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Bridging Curriculum and Industry: A Framework for Integrating Green Competency in Malaysia TVET Teacher Education

Abstract

Curriculum reform in Technical and Vocational Education and Training (TVET) teacher education is essential to address the evolving demands of green technologies, sustainable practices and industry transformation. Preparing future educators with relevant green competencies requires the integration of technological knowledge, innovative pedagogical approaches and sustainability principles into teacher education curricula. However, limited empirical consensus exists regarding the essential competency constructs needed to support such integration. This study aimed to identify and validate key constructs for embedding green competencies into TVET teacher education curricula using the Fuzzy Delphi Method (FDM). A panel of 15 experts representing diverse areas of expertise evaluated the proposed constructs through a questionnaire employing a seven-point Likert scale. Data were analysed using Triangular Fuzzy Numbers (TFN) and defuzzification techniques to establish expert consensus and determine construct priorities. The findings demonstrated that all eight proposed constructs achieved expert consensus, with Green Technology Knowledge receiving the highest priority. Problem-Solving and Analytical Skills, Innovative Teaching Methods and Green Principles shared second position, followed by Digital Sustainability Skills, Industry Collaboration, Adaptive Pedagogy and Resource Management. These findings emphasise the importance of integrating technical expertise, sustainability awareness, pedagogical innovation and industry engagement to strengthen educators' capacity to deliver environmentally responsive teaching and learning. The study provides an expert-validated foundation for curriculum reform by identifying prioritised competencies for curriculum design, professional development and institutional strategies. Ultimately, the proposed framework supports the preparation of future-ready TVET educators capable of advancing sustainable workforce development while aligning with Malaysia's National TVET Policy 2030 and National Education Blueprint 2026–2035, thereby strengthening the relevance and responsiveness of teacher education to emerging green industry requirements.

Keywords*: TVET teacher education, curriculum reform, green competency, sustainable development, Fuzzy Delphi Method*

1 Introduction

In an era defined by rapid technological proliferation and urgent environmental imperatives, the mandate of Technical and Vocational Education and Training (TVET) must be radically recontextualized. The convergence of these global challenges demands a holistic educational response that embeds higher-order cognitive, digital and socio-ecological skills directly into TVET curricula. Research increasingly demonstrates that standard technical proficiencies are insufficient to withstand shifting market demands (ILO 2019; OECD 2018). Therefore, contemporary TVET systems must bridge the gap between innovation and responsibility, reshaping human capital into a proactive agent of change (Vitalocca et al. 2026). By fostering an intersection of technological agility and sustainability consciousness, TVET serves as a foundational pillar for both sustainable economic growth and eco-industrial alignment.

While the broader structural and regional dimensions of this discourse highlight systemic shifts globally, a critical operational bottleneck remains largely unaddressed in the current literature: the actual implementation of green paradigms within Technical and Vocational Education and Training (TVET) teacher education (Chen 2025; Ramsarup et al. 2024). Ultimately, the macro-transition to a green economy is heavily dependent upon the micro-level capabilities of TVET educators, who serve as the primary conduits for workforce skill acquisition (Albertz & Pilz 2025; CEDEFOP 2023). Consequently, curriculum reform in TVET teacher education has become increasingly important for responding to evolving green technologies and sustainability requirements. Teacher educators play a pivotal role in preparing future TVET practitioners; therefore, green competency needs to be systematically embedded within teacher education curricula to strengthen knowledge transfer, pedagogical readiness and future workforce preparation. (UNESCO-UNEVOC 2017).

To resolve these operational challenges and bridge the gap between macro-level sustainability policies and micro-level classroom execution, this study establishes a foundational framework for targeted curriculum reform (Kaliappan et al. 2023; Kaliappan & Hamid 2022; Kaliappan & Hamid 2021). By shifting the scholarly focus from broad, conceptual debates to the specific structural dimensions of vocational and technical teacher preparation, this paper delineates the essential elements required to successfully operationalize green competency. Ultimately, this study contributes to the TVET teacher education literature by transforming an abstract environmental mandate into an actionable curricular roadmap (Chinedu et al. 2023). In doing so, it equips educational policymakers and institutional leaders with the theoretical and practical clarity necessary to cultivate an industry-responsive teaching corps capable of anchoring the global green transition (Yang et al. 2024).

1.1 Research Objectives

The objective of this study is to identify and validate key constructs for embedding green competency requirements into TVET teacher education curricula that is seen fundamental as these educators will be responsible for preparing students for environmental protection and conservation in the future. Moreover, the information obtained from this study will be

insightful for policy-makers, environmental learning program designers and lecturers of Vocational Colleges and Vocational Technical Education and Training Division, Ministry of Education to be prepared for the future. Therefore, this study aims to identify and validate key constructs for embedding green competency requirements into TVET teacher education curricula to answer the following research questions:

i. What are the key constructs for embedding green competency s requirements into TVET teacher education curricula according to the panel of experts?

ii. How did the key constructs for embedding green competency requirements rank for TVET teacher education curricula by a panel of experts?

2 Literature Review

While the need for sustainability is widely recognized in policy, translating these goals into actual TVET classrooms reveals serious operational challenges. Current research indicates that teacher education programs are underprepared for the green transition due to several systemic bottlenecks (Muhaemanurrohmah & Widiaty 2026). To understand why green curriculum reform has stalled, it is necessary to examine where current teacher preparation falls short. The following sections analyze the four primary gaps identified in the literature: limited educator knowledge, curriculum deficiencies, insufficient industry collaboration and weak pedagogical strategies. Exploring these interconnected barriers helps isolate exactly where a validated framework is most urgently needed.

2.1 Limited Knowledge and Training Among Educators

A major barrier to the green transition is that a substantial proportion of TVET educators lack adequate knowledge and understanding of green technologies. For instance, research shows that up to 68% of vocational teachers feel underprepared in this area, despite recognizing its importance for environmental sustainability and industry transformation (Li et al. 2023). This deficiency persists because current teacher training programs fail to embed green competency systematically (Parry & Metzger 2023). Instead of integrating sustainability deeply into the broader technical curricula, they treat it as an isolated, standalone topic. Consequently, educators are left without the robust subject-matter expertise needed to effectively teach modern sustainable practices (Morales-Aguilar et al. 2025).

2.2 Curriculum Deficiencies

Another significant challenge is that many TVET programs do not sufficiently reflect sustainability principles, limiting their ability to prepare pre-service teachers for green education (Adjei et al. 2024). This lack of integration is particularly concerning given the immense potential of TVET to address global sustainability challenges. The issue is further exacerbated by outdated curricula that lack alignment with contemporary industry needs, making it increasingly difficult for educators to teach green skills effectively (Tramonti &

Dochshanov 2025). The rigidity of current curricular frameworks, which remain tied to legacy industrial models, prevents them from providing the structured, updated competency that future teachers need to stay relevant in a rapidly changing economic landscape (Scarinci & Savino 2025).

2.3 Insufficient Industry Collaboration

A critical disconnect also exists due to the lack of collaboration between TVET institutions and industries to align green competency with real-world demands (Moshi et al. 2024). This separation hinders the development of relevant and practical green skills, as training programs remain isolated from actual workplace advancements (Subrahmanyam 2025). Without active partnerships, internship opportunities, and knowledge-sharing with green industries, TVET teacher education cannot keep pace with rapidly evolving environmental technologies and workplace standards (Al Yusuf & Alhamad 2025). Consequently, pre-service teachers are trained on outdated operational models, directly impacting their ability to prepare a future workforce that meets the immediate needs of sustainable businesses (Isbah et al. 2026).

2.4 Pedagogical Gaps

Finally, significant challenges persist around the teaching methods used to deliver green concepts. Although various theoretical frameworks exist to promote sustainability education, their actual adoption within vocational classrooms remains highly limited (Scarinci & Savino 2025). This slow uptake highlights a pressing need for systemic strategies to support adaptive and sustainable pedagogy. Many TVET educators continue to rely on traditional, passive instructional styles that are ill-suited for sustainability education (Pratama et al. 2026). Without concrete pedagogical guidelines and actionable training models, teachers struggle to move beyond theory and implement the hands-on, problem-solving methodologies required to cultivate practical green competency in their students (Ragagnin et al. 2025).

3 Methodology

This study employs a structured research design to systematically validate the developed constructs through an expert consensus process.

3.1 Research Design

Validation of the green competency constructs for TVET teacher education was achieved using the Fuzzy Delphi Method (FDM) (Murray et al. 1985). Feedback from 15 experts was converted into Triangular Fuzzy Numbers (m 1,m 2,m 3) and defuzzified into crisp scores for ranking. To ensure data reliability, each construct had to simultaneously meet three strict consensus conditions: a threshold value ($d \leq 0.2$), a minimum group agreement of 75%, and an α-cut value ($\alpha \geq 0.5$) (Ridhuan & Nurulrabihah 2020). Items failing any single criterion were systematically rejected to guarantee a rigorous final framework (Saedah 2013).

3.2 Instrument

Following established FDM traditions, the questionnaire items for this study were generated from a comprehensive literature review on green competency in TVET education (Subrahmanyam 2025; Vitalocca et al. 2026). A seven-point Likert scale was used because it reduces measurement fuzziness to 3.3% compared to 20% in five-point scales, ensuring a highly accurate reflection of expert evaluation (Ridhuan & Nurulrabihah 2020; Finstad 2010). The expert panel rated their agreement on the key constructs for embedding green competency into TVET teacher education curricula using this scale. These responses were then converted into fuzzy values and analyzed using the fuzzy Delphi linguistic scale.

3.3 Panel of Experts

This study employed a panel of 15 experts with extensive expertise in Technology, Technical and Vocational Education and Training (TVET) and Sustainable Development. The panel size is consistent with Delphi recommendations, which suggest involving between 10 and 20 experts to achieve reliable consensus while maintaining manageable fieldwork (Delbecq et al. 1975; Ludwig 1997). Since the Delphi technique relies on purposive rather than statistical sampling, the experts were intentionally selected based on their qualifications and relevance to the study (Adler & Ziglio 1996). Prior to participation, all experts provided informed consent and ethical approval.

To ensure the credibility of the findings, five inclusion criteria were established. The experts were required to (i) possess at least a Master's degree, (ii) have a minimum of five years of professional experience, (iii) represent diverse expertise in Technology, TVET and Sustainable Development, (iv) demonstrate full commitment throughout the study, and (v) have no personal or professional conflicts of interest (Hsu & Sandford 2007; Nurulrabihah et al. 2020). These criteria ensured that the selected experts possessed the necessary academic qualifications, knowledge and professional experience to provide reliable judgments throughout the Fuzzy Delphi process. The demographic profiles and areas of expertise of the expert panel are presented in Table 1.

Table 1: **Panel of Experts**

	Expert's Position	Areas of Expertise
1.	Head of Department (Ts, PhD)	Engineering and Technology
2.	Head of Unit	Technology and Sustainable Development
3.	Head of Unit	Engineering and Technology
4.	Senior Lecturer (PhD)	Engineering and Technology
5.	Lecturer (PhD)	Technology and Sustainable Development
6.	Lecturer (PhD)	Technology and Sustainable Development
7.	Lecturer (PhD)	Engineering and Technology
8.	Lecturer (PhD)	Engineering and Technology
9.	Lecturer (PhD)	Engineering and Technology
10.	Lecturer (PhD)	Engineering and Technology
11.	Lecturer (PhD)	Technology and Sustainable Development
12.	Lecturer (PhD)	Technology and Sustainable Development
13.	Lecturer (PhD)	Technology and Sustainable Development

14.	Lecturer	Technology and Sustainable Development
15.	Lecturer (Ts)	Technology

*Qualification(s): (i) Ts: Technologists; (ii) PhD: Doctor of Philosophy;

3.4 Data Analysis

Fuzzy Delphi data analysis is executed via Excel using a multi-step computational framework as outlined.

Step 1: An expert, denoted as K, was invited to evaluate the importance of the assessment criteria for the variables being measured using the linguistic variables presented in Table 2.

Table 2: **Level of agreement scale**

Linguistic Variable	Triangular Fuzzy Numbers			Likert Scale
	m1	m2	m3	
Completely Agree	0.9	1.0	1.0	7
Mostly Agree	0.7	0.9	1.0	6
Agree	0.5	0.7	0.9	5
Somewhat Agree	0.3	0.5	0.7	4
Disagree	0.1	0.3	0.5	3
Mostly Disagree	0.0	0.1	0.3	2
Completely Disagree	0.0	0.0	0.1	1

Step 2: Each expert's response on the seven-point linguistic scale was converted into a triangular fuzzy number (TFN), represented as n = (n1,n2,n3), using the fuzzy linguistic scale presented in Table 2. The three values represent the lower, modal and upper values of the expert's judgement.

Step 3: For each construct, the fuzzy responses of the 15 experts were aggregated by calculating the mean for each component of the triangular fuzzy number:

$$m = (m1, m2, m3)$$

where m1, m2 and m3 represent the aggregated lower, modal and upper fuzzy values, respectively.

Step 4: The distance between each expert's TFN and the aggregated TFN was calculated using the vertex distance method:

$$d\,(m,n) = \sqrt{\frac{1}{3}[(m_1 - n_2)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}$$

A threshold value of $d \leq 0.20$ was used to indicate acceptable agreement. The percentage of experts whose threshold values satisfied this criterion was subsequently calculated. A

construct was considered to have achieved group consensus when at least 75% of the experts met the threshold criterion.

Step 5: Following the establishment of expert consensus, the aggregated triangular fuzzy number for each construct was converted into a single fuzzy score (A) using:

$$A = (m_1 + m_2 + m_3) / 3$$

The fuzzy score ranges from 0 to 1. A construct was retained when $A \geq 0.50$. The accepted constructs were subsequently ranked in descending order according to their fuzzy scores, whereby a higher A value indicated a higher priority according to the expert panel.

Step 6: The aggregated fuzzy values were subsequently defuzzified. The defuzzification process converted the Triangular Fuzzy Numbers (TFNs) into a single crisp value, enabling the ranking of each evaluation criterion according to its level of importance. The acceptance of each item was determined based on the α-cut value, which should be equal to or greater than 0.50 (Bodjanova 2006; Tang & Wu 2010). An item was considered acceptable if its defuzzification value (A) exceeded the α-cut value of 0.50, indicating consensus among the experts regarding its importance. Conversely, items with $A < 0.50$ were rejected, as they reflected insufficient expert agreement as seen in Table 3. The final ranking of the evaluation criteria was then established according to the defuzzified values, with higher values indicating greater priority or importance.

Table 3: **Fuzzy Delphi Acceptance Criteria**

Criterion	Acceptance requirement	Purpose
Threshold value (*d*)	≤ 0.20	Determines distance/agreement between expert judgement and group judgement
Expert agreement	≥ 75%	Establishes group consensus
Fuzzy score (A)	≥ 0.50	Determines acceptance of construct
Ranking	Descending A value	Determines relative priority

4 Findings

The expert panel successfully achieved consensus on all eight green competency elements, with each element satisfying the Fuzzy Delphi acceptance criteria of a threshold value ($d \leq 0.20$), expert agreement of at least 80%, and a defuzzification value exceeding the required α-cut value of 0.50. Consequently, all eight elements Green Technology Knowledge, Digital Sustainability Skills, Adaptive Pedagogy, Industry Collaboration, Problem-Solving and Analytical, Innovative Teaching Methods, Resource Management and Green Principles were retained, providing a comprehensive framework of green competencies for Malaysian TVET teacher education as stated in Table 4. These findings demonstrate that the proposed

competency elements are considered essential for preparing future TVET teachers to meet the sustainability demands of contemporary education and industry.

The ranking of the validated elements provides important insights for curriculum planning and teacher preparation. Green Technology Knowledge emerged as the highest-ranked element (0.910), indicating that experts regard a strong understanding of green technologies as the foundation upon which all other green competencies are developed. This finding reflects the increasing demand for TVET educators who are capable of teaching emerging technologies such as renewable energy, energy-efficient systems, sustainable manufacturing and environmentally responsible production processes. Without adequate knowledge of green technologies, trainee teachers may struggle to integrate sustainability concepts into practical instruction or respond effectively to the rapid technological changes occurring across green industries (Martínez-Agut et al. 2025). Therefore, Green Technology Knowledge should be introduced during the early stages of teacher education programmes before progressing to more advanced pedagogical and technical competencies.

Meanwhile, Industry Collaboration was retained as a component of the framework (d = 0.190; expert agreement = 85%; A = 0.842), indicating that the expert panel considered collaboration with industry important for Green TVET teacher education. Nevertheless, this result should be interpreted as academic and TVET expert consensus regarding the importance of industry collaboration, rather than direct validation by industry stakeholders. As the present panel did not include a distinct group of employers or green-industry practitioners, subsequent validation should involve industry representatives, professional bodies and practitioners from relevant green technology sectors.

The equal ranking of Problem-Solving and Analytical, Innovative Teaching Methods, and Green Principles (0.890) further suggests that experts view technical knowledge alone as insufficient for developing competent Green TVET educators. Instead, future teachers must be equipped with higher-order thinking skills, learner-centred pedagogical approaches and strong environmental values to translate theoretical knowledge into authentic classroom and workplace learning experiences. This finding supports contemporary TVET reforms that advocate integrating sustainability through inquiry-based learning, project-based learning, and industry-oriented instructional approaches rather than treating sustainability as an isolated content area (Fitriyanto et al. 2023; Kuusalu et al. 2025). Consequently, teacher education curricula should embed these competencies across teaching methodology courses and professional practice experiences.

Although Resource Management received the lowest ranking (0.837), its acceptance by all experts indicates that it remains an essential component of Green TVET competency. Its relatively lower priority may reflect experts' perception that effective resource management represents an applied competency that builds upon more fundamental competencies, particularly Green Technology Knowledge and Green Principles. In other words, trainee teachers must first understand sustainable technologies and environmental concepts before they can effectively manage resources such as energy, materials and waste within educational

and industrial settings. Rather than suggesting that resource management is unimportant, the findings imply that it should be emphasised after learners have established sufficient conceptual and technical foundations.

These findings have several practical implications for Malaysian TVET teacher education. First, curriculum sequencing should prioritise Green Technology Knowledge as the foundational competency before progressively introducing pedagogical, analytical, collaborative, and resource management competencies. Second, professional development programmes should strengthen educators' technological competencies through continuous training in emerging green technologies and sustainable industrial practices. Third, stronger partnerships between teacher education institutions and industry should be established to provide authentic learning experiences that expose trainee teachers to current green technologies, sustainable workplace practices, and evolving industry standards. Such collaboration would ensure that teacher preparation remains aligned with the aspirations of Malaysia Education Blueprint 2026–2035, National TVET Policy 2030 and the nation's transition towards a sustainable and green economy. Collectively, these findings provide empirical guidance for designing competency-based Green TVET curricula that better prepare future teachers to develop a skilled and environmentally responsible workforce.

Table 4: **Elements of Green Competency for TVET Pre-service Teachers using Fuzzy Delphi Analysis (FDM)**

	Elements	Triangular Fuzzy Numbers		Defuzzification Process				Expert Consensus	Ranking
		Threshold Value, d	Percentage of Expert Group Agreement (≥75%)	m1	m2	m3	Fuzzy Score (A)		
1.	**Green Technology Knowledge**	0.103	90%	0.800	0.940	0.990	0.910	Accepted	1
2.	**Digital Sustainability Skills**	0.146	80%	0.750	0.900	0.970	0.873	Accepted	5
3.	**Adaptive Pedagogy**	0.198	85%	0.710	0.865	0.945	0.840	Accepted	7
4.	**Industry Collaboration**	0.190	85%	0.710	0.870	0.945	0.842	Accepted	6
5.	**Problem-Solving and Analytical**	0.118	90%	0.770	0.920	0.980	0.890	Accepted	2
6.	**Innovative Teaching Methods**	0.094	90%	0.760	0.920	0.990	0.890	Accepted	2
7.	**Resource Management**	0.187	85%	0.700	0.865	0.945	0.837	Accepted	8
8.	Green Principles	0.118	90%	0.770	0.920	0.980	0.890	Accepted	2

4.1 Discussion

The validated framework provides operational definitions, examples of expected learning outcomes, and curriculum implications for each Green TVET competency. Rather than functioning as isolated competencies, the eight constructs represent complementary dimensions of Green TVET teacher education. Green Technology Knowledge serves as the foundational competency upon which higher-order competencies, including Digital Sustainability Skills, Adaptive Pedagogy, and Problem-Solving and Analytical, are progressively developed. Industry Collaboration strengthens the alignment between teacher education and workforce requirements, while Innovative Teaching Methods enable the effective delivery of sustainability content. Resource Management translates sustainability

knowledge into responsible workplace practices, whereas Green Principles provide the ethical foundation underpinning all competencies as seen in Table 5. Collectively, these constructs offer curriculum designers, policymakers, and teacher educators a practical framework for systematically integrating sustainability into Malaysian TVET teacher education programmes.

Table 5: **Operational Definitions, Learning Outcomes and Curriculum Implications of the Validated Green Competency Constructs**

Construct	Definition	Examples of Learning Outcomes	Curriculum Implications
Green Technology Knowledge	Understanding green technologies, sustainable production systems, renewable energy, circular economy and environmentally responsible industrial practices relevant to TVET.	Explain green technologies, evaluate sustainable production methods and apply environmental regulations in vocational contexts.	Introduce as a foundational component of Green TVET curricula through dedicated sustainability and green technology modules.
Digital Sustainability Skills	Ability to utilise digital technologies to support sustainable practices, including data analysis, digital monitoring, simulation and smart technologies.	Use digital tools to monitor energy consumption, analyse sustainability data, and integrate Industry 4.0 technologies into green practices.	Integrate digital sustainability applications across practical and technology-based courses.
Adaptive Pedagogy	The capability to modify teaching strategies according to learners' needs while embedding sustainability concepts into instructional practices.	Design flexible, learner-centred lessons that incorporate sustainability principles using differentiated instructional approaches.	Strengthen pedagogical courses through problem-based, project-based and experiential learning approaches.
Industry Collaboration	The ability to establish and maintain partnerships with industry to ensure Green TVET programmes remain relevant to current workforce needs.	Collaborate with industry partners, participate in workplace-based learning and integrate industrial sustainability practices into teaching.	Expand industry attachments, collaborative projects and co-developed curricula with green industries.
Problem-Solving and Analytical	The ability to identify, analyse and solve sustainability-related problems using critical and analytical thinking.	Analyse environmental issues, evaluate alternative sustainable solutions and justify decisions using evidence-based reasoning.	Embed authentic sustainability case studies and real-world problem-solving activities throughout the curriculum.
Innovative Teaching Methods	The application of creative and technology-enhanced pedagogical approaches to improve sustainability learning.	Develop innovative learning activities using simulations, digital technologies, AR/VR, and project-based learning.	Encourage active learning, educational technologies and innovation-driven teaching practices in teacher education.
Resource Management	The ability to manage energy, materials, water,	Implement resource-efficient practices,	Integrate sustainable resource management

	waste and other resources efficiently while promoting environmental sustainability.	minimise waste and apply sustainable resource management principles during teaching and practical activities.	practices into laboratory work, workshops and campus-based learning activities.
Green Principles	Commitment to environmental ethics, sustainable values and responsible professional practices that support long-term sustainability.	Demonstrate environmentally responsible behaviour, apply sustainability ethics and promote green values in educational settings.	Embed sustainability values across all courses and reinforce them through institutional policies, community engagement and reflective practice.

5 Recommendation

Greening technical and vocational tracks requires systemic interventions rather than superficial changes. Educational authorities and TVET institutions must implement a coordinated strategy that simultaneously targets curriculum structures, educator training, and industrial alignment. Because isolated reforms fail, stakeholders must treat these changes as interdependent pillars of human capital development. The following sections outline actionable recommendations to resolve current institutional deficiencies and establish a resilient framework for TVET teacher preparation.

5.1 Comprehensive Teacher Training

TVET institutions must institutionalize comprehensive teacher training to resolve the lack of environmental expertise among faculty. First, institutions need to develop targeted professional development programs that actively enhance educators' knowledge of green technologies and sustainability practices (Chinedu et al. 2023). Second, instead of treating these concepts as optional or peripheral topics, training providers must systematically embed green competency into both pre-service and in-service teacher education frameworks. Shifting away from isolated workshops toward structured, mandatory training ensures that all educators acquire the robust subject-matter expertise needed to deliver modern environmental education confidently (Sholikhah et al. 2026).

5.2 Curriculum Reorientation

TVET institutions must comprehensively revise their curricula to integrate sustainability principles across all subjects. Rather than leaving environmental topics isolated, curriculum designers must embed these core principles into every technical track. This overhaul ensures direct alignment with both contemporary industry needs and the global Sustainable Development Goals (SDGs) (Lyu et al. 2025). By updating rigid, legacy frameworks to reflect modern green economies, institutions provide pre-service teachers with the relevant knowledge base they need to train a sustainable workforce (Feby et al. 2026).

5.3 Strengthen Industry Partnerships

Establishing active partnerships with the private sector allows TVET centers to align their training programs directly with real-world workplace demands. Through joint committees and knowledge-sharing networks, institutions can easily integrate current environmental technologies and operational standards into teacher preparation (Moshi et al. 2024; Muhaemanurrohmah & Widiaty 2026). This close collaboration provides pre-service teachers with the hands-on exposure they need to understand modern commercial green practices (Saputro 2024; Subrahmanyam 2025). By securing these vital market links, TVET institutions ensure their graduates possess the relevant, practical skills that sustainable businesses require.

5.4 Innovative Pedagogical Models

Implementing student-centered teaching frameworks transforms how educators deliver environmental concepts in the classroom. TVET institutions should adopt progressive, action-oriented training models to promote adaptive, collaborative and sustainability-focused learning (Al Hadi et al. 2025). Integrating these modern methodologies shifts instruction away from passive lectures toward dynamic, project-based problem-solving (McDonagh et al. 2026). This strategic shift allows pre-service teachers to master the hands-on, interactive techniques they need to cultivate practical green competency in their own future classrooms (Varma & Malik 2023).

6 Limitations

This study has two principal limitations. First, although the expert panel represented relevant expertise in TVET, engineering, technology and sustainable development, it consisted predominantly of academics and educational professionals. Consequently, the findings represent expert consensus within the TVET education context and should not be interpreted as direct industry validation. In particular, the Industry Collaboration construct reflects experts' assessment of its importance rather than the views of employers or industry practitioners themselves. Future studies should therefore extend the validation process to employers, professional bodies, green-technology practitioners and other industry stakeholders. Second, the Fuzzy Delphi Method establishes expert consensus and relative priority but does not empirically demonstrate the effectiveness of the proposed constructs in practice. Subsequent studies should examine the framework through curriculum implementation, competency assessment and validation across different TVET institutions and occupational sectors.

7 Conclusion

Malaysian TVET teacher education currently grapples with significant structural barriers that hinder the effective integration of green competency. Pervasive deficiencies in educator

expertise, inflexible curriculum frameworks, detached industry relations and conventional teaching methods stall the progress of environmental initiatives. Traditional instructional approaches and limited educator familiarity with emerging green technology leave theoretical sustainability policies isolated from actual classroom practice. These compounded institutional challenges effectively block both pre-service and in-service teachers from gaining the specialized knowledge required to upskill the nation's vocational workforce.

Successful transformation depends on holistic reforms that anchor teacher preparation directly to the strategic goals of the Malaysia Education Blueprint 2026–2035 and the National TVET Policy 2030. Educational authorities must deploy a unified strategy that mandates comprehensive instructor upskilling, Embeds green competency into core curricula, solidifies industry-led governance networks and introduces active pedagogical models. Replacing sporadic workshops with systemic, market-driven training ensures that vocational educators actively master modern environmental benchmarks and planetary health principles. This structural modernization ultimately secures the agile, high-income human capital pipeline essential for driving Malaysia's green industrial transition.

8 Implication

Systematically upskilling educators and embedding green competency will successfully elevate TVET into a high-prestige pathway that advances the goals of the modern economic framework. Proactive modernization allows institutions to cultivate a highly capable, future-ready workforce and accelerates national transitions into thriving sectors like green manufacturing, renewable energy and sustainable agriculture. Ultimately, these structural reforms secure the agile, high-income human capital pipeline necessary to achieve net-zero goals, drive industrial innovation and champion long-term competitiveness in the global green economy.

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