

Integrating Green Marine Technology into Maritime Education in Indonesia

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Abstract—Maritime decarbonization policies and industry practices are increasing the demand for green-technology competencies in ship and port operations, yet maritime vocational curricula in Indonesia may not uniformly translate these needs into measurable learning outcomes and assessment. This study aims to assess stakeholders' perceptions of curriculum readiness to integrate green marine technology and to identify priority improvements for implementation. An exploratory mixed-method approach was used with purposive sampling of nine stakeholders (three industry practitioners, three educators, and three recent graduates). Semi-structured interviews were synthesized thematically, and a simple 1–10 prioritization score was applied to summarize judgments across three indicators: integration, awareness, and relevance. The findings indicate consistently high perceived urgency (scores clustered at 9/10), while reporting uneven depth of coverage across modules and limited availability of standardized rubrics to assess sustainability performance beyond written knowledge. Stakeholders emphasized operational anchors such as emissions monitoring and reporting, energy-efficiency measures, and waste-handling routines, and noted constraints including limited simulator or laboratory access and the need for structured industry input. The paper contributes a stakeholder-informed competency mapping and an implementation roadmap to support competency-based learning, measurable outcomes, and industry-linked assessment in maritime vocational education.

Keywords— assessment rubrics; competency mapping; curriculum readiness; decarbonization; emissions monitoring; industry alignment; mixed-method; stakeholder perceptions; thematic synthesis; vocational training

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I. INTRODUCTION

The maritime industry is a cornerstone of global trade and economic development, and Indonesia's archipelagic geography makes shipping and ports central to national connectivity and growth [1]. At the same time, tighter environmental expectations and decarbonization targets are accelerating the adoption of green marine technologies, including energy-efficiency measures, cleaner fuels, shore power, and improved waste handling [2].

Figure 1 summarizes the logic chain underpinning this study: regulatory and industry decarbonization pressures (e.g., IMO GHG targets, EEXI/CII, and MARPOL Annex VI) translate into concrete operational requirements such as energy-efficiency measures, emissions monitoring/reporting, waste-handling routines, and alternative-fuel readiness. These operational shifts imply specific competency demands—particularly emissions-data literacy, compliance mindset, operational procedures, and energy-management skills—which should be reflected in Technical and Vocational Education and Training (TVET) curriculum design through competency-based learning, measurable outcomes, and assessment rubrics.

In marine engineering practice, these changes translate into new competencies: understanding

emissions and energy baselines, selecting and operating efficient machinery, applying digital monitoring, and complying with environmental regulation and reporting. Maritime vocational education therefore needs to prepare graduates not only for operational tasks but also for sustainability-driven engineering decisions [2].

Prior studies emphasize the integration of sustainability in vocational and higher education through competency-based approaches and closer industry collaboration [3], [4]. However, within the Indonesian maritime education context, implementation is frequently uneven across modules and often lacks measurable competency targets that can be assessed through performance-based evidence [5], [6]. In many cases, assessment still concentrates on knowledge recall rather than demonstrating green-technology skills aligned with operational routines, while institutional constraints (e.g., limited simulator/laboratory access) further restrict practice-oriented learning [7]. Broader evidence from ocean-sustainability and STEM-education research also highlights the importance of aligning curriculum content with stakeholder needs and real environmental challenges [8], [9], [10]. Moreover, sustainability-competency studies stress that targeted competencies must be matched with appropriate pedagogy and assessment design, rather than remaining as general awareness statements [11], [12]. These gaps are increasingly critical as digitalization and corporate sustainability practices in ports and maritime organizations demand technology-enabled, sustainability-oriented decision-making and documentation skills [13], [14], [15]. Therefore, the key problems addressed in this study are: (1) limited evidence on stakeholder-perceived curriculum readiness for measurable green-technology competencies, (2) weak translation of decarbonization requirements into operational learning anchors that can be practiced and

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assessed, and (3) insufficient assessment instruments and implementation support to evaluate sustainability performance beyond written knowledge.

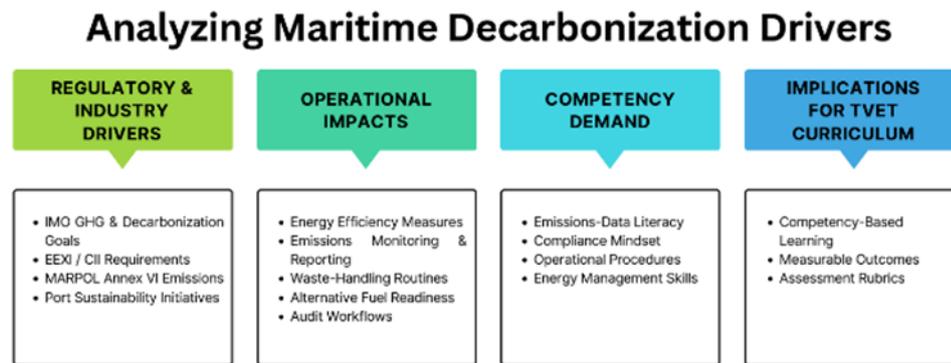


Fig. 1. Linkage from maritime decarbonization drivers to operational impacts, competency demand, and implications for TVET curriculum

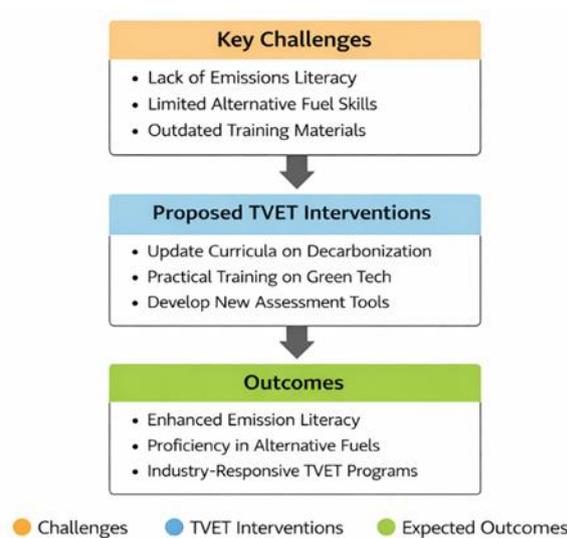


Fig. 2. Conceptual framework linking key competency gaps, proposed TVET interventions, and expected outcomes in maritime sustainability education.

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Figure 2 presents the study’s conceptual framing from problem to action: stakeholder-identified competency gaps (e.g., limited emissions literacy, alternative-fuel skills, and outdated training materials) motivate targeted TVET interventions, including curriculum updates aligned to decarbonization

requirements, practice-oriented green-technology training, and the development of assessment tools. These interventions are expected to strengthen emissions-related competencies, improve readiness for alternative-fuel operations, and support more industry-responsive maritime TVET programs.

This study offers a stakeholder-triangulated perspective on curriculum readiness by combining evidence from industry practitioners, educators, and recent graduates to identify converging priorities and practical constraints for implementing green-technology competencies in maritime vocational education. The novelty of this work lies in linking stakeholder findings to concrete operational task anchors (e.g., monitoring, reporting, and routine compliance workflows) and translating them into a competency-oriented mapping and implementation roadmap that supports measurable learning outcomes and rubric-based assessment. These priorities are consistent with the sector’s global decarbonization direction and greenhouse-gas reduction agenda [16], [17]. Accordingly, this paper addresses three questions: (1) How do stakeholders describe current curriculum alignment and assessment practices

for green marine technology? (2) What institutional and resource factors shape implementation? (3) Which practical priorities emerge for institutions and industry partners to strengthen sustainability-oriented learning outcomes?

The remainder of this paper is structured as follows. Section II describes the research design, participants, data collection, and analysis procedures. Section III presents the results and discusses stakeholder themes across the three indicators, supported by the proposed competency mapping and implementation roadmap. Finally, Section IV summarizes the main conclusions, practical implications, limitations, and directions for future work.

II. METHOD

This study used an exploratory mixed-method design to identify priority competencies and implementation barriers for green marine technology education in Indonesia. Qualitative semi-structured interviews were the primary source of evidence; a simple 1–10 rating exercise was used only to support prioritization across indicators (not to claim objective effectiveness) [18], [19], [20].

Participants (n=9) were selected purposively to represent three stakeholder groups: maritime industry practitioners (n=3), maritime educators (n=3), and recent graduates working in port/shipping contexts (n=3). Selection criteria emphasized direct exposure to sustainability, energy-efficiency, or environmental compliance initiatives, and/or experience delivering or evaluating maritime curricula.

Data collection was conducted through face-to-face or online interviews (approximately 45–60 minutes). The interview guide covered: (i) priority green-technology and compliance topics for maritime operations (e.g., energy efficiency, emissions reporting, waste management), (ii) perceived curriculum coverage and

gaps, (iii) preferred teaching and assessment methods, and (iv) barriers/resources required for implementation. After the interview, participants rated three indicators—curriculum integration, sustainability awareness, and industry relevance—on a 1–10 scale to express perceived priority for improvement.

Transcripts were analyzed using thematic analysis (familiarization, initial coding, theme development, review, and reporting). Triangulation across stakeholder groups was applied by comparing themes emerging from industry, educators, and graduates. Credibility was strengthened via member checking (participants reviewed short summaries of interpretations). Ethical practice was observed by informing participants about the study purpose, voluntary participation, and anonymization of statements [18], [19], [20]. Limitations: The sample size is intentionally small for an exploratory needs-assessment; findings should be interpreted as contextual stakeholder insights rather than statistically generalizable evidence. The 1–10 scores reflect perceived priority/consensus and may exhibit limited variability when panelists share similar sustainability exposure.

III. RESULT AND DISCUSSION

Results are reported as themes derived from stakeholder interviews and are used to inform a practical curriculum-improvement framework. The indicator scores represent stakeholder perceptions for prioritization rather than objective measurement of curriculum effectiveness.

Figure 3 below provides a concise overview of the three indicators assessed in this study—Integration, Awareness, and Relevance—and summarizes the panel's overall prioritization score. The figure helps frame the subsequent detailed indicator-by-indicator analysis and the supporting evidence presented in Table I and the following tables.

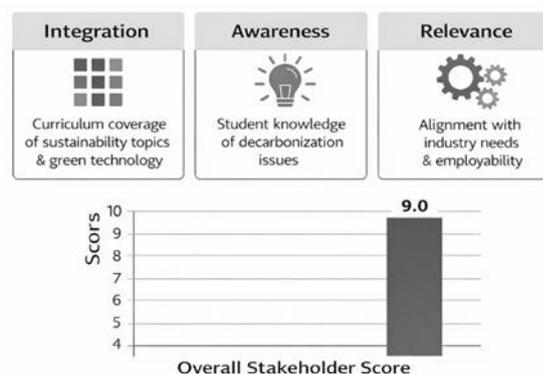


Fig. 3. Results overview of the three curriculum indicators and the overall stakeholder score

The consistently high ratings across the three indicators can be interpreted in light of the study's exploratory design and the characteristics of the selected panel. First, respondents were purposively recruited from industry, academia, and recent graduates who are directly exposed to the current sustainability discourse in maritime operations and education, which naturally increases alignment on the perceived urgency of green-

technology competencies. Second, the 1–10 scoring in this study served as a rapid prioritization tool rather than an objective performance measure; therefore, the scores reflect perceived importance and readiness priorities, not measured learning outcomes. Third, the small panel size (n = 9) and cross-group triangulation tend to amplify converging views, particularly when the topic (decarbonization and environmental compliance) is

widely recognized as a strategic direction for the sector. Hence, the high consensus should be viewed as an early signal of shared priority, while further validation using larger samples and curriculum/document audits is recommended.

This section summarizes stakeholder perspectives on how green marine technology and sustainability competencies should be strengthened within Indonesian maritime vocational and higher-education contexts. The emphasis is on actionable curriculum design, learning activities, and assessment evidence that align with emerging international requirements on maritime energy efficiency and emissions reporting [16], [17].

Overall, the interview evidence indicates that stakeholders perceive green-technology education as a high priority, but emphasize the need for clearer competency definitions, more applied learning activities, and stronger industry-linked assessment evidence. The following sub-sections present themes per indicator, followed by a concise proposed competency map to support curriculum planning.

A. Research Indicators

A.1. The study assessed three stakeholder-prioritized indicators to guide curriculum improvement.

Integration of Green Technology into Curriculum

This indicator assesses how well green technology concepts and practices are incorporated into the existing maritime education curriculum.

A.2. Awareness and Understanding of Sustainability Issues.

This indicator measures the extent to which students, educators, and industry professionals understand sustainability challenges and the role of green technology in addressing these challenges.

Each indicator was scored on a scale of 1 to 10, with 1 being "poor" and 10 being "excellent." The scores clustered at 9/10, indicating strong perceived priority and shared urgency across stakeholders rather than objective evidence of effectiveness.

TABLE I.
SCORING SUMMARY OF RESEARCH INDICATORS

Indicator	Score (1-10)	Analysis
Integration of Green Technology	9	Strong incorporation of green practices in curriculum.
Awareness and Understanding of Sustainability	9	High level of awareness among stakeholders.
Relevance of Education to Industry Needs	9	Curriculum meets industry expectations effectively.

B. Indicator Analysis

B.1. Integration of Green Technology into Curriculum

Priority content areas emphasized by participants included energy-efficiency measures, emissions monitoring/reporting practices, waste and ballast-water

management, and operational decision-making that reduces fuel consumption. Stakeholders also highlighted the need to translate these topics into measurable learning outcomes and practical competencies [16], [17].

TABLE II.
PROPOSED GREEN MARINE TECHNOLOGY COMPETENCY MAP (SUMMARY)

Competency Area	Example Learning Activity (1 column)	Assessment Evidence
Energy efficiency & operational optimization (EEXI/CII awareness)	Case-based exercise: compute and interpret operational efficiency indicators; discuss improvement actions in voyage planning.	Short report + rubric; oral defense; quiz on key terms.
Emissions monitoring & GHG reporting literacy	Workflow mapping: data needed for annual reporting; mock 'ship/port' data collection and validation.	Checklist-based assessment; dataset logbook; reflective memo.
Waste, sewage, and garbage management (MARPOL operational practices)	Scenario drill: design shipboard/port waste-handling plan; identify non-compliance risks.	Plan document; peer review; practical demonstration in lab/sim.
Alternative/low-carbon fuels & safety basics	Seminar + mini-project: compare fuel options and implications for operations, safety, and infrastructure readiness.	Comparative brief; presentation; concept map.
Port sustainability and green port operations	Field study / virtual tour: identify energy, water, and emissions hotspots in port operations and propose quick wins.	Observation sheet; improvement proposal; stakeholder interview summary.
Digitalization for sustainability (sensors, dashboards, decision support)	Prototype: simple dashboard for monitoring fuel/energy parameters (or simulated data) and alerts.	Working prototype; code/config checklist; usability test notes.

Educators and practitioners recommended applied learning approaches such as project-based tasks, case studies from port and ship operations, simulation/lab

exercises, and problem-based assignments linked to real compliance scenarios (e.g., audit preparation, reporting workflows) [10], [11], [12].

Stakeholders suggested strengthening structured industry input (guest lectures, joint projects, internships, and feedback on learning outcomes) so that curriculum updates remain current with technological and regulatory developments [3], [5], [6].

Collaboration with Industry: The involvement of industry experts in curriculum development has

ensured that the educational content remains relevant and current. This collaboration has facilitated the introduction of the latest advancements in green technology, ensuring students are well-prepared for their future careers.

TABLE III.
 DETAILED ANALYSIS OF INTEGRATION OF GREEN TECHNOLOGY INTO CURRICULUM

Aspect	Description	Evidence from Interviews
Curriculum Content	Modules on renewable energy, waste management, and emission reduction are included.	"Green technology is part of every module in our program." - Educator
Teaching Methods	Use of project-based learning and case studies to engage students.	"We often use real case studies to show practical applications." - Educator
Collaboration with Industry	Regular input from industry experts to update curriculum content.	"We collaborate closely with companies to ensure relevance." - Maritime Professional

TABLE IV.
 DETAILED ANALYSIS OF AWARENESS AND UNDERSTANDING OF SUSTAINABILITY ISSUES

Aspect	Description	Evidence from Interviews
Knowledge of Environmental Challenges	Participants demonstrate strong awareness of sustainability issues.	"We discuss carbon emissions and pollution in every class." - Graduate
Role of Education	Education is pivotal in developing understanding of sustainability.	"My education made me aware of the importance of sustainability." - Graduate
Engagement in Sustainability Initiatives	Graduates actively participate in sustainability efforts at work.	"I am part of the green team at my company." - Graduate

B.2. Awareness and Understanding of Sustainability Issues

The second indicator, "Awareness and Understanding of Sustainability Issues," also received a score of 9. This indicates a significant level of awareness among students and stakeholders regarding the environmental challenges facing the maritime industry. Key findings include:

Knowledge of Environmental Challenges: All participant groups demonstrated a strong understanding of key sustainability issues, such as carbon emissions, pollution, and resource depletion. This awareness is critical for future maritime professionals as they navigate the complexities of modern maritime operations [8], [14].

Role of Education: Participants emphasized the importance of education in promoting environmental awareness. Many stated that their training had equipped them with the necessary knowledge to engage in sustainable practices within their workplaces [11], [12].

Engagement in Sustainability Initiatives: Graduates reported actively participating in sustainability initiatives within their organizations, highlighting the practical application of their educational experiences. This engagement not only reflects their commitment to sustainability but also indicates the effectiveness of their education in preparing them for industry demands [6], [14].

C. Relevance of Education to Industry Needs

The final indicator, "Relevance of Education to Industry Needs," received a score of 9, reflecting a strong alignment between the educational offerings and industry expectations. The analysis reveals several important findings:

Alignment with Industry Trends: The curriculum is

closely aligned with current trends in the maritime industry, particularly regarding sustainability practices. This alignment ensures that students acquire relevant skills and knowledge that are in demand by employers [13], [15].

Employer Expectations: Industry professionals expressed satisfaction with the preparedness of graduates entering the workforce. They noted that recent graduates possess a solid understanding of green technologies and sustainability practices, making them valuable assets to their organizations.

Adaptability of Curriculum: Educators highlighted the curriculum's adaptability in responding to evolving industry needs. Regular feedback from industry stakeholders allows for continuous improvement and ensures that the educational content remains relevant.

D. Overall Findings

The overall results demonstrate that the integration of green technology into maritime education is not only effective but also essential for preparing future professionals to tackle environmental challenges in the industry. The high scores across all indicators indicate a strong commitment to sustainability and an awareness of its importance in maritime operations.

The qualitative data collected from interviews underscores the importance of collaboration between educational institutions and the maritime industry. This collaboration ensures that the curriculum remains relevant and meets the evolving demands of the sector. Furthermore, the positive feedback from graduates and industry professionals alike highlights the effectiveness of current educational practices in fostering environmental awareness and promoting the adoption of green technologies.

The research findings affirm the critical role of maritime education in advancing sustainability within the industry. The strong integration of green technology into the curriculum, combined with a high level of awareness and understanding of sustainability issues among stakeholders, indicates a promising trajectory towards a more sustainable maritime future. Continued collaboration between educational institutions and industry stakeholders will be essential in further enhancing the relevance and effectiveness of maritime education in Indonesia.

The research findings illuminate a critical intersection between maritime education, green technology, and sustainability, particularly within the context of Indonesia's rapidly evolving maritime industry. The results, demonstrating an effectiveness score of 9 out of 10 across three key indicators, reflect a strong commitment to integrating environmental awareness into vocational education. This discussion interprets these findings and situates them within the broader literature on maritime management and education, examining implications for future practices and research.

TABLE V.
 DETAILED ANALYSIS OF RELEVANCE OF EDUCATION TO INDUSTRY NEEDS

Aspect	Description	Evidence from Interviews
Alignment with Industry Trends	Curriculum is aligned with current trends in sustainability practices.	"Our curriculum reflects what the industry needs today." - Educator
Employer Expectations	Industry professionals express satisfaction with graduates' preparedness.	"They come ready to tackle sustainability issues." - Maritime Professional
Adaptability of Curriculum	Regular updates based on industry feedback ensure relevance.	"We adjust our programs based on industry input." - Educator

E. Integration of Green Technology into Curriculum

The findings indicate that the integration of green technology into the maritime curriculum is not only prevalent but is also considered essential for preparing students for the challenges of the contemporary maritime landscape. This is particularly relevant in Indonesia an archipelagic nation where maritime activities are integral to economic development. The inclusion of modules on renewable energy, waste management, and emission reduction within the curriculum signifies a proactive approach to addressing the pressing environmental issues that the maritime sector faces.

By adopting innovative teaching methods, such as project-based learning and case studies, educators are effectively engaging students in real-world sustainability challenges. These pedagogical approaches facilitate experiential learning, allowing students to apply theoretical concepts to practical situations. The active involvement of industry experts in curriculum development further enhances the relevance of the educational content, ensuring that it remains aligned with current industry practices and technological advancements.

This integration reflects a broader trend in educational practices across the globe, where sustainability is becoming a fundamental component of curricula in various fields. The maritime sector, often seen as a traditional industry, is now embracing the need for innovation and adaptation in response to global sustainability trends. As maritime education continues to evolve, it is crucial that curriculum developers remain vigilant in integrating emerging green technologies and sustainability practices, ensuring that graduates are equipped to navigate a future that demands environmental stewardship.

F. Awareness and Understanding of Sustainability Issues

The research reveals a high level of awareness among students, educators, and industry professionals regarding sustainability issues within the maritime sector. This awareness is essential for fostering a culture of

sustainability that permeates all levels of maritime operations. The recognition of environmental challenges, such as carbon emissions and pollution, highlights a growing consciousness among stakeholders about their roles in mitigating negative impacts on the environment.

Education plays a pivotal role in shaping this awareness. The curriculum's emphasis on sustainability is not merely about imparting knowledge; it is about cultivating a mindset that prioritizes environmental considerations in decision-making processes. Students who engage with sustainability concepts during their education are more likely to carry these principles into their professional lives, ultimately contributing to a more sustainable maritime industry.

Moreover, the active participation of graduates in sustainability initiatives within their organizations signifies a positive outcome of their education. Their commitment to implementing sustainable practices reflects an internalization of the values and knowledge acquired during their studies. This alignment between education and industry practice underscores the importance of preparing future professionals who are not only knowledgeable about sustainability but are also passionate advocates for green technologies.

The insights garnered from this research align with existing literature that emphasizes the importance of environmental education in fostering sustainable behaviors among future professionals. By equipping students with a robust understanding of sustainability challenges, educational institutions can play a significant role in driving systemic change within the maritime industry.

G. Relevance of Education to Industry Needs

The alignment of maritime education with industry needs emerged as a critical finding of the research. The strong satisfaction expressed by industry professionals regarding the preparedness of graduates indicates that vocational programs are effectively addressing the skills gap prevalent in the maritime sector. The integration of green technology and sustainability practices into the curriculum is not only relevant but is also essential for

meeting the demands of an industry that is increasingly focused on environmental responsibility.

The adaptability of the curriculum, in response to feedback from industry stakeholders, exemplifies a forward-thinking approach to education. This responsiveness ensures that the educational offerings remain relevant in a rapidly changing industry landscape. It also reinforces the notion that maritime education should not be static; rather, it must evolve in tandem with technological advancements and shifting industry expectations.

This alignment between education and industry needs is vital for enhancing the employability of graduates. As the maritime sector continues to evolve, employers seek individuals who are not only technically competent but also possess a comprehensive understanding of sustainability practices. By ensuring that educational programs provide relevant training, vocational schools can enhance the job readiness of their graduates, ultimately contributing to the industry's long-term sustainability goals.

IV. CONCLUSION

This research underscores the essential role of vocational education in shaping a sustainable maritime industry in Indonesia. By integrating green technology into the curriculum, maritime institutes can effectively prepare students for the challenges of a rapidly evolving sector increasingly focused on environmental stewardship. The findings demonstrate that innovative teaching methods significantly enhance students' awareness of sustainability issues, equipping them with the knowledge and skills necessary to implement sustainable practices in their future careers.

This exploratory study can be extended through (i) a larger-scale survey involving broader industry segments and multiple maritime education providers to test the generalizability of the identified priorities; (ii) curriculum and document audits (course syllabi, learning outcomes, assessment rubrics, and laboratory capacity) to verify the extent of green-technology integration beyond stakeholder perceptions; and (iii) pilot implementation studies that evaluate specific learning interventions—such as applied modules on energy-efficiency measures, emissions reporting, waste management, and alternative-fuel readiness—using pre/post assessments and industry-validated performance criteria. In addition, comparative studies across institutions and regions would help identify context-specific barriers and scalable implementation pathways.

Stakeholders emphasized that closer collaboration among industry, educators, and graduates can help align learning outcomes and assessment with practical sustainability-related tasks.

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