



Developing a Green-Energy-Based Ship Electrical Systems Curriculum for Maritime Education: A Qualitative Stakeholder and Competency-Mapping Study

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Abstract. The maritime energy transition is changing the knowledge and practical competencies expected of electro-technical personnel, yet ship electrical systems curricula may not explicitly connect conventional electrical training with battery energy storage, hybrid power architectures, power electronics, smart energy management, high-voltage safety, and decarbonization-oriented operation. This study develops a green-energy-based ship electrical systems curriculum through a qualitative descriptive curriculum-development approach. The revised design intentionally removes pre-test/post-test statistics and causal claims and instead focuses on stakeholder needs, regulatory competency mapping, and curriculum reproducibility. Purposive participants comprise 20 professional stakeholders: 10 ship-electrical/marine-engineering instructors, five curriculum experts, and five maritime industry practitioners. Data sources include semi-structured interviews, analysis of the existing ship electrical systems syllabus, and relevant IMO/STCW documents. Data are analyzed through iterative coding, category development, cross-source comparison, and competency mapping. The resulting framework organizes six curriculum priorities: hybrid shipboard power architecture; battery energy storage and battery management; power electronics and electric propulsion interfaces; power and energy management systems; high-voltage safety and fault diagnosis; and energy-efficiency, environmental, and regulatory literacy. The principal output is a reproducible curriculum matrix linking existing topics, green-energy integration, learning outcomes, learning activities, assessments, and competency standards. The framework is mapped primarily to STCW Code Table A-III/6 for electro-technical officers and complemented by IMO decarbonization and emerging training guidance for alternative fuels and new technologies. The study does not claim causal improvement in cadet achievement. Instead, it offers a stakeholder-informed curriculum structure that can be adapted and evaluated in future implementation studies.

Keywords: *maritime education and training; green energy; ship electrical systems; electro-technical officer; curriculum development; STCW; decarbonization; qualitative research*

1. INTRODUCTION

International shipping is undergoing a structural transition driven by decarbonization requirements, rapid electrification, digital control, and the increasing use of alternative energy technologies. The 2023 IMO Strategy on Reduction of GHG Emissions from Ships identifies progressively stronger ambitions for reducing the carbon intensity of international shipping and for increasing the uptake of zero- or near-zero-GHG technologies, fuels, and energy sources (International Maritime Organization [IMO], 2023). These changes affect not only ship design and fuel selection but also the competencies required to operate, monitor, troubleshoot, and maintain shipboard electrical and electronic systems.

For maritime education and training (MET), the transition is particularly relevant to electro-technical officer (ETO) preparation. STCW Code Table A-III/6 establishes competence in monitoring electrical, electronic, and control systems; operating generators and distribution systems; working with high-voltage power systems; operating shipboard computer networks; and maintaining and repairing electrical, electronic, and automation equipment (IMO, 2010). These competencies remain a strong regulatory baseline. However, the technologies through which they are now practiced are changing. Battery energy storage systems (BESS), power electronic converters, variable-speed drives, electric propulsion interfaces, power-management systems, energy-management systems, advanced sensors, and shore-power interfaces create new contexts in which conventional electrical competence must be applied.

The transition also changes the relationship between electrical competence and environmental performance. Energy-efficient operation increasingly depends on data-informed load management, generator scheduling, peak shaving, safe battery integration, and the effective use of automated control. Recent studies on maritime sustainability and seafarer training have emphasized that technological transition must be accompanied by relevant knowledge, practical skills, and training structures rather than treated solely as a technical or regulatory issue (Dewan & Godina, 2024; Dimitranov & Belev, 2024). Seafarers' acceptance of alternative technologies is likewise influenced by ease of use, safety, trust, and training readiness (Kim et al., 2025).

1.1 Terminological Scope

To avoid conceptual overlap, this study uses five terms consistently. Green energy is used as an instructional umbrella term for energy technologies and operating practices intended to reduce greenhouse-gas emissions and environmental impact in shipboard power systems. Renewable energy refers specifically to naturally replenished energy sources, such as solar and wind, where applicable to shipboard or auxiliary systems. Decarbonization refers to the broader reduction of life-cycle greenhouse-gas emissions from shipping. Energy efficiency refers to reducing energy demand or fuel use for a given operational output. Sustainable shipping is the broader operational and institutional objective that combines environmental performance with safety, reliability, and responsible resource use. In this article, green-energy curriculum integration therefore includes renewable sources but is not limited to them; it also

includes BESS, hybridization, power electronics, energy management, and safety practices necessary for lower-emission ship operation.

1.2 Research Gap and Contribution

A central curriculum problem is not the absence of electrical engineering content, but the weak visibility of the bridge between conventional ship electrical topics and emerging green-energy applications. A syllabus may already teach generators, switchboards, motors, protection, high-voltage systems, automation, and fault finding, while still leaving cadets without an explicit learning sequence for hybrid architectures, battery-management systems, energy-flow interpretation, converter-based propulsion, energy-management logic, or decarbonization-related operational decisions. When green topics are added only as stand-alone lectures, they risk becoming peripheral rather than integrated competencies.

Accordingly, this study does not attempt to demonstrate that a new curriculum statistically improves learning outcomes. Instead, it addresses a more fundamental design question: what should be integrated, where should it be placed within the existing ship electrical curriculum, how should it be taught and assessed, and how can the resulting structure be traced to relevant STCW/IMO requirements? This positioning responds directly to the need for a curriculum that is explicit, reproducible, and verifiable rather than dependent on unsupported claims of learning gain.

The study contributes a qualitative, stakeholder-informed curriculum framework with two distinguishing features. First, green-energy content is integrated into existing ship electrical competencies rather than treated as an independent environmental-awareness module. Second, every proposed integration is linked to a learning outcome, learning activity, assessment method, and competency reference. The resulting curriculum matrix is intended to function as both a curriculum-development tool and an audit trail for MET institutions.

1.3 Research Questions

1. What green-energy and decarbonization-related competencies should be integrated into ship electrical systems education for future electro-technical personnel?
2. How can these competencies be mapped to relevant STCW A-III/6 functions and current IMO decarbonization and training guidance?
3. What curriculum structure can translate these competencies into teachable learning outcomes, practical activities, and assessable tasks in MET institutions?

2. METHODOLOGY

2.1 Research Design

This study adopts a qualitative descriptive curriculum-development design. The design was selected because the research questions concern curriculum content, stakeholder judgments, competency alignment, and implementation requirements

rather than the measurement of a treatment effect. The revised design therefore excludes the earlier pre-test/post-test comparison, paired-sample t-test, percentage-agreement claims, and related causal interpretations. Qualitative description is appropriate when the purpose is to produce a clear, practice-oriented account that remains close to participants' professional experience and to the content of relevant documents.

Curriculum development proceeded through four linked stages: (1) analysis of the existing ship electrical systems syllabus and relevant regulatory documents; (2) stakeholder needs exploration; (3) thematic synthesis and competency mapping; and (4) structured stakeholder review of the draft curriculum. The final curriculum was organized only after the document evidence and stakeholder perspectives had been compared. This sequence creates a transparent chain from identified need to proposed curriculum element.

2.2 Study Setting and Participants

The study was conducted at Politeknik Pelayaran Banten during September 2025 until January 2026. Participants were selected purposively because they held direct knowledge of ship electrical education, curriculum design, or contemporary maritime electrical practice. The qualitative sample comprised 20 professional stakeholders: 10 instructors, five curriculum experts, and five maritime industry practitioners. The 60-cadet pre-test/post-test dataset reported in the earlier manuscript is not used in this qualitative redesign because the present study does not evaluate causal learning improvement.

Table 1. Participant groups and contribution to the qualitative study

Participant group	n	Selection rationale	Primary contribution
Ship-electrical / marine-engineering instructors	10	Teaching responsibility in ship electrical, automation, marine engineering, or related technical subjects.	Identify curriculum gaps, sequencing needs, laboratory feasibility, and assessment practices.
Curriculum experts	5	Experience in MET curriculum design, competency-based education, accreditation, or STCW-related curriculum work.	Review learning-outcome formulation, curriculum coherence, competency alignment, and assessment logic.

Participant group	n	Selection rationale	Primary contribution
Maritime industry practitioners	5	Operational or technical experience relevant to ship electrical systems, ETO work, fleet technical management, shipyard/commissioning, or green technology.	Identify current and emerging equipment, operational tasks, safety concerns, and industry-readiness requirements.

Purposive sampling was used to obtain information-rich professional perspectives; it was not intended to produce a statistically representative sample. Participant diversity should be described in the final submission using verifiable characteristics such as years of experience, highest qualification, current role, and relevant maritime certification. To preserve confidentiality, individual institutions or companies may be reported in aggregate where required by ethical approval.

2.3 Data Sources and Data Collection

Three qualitative data sources were used. First, document analysis examined the existing ship electrical systems syllabus, STCW provisions relevant to electro-technical officers, the 2023 IMO GHG Strategy, and current IMO guidance on training for ships using alternative fuels and new technologies. Document analysis focused on competencies, knowledge areas, practical tasks, safety requirements, and terminology that could be translated into curriculum outcomes.

Second, semi-structured interviews were conducted with the 20 professional stakeholders. Interview prompts asked participants to identify gaps in existing ship electrical education, priority green-energy technologies, practical tasks expected of graduates, safety-critical competencies, feasible teaching approaches, assessment methods, and infrastructure constraints. The interview guide was intentionally open-ended so that participants could introduce technologies or competency concerns not anticipated by the researchers.

Third, a draft curriculum matrix was returned to the five curriculum experts and five industry practitioners for a structured second-round review. Rather than using a numerical validity index, reviewers commented qualitatively on four criteria: relevance, technical accuracy, feasibility for MET implementation, and traceability to competency standards. Each comment was recorded in a revision log and classified as retain, revise, add, or remove. This process is treated as formative curriculum review, not as psychometric validation.

2.4 Data Analysis

Interview notes/transcripts and documentary extracts were analyzed using an iterative thematic procedure adapted for a qualitative descriptive study. Analysis involved: (1) familiarization with all textual material; (2) initial coding of statements

related to technology, competency, safety, learning activities, assessment, and implementation; (3) grouping similar codes into practical curriculum categories; (4) comparing categories across instructors, experts, industry practitioners, and regulatory documents; (5) translating categories into learning outcomes and curriculum elements; and (6) mapping each element against relevant STCW/IMO provisions. Coding was primarily semantic and practice-oriented, because the aim was curriculum construction rather than interpretation of latent psychological meanings.

A curriculum element was retained when it met two conditions: it was supported by at least one stakeholder source and it could be justified by a ship-electrical operational task, safety requirement, or regulatory/industry transition need. The analysis did not convert qualitative comments into percentages, mean scores, or statistical rankings. Where stakeholder views differed, the final choice was resolved through explicit consideration of safety criticality, ETO role relevance, regulatory traceability, and feasibility within the existing electrical curriculum.

2.5 Trustworthiness

Trustworthiness was addressed through methodological triangulation and an auditable curriculum-development trail. Document findings were compared with stakeholder perspectives; instructor feasibility judgments were compared with expert and industry judgments; and every final curriculum element was linked to a specific learning outcome and competency reference. A revision log documented why proposed content was retained, modified, added, or removed. In the final submitted manuscript, the authors should additionally report any member checking, peer debriefing, independent coding comparison, or transcript verification that was actually performed. These procedures should not be claimed unless documented in the study records.

2.6 Ethical Considerations

Participation was voluntary, and professional stakeholders were informed about the purpose of the study, confidentiality, and the use of their responses for curriculum development. Ethical approval/exemption was obtained from Politeknik Pelayaran Banten. Identifying information was removed from analytic summaries and no participant quotations are included in this draft because the raw transcripts were not available for verification during manuscript reconstruction.

3. RESULT AND DISCUSSION

3.1 Results

The qualitative synthesis was organized around curriculum requirements rather than learner-score changes. Six interrelated priorities formed the core of the proposed green-energy integration. These priorities did not replace foundational ship electrical competencies; instead, they specified new technological contexts in which existing electrical, electronic, control, safety, and maintenance competencies should be taught.

Qualitative Curriculum Priorities

Table 2. Qualitative curriculum priorities and educational implications

Curriculum priority	Need addressed	Core content	Educational implication
1. Hybrid shipboard power architecture	Conventional generator teaching does not always show how multiple energy sources interact in a modern shipboard microgrid.	Diesel-generator/BESS combinations; shore connection; DC/AC buses; energy flow; redundancy; basic renewable contribution where relevant.	Teach system-level energy flow and operating modes using single-line diagrams, load scenarios, and simulator/laboratory exercises.
2. Battery energy storage and battery management	BESS introduces electrical, thermal, monitoring, isolation, and emergency considerations not captured by conventional battery topics alone.	Battery chemistry awareness; BMS functions; state of charge/state of health; charging; isolation; alarms; thermal runaway awareness; emergency response interfaces.	Embed BESS into DC systems, protection, instrumentation, safety, and maintenance rather than offering it as a stand-alone sustainability lecture.
3. Power electronics and electric-propulsion interfaces	Green and hybrid systems rely heavily on conversion and variable-speed control.	Rectifiers, inverters, converters, DC links, variable-frequency drives, electric propulsion interfaces, harmonics and protection.	Move from component description to troubleshooting and safe operation of converter-based power chains.
4. Power and energy management systems	Energy efficiency increasingly depends on automated load decisions and system monitoring.	PMS/EMS logic; generator scheduling; load sharing; peak shaving; demand management; energy metering; alarm/trend interpretation.	Use operational scenarios requiring cadets to interpret data and make safe energy-management decisions.

5. High-voltage safety and fault diagnosis	Electrification can increase exposure to high-energy DC/AC systems and complex fault modes.	Isolation; lockout/tagout; verification of dead; HV switching principles; DC fault awareness; protection coordination; diagnostic reasoning.	Require practical safety and fault-diagnosis assessments, not knowledge-only examinations.
6. Energy-efficiency, environmental and regulatory literacy	Electrical decisions are increasingly connected to emissions and decarbonization objectives.	IMO GHG strategy; energy-efficiency measures; operational emissions awareness; alternative-fuel/new-technology interfaces relevant to ETO duties.	Connect technical choices to environmental outcomes while keeping the scope anchored to electrical/control responsibilities.

Proposed Curriculum Matrix

Table 3 makes the curriculum contribution explicit and reproducible. The first column preserves the logic of the existing ship electrical curriculum, while the remaining columns show where green-energy applications are integrated and how competence is taught and assessed.

Table 3. Green-energy integration matrix for ship electrical systems education

Existing topic	Green-energy integration	Learning outcome	Learning activity	Assessment	Competency standard
Electrical generation and distribution	Hybrid AC/DC architecture; BESS; shore-power interface; energy-	Analyze power flow and operating modes in a hybrid shipboard	Single-line diagram analysis; simulator/lab load scenario; source-changeover case.	Scenario-based system analysis and oral/practical explanation.	STCW A-III/6: monitor electrical/electronic/control systems; operate generators and distribution systems.

	flow logic.	distribution system and identify safe operating constraints.			
Generator synchronization and load sharing	Battery-assisted peak shaving; generator scheduling; PMS logic.	Configure or explain safe load sharing and source coordination under changing demand.	Simulator exercise with changing hotel/propulsion loads and BESS support.	Observed simulator task using a performance checklist and debrief.	STCW A-III/6: operate generators and distribution systems; monitor automatic control systems.
Power electronics and electrical drives	Converters, inverters, DC links, variable-frequency drives, electric-propulsion interface s.	Explain energy conversion paths and diagnose basic converter/drive faults using system evidence .	Converter/VFD lab; waveform or alarm interpretation ; propulsion-drive case study.	Fault-diagnosis worksheet or practical troubleshooting task.	STCW A-III/6: electrical machines; power electronics; electrical drives; control systems.
High-voltage systems	High-voltage BESS/electric propulsion; DC/AC isolation; switching	Apply safe isolation and risk-control procedures to high-energy	LOTO/tablet top switching scenario; HV safety demonstration; protection case.	Practical safety assessment and switching/isolation plan.	STCW A-III/6: operate and maintain power systems in excess of 1,000 V; electrical propulsion safety.

	g and protection.	green-power equipment.			
Automation and control	PMS/EMS; optimization logic; automated source selection; sensor-driven energy control.	Interpret control logic and operating data to maintain stable and efficient power-system operation.	PMS/EMS simulator; control-sequence tracing; trend analysis.	Troubleshooting scenario and control-logic explanation.	STCW A-III/6: monitor automatic control systems; instrumentation, alarm and monitoring systems.
Instrumentation, alarms and monitoring	Energy meters; BMS alarms; SoC/SoH indicators; thermal monitoring; efficiency KPIs.	Interpret green-power monitoring data and distinguish normal, degraded, and unsafe conditions.	BMS/PMS trend review; alarm-prioritization exercise.	Diagnostic report based on an alarm/trend dataset.	STCW A-III/6: instrumentation, alarm and monitoring systems; control-system monitoring.
Maintenance and fault finding	BMS sensors; converters; DC contactors; insulation monitoring; power-quality issues.	Develop a safe diagnostic sequence for faults in hybrid and battery-supported electrical systems.	Fault-injection lab or structured case; diagram tracing; maintenance planning.	Practical troubleshooting / written diagnostic sequence.	STCW A-III/6: maintenance and repair of electrical/electronic equipment and automation/control systems.

Computers and shipboard networks	Networked energy monitoring; data acquisition; interfaces between PMS, BMS, automation and dashboards.	Trace essential data flows and identify basic failures affecting energy-system monitoring and control.	Network architecture exercise; simulated sensor/communication failure.	Network/data-flow mapping and fault-isolation task.	STCW A-III/6: operate computers and computer networks on ships.
Environmental and safety practice	Energy-efficiency decisions; IMO decarbonization context; alternative-fuel/new-technology awareness relevant to ETO interfaces.	Explain how electrical operating decisions affect energy use, safety, and environmental performance.	Regulatory case study; emergency scenario; energy-efficiency decision exercise.	Scenario response, short technical brief, or oral defense.	STCW environmental/safety functions; 2023 IMO GHG Strategy; STCW.7/Circ.25 generic training framework where applicable.

STCW/IMO Competency Mapping

The curriculum is anchored in STCW A-III/6 because the proposed content is intended to modernize the context in which ETO competencies are learned, not to create a separate certification scheme. Current IMO decarbonization and interim training guidance are used as complementary references where the content extends to energy transition, new technologies, safety, and environmental responsibilities.

Table 4. Competency mapping for the proposed curriculum

Green-energy area	Relevant competency/reference	Curriculum interpretation	Evidence of competence
Hybrid generation, BESS and distribution	STCW A-III/6: monitor electrical/electronic/control systems; operate generators and distribution systems.	Conventional generation/distribution competence is applied to multi-source hybrid architectures and automated source coordination.	Correct interpretation of energy flow, source status, load sharing, protections, and safe changeover decisions.
Power electronics and electric propulsion	STCW A-III/6 knowledge of power electronics, electrical drives, electrical propulsion and associated control.	Converter-based propulsion and battery-supported drives become explicit teaching contexts.	Explain conversion chain, interpret alarms/waveforms, and diagnose basic drive/converter faults.
High-voltage green-power systems	STCW A-III/6: operate and maintain power systems in excess of 1,000 V.	HV competence is extended to BESS, propulsion converters, and associated isolation/protection scenarios.	Safe isolation plan, hazard identification, switching logic, and fault-response reasoning.
PMS/EMS, automation and monitoring	STCW A-III/6: monitor automatic control systems; instrumentation, alarm and monitoring systems.	Energy efficiency is operationalized through control logic, metering, alarms, trends, and source scheduling.	Interpret system trends and select safe control responses under changing load and equipment states.
Maintenance and diagnosis	STCW A-III/6: maintenance and repair of electrical/electronic equipment and automation/control systems.	Maintenance tasks include BMS sensors, converters, insulation monitoring, DC contactors, and networked monitoring.	Structured fault isolation, diagram interpretation, safe maintenance planning, and restoration checks.
Energy transition and	IMO 2023 GHG Strategy; STCW.7/Circ.25	Cadets connect technical electrical decisions to	Scenario-based explanation of safe operation,

environmental awareness	generic interim training guidance, where applicable.	decarbonization, new-technology safety, pollution prevention, and emergency preparedness without exceeding the ETO role.	hazard controls, energy-efficiency consequences, and relevant regulatory context.
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Qualitative Expert and Industry Review

The second-round review was designed to make curriculum revision visible rather than to produce a numerical 'validity score.' Expert and industry comments were converted into an auditable revision log. Table 5 provides the form in which those revisions should be reported.

Table 5. Structured curriculum-review and revision log

Issue raised in review	Decision	Revision to curriculum	Rationale
Battery content was too generic and did not adequately address safety-critical conditions.	Revise / add	Expanded BESS content to include BMS, SoC/SoH, isolation, thermal monitoring, and thermal-runaway awareness.	Makes battery competence operational and safety-oriented rather than descriptive.
Power electronics was embedded too broadly within electrical generation.	Revise	Created a distinct integration line for converters, inverters, DC links, VFDs, and electric-propulsion interfaces.	Reflects the central role of converter-based systems in electrified vessels.
Energy efficiency was presented as environmental theory rather than an electrical operating task.	Revise	Added PMS/EMS, load scheduling, peak shaving, metering, alarm/trend interpretation, and energy-flow decisions.	Connects environmental outcomes to ETO-relevant control and operational competence.
Assessment relied too heavily on written knowledge checks.	Revise	Prioritized simulator, laboratory, troubleshooting, isolation, and scenario-based assessments.	Improves constructive alignment between practical competence and assessment evidence.

Regulatory alignment was stated but not traceable.	Revise	Added explicit mapping to STCW A-III/6 and complementary IMO decarbonization/training guidance.	Allows reviewers and institutions to audit the competency basis of each curriculum element.
Alternative fuels could expand the course beyond the ETO role.	Retain with scope control	Restricted alternative-fuel content to electrical/control interfaces, hazard awareness, monitoring, emergency interfaces, and relevant training context.	Maintains curriculum focus while acknowledging energy-transition technologies.

3.2 Discussion

The revised study reframes the contribution from 'evidence that a curriculum improves cadet performance' to 'evidence-informed specification of what a green-energy ship electrical curriculum should contain and how it can be implemented.' This distinction is methodologically important. Without a control or comparison group and without sufficiently documented measurement instruments, pre-test/post-test gains cannot by themselves establish that a curriculum caused broader improvements in technical competence, analytical ability, environmental awareness, employability, or long-term industry competitiveness. A qualitative curriculum-development study can make a strong contribution without making those claims.

Integrating Green Energy into Existing ETO Competence

The proposed framework treats the energy transition as an application layer across established ETO functions. This is preferable to adding a single 'green shipping' topic at the end of a conventional course. Hybridization affects generation and distribution; batteries affect DC systems, protection, instrumentation, thermal safety, and maintenance; converters affect power electronics and drives; smart energy management affects automation and monitoring; and electrification strengthens the importance of high-voltage safety and diagnostic competence. Integration therefore preserves the logic of STCW A-III/6 while modernizing the operational examples and performance tasks through which competence is developed.

This approach is consistent with broader literature arguing that sustainability in shipping requires educational adaptation and practical seafarer engagement rather than policy knowledge alone (Dewan & Godina, 2024; Dimitranov & Belev, 2024). It also responds to evidence that acceptance of alternative technologies is shaped by practical usability, trust, safety, and readiness, which supports the inclusion of scenario-based training and risk-oriented competence rather than purely conceptual content (Kim et al., 2025).

Why the Curriculum Matrix Matters

A major weakness of many curriculum-development manuscripts is that the proposed curriculum remains implicit in narrative discussion. The matrix in Table 3 addresses that problem by specifying six elements for every curriculum decision: the existing topic, the green-energy integration, the intended learning outcome, the learning activity, the assessment, and the competency standard. This structure supports constructive alignment and makes the proposal reproducible. An institution can adopt the framework without copying every activity; it can preserve the competency logic while adapting equipment, simulator availability, contact hours, and local industry priorities.

The matrix also prevents regulatory alignment from becoming a general claim. Instead of stating that the curriculum is 'aligned with STCW,' the mapping shows which electrical function is being extended and what evidence of competence could demonstrate the learning outcome. The 2023 IMO GHG Strategy supplies the decarbonization context, while the IMO's generic interim training guidance for alternative fuels and new technologies reinforces the need for training that addresses safe operation, hazards, emergency response, pollution prevention, and advanced operational competence where applicable. These references should be treated as complementary to, not substitutes for, the mandatory STCW competence framework.

Practical Implementation in MET Institutions

Implementation should be modular. Institutions with limited laboratory infrastructure can begin with single-line diagrams, data sets, digital-twin or simulator scenarios, BMS/PMS screenshots, fault trees, and structured case studies before investing in dedicated BESS or converter trainers. Where hardware is available, the strongest assessments are performance-based: safe isolation, load-management decisions, alarm interpretation, fault diagnosis, and restoration planning. The aim is not to turn an ETO course into a naval architecture or fuel-chemistry course, but to ensure that cadets can safely operate and reason about the electrical and control interfaces through which the energy transition is implemented onboard.

Because new fuels and technologies are developing faster than formal curriculum cycles, the framework should be reviewed periodically. Content on battery-powered ships, hydrogen, ammonia, methanol, fuel cells, or other technologies should be updated when IMO requirements and industry practice become more specific. The stable component of the curriculum is therefore not a fixed list of technologies but a competency architecture: electrical system understanding, control, monitoring, safety, diagnosis, maintenance, and environmentally informed operation.

Limitations

This study has four principal limitations. First, purposive sampling provides depth and professional relevance but does not support statistical generalization. Second, the design focuses on professional stakeholders and document evidence; it does not test whether the proposed curriculum causes measurable learning gains. Third,

transferability depends on local curriculum hours, laboratory resources, vessel types, instructor competence, and national implementation of STCW requirements. Fourth, IMO training guidance for alternative fuels and new technologies continues to evolve, meaning that technology-specific curriculum content requires periodic review. Future research should implement the matrix in a clearly defined course, use validated performance assessments, and—if causal effectiveness is the research question—employ an appropriate comparison design.

4. CONCLUSION

This qualitative curriculum-development study proposes a structured way to integrate green-energy competencies into ship electrical systems education. The central contribution is not a statistical claim of improved cadet performance, but a transparent curriculum architecture that connects conventional ship electrical topics with hybrid power systems, battery energy storage, power electronics, smart power and energy management, high-voltage safety, fault diagnosis, and decarbonization-related operational awareness. By linking each integration to learning outcomes, learning activities, assessments, and STCW/IMO references, the framework makes curriculum alignment visible and reproducible. The proposed curriculum should be interpreted as a stakeholder-informed and competency-mapped framework whose educational effectiveness remains to be evaluated through future implementation research. Claims concerning employability, long-term competitiveness, or maritime-sector resilience are therefore implications of improved curriculum relevance rather than demonstrated outcomes of the present study.

References

- [1] Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101. <https://doi.org/10.1191/1478088706qp063oa>
- [2] Dewan, M. H., & Godina, R. (2024). An overview of seafarers' engagement and training on energy efficient operation of ships. *Marine Policy*, 160, 105980. <https://doi.org/10.1016/j.marpol.2023.105980>
- [3] Dimitranov, D., & Belev, B. (2024). Sustainable shipping requires sustainable education and training. *Sustainability*, 16(24), 11270. <https://doi.org/10.3390/su162411270>
- [4] International Maritime Organization. (2010). The Manila Amendments to the Annex to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, and the STCW Code. IMO.
- [5] International Maritime Organization. (2023). 2023 IMO Strategy on Reduction of GHG Emissions from Ships (Resolution MEPC.377(80)). IMO.
- [6] International Maritime Organization. (2025). Generic interim guidelines on training for seafarers on ships using alternative fuels and new technologies (STCW.7/Circ.25). IMO.
- [7] Kim, K., Lee, C.-h., & Lim, D. (2025). Understanding seafarers' acceptance of the transition to alternative fuels in shipping through the Technology Acceptance

- Model. Journal of Marine Science and Engineering, 13(12), 2308. <https://doi.org/10.3390/jmse13122308>
- [8] Sandelowski, M. (2000). Whatever happened to qualitative description? Research in Nursing & Health, 23(4), 334-340. [https://doi.org/10.1002/1098-240X\(200008\)23:4<334::AID-NUR9>3.0.CO;2-G](https://doi.org/10.1002/1098-240X(200008)23:4<334::AID-NUR9>3.0.CO;2-G)

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