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Green Port Management and Emission Reduction Strategies in Sea Transportation Operations

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Abstract. *Sea transportation management increasingly requires ports and training institutions to reconcile operational efficiency with emission reduction obligations arising from international and domestic decarbonization agendas. This paper examines green port management practices and emission reduction strategies as they apply to sea transportation operations, using the port and training environment of Politeknik Pelayaran Sulawesi Utara as a reflective case setting for the period April 2025 to January 2026. Drawing on institutional document review, field observation of cadet training and port-facing activities, and a synthesis of the sustainability and marine engineering literature, the paper identifies three interacting dimensions of green port management: sustainable ship design and operational innovation, shore-based emission control instruments such as shore power and differentiated port charges, and the institutional readiness of maritime education providers to embed green competencies in seafarer training. The discussion argues that emission reduction in archipelagic sea transportation cannot be achieved through vessel-level engineering measures alone; it depends on coordinated port infrastructure investment, tariff and regulatory instruments, and a training pipeline capable of producing engineers and officers fluent in green operational practice. The paper concludes with a management framework linking these three dimensions and identifies areas where Poltekpel Sulut and comparable maritime polytechnics can strengthen their contribution to national emission reduction targets.*

Keywords: *green port management, sea transportation, emission reduction, shore power, marine engineering, maritime education*

1. Introduction

The management of sea transportation in an archipelagic state such as Indonesia sits at the intersection of two pressures that are not always easy to reconcile. On one hand, domestic shipping and port operations must expand to keep pace with inter-island trade, passenger mobility, and the logistics demands of a growing economy. On the other hand, international and national decarbonization commitments require that this expansion occur with a shrinking carbon and emissions footprint. Ports, as the fixed nodes where ships, cargo, energy, and shore infrastructure meet, are a natural point of intervention for emission reduction strategies, because measures implemented at the port level can influence the behaviour of every vessel that calls, regardless of flag or ownership.

Green port management refers to the set of operational, infrastructural, and policy practices through which a port authority or port-adjacent institution reduces the environmental footprint of shipping and cargo-handling activity while maintaining or improving throughput and service levels. The concept has matured considerably in the sustainability literature, moving from an early focus on waste and effluent control toward a broader agenda that includes shore power provision, differentiated emission-based

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charging, renewable energy integration, and the digitalization of port operations (Zhou et al., 2024; Qi et al., 2022). For maritime education and training institutions such as Politeknik Pelayaran Sulawesi Utara (Poltekpel Sulut), green port management is not only an operational concern but also a curriculum concern, because the cadets and engineering trainees who pass through such institutions will staff the vessels and shore facilities where these practices are implemented.

This paper uses Poltekpel Sulut as a reflective case setting for the period April 2025 to January 2026 to examine how green port management and emission reduction strategies manifest in a sea transportation training environment. The paper does not present a controlled empirical trial; rather, it synthesizes institutional document review, field observation of cadet training activity and port-facing operations during the stated period, and the sustainability and marine engineering literature available through the accompanying Scopus reference library, to build a management-oriented account of what green port practice looks like at the level of a maritime polytechnic and its immediate port environment. The objective is threefold: first, to characterize the sustainable ship design and operational innovation dimension of green port management; second, to examine shore-based emission control instruments, particularly shore power and differentiated port charges; and third, to assess the institutional readiness of a maritime training provider to embed these practices into seafarer and engineer preparation.

2. Literature Review

2.1 Sustainable Ship Design and Operational Innovation

Stakeholder-based studies of marine engineering practice consistently identify ship design and onboard operational choices as the first layer of emission reduction available to sea transportation operators. Winarno et al. (2025) report that stakeholders across shipowning, classification, and training institutions view sustainable ship design less as a single retrofit decision and more as a continuous set of operational adjustments, ranging from hull and propeller maintenance to voyage optimization, that collectively reduce fuel consumption and emissions without requiring wholesale fleet replacement. This operational framing is important for a country such as Indonesia, where much of the domestic fleet is older and where wholesale newbuild replacement is not a near-term option for most operators.

Complementary work by Simanjuntak et al. (2025) on green engineering innovation extends this argument to the training pipeline, noting that engineering innovation in sea transportation is most effective when paired with crew competency in

operating and maintaining the relevant systems. In other words, the presence of more efficient engines or hull coatings does not translate automatically into emission reduction; it depends on engine-room and deck personnel who understand why particular operational parameters matter and who are trained to sustain them across a voyage cycle. This positions maritime polytechnics not as passive recipients of green technology but as active participants in whether that technology delivers its intended environmental performance.

2.2 Shore-Based Emission Control: Shore Power and Port Charging Instruments

A second and distinct layer of green port management operates at the shore side rather than onboard the vessel. Qi et al. (2022) model the shore power deployment problem, showing that the environmental benefit of shore power, in which a berthed vessel draws electricity from the shore grid instead of running auxiliary engines, depends heavily on deployment sequencing and the electrical capacity of the port. Ports that deploy shore power without matching grid capacity or without a critical mass of compatible vessels tend to see the facility underused, which limits its emission reduction potential relative to its capital cost. This finding is directly relevant to smaller regional ports, including those serving Sulawesi Utara, where investment in shore power needs to be sequenced against realistic vessel traffic and electrical infrastructure constraints rather than adopted as a blanket policy.

Pricing and regulatory instruments form a related mechanism. Pian et al. (2020) examine global emission taxes alongside port privatization policies and find that the emission-reduction effect of a port charge depends on how the charge interacts with the port's ownership and competitive structure; a well-designed emission-differentiated tariff can shift vessel behaviour toward cleaner operation, but only where the port has sufficient market power or coordination with neighbouring ports to make the charge binding rather than easily avoided through rerouting. Zhou et al. (2024) similarly find, in an evaluation of green port policy, that policy effectiveness is closely tied to the credibility and consistency of enforcement rather than the stringency of the policy on paper. For Indonesian sea transportation management, where regulatory capacity varies considerably between major hub ports and smaller regional ports, this literature suggests that green charging instruments are more likely to succeed where they are matched to the port's actual capacity to monitor and enforce compliance.

2.3 Institutional and Educational Dimensions of Green Port Management

The third dimension concerns the institutions that prepare the workforce operating within green port systems. Barasa et al. (2025) examine the impact of educational

programs on green practices in cargo handling at ports and find that structured training measurably changes how cadets and trainees describe and prioritize environmentally sound handling procedures, suggesting that green competency is teachable rather than incidental to workplace exposure. Sijabat and Simanjuntak (2025) extend this to the concept of the smart eco-port, arguing that collaboration and information sharing between port operators, shipping lines, and training institutions is a precondition for green practices to be adopted consistently rather than in isolated pockets. Cahyadi et al. (2025) reinforce this institutional view, reporting that leadership development within maritime vocational schools is a meaningful lever for embedding sustainable port and shipping practices, because leadership commitment shapes how consistently green procedures are reinforced in day-to-day training. Related work on renewable-energy-integrated smart ports (Winarno et al., 2025) and on the integration of maritime energy networks into coastal development planning (Simanjuntak et al., 2025) situates the individual training institution within a wider smart port ecosystem, implying that a polytechnic's contribution to emission reduction is best understood as one node within a larger regional infrastructure and policy system rather than as a self-contained achievement.

3. Methodology

This paper adopts a qualitative, case-based management analysis rather than a quantitative empirical design. The case setting is Politeknik Pelayaran Sulawesi Utara and its associated port-facing training operations, observed over the period April 2025 to January 2026. Three sources inform the analysis. First, institutional documentation relating to cadet training schedules, engineering workshop activity, and port-facing practical modules was reviewed to identify where green port practices are already embedded in the curriculum and where they are absent. Second, field observation of training activity during the stated period was used to describe, in qualitative terms, how sustainability-related procedures were discussed and practiced in engine-room and deck training contexts; these observations are reported descriptively and are not presented as statistically representative survey findings. Third, the sustainability and marine engineering literature drawn from the accompanying Scopus reference library was used to interpret these institutional observations against a wider body of evidence on green port management in comparable maritime settings internationally.

The analytic approach follows the three-dimension structure established in the literature review: sustainable ship design and operational innovation, shore-based emission control instruments, and institutional readiness. For each dimension, the paper asks what

the literature indicates as good practice, what was observed or documented at Poltekpel Sulut during the study period, and what gap or opportunity this comparison reveals. This approach is consistent with case-based management research in maritime education, where the objective is to generate a structured, literature-grounded account of institutional practice rather than to test a formal hypothesis.

4. Results and Discussion

4.1 Ship Design and Operational Practice in the Training Environment

Engineering workshop and simulator-based training at Poltekpel Sulut during the observed period placed consistent emphasis on maintenance discipline, hull and propeller condition, and voyage-planning practices that reduce fuel consumption, echoing the operational framing described by Winarno et al. (2025). This is a reasonable institutional response to the reality that most vessels the graduating cadets will serve on are existing tonnage rather than newbuild green ships; the training emphasis on operational discipline over design retrofit reflects the fleet composition of Indonesian domestic shipping more broadly. Consistent with Simanjuntak et al. (2025), the more effective components of this training appeared to be those that paired a technical explanation of why a procedure reduces emissions with hands-on repetition, rather than treating environmental performance as a compliance checklist to be memorized.

A gap identified through document review is that formal integration of emission-tracking or fuel-consumption monitoring exercises into cadet coursework remains limited compared to the monitoring practices described in the marine engineering literature. Strengthening this component would give future officers direct experience with the kind of operational data that underpins fleet-level emission reduction claims, rather than relying solely on procedural instruction.

4.2 Shore-Side Instruments: Applicability of Shore Power and Emission Charging

Poltekpel Sulut 's port-facing operations during the study period did not include shore power infrastructure, which is consistent with the broader pattern described by Qi et al. (2022): shore power deployment is capital-intensive and depends on grid capacity and vessel compatibility that smaller regional ports, including training-oriented facilities, are unlikely to secure independently. This suggests that emission reduction contribution from a training-port context such as Poltekpel Sulut is more realistically achieved through the operational-training pathway discussed above than through shore infrastructure investment, at least in the near term. Where shore power investment does occur in the wider Sulawesi Utara port system, the sequencing logic identified by Qi et al. (2022)

implies that it should be planned around vessel traffic patterns at the specific berths concerned rather than applied uniformly across the port estate.

On charging instruments, the absence of a differentiated emission-based tariff at the regional level observed during the study period aligns with the pattern described by Pian et al. (2020) and Zhou et al. (2024), in which smaller or less centrally coordinated ports tend to lag behind major hub ports in adopting environmentally differentiated pricing. For sea transportation management purposes, this indicates an opportunity rather than a criticism: regional maritime authorities and training institutions are positioned to advocate for phased introduction of such instruments once monitoring capacity, which training institutions can help build through applied research and cadet-supported data collection, is established.

4.3 Institutional Readiness and the Role of a Maritime Polytechnic

The clearest area of documented strength during the observed period was institutional engagement with green competency training, consistent with Barasa et al. (2025) and Cahyadi et al. (2025). Poltekpel Sulut 's training activity showed evidence of leadership attention to sustainability themes within vocational programming, and cadet-facing modules referenced green cargo-handling and port-collaboration concepts consistent with the smart eco-port framing advanced by Sijabat and Simanjuntak (2025). This positions the institution as a credible contributor to the wider ecosystem described by Winarno et al. (2025) and Simanjuntak et al. (2025), in which individual training providers function as nodes supplying competent personnel into a regional smart port and maritime energy network, rather than as isolated emission-reduction actors.

Taken together, the three dimensions suggest a layered management framework for institutions in Poltekpel Sulut 's position: (1) prioritize operational training that builds fuel- and emission-conscious habits in cadets, since this is the most directly controllable lever; (2) treat shore infrastructure investment such as shore power as a medium-term, traffic-sequenced regional planning matter rather than an institution-level responsibility; and (3) use institutional and leadership capacity to advocate for, and prepare cadets to operate within, future differentiated charging and monitoring regimes as regional port governance matures.

5. Conclusion

Green port management in sea transportation operates across three interacting layers: onboard ship design and operational practice, shore-based infrastructure and pricing instruments, and the institutional readiness of the training providers who prepare

the workforce operating within the system. The case setting of Politeknik Pelayaran Sulawesi Utara over April 2025 to January 2026 indicates that the most immediately controllable and best-supported contribution a maritime polytechnic can make is at the operational-training layer, reinforced by leadership commitment to embedding sustainability content in cadet programming. Shore-side instruments such as shore power and emission-differentiated charging remain constrained by capital and regulatory capacity at the regional level and are better understood as medium-term regional planning objectives that training institutions can support through applied research and advocacy rather than direct investment. Future work could usefully track fuel-consumption and emissions data from cadet training vessels over successive cohorts to build a locally grounded evidence base for the operational-training claims advanced here.

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