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Engineering Management of Green Campus Infrastructure and Climate Education in Indonesian Higher Education

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ABSTRACT

Indonesian universities face a coupled implementation problem: climate policies and sustainability education are expanding, yet campus infrastructure is rarely monitored to verify environmental performance. This study develops an engineering management framework for connecting institutional decisions, multi-sector delivery, green campus assets, and climate change education. A review of 50 studies was integrated with surveys and interviews involving 131 participants at 12 state-university science teacher education faculties (12 leaders, 39 lecturers, and 80 pre-service teachers). In the reviewed set, 25/50 studies described green campus programs and 28/50 examined partnerships; these are frequencies of publication themes, not measured intervention effects. Leaders rated SDG-aligned strategy at 4.0 but learning resources at 3.3 and innovation incentives at 3.2; lecturers rated responsibility for climate education at 4.6 but training at 3.6; students rated readiness at 4.4 but confidence in explaining climate concepts at 3.64. These descriptive gaps identify execution constraints. The proposed stage-gated framework assigns an asset owner and external partners, records baselines, prioritizes projects based on cost and performance criteria, and verifies energy, water, waste, and emissions outcomes before operational data is used in teaching. No campus meter, cost, or emissions dataset was collected; therefore, infrastructure savings and causal effects cannot be estimated. The framework offers a reproducible measurement and governance protocol for a prospective campus pilot.

1. Introduction

1.1 Engineering management problem

Universities can commit to climate change education (CCE) while operating their buildings, lighting, water, waste, and renewable-energy assets without a common baseline or a performance

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owner. In Indonesian higher education, this disconnect makes it difficult to verify a green campus program: the presence of a policy, course, or installation does not demonstrate avoided energy use or greenhouse gas emissions. The engineering management problem is to translate institutional climate goals into funded projects, defined operating responsibilities, monitored assets, and feedback to teaching [1–3].

The present real-world setting comprises 12 Faculties of Mathematics and Natural Sciences at Indonesian state universities, where policy leaders, lecturers, and preservice teachers participate in climate education. The study does not claim that the 12 campuses operated a common infrastructure retrofit. Instead, it examines whether the organizational conditions needed to commission, operate, and learn from such interventions are in place. Campus infrastructure supplies a technically testable use case for an integrated management system.

Sustainability education can serve an applied role when students use metered campus data to estimate loads, compare design alternatives and communicate uncertainty. CCE then becomes part of the implementation loop: facilities teams expose suitable anonymized data, lecturers translate the data into projects, and students evaluate whether a physical intervention meets its design target [4–8]. An educational activity alone cannot substantiate a carbon reduction; that claim requires measured energy or material flows and an explicit emission factor.

A review of campus sustainability in Indonesia describes fragmented policies, uneven investment, and inconsistent partnerships, and these concerns have operational consequences [9–12]. Without an agreed-upon asset boundary, baseline, accountable owner, and maintenance budget, universities cannot compare a lighting retrofit with a photovoltaic system, demonstrate savings after commissioning, or allocate responsibility for data quality to a partner. Existing engineering management tools address parts of this problem but not its combination: energy management systems and measurement and verification protocols presuppose a defined facility owner and a metered boundary, and stage-gate project management supplies go/no-go decisions without sustainability baselines or emission factors, whereas none of them is designed to allocate university–government–industry responsibilities or to return audited data to climate education [13,14]. A conventional program inventory records activities; an engineering management approach links each decision to a technical acceptance criterion and a verification record; the reviewed Indonesian literature, however, chiefly reports program existence and rankings rather than this link.

Campus assessment and management frameworks illustrate the contrast: readiness analyses based on UI GreenMetric and multi-method sustainability frameworks assess institutions across several dimensions, and whole-institution approaches embed the Sustainable Development Goals in governance, operations and reporting [7,15–18]. Carbon-management and campus technology studies come closer to physical assets, as in strategies that proceed from carbon assessment to action and in LED-lighting innovation in universities, but they are organized around carbon assessment or a single technology, so the allocation of decision rights, partner duties and teaching use is not their primary object [19,20]. The present framework therefore does not claim novelty for baselines, normalized savings or stage gates, which are established practice in energy management and project management; its novelty claim is limited to coupling them in one protocol with an explicit responsibility matrix for universities, public agencies and suppliers and with the return of audited data to climate change education [21,22]. This coupling, rather than any single component, is the element offered for testing, and the evidence in this article supports only the diagnosis of the gap it addresses, not the framework's performance.

We formulate a five-stage management framework: (1) scope the asset and assign decision rights; (2) establish baseline resource flows and climate factors; (3) rank feasible interventions subject to budget and operational constraints; (4) commission and operate the chosen systems with a

university–government–industry responsibility matrix; and (5) verify outcomes and use audited data in CCE. This is a proposed systems engineering model derived from the reviewed evidence, not an empirically validated optimization algorithm.

The engineering object is an existing campus portfolio comprising building energy and lighting, onsite generation, water and waste systems. Its outcomes are annual electricity intensity (kWh/m²/year), normalized electricity savings (%), avoided operational emissions (tCO_2e/year), water use (m³/person/year), waste diversion (%), availability (%) and whole-life cost. These indicators specify what must be collected in a future campus pilot. They are not reported as achieved improvements in the current dataset.

The field component tests a narrower, observable issue: readiness to execute climate commitments across leadership, teaching staff and students. The 12-faculty study includes 12 leaders, 39 lecturers and 80 preservice teachers. Comparing commitment with resources, training, and applied confidence yields an implementation diagnosis; it does not measure energy, water, or emissions. The review and field evidence are therefore integrated into management requirements rather than presented as a completed infrastructure trial.

This article contributes an evidence-based framework and a technical monitoring specification for Indonesian university decision-makers. It separates observed educational and governance scores from proposed engineering performance indicators, enabling a future facilities team to test whether infrastructure investment delivers both verified environmental outcomes and usable teaching data. Relative to existing green campus management systems, sustainability assessment frameworks, and engineering project management approaches, the new elements are the explicit coupling of stage gates with adjusted-baseline verification, a responsibility matrix spanning university, government and industry roles, and the educational reuse of audited asset data, while the individual components are adopted from established practice. The study does not demonstrate that this combination outperforms those alternatives, so the comparison presented in the Discussion is analytical rather than empirical.

1.2 Research questions and scope

The analysis asks: Which implementation gaps occur between institutional climate goals, campus operations, and CCE? What monitoring and decision process would make green campus investments technically verifiable? Which roles should universities, public agencies and suppliers assume at each project gate? The empirical boundary is science teacher education in 12 Indonesian state-university faculties; the infrastructure framework is a design implication, not an observed intervention at any of the 12 sites.

The study has three objectives: to synthesize existing review evidence on policy, infrastructure, and collaboration; to quantify descriptive differences among leadership, lecturer, and student responses; and to specify a reproducible engineering management protocol for prioritizing and verifying campus projects. Cross-campus energy or carbon savings are outside the observable scope because building-level resource, weather, occupancy, capital cost, and emission factor data were not supplied.

2. Materials and methods

2.1 Convergent evidence and system boundary

We combine a literature review with a cross-sectional mixed-methods study and translate their findings into a prospective engineering management specification [23–26]. The review characterizes

documented programs and governance arrangements; survey summaries and interviews characterize implementation capacity. The unit of field observation is a respondent within a participating faculty. The unit of a future technical evaluation would be an individually metered building or asset, with an explicit temporal baseline and intervention boundary. This distinction prevents respondent scores from being treated as engineering performance.

2.2 Literature identification and synthesis

This review identified 50 included studies on higher education in Indonesia, CCE, sustainability practices, governance, and collaboration, with searches conducted in Scopus, Web of Science, ERIC, and ScienceDirect, as well as backward and forward citation tracking and thematic screening during the specified period of 2010–2024. These sources reported 121 records initially identified and 187 records subsequently screened, as shown in Figure 1; since the screening process could not exceed the number of records identified in a single database search, the difference of 66 records most likely reflects records added through citation tracking. However, the source does not elaborate on this, so both figures are reported as is; neither was used in any calculations, and the 50 included studies are the only figures used in subsequent analysis. No complete, dated search logs, duplicate counts, or exclusion lists are available; therefore, this search cannot be independently replicated in accordance with PRISMA guidelines until the original records are reconciled. The 2010–2024 timeframe defines only the search period for this review, and the number of themes is presented as reported rather than recalculated from this bibliography. Meanwhile, entries published outside this period—namely, six publications from 2025 and two earlier methodological sources—serve as contextual or comparative support and are not included in the calculated evidence base.

We retained the review's reported frequencies as descriptive counts of themes. Studies could receive multiple codes, so counts must not be summed as mutually exclusive observations. Policy, green campus, collaboration, research, and governance were mapped against the asset lifecycle: policy and scope; feasibility and finance; procurement and installation; operation and maintenance; measurement and verification; and educational use. The review did not supply comparable measured energy, water, cost, or emissions outcomes for pooled effect estimation. Theme counts are interpreted as evidence coverage, not effectiveness rates.

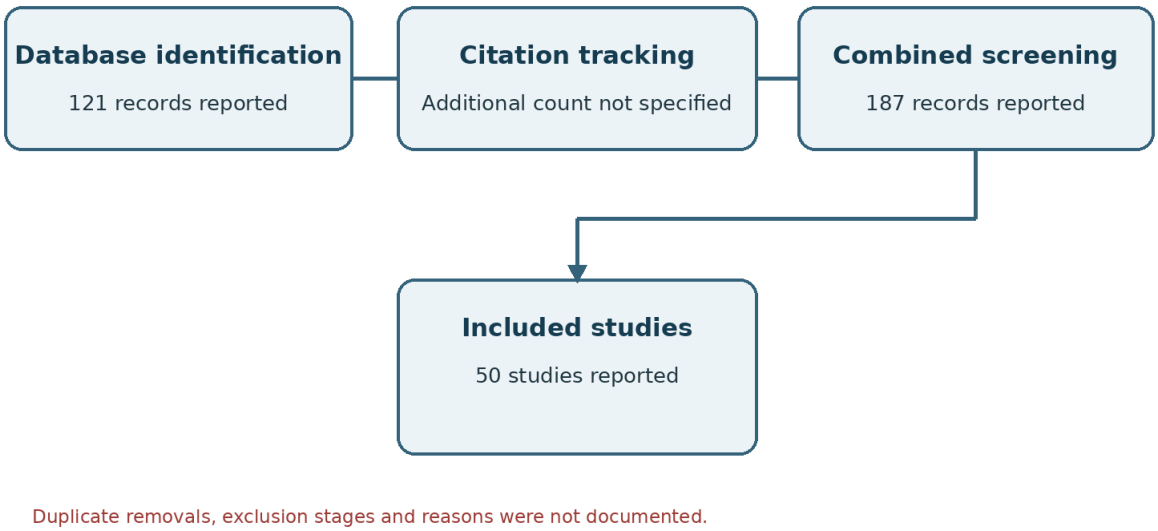


Fig. 1. Reported literature flow; intermediate screening and exclusion details were unavailable

2.3 Cross-sectional field study

Fieldwork covered 12 Faculties of Mathematics and Natural Sciences at state universities in western, central, and eastern Indonesia between May and September 2025, with 12 institutional leaders, 39 lecturers, and 80 preservice teacher students (total n = 131), structured lecturer and student surveys addressing the aspects in Table 1, and semi-structured interviews with leaders and selected lecturers that lasted approximately 45–60 minutes and were transcribed. The source does not document how the 12 faculties or the 131 respondents were selected, so the sample is treated as a non-probability sample of accessible faculties; voluntary participation is documented only through consent for the recorded interviews, while survey consent, response rates, item wording, response scale, missing-data handling, and the interview coding audit trail require clarification before independent reproduction. Selection bias is therefore addressed by restriction rather than correction: with about 3.3 lecturers and 6.7 students per faculty on average, no between-faculty comparisons, institutional percentages, or population estimates are made, and respondents more engaged with climate education may be over-represented. Descriptive means are reported as supplied for selected items. However, the source describes chi-square and ANOVA procedures; no distributions, test statistics, confidence intervals, or p-values are available, so no inferential significance is claimed, and interview themes interpret the descriptive pattern without proving causal relations.

Table 1
Assessment aspects examined for each respondent group in the empirical study

Respondent Group	n	Assessment Aspects
Institutional leaders	12	Community engagement commitment; institutional strategy for the SDGs; explicit curriculum integration; formal written policies; faculty training support; provision of learning resources; incentives for innovation
Lecturers	39	CCE responsibility; technological innovation in teaching; course linkage to climate issues; sustainability integration; experiential learning; interdisciplinary approaches; competency assessment tools
Prospective teacher students	80	Integration of CCE into future teaching roles; awareness of climate impacts; interdisciplinary understanding; motivation for climate action; access to learning resources; application of concepts to daily life; participation in reflective projects; confidence in explaining climate concepts

3. Results

3.1 Literature coverage and infrastructure evidence

Among 50 reviewed studies, 25 described green campus programs (50% of the reviewed set), 28 examined partnerships (56%), 22 addressed research promotion (44%), and 27 highlighted governance (54%). These are study frequencies, not university adoption rates. The overlap is expected because one publication may cover multiple themes. Taken together, the publications document growing interest in policy and collaboration but do not establish comparable campus-level operational outcomes.

Energy efficiency, renewable energy generation, water conservation, waste management, and building operations recur as proposed campus interventions. Their deployment depends on infrastructure funding, technical staffing, procurement and maintenance. The original synthesis also identifies 12 studies on curricular integration. An installation is a useful teaching asset only when

operating data, safety controls and a clear explanation of baseline conditions are available to lecturers and students.

Table 2 translates each sustainability domain into an engineering system and a candidate acceptance indicator. The literature chiefly reports program existence and rankings, while the 12-faculty field study did not collect facility-level meter readings. Consequently, no kWh/m² improvement, percentage water savings, waste diversion gains, or tCO_2e reductions can be calculated from these data. This missing measurement is itself an implementation finding: projects cannot be compared or verified consistently when the institution collects only program descriptors.

Table 2
Engineering-relevant domains of campus sustainability frameworks cited in the reviewed literature, and the technical performance indicators that would substantiate them

Sustainability domain	Underlying engineering system	Performance indicator required for verification	Evidence reported in the reviewed literature
Energy and climate change	Building energy systems and renewable energy generation	Energy intensity (kWh/m²/year); installed renewable capacity (kWp); renewable energy generation (kWh/year)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Lighting retrofit and green facilities	Luminaire, lighting control, and building electrical systems	Luminaire efficacy (lm/W); electricity reduction (%); annual energy savings (kWh/year)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Solar photovoltaic adoption	PV and PVPCM thermal management systems	Electrical conversion efficiency (%); thermal efficiency (%); annual energy yield (kWh/year)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Waste management	Waste sorting, treatment, recycling, and disposal systems	Waste generation (kg/capita/year); diversion rate (%); recycling rate (%); treatment efficiency (%)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Water management	Water supply, treatment, reuse, and distribution systems	Water consumption (L/capita/day); water reuse fraction (%); treatment efficiency (%)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Carbon capture and storage research	Carbon capture, processing, and storage systems	Capture efficiency (%); storage capacity (tCO_2); energy consumption per unit of CO_2 captured	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Transportation and campus mobility	Campus mobility, fleet, charging, and transport support systems	Transport mode share (%); fuel consumption (L/km); electricity consumption (kWh/km); emissions ($kgCO_2$/passengerkm)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.
Green building operation	Building envelope, HVAC, electrical, and environmental control systems	Building energy intensity (kWh/m²/year); thermal performance; indoor environmental quality; operational energy savings (%)	Indicator specified for future campus measurement; no comparable result was collected in the 12-faculty field study.

3.2 Gap between institutional intent and operational capacity

The original comparative visualization in Figure 2 summarises qualitative strengths and weaknesses across governance dimensions. It is interpreted as a descriptive synthesis, since its aggregation rules and underlying item-level observations are not available for an independent performance score. Its relevant management signal is the weaker monitoring and institutional-capacity dimension relative to reported strategic intent. It should not be interpreted as a measured infrastructure index.

A traceable project record would require asset inventory, interval electricity or water data, floor area or user denominators, maintenance and operating hours, weather and occupancy covariates where relevant, and documented emission factors. A project without these inputs may still be a useful educational or policy activity; the available evidence cannot verify its net environmental effect. The proposed management response is to make measurement design a requirement before procurement.

For each candidate asset, the proposed decision gate records an owner, responsible operator, required baseline, expected technical range, capital and recurring cost, source of finance, commissioning criterion, and verification period. A campus program passes from commitment to implementation only when these items have named owners and a review schedule. This is a design recommendation motivated by the observed governance and resource gaps; the present study has not tested whether the gate increases savings.

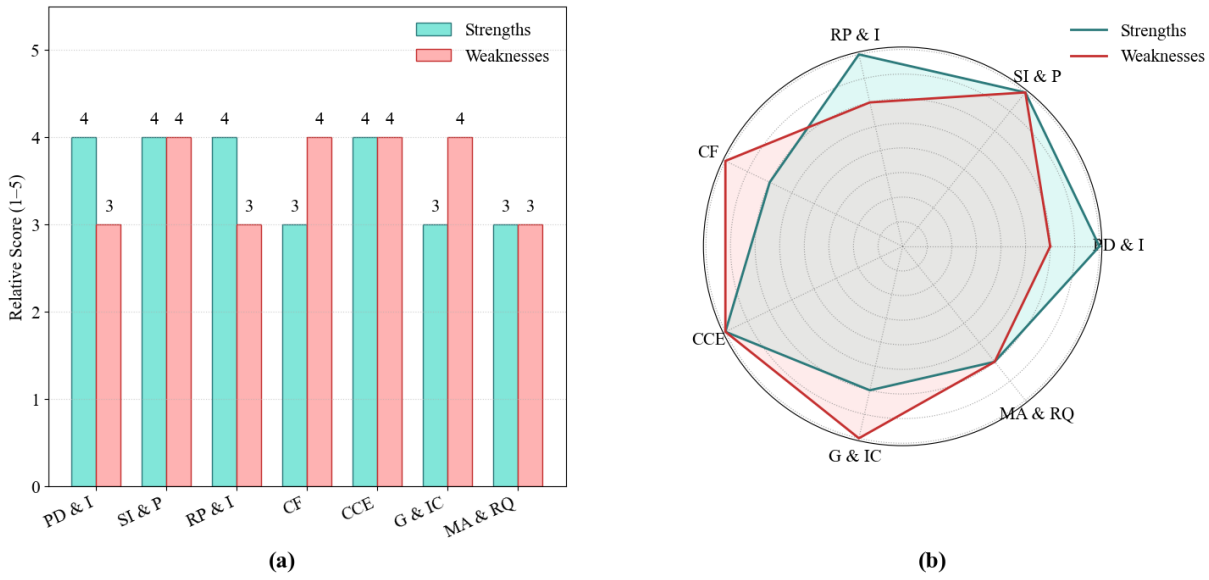


Fig.2. Comparative Assessment of Sustainability Practices and Governance Frameworks: (a) Strengths and Weaknesses Across Key Aspects; (b) Radar Chart of Overall Comparison

3.3 Policy, collaboration and education themes

The original theme coding identifies policy integration in 28 studies, green campus programs in 25, collaboration approaches in 21, and CCE or curriculum integration in 20. The broader descriptive tally of partnership-related publications is 28; these two collaboration counts use different coding

labels and cannot be substituted for one another. Together they suggest substantial attention to stakeholder engagement without a corresponding body of comparable technical outcomes.

Research and innovation appeared as a separate theme in 17 studies and institutional leadership in 15. These observations point to potential project sponsors and knowledge partners, but they provide no measured effect of a specific multi-sector arrangement on retrofit delivery time, system availability or lifecycle cost. The proposed framework therefore treats the effectiveness of partnership as a metric to collect in a pilot rather than as a result already demonstrated.

A collaboration register can quantify implementation through the proportion of assigned tasks completed by the due date and the proportion of verified deliverables accepted at commissioning. Both indicators require a signed responsibility matrix and a consistent denominator. They allow a project manager to trace delays and accountability across the university facilities office, public authorities, vendors and teaching programs, while avoiding an unsupported claim that collaboration itself has reduced emissions.

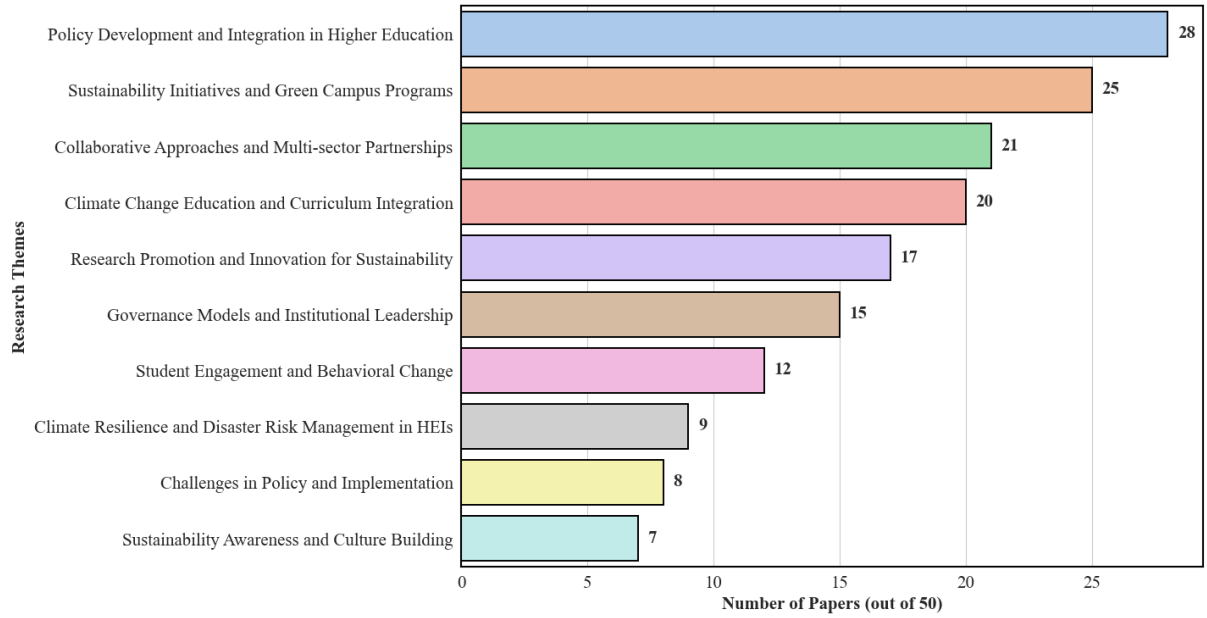


Fig. 3. Thematic Analysis of Sustainability Practices and Policies in Higher Education

3.4 Development of the evidence base

Figure 4 reproduces the source manuscript's chronology of research themes. It is descriptive context rather than evidence that campus infrastructure has improved over time. A trend in publication topics does not measure the performance of installed systems.

For a longitudinal technical test, campuses would record at least one comparable pre-intervention and post-commissioning operating period, document changes in occupancy and weather, and report uncertainty and missing readings. Publication year should not substitute for an operational baseline.

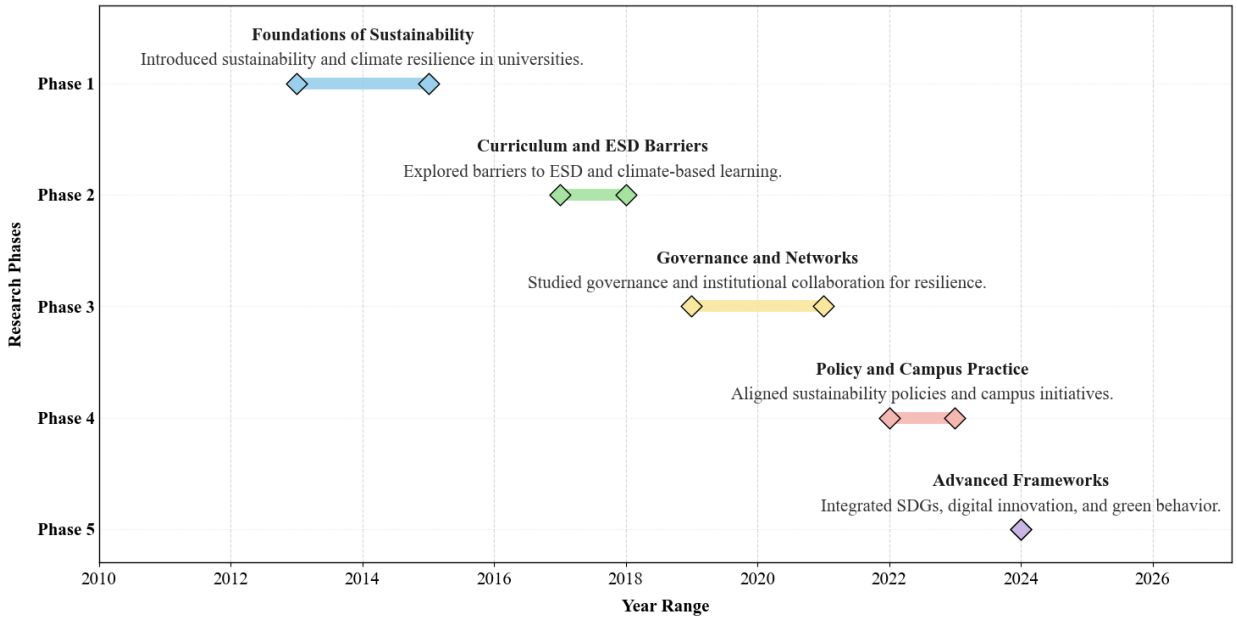


Fig. 4. Evolution of Research Directions on Sustainability and Climate Change in Indonesian Higher Education Institutions

3.5 Convergent findings and unresolved trade-offs

Figure 5 summarises agreement about the importance of leadership and collaboration and divergence about implementation capacity. In engineering management terms, the unresolved issue is decision integration: a curriculum sponsor, asset owner, financier, and supplier may support the same target yet lack shared specifications for cost, data access, and acceptance testing. The study does not provide project-level evidence to rank partner configurations.

Technical options also trade off differently. A lighting retrofit may have modest capital requirements but depends on operating hours and lighting quality; rooftop photovoltaic generation requires suitable structure, grid integration and maintenance; water reuse needs appropriate treatment, health safeguards and a reliable demand profile. Ranking by a single sustainability score would conceal these constraints. A feasibility screen should reject unsafe or technically infeasible options before comparing annualized cost per verified unit of energy, water, or emissions reduction.

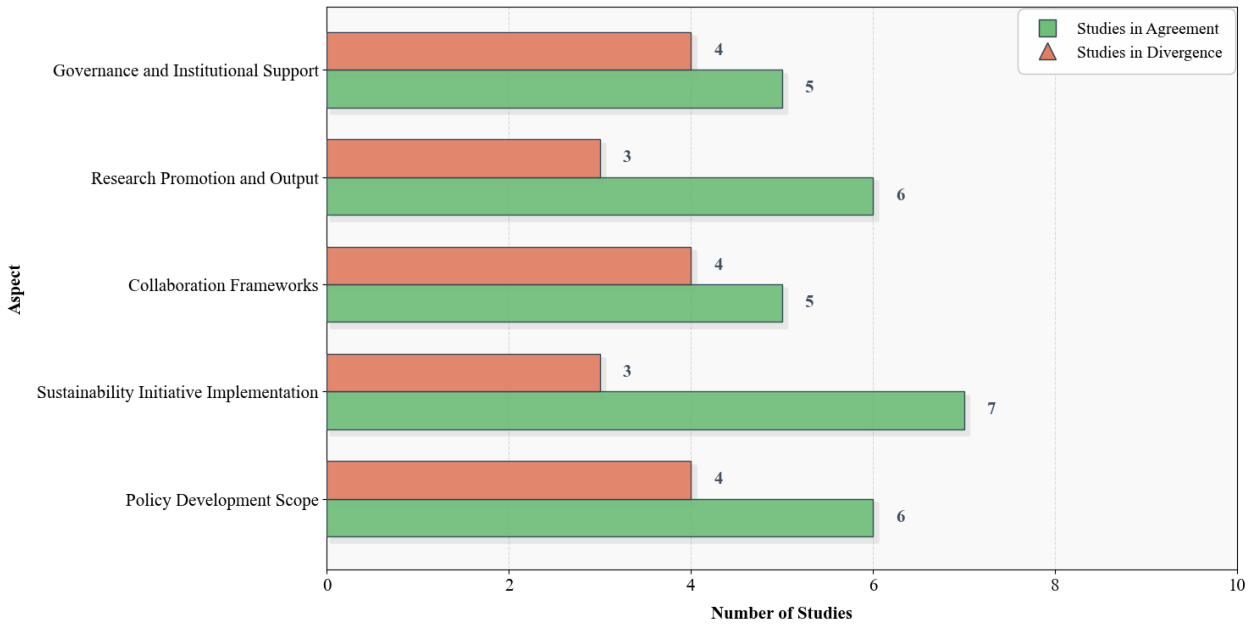


Fig. 5. Comparative Synthesis of Converging and Diverging Findings on Sustainability Practices in Indonesian Higher Education Institutions

3.6 Field evidence on implementation readiness

Leaders reported mean scores of 4.2 for community engagement and 4.0 for SDG-aligned strategy, compared with 3.3 for learning resources and 3.2 for innovation incentives. The descriptive within-group differences are 0.7 and 0.8 score points relative to strategy, respectively; they are not effect sizes. Lecturers reported 4.6 for responsibility to teach CCE and 3.6 for training, a 1.0-point difference. Preservice teachers reported readiness of 4.4 and confidence in explaining climate concepts of 3.64, a 0.76-point difference; they reported project engagement of 3.73. Figure 6 depicts these self-reported means. No uncertainty interval or between-group hypothesis test is available.

Interviews, as shown in Figure 7, describe weak enforcement and resource provision at the leadership level, limited guidance and development time for lecturers, and limited opportunities for applied projects for students. These themes are compatible with a stage-gate failure between strategy and delivery. They cannot establish that adding a meter or a partnership will by itself improve CCE learning outcomes.

The quantitative impact demonstrable in this dataset is an implementation-capacity gap measured in survey score points, not an environmental improvement. Engineering impact remains a testable prospective claim. A campus pilot should define baseline electricity and water use, asset uptime, costs, and teaching use before interventions, then report the achieved changes with denominators and uncertainty estimates.

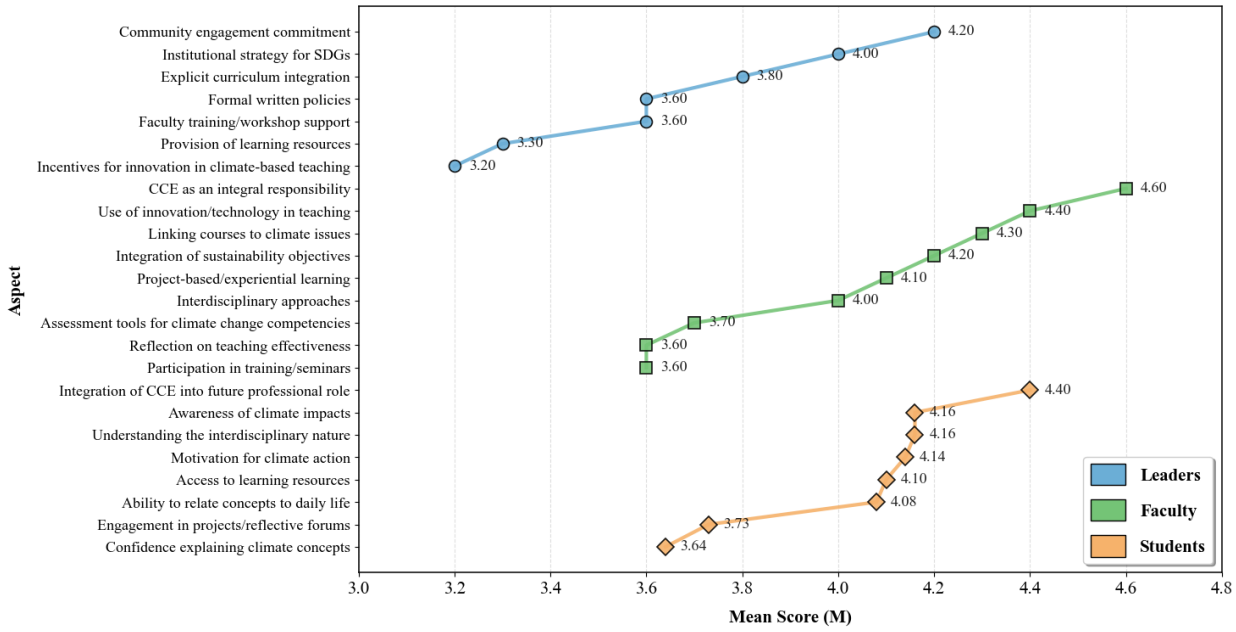


Fig. 6. Perspectives on Climate Change Education among Leaders, Faculty, and Pre-Service Teachers

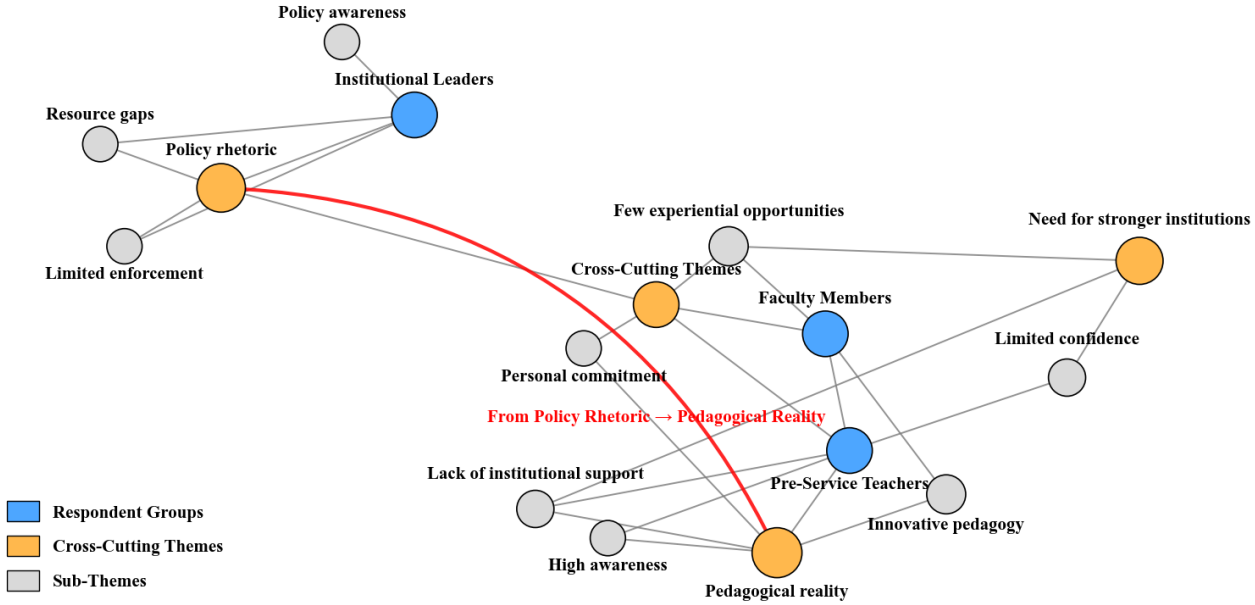


Fig. 7. Thematic Map of Qualitative Findings

4. Discussion

What the collected evidence establishes is limited and specific: across 12 faculties, climate strategy and educator motivation are visible (leaders rated SDG-aligned strategy at 4.0 and lecturers rated responsibility to teach CCE at 4.6), while resources, training and technical verification are weaker (3.3, 3.6 and no facility-level measurement), a pattern consistent with wider accounts of fragmented policy and uneven investment and with the contribution expected of higher education institutions to sustainable development [1,2,27]. These observations are descriptive score gaps from a non-probability sample, so they indicate where execution appears to stall; they do not show why it

stalls, and they do not show that any intervention would close the gap. The five-stage delivery process is a design response to that diagnosis, and its claimed advantage over program counting, auditability through a physical boundary, baseline, measurement period and accountable sign-off, is an analytical argument that follows from how the stages are specified rather than an observed outcome. No comparative evaluation of the framework against conventional practice was conducted, so the discussion that follows interprets each observed gap against the stage it implicates and states what remains to be tested.

Table 3 compares the proposed framework with five families of established practice: sustainability rankings and readiness analyses, whole-institution and campus environmental management frameworks, carbon-management and campus technology studies, energy management and verification standards, and stage-gate project management. The comparison shows that each family already supplies part of what the framework combines: for example, institution-wide assessment of governance and infrastructure in readiness analyses; embedding sustainability across operations and reporting in whole-institution approaches; baseline and savings verification in energy standards; and go/no-go control in stage-gate management [13,14,21,22]. What none of these families is shown to specify, in the sources compared, is a single protocol that assigns asset-level decision rights, partner duties and teaching use together, which is where the present evidence of weak resources, training and verification locates the problem. The result is a claim of integration rather than superiority, because the comparison rests on the published scope of those approaches rather than on a head-to-head test.

Table 3
Comparison of the proposed five-stage framework with existing green campus, sustainability assessment, energy management and project management approaches

Approach (representative sources)	Principal focus	Open issue for verifying campus infrastructure outcomes	Treatment in the proposed framework	Reference
Sustainability rankings and readiness analyses	Institution-level assessment of governance, infrastructure and education dimensions	Scores summarise reported institutional status; asset-level baselines and verified savings are not their primary output.	Keeps structured assessment but requires an asset-level baseline and acceptance criterion before a project is counted	[21,22]
Whole-institution and campus environmental management frameworks	Embedding sustainability in governance, curricula, operations and reporting	Asset-level technical acceptance and verification rules are not their primary object.	Adopts the whole-institution scope and adds stage gates, a named owner for each asset and a verification record	[18,28]
Carbon-management and campus technology studies	Carbon assessment leading to action; adoption of a specific technology such as LED lighting	Organized around carbon assessment or one technology; allocation of decision rights, partner duties, and teaching use is not the primary object	Generalizes the assessment-to-action sequence across asset types and links it to a responsibility matrix and educational reuse of data	[29,30]
Energy management and verification standards	Systematic energy performance improvement; verification of savings	Assume an organization with a defined energy owner and metered boundary; not designed to assign university–government–	Adopts the adjusted-baseline savings logic and extends it with a responsibility matrix and a data loop to CCE	[31,32]

	against an adjusted baseline	industry duties or to return audited data to teaching.		
Stage-gate project management	Staged go/no-go decisions with defined deliverables	Does not itself specify sustainability baselines, emission factors, or normalization for operating conditions	Adapts gate logic to campus assets with technical acceptance criteria, an owner and a verification period at each gate	[33,34]
Proposed five-stage framework (this study)	Stage-gated coupling of ownership, baseline, ranking, delivery matrix and verification with CCE use	Untested: no meter, cost, or emissions data were collected	Requires prospective pilot validation (Table 5)	(this study)

Studies of campus energy and carbon management, such as the strategic approach from carbon assessment to action and LED-lighting innovation in universities, indicate that physical interventions are feasible in university settings. Still, the evidence collected here cannot show how Indonesian faculties would compare with those settings, as no meter, cost, or emissions data were collected. The same limitation applies to Indonesian campus case studies of green campus readiness and management, whose program-level evidence the reviewed literature mostly reports as existence and rankings rather than measured performance. [7,35,36]. Where the present study differs from these sources is in pairing an observed implementation diagnosis with a verification specification, so that a future pilot can be judged against the same indicators across all sites. Until such a pilot is conducted, the defensible conclusion is that the framework is consistent with established energy management logic and with the observed gaps. At the same time, its added value over those approaches remains untested.

4.1 Policy as technical requirements

The leader-level pattern, in which SDG-aligned strategy (4.0) and community engagement (4.2) outscored learning resources (3.3) and innovation incentives (3.2), indicates that commitment exists without the instruments that make a target executable, which is the point at which a project charter would intervene [37,38]. Such a charter would specify an emissions accounting boundary, asset priorities, procurement authority, resource budget, and reporting frequency; each target would include a baseline and an acceptance criterion, for example, annual building electricity intensity equal to metered building kWh divided by conditioned floor area (m^2) over the same reporting period. Where floor area, weather, or occupancy changes, the comparison must be normalized or explained; otherwise, a policy label can be mistaken for operational evidence. Whether a charter would close the observed resource and incentive gap cannot be inferred from the survey, which measured perceptions rather than budgets. Hence, the charter remains a specification to be tested.

4.2 Delivery responsibilities and collaboration

The reviewed literature includes 28 studies on partnerships. Yet, it offers no measured effect of a multi-sector arrangement on delivery. Hence, the evidence supports treating collaboration as a coordination problem to be specified rather than a demonstrated remedy, in line with accounts of university–school and multi-sector partnerships and of sectoral coordination and capacity building as institutional requirements. An integrated responsibility matrix would give the facilities unit

ownership of meter quality and maintenance, academic staff ownership of learning tasks and competency assessment, public authorities responsibility for applicable standards and approvals, and industry partners responsibility for equipment specifications, commissioning documents and warranty support. A steering group could resolve cross-unit scope, cost, and data-access decisions, which are the points where leaders described weak enforcement and resource provision in the interviews. On-time milestone completion and accepted commissioning deliverables are candidate measures of collaboration, but neither was measured in this study.

4.3 Infrastructure as a measured learning system

Pre-service teachers reported readiness of 4.4, confidence in explaining climate concepts of 3.64, and project engagement of 3.73, and lecturers reported 4.6 for responsibility to teach CCE against 3.6 for training. This combination matches earlier descriptions of CCE implementation in Indonesia and of teachers' conceptions of climate change as constraints on delivery. Professional development for teachers has been examined as a lever for teacher quality in Indonesia, making the lecturer training gap a plausible yet untested target for applied, data-driven tasks. In such tasks, students would compare baseline and post-retrofit building load profiles, estimate energy savings, examine uncertainty, and explain the difference between electricity reduction and avoided CO_2e. At the same time, lecturers would need access to safe, suitably anonymized data and a validated assessment rubric. The lower reported confidence and project engagement provide a reason to test this approach, not evidence that it has already raised competence.

4.4 Decision model and project gates

Because the reviewed programs report existence and rankings rather than comparable cost or performance outcomes, the present evidence cannot rank interventions, and a prioritization model is offered only as the decision logic that such evidence would feed, consistent with the staged go/no-go control used in project management. The model first screens candidate interventions for safety, legal compliance, technical compatibility and data availability, and then compares feasible alternatives using discounted lifecycle cost, expected verified resource reduction, operational risk and teaching value. Decision-makers would publish criterion definitions, weights, and a sensitivity analysis, because a rank must not be claimed without site-specific estimates. After selection, a project would advance through baseline approval, design review, commissioning and post-occupancy verification, with a documented go/no-go decision at each gate, and the weights and thresholds remain assumptions until a pilot supplies data.

4.5 Measurement and verification

For an intervention with comparable operating conditions, electricity savings (%) = 100 × (Ebaseline, adjusted − Epost)/Ebaseline, adjusted. Avoided operational emissions (tCO_2e/year) = net grid electricity saved (kWh/year) × the stated grid factor ($kgCO_2e$/kWh)/1,000, with other fuels and exported generation reported separately. Water savings use the same adjusted-baseline logic: waste diversion (%) = 100 × mass diverted from disposal / total waste mass, using weighted flows and a defined reporting boundary. Data quality, temporal matching, rebound effects and missing readings must be reported. These equations specify future analysis; the present sample supplies none of their required meter or cost inputs.

4.6 Interpretation, economics and limitations
4.6.1 Cost and operational trade-offs

Capital allocation should compare options based on net present cost or cost per verified tCO_2e avoided over a stated service life, with the discount rate, equipment replacement, maintenance, tariff, and emission-factor trajectory and uncertainty disclosed. A low initial bid may be inferior if it lacks commissioning and metering support. Likewise, a technically efficient asset may have little educational use without dependable data access. The available manuscript has no capital budgets, tariff records, or operating cost series, so no numerical benefit–cost ratio or payback period can be responsibly calculated.

4.6.2 Applicability

The framework can guide a pilot at one or more of the participating faculties: nominate a facilities and academic co-owner; instrument one well-defined building or utility system; obtain twelve months of baseline observations where seasonal variation matters; prioritize alternatives with a transparent cost and risk register; commission the selected work; and publish verified results and a paired learning activity. The 12 faculties provide evidence on organizational readiness, not 12 completed engineering case studies.

4.7 Evidence limits

Table 4 summarises limits of the review evidence. The review search cannot be independently replicated from the supplied query and screening detail, and some bibliography dates extend beyond the stated search period. Most campus program descriptions omit measured system output. Field participants are limited to science teacher education at state universities, and the survey provides only selected item means, without raw responses, variance, validated scale information, or adjusted institutional comparisons.

Table 4 summarises limits of the review evidence and of the field evaluation. The review search cannot be independently replicated from the supplied query and screening details; the reported 121 identified and 187 screened records have not been reconciled; and the 2025 publications and two earlier methodological sources in the bibliography fall outside the stated search period and are used only for context or comparison. Most campus program descriptions omit measured system output, and field participants are confined to science teacher education at state universities, selected through a procedure the source does not document, so selection bias cannot be quantified. The survey provides selected item means without raw responses, variance, validated scale information, or adjusted institutional comparisons, which limits any conclusion to descriptive patterns in this sample.

Table 4
Limitations of the reviewed literature and the present evaluation

Limitation	Description	Representative References
Absence of national policy frameworks	Fragmented and compliance-oriented initiatives with greater emphasis on external indicators than institutional strategy	[39,40]
Small or unrepresentative samples	Concentration on a limited number of established universities reduces generalisability.	[3,4]

Predominantly qualitative or single-case designs	Limited longitudinal and large-scale quantitative validation reduces robustness and replicability.	[39–41]
Policy misalignment	Differences between climate change and education policies weaken institutional coherence.	[3]
Underdeveloped collaboration analysis	Limited empirical analysis of university-government-industry collaboration dynamics	[16,42]
Scarcity of longitudinal data	Restricts understanding of how sustainability initiatives evolve and perform over time	[15,43]
Thematic imbalance	Strong emphasis on environmental dimensions, with social and economic aspects less explored	[39,44]
Institutional sampling bias	Greater attention to leading universities, with smaller and less-resourced institutions underrepresented	[45,46]
Engineering and technical-performance reporting gap	Energy, waste, and water infrastructure are often reported by program existence rather than measured technical performance.	[47,48]
Unreconciled review search record	121 records reported as identified versus 187 as screened, without a dated query log, duplicate counts or exclusion ledger; some bibliography dates fall outside the 2010–2024 search period	This study (Fig. 1)
Undocumented sample selection	Selection of the 12 faculties and 131 respondents, voluntary participation in the surveys and response rates are not documented; selection bias cannot be quantified.	This study (Section 2.3)

These limitations constrain claims about prevalence, causality and generalisability. Respondent ratings should not be converted into percentages of institutions, and reviewed study counts should not be converted into campus adoption rates. Interview observations add context but do not independently validate technical savings. An engineering impact assessment requires a prospective protocol, a comparison strategy for changes in operating conditions, documented financial inputs, and access to auditable resource data.

4.8 Future validation study

Table 4 lists priority evidence and implementation gaps. A future study should preregister site and asset selection, define the same baseline and post-intervention boundaries, publish meter coverage and calibration, and document how missing intervals and changes in weather, floor area, and occupancy are handled. It should evaluate both infrastructure outcomes and a prespecified CCE competency task. Where feasible, a matched building or stepped deployment can help distinguish the intervention from background changes.

Table 4
Priority gaps and next steps for engineering management validation

Research Gap	Priority Direction for Future Research
Fragmented policy development	Integrated national policy frameworks with clear accountability mechanisms
Limited CCE curriculum integration	Structured teacher training and interdisciplinary curriculum reform
Uneven green-campus implementation	Infrastructure investment with standardized monitoring and reporting
Weak multisector collaboration	Formal university-government-industry partnership models based on the Triple Helix
Weak governance and institutional capacity	Dedicated sustainability structures with monitoring responsibilities
Small-scale and cross-sectional designs	Longitudinal, multiinstitutional, and mixed-methods studies

Limited student engagement research	Studies of behavioral change and experiential or project-based learning outcomes
Underused digital transformation	Digital tools for sustainability learning, data collection, and monitoring
Engineering performance-data gap	Energy audits, metered consumption, and techno-economic or lifecycle assessment

The core validation outcomes are adjusted energy intensity and percentage saving, annual avoided operational emissions, water use and waste diversion, system availability, lifecycle cost and delivery milestone completion. Reports should supply observed numerator and denominator values, uncertainty intervals, implementation costs and data provenance. Results can then establish whether an integrated policy–infrastructure–education framework performs better than the existing local process; this manuscript cannot make that comparative claim.

5. Conclusion

In the 50-study review, 25 publications described green campus programs, but the available synthesis did not provide comparable measured energy, water, emissions, or cost outcomes. Across 131 respondents in 12 Indonesian state-university faculties, strategy and professional commitment scored above operational support: leaders rated strategy 4.0 versus resources 3.3, lecturers rated responsibility 4.6 versus training 3.6, and students rated readiness 4.4 versus confidence 3.64. These are descriptive score gaps, not causal or engineering savings estimates.

For university leaders and facilities engineers, the immediate recommendation is to make a policy target executable through a named asset owner, funded baseline metering, feasibility and lifecycle-cost screening, an accountable multi-sector delivery matrix, commissioning, and post-installation measurement and verification. For educators, verified asset data should be used in an assessed CCE exercise. This sequence offers a concrete implementation protocol for green campus projects while keeping the environmental claim conditional on measured performance.

A prospective campus pilot should test the framework against actual meter, occupancy, weather, cost, emissions factor, and learning outcome records. The main contribution of the current study is an engineering management specification grounded in observed institutional gaps; its effectiveness and any percentage reduction in carbon or energy remain unproven until an intervention is deployed and independently verified.

Author Contribution

Hadi Suwono - Conceptualized the study, designed the framework for the literature review, and coordinated the overall research effort. Contributed significantly to the writing and revision of the manuscript. **Marsya Aulia Rizkita** - Conducted a comprehensive analysis of sustainability practices in Indonesian higher education institutions. Contributed to manuscript drafting, particularly in highlighting the gaps and limitations identified in the study. **Devi Mariya Sulfa** - Assisted in the literature review process, synthesizing findings from various studies on sustainability and climate change education. Contributed to the development of the abstract and keywords for the manuscript. **Chun-Yen Chang** - Provided methodological guidance and support in data analysis. Contributed to the review of the manuscript, ensuring the clarity and coherence of the findings presented. **Chokchai Yuenyong** - Offered expertise in education systems and climate governance, contributing to the discussion section of the manuscript and playing a key role in framing future research directions.
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The authors declare that they have no conflicts of interest. The funders had no role in this manuscript's design, analysis, interpretation, or writing.

Ethical Approval
The source manuscript does not report an ethics committee approval number or exemption determination for the surveys and interviews. The authors should supply the applicable institutional determination before submission.

Consent to Participate
The source reports consent for recorded interviews. The survey consent procedure was not documented and requires confirmation from the authors.

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Not applicable.

HUMAN AND ANIMAL RIGHTS
This study involved surveys and interviews with adult university participants. No animal experimentation was reported. The applicable human-participant ethics determination requires confirmation by the authors.

INFORMED CONSENT AND PATIENT DETAILS
No patients were involved. The source reports that interviews were recorded with participant consent; survey consent procedures require author confirmation.

DATA AVAILABILITY STATEMENT
Requests for the data mentioned in this study can be made to the corresponding author.

CONFLICTS OF INTEREST
The authors declare that no conflicts of interest are associated with this work.

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APPENDIX

Appendix 1. Comparative Study of Sustainability Practices and Governance Frameworks

Study	Policy Development Scope	Sustainability Initiative Implementation	Collaboration Frameworks	Research Promotion and Output	Governance and Institutional Support
[39]	Limited national guidance, fragmented HEI policies	Partial compliance with GreenMetric, uneven policy structure	Weak formal collaboration, compliance-driven	Moderate research integration, policy recommendation focus	Lack of systematic governance, weak leadership commitment
[49]	Government-led comprehensive sustainable development policies	Emphasis on renewable energy and urban sustainability	Strong government-industry collaboration	Policy-driven research promotion, with a focus on energy and urban planning	Centralized governance with multi-sector engagement
[50]	Climate education policy emerging, linked to social welfare	Framework for climate education integration in HEIs	University-led community engagement, limited formal partnerships	Action-oriented climate education research	Institutional support for education innovation, moderate leadership role
[3]	Discrepancy between climate and education policies	Marginalization of climate education in formal curricula	Lack of synergy among stakeholders	Limited research alignment with policy	Weak policy coordination, fragmented governance
[44]	Broad sustainability dimensions assessed	Strong faculty development, weak curriculum, and research	Cluster-based institutional collaboration	Research and scholarship are weak but recognized	Governance is linked to mission planning and staff rewards

[35]	Institutional policies focused on the Eco-Campus program	Effective green campus practices: energy, waste, water	Internal university collaboration, limited external links	Applied sustainability research in campus operations	Leadership commitment is evident, and grassroots engagement
[36]	Policy alignment with global benchmarks	Green management and innovation positively impact sustainability	Collaboration is mainly internal, with some industry links	Research on green innovation mediates sustainability	Organizational culture supports sustainability initiatives
[45]	International collaboration policies for technology development	Innovation-driven sustainability efforts	Strong university-university and university-industry partnerships	Research focused on technology transfer and commercialization	Governance supports cross-border collaboration
[51]	The university's third mission is aligned with the SDGs	Sustainability linked to entrepreneurial university practices	Multi-sector partnerships emphasized	Research collaboration with industry and government	Governance fosters autonomy and societal engagement
[52]	Climate mitigation policies integrated into service-learning	Campus-level mitigation actions and governance networks	Networks include local communities and government	Research promotes local emission reduction strategies	Institutional regulation and community engagement
[53]	Strategic sustainability plans at the university level	Comprehensive sustainability practices are being developed	Partnerships with the community and stakeholders	Research integrated with sustainability values	Strong leadership and governance structures
[54]	Waste management policies align with the green campus	Waste reduction programs, but limited recycling	Internal campus collaboration	Operational research on waste management	Governance gaps in supervision and funding
[47]	Regulatory framework for carbon capture and storage	Research promotion in CCS technology	Collaborative research with government and industry	High-impact research on CCS	Institutional support for innovation and partnerships
[55]	Global partnership policies for science and technology	Sustainability is linked to a knowledge-based economy	University-government-industry collaboration	Research collaboration enhances economic sustainability	Governance supports competitive positioning
[56]	SDG integration policies in HEIs	Curriculum redesign for SDG awareness	External collaboration for policy formulation	Research applied to SDGs	Governance challenges in contextualizing SDGs
[27]	Sustainability research focuses on post-2015 SDGs	Research clusters in technology and education	Research networks among HEIs	High volume and thematic diversity of research	Institutional support for research leadership
[48]	Climate change policy evolution with global insights	Policy gaps in the economic and infrastructure sectors	Need for enhanced cross-sector coordination	Research focused on policy and environmental sciences	Governance requires adaptive regulation and funding
[57]	Environmental laws and green awareness policies	Green awareness enhances sustainability performance	Partnerships promote sustainability initiatives	Research supports policy effectiveness	Governance integrates environmental standards

[5]	Public climate policies with a multi-sectoral approach	Integrated sustainability programs	Stakeholder engagement emphasized	Policy outcome evaluations	Governance supports international cooperation
[46]	Decentralized climate governance policies	Sub-national climate action innovation	Multi-level governance with provincial autonomy	Research on land use and emissions	Governance benefits and challenges from decentralization
[58]	Multilevel environmental governance analysis	Adaptive governance mechanisms	Stakeholder engagement across levels	Research on governance effectiveness	Critical institutional capacity building
[59]	Local government climate resilience policies	Innovation and community participation	Cross-sectoral collaboration at the local level	Research supports resilience strategies	Governance addresses bureaucratic and resource barriers
[60]	Policy gaps in built environment education	Curriculum challenges in low-carbon design	Limited industry-university collaboration	Research on professional education	Governance requires awareness of the institutional framework
[61]	Local government and civil society collaboration policies	Community forestry and environmental preservation	Tri-sector collaboration model	Research on climate risk reduction	Governance supports multi-actor partnerships
[62]	Disaster resilience policy framework	University disaster preparedness initiatives	Partnerships with the government and the campus community	Research on disaster risk management	Governance integrates safety and resilience planning
[63]	Network governance for climate resilience	Multi-institutional collaboration networks	International-local institutional partnerships	Research on network effectiveness	Governance fosters partnership maintenance
[64]	Sustainable development education policies	Holistic curriculum integration	Partnerships for societal well-being	Research on sustainability frameworks	Governance supports educational reforms
[65]	Triple helix collaboration model	Proposed mutual collaboration framework	Government-industry-university partnerships	Research linked to innovation and the economy	Governance encourages role reconstruction
[40]	Green campus readiness policies	Low readiness, infrastructure, and funding gaps	Limited collaboration, weak policy support	Research on green campus indicators	Governance challenges in supervision and funding
[66]	Multi-sector partnership policies	Sustainable business development projects	Strong multi-stakeholder partnerships	Research linked to value chain analysis	Governance supports partnership management
[15]	Post-COVID sustainability framework policies	Educational reform and digital transformation	Emphasis on industry-academia linkages	Research on sustainability education	Governance includes leadership and resilience
[41]	Sustainability integration policies	Management system and student behavior focus	Collaboration between management and students	Research on sustainability knowledge and attitudes	Governance leadership is critical for sustainability

[9]	Sustainable community development policies	Student engagement in sustainability projects	University-community partnerships	Research on sustainability perceptions	Governance supports energy and resource independence
[37]	Green HRM and sustainability teaching policies	Institutional sustainability models	Partnerships with business and industry	Research on the impact of green HRM	Governance integrates policy and program sustainability
[67]	Institutional pathways for climate resilience	Institutionalization of adaptation and resilience	Policy entrepreneur networks	Research on institutionalism and adaptation	Governance shaped by hybrid institutionalism
[19]	Innovation policies using LED technology	Technology-driven sustainability initiatives	Community involvement in sustainability	Research on energy consumption and innovation	Governance supports strategic innovation planning
[68]	Local adaptation policy development	Capacity building and sectoral coordination	Government and NGO partnerships	Research on policy development effectiveness	Governance emphasizes institutional strengthening
[16]	Organizational learning policies	Sustainability reporting promotes broad learning	Limited deep organizational learning	Research on the impact of sustainability reporting	Governance encourages a culture shift
[43]	Environmental and sustainability policy nexus	Separate streams of environmental and sustainability efforts	Community-level activity integration	Research on environmental and sustainability synergy	Governance calls for policy integration