38 MJ nmi^{-1} compared with 17.64 ± 5.63 MJ nmi^{-1} for Pertalite, a reduction of approximately 44% ($p < 0.001$). Catch per unit of fuel was higher for LPG (4.66 kg kg^{-1}) than for Pertalite (2.38 kg L^{-1}; $p = 0.011$); however, catch per unit of energy did not differ significantly between fuels (0.101 vs. 0.074 kg MJ^{-1}; $p = 0.107$), and catch per trip was similar. These results indicate that LPG reduced the energy required for vessel propulsion without affecting fishing success, and that the apparent advantage in raw catch-per-fuel ratios arises partly from the different units and energy densities of the fuels. LPG conversion therefore represents a promising option to reduce energy use in small-scale handline fisheries, but its benefits should be evaluated on an energy-equivalent basis and confirmed with direct, multi-vessel measurements.

Keywords: catch per unit effort; energy efficiency; handline; liquefied petroleum gas; small-scale fisheries

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INTRODUCTION

Capture fisheries are among the most fuel-dependent food production systems, because almost all the energy used in fishing is consumed by vessel propulsion and gear operation during the harvesting phase. A global assessment estimated that fisheries consumed about 40 billion litres of fuel in 2011 and generated 179 million tonnes of CO_2-equivalent emissions, and that emissions grew by 28% between 1990 and 2011 with little increase in production (Parker et al., 2018). Fuel use is also a central determinant of profitability, because fuel-intensive fisheries can remain viable only when prices are low or subsidised (Bastardie et al., 2022). Globally, fisheries subsidies were estimated at USD 35.4 billion in 2018, a large share of which supports fuel consumption and fishing capacity (Sumaila et al., 2019). Improving fuel efficiency therefore offers simultaneous benefits for fishers' incomes, government budgets, and climate mitigation.

Small-scale fisheries deserve particular attention in this context. They provide at least 40% of global fisheries catches, equivalent to about 37.3 million tonnes, and supply

a substantial share of essential micronutrients to approximately 2.3 billion people (Basurto et al., 2025). In Asia, including Indonesia, small-scale fisheries are central to coastal livelihoods and food security. Although small-scale fleets are often assumed to be energy-efficient, their fuel use intensity varies widely with vessel type, engine choice, fishing technique, and operational behaviour. In southeast India, for example, fuel use intensity among small-scale vessels ranged from 0.08 to 0.80, reflecting large differences in engine type and vessel design (Asokan et al., 2023). In the Basque albacore fishery, trolling vessels showed a fuel use intensity of 899.2 L t^{-1} compared with 632.6 L t^{-1} for pole-and-line vessels, mainly because of lower catches and longer distances travelled, and vessel speed was identified as a key factor in fuel consumption (Gabiña et al., 2025).

The energy efficiency of a fishery is commonly described using fuel use intensity, defined as the volume of fuel consumed per unit of catch landed, or its inverse, catch per unit of fuel (Bastardie et al., 2022). These indicators are useful because they connect operational performance with economic and environmental outcomes. Energy audits of Mediterranean trawl fleets, for instance, showed an average consumption of about 2.9 L of fuel per kilogram of landed fish and emissions of approximately 7.6 kg CO_2 per kilogram (Sala et al., 2022). Fuel use intensity is also influenced by the status of the exploited resources: in small-scale fisheries of northwest Mexico, fuel use per kilogram of seafood increased sharply when stock biomass fell below the level supporting maximum sustainable yield (Ferrer et al., 2022). Catch per unit effort expressed relative to engine power and fishing days provides a complementary perspective on productivity in small-scale fleets (Zeller et al., 2021). Collectively, these studies show that energy efficiency depends on both technical and ecological factors and that comparisons must be made on consistent bases.

Among the technical options for improving efficiency in small vessels, fuel switching has received increasing attention. Liquefied petroleum gas (LPG), a mixture of propane and butane, has a high-octane rating, burns with lower carbon intensity than gasoline, and can be used in spark-ignition engines after relatively simple conversion. An analysis of registered ships in South Korea showed that converting suitable vessels to LPG could reduce annual fuel consumption by 7.5–10.4%, fuel costs by 8.8–25.9%, and CO_2 emissions by 10–14%, with fishing vessels identified as particularly suitable for conversion (Yeo et al., 2022). A life cycle assessment of LPG engines designed for small fishing vessels indicated that LPG could reduce greenhouse gas emissions by more than 30% compared with conventional gasoline engines (Kim et al., 2023). Simulation and economic analyses of LPG, gasoline, and diesel engines for small marine vessels further suggested that LPG offers environmental and long-term cost advantages (Kim et al., 2024).

Engine studies, however, show that the performance of LPG relative to gasoline depends on engine design and operating conditions. In a spark-ignition engine operated on both fuels, LPG reduced brake thermal efficiency by 4.52% but improved brake specific fuel consumption by 5.42% and reduced CO_2 and CO emissions by 14.4% and 11.54%, respectively (Hashem et al., 2023). Another experimental study reported that LPG lowered brake specific fuel consumption by 15.13% and increased brake thermal efficiency by 14.34%, although gasoline produced about 23.74% higher brake power (Usman et al., 2023). Under a standardised driving cycle, fuel consumption expressed in energy units decreased by 10.38% when a gasoline car was operated on LPG (Manko et al., 2022). These findings highlight an important methodological point: because LPG and gasoline differ in density and energy content, comparisons based on litres or kilograms alone may

overstate or understate the real difference in energy use. Fair comparisons require conversion to a common energy unit.

In Indonesia, small-scale fishers rely heavily on gasoline-powered outboard and inboard engines, and fuel is a major component of operating costs. Fishers on small islands face additional constraints, including higher transport costs and irregular supply of subsidised fuel. Barrang Caddi Island, located in the Spermonde Archipelago off Makassar, South Sulawesi, is home to a fishing community that depends largely on handline fishing using small boats. Handlines are selective, low-impact gears, but their economic performance is closely tied to fuel costs because trips involve repeated travel between fishing spots. Some fishers on the island have begun to convert engines to run on LPG, which is widely available in household cylinders, but empirical evidence on whether this conversion improves energy efficiency under real operating conditions is lacking.

Previous studies on LPG in marine applications have been conducted mainly in developed countries, through simulations, engine-bench tests, or fleet-level estimates (Yeo et al., 2022; Kim et al., 2023, 2024). Field-based comparisons that monitor the same small vessel operating alternately on LPG and gasoline during actual fishing trips are rare, particularly in tropical artisanal fisheries. Moreover, few studies have examined whether differences in fuel consumption translate into differences in catch per unit of energy, which is the more relevant indicator for both fishers and policymakers. This study therefore aimed to (1) quantify fuel and energy consumption per nautical mile when a small handline vessel at Barrang Caddi Island was operated on LPG and on Pertalite, (2) test whether energy use differed significantly between the two fuels, and (3) compare catch per unit of fuel and per unit of energy between fuels. It was hypothesised that LPG would reduce energy use per distance travelled and increase energy-based catch productivity compared with Pertalite.

METHOD

The study was conducted from November to December 2025 at Barrang Caddi Island, Sangkarrang Islands District, Makassar City, South Sulawesi, Indonesia, using a quantitative comparative design. A single small-scale handline vessel powered by a 10 HP (360 cc) spark-ignition engine was monitored, with the same vessel, engine, operator, and fishing grounds used throughout, and trips with LPG and Pertalite (RON 90) were alternated to reduce the influence of day-to-day variation in weather and sea conditions. Twenty-five trips were recorded for each fuel. For each trip, the fuel type, departure and return times, distance travelled (nautical miles, nmi), fuel consumed, and total catch weight (kg, digital scale) were recorded in a logbook. Pertalite consumption was measured volumetrically as the difference between the initial and remaining volumes, whereas LPG consumption was recorded as liquid volume and converted to mass using a density of 0.54 kg L^{-1}. Following the fuel use intensity framework used in fisheries energy audits (Bastardie et al., 2022; Sala et al., 2022), fuel use per distance (L nmi^{-1} for Pertalite and kg nmi^{-1} for LPG) and catch per unit of fuel (kg L^{-1} and kg kg^{-1}) were calculated for each trip, with distance used as the effort proxy because vessel speed and distance travelled strongly determine fuel demand in small-scale fleets (Gabiña et al., 2025; Zeller et al., 2021).

Because LPG and gasoline differ in density and energy content, consumption was converted to a common energy basis before comparison, as recommended in engine studies comparing these fuels (Hashem et al., 2023; Manko et al., 2022; Usman et al., 2023). Lower heating values of 32.3 MJ L^{-1} for Pertalite (43.4 MJ kg^{-1} at a density of 0.745

kg L^{-1}) and 46.0 MJ kg^{-1} for LPG were applied to obtain energy use per distance (MJ nmi^{-1}) and catch per unit of energy (kg MJ^{-1}). A sensitivity analysis was performed using alternative values of 30–35 MJ L^{-1} for Pertalite and 45.5–46.5 MJ kg^{-1} for LPG. Data were summarised as means, standard deviations, medians, and ranges. Normality was tested using the Shapiro–Wilk test, and because all efficiency variables deviated significantly from normality ($p < 0.01$), differences between fuels in distance per trip, catch per trip, fuel and energy use per distance, and catch per unit of fuel and energy were tested using the two-sided Mann–Whitney U test at $\alpha = 0.05$. All analyses were performed in Python using the SciPy library.

RESULT AND DISCUSSION

Operational conditions were comparable between the two fuels (Table 1). The distance travelled per trip did not differ significantly between Pertalite (mean 8.40 nmi, median 5.0 nmi) and LPG (mean 7.28 nmi, median 4.0 nmi; Mann–Whitney $p = 0.72$), and catch per trip was also statistically similar (7.40 ± 5.65 kg vs. 5.47 ± 4.43 kg; $p = 0.18$). This similarity indicates that differences in efficiency indicators were not caused by systematically longer trips or larger catches with one fuel. The Shapiro–Wilk test showed that fuel use per distance deviated strongly from normality for both Pertalite ($W = 0.54$, $p < 0.001$) and LPG ($W = 0.55$, $p < 0.001$), as did catch per unit of fuel, so non-parametric tests were applied.

Table 1.

Lama Operational and energy-efficiency indicators of a 10 HP handline vessel operated on Pertalite and LPG at Barrang Caddi Island (n = 25 trips per fuel)

Indicator	Pertalite (mean ± SD; median)	LPG (mean ± SD; median)	Mann–Whitney p
Distance per trip (nmi)	8.40 ± 7.20; 5.0	7.28 ± 6.93; 4.0	0.72
Catch per trip (kg)	7.40 ± 5.65; 6.0	5.47 ± 4.43; 5.0	0.18
Fuel use per distance	0.546 ± 0.174 L nmi^{-1}; 0.50	0.213 ± 0.008 kg nmi^{-1}; 0.216	—
Energy use per distance (MJ nmi^{-1})	17.64 ± 5.63; 16.15	9.80 ± 0.38; 9.94	< 0.001
Catch per unit of fuel	2.38 ± 1.97 kg L^{-1}; 2.25	4.66 ± 3.40 kg kg^{-1}; 4.63	0.011
Catch per unit of energy (kg MJ^{-1})	0.074 ± 0.061; 0.070	0.101 ± 0.074; 0.101	0.107

Fuel use per distance is reported in the native unit of each fuel and was therefore not tested directly; the statistical comparison of propulsion efficiency is based on energy use per distance

Mean fuel consumption was 0.546 L nmi^{-1} for Pertalite (range 0.40–1.00) and 0.213 kg nmi^{-1} for LPG (range 0.193–0.221). Because these values are expressed in different units, they cannot be compared directly. After conversion to energy, the vessel required 17.64 ± 5.63 MJ nmi^{-1} when running on Pertalite and 9.80 ± 0.38 MJ nmi^{-1} when running on LPG, a reduction of approximately 44% that was highly significant (Mann–Whitney $U = 625$, $p < 0.001$). The difference remained large under all combinations of heating values tested in the sensitivity analysis (16.4–19.1 MJ nmi^{-1} for Pertalite vs. 9.7–9.9 MJ nmi^{-1} for LPG). Lower energy use with LPG is consistent with fleet-level estimates showing that conversion of suitable vessels to LPG reduces annual fuel consumption by 7.5–10.4% (Yeo et al., 2022) and with vehicle tests in which energy-based fuel consumption decreased by 10.38% on LPG (Manko et al., 2022). The magnitude of the reduction observed here is considerably larger than those values. Engine-bench studies have reported both higher

and lower thermal efficiency with LPG compared with gasoline, depending on engine design and load (Hashem et al., 2023; Usman et al., 2023), so a reduction of 44% in energy demand is unlikely to be explained by combustion characteristics alone.

The pattern of variability in the data provides an important clue. Pertalite consumption varied widely among trips, from 0.40 to 1.00 L nmi^{-1}, with the highest values on short trips where idling during setting and hauling of handlines represents a larger share of engine running time. In contrast, LPG consumption per distance was almost constant (coefficient of variation about 4%), with most trips showing exactly the same ratio of fuel to distance. In real fishing operations, fuel use per distance is expected to fluctuate with speed, sea conditions, and time spent idling, as demonstrated in artisanal fleets where speed over ground was the main determinant of fuel demand (Gabiña et al., 2025). The near-constant LPG values therefore suggest that LPG consumption may have been estimated from distance or from a fixed refilling pattern rather than measured independently for each trip. If so, the apparent stability and part of the energy saving of LPG could reflect the measurement procedure rather than engine performance. The results on propulsion efficiency should thus be interpreted with caution and confirmed through direct gravimetric measurement of LPG cylinders before and after each trip.

Catch per unit of fuel was significantly higher for LPG (4.66 kg kg^{-1}) than for Pertalite (2.38 kg L^{-1}; $p = 0.011$). However, this comparison is confounded by the different units and energy densities of the two fuels: a kilogram of LPG contains more energy than a litre of gasoline, so a higher catch per kilogram does not necessarily imply higher productivity per unit of energy. When catch was expressed per unit of energy, the difference between LPG (0.101 kg MJ^{-1}) and Pertalite (0.074 kg MJ^{-1}) was not statistically significant ($p = 0.107$), and this result was consistent across the sensitivity analysis ($p = 0.06$–0.16). Catch per trip was also similar between fuels. Fuel type is therefore unlikely to have influenced fishing success directly; rather, differences in catch per unit of fuel arise mainly from differences in fuel consumption and units. This distinction is important, because fuel use intensity in fisheries is driven by gear type, operational behaviour, and stock status (Bastardie et al., 2022; Ferrer et al., 2022), and productivity indicators must be expressed on comparable effort bases to be meaningful (Zeller et al., 2021).

Despite these caveats, the findings are relevant for small-scale fisheries in Indonesia and elsewhere. Small-scale fleets differ widely in fuel use intensity depending on engine type and vessel design (Asokan et al., 2023), and fuel switching is one of the few technical options available to artisanal fishers without replacing vessels. LPG is attractive because it is widely distributed in household cylinders, often cheaper per unit of energy than gasoline, and associated with lower emissions. Life cycle assessment indicates that LPG can reduce greenhouse gas emissions from small fishing vessels by more than 30% compared with gasoline (Kim et al., 2023), and simulation studies suggest that LPG engines for small marine vessels offer environmental and long-term economic benefits (Kim et al., 2024). Reducing energy demand per distance travelled would also lower the carbon intensity of seafood production, which is already a concern given the growth of fisheries emissions worldwide (Parker et al., 2018) and the energy-intensive nature of many fleets (Sala et al., 2022).

From a policy perspective, fuel subsidies are a major form of support to fisheries globally (Sumaila et al., 2019), and redirecting part of this support towards safe engine conversion and LPG supply could help small-scale fishers reduce costs while contributing to climate commitments. Because small-scale fisheries supply a large share of the catch and micronutrients consumed by coastal populations (Basurto et al., 2025), improving

their energy efficiency has implications for food security as well as for livelihoods. However, the use of LPG on small open boats requires attention to safety, including secure cylinder storage, leak detection, and ventilation, because LPG is heavier than air and can accumulate in the bilge. The present study was limited to one vessel and one operator, so the results may not represent the variability among engines, hull forms, and operators in the wider fleet. Future research should include multiple vessels, direct gravimetric measurement of LPG use, engine running time and idling records, fuel cost per kilogram of catch, and emission estimates, to provide a robust basis for policy decisions on fuel switching in small-scale fisheries.

CONCLUSION

This study compared the energy efficiency of liquefied petroleum gas and gasoline (Pertalite) in a small-scale handline vessel operating at Barrang Caddi Island, Indonesia. Mean fuel consumption was 0.546 L nmi^{-1} for Pertalite and 0.213 kg nmi^{-1} for LPG. When converted to a common energy basis, the vessel required approximately 44% less energy per nautical mile when operating on LPG (9.80 MJ nmi^{-1}) than on Pertalite (17.64 MJ nmi^{-1}), and this difference was statistically significant and robust to the choice of heating values. Catch per unit of fuel was higher with LPG (4.66 kg kg^{-1}) than with Pertalite (2.38 kg L^{-1}), but catch per unit of energy and catch per trip did not differ significantly between fuels, indicating that LPG reduced propulsion energy demand without changing fishing success. The near-constant LPG consumption per distance suggests that part of the observed difference may reflect the measurement procedure, so the magnitude of the energy saving should be regarded as provisional. Overall, LPG conversion appears to be a promising strategy to reduce energy use, operating costs, and emissions in small-scale handline fisheries on small islands. Future studies should involve multiple vessels and operators, measure LPG use gravimetrically on every trip, record engine running and idling time, and evaluate costs, emissions, and safety to support evidence-based policies on fuel switching in Indonesian small-scale fisheries.

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