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GREEN LOGISTIC SHIPS (GLS) AND DECARBONIZATION IN ARCHIPELAGIC MARITIME TRANSPORTATION: TECHNICAL FEASIBILITY, COLD IRONING INTERACTION, AND EMPIRICAL EVIDENCE FROM INDONESIAN PORT STATISTICS

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ABSTRACT

Maritime decarbonization in Indonesia requires a coordinated approach linking vessel operations and port electricity infrastructure. This paper examines the feasibility of Green Logistic Ships (GLS) combining energy-efficient propulsion, just-in-time (JIT) arrival, shore power (cold ironing), and emissions monitoring. The study uses a traceable document-based review of Statistics Indonesia (BPS) sea transport publications for 2021–2024, International Maritime Organization (IMO) instruments, a shore-connection technical standard, and peer-reviewed research. A four-layer integration framework is proposed, with a reproducible method for evaluating fuel use, transport work, port electricity demand, and grid-adjusted emissions. The review establishes the relevance of shore power and operational optimisation but does not treat unverified fleet-wide efficiency estimates, port power-capacity values, or financial payback figures from an earlier draft as observed results. The principal output is an evidence-based technical assessment framework and a list of vessel- and port-level data needed to quantify Indonesia-specific benefits.

Keywords: Cold Ironing; EEOI; Green Logistic Ships; Indonesia; Just-In-Time Arrival; Maritime Decarbonization; Shore Power

1. Introduction

The International Maritime Organization (IMO) adopted the 2023 Strategy on Reduction of GHG Emissions from Ships, which calls for net-zero greenhouse gas emissions from international shipping by or around 2050 and an average carbon-intensity reduction of at least 40% by 2030 relative to 2008 [1]. The strategy also calls for greater uptake of zero- or near-zero-emission fuels and energy sources. Such targets place new attention on technical measures aboard vessels and on the infrastructure that supports ships during port calls.

Indonesia's archipelagic geography makes the interaction between ships, terminals, and inland distribution particularly important. Statistics Indonesia (BPS) publishes annual Sea Transportation Statistics, including ship calls, loaded and unloaded freight, and passenger flows [2]–[5]. These publications provide a defensible basis for describing port activity, but port aggregates alone cannot establish vessel-specific fuel consumption, voyage transport work, actual emissions, shore-side electricity loads, or commercial payback.

This paper therefore reassesses the Green Logistic Ship (GLS) concept as an integrated feasibility framework. Its objectives are to (i) review verifiable evidence on JIT arrival, wind assistance, fuel alternatives, and shore power; (ii) specify calculation boundaries consistent with IMO guidance; (iii) propose a four-layer ship–port integration architecture; and (iv) identify the additional operating records necessary for a reproducible empirical evaluation in Indonesian ports.

2. Literature Review

Shore power, also known as cold ironing, transfers a berthed ship's electrical load from onboard auxiliary engines to a shore-based source. Abu Bakar et al. [6] review the equipment, power requirements, standardisation and economic constraints of this technology. Benefits depend on the displaced auxiliary fuel consumption and the carbon intensity of the electricity supplied; therefore, the elimination of exhaust at the berth should not be presented as automatic elimination of upstream power-generation emissions.

For vessel operations, Liu, Zhang and Yan [7] develop speed-optimisation models under JIT arrival conditions that explicitly consider meteorological information and trade-offs among punctuality, fuel use and cost. Their contribution supports modelling JIT as a context-specific operating strategy rather than assigning one universal percentage saving to every Indonesian route.

Fuel switching also requires lifecycle assessment. Roux et al. [8] identify important methodological differences and transparency gaps in published marine-fuel LCAs, while Kanchiralla, Brynolf and Mjelde [9] compare environmental and economic implications of alternative marine fuels and propulsion pathways. Wind-assisted propulsion can reduce propulsion-engine loading in favourable conditions, but Vigna and Figari [10] show that propulsion-system matching and operating conditions influence performance.

Table 1. Verified scientific and regulatory basis for the GLS framework

Technology / Criterion	Traceable Reference	Supported Interpretation
JIT arrival / speed	Liu et al. (2026) [7]	Potential fuel and schedule optimisation; vessel and weather dependent.
Shore power / cold ironing	Abu Bakar et al. (2023) [6]; IEC/IEEE [12]	Displaces auxiliary engines at berth; requires shore and ship compatibility.
Alternative marine fuels	Roux et al. (2024) [8]; Kanchiralla et al. (2024) [9]	Evaluate well-to-wake impacts and supply-chain assumptions.
Wind-assisted propulsion	Vigna and Figari (2023) [10]	Potential engine-load reduction contingent on route and propulsion matching.
Operational emissions indicators	IMO MEPC.1/Circ.684 [11]; IMO CII [13]	EEOI and CII are distinct indicators with different accounting inputs.

3. Materials and Methodology

The study is a structured documentary and engineering-feasibility assessment, not a survey of measured vessel emissions. The source hierarchy is: (1) official IMO regulatory and indicator guidance; (2) BPS national transport publications; (3) the IEC/IEEE shore-connection specification; and (4) peer-reviewed literature whose titles, authorship and DOI can be traced to publisher or institutional pages. No unprovided vessel logbook, electricity invoice, emissions inventory or project financing record is assumed.

The analysis separates three evidence levels: reported official publication scope; conceptual or literature-supported technology mechanisms; and illustration-only calculations. BPS tables must be checked for consistent definitions, province coverage, domestic versus international routes, and the distinction between vessel calls, gross tonnage, and loaded or unloaded cargo [2]–[5].

The basic IMO Energy Efficiency Operational Indicator (EEOI) relates fuel-derived CO_2 to transport work [11]:

$$EEOI = \Sigma(FC_j \times CF_j) / (m_cargo \times D) \quad [t\ CO_2/(t \cdot NM)]$$

FC_j is the mass of fuel type j consumed at sea and in port; CF_j is the corresponding CO_2 mass-conversion factor; m_cargo is cargo mass; and D is nautical distance. For diesel/gas oil, IMO MEPC.1/Circ.684 specifies CF = 3.206 t CO_2/t fuel [11]. For an average over several voyages, the numerator and denominator must be accumulated over the relevant voyages; a simple arithmetic mean of voyage-level ratios is not the recommended aggregate measure [11].

Where shore electricity is used, the grid-related emissions should be recorded in a separate energy-system or well-to-wake comparison, rather than subtracted from the IMO fuel-based EEOI numerator. For a berth call, define E_baseline = FC_aux × CF_fuel and E_shore = kWh_shore × EF_grid / 1000, both in tonnes of CO_2 when EF_grid is expressed in kg CO_2/kWh. The net difference is ΔE = E_baseline − E_shore; it is positive only when the baseline auxiliary-generator emissions exceed electricity-related emissions. Grid factors must be documented for the applicable location, period and accounting boundary.

High-voltage shore connections are evaluated against IEC/IEEE 80005-1:2019, which specifies relevant components and safety interfaces for shore and ship electrical systems [12]. The study does not calculate CII ratings from EEOI values: IMO annual CII ratings depend on the ship category, reference lines, yearly required CII and attained operational indicator [13].

4. Results and Discussion

4.1 Official Data Coverage and Empirical Limitations

The four BPS publications relevant to the submitted study can be verified at the official publication portal [2]–[5]. They establish the availability of port activity measures over 2021–2024. However, the year-by-year cargo totals, ship-call aggregates, selected terminal unloading quantities and assumed port capacities in the initial manuscript were not independently verified against downloadable source tables in this audit. They are consequently excluded from quantitative findings rather than restated as authenticated statistics.

Table 2. Traceability of BPS statistical publications used in the study

Reference Year	Release Date	Publication Coverage Noted by BPS	Publication ID
2021	28 Nov 2022	33 provinces (excluding D.I. Yogyakarta)	06100.2263
2022	27 Nov 2023	33 provinces (excluding D.I. Yogyakarta)	06100.2361
2023	25 Nov 2024	36 provinces (excluding D.I. Yogyakarta and Papua Pegunungan)	06100.24059
2024	01 Dec 2025	36 provinces (excluding D.I. Yogyakarta and Papua Pegunungan)	06100.25048

This change in geographic coverage is a comparability issue when interpreting year-on-year growth. A port-level panel or a matched-province series should be reconstructed from original BPS tables before claiming a consistent 2021–2024 national trend. Moreover, port throughput and call counts should not be used as proxies for mean fleet EEOI because they do not contain ship fuel consumption and cargo-distance denominators.

4.2 Four-Layer Integrated GLS Architecture

Building on the evaluated technologies, an integrated architecture links ship machinery and controls with port-side electricity and carbon reporting. The arrangement is a proposed conceptual design by the authors; it is not described as an implemented or tested fleet-wide system.

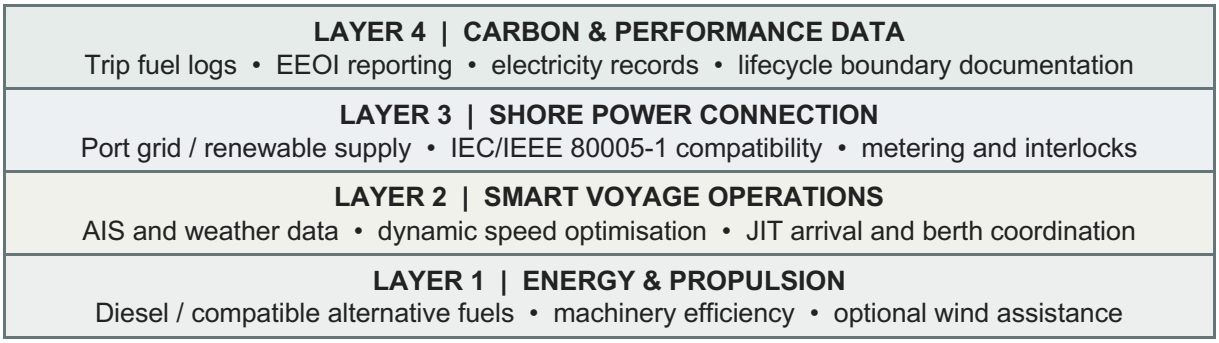


Figure 1. Proposed four-layer Green Logistic Ship–port architecture

The layers exchange time-stamped data, but equipment interoperability and cybersecurity must be tested at each port. The monitoring layer should retain calculation inputs and source metadata so that estimated reductions can be independently recomputed.

4.3 Illustrative Shore-Power Break-Even Analysis

An algebraic sensitivity check illustrates why an Indonesian grid emission factor must be confirmed before reporting the net CO_2 effect of cold ironing. Assume, solely for illustration, that a berthed ship would consume 1.0 t of marine gas oil (MGO) in its auxiliary generator. Using the IMO factor, baseline operational emissions equal 3.206 t CO_2 [11]. The break-even electricity emission factor is EF_grid* = 3,206 / kWh_shore, expressed in kg CO_2/kWh. Below that threshold shore power reduces operational CO_2 for the stated boundary; above it, the grid-related CO_2 is greater.

Table 3. Illustration only: shore-electricity intensity required to outperform 1.0 t MGO

Illustrative Shore Electricity	Baseline MGO CO_2	Break-Even Grid Factor	Interpretation
3,000 kWh	3.206 t	1.069 kg CO_2/kWh	Benefit if actual factor is lower
5,000 kWh	3.206 t	0.641 kg CO_2/kWh	Benefit if actual factor is lower
7,000 kWh	3.206 t	0.458 kg CO_2/kWh	Benefit if actual factor is lower

The figures in Table 3. are mathematically derived examples, not measurements from any Indonesian vessel or port. Shore-power infrastructure sizing requires simultaneous berth occupancy, design load per vessel, diversity factor, harmonics, transformer capacity, grid connection limits, and actual utilisation. Port cargo tonnage alone does not justify an MW estimate or payback period.

4.4 Technical and Financial Evidence Requirements

Table 4. Minimum datasets required before an empirical GLS claim

Target Indicator	Necessary Input	Appropriate Validation
Vessel EEOI	By-fuel tonnes consumed, cargo moved, nautical miles, voyage boundaries	Ship logs and IMO method [11]
Port CO_2 change	Auxiliary fuel displaced, shore kWh, defensible grid factor	Measured berth records and sensitivity cases
CII rating	Ship type, calendar-year fuel and activity, applicable CII reference	IMO CII criteria [13]
Capacity (MW)	Coincident berth loads, peak demand, diversity and power quality	Electrical engineering study [12]
CAPEX / OPEX / payback	Costed equipment scope, tariffs, maintenance, utilisation, discounting	Vendor quotations and independently audited financial model

These requirements delineate a feasible evidence pathway for the Indonesian context. A useful field study could start with a paired comparison of similar port calls before and after shore-connection use, using meter-verified electricity and onboard auxiliary consumption. For route optimisation, a voyage-level counterfactual should control for weather, cargo, route length and schedule constraints. For fuel switching, well-to-wake factors must reflect the actual production pathway and fuel specification [8], [9].

5. Conclusion

The traceable evidence supports the technical relevance of Green Logistic Ships implemented as a combined ship–port system. Published research establishes reasons to evaluate shore power, JIT speed optimisation, alternative fuels and wind-assisted propulsion, while IMO rules and IEC/IEEE standards supply the principal accounting and electrical-interface foundations. BPS Sea Transportation Statistics provides official context for Indonesian port activity, but port aggregates cannot alone demonstrate national fleet emissions, route-level fuel savings or financial returns.

Policy Implications

Priority steps for Indonesia include identifying vessels and berths with compatible electricity loads, gathering matched fuel and meter data, applying grid-aware lifecycle comparisons, and validating results against relevant IMO indicators. The originally submitted percentages for lifecycle emissions savings, fleet-average EEOI improvements and retrofit payback have not been retained as findings because their underlying calculations and measurement data were unavailable for independent verification. Future claims should state vessel types, baseline years, calculation boundaries, uncertainty and complete traceable sources.

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