

A Reproducible Python Framework for RA 11396 LUDIP Compliance with Building-Energy Benchmarking and Embodied-Carbon Screening

Niño Louie Boloron^{1,2*}, *Clara A. Acebes*⁷, *Antonio A. Pescadera*⁸, *Eric Bruno*^{3,6}, *Richard Aquino*⁴, *Michael Arie Medina*^{3,6}, and *Jupiter Casas*^{5,6}

¹Department of Mechanical Engineering, College of Engineering, Central Mindanao University, Philippines

²Department of Mechanical Engineering, College of Engineering and Architecture, Mapua Malayan Colleges Mindanao, Philippines

³Department of Environmental Science, College of Forestry and Environmental Science, Central Mindanao University, Philippines

⁴Department of Civil Engineering, College of Engineering, Central Mindanao University, Philippines

⁵Department of Forest Resources and Management, College of Forestry and Environmental Science, Central Mindanao University, Philippines

⁶Center for Geomatics Research and Extension, Central Mindanao University, Philippines

⁷Planning and Development Office, Davao del Sur State College, Philippines

⁸Planning and Development Office, Sulu State College, Philippines

Abstract. State Universities and Colleges (SUCs) in the Philippines are required to prepare Land Use Development and Infrastructure Plans (LUDIPs) that rationalize campus land allocations and development pipelines. While the legal and planning intent is clear, implementation is often hindered by fragmented datasets, manual workflows, and limited integration of building-energy and embodied-carbon indicators into spatial planning and LUDIP compliance workflows. This paper presents a reproducible computational framework that automates LUDIP compliance analytics under Republic Act No. 11396 and extends the planning pipeline with lightweight green-building modules: (i) energy use intensity (EUI) computation from utility bills or submeters, (ii) a structured retrofit-scenario evaluator with an optional pathway to EnergyPlus/OpenStudio simulation, and (iii) a screening-level embodied-carbon workflow aligned with life-cycle assessment (LCA) principles. The framework is demonstrated on three SUCs representing distinct campus contexts (highland, lowland multi-campus, and coastal), producing standardized functional-core shares, transition deltas, and planning signatures from actual LUDIP datasets. Although energy and embodied-carbon outputs are presented as representative schematic outputs pending detailed building-level data collection, the land-use compliance and morphology results are grounded in

* Corresponding author: nlboloron@mcm.edu.ph

real campus records, confirming the framework's applicability across diverse institutional settings.

1 Introduction

Universities are increasingly expected to operationalize sustainability not only through instruction and research but also through measurable improvements in campus development and operations. This expectation aligns with global development agendas that place education and sustainable cities at the center of long-term societal transformation [1]. It is also consistent with international education guidance that frames sustainability as an institutional practice supported by governance, monitoring, and continuous improvement cycles rather than one-off projects [2].

In the Philippines, campus planning in State Universities and Colleges (SUCs) has been formalized through Republic Act No. 11396, which mandates that SUCs prepare Land Use Development and Infrastructure Plans (LUDIPs) and categorize landholdings into statutory functional cores (Academic, Administrative, Allied Services, Research-Development-Extension, and Production) to improve land governance and development rationality [3]. Parallel policy instruments also point toward environmental performance in buildings, including a national green building code framework and energy-efficiency legislation that encourages systematic energy management and reporting [4], [5].

Despite these policy signals, many SUCs still develop LUDIPs using workflows that are difficult to reproduce and update. Planning datasets are commonly distributed across spreadsheets, narrative documents, and GIS exports, and building-energy considerations are often handled separately (if at all) from land-use allocation decisions. This separation matters. Campus development choices influence operational energy demand (through building typologies, floor-area intensification, and service provision) and embodied impacts (through construction materials and project sequencing). Contemporary buildings research increasingly treats operational and embodied impacts as a coupled problem, where narrow emphasis on one can shift burdens to the other [6].

This paper addresses a practical gap: SUCs need a quantitative, auditable workflow that (i) automates LUDIP compliance analytics and morphology indices, and (ii) integrates green-building indicators in a way that is feasible under constrained data availability. The principal contribution is a computational framework that transforms heterogeneous LUDIP and campus records into a standardized campus asset registry and produces reproducible outputs for planners and researchers. A secondary contribution is an implementation pattern: the framework is designed so that campuses can begin with minimal data, such as land-use tables, basic building lists, and utility bills, and progressively add simulation-grade models as capacity improves. Although the present demonstration focuses on Philippine SUCs under RA 11396, the modular workflow structure is intended to support adaptation to other educational and public-sector planning contexts where land-use, energy, and materials decisions must be analyzed together.

2 Related Work and Conceptual Basis

Sustainability assessment in higher education has a long tradition of using structured scorecards and benchmarking systems, which emphasize standardized definitions, transparent accounting, and periodic reporting. The STARS framework, for example, illustrates how institutions can structure sustainability data into comparable categories and update them iteratively as information quality improves [7]. While such frameworks are valuable, they do not prescribe a computational method for converting LUDIP-style planning

datasets into analyzable inventories, nor do they inherently bind land-use planning to building-energy and materials consequences. More critically, no existing framework operationalizes the specific compliance logic of RA 11396: the mapping of campus landholdings to five statutory functional cores, the computation of core shares and transition deltas across planning scenarios, and the generation of audit flags for non-compliant or ambiguous allocations. This paper fills that gap by providing a computational environment specifically designed for the LUDIP pipeline, while extending it with green-building modules absent from policy-compliance tools.

On the building side, operational performance analysis ranges from simple energy accounting (e.g., energy use intensity derived from bills) to detailed physics-based simulation. EnergyPlus is widely used for building-energy simulation, and OpenStudio provides a workflow layer for model management and scenario testing [8], [9]. These tools are powerful but can be burdensome for institutions lacking detailed building data. A common planning challenge, therefore, is not whether simulation exists but how to build a pragmatic “on-ramp” that starts with utility bills and inventory data and transitions to calibrated simulation only when inputs mature.

For materials, LCA standards emphasize clear functional units, system boundaries, and transparent inventory assumptions, with screening-level assessments often used for early-stage comparisons and decision support [10], [11]. In building decarbonization literature, evidence syntheses highlight that embodied impacts can be substantial and must be considered alongside operational energy, particularly as operational efficiency improves [6]. Global and regional reports also propose practical embodied-carbon target ranges and underscore the policy relevance of upfront carbon, especially for new construction [12]. Case-study evidence from commercial building stocks further illustrates the scale and variability of embodied-carbon intensities, which supports the use of benchmarking and screening methods when detailed quantities are not yet available [13]. Interest in bio-based materials, including engineered bamboo, is growing because sequestration and substitution effects can reduce life-cycle carbon footprints in certain contexts, though outcomes remain sensitive to system boundaries and assumptions [14].

Taken together, the literature supports a planning logic that combines (i) standardized inventories and auditable metrics, (ii) staged energy modeling that matches data maturity, and (iii) screening-level embodied-carbon comparison aligned with formal LCA principles. This paper operationalizes that logic specifically for SUC LUDIP environments under RA 11396.

3 Materials and Methods

3.1 Case context and input datasets

The demonstration uses three SUCs that represent distinct campus conditions: a highland flagship campus with extensive landholdings, a lowland institution distributed across multiple campuses, and a coastal institution with comparatively compact landholdings. The intent is not to claim national representativeness but to show that the workflow can harmonize heterogeneous inputs into a common schema.

The framework is designed around four core data classes. First, LUDIP land-use tables that report existing and proposed allocations by RA 11396 functional cores. Second, campus GIS-derived summaries or shapefile exports that provide land-area totals and land-use groupings. Third, demand indicators such as enrollment histories and planning projections (e.g., a target horizon year), which support density-like indicators and facility scaling. Fourth, a building inventory that, at a minimum, includes building IDs, use types, gross floor area

estimates, and meter linkage. Where available, monthly utility bills (electricity and other fuels) are added and mapped to meters and buildings.

Table 1 summarizes the demonstration inputs and highlights a practical reality: energy and building records are often the limiting factor, so the framework explicitly supports partial adoption.

Table 1. Demonstration dataset inventory and minimum-required fields for the integrated LUDIP–green-building workflow.

Institution (context label)	Campus landholdings (classified area)	Baseline & horizon student series available	LUDIP core-allocation tables	GIS area summaries	Building list + floor area	Utility bills / meters
SUC-H (highland)	3,080.83 ha (1 campus)	Yes	Yes	Yes	Partial/Recommended	Recommended
SUC-L (lowland, multi-campus)	39.92 (3 campuses)	Yes	Yes	Yes	Partial/Recommended	Recommended
SUC-C (coastal)	31.93 (3 campuses)	Yes	Yes	Yes	Partial/Recommended	Recommended

3.2 System architecture: the campus asset registry

The computational core is a “campus asset registry,” implemented as linked tables (CSV/Parquet) that define consistent identifiers across land units, buildings, and meters. The registry contains (i) campus and sub-campus entities, (ii) land parcels or planning zones, (iii) RA 11396 functional core labels, (iv) buildings with use categories and gross floor area, and (v) utility meters mapped to buildings or groups of buildings. The registry is designed to support two levels of spatial specificity. At minimum, it can operate with campus-level aggregates; at higher fidelity, it can use zone-level and building-level records as they become available. Python is used for ingestion, cleaning, joining, and metric computation. Tabular transformations rely on standard Python data-processing libraries, while plotting and report graphics use widely adopted visualization tools to support reproducible analytics. As shown in Fig. 1, the workflow links planning inputs, data harmonization, registry construction, morphology metrics, utility-bill processing, optional simulation, and embodied-carbon screening in a single auditable sequence. This integration is important because it allows LUDIP compliance outputs to be traced directly into building-energy and materials assessments rather than being treated as separate planning exercises.

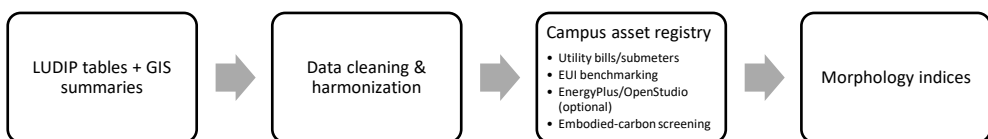


Fig. 1. End-to-end computational workflow linking LUDIP compliance analytics to building-energy benchmarking and embodied-carbon screening.

3.3 LUDIP compliance analytics and morphology metrics

The LUDIP module produces two main outputs: compliance checks and morphology indices. Compliance checks confirm the presence and internal consistency of required LUDIP elements (e.g., that core categories are complete and that area totals reconcile within a tolerance after unit harmonization). Morphology indices quantify planning structure. The framework calculates core shares (the percentage of total classified land allocated to functional cores), transition deltas between existing and proposed allocations, and support intensity ratios, such as the Allied-to-Academic area ratio. These indices are designed to be comparable across SUCs even when absolute land estates differ.

To avoid over-interpretation, the system treats indices as diagnostic signals rather than deterministic judgments. For example, a higher Allied-to-Academic ratio may reflect a deliberate shift toward student services, housing, or circulation investments, but it may also reflect classification differences that require planner review. The automation, therefore, outputs both computed indicators and “audit flags” that prompt human validation when anomalies are detected.

3.4 Building-energy module: EUI from bills and an EnergyPlus/OpenStudio pathway

The building-energy module is staged to match data maturity. In the base mode, it computes annual energy use intensity (EUI) as:

$$EUI = \frac{\sum_{m=1}^{12} E_m}{A} \quad (1)$$

where E_m is monthly energy consumption in kWh (or kWh-equivalent for multi-fuel campuses), A is the conditioned gross floor area in m^2 , and the resulting EUI has units of kWh/ m^2 -year. Where campus operations involve multiple energy carriers—such as electricity, diesel for standby generators, and LPG for cooking or laboratory use, which is common across Philippine SUCs—each fuel type must first be converted to a common energy unit before summation. The conversion uses established lower or higher heating values (e.g., 1 L diesel \approx 9.83 kWh; 1 kg LPG \approx 12.79 kWh) so that E_m in Equation (1) represents total campus energy in kWh-equivalent for month m . The framework requires that the fuel type, quantity, and conversion factor for each carrier be documented explicitly in the asset registry, and that multi-fuel EUI outputs be clearly labeled to distinguish them from single-carrier (electricity-only) benchmarks. When bills are campus-wide rather than building-specific, the module supports allocation rules (e.g., proportional to floor area by building type) and labels outputs as “allocated estimates” rather than metered truths.

In the advanced mode, the framework creates a plug-in path to physics-based simulation using EnergyPlus and OpenStudio. The intention is not to force full calibration in early planning stages, but to enable representative archetype modeling for priority buildings or future projects. EnergyPlus provides the simulation engine, and OpenStudio supports model management and batch scenario runs [8], [9]. The toolchain is linked to the asset registry so that simulated buildings inherit consistent IDs, use types, and scenario labels.

Retrofit scenario evaluation is handled using parameterized deltas that the user can define transparently (e.g., changes in lighting power density, HVAC efficiency, operating schedules). Where simulation is available, the same scenario labels can be run in

EnergyPlus/OpenStudio for more detailed estimates. This dual-mode design allows campuses to begin with bill-based EUI benchmarking and gradually move toward simulation-based retrofit appraisal without changing the underlying data schema.

3.5 Embodied-carbon screening aligned with LCA principles

The embodied-carbon module is explicitly screening-level. Its purpose is to compare options and support early-stage decisions, not to replace detailed quantity surveying or full EPD-driven LCA. The workflow follows LCA principles by requiring a defined functional unit (commonly kgCO_{2e} per m² of gross floor area) and transparent system-boundary declarations (e.g., A1–A5 for upfront stages versus whole-life boundaries) [10], [11].

Two implementation modes are supported. In the factor-based mode, users assign an embodied-carbon intensity factor (kgCO_{2e}/m²) to a building typology or structural system, and compute total upfront carbon as the factor multiplied by the floor area. In the bill-of-materials mode, users input material quantities (or proxy quantities using structural rules of thumb) and multiply them by emission factors from EPDs or recognized databases, again maintaining boundary transparency.

Bio-based materials are included as a structured option class rather than an assumed improvement. The framework allows users to represent engineered bamboo or timber alternatives and record whether sequestration is counted, consistent with the need for explicit methodological choices. The literature supports the potential for lower production-phase emissions in engineered bamboo systems under certain assumptions, while also emphasizing that operation often remains a dominant life-cycle contributor [14]. The automation, therefore, treats bio-based options as scenario alternatives that require documentation rather than as default “green” outcomes.

4 Results and Discussion

4.1 Standardization outcomes and auditability

The first result is procedural: the framework converts heterogeneous LUDIP tables and planning summaries into a single harmonized registry that supports repeatable analysis. In practice, the largest source of inconsistency is not computation but definition—units (ha vs m²), scope (campus vs landholding), and classification conventions. The automated checks reduce error propagation by identifying mismatches early and by forcing explicit scope labels in the registry (e.g., “classified land in LUDIP table” versus “surveyed campus area”).

In the demonstration, the harmonized outputs support direct comparison of functional-core shares and planning transitions. For example, one campus’s proposed scenario shows a higher Allied Services share than its existing scenario, which is consistent with a planning narrative oriented toward services and circulation expansion. The method does not claim that such a shift is universally correct; rather, it makes the shift computable, comparable, and reviewable.

4.2 Morphology indices as a bridge from land-use planning to green-building decisions

A central rationale for integrating building modules into LUDIP analytics is that land-use changes are frequently realized through building projects (new construction, retrofits, service expansions) that carry operational and embodied consequences. Morphology indices provide a bridge. When a campus increases Allied Services allocation, for instance, it often implies

additional building floor area for housing, clinics, student centers, or transport facilities. Those projects can improve student experience and service delivery, but they also influence energy demand and materials impacts.

Table 2 reports functional-core shares computed directly from the LUDIP datasets of the three demonstration campuses. The figures are derived from actual classified-area records (CMU_main: 3,080.83 ha; DSSC combined: 39.92 ha; SuSC combined: 31.93 ha) and reflect each institution's existing and proposed core allocations. The key analytical point is that the same computation is applied consistently across campuses, enabling planners to connect land-allocation decisions to downstream building-energy and materials modules.

Table 2. Functional-core shares computed from actual LUDIP datasets for the three demonstration SUCs (CMU, DSSC, SuSC).

Campus label	Scenario	Academic (%)	Administrative / GAS (%)	Allied Services (%)	RDE (%)	Production (%)
SUC-H (CMU)	Existing	2	0.2	5.6	42	50.2
SUC-H (CMU)	Proposed	7.2	2	6.1	48.1	36.6
SUC-L (DSSC)	Existing	64.8	19.9	3.4	0.2	11.7
SUC-L (DSSC)	Proposed	60.5	21.1	10.5	0.6	7.3
SUC-C (SuSC)	Existing	51.5	0.9	16	2.2	29.4
SUC-C (SuSC)	Proposed	39.4	2.2	29.4	6.6	22.4

These indices function as institutional planning "signatures" that are both quantifiable and interpretable. SUC-H (CMU), a land-grant institution, shows that RDE and Production together account for 92.2% of existing classified land — a pattern consistent with its agricultural and research mandate. Its proposed scenario redistributes area toward Academic (+5.2 pp) and GAS (+1.8 pp), reflecting a campus rationalization trajectory toward instructional intensification. SUC-L (DSSC) exhibits a contrasting signature: Academic land already dominates at 64.8%, consistent with a compact multi-campus system in which instructional space is the primary driver of land use. Its most notable proposed change is a near-tripling of Allied Services (3.4% → 10.5%), signaling planned expansion of student support facilities. SUC-C (SuSC) shows the most pronounced transition: Allied Services nearly doubles (16.0% → 29.4%) while Production decreases (29.4% → 22.4%), consistent with an island-coastal campus prioritizing residential and service infrastructure. In a green-building planning context, these signatures are consequential because they forecast building project types — research facilities for CMU, student-service buildings for DSSC, and residential or mixed-use structures for SuSC — each carrying distinct operational energy and embodied-carbon profiles, which the subsequent EUI, retrofit, and embodied-carbon modules quantify.

4.3 Energy benchmarking outputs and the staged pathway to simulation

The framework's energy module is intentionally designed to produce useful outputs even under common SUC constraints. With only monthly electricity bills and a basic floor-area inventory, planners can compute EUI at the campus level and track changes year-on-year. With submeters or building-level allocation, the framework can compare building categories such as classrooms, offices, laboratories, and dormitories and identify candidates for retrofit

feasibility screening. Figure 2 summarizes the types of outputs that can be generated from the asset registry. Specifically, Fig. 2a compares mean EUI across building categories, Fig. 2b shows monthly campus electricity consumption from bills or meters, Fig. 2c relates EUI to gross floor area to support outlier detection, and Fig. 2d reports data-quality flags that help planners distinguish stronger records from incomplete or estimated entries. Together, these panels show that the framework is not limited to producing a single benchmark value; it also supports temporal interpretation, category comparison, and data-quality diagnosis.

Where higher fidelity is required—such as for major new buildings or deep retrofits—the EnergyPlus/OpenStudio pathway allows users to move from benchmarking to scenario modeling using the same asset registry IDs. This avoids a frequent failure mode in institutional analytics: energy-model files exist but are disconnected from the planning tables and cannot be reconciled with budgets, land allocations, or LUDIP project lists. EnergyPlus and OpenStudio are suitable for this staged approach because they support detailed building physics and enable batch workflows for scenario evaluation when integrated into a scripting environment [8], [9]. As described in Section 3.3, retrofit scenarios are implemented as parameterized deltas applied to the same asset registry, allowing direct comparison with simulation-based estimates when EnergyPlus/OpenStudio inputs become available. Figure 3 illustrates how this scenario logic can be communicated through a baseline-versus-retrofit EUI comparison. In practical terms, such a figure helps planners determine whether a measure package yields only marginal gains or is large enough to justify deeper study, procurement review, or simulation-based refinement.

The method explicitly avoids overstating precision. When bills are campus-wide, and the floor area is incomplete, EUI outputs are labeled as estimates with documented allocation rules. The transparency aligns with energy-policy practice that favors traceable accounting over overly confident point estimates, particularly when the intent is decision support rather than final verification.

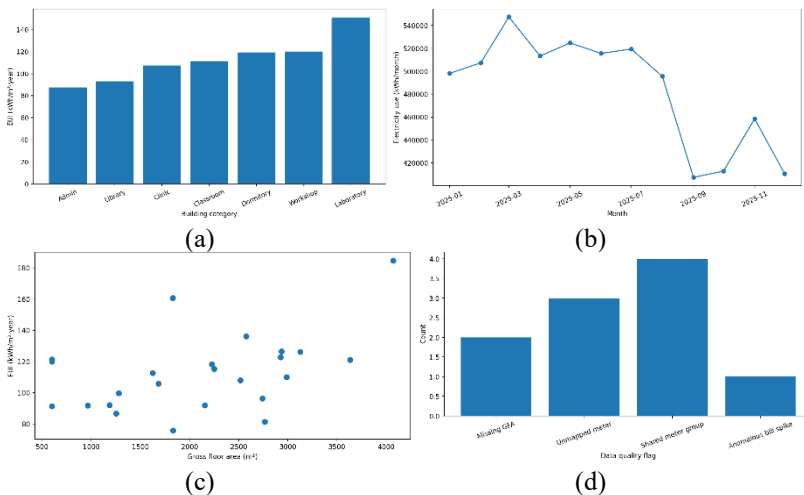


Fig. 2. Example EUI benchmarking dashboard output produced from the asset registry. (a) Mean EUI by building type, (b) Monthly campus kWh from bills/meters, (c) EUI vs gross floor area (GFA) scatter, (d) Data-quality flags bar chart

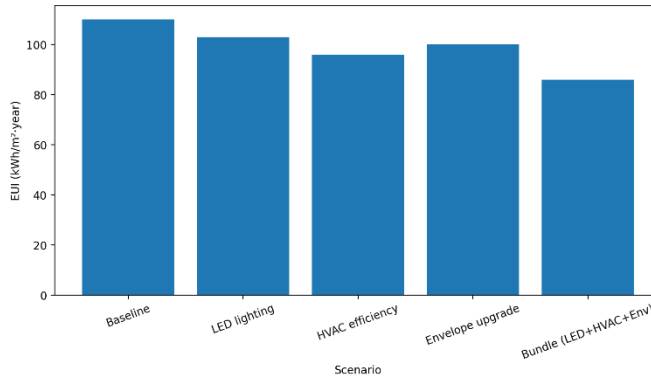


Fig. 3. Retrofit scenarios vs baseline EUI (illustrative sample).

4.4 Embodied-carbon screening and the energy–materials trade-off in campus development

For many campuses, development pipelines involve new construction, which introduces upfront embodied-carbon impacts that occur immediately and can be significant relative to long-term operational savings. The IPCC identifies buildings as a major mitigation domain in which both operational efficiency and materials choices matter [15]. Evidence syntheses likewise show that treating embodied and operational impacts separately can create blind spots and burden shifting, which is why integrated assessment remains useful even at a screening level [6]. To provide practical context for early-stage comparison, the framework incorporates default reference ranges drawn from widely cited studies and benchmark-oriented sources. Commercial building case studies indicate that embodied-carbon intensities can vary substantially across structural systems and project types, reinforcing the need to present ranges and documented assumptions rather than a single deterministic value [12], [13].

Table 3 provides the conceptual structure used by the framework for embodied-carbon screening. It identifies the minimum elements needed for meaningful comparison: the functional unit, the declared system boundary, the source of emission factors, the treatment of alternative material systems, and the resulting output metric. In this sense, Table 3 serves as a methodological checklist to ensure transparency even when project-specific bills of quantities or environmental product declarations are not yet available.

Table 3. Example screening inputs and outputs for upfront embodied carbon (A1–A5) used in early-stage campus project comparison.

Item	Screening representation	Typical benchmarking signal (illustrative)
Functional unit	kgCO ₂ e per m ² gross floor area	Enables comparison across projects
Boundary	A1–A5 (upfront) vs whole-life option	Makes timing of impacts explicit
Baseline factor source	Literature-based range / targets	Use ranges, not single values
Bio-based option	Engineered bamboo / timber scenario	Document sequestration assumption
Output	Upfront kgCO ₂ e for each project scenario	Comparable across a project list

The framework is intentionally designed to accommodate multiple structural or material scenarios, including conventional systems and lower-carbon alternatives. These alternatives may include revised concrete mixes, higher recycled-content steel, or bio-based and other lower-impact material options, provided that the underlying assumptions and boundaries are documented explicitly. The objective is not to predetermine which material is superior, but to create a consistent comparison structure that planners can apply during early project screening. Figure 4 complements Table 3 by illustrating how these assumptions can be translated into a comparative A1–A5 embodied-carbon plot for alternative building options. Read together, Table 3 and Fig. 4 show both the logic of the screening method and the type of decision-facing output that planners can generate when comparing baseline and lower-carbon project pathways.

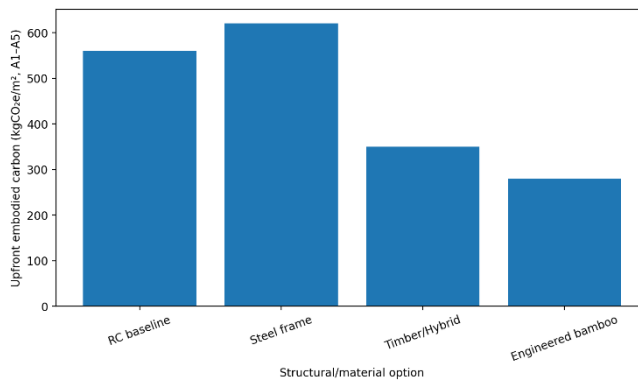


Fig. 4. Embodied carbon options A1–A5 (illustrative sample).

5 Limitations and implementation guidance

The framework’s main limitation is that it can only be as strong as the underlying inventories. Floor areas are often incomplete, building-use labels may be inconsistent, and meter mapping can be ambiguous when campuses share feeders; the framework mitigates this by requiring explicit scope labels (e.g., "shared feeder — proportional allocation") and by flagging records where meter-to-building assignments are inferred rather than metered directly. The framework mitigates this by requiring scope labels, audit flags, and explicit allocation rules. A second limitation concerns embodied-carbon factors: screening-level values are useful for prioritization, but detailed decisions should transition to quantity-based LCA with EPD-backed factors where feasible. Finally, the EnergyPlus/OpenStudio pathway requires technical capacity and building input data, including geometry, envelope properties, and schedules. The staged design is intended to address this by ensuring that early-stage outputs remain useful even before simulation-grade inputs exist.

A practical next step is to extend the framework toward life-cycle cost analysis (LCCA). Because the asset registry already links building identity, floor area, scenario labels, and environmental indicators, the same structure can accommodate capital costs, operating costs, maintenance costs, replacement cycles, and discount-rate assumptions. This would allow planners to compare retrofit or new-build scenarios not only in terms of energy and embodied carbon, but also in terms of long-term economic implications.

The framework can also be extended with social impact indicators. Examples include access to student support facilities, walkability to key services, building-use intensity, thermal comfort proxies, health and safety access, and equity-oriented service distribution across campuses. These additions would strengthen the paper’s relevance to planning by

recognizing that campus sustainability extends beyond environmental and technical factors to include operational and social dimensions.

Although the workflow is demonstrated using SUC LUDIP datasets, its logic is transferable. In private universities, the same approach can support campus master planning and building-performance tracking even without RA 11396 compliance as the primary driver. In local governments and other public institutions, the registry-based structure can be adapted to estates such as civic centers, hospital compounds, public-school systems, or administrative clusters, where building energy use, land allocation, and project sequencing must likewise be evaluated together.

6 Conclusion

This paper presents a reproducible computational framework that automates RA 11396 LUDIP compliance analytics and extends campus planning workflows with practical green-building modules: bill-based energy benchmarking (EUI), an optional pathway to EnergyPlus/OpenStudio simulation for retrofit and new-build scenarios, and screening-level embodied-carbon comparisons aligned with LCA standards. Demonstration across three distinct SUC contexts — using actual LUDIP classified-area records for CMU, DSSC, and SuSC — shows that the main value is methodological: the framework unifies LUDIP tables, GIS summaries, demand projections, and building records into an auditable asset registry and produces standardized, empirically grounded indicators that planners can update iteratively.

Beyond the present SUC application, the framework is structured as a modular decision-support system that can be adapted to other institutional settings. Future work should focus not only on expanding Philippine-specific benchmarks for campus building typologies and developing streamlined templates for EPD-based embodied-carbon inventories, but also on integrating life-cycle cost analysis and social impact indicators into the same computational environment. Such extensions would allow the framework to support more balanced environmental, economic, and social planning decisions in private universities, local governments, and other public institutions.

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