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Designing a Sustainable Cultural Ecosystem Framework for Malaysian Polytechnics Using the CDIO Approach

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ABSTRACT

This study introduces a purpose-driven Sustainable Cultural Ecosystem Framework (SCEF) designed specifically for Malaysian Polytechnics to embed sustainability comprehensively within institutional culture and educational practices across all facets of Technical and Vocational Education and Training (TVET). Guided by a Design-Based Research (DBR) methodology, the investigation progressed through four phases—assessing contextual needs, developing the framework model, engaging in expert validation, and executing successive refinements—drawing participation from 386 polytechnic staff and domain experts to ensure contextual and practical relevance. The proposed framework strategically integrates sustainability principles with the CDIO (Conceive–Design–Implement–Operate) engineering education model, fostering alignment between technical innovation and sustainable transformation while promoting curricular reform, inclusive governance, and value-driven cultural change. Four enabling dimensions emerged—sustainable leadership, strategic communication, staff engagement, and eco-oriented management competence—which collectively shape the SCEF model as a comprehensive institutional sustainability roadmap. The novelty of this work lies in merging cultural ecosystem theory and the CDIO methodology to produce a scalable, locally contextualized sustainability model for TVET, offering strategic guidance for policy-makers, educators, and administrators in nurturing future-ready polytechnics.

1.0 Introduction

The integration of sustainability into higher education institutions, particularly within Technical and Vocational Education and Training (TVET), has become an urgent global priority. In the context of Malaysia's commitment to the Sustainable Development Goals (SDGs), polytechnics are uniquely positioned to serve as catalysts for producing graduates who are not only technically competent but also sustainability conscious. Central to this mission is the concept of *Sustainable Culture*, which refers to the shared values, norms, and practices that embed sustainability into the daily life, governance, and operations of an institution. A strong sustainable culture extends beyond compliance with environmental policies; it influences decision-making, pedagogical approaches, campus operations, and community engagement, thereby shaping both institutional identity and graduate outcomes. Globally, research indicates that embedding

sustainability as a cultural norm enhances institutional resilience, strengthens stakeholder commitment, and produces graduates better prepared for green and circular economies (Sterling, 2020; UNESCO, 2023). For TVET institutions, where hands-on and industry-relevant training is core, a sustainability-oriented culture is critical to aligning technical expertise with environmental stewardship and social responsibility.

This study is grounded in three complementary theoretical perspectives. First, **Ecological Systems Theory** (Bronfenbrenner, 1979) explains how individual attitudes and behaviours toward sustainability are shaped by interconnected layers of influence, from institutional governance to community partnerships. Second, **Organizational Change Theory** (Lewin, 1951) provides a structured lens for guiding transformation through its "unfreeze–change–refreeze" model, ensuring that sustainability becomes a permanent feature of institutional practice. Third, the **CDIO Educational Framework** (Crawley et al., 2014) offers a systematic, real-world problem-solving approach, making it an effective vehicle for integrating sustainability into engineering and technical education. Together, these theories support the development of a framework that is both culturally relevant and operationally effective for Malaysian polytechnics.

Despite numerous sustainability initiatives in Malaysian higher education, most efforts remain fragmented, often focusing on isolated environmental campaigns or ad hoc projects rather than systemic integration. There is currently no culturally tailored, whole-institution model for embedding sustainability into polytechnic culture. This gap motivates the present study, which proposes the **Sustainable Cultural Ecosystem Framework (SCEF)**—a model that strategically combines sustainability principles, cultural ecosystem theory, and the CDIO approach to drive institutional transformation.

Aim of the Study: The aim of this investigation is to design, validate, and pilot a Sustainable Cultural Ecosystem Framework (SCEF) that enables Malaysian polytechnics to embed sustainability as an institutional identity, aligning leadership, curriculum, campus operations, community engagement, and student empowerment with the SDGs through a structured, iterative process.

2.0 Literature review

Sustainability integration within Technical and Vocational Education and Training (TVET) has been widely recognized as essential for equipping learners with the skills, values, and mindsets required in the 21st-century workforce. Globally, UNESCO (2023) and OECD (2022) have emphasized that TVET must not only provide technical proficiency but also embed environmental stewardship, social responsibility, and economic viability into institutional systems. Countries such as Finland, Germany, and Australia have adopted whole-institution sustainability models that align curriculum, operations, and stakeholder engagement with the SDGs, demonstrating how cultural integration of sustainability can improve both educational outcomes and institutional performance. These global examples illustrate that sustainable transformation is most successful when it becomes a shared cultural norm rather than a series of isolated initiatives.

In Malaysia, the Ministry of Higher Education has advanced multiple green and sustainability policies, including the *Dasar Amalan Hijau* and the *SDG Malaysia Roadmap*, yet implementation across TVET institutions has been uneven (Norazah et al., 2021). Polytechnics, which form a significant segment of Malaysia's public TVET system, face unique challenges: diverse geographical contexts, varying resource availability, and differing levels of leadership commitment to sustainability. While individual polytechnics have undertaken notable projects—such as renewable energy adoption, campus greening, and SDG-focused curricula—these efforts often remain siloed. A unified, contextually relevant framework is needed to institutionalize sustainability across the entire system. This justifies the focus of the present study on Malaysian polytechnics as a critical site for developing a culturally embedded sustainability framework.

Three interrelated constructs form the conceptual foundation of this study:

2.1. Sustainability

In the educational context, sustainability encompasses environmental, social, and economic dimensions, ensuring that institutional policies, teaching practices, and campus operations align with long-term ecological balance and societal well-being (Sterling, 2020). For TVET institutions, sustainability also implies preparing graduates for emerging green industries and sustainable entrepreneurship.

2.2. Cultural Ecosystem

The concept of a cultural ecosystem refers to the network of shared values, norms, symbols, and practices that shape institutional identity and guide behaviour (Schein, 2010). In a sustainable cultural ecosystem, sustainability principles are reflected in leadership priorities, staff engagement, student activities, and community partnerships, creating a reinforcing cycle of sustainable practice (Azman & Yusoff, 2022).

2.3. CDIO Educational Framework

Originally developed for engineering education, the CDIO (Conceive–Design–Implement–Operate) model promotes experiential, systems-oriented learning that mirrors real-world engineering processes (Crawley et al., 2014). CDIO has been increasingly adopted in TVET as a pedagogical and organisational framework, offering a structured pathway for embedding sustainability into both curriculum design and institutional change processes (Roos & Malmqvist, 2020).

The intersection of these constructs remains underexplored, particularly within Malaysian TVET. Existing studies often address sustainability in isolation from institutional culture or pedagogical frameworks. This study addresses this gap by integrating sustainability, cultural ecosystem theory, and the CDIO approach into a single Sustainable Cultural Ecosystem Framework (SCEF) tailored for Malaysian polytechnics.

3.0 Methodology

This study employed a **Design-Based Research (DBR)** methodology to develop, validate, and refine the Sustainable Cultural Ecosystem Framework (SCEF) for Malaysian polytechnics. DBR is well-suited to educational innovation because it integrates theory-driven design with iterative cycles of testing and refinement in authentic settings (Wang & Hannafin, 2005; Anderson & Shattuck, 2012). The approach allows researchers to collaborate closely with practitioners, ensuring that the resulting framework is both theoretically sound and contextually relevant.

The DBR process in this study was structured around the **CDIO (Conceive–Design–Implement–Operate)** model, providing a logical sequence for integrating sustainability into institutional culture. Rather than treating these as discrete stages, the CDIO phases were embedded in a continuous improvement cycle where insights from one phase informed refinements in the next.

3.1 Phase 1: Conceive – Needs Analysis and Problem Identification

The study began with a situational analysis of Malaysian polytechnic sustainability practices. This involved reviewing key policy documents such as the *Dasar Amalan Hijau*, the *SDG Malaysia Roadmap*, and institutional strategic plans to identify national priorities and institutional commitments. To capture on-the-ground perspectives, **semi-structured interviews** and **focus group discussions (FGDs)** were conducted with 386 participants, including academic staff, sustainability officers, administrators, and student leaders from five selected polytechnics representing diverse geographical and operational contexts. Semi-structured interviews were chosen for their flexibility in eliciting detailed, context-rich responses while allowing for comparison across participants (Creswell & Guetterman, 2021). Participant selection followed

purposive sampling to ensure representation from institutions with varying levels of sustainability maturity.

3.2 Phase 2: Design – Framework Development and Expert Validation

Findings from Phase 1 informed the preliminary design of the SCEF, integrating sustainability principles, cultural ecosystem theory, and the CDIO model. The framework was further structured around the **Whole-Institution Approach (WIA)**—emphasizing leadership, operations, curriculum, and community engagement—and a **5P Green Project Management** lens (Product, Process, People, Planet, Performance) to ensure measurable outcomes.

To validate and refine the framework, the **Delphi technique** was applied with a panel of 12 experts, including sustainability scholars, TVET administrators, industry partners, and CDIO practitioners. Experts were selected based on published work, institutional roles, and professional experience in sustainability integration. Two Delphi rounds were conducted:

- **Round 1:** Experts reviewed the framework and provided qualitative feedback on conceptual clarity, feasibility, and scalability.
- **Round 2:** Revised elements were re-circulated, and experts rated their level of agreement using a 5-point Likert scale. **Consensus** was defined as ≥80% agreement on each component.

3.3 Phase 3: Implement – Pilot Testing and Iteration

The validated framework was piloted at two polytechnics over a six-month period. Implementation activities included curriculum mapping against SDG indicators, the establishment of "Green Ambassadors" student programmes, deployment of digital dashboards for tracking energy, water, and waste, and targeted staff training on sustainability competencies. Data collection involved participant observation, post-implementation surveys, and reflective journals to capture experiences and challenges during the pilot phase.

3.4 Phase 4: Operate – Evaluation and Finalization

A formative evaluation was conducted using the **Kirkpatrick Model** (Levels 1–3), assessing participant reaction, learning outcomes, and observable behavioural changes. Impact indicators were aligned with both SDG targets and institutional Key Performance Indicators (KPIs), ensuring compatibility with existing quality assurance mechanisms such as COPPA and ISO 14001. Based on the evaluation results and a final expert review, refinements were incorporated into the SCEF to ensure adaptability across polytechnics with different resource capacities and cultural contexts.

3.5 Ethical Considerations

Ethical clearance was obtained from the Polytechnic Education Research Ethics Committee. All participants provided informed consent, and confidentiality was maintained through anonymisation of data and secure storage of research records.

4.0 Discussion of analysis and findings

The analysis revealed a set of interrelated cultural, organisational, and pedagogical factors that influence the integration of sustainability within Malaysian polytechnics. Findings are presented according to the CDIO-informed development phases of the Sustainable Cultural Ecosystem Framework (SCEF), with supporting evidence from the pilot implementation and alignment to existing literature.

4.1 Cultural Fragmentation and Lack of Systematic Sustainability Integration (Conceive Phase)

Stakeholder interviews and FGDs consistently indicated that sustainability within polytechnics was largely perceived as limited to environmental activities—such as tree planting or recycling drives—rather than a systemic, cross-functional mandate. Policies often existed in

name but lacked operational alignment and institutional ownership. This mirrors UNESCO's (2021) assertion that sustainability efforts fail when disconnected from institutional culture and strategic governance. The absence of integrated policies, structured capacity-building, and interdepartmental coordination created siloed initiatives, with limited cross-campus learning or scaling of best practices. These findings confirmed the need for a whole-institution, culturally embedded approach that would unify academic, operational, and community sustainability efforts.

4.2 Core Pillars of the Sustainable Cultural Ecosystem Framework (Design Phase)

Expert consultation and thematic analysis yielded **five core pillars** that together form the backbone of the SCEF:

i. **Leadership and Governance for Sustainability** – Integrating sustainability into strategic plans, governance structures, and decision-making processes, ensuring top-down commitment that cascades institution-wide.

ii. **Curriculum Transformation** – Embedding Education for Sustainable Development (ESD) principles and CDIO-aligned sustainability modules into course design and assessment, promoting interdisciplinary problem-solving.

iii. **Green Campus Operations** – Implementing sustainable infrastructure, procurement, and resource management policies to reduce environmental impact.

iv. **Community and Industry Engagement** – Establishing partnerships to co-create sustainability solutions, enhancing real-world relevance and impact.

v. **Student Empowerment and Cultural Shift** – Fostering student-led sustainability projects, peer learning, and eco-entrepreneurship to embed values at the grassroots level.

These pillars are interconnected through a CDIO-aligned cycle, ensuring that sustainability is continuously conceived, designed, implemented, and operated in practice. Similar frameworks have been effective in Europe and Australia (Lozano et al., 2021), suggesting strong transferability of the SCEF model to global TVET contexts.

4.3 Pilot Implementation Outcomes (Implement Phase)

The six-month pilot in two polytechnics tested the operational feasibility of the SCEF. Key initiatives included curriculum mapping to SDG indicators, establishing "Green Ambassador"

Student structured, iterative design process provided a clear mechanism for translating sustainability concepts into tangible, curriculum-linked actions.

Teams, developing real-time digital dashboards to track resource consumption, and conducting targeted sustainability training for staff.

- **Staff impact**: Post-pilot surveys showed a 45% increase in self-reported sustainability literacy, with notable improvements in the ability to integrate SDGs into teaching.

- **Student impact**: 70% of students expressed greater willingness to participate in campus sustainability initiatives, and student-led projects received increased visibility at institutional events.

- **Operational outcomes**: One pilot campus recorded a 12% reduction in electricity use over the period, attributed partly to behaviour change campaigns and improved monitoring.

These results align with findings by Sterling (2020) and Fullan (2019), who note that visible early wins in sustainability efforts strengthen institutional buy-in and cultural adoption.

4.4 Behavioural and Institutional Change (Operate Phase)

Using the **Kirkpatrick Model** for evaluation:

- **Level 1 (Reaction)**: Participants described the SCEF as relevant, adaptable, and practical for the polytechnic context.
- **Level 2 (Learning)**: Gains in sustainability knowledge and systems thinking were reported across both staff and student cohorts.
- **Level 3 (Behaviour)**: Observable changes included incorporation of sustainability rubrics into course assessments, proactive student-led initiatives, and cross-departmental sustainability committees.

Notably, institutional transformation was strongest in cases where leadership visibly championed sustainability—echoing Drucker's view that "culture eats strategy for breakfast." CDIO's

4.5 Key Insights and Strategic Implications

Three critical insights emerged:

i. **Sustainability as a Cultural Practice** – Success depends on embedding sustainability into the institution's cultural fabric through rituals, language, symbols, and shared narratives, not just through policies.

ii. **CDIO as a Change Enabler** – CDIO offers a flexible yet disciplined approach for integrating sustainability into both learning and institutional processes, promoting systems thinking and interdisciplinary collaboration.

iii. **Scalability and Adaptability** – The modular nature of the SCEF allows adaptation to varied campus contexts (urban/rural, resource-rich/resource-limited) and alignment with existing quality assurance systems such as COPPA and ISO 14001.

These findings position the SCEF not only as a framework for Malaysian polytechnics but also as a potential model for sustainable transformation across regional and international TVET systems.

5.0 Conclusion and Future Research

This study set out to design, validate, and pilot the **Sustainable Cultural Ecosystem Framework (SCEF)** to address the fragmented and ad hoc nature of sustainability practices within Malaysian polytechnics. Guided by the **Design-Based Research (DBR)** methodology and anchored in the **CDIO (Conceive–Design–Implement–Operate)** approach, the SCEF integrates sustainability principles, cultural ecosystem theory, and systemic institutional change strategies into a cohesive, contextually relevant model. The framework's five core pillars—leadership and governance, curriculum transformation, green campus operations, community and industry engagement, and student empowerment—provide a comprehensive roadmap for embedding sustainability as an institutional identity rather than a peripheral initiative.

The pilot implementation demonstrated that when sustainability is approached as a cultural practice, supported by strong leadership and CDIO's iterative design process, measurable gains can be achieved in sustainability literacy, behavioural change, and cross-departmental collaboration. The results also confirmed that a modular, adaptable framework can be tailored to diverse campus contexts while aligning with existing quality assurance systems such as COPPA and ISO 14001. In doing so, the SCEF responds directly to the study's aim of creating a scalable, culturally embedded sustainability model for Malaysian polytechnics that aligns with the SDGs and national education policy priorities.

Future research should explore the **long-term impact** of SCEF adoption through longitudinal studies that track cultural and operational shifts over multiple years. **Quantitative validation** of the framework's effectiveness in improving sustainability-related learning outcomes, operational efficiency, and SDG performance metrics is also warranted. Cross-institutional **benchmarking** within Malaysia and internationally would provide insights into best practices and adaptability across TVET systems. Moreover, there is potential for **AI and digital integration**—such as AI-powered dashboards, predictive analytics, and immersive learning tools—to monitor and accelerate sustainability progress in real time. Investigating **policy integration pathways** could ensure that SCEF principles are embedded within national accreditation and governance frameworks, while examining **student-led innovation and green entrepreneurship** could extend sustainability culture beyond the campus into the wider community.

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Author Contributions

M.R. Author: Conceptualization, Methodology, Software, Writing- Original Draft Preparation; **Y.Y. Author**: Data Curation, Validation, Supervision; **T.A. Author**: Software, Validation, Writing-Reviewing and Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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