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Decarbonization Strategy and Sustainable Competitive Advantage: Multi-Criteria Analysis and Transformation Roadmap for PT. SET

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ABSTRACT

***Objectives**: This study aims to formulate an effective decarbonization strategy and roadmap for PT. SET in responding to global regulatory pressures, specifically related to reducing the Carbon Intensity Indicator (CII) for its fleet. The research focus is to identify the most feasible strategic options to improve the CII Rating to level B within 2-3 years.*
***Methodology**: The research uses an explanatory sequential mixed methods approach with a single case study design. Data was collected through in-depth interviews, discussions, Focus Group Discussions (FGD) with management, and documentation studies. Analysis was conducted sequentially using the PESTEL framework, Porter's Five Forces, SWOT, Gap Analysis, Fishbone Diagram, and Multi-Criteria Decision Analysis (MCDA) to evaluate decarbonization solution options.*
***Finding**: The research results indicate that two of SET's four main vessels (Sinar MDLK and Sinar MSL) are at risk of reaching CII Rating E by 2025. The MCDA analysis ranked Voyage Optimization & Voyage Management System (VMS) as the best option (score 4.80) due to its direct impact on fuel savings (10–20%), fast payback period (<1 year), and its function as a digital foundation for long-term transformation.*
***Conclusion**: This research concludes that PT. SET faces multi-dimensional strategic challenges in decarbonization implementation. Based on the MCDA analysis, priority strategic recommendations include implementation of Voyage Optimization & VMS as the digital foundation, Exit Strategy for old vessels that are economically unfeasible, and acquisition of second-hand vessels that are already digitalized and have CII Rating A/B. The 2026–2030 decarbonization roadmap is designed in five phases not only to achieve the target CII Rating B by 2028 and ensure compliance but further to transform regulatory pressure into a foundation for sustainable competitive advantage, with digital transformation as its main driver.*

***Keywords**: Decarbonization; CII Rating; Sustainable Competitive Advantage; MCDA; VMS.*

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INTRODUCTION

Decarbonization of the maritime sector has become an urgent global agenda, driven by International Maritime Organization (IMO) regulations such as the Carbon Intensity Indicator (CII) and the Energy Efficiency Existing Ship Index (EEXI). These regulations are a response to the shipping sector's contribution to global greenhouse gas emissions, estimated to reach 2-

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3% of total global emissions (IMO, 2021). PT. SET, as a national shipping company, faces operational and reputational pressure due to the declining CII performance of its fleet. Two of its main vessels, Sinar MDLK and Sinar MSL, are projected to reach CII Rating E in 2025, which could lead to restrictions on international operations, reduced revenue, and damage to the company's image.

This research stems from the gap between the CII performance of SET's fleet and regulatory and market demands. Previous studies have extensively discussed decarbonization technologies but are still limited in applying integrated strategic analysis frameworks for the context of national shipping companies with aging fleets. Therefore, this research is designed to: (1) analyse the root causes of declining CII, (2) evaluate decarbonization solution options using a multi-criteria approach, and (3) formulate a feasible implementation roadmap for PT. SET. This research provides practical contributions for PT. SET's management in strategic decision-making and academic contributions to the development of strategic management science in the context of decarbonizing Indonesia's maritime industry.

LITERATURE REVIEW

Global Maritime Decarbonization Regulations

The IMO has set ambitious targets to reduce carbon intensity by 40% by 2030 and cut total GHG emissions by 50% by 2050 compared to 2008 levels (IMO, 2023). Key instruments include the Carbon Intensity Indicator (CII), Energy Efficiency Existing Ship Index (EEXI), and the EU Emissions Trading System (ETS). CII performance is a critical indicator for the operational viability of vessels internationally, with ratings from A (very efficient) to E (very inefficient).

Decarbonization Technologies and Strategies

Previous studies showed that there is no single solution for maritime decarbonization. An effective approach involves a combination of:

- Energy-Efficient Technologies: such as Propeller Boss Cap Fins (PBCF), air lubrication systems, and waste heat recovery systems (Bouman et al., 2017; Hansen et al.,2011; Kimura et al., 2018).
- Operational Optimization: including slow steaming, voyage optimization, and hull maintenance (Psaraftis & Kontovas, 2021).
- Alternative Fuel Transition: biofuels, green methanol, ammonia, and hydrogen (Balcombe et al., 2019; Robalo-Cabrera et al., 2025).

Research Frameworks

PT. SET is a shipping company whose primary assets are vessels. Among the company's assets, vessels have the most significant impact on carbon emissions. The assets of PT. SET that contribute to emissions are vessels, vehicles, and offices. For a shipping company like SET, the asset contributing the most to carbon emissions is the vessel, accounting for 98% of the total. Therefore, this research will focus on vessels as the company's main asset and their CII Rating, as they are the largest contributors to emissions and will affect the company's continuity and sustainability.

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With the International Maritime Organization (IMO) implementing international shipping requirements for decarbonization according to a phased timeline, the IMO mandates that vessels with a gross tonnage of ≥ 5,000 GT must maintain a minimum CII Rating of C. Currently, PT. SET operates 4 vessels meeting this size requirement. Thus, the company must comply with this CII Rating requirement to ensure the vessels remain eligible for international operation, maintain the company's reputation, and meet customer demands.

To ensure the company's ability to continue operating its vessels while maintaining a minimum CII Rating of C, several solution options are required, including:

1. Optimal vessel operations (Bureau Veritas, 2012; Du, Y et al., 2023)
2. Energy efficient vessel technology, including the installation of Energy-Saving Devices (Scarbrough, 2022)
3. The use of low-carbon or carbon-free fuels (Lindstad et.al,2021; Shi et.al, 2023; Mallouppas et al., 2021; Manias et al., 2024)

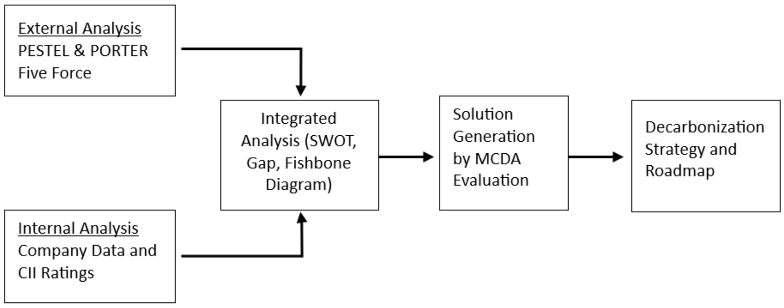
The solution options chosen by the company will heavily depend on current vessel conditions, vessel age, planned shipping routes, fuel availability, human resource capabilities, and financial capacity to support decarbonization policies (Faltinsen, 2019; Rehmatulla & Smith, 2015; Roar et al., 2018; Tran et al., 2023; Dong et al., 2022; Pereda et al., 2025). It is not easy for a shipping company to make the right choice, considering the company's strengths and limitations in formulating its strategy in this era of decarbonization. Therefore, a thorough and precise study tailored to the company's business is necessary. Determining the optimal decarbonization strategy for a shipping company is a complex challenge, given the diverse range of technology and alternative fuel options, each with trade-offs in cost and varying levels of technological maturity (Balcombe et al., 2019; Cullinane & Yang, 2022). This situation requires an in-depth analysis that considers the company's internal strengths and constraints, such as the technical condition of the fleet and human resource competency (Bouman et al., 2017; Dewana & Godina, 2022), as well as the dynamic regulatory landscape (IMO, 2023). Consequently, a one-size-fits-all approach is no longer viable. A specific study customized to each company's business model has become imperative (DNV, 2024; Psaraftis & Kontovas, 2021).

This research integrates several analysis frameworks:

- PESTEL & Porter's Five Forces for external environment analysis.
- SWOT Analysis for strategic positioning mapping.
- Gap Analysis & Fishbone Diagram for gap diagnosis and root cause analysis.
- Multi-Criteria Decision Analysis (MCDA) for objective evaluation of solution options.

Based on the explanation above, the conceptual framework used in conducting this research is described Figure 1.

Figure 1. Conceptual Framework for Decarbonization Strategy Development



The conceptual framework (Figure 1) guides the strategic analysis, while the methodological details of each step are elaborated in the Method section.

Research Gap
Previous studies have extensively discussed technical aspects of decarbonization but are still limited in applying integrated strategic analysis frameworks for the context of national shipping companies with aging fleets. This research fills that gap by integrating various strategic analysis tools within the specific context of an Indonesian shipping company.

METHOD

Research Approach
This research uses an explanatory sequential mixed methods approach with a single case study design at PT. SET. This approach was chosen because it allows the collection of quantitative data to identify patterns and trends, followed by qualitative data collection to understand the context and meaning behind those patterns.

Population and Sample
The research population includes four chemical tanker vessels of 8K-12K DWT with eight key informants from the directorate to managerial levels.

Data Collection Techniques
1. Primary Data:
   - In-depth interviews and discussions with director and managers.
   - Focus Group Discussion (FGD) with participants from various divisions.
   - Participatory observation in the decision-making process.
2. Secondary Data:
   - Company operational reports (2023-2025).
   - Engineering and maintenance documents.
   - Company profile and internal policies.
   - Literature studies and related regulations.

Data Analysis Techniques
Analysis was conducted sequentially:
1. Quantitative Descriptive Analysis: Calculation of CII Rating, fuel consumption, and performance projections.
2. Qualitative Analysis: Interpretation of interviews and FGD using a thematic approach.
3. Integrated Analysis:

- PESTEL & Porter's Five Forces for external environment scanning.
- SWOT Analysis for internal-external mapping.
- Gap Analysis for measuring performance gaps.
- Fishbone Diagram for identifying root causes.
- Multi-Criteria Decision Analysis (MCDA) with a weighting method for evaluating solution options.

MCDA Procedure
The MCDA process was carried out through the following stages:
1. Identification of evaluation criteria (Economic, Technical, Risk, Strategic).
2. Determination of criterion weights through FGD with management.
3. Assessment of solution options using a 1-5 Likert scale.
4. Calculation of weighted scores and option ranking.

Validity and Reliability
1. Data Triangulation: Comparing results from interviews, documents, and observations.
2. Member Check: Verification of data interpretation with key informants.

Quantitative Data Reliability: Cross-checking operational data from various sources.

RESULTS AND DISCUSSION

Results
CII Performance and Gap Analysis
Fleet CII Performance Profile: 2023–2025 CII Rating data shows significant polarization in fleet performance, as seen in Table 1.

Table 1. Comparison of SET Fleet CII Rating (2023–2025)

Vessel Name	Year Built	Age (Years)	Power/DWT Ratio	CII 2023	CII 2024	CII 2025 (Projection)
Sinar AGR	2006	19	0,395	C	C	B
Sinar BSN	2006	19	0,395	D	D	B
Sinar MDLK	2005	20	0,442	B	D	E
Sinar MSL	2003	22	0,442	D	C	E

Source: Internal Data of PT. SET, 2025

Performance Gap
There is a significant gap between actual performance and the target of CII Rating B by 2028:
- Sinar AGR & Sinar BSN: show a positive trend with projections to reach Rating B by 2025.
- Sinar MDLK & Sinar MSL: show a critical trend with projections to reach Rating E by 2025.

This gap is caused by a combination of factors:

- Design Factor: High power/DWT ratio (0.442 kW/ton vs 0.395 kW/ton) causing Sinar MDLK & Sinar MSL to be approximately 11% more fuel-intensive than Sinar BSN & Sinar AGR.
- Operational Factor: Unstable spot charter patterns cause difficulties in scheduling vessels and optimizing voyages.
- Technological Factor: Lack of a real-time monitoring system for vessel position, weather conditions, and fuel consumption, making it difficult for the company to evaluate fuel consumption efficiency in real-time and intervene operationally during voyages.
- Management Factor: Limited budget for green investment.

SWOT Analysis: This analysis was used to identify relevant company Strengths, Weaknesses, Opportunities, and Threats. The SWOT analysis results are as follows:

Strengths
1. Deep operational experience in Southeast Asian routes.
2. Ownership of detailed and measurable operational data.
3. Organizational flexibility in decision-making.
4. Technical capability in operating chemical tankers.

Weaknesses
1. Aging fleet (average 20 years) with low energy efficiency.
2. Low level of fleet digitalization.
3. Limited capital for major investments.
4. Two vessels with CII Rating D/E damaging reputation.

Opportunities
1. Second-hand vessel market providing affordable modernization options.
2. Access to green financing for green technology investments.
3. Increasingly affordable digital technologies (VMS & FMS).
4. Market demand for sustainable logistics services.

Threats
1. High volatility of fuel prices.
2. Competition from operators with more efficient fleets.
3. Increasingly stringent decarbonization regulations.
4. Widening competitive gap.

Fishbone Diagram Analysis: The Fishbone analysis identified four main categories (Human, Method, Vessel, Management) through FGD with managers, finding the causes of low CII Rating as follows:
1. **Human**: Lack of efficient operation training, operational culture not yet focused on carbon emissions.
2. **Method**: Non-optimal speed and routes, absence of a real-time monitoring system.
3. **Vessel**: Old and inefficient vessel design, conventional propulsion technology.
4. **Management**: Slow adoption of technology, limited green investment budget.

Each cause of low CII Rating was addressed with solution options, including voyage optimization, installation of Voyage Management System (VMS) for real-time monitoring,

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installation of a Fuel Monitoring System (FMS), installation of energy-saving devices (PBCF), and the use of biofuels. To determine the priority solution option, analysis was conducted using MCDA.

Multi-Criteria Decision Analysis (MCDA)

Evaluation Criteria and Weights: The selection and structuring of the evaluation criteria were informed by established multi-criteria decision-making frameworks and prior studies in technology assessment (Julia et al. (2019); Saaty, 2008; Purwanto et al., 2017). Subsequently, through a focused group discussion (FGD) with the company's managers, four primary criteria were finalized and assigned the following priority weights:

- **Economic (30%):** Considering CAPEX, Payback Period, and Net Present Value (NPV).
- **Technical (40%):** Emphasizing CII Impact, Implementation Complexity, and System Downtime.
- **Risk (20%):** Covering Technology Maturity, Market Acceptance, and Regulatory Compliance.
- **Strategic (10%):** Pertaining to alignment with the company's long-term decarbonization roadmap.

This resultant weighting scheme, dominated by technical and economic factors, underscores the company's immediate strategic posture of prioritizing regulatory compliance and financial viability—a common theme among shipping companies navigating the energy transition (Caprace et al., 2025; DNV, 2024).

Solution Option Evaluation Results: The calculation results using MCDA to determine solution option priorities can be seen in Table 2.

Table 2. MCDA Results for Decarbonization Solution Options

Solution Option	Economy Score	Technical Score	Risk Score	Strategic Score	Total Score	Rank
Voyage Optimization + VMS	1,50	1,88	0,92	0,50	4,80	1
Fuel Monitoring System (FMS)	1,11	1,60	0,88	0,30	3,89	2
Biofuel	0,39	1,48	0,60	0,40	2,87	3
Propeller Boss Cap Fin	0,42	1,12	0,82	0,20	2,56	4

Note: Total weight = 100%; maximum score = 5.00 Source: Author

Based on Table 2 above, the main priority option is Voyage Optimization + VMS with a score of 4.80, representing a low-cost solution with significant impacts on fuel savings and emission reductions. This is followed by the installation of a Fuel Monitoring System as a tool

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to monitor fuel consumption and as data for evaluating vessel and machinery performance. The use of biofuels, while directly impacting CO_2 reduction by about 22%, requires additional expensive fuel costs of around 30% - 80%. The last option is the installation of a Propeller Boss Cap Fin, which can be done during dry docking; installing it outside of dry docking would incur high downtime costs.

Sensitivity Analysis: Sensitivity analysis was conducted with three alternative scenarios to determine if the main solution option changes due to a shift in the company's focus.

1. **Financial Focus Scenario**: Voyage Optimization + VMS remains rank 1 (score 4.83).
2. **Risk Focus Scenario**: Voyage Optimization + VMS remains rank 1 (score 4.78).
3. **Technical Focus Scenario**: Voyage Optimization + VMS remains rank 1 (score 4.82).

Based on the sensitivity analysis, the Voyage Optimization + VMS solution consistently ranks first.

Synthesis of Preliminary Findings

The research results indicate that digital transformation through VMS is the most feasible strategy for PT. SET. The MCDA results are consistent with the findings from SWOT and Gap Analysis. The weakness of low digitalization (W2) and the threat of competition (T2) can be directly addressed by VMS implementation. Expensive retrofit options (PBCF, Biofuel) are not feasible for old vessels due to long payback periods and limited remaining economic life. Digitalization through VMS is not only a technical solution but also a strategic enabler that opens opportunities for green financing, enhances competitiveness, and meets stakeholder demands for emission transparency. The proposed decarbonization roadmap integrates a phased approach: short-term stabilization (VMS), mid-term fleet renewal (acquisition of second-hand vessels), and long-term fuel transition (biofuel/ammonia study).

Discussion

Interpretation of MCDA Weighting as Strategic Diagnosis

Beyond merely a ranking tool, the MCDA weighting structure (Technical: 40%, Economic: 30%, Risk: 20%, Strategic: 10%) derived from the FGD reflects PT. SET's profound strategic priorities in responding to decarbonization pressure. The dominance of the technical criterion signals a survival mode triggered by the imperative of regulatory compliance. Meanwhile, the significant economic weight mirrors the real financial constraints (capital constraint) faced by the company. This configuration explains why digital-based and operational optimization solutions (VMS) excel, as they are most aligned with the company's current 'compliance-first, cost-saving-second' priority logic. However, the relatively low strategic weight serves as a crucial note for strategy evaluation in the subsequent phases, indicating a potential short-term focus that must be consciously elevated as the company moves from survival to establishing a sustainable competitive advantage.

Synthesis of Findings and Strategic Alignment

Building on this interpretation, the top-ranked solution, Voyage Optimization and VMS, directly addresses the critical technical weakness (W2: Low fleet digitalization) and the immediate threat (T2: Regulatory stringency and competition from efficient fleets) identified in the SWOT analysis. This synergy between the analytical frameworks confirms that VMS is not just an isolated technical fix but a coherent strategic response to the most pressing challenges. Furthermore, the solution capitalizes on key opportunities (O3: Affordable digital technologies) to mitigate a core weakness. The gap analysis, which highlighted the risk of CII Rating E for two vessels, is precisely closed by the operational efficiency gains (10-20% fuel savings) promised by VMS. Therefore, the MCDA outcome validates and quantifies the strategic direction implied by the earlier qualitative analyses. The high score of VMS across the dominant economic and technical criteria demonstrates its role as a foundational digital capability. This capability does more than ensure compliance; it creates a data-driven platform for continuous improvement, enabling the company to transform regulatory pressure into a source of operational excellence and informed decision-making for the upcoming fleet renewal phases outlined in the roadmap.

Theoretical Implications: This research contributes to developing an integrated strategic analysis model for maritime industry decarbonization. The PESTEL framework provided the macro-environmental context, while Porter's Five Forces illuminated the competitive industry pressures that make decarbonization a strategic imperative beyond mere compliance. SWOT Analysis mapped the internal and external strategic positioning, and Gap Analysis & Fishbone Diagram diagnosed the root causes of performance shortfalls. Finally, Multi-Criteria Decision Analysis (MCDA) offered a systematic, weighted evaluation of solution options. The integration of these complementary frameworks provides a holistic, multi-layered approach applicable to similar contexts in asset-heavy, regulation-driven industries.

Practical Implications

- For SET: Implementation of VMS as the foundation for digital transformation. VMS adoption not only improves operational efficiency but can also build sustainable competitive advantage by creating valuable, rare, and difficult-to-imitate data-based capabilities in the short term.
- For the Industry: An MCDA-based model for evaluating decarbonization options.
- For Regulators: Information on the challenges of regulation implementation for national shipping companies.

Limitations: Research limitations include a scope limited to 4 vessels and a data horizon of 2023-2025.

CONCLUSION

Main Conclusions: This research concludes that PT. SET faces multi-dimensional strategic challenges in decarbonization implementation. Two main vessels (Sinar MDLK and Sinar MSL) are at risk of reaching CII Rating E by 2025, which could threaten the continuity of international operations.

Strategic Recommendations: Based on the MCDA analysis, priority recommendations are as follows.

1. Implementation of Voyage Optimization & VMS as the digital foundation.
2. Exit Strategy for old vessels that are economically unfeasible.
3. Acquisition of Second-hand vessels that are already digitalized and have CII Rating A/B.

4. Decarbonization Roadmap 2026-2030 in five implementation phases:

Phase 1 (2026): Critical Stabilization & Digital Foundation (VMS & FMS)
Phase 2 (2027): Initial Vessel Renewal & Data-Driven Decisions
Phase 3 (2028): Consolidation & Performance Enhancement
Phase 4 (2029): Efficiency Acceleration & Alternative Fuel Exploration
Phase 5 (2030): Long-Term Strategy & Green Leadership

Managerial Implications: Implementing the recommendations requires the following:
- Allocation of strategic budget for VMS and FMS digitalization installation.
- Restructuring of data-based operational processes.
- Development of human resource competencies in VMS and FMS digital technologies.
- Formation of a cross-functional team to monitor strategy implementation and the Decarbonization Roadmap.

Research Contributions: This research provides dual contributions:
- Strategic Contribution: Presents a framework for converting decarbonization pressure into a source of competitive advantage through digital transformation and selective fleet renewal.
- Practical Contribution: Concrete implementation roadmap for PT. SET.
- Academic Contribution: Integrated strategic analysis model for maritime decarbonization.

Future Research Directions: Future research can focus on:
- Techno-economic study of alternative fuels in Southeast Asia.
- Analysis of the impact of carbon pricing mechanisms on shipping business models.

Development of artificial intelligence-based predictive models for fleet optimization.

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