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Integrating Waste-Emission Reduction And Campus Carbon Sinks: A Faculty- Scale Case Study From A Malaysian University

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Abstract

This study evaluates the effectiveness of low-carbon initiatives in reducing greenhouse gas (GHG) emissions at Sultan Idris Education University (UPSI) through a quantitative framework that integrates both carbon emission reduction and carbon sequestration. The study adopts the “Measure–Manage–Mitigate” approach by comparing baseline year data (2022) and target year data (2023), focusing on solid waste management and campus greening. Carbon emissions from waste were calculated using emission factors, while carbon sequestration was estimated based on landscape area and tree inventory. The findings show that waste management successfully reduced carbon emissions by 33.45% at Faculty of Human Sciences (FSK) and 27.77% at Faculty of Science and Mathematics (FSM), exceeding the typical benchmarks for higher education institutions. At the same time, campus greening increased carbon sequestration by 7.63%, highlighting the complementary role of nature-based solutions. The study’s results indicate that carbon source reduction has a greater impact than increasing carbon sinks, although both are important in integrated low-carbon strategies. This study contributes by providing a micro-scale, data-driven framework that integrates both components. This approach offers a replicable model for other higher education institutions, especially in developing countries, and supports policy development towards carbon neutrality. A one-way sensitivity analysis using -20% to +20% emission-factor scenarios showed that avoided emissions remained positive at both faculties; absolute estimates changed proportionally, whereas the reported percentage reductions were unchanged by construction.

Keywords:

Low-Carbon Campus; Waste Management; Carbon Sequestration; Nature-Based Solutions; Higher Education Sustainability

1.0 Introduction

This study evaluates the effectiveness of low-carbon initiatives in reducing greenhouse gas (GHG) emissions at Sultan Idris Education University (UPSI) through a quantitative framework that integrates both carbon emission reduction and carbon sequestration. The study adopts the “Measure–Manage–Mitigate” approach by comparing baseline year data (2022) and target year data (2023), focusing on solid waste management and campus greening. Carbon emissions from waste were calculated using emission factors, while carbon sequestration was estimated based on landscape area and tree inventory. The findings show that waste management successfully reduced carbon emissions by 33.45% at Faculty of Human Sciences (FSK) and 27.77% at Faculty of Science and Mathematics (FSM), exceeding the typical benchmarks for higher education institutions. At the same time, campus greening increased carbon sequestration by 7.63%, highlighting the complementary role of nature-based solutions. The study’s results indicate that carbon source reduction has a greater impact than increasing carbon sinks, although both are important in integrated low-carbon strategies. This study contributes by providing a micro-scale, data-driven framework that integrates both components. This approach offers a replicable model for other higher education institutions, especially in developing countries, and supports policy development towards carbon neutrality. A one-way sensitivity analysis using -20% to +20% emission-factor scenarios showed that avoided emissions remained positive at both faculties; absolute estimates changed proportionally, whereas the reported percentage reductions were unchanged by construction.

2.0 LOW-CARBON DEVELOPMENT AND THE ROLE OF HIGHER EDUCATION INSTITUTIONS

Global climate change demands a shift towards low-carbon development, with higher education institutions (HEIs) playing a crucial role as agents of change in society. HEIs not only function as centers of knowledge production but also as operational entities with significant carbon footprints, making them strategic platforms for the implementation of sustainability practices [1]. However, recent studies indicate that the implementation of sustainability in HEIs remains inconsistent, with gaps between policy commitments and actual execution [2].

From a theoretical perspective, this phenomenon can be explained through Institutional Theory, which emphasizes that organizational change is influenced by regulatory and normative pressures. Nevertheless, without empirical data support, sustainability reporting risks becoming merely symbolic and not reflecting actual performance. Therefore, carbon assessment based on operational data is increasingly important in the context of HEIs.

2.1 Carbon Accounting in University Campuses

Carbon accounting is a primary approach for measuring and assessing carbon emissions on campus. A study by Kiehle et al. [3] indicates that the calculation of carbon footprints in higher education institutions must consider the unique characteristics of campuses, such as space usage, mobility, waste, and academic activities. In addition, indirect emissions (Scope 3) often represent the largest component but are the most difficult to measure [4].

Recent studies also emphasize the need for an integrated approach that combines various sectors in campus carbon management. However, many previous studies remain limited to the energy or building sectors, without integrating other elements such as waste management and carbon sequestration. These limitations highlight the need for a more comprehensive carbon assessment model based on actual data.

2.2 Circular Economy and Campus Waste Management

In the context of carbon reduction, solid waste management plays an important role, particularly through waste reduction at the source and increased recycling rates. Circular Economy theory emphasizes the reuse of resources and waste reduction as key strategies towards a more sustainable system. Vergani [5] states that higher education institutions can serve as a microcosm of the circular economy, integrating material flows, user behavior, and institutional policies.

A study by Haksevenler et al. [6] shows that the effectiveness of waste segregation systems on campus depends on the integration of technical and social aspects. El-Halwagy [7] also emphasizes the importance of a closed-loop approach in waste management. However, critically, many institutions still practice a linear model (collect-and-dispose), which significantly limits the potential for carbon reduction.

2.3 Nature-Based Solutions and Campus Greening

Campus greening is one form of Nature-based Solutions that serves as a carbon sequestration mechanism and enhances environmental quality. The implementation of campus greening varies according to the institution's capacity and the level of integration within campus planning.

However, a study by Wang et al. [8] emphasizes that carbon sequestration through greening is limited compared to operational emission reductions. Therefore, greening should be seen as a complementary strategy that supports overall carbon mitigation efforts, rather than as a standalone solution.

2.4 Behavioral Change and Community Engagement

In addition to technical factors, the success of a low-carbon campus also depends on changes in the behavior of campus members. The Value–Belief–Norm theory explains that sustainable behavior is influenced by individual values, beliefs, and norms. A study by Wongsachia et al. [9] shows that perceptions of carbon impact have a significant influence on sustainable behavior.

However, there is a gap between intention and action in sustainability practices, indicating that awareness alone is not sufficient to drive behavioral change. Therefore, campus interventions need to combine technical and social approaches to ensure the effectiveness of low-carbon strategies.

2.5 Research Gaps and Study Contributions

Although the literature on low-carbon campuses is expanding, several key gaps remain. First, most studies focus on a single component such as energy or waste without integrating carbon sequestration. Second, empirical data-based research is still limited, especially in the context of developing countries. Third, micro-scale analysis at the faculty level has received little attention.

Accordingly, this study addresses these gaps by integrating the analysis of carbon emission reduction and carbon sequestration within a quantitative framework based on actual data at the faculty level. This approach contributes to the development of a more comprehensive and evidence-based low-carbon campus model.

This study argues that the current approaches to low-carbon campus development remain fragmented and are insufficient to address the true complexity of campus systems. Although Carbon Accounting provides a basis for

quantifying emissions, its effectiveness is often limited by operational data constraints and narrowly defined system boundaries, raising questions about the accuracy of actual carbon performance assessments [3,4]. At the same time, Circular Economy is often narrowly interpreted as waste management without comprehensive structural system changes, resulting in its impact on carbon mitigation not being maximized [5,6].

Additionally, while Nature-Based Solutions through campus greening are recognized as a carbon sequestration mechanism, their contribution is relatively small compared to operational emission reductions and may be misinterpreted as a primary solution if not integrated with other strategies[8]. Furthermore, the Value–Belief–Norm theory shows that behavioral change is a critical factor, yet the gap between awareness and action remains a major challenge in the campus context [9].

Therefore, this study proposes that low-carbon campus development should be understood as an integrated socio-technical system, where carbon measurement, technical interventions, ecological functions, and behavioral change need to be combined simultaneously. Without this integration, implemented interventions risk remaining isolated and unable to achieve significant and sustained carbon reductions. Based on this argument, the study aims to quantitatively evaluate the effectiveness of low-carbon initiatives by integrating carbon emission reduction from solid waste management and increased carbon sequestration through campus greening at the faculty level, in order to provide empirical evidence supporting the development of a more comprehensive and data-driven low-carbon campus model.

The conceptual framework integrating carbon emission reduction and sequestration in a low-carbon campus system is shown in Fig. 1. This framework integrates theoretical perspectives, institutional drivers, interventions, carbon measurement, and performance outcomes of a low-carbon campus.

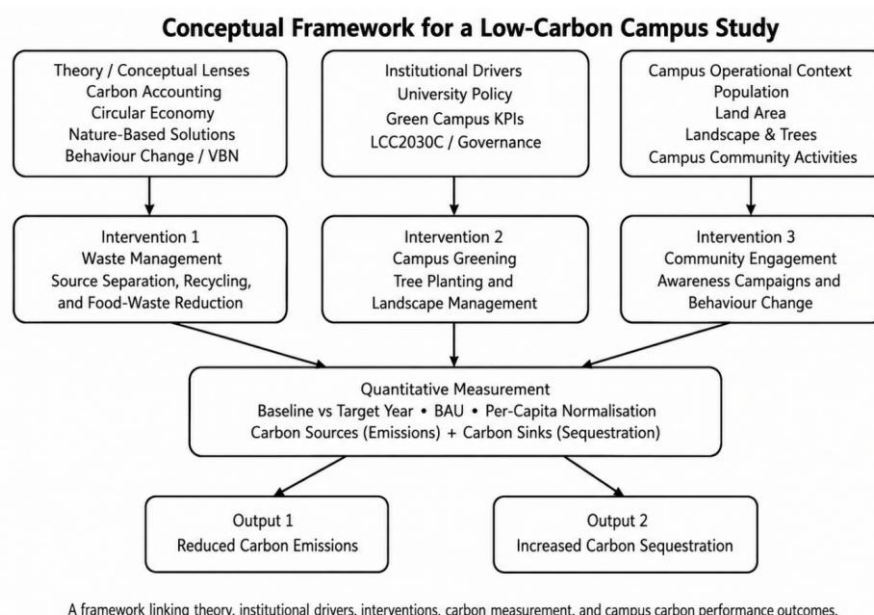


Figure 1. Conceptual framework integrating carbon emission reduction and sequestration in a low-carbon campus system.

3.0 Methods

3.1 Study Design

This study employs a quantitative approach based on empirical measurement to evaluate the effectiveness of green initiatives in reducing carbon emissions at UPSI. The study design is founded on the “Measure–Manage–Mitigate” principle outlined in the low-carbon city framework [12], where the measurement of carbon emissions is the fundamental step before management and mitigation strategies can be systematically implemented. This approach emphasizes that carbon emission measurement is a critical initial step in developing effective carbon reduction strategies.

The quantitative approach allows for an objective and measurable assessment of changes in carbon emissions by comparing baseline year data with target year data. This design also supports longitudinal analysis of low-carbon interventions at the institutional scale.

3.2 Study Area and Unit of Analysis

This study was conducted at UPSI, focusing on two main units of analysis: the Faculty of Human Sciences (FSK) and the Faculty of Science and Mathematics (FSM). The selection of these two faculties was based on purposive sampling, with the following justifications:

1. Both are pilot projects for the low-carbon campus at UPSI.
2. They have complete and accessible operational data, especially related to waste and landscaping.
3. The existing expertise and academic programs offered by these faculties are most closely aligned with sustainability and environmental stewardship.

This approach enables analysis at the micro (faculty) scale, thereby enhancing the accuracy of the assessment compared to aggregate analysis at the overall campus level.

3.3 Determination of Study Boundaries and Analysis Period

This study defines its analytical boundaries through two dimensions: temporal and system boundaries. Carbon measurement within temporal boundaries requires a baseline year as the reference for existing emission levels and a target year for assessing carbon-reduction achievement. The low-carbon elements examined must also be clearly identified to ensure accurate carbon-emission calculation and analysis [10].

Once baseline-year emissions and target-year reductions have been established, researchers can systematically develop carbon management and mitigation strategies according to the intended reduction rate [11]. This approach enables quantitative assessment of carbon performance by comparing the BAU scenario with actual achievements.

In this study, 2022 is designated as the baseline year and 2023 as the target year, with a minimum carbon-reduction target of 5%. This time frame was selected based on the availability of university operational data and its alignment with the implementation of UPSI’s low-carbon initiatives.

The system boundaries encompass two elements: (i) solid waste management as a carbon-emission source (carbon source), and (ii) campus greening as a carbon-sequestration mechanism (carbon sink). Their selection was based on data availability and approval from UPSI’s top management.

These boundaries ensure that the analysis remains focused, transparent, and comparable across the baseline and target years of the study. Consistent with carbon-accounting principles, this approach integrates emission and sequestration components to determine net carbon performance. By considering both carbon emissions and absorption, it provides a more comprehensive assessment of campus carbon performance.

3.4 Data Collection and Analysis

3.4.1 Primary Data

The primary data for this study were obtained through two methods, namely the measurement of carbon emission data (quantitative method). Details of the data collection are as follows:

3.4.1.1 Measurement of Carbon Emission Data from Waste and Carbon Sequestration

Baseline-year carbon emissions for 2022 were quantified using the total waste sent to disposal centres, green areas, and existing trees. These data were converted using MGTC carbon factors to determine baseline emissions and estimate target-year emissions under the BAU scenario. The initial measurement covered conditions throughout the baseline year and provided the reference against which subsequent reductions were evaluated.

After establishing the baseline, the researchers set the carbon-reduction target for 2023. Low-carbon initiatives, including awareness campaigns, recycling programmes, and tree planting, were implemented throughout the year, while related emission data were collected and recorded. The activities were designed to achieve the specified campus carbon-reduction target during the target year.

Waste-related carbon emissions were calculated from solid waste generated by both faculties and disposed of in landfills. Faculty landfill-disposal quantities served as the primary activity data for estimating waste-related carbon emissions. Total waste from January to December 2022 was compared with 2023 disposal data. Results were normalised by population, defined as the number of occupants in both faculty buildings.

Carbon sequestration was calculated from the total campus area comprising forests, urban landscapes, and water bodies. Values recorded between January and December 2022 were compared with the corresponding 2023 target-year data using the following calculation method.

3.4.1.2 Data Normalization

To ensure data comparability between years, a per capita normalization approach is used. This approach is important for controlling variations resulting from changes in faculty population during the years analyzed.

3.4.1.2 Carbon Calculation Methods

a) Calculation of Carbon Emissions from Waste

Carbon emission data for the baseline year (2022) were obtained by calculating the total amount of solid waste sent to landfill sites during the period from January to December. This data was then converted to carbon emissions using the emission factor set by the Malaysian Green Technology and Climate Change Corporation (MGTC), which is 586.5313 kgCO₂e/ton [13].

Carbon emissions from solid waste are calculated using the formula: $E = W \times EF$
where:

- E = total carbon emissions (kgCO₂e)
- W = total solid waste (tons)
- EF = carbon emission factor (586.5313 kgCO₂e/ton)

To improve the accuracy of year-to-year comparisons, a per capita normalization approach is used based on the faculty population:

$$E_{per\ capita} = \frac{E}{P}$$

where:

- P = total population

Based on the data obtained, total carbon emissions for the baseline year 2022 were 1.29 tCO₂e (11.06 kgCO₂e per capita) from 2.2 tons of solid waste. For the target year 2023, carbon emissions decreased to 0.93 tCO₂e (7.34 kgCO₂e per capita) from 1.58 tons of solid waste.

To assess carbon reduction performance, the BAU value is used as a reference, which is 1.39 tCO₂e. The analysis shows that a carbon reduction of 33.45% was achieved in 2023 compared to the BAU scenario.

b) Calculation of Carbon Sequestration

Carbon sequestration is estimated based on two main components: the landscape area and the number of trees in the study area. The carbon sequestration factors used are as follows:

- Landscape: 2000 kgCO₂/hectare/year
- Tree: 40 kgCO₂/tree/year

Total carbon sequestration is calculated using the formula:

$$C_{total} = (A \times CF_{landscape}) + (N \times CF_{tree})$$

where:

- A = landscape area (hectares)
- N = number of trees

For the baseline year 2022, the total carbon sequestration was 2.62 tCO₂, based on a landscape area of 0.271 hectares and 52 trees. In the target year 2023, total sequestration increased to 2.82 tCO₂ with the number of trees rising to 57.

3.4.2 Secondary Data

Secondary data of this research were obtained from university policies and reports, working papers, records from the Department of Development and Asset Management, related documents to LCC2030C, media, photographs, websites, and so forth. These documents serve as a method to strengthen the information obtained from the primary data collection in this study and to enhance the validity of the study's findings.

3.4.3 Carbon Performance Assessment

Overall, the approach used in this study enables an integrated assessment of carbon performance, taking into account two main components: the reduction of carbon emissions from waste and the increase in carbon sequestration through campus greening.

The combination of these two components provides a more comprehensive picture of the effectiveness of the implemented low-carbon initiatives, as well as supporting the analysis of net carbon performance at the faculty level.

3.4.4 Emission-Factor Uncertainty and Sensitivity Analysis

A deterministic one-way sensitivity analysis was performed to examine how uncertainty in the solid-waste emission factor affects the estimated actual, BAU, and avoided emissions. The manuscript does not report a statistical uncertainty range for the nominal factor of 586.5313 kgCO₂e/ton. Therefore, transparent stress-test scenarios of -20%, -10%, the nominal value, +10%, and +20% were used. These bounds are analytical assumptions, not confidence intervals or a probability distribution.

For scenario s , $EF_s = EF_0(1 + \delta)$, where EF_0 is the nominal factor and δ is the assumed proportional change. BAU waste was retained from the study's population-normalized projection ($W_{BAU} = W_{2022} \times P_{2023}/P_{2022}$). Actual emissions were recalculated as $E_s = W_{2023} \times EF_s$, BAU emissions as $BAU_s = W_{BAU} \times EF_s$, avoided emissions as $R_s = BAU_s - E_s$, and the reduction rate as $100(R_s/BAU_s)$. Monthly waste quantities, faculty populations, and all other assumptions were held constant so that the effect of the emission factor was isolated.

This analysis addresses parameter sensitivity only for waste-related emissions. It does not quantify uncertainty in monthly activity data, population-based BAU construction, waste composition, or carbon-sequestration factors because validated uncertainty ranges for those inputs were unavailable in the manuscript.

3.4.5 Reliability and Validity of the Study

To ensure the reliability and validity of the study:

- Data were obtained from official institutional sources.
- Calculation factors use MGTC standards.
- The analysis methods are replicable.

Data triangulation was conducted using secondary documents.

4.0 Findings

The Faculty of Human Sciences (FSK) operates in the Malim Sarjana Complex located at the Sultan Abdul Jalil Shah Campus (KSAJS), UPSI. It covers an area of 10,485 square meters (2.59 acres) [14]. The Faculty of Human Sciences consists of five departments: the Department of Geography and Environment, Department of History, Department of Malaysian Studies, Department of Islamic Studies, and Department of Moral, Civic, and Character Development. The faculty houses administrative offices, meeting rooms, student interaction rooms, and lecturers' offices, accommodating 199 staff and students in 2022 and 215 in 2023.

The Faculty of Science and Mathematics (FSM), UPSI, covers Blocks 1, 2, 3, 4, and 5 at the Sultan Azlan Shah Campus, UPSI, with a total area of 19.67 acres [14]. The buildings under FSM include faculty and departmental offices, lecture rooms, meeting rooms, and teaching and research laboratories, accommodating 3,160 staff and students in 2022 and 3,932 in 2023,

To achieve the targeted reduction in carbon from the waste sector and carbon sequestration as promised, both FSK and FSM have conducted various low-carbon awareness, education, recycling, and campus greening programs. These programs and activities successfully reduced waste disposal from FSK by 33.45% and from FSM by 27.77%. They also increased carbon sequestration in FSK by 7.63% in 2023 compared to the previous year. Additionally, these programs managed to recycle 6.38 tonnes of recyclable materials and fabrics from FSK and 1.81 tonnes from FSM.

4.1 Carbon Emission Reduction through Solid Waste Management

The findings show that the total amount of waste recycled at FSK and FSM reached 8,190 kg, resulting in a carbon reduction of 4,803 kgCO₂e. The largest contribution came from fabric waste at FSK, highlighting the high potential of textiles in carbon reduction strategies (Table 1).

These findings are consistent with the principles of the Circular Economy, where material recovery and waste reduction to landfill can significantly reduce carbon emissions [5,6]. Critically, the variation between faculties indicates that waste composition and operational activities play important roles in determining the effectiveness of recycling strategies, aligning with findings that waste management systems need to be tailored to the institutional context [7].

Table 1: Recycled Waste at FSK and FSM in 2023

Faculty	Type of Recycled	Recycled Waste (kg)	Carbon Reduction (kgCO ₂ e)	Total Recycled (kg)
FSK	Recyclables Waste	730	428	6,379
	Fabrics	5,649	3,313	
FSM	Recyclables Waste	1,811	1,062	1,811
Total		8,190	4,803	8,190

The study findings (Table 2) show that the implementation of low-carbon initiatives at the faculty level has resulted in a substantial reduction in carbon emissions from solid waste management. Total carbon emissions decreased from 1.29 tCO₂e in 2022 to 0.93 tCO₂e in 2023, equivalent to a 33.45% reduction compared to the BAU scenario.

This reduction reflects the effectiveness of waste management interventions and changes in campus users' behavior. The decrease in per capita waste from 11.06 to 7.34 kg/pax further strengthens the role of behavioral

factors in supporting carbon reduction, consistent with the Value–Belief–Norm theory, which emphasizes the link between awareness and pro-environmental actions [9].

In addition, the gap between the BAU value (1.39 tCO₂e) and actual emissions (0.93 tCO₂e) shows that, without intervention, carbon emissions would have increased. These findings reinforce the need for data-driven carbon accounting approaches to evaluate the effectiveness of carbon mitigation strategies [3,4].

Table 2: Annual Waste Generation at FSK

Waste Generation at FSK		
Month (kg)	Baseline Year (2022)	Targeted Year (2023)
January	128.32	128.32
February	128.32	128.32
March	174.82	128.50
April	128.32	128.32
May	342.32	128.32
June	520.00	125
July	121.69	121.69
August	146.87	146.87
September	119.70	119.7
October	128.32	126.44
November	128.32	137.56
December	128.32	159.52
Total Waste (Tonne)	2.20	1.58
Carbon Emission (tCO₂e)	1.29	0.93
Bussiness As Usual (tCO₂e)	1.29	1.39
Waste per capita (kg/pax)	11.06	7.34
Reduction (tCO₂e/year)	-	0.46
% Reduction	-	33.45

Carbon emission reduction is calculated by comparing the actual emission value in the target year with the BAU scenario, which represents the projected carbon emissions if no interventions are implemented. In this study, the BAU value for 2023 is estimated at 1.39 tCO₂e, while the actual recorded emissions are 0.93 tCO₂e. Therefore, the total carbon reduction is calculated as the difference between these two values, as follows:

$$\text{Carbon reduction} = \text{BAU} - \text{Actual Emissions} = 1.39 - 0.93 = 0.46 \text{ tCO}_2\text{e}$$

This value represents the total carbon emissions successfully avoided as a result of the implementation of low-carbon initiatives, particularly in solid waste management. The use of the BAU scenario as a reference is important because it takes into account growth factors such as population increase and campus activities, thus providing a more realistic assessment of the effectiveness of the interventions carried out.

This reduction is directly linked to the implementation of programs such as recycling, source reduction of waste, and awareness campaigns, which succeeded in reducing the amount of solid waste sent to landfill from 2.2 tons to 1.58 tons. From a carbon accounting perspective, this decrease demonstrates the effectiveness of waste management strategies as one of the main interventions in reducing carbon emissions at the institutional level.

When normalized per capita, carbon emissions also show a decrease from 11.06 kgCO₂e to 7.34 kgCO₂e, reflecting improved resource use efficiency among campus members. These findings are consistent with previous studies, which show that systematic waste management can significantly reduce an institution's carbon footprint [15].

Table 3 shows a reduction in carbon emissions from 5.70 to 5.13 tCO₂e, equivalent to a 27.77% reduction. Although the percentage reduction is lower compared to FSK, the absolute reduction amount (1.97 tCO₂e) is higher, reflecting the larger scale of operations at FSM.

Table 3: Annual Waste Generation at FSM

Waste Generation at FSM		
Month (kg)	Baseline Year (2022)	Targeted Year (2023)
January	725.95	725.95
February	725.95	725.95
March	725.95	725.95
April	732.45	725.95
May	725.95	725.95
June	1136.00	1042.00
July	958.80	958.80
August	1303.40	513.00
September	514.30	484.60
October	725.90	561.00
November	725.90	810.30
December	725.90	741.90
Total Waste (Tonne)	9.73	8.74
Carbon Emission (tCO₂e)	5.70	5.13
Business As Usual (tCO₂e)	5.70	7.10
Waste per capita (kg/pax)	3.08	2.22
Reduction (tCO₂e/year)	-	1.97
% Reduction	-	27.77

Significant monthly variations indicate that carbon emissions are influenced by operational and temporal factors, consistent with studies that emphasize the importance of a dynamic approach in campus carbon accounting [3]. Additionally, the lower per capita waste reduction compared to FSK suggests that behavioral interventions may be less effective, highlighting that behavioral change requires more targeted and sustained strategies [9].

Critically, these findings indicate that although reductions are occurring, the potential for carbon mitigation in FSM has not yet been maximized, especially in the context of large-scale waste management.

4.2 Increase in Carbon Sequestration Through Campus Greening

In addition to the reduction of carbon emissions, this study also demonstrates an increase in carbon sequestration capacity through campus greening activities. Total carbon sequestration increased from 2.62 tCO₂ in 2022 to 2.82 tCO₂ in 2023, representing a 7.63% increase (Table 4).

This increase was driven by the addition of trees from 52 to 57, even though the landscape area remained unchanged. This indicates that planting new trees is an effective intervention for increasing carbon absorption capacity without requiring significant changes to land use.

These findings support the role of Nature-based Solutions as a carbon absorption mechanism in the campus environment. However, critically, the contribution of sequestration is small compared to emission reductions from waste management, consistent with findings that NbS serves as a complementary strategy in carbon mitigation [8].

Table 4: Annual Carbon Sequestration Potential at FSK

Carbon Sequestration at FSK		
Month	Baseline Year (2022)	Targeted Year (2023)
Landscape (hectare)	0.271	0.271
Trees (nos)	52	57
Carbon Sequestration (tCO ₂)	2.62	2.82
Carbon Sequestration increase (tCO ₂ /year)	-	0.2
% Increase	-	7.63

This shows that while greening is important from an ecological and well-being perspective, its impact on net carbon reduction is limited if not supported by direct emission reduction efforts.

From the perspective of nature-based solutions, these findings support the role of urban greening as a cost-effective carbon mitigation strategy, while also providing additional benefits such as reducing microclimate temperatures, increasing biodiversity, and improving campus environmental quality [16].

FSM demonstrates a high carbon sequestration capacity (26.69 tCO₂), which far exceeds that of many other campus studies (Table 5). Global studies show that campus carbon sequestration usually ranges from 5–20 tCO₂, depending on the extent of green areas.

Table 5: Annual Carbon Sequestration Potential at FSM

Carbon Sequestration in FSM		
Month	Baseline Year (2022)	Targeted Year (2023)
Landscape (hectar)	3.7239	3.7239
Trees (nos)	481	481
Carbon Sequestration (tCO ₂)	26.69	26.69
Carbon Sequestration increase (tCO ₂ /year)	-	-
% Increase	-	-

However, the absence of further increases indicates that FSM is in a static carbon sink state, where additional potential is not being utilized. Critically, this is a common issue reported in the global literature, where existing green areas are not optimized through active management strategies [8]. This shows that high capacity alone is insufficient without ongoing interventions to enhance carbon performance.

4.3 Integrated Carbon Emission Reduction Performance

An integrated analysis combining both components—carbon emission reduction and increased sequestration—shows that the low-carbon strategies implemented at UPSI are holistically effective. Overall, carbon emission reduction was 0.46 tCO₂e and the increase in sequestration was 0.20 tCO₂. This indicates that more than 30% of the carbon reduction was achieved through waste interventions alone, while campus greening acts as an additional mechanism for improving net carbon balance.

This approach is in line with best practices in institutional carbon management that integrate reduce and offset strategies: reducing emissions at the source while simultaneously increasing carbon absorption capacity.

Overall, UPSI's performance is on par with or better than many global campus studies in terms of carbon reduction rates (27–33% vs. 10–30% globally) and increases in sequestration (~7%, consistent with global averages). However, the findings also show that emission reduction remains the most dominant strategy, carbon

sequestration has a limited additional impact, and the scale of operations affects the effectiveness of interventions.

This aligns with global literature emphasizing that achieving carbon neutrality requires an integrated approach that combines carbon source reduction and carbon sink enhancement within a systemic framework [4,8].

Critically, this study contributes to the literature by demonstrating that micro-scale interventions at the faculty level can achieve performance comparable to global campus studies, challenging the notion that significant impact can only be achieved at a large scale.

The findings of this study are consistent with previous research showing that the higher education sector has great potential to contribute to carbon reduction through integrated approaches [8].

However, compared to earlier studies, which are mostly conceptual, this study provides empirical evidence based on actual data at the faculty level, thus filling a research gap in the context of developing countries.

Furthermore, the carbon reduction rate of 33.45% achieved here is much higher than the faculties' minimum target of 5%, showing that small-scale but consistent interventions can deliver substantial impact.

4.4 Sensitivity Analysis of the Waste Emission Factor

Changing the emission factor altered the absolute magnitude of estimated emissions but did not reverse the finding that both faculties avoided waste-related emissions. Across the tested range, avoided emissions varied from 0.372 to 0.558 tCO₂e at FSK and from 1.577 to 2.366 tCO₂e at FSM (Table 6).

Table 6: Sensitivity of Avoided Waste Emissions to the Emission Factor

Scenario	Emission factor (kgCO ₂ e/ton)	FSK avoided emissions (tCO ₂ e)	FSM avoided emissions (tCO ₂ e)	Reduction rate FSK/FSM (%)
-20%	469.2250	0.372	1.577	33.45 / 27.77
-10%	527.8782	0.419	1.774	33.45 / 27.77
Nominal	586.5313	0.465	1.972	33.45 / 27.77
+10%	645.1844	0.512	2.169	33.45 / 27.77
+20%	703.8376	0.558	2.366	33.45 / 27.77

Note: Scenario bounds are assumed stress tests. Avoided emissions were recalculated from the monthly waste totals and population-normalized BAU quantities reported in the manuscript; values are rounded to three decimal places.

As the same scenario-specific emission factor appears in both BAU and actual emissions, it cancels algebraically when the proportional reduction is calculated. The reported reduction rates therefore remain 33.45% for FSK and 27.77% for FSM in every emission-factor scenario, and both remain above the institutional target of 5%. This invariance is a mathematical consequence of the calculation structure; it is not evidence that the reduction rates are free from uncertainty. Their robustness still depends on the accuracy of activity data, faculty population counts, and the BAU specification.

4.5 Implications for Policy

The carbon reduction of 0.46 tCO₂e achieved in this study can be translated into more easily understood effects using a carbon equivalency approach. Based on local carbon sequestration factors, a single tree is estimated to absorb about 40 kgCO₂ per year, so this reduction is equivalent to approximately 15 mature trees per year. However, when compared to the global average value of around 20–22 kgCO₂ per tree per year, this reduction can be equated to approximately 21 mature trees, depending on the species and growth rate [16].

Additionally, from the perspective of transportation emissions, a reduction of 0.46 tCO₂e is also equivalent to avoiding a journey of about 1,800 km in a passenger vehicle, based on an average emission factor of approximately 0.25 kgCO₂/km [10]. This approach not only facilitates the interpretation of the study's findings but also enhances stakeholders' understanding of the actual impact of the low-carbon initiatives implemented.

The findings of this study provide several important policy implications for the development of low-carbon campuses, especially in the context of higher education institutions in developing countries.

First, the results show that solid waste management is the most effective and immediate carbon mitigation strategy, with a reduction rate exceeding global benchmarks. Therefore, low-carbon campus policies should prioritize source reduction, waste segregation, and increased recycling rates as primary interventions. This approach is consistent with the principles of the Circular Economy, which emphasize maximizing resource use and reducing landfill waste [5].

Second, although campus greening contributes to increased carbon sequestration, the findings indicate that its impact is relatively small compared to emission reduction. Therefore, greening policies should be structured as complementary strategies that support carbon mitigation, while also providing additional benefits such as improved microclimate and environmental well-being. This includes strategic landscape planning, selection of high-capacity species, and long-term green space management.

Third, the findings show that behavioral change among campus members is a critical factor in determining the effectiveness of low-carbon interventions. Therefore, institutional policies should integrate behavior-based approaches such as awareness campaigns, incentives, and feedback mechanisms to enhance user participation, in line with the Value–Belief–Norm theory [9].

Fourth, differences in performance between faculties indicate that contextual and micro-scale approaches are more effective than uniform campus-wide approaches. Therefore, policymakers should consider implementing carbon strategies at the faculty or operational unit level as a practical entry point before expanding to the campus as a whole.

Finally, this study emphasizes the need for a carbon accounting system based on actual operational data to support the measure–manage–mitigate process. Without a robust measurement system, the effectiveness of carbon policies cannot be accurately assessed [4]. Thus, the development of a systematic institutional carbon database should be prioritized in low-carbon campus planning. Overall, the policy implications of this study indicate that an integrated approach combining emission source reduction, carbon sink enhancement, and behavioral change is critical to achieving carbon neutrality targets in higher education institutions. The framework of an integrated low-carbon campus system is shown in Fig. 2.

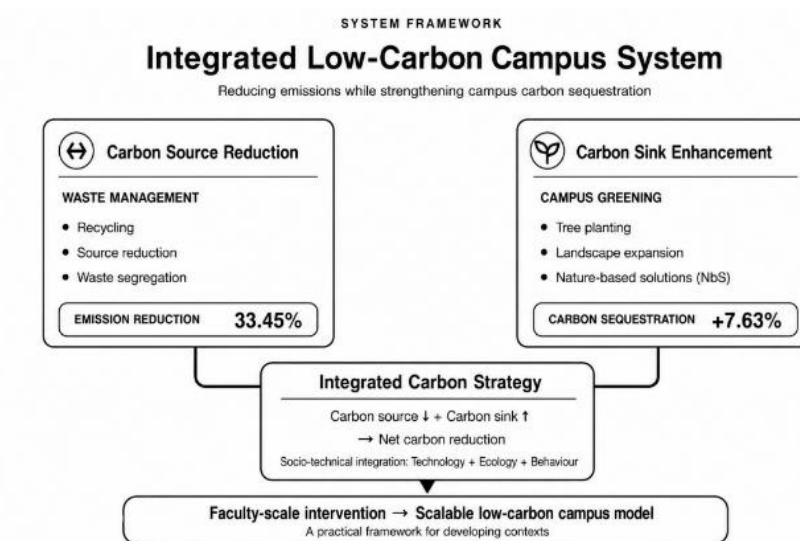


Figure 2. The framework of an integrated low-carbon campus system

5.0 Conclusion

This study evaluated the effectiveness of low-carbon campus initiatives at UPSI using an integrated quantitative approach that considers both carbon emission reduction and carbon sequestration. Solid waste management reduced carbon emissions by 33.45% at FSK and 27.77% at FSM, while campus greening increased carbon sequestration capacity by 7.63%. Across emission-factor scenarios ranging from -20% to +20%, avoided waste emissions remained positive, although their absolute values changed proportionally with the assumed emission factors.

Overall, carbon source-reduction strategies produced a greater impact than carbon sink enhancement, although both remain essential for achieving carbon balance. Comparisons with global benchmarks suggest that the recorded performance is competitive and demonstrate that faculty-level interventions can generate impacts comparable to those of larger-scale initiatives.

The study's main contribution is an integrated assessment framework combining carbon accounting, Circular Economy principles, and Nature-based Solutions using actual operational data. This framework provides a replicable model for higher education institutions, particularly in developing countries. Nevertheless, the study has several limitations. The analysis covered only waste management and campus greening, excluding other major emission sources such as energy consumption, transportation, and building operations. Its faculty-level scope may not fully represent the complexity of campus-wide activities. Furthermore, the emission-factor analysis was scenario-based rather than probabilistic and did not incorporate uncertainty in activity data, business-as-usual assumptions, or sequestration parameters.

Future research should expand the assessment to all campus emission sources, particularly energy and mobility, and incorporate life cycle assessment for a more comprehensive carbon footprint evaluation. Longitudinal studies should also examine the effectiveness of behavioural interventions and assess the scalability of this framework at campus and city levels.

In conclusion, achieving a low-carbon campus requires an integrated strategy combining technical, ecological, and behavioural interventions within a systemic framework. The findings contribute to the literature and provide empirical support for faculty-scale carbon mitigation planning in higher education institutions. They also support Malaysia's aspirations for low-carbon development and carbon neutrality by 2050, while highlighting the role of universities as catalysts for sustainability transformation.

Declarations

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Ethics declaration

Ethics declaration: not applicable.

Competing interests

The authors declare no competing interests.

Consent to participate

Not applicable

Clinical Trial

This study is not a clinical trial. Therefore, clinical trial registration details are not applicable

Consent to publish

Not applicable

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable

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