



# Evaluating LNG-Diesel Dual-Fuel Systems in Trawling: Results from Trials off Cochin, Kerala

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## Abstract

The trawling sector, though contributes significantly to the Indian marine fisheries, is characterized by high energy consumption and significant environmental impacts. This study investigates the feasibility and effectiveness of using a dual fuel system, combining traditional High-Speed Diesel (HSD) with Liquefied Natural Gas (LNG) in trawling operations along the Kerala coast. The field trials, conducted over four months, demonstrated that the LNG substitution rate could reach up to 24%, resulting in reductions in fuel costs and emissions.

The fuel consumption pattern showed an average HSD consumption of 25.5±1.12 litres per hour during steaming and 20.4±0.74 litres per hour during trawling operations. LNG contributed to reducing HSD use by 21.0±0.56% during steaming and 29.6±0.69% during trawling. The dual-fuel system showed no significant differences in power output. The environmental impact assessment using Life Cycle Assessment (LCA) methodologies indicated significant reductions in global warming potential (19.42%), acidification potential (24.20%), and other environmental parameters when using the dual-fuel system compared to HSD alone.

The study concludes that LNG can be effectively used in a diesel dual-fuel mode for trawling without any significant reduction in power or other operational parameters. Within the tested limits, it offers both economic and environmental benefits. However, the long-term viability of LNG as a sustainable

fuel source requires further research, particularly concerning infrastructure costs and lifecycle environmental impacts.

**Keywords:** LNG, fishing vessels, dual-fuel systems, environmental sustainability, fuel substitution, Kerala marine fisheries

## Introduction

Mechanized fishing vessels play a crucial role in the marine sector, contributing about 77% of the marine fish landings in India (CMFRI, 2023). Among the mechanized fishing vessels, trawlers, with different size classes and totaling around 30,000, contribute over 50% of the total landings, underscoring their importance in the Indian marine fisheries (DoF & CMFRI, 2020).

However, trawling is a highly energy intensive fishing method, and is also implicated with generation of large quantities of non-targeted catches along with impacts to the sea-bottom (Kaiser, Collie, Hall, Jennings, & Poiner, 2002; Devi et al., 2021; Jarvis, 2024; Jarvis & Brennan, 2024) Despite these drawbacks, trawling remains a popular fishing method for capture of shrimp and fishes in many countries, including India.

With significant shifts happening globally towards conservation of energy and reduction in greenhouse gas emissions, the negative aspects of trawling, such as high emissions and bottom impacts, remain contentious issues.

It is estimated that the global fishing fleets consume approximately 40 billion litres of gasoline and emit 179 million tonnes of CO<sub>2</sub> equivalent into the environment (Parker et al., 2018), which is approximately 2.2 tonnes of CO<sub>2</sub>-eq per tonne of fish landed. The comparative figure from the Indian

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marine fisheries is 1.52 tonnes, (Dineshbabu et al., 2024), which is now lower than the global average. However rapid structural changes are reported in the Indian fisheries, particularly in the trawling sector (Ravi, Vipin, Boopendranath, Joshy, & Edwin, 2014; Sayana & Remesan, 2020), which means that the trawlers have been increasing in size and in the installed engine power over the years. Concurrent to this, there has been significant increase in the gear size also (Edwin et al., 2014), which will eventually result in increased consumption of fuel and associated emissions from these fishing vessels. The emissions from the trawling sector along the northwest coast of India has been reported by Devi et al. (2021) and Ghosh et al. (2014), reported the carbon footprint of marine fisheries, using LCA along the northeast coast of India. The other study by Das and Edwin (2016) have assessed the life cycle of Indian Oil Sardine fishery along the Southwest coast; all these studies collectively highlight growing concerns regarding fossil fuel use in Indian fisheries.

In response to growing concerns over the environmental impact of conventional fuels, there is an urgent need to explore cleaner, greener, and more sustainable alternative energy sources for fishing vessels (Perèia, Vladimir, Koriàn, Jovanovia, & Haramina, 2023). India has also made attempts to use solar energy (Baiju et al., 2017) and develop energy-efficient technologies (Baiju, 2019) to minimize emissions during fishing operations. However, significant reductions in the emission can happen only when the traditional fuels are either replaced or mixed with low emission fuels (Livaniou & Papadopoulos, 2022; Taghavifar & Perera, 2023) thereby reducing the overall emissions due to fishing.

Liquefied natural gas (LNG) has emerged as a promising alternative due to its lower emissions profile and its abundance as a natural resource (Kumar et al., 2011; Iannaccone, Landucci, Tugnoli, Salzano, & Cozzani, 2020; Livaniou & Papadopoulos, 2022; Aakko-Saksa et al., 2023; Taghavifar & Perera, 2023) Moreover, it is shown that use of LNG reduces GHG emissions by around 10% when compared to HSD (Arteconi, Brandoni, Evangelista, & Polonara, 2010), and concurrently with significantly lower levels of sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter compared to HSD (EPA, 2014), thereby reducing health risks related to emissions.

Since trawling requires intensive energy compared to other fishing methods, powerful engines are used for extended periods, which necessitates significant quantities of fuel to be carried on board. Though dual fuel system has been tried in large merchant vessels (Bilgili, 2021), there have been no trials using LNG as fuel in trawling operations for comparisons and hence the aim of this pioneering study, was to explore the feasibility of using dual fuel – combining traditional HSD with LNG as an alternative to traditional trawling that relies solely on HSD. Additionally, the study aimed to understand the changes in power output, ease of operation, and other operational challenges associated with this novel concept in trawling operations.

## Materials and Methods

The research vessel R.V. Matsyakumari-II (Table 1 & Fig. 1), a stern trawler classed by Indian Register of Shipping with the class notation + SU “FISHING VESSEL”, was selected for the conversion and subsequent field trials using the dual-fuel system. Necessary modifications were made in the engine room, wheelhouse, fuel storage area and structural modifications to the under deck of the vessel to accommodate LNG tank, pipelines, and other essential apparatus.

The diesel propulsion system was converted into a Diesel Dual Fuel (DDF) flow system, capable of utilizing both HSD and LNG. This conversion process did not include any modifications to the existing marine diesel engine but was integrated to the existing system to enable the use of LNG fuel from the LNG storage tank, by installing associated equipment and pipelines. The process involved the installation of a DDF (Diesel Dual Fuel) system switch (on/off) on the vessel bridge, as well as the design, fabrication, and installation of a retrofit kit, including a Chief Controller of Explosives (CCOE) approved two-layer cryogenic chromium nickel stainless steel (X5 Cr-Ni 18-10) LNG tank with a capacity of 450 litres, tested up to a pressure of 32.5/33.1 kg/cm<sup>2</sup> (Fig. 2). All design, fabrication, and inspection procedures were conducted in compliance with ISO 12991 and ISO 21029-1 standards.

The entire process was so designed to seamlessly switch to 100% diesel operation, without any delay in case of malfunction, exhaustion or an LNG fuel leakage. The engine was calibrated initially for a maximum substitution of up to 30% - 40% of HSD

Table 1. General details the research vessel R V Matsyakumari-II

Main particulars	
Length Over All (LOA)	17.70 m
Breadth max.	6.0 m
Depth	3.00 m
Draft, max	2.00 m
Tonnage (GRT)	66
Engine horsepower	325 hp @ 1800 rpm
Free running speed	9.0 knots
Trawling speed	3.5 to 4.5 knots
Refrigerated fish hold	350 kg at -20°C
Endurance	9 days
Types of fishing	Stern trawling (Bottom and Midwater)
Accommodation	Scientists: 2; Crew: 10
Post-harvest handling	Platform for hygienic landing

with LNG, at 80% engine load and to ensure that the engine output power remained consistent when transitioning from diesel to DDF fuel system. Furthermore, to ensure safety, an alarm display unit was installed on the bridge to provide real-time monitoring and alerts.

Handling LNG presents inherent risks due to its low temperature and flammability, and this could include cryogenic burns from direct contact, flammability when vaporized and mixed with air, rapid phase transition leading to over-pressurization, or potential asphyxiation due to odourless vapor (Woodward & Pitbaldo, 2010; Iannaccone, 2021). Therefore, training sessions on LNG handling and safety were conducted for project officials and crew at Petronet LNG terminal, Kochi, which covered procedures for conducting LNG trials and filling

operations, safety measures, firefighting demonstrations, and technical aspects of LNG dispensing (PNGRB, 2024).

The fishing trials were conducted over a period of four months from September 2021 to December 2021, during which 38 hauls were carried out to assess the fuel consumption pattern. A total of 16 valid hauls were considered for analysis with DDF and 19 hauls were considered using HSD alone. Three hauls were excluded from the analysis, since the towing had to be stopped prematurely due to trawl net damage. All fishing trials were conducted in coastal area restricted to a depth of 30m, to ensure that the data collected across hauls were consistent and comparable. Data on fuel usage was monitored using a fuel flow meter (Aquametro CONTOIL® DFM 12ECO fuel meter) and the vessel speed, engine running time, and engine RPM for each haul were noted and recorded separately.

To compare and understand the environmental impact of HSD and dual fuel (LNG and diesel) powered operations, an LCA was performed using the GaBi 6 LCA software package (Thinkstep, 2014), adhering to the guidelines outlined in ISO 14040 (ISO, 2006). The CML 2001 methodology was



Fig. 1. Research vessel R.V. Matsyakumari

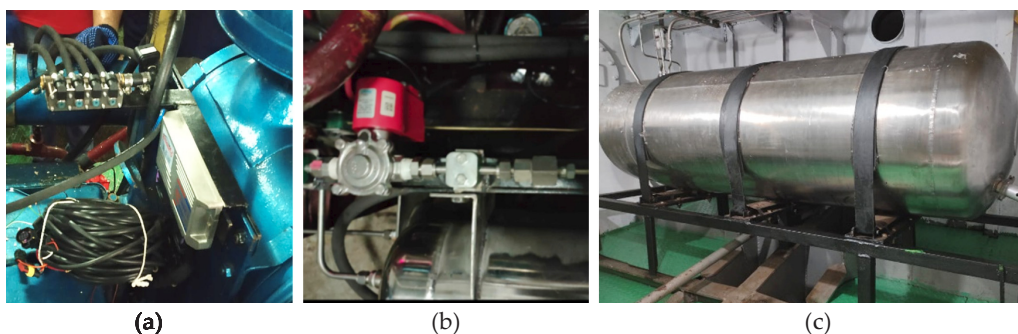


Fig. 2. (a) Cylinder conversion kit; (b) Solenoid valve for auto trip off fuel to engine in case of gas leakage; (c) Cryogenic LNG storage tank of 450L capacity.



adopted to ensure accuracy and reliability of the LCA results. The specific parameters analyzed in this study were Abiotic Depletion Potential (ADP fossil): measured in megajoules (MJ), Acidification Potential (AP): measured in kilograms of SO<sub>2</sub> equivalents (kg SO<sub>2</sub>-Equiv.) Eutrophication Potential (EP): measured in kilograms of phosphate equivalents (kg Phosphate-Equiv.), Freshwater Aquatic Ecotoxicity Potential (FAETP inf.): measured in kilograms of dichlorobenzene equivalents (kg DCB-Equiv.), Global Warming Potential (GWP 100 years): measured in kilograms of CO<sub>2</sub> equivalents (kg CO<sub>2</sub>-Equiv.), Human Toxicity Potential (HTP inf.): measured in kilograms of dichlorobenzene equivalents (kg DCB-Equiv.), Marine Aquatic Ecotoxicity Potential (MAETP inf.): measured in kilograms of dichlorobenzene equivalents (kg DCB-Equiv.), Ozone Layer Depletion Potential (ODP, steady state): measured in kilograms of R11 equivalents (kg R11-Equiv.), Photochemical Ozone Creation Potential (POCP): measured in kilograms of ethene equivalents (kg Ethene-Equiv.), Terrestrial Ecotoxicity Potential (TETP inf.): measured in kilograms of dichlorobenzene equivalents (kg DCB-Equiv.) (Guinée et al., 2001).

A Welsh two sample t-test was used to find significant differences in the hourly consumption of fuel when trawling, between the DDF and HSD mode. An Analysis of Covariance (ANCOVA) test was carried out to find significant differences if any in the relationship between the RPM and the speed of the vessel in the two scenarios (DDF and HSD). All the statistical analysis was carried out using R software (R core Team, 2024).

### Results and Discussion

The fuel consumption pattern was estimated separately for two phases: steaming to the fishing ground (at a speed of about 6-7 knots) and trawling operations (typically done at a lower speed of about 3 knots). The total running time, including both steaming and trawling, using a combination of HSD and LNG, was 1300 minutes (21.7 hours). During this period, 508.0 litres of HSD and 160.0 litres of LNG were consumed, resulting in an approximate 24.2% substitution of HSD with LNG when considering the entire operation, including both steaming and fishing.

The average speed of the vessel during steaming was 7.6 ± 0.18 (standard error) knots at an average RPM of 1499 ± 6.2. The average HSD consumption was recorded at 25.5 ± 1.12 litres per hour, and concurrently, an average of 6.8 ± 0.39 litres of LNG was used. This resulted in a total combined fuel consumption of 32.3 ± 1.5 litres per hour when the vessel steamed to the fishing ground.

During trawling the average RPM recorded for the engine was 1144 ± 19 at an average speed of 3.1 ± 0.08 knots. The average HSD consumption per hour during trawling was estimated as 20.4 ± 0.74 litres, with a concurrent LNG consumption of 8.5 ± 0.27 litres. The total combined fuel consumption rate (HSD + LNG) during trawling was 28.9 ± 0.9 litres per hour, with the average substitution of HSD observed to be 29.6 ± 0.69%. The average consumption for the control operations viz., only using HSD was worked out as 26.8 ± 0.94 litres per hour during trawling, and for steaming the average consumption was 32.5 litres per hour.

Table 2. Percentage reduction in environmental impact parameters for dual-fuel systems compared to diesel systems

LCA Environmental Parameters	Trawling	Steaming	All together
Abiotic Depletion [MJ]	15.95%	15.30%	15.60%
Acidification Potential (AP) [kg SO <sub>2</sub> -Equiv.]	26.28%	22.41%	24.20%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	20.30%	18.29%	19.22%
Freshwater Aquatic Ecotoxicity Pot. [kg DCB-Equiv.]	33.28%	27.22%	30.01%
Global Warming Potential [kg CO <sub>2</sub> -Equiv.]	20.55%	18.46%	19.42%
Human Toxicity Potential [kg DCB-Equiv.]	31.93%	26.29%	28.89%
Marine Aquatic Ecotoxicity Pot. [kg DCB-Equiv.]	32.90%	26.96%	29.70%
Ozone Layer Depletion Potential [kg R11-Equiv.]	23.38%	20.41%	21.78%
Photochem. Ozone Creation Potential [kg Ethene-Equiv.]	21.27%	18.96%	20.02%
Terrestrial Ecotoxicity Potential [kg DCB-Equiv.]	32.13%	26.43%	29.06%

The average fuel consumption per hour during trawling which was  $28.9 \pm 0.9$  liters for DDF and  $26.8 \pm 0.94$  litres for HSD alone, was not significantly different,  $t(33.955) = 1.1295$ ,  $p = 0.266$ . Similarly, no significant difference was observed in the mean fuel consumption during steaming, which was  $32.3 \pm 1.5$  litres/hour for DDF and  $32.5 \pm 1.9$  litres/hour when HSD alone was used. The analysis of covariance (ANCOVA) revealed no significant difference in the intercept ( $F=3.52$ ,  $p=0.069$ ) but showed a significant increase in speed with increasing engine RPM ( $F=11.57$ ,  $p<0.01$ ). The slopes, however, did not differ significantly ( $F=2.53$ ,  $p=0.12$ ), indicating that the fuel consumption mode did not affect the power output, with RPM and vessel speed used as proxies in the analysis (Fig. 3).

Analysis of fuel costs for one hour of operation, using prices of INR 95.5 for HSD and INR 68.5 for LNG, showed a 1.5% reduction in fuel costs in DDF mode during trawling and a 6.5% reduction in fuel costs while steaming, compared to the HSD-only mode of operation (Fig. 4).

The LCA analysis indicated significant reductions in all the environmental parameters when converting diesel propulsion systems to dual-fuel systems. For Global Warming Potential (GWP 100 years), dual-fuel systems emitted 178.20 kg CO<sub>2</sub>-equivalents per hour of operation, compared to 221.16 kg CO<sub>2</sub>-equivalents from diesel systems, resulting in an overall reduction of 19.42% per hour. Specifically, during trawling operations, the reduction was 20.55%, and during steaming operations, it was 18.46%. The percentage reduction in environmental impact parameters for dual-fuel systems compared to HSD is detailed in Table 2.

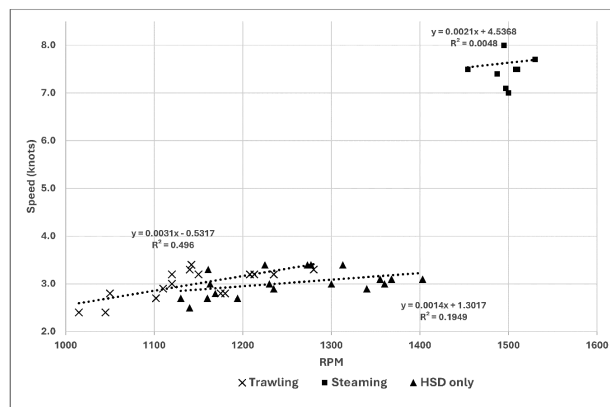


Fig. 3. Change in the speed (knots) with increase in the engine RPM

The environmental benefits highlighted are only due to the reduction in the quantity of HSD use because of substitution and it is crucial to evaluate the entire lifecycle environmental impact of both High-Speed Diesel (HSD) and Liquefied Natural Gas (LNG) fuels, for a complete understanding of the benefits or drawbacks of this technology. Such assessments should encompass extraction, production, transportation, and combustion stages. It is observed that while LNG combustion reduces operational pollutants, the extraction and processing of natural gas can lead to methane leakage, which is a potent greenhouse gas (Stern, 2020). Additionally, LNG transportation and storage involve energy-intensive processes that contribute to its overall carbon footprint. Although LNG demonstrates notable environmental advantages, including reduced emissions and lower spill risks compared to HSD, further research is necessary to explore its

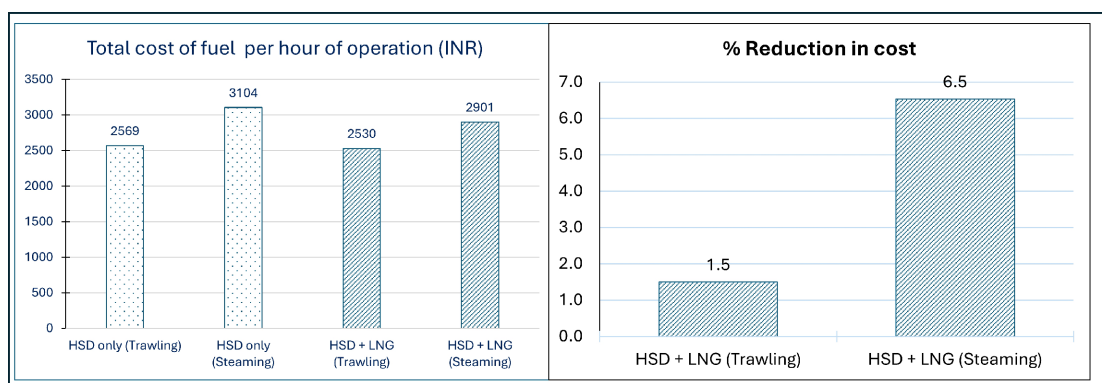


Fig. 4. (a) Total cost of fuel (INR) per hour of operation in two modes of operation during fishing and steaming; (b) Percentage reduction in the cost of operation per hour of operation during trawling and steaming of the vessel

long-term economic benefits and feasibility as an alternative fuel in the trawling sector.

The trials conducted onboard MFV Matsyakumari-II utilizing LNG with a substitution rate of up to 24% (steaming and trawling combined) yielded promising outcomes. Safety concerns were effectively addressed, and the switching operations between fuels proceeded smoothly and regularly. Notably, no significant variations in power were observed, with engine RPM and corresponding speed of the vessel serving as a proxies, during the trials with LNG substitution.

These preliminary results suggest that LNG could be a technically viable option in DDF systems, which will contribute to improved emission standards and thus related environmental parameters, as indicated by the LCA analysis. However, even though LNG offers potential fuel cost savings of approximately 4% compared to commercially available HSD, it is crucial to consider additional overhead costs associated with installation, transport, bunkering infrastructure requirements, and crew training.

Though preliminary in its scope, the positive results of this study would pave way for continued trials for optimal use of LNG, Diesel Dual Fuel (DDF) in commercial trawling operations, as a source of sustainable and cleaner energy for fishing, considering the ongoing efforts aimed at optimizing efficiency, mitigating costs, and enhancing environmental performance.

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