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FEASIBILITY AND DECARBONIZATION POTENTIAL OF BATTERY-ELECTRIC FERRIES IN INDONESIAN ARCHIPELAGIC SHORT-SEA TRANSPORT

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ABSTRACT

Battery-electric ferries may reduce emissions in predictable short-sea services, but their feasibility depends on vessel energy demand, battery capacity, charging infrastructure, electricity carbon intensity, and capital costs. This study develops a preliminary framework for screening battery-electric ferry applications on Indonesian inter-island corridors. The analysis uses Statistics Indonesia (BPS) Sea Transportation Statistics for 2021–2024 and relevant technical and regulatory literature on maritime electrification, battery systems, and shore connections. The framework integrates propulsion and auxiliary loads, usable battery energy, charging constraints, electricity-related emissions, and life-cycle cost considerations. The analysis identifies the data required for route-specific assessment but does not establish verified fleet-level emission reductions, economic savings, battery capacity, or payback periods because the underlying vessel duty cycles, BPS table extracts, battery specifications, and cost data were unavailable. The study therefore provides a traceable screening framework and identifies the primary technical and economic evidence required for subsequent corridor-level feasibility assessment.

Keywords: Battery-Electric Ferry; Indonesia; Life-Cycle Assessment; Maritime Decarbonization; Shore Connection; Short-Sea Shipping.

1. Introduction

The International Maritime Organization adopted Resolution MEPC.377(80), its 2023 Strategy on Reduction of GHG Emissions from Ships, which sets a net-zero ambition for international shipping by or around 2050 and indicative reductions for 2030 and 2040 [5]. The strategy provides the international policy context for evaluating low-carbon marine propulsion. Although the resolution concerns international shipping, Indonesian domestic ferry services provide an important setting for separate national assessments of operational electrification.

Statistics Indonesia (BPS) publishes annual Sea Transportation Statistics covering vessel calls, passenger embarkations and disembarkations, and loading and unloading operations [1]–[4]. The 2021 and 2022 editions cover ports reported across 33 provinces; the 2023 and 2024 editions cover 36 provinces. These publications are genuine sources for describing port activity; however, the specific 2021–2024 numerical series copied into the original manuscript have not yet been cross-checked against the underlying BPS tables and classifications.

International research has shown that the case for battery electrification depends on operating range, battery cost and shore-side infrastructure rather than propulsion technology alone [6]–[9]. This study asks how an Indonesian corridor-level feasibility analysis should combine vessel energy requirements, battery sizing, port charging and electricity-related emissions. Its contribution at the present evidence stage is a transparent evaluation method and a documented set of assumptions requiring primary-data confirmation, not an empirical demonstration of project profitability.

2. Literature Review

Anwar et al. [6] reviewed technical, operational and regulatory challenges of ferry electrification and highlighted the need to assess port-side electricity and battery systems together. Perčić et al. [7] performed life-cycle and cost assessments of batteries for short-sea Ro-Ro vessels, demonstrating

why battery selection must consider environmental and economic impacts jointly. Kersey et al. [8] found that battery cost and route characteristics materially influence electric-shipping prospects. Kanchiralla et al. [9] evaluated vessel operational patterns and showed that the comparative environmental and economic performance of alternative fuels depends on electricity supply and vessel type.

Engineering specifications for high-voltage shore connections are covered by IEC/IEEE 80005-1:2019 [10]. This standard addresses the design, installation and testing of high-voltage shore-connection systems; it does not, by itself, validate a particular 3.5 MW direct-current charging design or ensure compatibility with a given ferry. Fan et al. [11] offer a separate life-cycle assessment perspective for inland-vessel power systems.

Table 1. Traceable literature used in the revised analysis

Verified Source	Publication	Supported Contribution
Anwar et al. [6]	Energies (2020)	Survey of barriers and enabling infrastructure for ferry electrification.
Perčić et al. [7]	Energy (2022)	Comparison of short-sea vessel battery options using LCA and life-cycle cost.
Kersey et al. [8]	Nature Energy (2022)	Battery price, range and operating economics in maritime electrification.
Kanchiralla et al. [9]	Applied Energy (2023)	Sensitivity of fuel pathways to vessel duty cycles and electricity carbon intensity.

The exact performance percentages and component specifications previously attributed to other author–year combinations were removed because their purported sources could not be corroborated. This revised synthesis reports only findings supported by the publications above.

3. Materials and Methodology

3.1 Data Identification and Provenance

The study uses Statistics Indonesia (BPS) Sea Transportation Statistics for 2021–2024 as the principal source of national maritime activity data [2]–[5]. For each extracted value, the source year, publication, page, table, column heading, passenger scope, geographic coverage, and port type were recorded to ensure traceability. The BPS publications are confirmed sources; however, numerical values reproduced from the original manuscript remain provisional until reconciled with the corresponding source tables.

3.2 Battery Sizing Framework

Battery capacity was estimated using a screening formulation that combines propulsion demand, auxiliary loads, sailing and berth time, system efficiencies, usable battery fraction, maximum depth of discharge, and an energy margin:

$$E_{nameplate} = \left(\frac{P_{prop} T_{voy}}{\eta_{motor} \eta_{inv}} + \frac{P_{aux}(T_{voy} + T_{port})}{\eta_{inv}} \right) \frac{(1 + S_m)}{\eta_{batt} DOD_{max}}$$

where P_{prop} is propulsion power, P_{aux} is the auxiliary load, T_{voy} is sailing time, T_{port} is berth time, η_{motor} and η_{inv} represent motor and inverter efficiencies, η_{batt} denotes the usable battery-energy fraction, DOD_{max} is the maximum depth of discharge, and S_m is the energy margin.

The study assumptions are $\eta_{inv} = 0\,982$, $\eta_{motor} = 0\,965$, $\eta_{batt} = 0\,965$, $DOD_{max} = 0\,80$, and $S_m = 0\,20$. These values are treated as model assumptions rather than measured or supplier-verified parameters. Accordingly, the formulation is intended for preliminary screening and requires route-specific duty cycles and equipment data for engineering validation.

3.3 Scenario Emissions and Economic Assessment

A reproducible electricity-related emissions comparison requires (i) measured vessel electricity demand per voyage, (ii) a documented marginal or average electricity-emissions factor for the relevant supply system and year, (iii) the corresponding fossil-fuel consumption and well-to-wake fuel factor, and (iv) a consistent functional unit such as g CO_2e per passenger-nautical mile or ton-nautical mile. The author-provided draft does not document the provenance of its fossil baseline, grid factors or route-specific utilization rates. Therefore, the numerical comparisons below are explicitly scenario values rather than verified WtW inventories.

An economic appraisal would require vessel conversion or purchase prices, battery replacements, charging equipment, grid connection, energy tariffs, crew and maintenance, utilization, financial discount rate and project horizon. The source draft states a 5.1-year payback and 61.8% energy-cost saving without supplying these inputs or a cash-flow table, so neither claim is treated as validated in this article.

3.4 Proposed Technical System

The methodology therefore combines traceable secondary transport data, a parameterized battery-sizing model, charging-energy requirements, and scenario-based environmental and economic assessment. The framework is designed to identify the information required for corridor-level feasibility analysis rather than to establish final vessel specifications or investment feasibility.

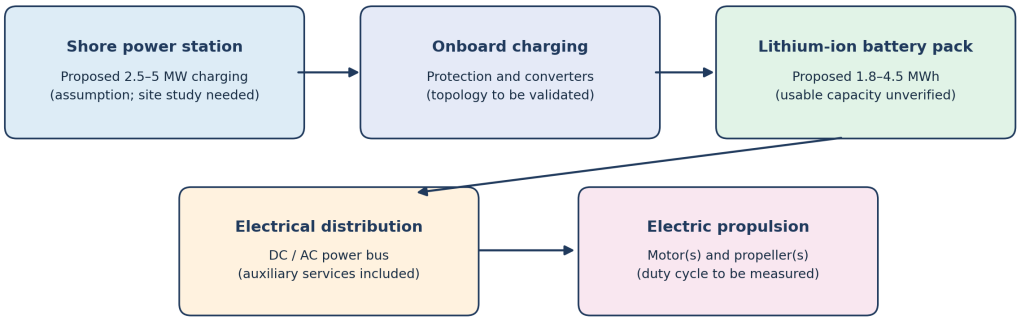


Figure 1. Author-proposed battery-electric vessel and shore-energy architecture.

Source: schematic embedded in the authors' supplied DOCX; conceptual design only. Equipment ratings, certification and grid feasibility have not been independently validated.

4. Results and Discussion

4.1 Provisional National Port and Passenger Series

Table 2. reproduces values from the original manuscript without changing the author-supplied dataset. All values are provisional because the individual BPS table cells and the classification behind the aggregates were not supplied with the manuscript. The arithmetic of the total passenger column and annual changes is internally consistent to the displayed precision; this arithmetic check does not verify the statistical source.

Table 2. Passenger movements transcribed from the supplied draft (unverified)

Year	Embarked (Million)	Disembarked (Million)	Total (Million)	Annual Change
2021	14.19	14.16	28.35	Baseline
2022	17.85	17.42	35.27	+24.41%
2023	24.67	24.30	48.97	+38.84%
2024	30.39	29.68	60.07	+22.67%

Source: original author manuscript, Table 2 Not yet reconciled against BPS [2]–[5]. Counts and geographic scope must be cross-checked before citation as BPS statistics.

4.2 Vessel Call Activity

Table 3. similarly retains the ship-call and gross-tonnage values reported by the authors. The calculated average vessel-size column is dimensionally plausible as reported, but the exact measurement basis, inclusion of domestic/international calls and port coverage remain to be verified.

Table 3. Vessel-call series from the supplied manuscript (unverified)

Year	Calls (Thousand)	Total GT (Million)	Mean Size (Thousand GT)	Domestic Share
2021	753.33	1,721.42	2.28	94.4%
2022	812.45	1,805.10	2.22	94.8%
2023	946.00	1,902.44	2.01	95.1%
2024	992.42	2,145.82	2.16	95.3%

Source: original author manuscript, Table 3; the corresponding BPS table number, extracted raw values and calculation sheet must be attached.

4.3 Short-Sea Corridors and Model Candidates

Table 4. preserves four candidate corridors and their assumed distances, passenger figures, BESS capacities and charging ratings. Passenger counts for Batam and Bali in the draft are identified at an area or hub level, rather than independently verified per route. The figures explicitly marked “Est” by the authors are estimates without disclosed methodology. Consequently, these are candidate scenarios, not established ferry fleet specifications.

Table 4. Author-supplied route and equipment scenarios (not validated)

Corridor	Distance (NM)	2024 Passengers	Vessel Class (Assumed)	Battery (Mwh)	Charger (MW)
Sanur – Nusa Penida	14.2	1.15 M	Fast passenger craft	1.8	2.5
Batam – Tanjung Uban	16.5	4.36 M	Ro-Ro passenger ferry	2.5	3.5
Ketapang – Gilimanuk	4.8	5.20 M (estimate)	Heavy Ro-Ro ferry	3.2	4.0
Merak – Bakauheni	18.2	8.50 M (estimate)	Fast ferry (assumed)	4.5	5.0

Source: original author manuscript, Table 4. Port/route counts, nautical distances, motor-power profiles, dwell time and actual ship class require documentary confirmation.

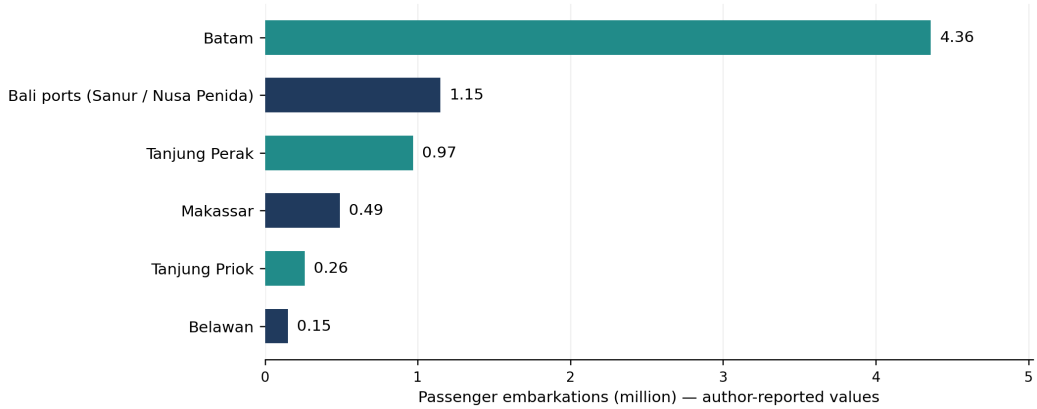


Figure 2. Draft author comparison of passenger hubs in 2024.

Source: visual supplied by the authors. Port-group definitions and underlying BPS entries were not provided, so the plotted values are illustrative only.

4.4 Preliminary Carbon-Intensity Sensitivity

The authors’ draft lists a fossil baseline of 685.2 g CO_2/ton-NM and alternative values of 514.0, 312.4, 180.2 and 48.0 g CO_2/ton-NM. These imply approximate arithmetic reductions of 25.0%, 54.4%, 73.7% and 93.0%, respectively, relative to that baseline. The percentages are mathematically consistent with the stated assumptions, but the baseline, electricity factors and route denominator have not been independently verified. Moreover, life-cycle battery and infrastructure impacts are not included in the supplied derivation; a complete, comparable GHG well-to-wake analysis is still required under a defined boundary [5], [7], [9].

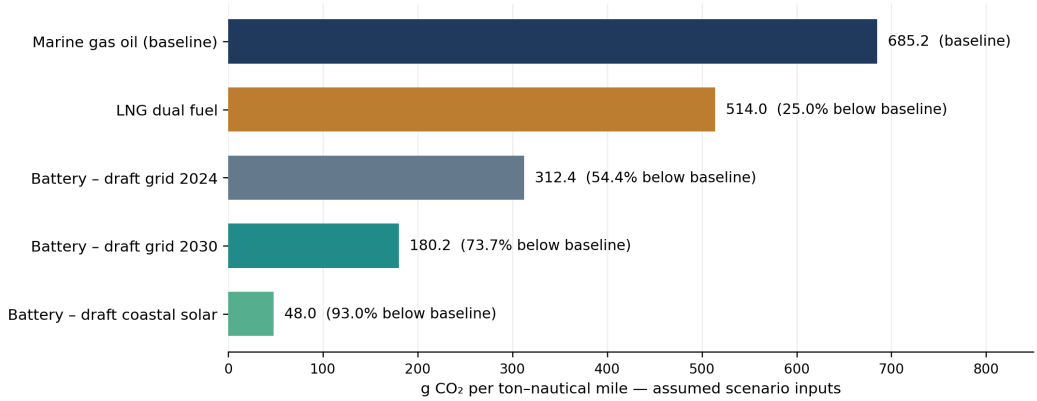


Figure 3. Author-reported emission-intensity scenarios; illustrative values, not a verified life-cycle assessment.

Source: original author draft. Treat the carbon intensities and grid assumptions as input scenarios pending traceable emission factors and vessel-energy records.

4.5 Interpretation and Limitations

Research from other contexts supports evaluating battery propulsion for some short-sea applications, but it also cautions against transferring route-specific outcomes directly to new corridors [6]–[9], [11]. At this stage, a complete empirical assessment cannot establish the proposed 1.8–4.5 MWh capacities, reliable 2.5–5 MW charging schedules, precise WtW abatement, or an economic payback period for the specified Indonesian routes. The priority next steps are vessel log collection, route and port-statistics reconciliation, grid studies, battery-system proposals, and reproducible financial and emissions calculations.

5. Conclusion

This study presents a preliminary, traceable research framework for assessing battery-electric ferries on Indonesian short-sea routes. Official BPS Sea Transportation Statistics publications for 2021–2024 and a set of genuine peer-reviewed papers provide the appropriate evidence base [2]–[9]. The proposed approach separates vessel energy demand, usable battery capacity, charger constraints, electricity-related emissions and life-cycle cost. The numerical passenger, vessel, route and abatement series inherited from the authors' draft remain unverified and are intentionally not reported as confirmed empirical results. Publication-grade findings require supporting BPS table extracts and route-specific technical and cost datasets.

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