

Assessing Energy Efficiency Potential and CO₂ Emission Reduction Through Energy Use Intensity and Vegetation-Based Carbon Balance in University Campuses

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Abstract. Greenhouse gas (GHG) emissions from anthropogenic activities are causing an increase in global average temperatures and climate change. Buildings and construction contribute significantly to global climate change, accounting for about 21 percent of global greenhouse gas emissions, including the higher education sector. Therefore, universities play a role in achieving the Net Zero Emission 2060 target to reduce carbon emissions on campus so that it requires energy efficiency efforts on energy consumption and the provision of green land in carbon sequestration. This study aims to analyze (1) energy consumption and Energy Use Intensity (EUI) with various scenarios, (2) carbon footprint with various scenarios, (3) the value of carbon sequestration by trees and carbon balance with various scenarios. It was found that the laboratory building produced the highest electrical energy consumption with an average of 6,916.94 kWh/month. The highest EUI was obtained by laboratory building D12 and has efficient criteria, which is 10.08 kWh/m²/month. The energy-saving scenario shows that all buildings have very efficient criteria. The carbon footprint in existing conditions, wasteful and efficient scenarios respectively amounted to 52,680 kgCO₂eq and has the potential to increase to 71,269.76 kgCO₂eq and decrease to 39,715.93 kgCO₂eq. Vegetation in the form of existing trees in the area has an absorption capacity of 1,067,414.24 kgCO₂eq so that trees are able to absorb all CO₂ emissions produced so that the carbon balance produces a negative value.

Keywords: Carbon Balance, CO₂ Emission, Carbon Sequestration, EUI

1. Introduction

Greenhouse gas (GHG) emissions from anthropogenic activities cause an increase in global average temperatures and climate change (Wang et al., 2021). According to the latest GHG emissions report published by the United Nations Environment Programme (UNEP) (2024), global anthropogenic emissions doubled in 2023 compared to 1970 (from 28.7 to 57.1 Gigatonnes CO₂eq). Similarly, in Indonesia, data from the Ministry of Environment and Forestry in 2024 shows that GHG emissions increased from 1,156.055 million tons of CO₂eq in 2021 to 1,228.721 million tons of CO₂eq in 2022. GHG can be classified into five sectors: energy, industry, buildings, transport, and AFOLU (Agriculture, Forestry and Other Land Use) (Lamb et al., 2021). The Global Alliance for Building and Construction states that the building and construction sector contributes significantly to global climate change, accounting for around 21 per cent of global greenhouse gas emissions, such as offices, shopping centers, and the higher education sector (UNEP, 2024).

On a global scale, higher education is increasingly recognized as a vital player in meeting the targets set by the Paris Agreement and the Sustainable Development Goals (SDGs). Universities not only make significant contributions to greenhouse gas emissions but also have research capabilities, innovative potential, and practical applications that can be adapted and used worldwide (Aghamolaei & Fallahpour, 2023). In line with Indonesia's pledge to achieve Net Zero Emissions by 2060, universities are urged to minimize their carbon footprint through measures focused on energy efficiency and conservation (Kementerian Lingkungan Hidup dan Kehutanan, 2024). One of the critical resources on campuses is vegetation, especially trees, which serve as both carbon sinks and vital contributors to local environmental quality (Grossi et al., 2023; Zheng et al., 2021).

Higher education institutions, including universities, institutes, and colleges, have at least buildings for classrooms, laboratories, offices, canteens, and dormitories. These areas show high energy consumption (Khoshbakht et al., 2018). In addition, the activities of students, lecturers, and teaching staff also contribute to CO₂ emissions (Genta et al., 2022). Therefore, several studies consider higher education institutions to contribute significantly to CO₂ emissions (Paredes-Canencio et al., 2024). Thus, as a place for the development of science, technology, and innovation, universities have a fundamental role in contributing to reducing GHG emissions as part of achieving sustainability (Lozano et al., 2019). Higher education institutions can be referred to as ‘Small Cities’ due to their size and the different impacts achieved through the community on society and the environment (Abdullah et al., 2019).

Research on carbon balance has not been widely conducted in developing countries (Zhang et al., 2023). Globally and in Indonesia, most carbon balance studies in universities estimate carbon footprints and vegetation sequestration in general approaches (Liu et al., 2023; Y. Wang et al., 2024; Ngabekti & Sultan, 2024). However, carbon balance studies at universities require a detailed approach to determine the appropriate actions, especially the differences in energy consumption, where each building has differences based on function or duration of use (Khoshbakht et al., 2018). In these studies, scenario modeling is used to assess how alternative tree planting and management strategies influence carbon and climate outcomes, emphasizing ranges of plausible futures (Grossi et al., 2023; Lazzarini et al., 2022; Brilli et al., 2022). Therefore, this study aims to analyze electricity use intensity (EUI) and carbon footprints with various scenarios (i) and quantify direct tree carbon sequestration values using allometric AGB model (ii). Unlike conventional carbon footprint assessments, this study introduces scenarios of electricity-use duration to evaluate whether tree-based sequestration can offset emissions during periods of high electricity demand as part of campus mitigation strategies. The scientific contribution lies in assessing the campus’s capacity to manage energy consumption in a way that enables the achievement of net-zero electricity-related emissions.

2. Method

2.1. Study Area

This research was conducted in Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang (FMIPA UNNES), as shown in Figure 1. The buildings counted were lecture buildings, lecturer office buildings, laboratory buildings, and faculty administration buildings. The research period was 4 months from April to July 2025. Primary data collection was conducted by taking direct measurements in the field over a period of two months to measure energy consumption, carbon footprint and trees in the FMIPA UNNES area. The data was then analyzed to determine the EUI value, CO₂ emissions, energy efficiency and tree carbon absorption, as well as the carbon balance.

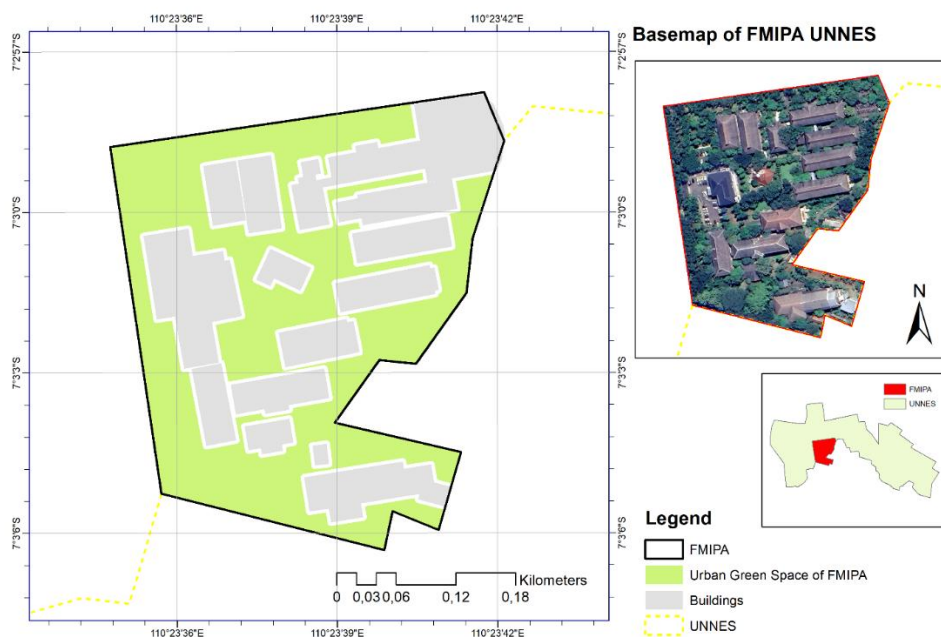


Figure 1. Area of FMIPA UNNES

2.2. Electronic Devices Data Collection

The building's electricity consumption is calculated based on direct measurements of the electronic devices used in each lecture building, lecturer office building, laboratory building, and faculty administration building. The electronic devices measured include lights, air conditioners (AC), fans, televisions, and high-intensity or non-stop laboratory equipment. The data collection of electronic devices includes type and electrical power. The room usage schedule is used to obtain the time of use of electronic devices so that electricity consumption can be obtained. In addition to calculating the electricity consumption of buildings, the building area is calculated using measurements based on aerial photographs by Google Earth to obtain the EUI value for each building.

2.3. Tree Data Collection

All trees in the FMIPA UNNES area were counted with a minimum diameter of 10 cm. The trees counted included the type or species of tree and the diameter at breast height (DBH) \pm 1.3 m.

2.4. Energy Consumption Analysis

Electricity consumption is calculated using data collected from electronic equipment, including lights, air conditioners, televisions, fans, and laboratory equipment. Electricity consumption is calculated based on type, electrical power, and usage time using the following equation (1):

$$E = \frac{P}{1000} \times t \quad (1)$$

Where E is the electrical energy (kWh), P is the electrical power (W), and t is the time (hours).

2.5. Scenario Modelling

The scenario model was applied to the electricity consumption data using two approaches:

Scenario 1: Describes conditions of continuous overuse, assuming all rooms are occupied for 10 hours (6:00 AM – 4:00 PM) every weekday, except for the hall, which is assumed to remain occupied on weekends (Saturday and Sunday).

Scenario 2: Demonstrates efficient energy use by considering energy-saving principles regarding the usage time of electronic devices. The energy-saving principles implemented include discontinuing lighting in non-AC rooms during the day (8:00 AM–3:00 PM), establishing a break time in the office, and using floor lamps on the terrace only at night (5:00 PM–6:00 AM). This model only changes the duration of use, without changing the type of electronic equipment used.

2.6. EUI Analysis

The EUI calculation determines the amount of energy consumed (kWh) per specific area (m²) each month. The EUI calculation is obtained by dividing the monthly electricity consumption by the building area using the following equation:

a. Building Conditions without Air Conditioning

The EUI calculation for conditions where the percentage of air-conditioned floor area to total floor area is <10% uses the following equation (2):

$$EUI_1 = \frac{\text{Energy Use Intensity (kWh)}}{\text{non-AC Floor area (m}^2\text{)}} \quad (2)$$

b. Buildings Conditions with air conditioning

The EUI calculation for conditions where the percentage of air-conditioned floor area to total floor area is >90%, then the following equation (3) is used:

$$EUI_2 = \frac{\text{Energy Use Intensity (kWh)}}{\text{AC Floor area (m}^2\text{)}} \quad (3)$$

c. Partially air-conditioned building conditions

The EUI calculation for a building with a ratio of 10% to 90% of the air-conditioned floor area to the total floor area is considered a combination of air-conditioned and non-air-conditioned buildings. The following equation (4) and (5) is used:

- Floor with AC

$$IKE_3 = \frac{\text{Total Energy Use (kWh)} - \text{AC Energy Use (kWh)}}{\text{Non-AC Floor area (m}^2\text{)}} \quad (4)$$

- Floor without AC

$$IKE_4 = \frac{\text{AC Energy Use (kWh)}}{\text{AC Floor area (m}^2\text{)}} + IKE_3 \quad (5)$$

The results obtained were then analyzed according to the EUI standard values used for commercial or office buildings, divided into two criteria: air-conditioned buildings and non-air-conditioned buildings, as shown in Table 1.

Table 1. EUI Standards for Air-Conditioned and Non-Air-Conditioned Buildings

No	EUI Criteria	AC EUI Standards (kWh/m ² /month)	non-AC EUI Standards (kWh/m ² /month)
1	Very Efficient	< 8.5	< 3.4
2	Efficient	8.5 ≤ x < 14	3.4 ≤ x < 5.6
3	Quite Efficient	14 ≤ x < 18.5	5.6 ≤ x < 7.4
5	Wasteful	≥ 18.5	≥ 7.4

2.7. CO₂ Analysis

The carbon footprint calculation uses the following equation (6) according to the IPCC Guidelines (2006):

$$\text{CO}_2 \text{ Emissions} = \text{DA} \times \text{FE} \times \text{GWP} \quad (6)$$

where CO₂ Emissions is Total emissions in units of (kgCO₂eq), DA is Electricity usage activity data (kWh), FE is Electrical energy emission factor (0.844 kgCO₂e/kWh), and GWP is Global Warming Potential in (CO₂eq)

2.8. Tree Biomass Analysis

Tree biomass is calculated using the allometric equation (7) by Chave et al., (2005) as follows:

$$\text{AGB} = \rho \times \exp(-1.499 + 2.148 \ln(\text{DBH}) + 0.207 (\ln(\text{DBH}))^2 - 0.0281(\ln(\text{DBH}))^3) \quad (7)$$

where AGB is Aboveground Biomass (kg), ρ is Wood Density (gr/cm³), and DBH is Diameter Breast Height (cm).

2.9. Carbon Stock and Carbon Sequestration Analysis

The calculation of carbon stock is calculated by assuming that the amount of carbon is half of the tree biomass according to the IPCC method (Eggleston et al., 2006) as follows equation (8):

$$C = 0.5 \times W \quad (8)$$

where C is Carbon stock (kg), W is Biomass (kg), 0.5 is Plant carbon content coefficient. The calculation of carbon dioxide (CO₂) uptake by trees uses the results of the carbon stock calculations for each tree as follows equation (9):

$$\text{CO}_2 = 3.67 \times C \quad (9)$$

where CO₂ is Carbon dioxide uptake (kgCO₂eq), C is Carbon stock (kg), 3.67 is Conversion equivalent number of carbon (C) to carbon dioxide (CO₂).

2.10. Carbon Balance Analysis

The carbon balance calculation is based on the addition of positive tree carbon uptake data and negative carbon emission data, using the following equation (10):

$$\text{Carbon Balance} = \sum CO_{2\text{tree}} + \sum CO_{2\text{emission}} \quad (10)$$

where *Carbon Balance* is Carbon Balance Analysis (KgCO₂eq), $\sum CO_{2\text{emission}}$ is Total carbon emissions, negative value (KgCO₂eq), $\sum CO_{2\text{tree}}$ is Total carbon absorption capacity of trees is positive (KgCO₂eq)

3. Result and Discussion

3.1. Electrical Energy Consumption and EUI Value of the FMIPA Building at UNNES

The FMIPA at UNNES produces significantly different electrical energy consumption, so calculations or data collection on campus energy use must be classified based on building function. Based on the results of the electrical energy consumption analysis, the data are presented in Table 2, and the scenario implementation is presented in Figure 2.

Table 2. Electrical Energy Consumption

No	Build- ing	Main function	Operating Hours	Electrical Energy Consumption (kWh)	Average Electricity Consumption (kWh)
1	D1			3,431.71	
2	D2	Lecture	7 - 17 (±5 hours)	1,943.92	2,734.29
3	D3			2,108.34	
4	D4			3,453.17	
5	D5			4,851.30	
6	D6	Lecturer Office	7 - 16	6,700.60	5,975.41
7	D7			6,374.32	
8	D8			4,909.85	
9	D9	Laboratory	7 - 16	5,310.50	6,916.94
10	D10			7,552.45	
11	D11			9,894.97	
12	D12	Administra- tion	7 - 16	5,886,80	5,886.80
		Total		62,417.30	5,487.43

The laboratory building produces the highest electrical energy consumption (32.1%) with an average of 6,916.94 kWh. Meanwhile, the lecture building produces the lowest electrical energy consumption (12.7%) with an average of 2,734.29 kWh. The lecturer office building and the faculty administration building produce electrical energy consumption twice as high as the lecture building with an average of 5,975.41 kWh and 5,886.80 kWh (27.4%). The building with the lowest electrical energy consumption (3.1%) is D2 as the lecture building. Conversely, the building with the highest energy consumption (15.8%) is D11 as the laboratory building. All buildings have an electrical energy consumption of 62,417.30 kWh, with an average of 5,487.43 kWh per building.

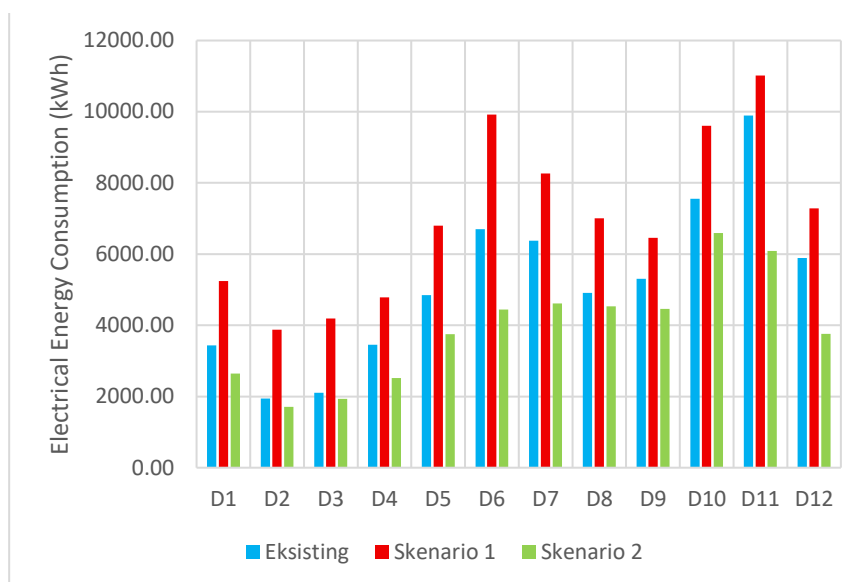


Figure 2. Scenario Model for the FMIPAs' Electrical Energy Consumption

Scenario 1, overall, results in a 35.28% increase in electrical energy consumption, from 62,417,928 kWh to 84,442.84 kWh. Building D2 doubles its consumption to 3,879.92 kWh if all rooms are fully utilized. Meanwhile, building D9 only increases by 1.09 times to 6,456.45 kWh. Overall, Scenario 2 reduces electrical energy consumption by 32.64%, from 62,417,928 kWh to 47,056,788 kWh. Building D11 experiences a significant reduction in this scenario, decreasing by 38.2% to 6,118.45 kWh. Building D3 only experiences a 6.9% decrease to 1,962.42 kWh.

The laboratory building has the highest electricity consumption because some rooms are air-conditioned and contain high-intensity electronic laboratory equipment that must be used continuously 24 hours a day. Additionally, some laboratories are used on a scheduled basis or continuously throughout working hours. The lecture building has rooms that are generally just classrooms without air conditioning. Furthermore, the hours of use for lecture rooms adjust to the class schedule, with an average usage of around 5 hours per day, so that the electricity consumption generated by the lecture building is not as high as that of other buildings with longer usage times. The lecturer's office building and the administration building have relatively high electricity consumption because almost all rooms in these buildings are air-conditioned and used as offices, with regular hours of use from 07:00 to 16:00, a duration of 9 hours every week-day.

Rooms in lecture buildings are often found lit after teaching and learning activities are completed or are not actively used. Lecture offices are also sometimes used for more than one hour beyond working hours, reaching up to 10 hours (7:00-17:00). Furthermore, students or lecturers often use laboratory rooms for research purposes. Hence, they are in constant use throughout the day, often until late at night. Due to these unscheduled conditions, scenario one is applied to illustrate if electricity consumption results from continuous or excessive room use. On the other hand, scenario two is applied to illustrate whether energy-saving management is implemented optimally. Laboratory buildings, especially D11, experienced a significant decrease in this scenario, specifically a 38.2% decrease. This building produces the highest consumption due to routine room use, high-intensity laboratory equipment, and numerous office spaces.

Scenario 1 projects a significant increase in energy consumption, this scenario was modelled to represent a worst-case estimate rather than a typical operational state. It assumes extended and unregulated use of facilities conditions that are plausible but not consistently sustained across all campus buildings simultaneously. The application of scenario modeling enables analysis beyond current conditions by identifying potential maximum and minimum electricity consumption outcomes in faculty. Electricity demand is strongly influenced by students' and lecturers' occupancy patterns and building use (Laaroussi et al., 2020). Within the university scope, in general, FMIPA is one of the faculties with the highest electricity consumption (Yuan et al., 2018). In response to observed overuse and the need for energy conservation, this study applies scenario modeling under conditions of excessive consumption and energy-saving measures. Similar approaches have been adopted in prior studies, including electricity consumption scenarios reflecting COVID-19 impacts and energy efficiency strategies at University Kebangsaan Malaysia (Nasir et al., 2023), as well as scenario-based evaluations of HVAC system operation for energy conservation in French university campus (Allab et al., 2017).

To calculate a building's efficiency in generating electrical energy consumption, the building area is required to obtain the EUI value. The EUI value for each building is divided into categories of air-conditioned and non-air-conditioned floor area, as shown in Figure 3.

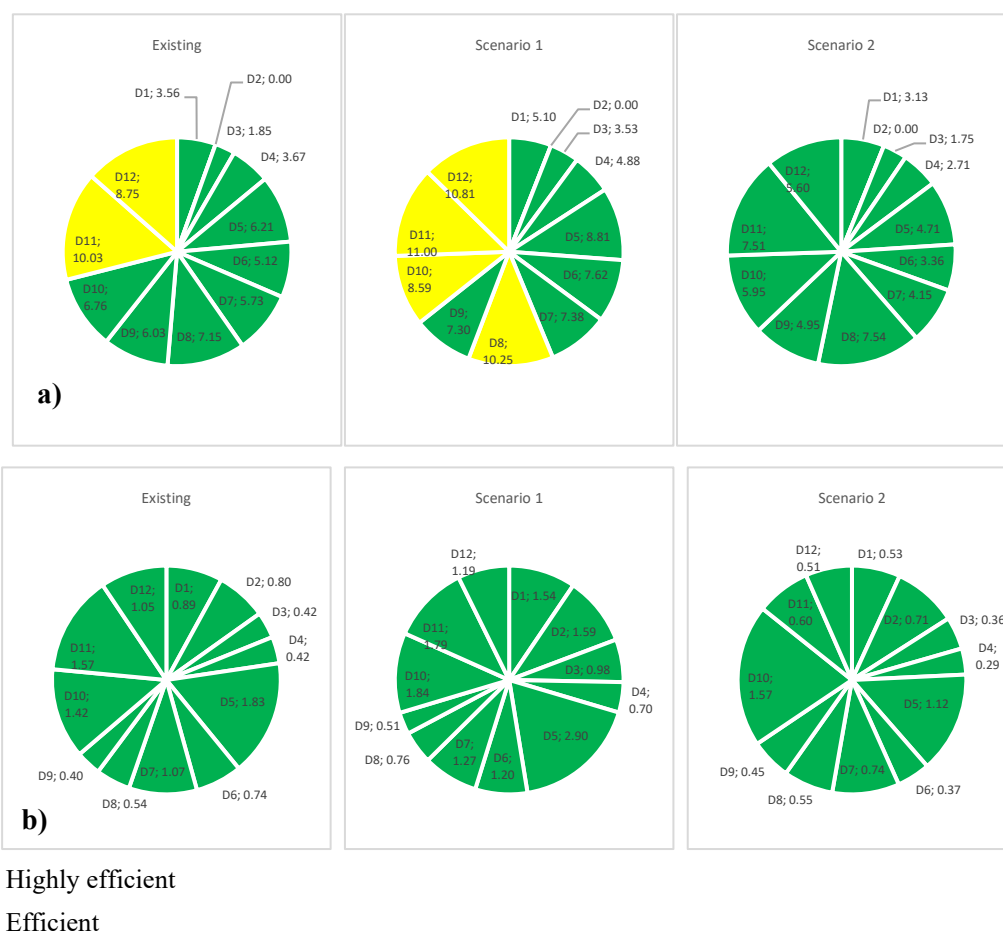


Figure 3. a) EUI Values for the AC Scenario Model. b) EUI Values for the Non-AC Scenario Model.

For the EUI value of air-conditioned floor area, building D11 has the highest EUI value at 10.03 kWh/m² and is classified as Efficient (>8.5 kWh/m²). In scenario 1, all laboratory buildings, except building D9, meet the efficiency criteria. In scenario 2, all buildings meet the highly efficient criteria. The EUI values for non-air-conditioned floor area indicate that all buildings, both in existing and scenario conditions, meet highly efficient criteria.

The lecture building, under three different conditions, is classified as Very Efficient. This is because the electricity consumption generated is relatively low compared to the large floor area of the lecture building, resulting in a low EUI value. Meanwhile, the laboratory building has a high EUI value in all three conditions, indicating that both the existing and scenario one buildings meet the efficient criteria. Meanwhile, in scenario 2, the building meets the highly efficient criteria.

3.2 Carbon Footprint of the FMIPA UNNES Building

The calculated carbon footprint reflects indirect (Scope 2) emissions generated from the electrical energy consumption of each building. Table 4 presents the monthly CO₂ emissions under the existing condition and two scenario models to illustrate potential changes in energy-related impacts. Buildings are grouped by their main functions to clarify differences in consumption patterns. This overview provides the basis for further evaluation of energy efficiency and mitigation strategies.

The carbon emissions of the FMIPA UNNES reached 526.80 tons of CO₂/year, a 1.73-fold increase compared to the previous year's study by Ngabekti & Sultan (2024), which obtained CO₂ emissions of 364.95 tons of CO₂eq/year. Carbon emissions generated in the FMIPA building show that the laboratory building contributes the highest emissions compared to the lecturer and administration office buildings. The total carbon emissions generated under existing conditions are 52,680.73 kgCO₂eq. In scenario 1, a 35.29% increase was obtained. Carbon emissions generated from lecture buildings increased significantly and evenly, by 65.47%, due to the previously low intensity of room use in lecture buildings, while laboratory buildings increased by 23.16%. Calculations using scenario 2 indicate that total CO₂ emissions from existing conditions have the potential to be reduced by 32.64%. Office and administrative buildings had the highest reductions, with percentages of 39.90% and 56.54%, respectively.

Table 4. Carbon Footprint with scenario models in FMIPA.

Building	Main Function	Carbon Emission (kgCO ₂ eq/month)				
		Existing	Scenario 1	CO ₂	Scenario 2	CO ₂
				Increasing Potency		Reduction Potency
D1	Lecture	2,896.36	4,423.51	+1,527.14	2,228.76	-667.60
D2		1,640.67	3,274.65	+1,633.98	1,439.86	-200.80
D3		1,779.44	3,537.55	+1,758.11	1,633.60	-145.84
D4		2,914.47	4,039.06	+1,124.59	2,129.14	-785.34
D5	Lecturer Office	4,094.49	5,739.63	+1,645.14	3,165.88	-928.61
D6		5,655.31	8,372.33	+2,717.02	3,752.22	-1,903.09
D7		5,379.93	6,977.31	+1,597.39	3,896.88	-1,483.05
D8	Laboratory	4,143.91	5,912.83	+1,768.92	3,824.27	-319.64
D9		4,482.05	5,449.24	+967.19	3,765.15	-716.90
D10		6,374.27	8,103.23	+1,728.96	5,564.93	-809.34
D11		8,351.36	9,294.67	+943.31	5,141.28	-3,210.08
D12	Administration	4,968.46	6,145.74	+1,177.28 (23.70%)	3,173.95	-1,794.51 (56.54%)
Total		52,680.73	71,269.76	+18,589.03 (35.29%)	39,715.93	-12,964.80 (32.64%)
Total per tahun		526,807.31	712,697.57		397,159.29	

3.3 Tree Carbon Absorption and Carbon Balance

Fifty-four tree species were identified throughout the FMIPA UNNES area out of 318 recorded trees are presented in Figure 4.

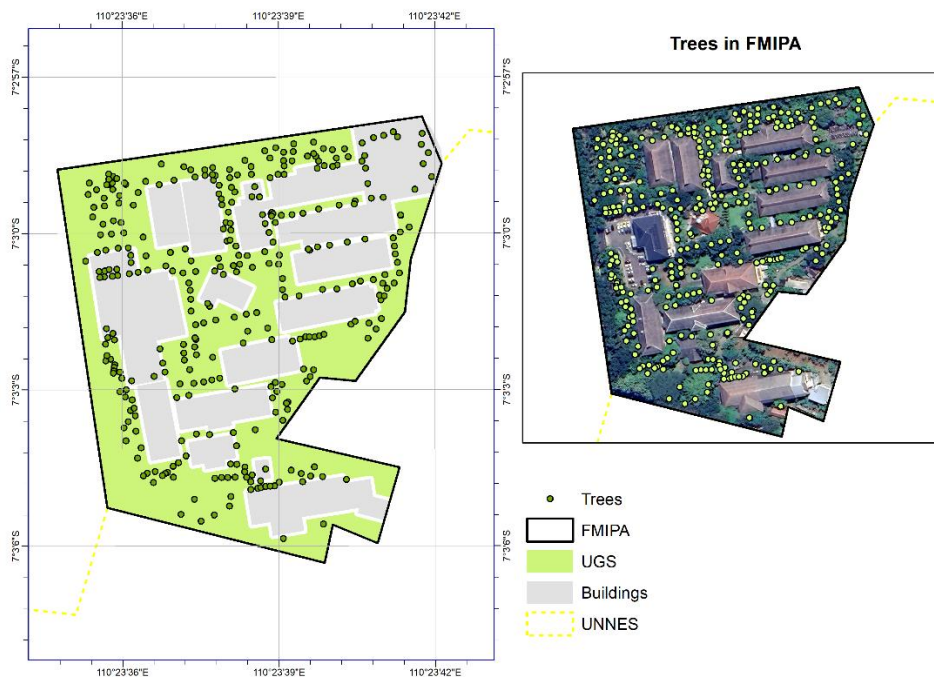


Figure 4. Tree Location in FMIPA UNNES

The following tree species and their total carbon sequestration potential at FMIPA UNNES are presented in Table 5 below.

Table 5. Tree Carbon Sequestration

Name/Type of Trees		Amount	Biomass (kg)	Carbon Stock (kg)	Carbon Sequestration (kg)
Scientific Name	Common Name				
<i>Swietenia mahagoni</i>	West Indian Mahogany	76	264.944,42	132.472,21	486.173,02
<i>Mangifera indica L</i>	Mango	53	50.920,55	25.460,28	93.439,22
<i>Polyalthia longifolia</i>	False Ashoka / Mast Tree	39	43.617,63	21.808,82	80.038,36
<i>Roystonea regia</i>	Royal Palm	26	9.838,49	4.919,25	18.053,64
<i>Maniltoa grandiflora</i>	Handkerchief Tree	12	8.162,88	40.81,44	14.978,88
<i>Pterocarpus indicus</i>	Narra / Burmese Rosewood	11	28.854,18	14.427,09	52.947,42
<i>Casuarinaceae</i>	Casuarina / Australian Pine	7	5.978,54	2.989,27	10.970,62
<i>Ficus benjamina</i>	Weeping Fig	6	9.797,80	4.898,90	17.978,96
<i>Cerbera manghas L</i>	Sea Mango	6	8.455,10	4.227,55	15.515,11
<i>Terminalia catappa</i>	Tropical Almond / Sea Almond	6	17.406,03	8.703,02	31.940,07
<i>Artocarpus heterophyllus</i>	Jackfruit	6	3.362,08	1.681,04	6.169,42
<i>Parkia speciosa</i>	Stink Bean / Bitter Bean	5	3.260,13	1.630,07	5.982,35
<i>Tectona grandis</i>	Teak	4	27.628,23	13.814,12	50.697,80
<i>Persea americana</i>	Avocado	3	5.976,52	2.988,26	10.966,91
<i>Leucaena leucocephala</i>	Lead Tree	3	3.519,39	1.759,69	6.458,08
<i>Samanea saman</i>	Rain Tree / Monkeypod	2	17.537,23	8.768,62	32.180,82
<i>Adenanthera pavonina</i>	Red Bead Tree / Saga Tree	2	5.466,86	2.733,43	10.031,69
<i>Acacia longifolia</i>	Sydney Golden Wattle	2	3.119,32	1.559,66	5.723,95
<i>Delonix regia</i>	Royal Poinciana / Flame Tree	2	2.069,89	1.034,95	3.798,26
<i>Syzygium samarangense</i>	Water Apple / Rose Apple	2	1.979,89	989,95	3.633,10
<i>Spondias dulcis Soland</i>	Ambarella	2	1.771,57	885,79	3.250,84
<i>Averrhoa bilimbi</i>	Bilimbi	2	1.618,41	809,20	2.969,78
<i>Erythrina crista-galli</i>	Cockspur Coral Tree	2	593,37	296,69	1.088,84

Name/Type of Trees		Amount	Biomass (kg)	Carbon Stock (kg)	Carbon Sequestration (kg)
Scientific Name	Common Name				
<i>Melaleuca leucadendra</i>	Cajeput Tree / Paperbark	2	509,84	254,92	935,55
<i>Averrhoa carambola</i>	Starfruit / Carambola	2	366,97	183,48	673,38
<i>Eugenia uniflora</i>	Surinam Cherry	2	365,50	182,75	670,69
<i>Nep helium lappaceum</i>	Rambutan	2	309,28	154,64	567,52
<i>Manilkara kauki</i>	Sapodilla	2	256,17	128,09	470,08
<i>Ficus altissima</i>	Council Tree	1	22.677,32	11.338,66	41.612,89
<i>Dalbergia latifolia</i>	Indian Rosewood	1	5.342,30	2.671,15	9.803,13
<i>Diospyros discolor</i>	Velvet Apple	1	4.379,10	2.189,55	8.035,65
<i>Shorea roxburghii</i>	Red Meranti	1	3.858,20	1.929,10	7.079,80
<i>Artocarpus altilis</i>	Breadfruit	1	3.475,08	1.737,54	6.376,78
<i>Bauhinia purpurea</i>	Purple Orchid Tree	1	2.054,65	1.027,32	3.770,28
<i>Ficus religiosa</i>	Sacred Fig / Bodhi Tree	1	1.967,18	983,59	3.609,77
<i>Cynometra cauliflora</i>	Namnam Tree	1	1.809,47	904,73	3.320,38
<i>Schefflera actinophylla</i>	Umbrella Plant / Dwarf Schefflera	1	1.215,12	607,56	2.229,75
<i>Araucaria heterophylla</i>	Norfolk Island Pine	1	759,35	379,67	1.393,41
<i>Syzygium cumini</i>	Java Plum / Jambolan	1	600,68	300,34	1.102,26
<i>Cananga odorata</i>	Ylang-ylang	1	526,51	263,25	966,14
<i>Theobroma cacao</i>	Cacao / Chocolate Tree	1	518,06	259,03	950,64
<i>Stelechocarpus burahol</i>	Kepel Fruit Tree	1	455,61	227,80	836,04
<i>Mimusops elengi</i>	Spanish Cherry / Tanjung	1	374,41	187,20	687,04
<i>Dyera costulata</i>	Jelutong	1	317,93	158,96	583,39
<i>Magnolia champaca</i>	Champak / Yellow Champaca	1	289,81	144,90	531,80
<i>Artocarpus integer</i>	Chempedak	1	286,55	143,28	525,82
<i>Dimocarpus longan</i>	Longan	1	271,73	135,87	498,63
<i>Areca catechu</i>	Betel Nut Palm / Areca Palm	1	117,11	58,56	214,90
<i>Ficus Elastica</i>	Rubber Fig / India Rubber Tree	1	59,53	29,76	109,23

Name/Type of Trees		Amount	Biomass (kg)	Carbon Stock (kg)	Carbon Sequestration (kg)
Scientific Name	Common Name				
<i>Ficus natalensis hochs</i>	Cluster Fig	1	47,71	23,86	87,55
<i>Annona muricata L</i>	Soursop	1	38,52	19,26	70,69
<i>Phaleria macrocarpa</i>	God's Crown Fruit	1	21,95	10,97	40,27
<i>Carica papaya L.</i>	Papaya	1	11,58	5,79	21,25
<i>Total</i>					1.067.414,24

The total tree biomass obtained was 581,697.13 kg, and the total carbon stock was 290,848.57 kg, so that the total carbon that trees can absorb in a year is 1,067,414.24 kgCO₂eq or 1.06 tonsCO₂eq. Based on the number of trees in FMIPA, *Swietenia mahagoni* or Mahogany, with a total of 76 trees and DBH with an average of 47.44 cm and the highest of 78.8 cm, can absorb up to 486,173.02 kgCO₂eq or 46% of the total absorption by all trees. Followed by *Mangifera indica* and *Polyalthia longifolia* with a total of 53 and 39 trees able to absorb up to 93,439.22 kgCO₂eq and 80,038.36 kgCO₂eq. The *Ficus benjamina* tree, with a DBH of 141.72 cm, recorded the highest carbon absorption, at 41,612.89 kgCO₂eq/tree, followed by *Tectona gandis*, *Terminalia catappa*, *Swietenia mahagoni*, and *Samanea saman*.

The potential carbon absorption of trees in the FMIPA UNNES is one of the most significant contributors to the carbon balance process. The carbon balance process at FMIPA UNNES is divided into three conditions: existing, scenario 1, and scenario 2, as shown in Figure 5.

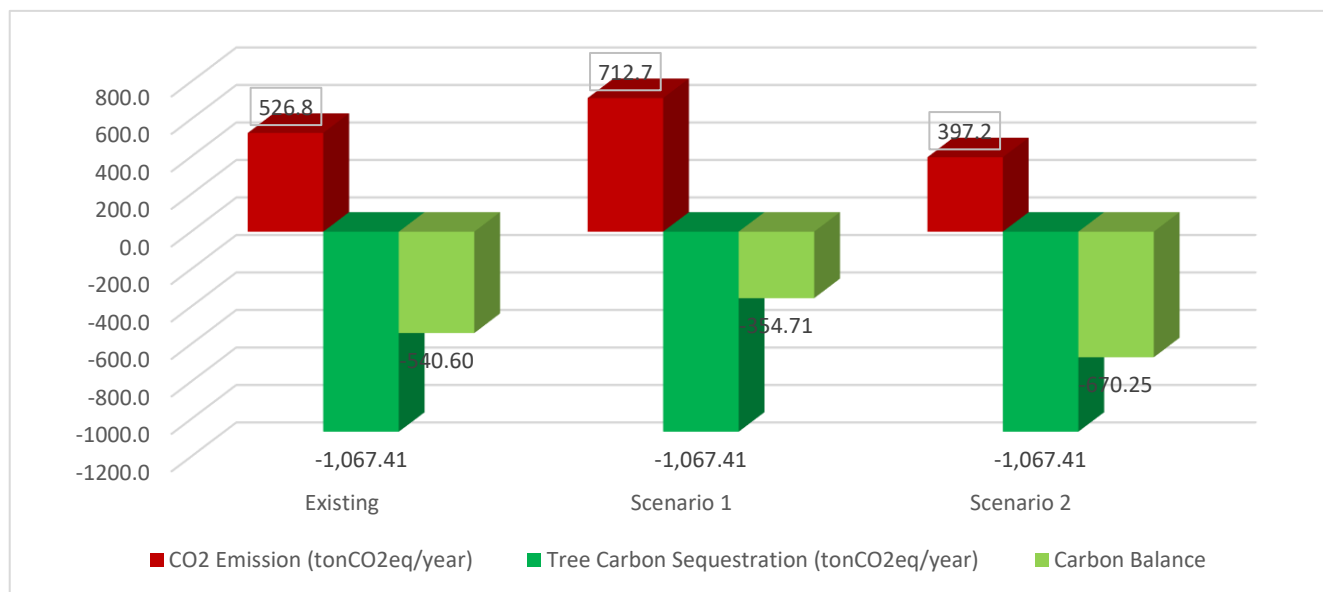


Figure 5. Carbon Balance in FMIPA UNNES

Under existing conditions, total CO₂ emissions can be fully absorbed by existing vegetation, resulting in a negative carbon balance, leaving an absorption capacity of 526.11 tons of CO₂eq. This indicates that approximately 51% of the total carbon absorption capacity by vegetation has been used to offset the emissions produced. In scenario 2, total CO₂ emissions can also be fully absorbed by vegetation, leaving an absorption capacity of 670.25 tons of CO₂eq. Only 33% of the total carbon absorption capacity by vegetation is utilized. LEUIwise, in scenario 1, total CO₂ emissions can also be fully absorbed by existing vegetation. However, this leaves an absorption capacity of 354.71 tons of CO₂, utilizing approximately 63% of the total capacity to offset the emissions produced by this scenario. This indicates that under existing conditions, efficient/environmentally friendly use, or excessive use, vegetation in the FMIPA environment can absorb the resulting CO₂ emissions, thus achieving a negative carbon balance value.

Based on the actual carbon balance process, trees in FMIPA can absorb all carbon emissions generated from electricity consumption, resulting in a negative carbon balance or a remaining absorption capacity. This is very possible because the comparison of the ratio of green space to buildings has a very different percentage, namely 77.14% green space and 22.86% buildings, so that the area of green space and the large number of trees have the potential to absorb

all carbon emissions produced (Chamid et al., 2018). Thus, currently, the vegetation on the FMIPA UNNES campus, in the form of trees, can absorb all CO₂ emissions produced; however, the passage of time, increasing consumption patterns among the academic community, and changes in facilities with high electricity consumption affect the carbon balance process. Additionally, limited and inaccurate data on electricity consumption significantly impacts the resulting CO₂ emissions. Therefore, this study encourages the campus to implement energy efficiency properly and maintain its vegetation to achieve Carbon Neutrality or Net Zero Emissions by 2060.

4. Conclusion

The electrical energy consumption generated in the FMIPA varies across its buildings. The laboratory building produces the highest electrical energy consumption and EUI compared to other buildings. The carbon footprint at FMIPA UNNES increased by 1.73-fold in CO₂ emissions compared to the previous year, reaching 54,130.63 kg CO₂eq. Based on scenario 1, excessive use of CO₂ emissions has the potential to increase by 35.29%. As an effort to reduce CO₂ emissions, scenario 2, energy-efficient use, shows a potential reduction in emissions of 32.64%. The lecturer's office and faculty administration buildings have the highest potential for CO₂ emission reduction if they implement energy-efficient management. Vegetation in the form of trees in the FMIPA UNNES environment also contributes to achieving a carbon balance. Existing trees can absorb all CO₂ emissions produced in all three scenarios, resulting in a negative carbon balance, meaning that trees have remaining carbon absorption capacity. This demonstrates that campus vegetation plays a crucial role in supporting efforts to reduce emissions and achieve sustainable campus targets.

From a policy and institutional perspective, the outcomes of this research provide an evidence-based foundation for sustainability recommendations to be communicated to the Ministry of Higher Education, Science, and Technology (Kemdiktisaintek) through rector forums and national higher education networks. Additionally, the results are directly relevant to sustainability indicators used in international campus assessment and ranking frameworks, including UI GreenMetric, Times Higher Education World University Rankings (THE WUR), and QS Rankings, particularly in relation to energy efficiency, emissions reduction, and sustainable campus operations. Ultimately, the implementation of integrated energy management and vegetation-based mitigation strategies contributes not only to emissions reduction but also to the creation of a healthier, more comfortable, and more resilient campus environment. Such conditions are essential for enabling optimal learning, research, and working performance among the academic community, reinforcing the role of universities as key actors in advancing sustainable development and climate action.

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