

SPATIAL ASSESSMENT OF VEHICULAR CO₂ EMISSIONS, VEGETATION CARBON STOCK AND GREEN-CAMPUS POLICY PRIORITIES AT UNIVERSITAS NEGERI PADANG, INDONESIA

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ABSTRACT

Campus carbon management requires integrated assessment of mobility, Green Open Space (GOS), vegetation carbon assets, and institutional strategies within a defined spatial boundary. This study was conducted at the main campus of Universitas Negeri Padang (UNP), Indonesia. The objectives were to quantifies vehicle activity and associated CO₂ emission loads, inventories vegetation and estimates standing above-ground carbon stock, maps existing and potential GOS, and prioritises campus carbon-management strategies using Interpretive Structural Modelling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC). Vehicle activity was recorded manually at four gates for five working days, while vegetation was assessed through a campus-wide tree census and non-destructive allometric estimation. Spatial mapping delineated existing and potential GOS. The survey recorded 19,921 vehicle entries, with motorcycles accounting for 86.9%. Annualised vehicular emissions were estimated at 1,993.8 tonnes CO₂ year⁻¹, with motorcycles contributing 68.5%. Existing GOS covered 10.58 ha, or 29.8% of the 35.51-ha campus, and 1,335 trees representing 31 species were recorded. Allometric estimation across 20 zones yielded 1,620.7 tonnes CO₂-eq of standing vegetation carbon stock, which was not subtracted from annual vehicular emissions because it represents an inventory-date stock rather than annual sequestration. ISM/MICMAC identified institutional commitment as the fundamental driver, followed by transport and land-based measures. The study provides an integrated spatial-environmental framework for campus carbon management while preserving the temporal distinction between annual emission flow and standing carbon stock.

Keywords: *urban green space; university mobility; allometric biomass; spatial assessment; policy prioritisation; campus carbon management.*

1. INTRODUCTION

Higher-education campuses are increasingly recognised as micro-scale territorial systems for climate-mitigation planning because transport activity, buildings, land cover, vegetation, and institutional infrastructure are concentrated within clearly defined spatial boundaries. Campus carbon-footprint assessments can provide an empirical basis for mitigation planning, but their comparability depends on clearly defined inventory boundaries, reliable activity data, and appropriate emission factors (Paredes-Canencio et al., 2024).

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Mobility is often a major contributor to institutional carbon footprints, and its estimated magnitude is sensitive to travel behaviour, vehicle use, and methodological assumptions (Cano et al., 2023; Kiehle et al., 2023). Gate-based vehicle observations can therefore provide a practical basis for identifying campus mobility interventions. Vegetation is a complementary component of campus carbon management. Green Open Space (GOS) supports ecological functions and stores carbon in woody biomass (Handika et al., 2020), although standing stock varies with tree size, species composition, vegetation structure, growth, mortality, and management practices (Nowak et al., 2013; Hundertmark et al., 2021). Spatially explicit assessment is important because biomass and carbon are unevenly distributed across managed landscapes. Field and remote-sensing approaches can support biomass estimation (Laosuwan et al., 2025), while spatial analysis can identify areas requiring green-space intervention (Asmiwyati et al., 2025).

Universitas Negeri Padang UNP has experienced substantial infrastructure development accompanied by increasing mobility and pressure on available GOS. An earlier assessment reported that GOS occupied approximately 23% of the campus area (Sari, 2021). Dewata et al. (2025) showed that green-campus management at UNP can be strengthened by linking measured environmental conditions with coordinated institutional strategies, although their study focused mainly on water quality and solid-waste management. Indonesia's Law No. 26/2007 establishes a 30% GOS benchmark for urban jurisdictions; although it is not a campus-specific statutory requirement, it provides a useful spatial-planning reference (Oktorie et al., 2019).

Previous campus studies have generally examined carbon footprints, vegetation characteristics, GOS availability, or sustainability management separately. A methodological gap therefore remains in integrating vehicle-emission pressure, field-derived vegetation carbon stock, spatial GOS information, and structured policy prioritisation within a single campus-scale framework. This study quantifies vehicle activity and associated CO₂ emission loads, inventories vegetation and estimates standing above-ground carbon stock, maps existing and potential GOS, and prioritises campus carbon-management strategies using Interpretive Structural Modelling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC). The novelty lies in integrating spatially explicit vehicular CO₂ pressure, field-derived vegetation carbon stock, and an ISM–MICMAC implementation hierarchy within a unified spatial-environmental framework for campus carbon management and green-campus policy prioritisation, while preserving the temporal distinction between annual emission flow and standing carbon stock.

2. STUDY AREA

The study was conducted at the main campus of UNP, located on Prof. Dr. Hamka Street, Air Tawar, Padang City, West Sumatra, Indonesia. The study area is centered at approximately 0°54'35" S and 100°21'47" E, covers approximately 35.51 ha, and lies on the low-lying coastal plain of Padang City at an elevation of approximately 0–4 m above sea level and about 250 m from the coastline. The spatial boundary of the study corresponds to the UNP main-campus area delineated by the yellow line in **Fig. 1**. Within this boundary, the campus comprises academic and administrative buildings, laboratories, sports facilities, student facilities, internal roads, parking areas, and distributed GOS. The map identifies 66 principal buildings and facilities that provide spatial reference for field observations, vehicle-access locations, vegetation inventory, and GOS assessment.

3. MATERIALS AND METHODS

3.1. Data Collection and Spatial Mapping

Field data were collected in 2025 within the mapped boundary of the UNP main campus. Vehicle activity was recorded manually at four campus entry gates, namely the Main Gate, Trans Padang Halte Gate, Faculty of Sport Science Gate, and Senior High School (SHS) Pembangunan Gate. Counts were conducted on five consecutive working days (Monday–Friday) and classified by vehicle type for use in the emission-load calculation.

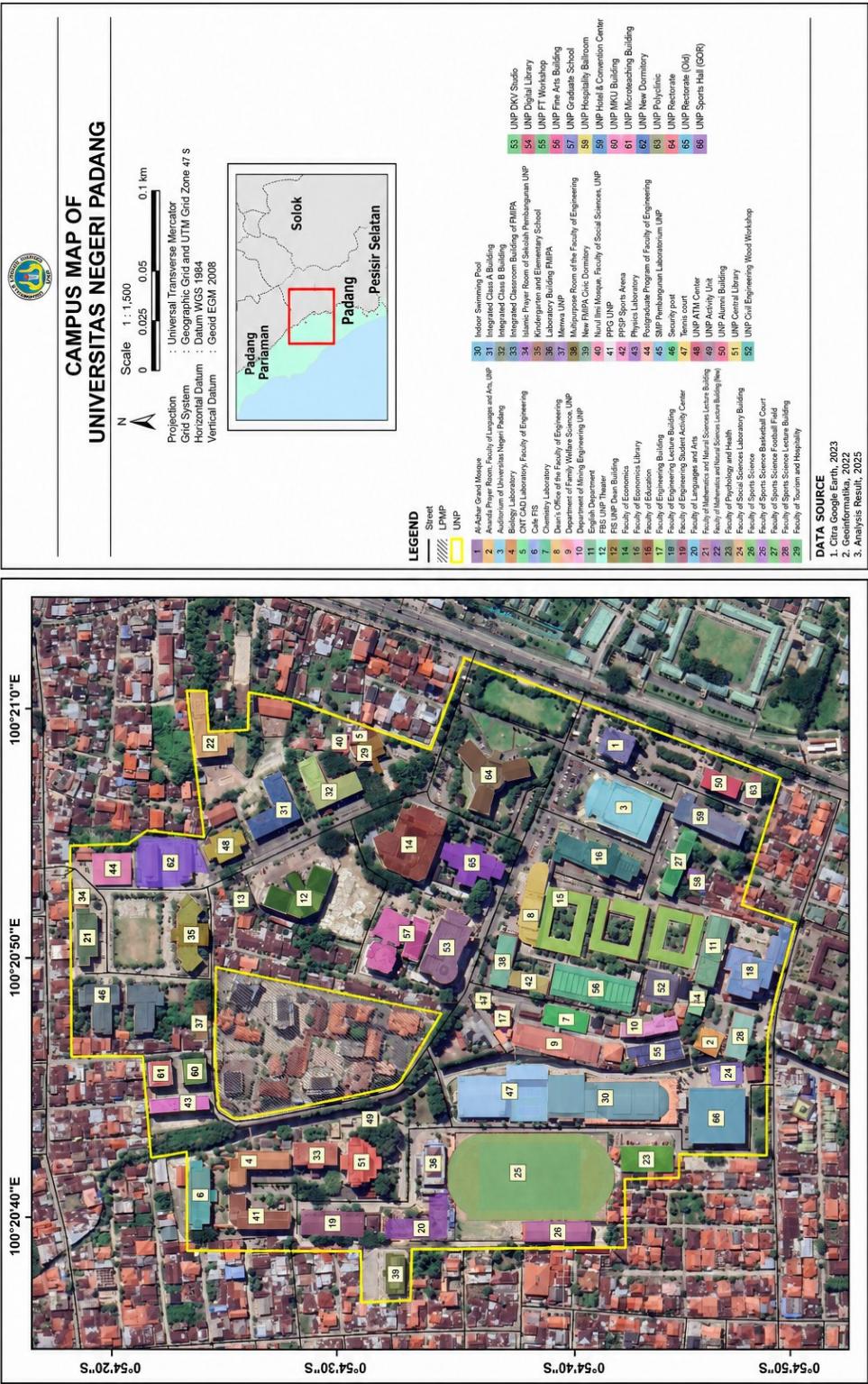


Fig. 1. Location and spatial boundary of the UNP main campus.

Vegetation data were obtained through a field census of every tree with a diameter at breast height (DBH) ≥ 21 cm along vehicle corridors and within GOS. For each eligible tree, species identity, stem circumference, abundance, and campus zone were recorded to support the allometric biomass calculation and zonal carbon-stock assessment. Semi-structured interviews with lecturers, environmental experts, and students were used to support the identification of campus locations with potential for additional vegetation. Secondary data comprised campus spatial maps and the 2016–2020 UNP Research Master Plan (UNP, 2016). Existing GOS and candidate expansion areas were delineated within the campus study boundary by integrating the campus maps with field observations and interview information.

3.2. Vehicular CO₂ Emission-Load Estimation

Vehicular CO₂ emission loads were estimated for each vehicle category using the mobile-source emission-loading equation:

$$Q = N_i \times F_{ei} \times K_i \times L \quad (1)$$

where:

Q is the category-specific CO₂ emission load (g h⁻¹),

N_i is the vehicle activity derived from the gate-count dataset (vehicles h⁻¹),

F_{ei} is the category-specific fuel-based CO₂ emission factor (g CO₂ L⁻¹),

K_i is fuel consumption expressed in litres per kilometre (L km⁻¹),

L is the travel distance represented in the calculation (km); where source fuel-consumption values were expressed in L 100 km⁻¹, they were converted to L km⁻¹ before application in Eq. (1).

Calculations were performed separately for motorcycles, petrol cars, diesel cars, light trucks/minibuses, and heavy trucks/buses and were then aggregated to obtain the reported campus vehicle-emission load.

The daily CO₂ emission load reported by the study was annualised by multiplying the daily value by 365 days. This conversion is an extrapolation used to express the reported daily load on an annual basis. It does not represent an independently measured year-round traffic total. Accordingly, the annualised values are interpreted as scenario-based estimates under the adopted traffic-activity assumptions.

3.3. Vegetation Biomass and Carbon-Stock Estimation

The vegetation analysis was designed to estimate standing above-ground biomass and the corresponding carbon stock at the inventory date rather than an annual carbon-sequestration rate. A non-destructive allometric approach was applied following Ketterings et al. (2001) and Indonesia's national Greenhouse Gas (GHG) inventory guideline (KLH, 2012), consistent with broader tropical allometric guidance (Chave et al., 2014) and the 2019 Refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). DBH was derived from measured stem circumference by dividing circumference by π (3.14). Above-ground biomass (W) for each tree was then estimated using:

$$W = 0.11 \times BJ \times D^{2.62} \quad (2)$$

where:

ρ is wood density (g cm⁻³),

D is DBH (cm).

Individual-tree biomass estimates were summed by campus zone. Stored carbon was calculated as 46% of dry above-ground biomass, and the resulting carbon mass was converted to CO₂-equivalent standing stock using the molecular-weight ratio 44/12 (3.67). These secondary conversions are described in prose because they are direct scalar transformations of the principal allometric estimate.

The resulting values are reported as standing vegetation carbon stock at the inventory date, not as tonnes CO₂ year⁻¹. They were therefore not subtracted directly from the annualised vehicle-emission estimates. Estimating an annual vegetation offset would require repeated inventories or a validated growth-increment model that quantifies annual biomass accumulation.

3.4. Policy Strategy Prioritisation (ISM and MICMAC)

Policy priorities were analysed using ISM and MICMAC. ISM was used to structure the directional relationships among the candidate strategies and to organise them into a hierarchy based on expert judgement (Warfield, 1974). Nine strategy elements (E1–E9) were identified from the literature review and expert consultation. Pairwise relationships were recorded in a Structural Self-Interaction Matrix (SSIM), where V indicates that element *i* influences element *j*, A indicates that element *j* influences element *i*, X indicates a bidirectional relationship, and O indicates no direct relationship. The SSIM was converted to a binary reachability matrix using the standard ISM rules: V = (1,0), A = (0,1), X = (1,1), and O = (0,0) for the corresponding *i*–*j* and *j*–*i* cells. The matrix was then checked for transitivity to obtain the final reachability matrix. Driving Power (DP) was calculated as the row sum and Dependence Power (D) as the column sum.

Hierarchy levels were derived iteratively from each element's reachability, antecedent, and intersection sets until all elements were assigned to a level. MICMAC analysis then positioned the nine strategies according to their DP and D values, providing the basis for interpreting which strategies functioned primarily as system drivers and which depended on upstream interventions. The procedure therefore produced a structural policy-prioritisation framework.

4. RESULTS

4.1. Spatial Distribution of Existing GOS

Mapped GOS within the UNP main-campus boundary covers 10.58 ha, equivalent to 29.8% of the 35.51-ha study area (**Fig. 2**). This proportion is higher than the 23% reported in the earlier campus assessment by Sari (2021) and remains slightly below the 30% urban RTH benchmark established by Law No. 26/2007. Because the statutory benchmark applies to urban jurisdictions rather than individual campuses, it is used here only as a planning reference. The mapped GOS is distributed across managed campus spaces associated with academic, administrative, sports, circulation, and supporting facilities.

4.2. Vehicle Traffic and Reported CO₂ Emission Load

The compiled traffic dataset contained 19,921 vehicle entries across the four monitored campus gates (**Table 1**). Motorcycles dominated the observations with 17,316 entries (86.9%), followed by petrol cars (2,392), diesel cars (200), minibuses (8), trucks (4), and buses (1). The Main Gate recorded the largest combined traffic volume among the four observation points.

Table 1.

Vehicle counts at the four campus entry gates.

Gate/Location	Car (Petrol)	Car (Diesel)	Motorcycle	Minibus	Truck	Bus
Main Gate	1462	108	5379	3	2	1
Trans Padang Halte Gate	282	45	2579	–	2	–
Faculty of Sport Science Gate	146	25	3641	–	–	–
SHS Pembangunan	502	22	5717	5	–	–
Total	2,392	200	17,316	8	4	1

Source: field survey, 2025.

Using the emission parameters and calculation procedure, the traffic data yielded a reported daily CO₂ emission load of 5,462.4 kg CO₂ day⁻¹. Applying the study's 365-day annualisation factor produced an estimated 1,993.8 tonnes CO₂ year⁻¹ (Table 2). Motorcycles accounted for 1,365.2 tonnes CO₂ year⁻¹ (68.5% of the total), followed by petrol cars at 566.1 tonnes CO₂ year⁻¹ (28.4%). These results identify motorcycle-based mobility as the dominant source within the vehicle categories assessed.



Fig. 2. Existing GOS at UNP.

Table 2.

Reported daily and annualised vehicular CO₂ emission loads by vehicle category.

Vehicle category	Reported daily emission (kg CO ₂ day ⁻¹)	Annualised emission* (kg CO ₂ year ⁻¹)	Annualised emission* (t CO ₂ year ⁻¹)
Motorcycle	3,740.256	1,365,193.44	1,365.19
Car (Petrol)	1,550.592	566,066.08	566.07
Car (Diesel)	150.6	54,969.00	54.97
Light Truck	18.72	6,832.80	6.83
Heavy Truck/Bus	2.205	804.83	0.80
Total	5,462.373	1,993,766.15	1,993.77

Note. Annualised values were obtained by multiplying the reported daily emission load by 365 days.

4.3. Vegetation Inventory

The field census identified 1,335 trees representing 31 species within the mapped GOS areas (**Table 3**). Tanjung (*Mimusops elengi* L.; 373 trees), Ketapang Kencana (*Terminalia mantaly*; 195), and Pucuk Merah (*Syzygium myrtifolium*; 163) were the three most abundant species and together accounted for 55.7% of the recorded trees. Trembesi (*Samanea saman* Merr.) represented only 32 individuals (2.4%). The inventory therefore shows that the campus tree population is numerically concentrated in a limited number of species, providing a baseline for subsequent carbon-stock and planting-priority assessments.

Table 3.

Tree species and abundance at UNP.

No.	Species (scientific name)	Number of Trees
1	Tanjung (<i>Mimusops elengi</i> L.)	373
2	Ketapang Kencana (<i>Terminalia mantaly</i>)	195
3	Pucuk Merah (<i>Syzygium myrtifolium</i>)	163
4	Glodokan Tiang (<i>Polyalthia longifolia</i> Sonn.)	125
5	Mahogany (<i>Swietenia macrophylla</i>)	88
6	Ketapang (<i>Terminalia catappa</i>)	77
7	Angsana (<i>Pterocarpus indicus</i> Willd.)	47
8	Mango (<i>Mangifera indica</i>)	38
9	Banyan (<i>Ficus benjamina</i>)	41
10	Trembesi (<i>Samanea saman</i> Merr.)	32
11	Kerai Payung (<i>Filicium decipiens</i>)	21
12	Cemara Laut (<i>Casuarina equisetifolia</i> L.)	26
13	Dadap (<i>Erythrina variegata</i> L.)	23
14	Water Apple (<i>Syzygium aqueum</i>)	16
15	Mangosteen (<i>Garcinia mangostana</i> L.)	12
16	Salam (<i>Syzygium polyanthum</i>)	11
17	Frangipani (<i>Plumeria</i> sp.)	6
18	Moringa (<i>Moringa oleifera</i> L.)	6
19	Sapodilla (<i>Manilkara zapota</i>)	5
20	Jamaica Cherry (<i>Muntingia calabura</i> L.)	5
21	Jackfruit (<i>Artocarpus integra</i> Merr.)	5
22	Pine (<i>Pinus merkusii</i>)	4
23	Teak (<i>Tectona grandis</i>)	2
24	Acacia (<i>Acacia mangium</i>)	2
25	Rambutan (<i>Nephelium lappaceum</i>)	2
26	Avocado (<i>Persea americana</i>)	2
27	Starfruit (<i>Averrhoa carambola</i> L.)	2
28	Noni (<i>Morinda citrifolia</i> L.)	2
29	Petai Cina (<i>Leucaena leucocephala</i>)	2
30	Guava (<i>Psidium guajava</i>)	1
31	Kapok (<i>Ceiba pentandra</i> L.)	1
Total		1,335

Source: field survey, 2025.

4.4. Standing Vegetation Carbon Stock

Application of the allometric estimation procedure in the 20 listed campus zones produced an arithmetic total of 1,620,680.56 kg CO₂-eq (1,620.7 tonnes CO₂-eq) of standing vegetation carbon stock (**Table 4**). This value represents carbon stock at the time of inventory and is not an annual sequestration rate. The Faculty of Sport Science and the new Rectorate zone recorded the two largest standing-stock values, 249,878.26 and 237,493.63 kg CO₂-eq, respectively, together representing approximately 30.1% of the zonal total. The zonal inventory in Table 4 contains 1,358 trees, whereas the species-based campus census contains 1,335 trees. This difference is treated as an inventory-consistency issue and is addressed as a study limitation.

Table 4.

Estimated standing vegetation carbon stock by campus zone.

No.	Campus Zone	Trees (n)	Standing stock (kg CO ₂ -eq)
1	Rectorate (new)	157	237,493.63
2	Rectorate (old)	26	43,269.97
3	Auditorium	2	31,206.52
4	Graduate School	82	212,570.67
5	Faculty of Education	69	177,010.69
6	Faculty of Economics	6	32,990.47
7	Faculty of Social Sciences	14	17,540.50
8	Integrated Building A	37	2,592.70
9	Integrated Building B	32	2,016.00
10	Faculty of Tourism and Hospitality	5	56,837.17
11	Faculty of Engineering	119	121,560.34
12	Faculty of Languages and Arts	87	95,179.06
13	Faculty of Sport Science	214	249,878.26
14	Faculty of Mathematics and Natural Sciences	205	144,250.96
15	Student Activity Centre	15	9,981.62
16	Al-Azhar (campus mosque)	85	82,472.49
17	Hospitality UNP	9	20,628.72
18	Rector's Residence	81	54,021.70
19	General Courses Unit (MKU)	17	9,981.62
20	Sekolah Pembangunan (lab school)	96	19,197.47
Total		1,358	1,620,680.56 kg

Source: field survey and allometric estimation, 2025.

The zonal tree counts sum to 1,358, whereas the campus-wide species census reports 1,335 trees (**Table 3**); this difference is treated as an inventory-consistency limitation.

4.5. Joint Interpretation of Annual Emission Flow and Standing Carbon Stock

The annualised vehicular emission estimate and the allometrically derived standing vegetation carbon stock represent different temporal quantities: the former is expressed as an annual CO₂ flow (tonnes CO₂ year⁻¹), whereas the latter represents standing stock at the inventory date (tonnes CO₂-eq). Accordingly, both indicators are reported jointly to characterise campus emission pressure and existing vegetation carbon assets but are not arithmetically subtracted. Estimating an annual vegetation offset would require repeated inventories or a validated growth-increment model capable of quantifying annual biomass accumulation. Therefore, no annual carbon deficit or percentage vegetation offset is calculated in this study.

4.6. Potential for GOS Expansion

Field mapping identified campus locations with relatively limited existing vegetation and potential for additional GOS, namely the Auditorium area, Faculty of Engineering parking area, Faculty of Economics, student dormitories, Faculty of Social Sciences graduate-school parking area, General Courses Unit, Teacher Professional Education building, and the women's dormitory of the Faculty of Mathematics and Natural Sciences (**Fig. 3**). These mapped locations are treated as priority sites for subsequent site-level evaluation of planting feasibility, species suitability, infrastructure constraints, and maintenance requirements rather than as final planting prescriptions.

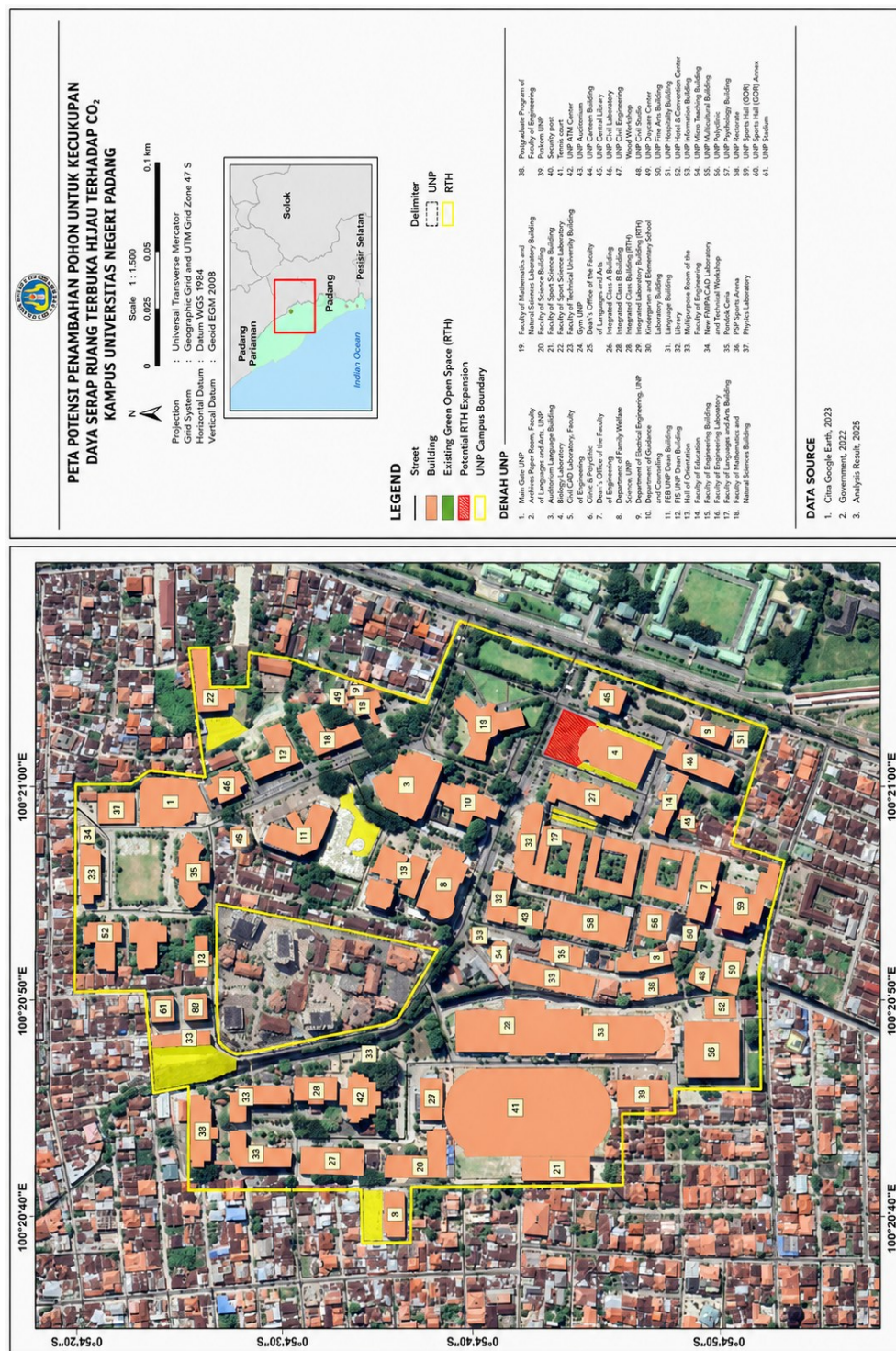


Fig. 3. Potential areas for expanding RTH at UNP.

4.7. ISM/MICMAC-Based Policy Strategy Analysis

Nine policy strategies were evaluated using Interpretive Structural Modelling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) (**Tables 5 and 6**), namely (E1) green roofs and vertical gardens; (E2) expansion of RTH and vegetation; (E3) stronger institutional participation and commitment to a green campus policy; (E4) establishment of the campus as a living laboratory; (E5) creation of a low-emission zone; (E6) development of an electric campus bus system; (E7) development of safe pedestrian and cycling infrastructure; (E8) construction of biopores and rain gardens; and (E9) development of centralised parking areas.

Table 5.

SSIM of campus carbon-management strategies.

Element	E1	E2	E3	E4	E5	E6	E7	E8	E9
E1		A	A	A	X	A	A	A	A
E2			A	X	X	A	A	X	A
E3				V	V	V	V	V	V
E4					X	A	A	X	A
E5						A	A	X	A
E6							X	V	X
E7								V	X
E8									X
E9									

Table 6.

Final reachability matrix with DP, rank, D, and hierarchical level of the policy strategy elements.

Element	E1	E2	E3	E4	E5	E6	E7	E8	E9	DP	Rank
E1	1	0	0	0	1	0	0	0	0	2	4
E2	1	1	0	1	1	0	0	1	0	5	3
E3	1	1	1	1	1	1	1	1	1	9	1
E4	1	1	0	1	1	0	0	1	0	5	3
E5	1	1	0	1	1	0	0	1	0	5	3
E6	1	1	0	1	1	1	1	1	1	8	2
E7	1	1	0	1	1	1	1	1	1	8	2
E8	1	1	0	1	1	0	0	1	0	5	3
E9	1	1	0	1	1	1	1	1	1	8	2
D	9	8	1	8	9	4	4	8	4		
Level	1	2	4	2	1	3	3	2	3		

The final reachability matrix (**Table 6**) identifies E3, institutional commitment to a green campus policy, as the strongest structural driver, with the highest driving power (DP = 9) and the lowest dependence (D = 1), placing it at Level 4. Transport-related strategies E6, E7, and E9 occupy Level 3 with DP = 8, followed by RTH expansion, the living-laboratory concept, and biopores/rain gardens (E2, E4, and E8) at Level 2. Green roofs/vertical gardens (E1) and the low-emission zone (E5) occupy Level 1.

The MICMAC matrix (**Fig. 4**) places E3 and the three transport strategies in the high-driving, low-dependence sector, whereas the remaining measures are more dependent on upstream institutional and mobility interventions. Together with the ISM hierarchy (**Fig. 5**), the analysis indicates a sequential pathway from institutional commitment to mobility management and then to land- and infrastructure-based measures.

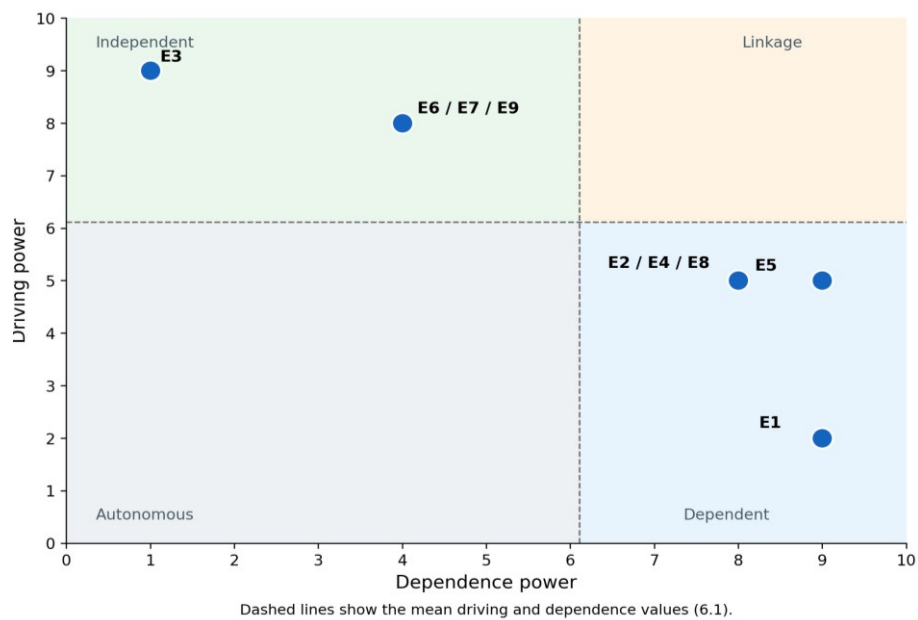


Fig. 4. MICMAC DP-D matrix for the campus carbon-management strategies. Dashed lines indicate the mean DP and D values (6.1).

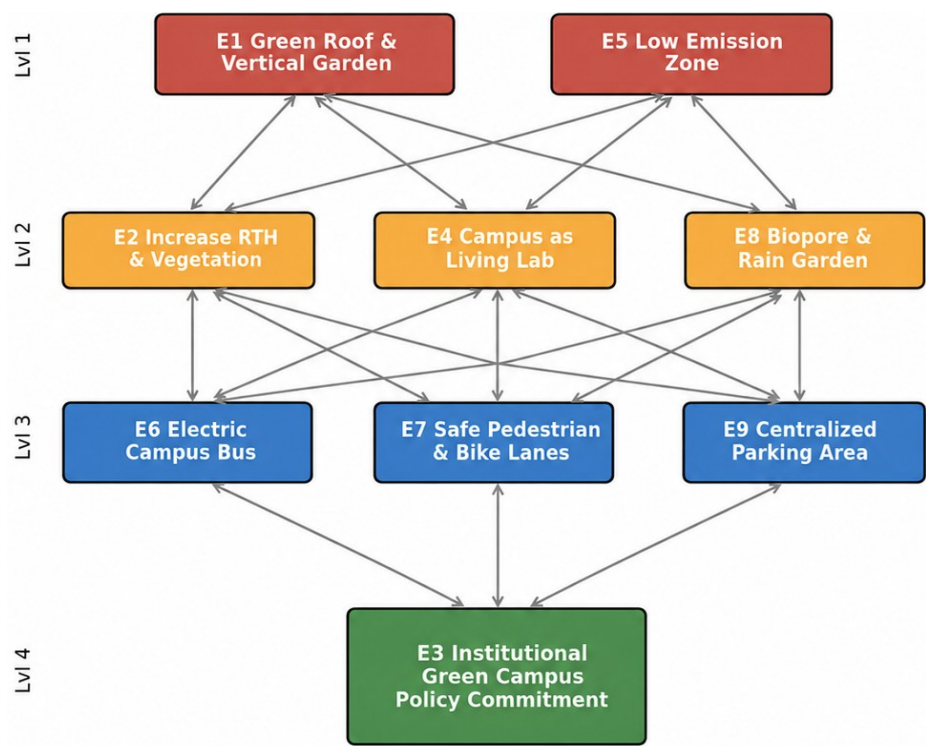


Fig. 5. ISM hierarchy of campus carbon-management strategies at UNP.

5. DISCUSSION

The vehicle observations show that mobility pressure at UNP is dominated by motorcycles, which represented 86.9% of recorded entries and 68.5% of the annualised vehicular CO₂ estimate. This pattern is consistent with evidence that commuting behaviour and transport mode can substantially influence university carbon footprints (Cano et al., 2023), although estimates depend on activity data, inventory boundaries, and annualisation assumptions (Kiehle et al., 2023). For UNP, the result indicates that centralised parking, campus public transport, and safe pedestrian and cycling infrastructure are more directly connected to the measured emission source than vegetation interventions alone.

The spatial and vegetation assessments provide a complementary view of campus carbon assets. Existing GOS covers 10.58 ha, or 29.8% of the mapped campus area, compared with approximately 23% in the earlier assessment; this difference should be interpreted cautiously because mapping boundaries and classification criteria may differ. The campus census identified 1,335 trees across 31 species, while the allometric assessment yielded 1,620.7 tonnes CO₂-eq of standing vegetation carbon stock. Carbon storage depends on tree dimensions, wood density, species characteristics, and the selected allometric model (Chave et al., 2014). Standing stock is not an annual sequestration rate (Nowak et al., 2013) and should not be subtracted directly from annualised vehicular emissions.

GOS mapping extends the inventory to spatial planning by identifying locations where additional vegetation can be evaluated. These areas are candidates for site-level assessment of species suitability, planting space, infrastructure constraints, and maintenance rather than final planting prescriptions. This is consistent with spatial approaches to green-space prioritisation (Asmiwyati et al., 2025) and with previous UNP research linking environmental measurements to coordinated institutional strategies (Dewata et al., 2025). Future monitoring could combine repeated field inventories with high-resolution imagery and spatio-temporal land-cover analysis to evaluate carbon-stock change through time (Azzahra et al., 2025; Maulsyid et al., 2026; Mayzura et al., 2025; Rahmajati et al., 2026).

The ISM–MICMAC results add an implementation dimension to the spatial assessment. Institutional commitment (E3) has the highest driving power and lowest dependence, identifying governance as the fundamental structural driver. Electric campus buses, pedestrian and cycling infrastructure, and centralised parking form the next implementation level, followed by more dependent land- and infrastructure-based measures. This sequence is consistent with research emphasising governance as an enabling condition for coordinated campus mitigation (Yang et al., 2024). It also extends spatial decision-support approaches using GIS, AHP, weighted indicators, and expert evaluation (Barlian et al., 2025; Oktorie et al., 2025) by explicitly representing structural dependencies among strategies.

Overall, the findings support an integrated spatial-environmental framework in which annual mobility-related emission pressure, mapped GOS, standing vegetation carbon stock, and policy hierarchy are interpreted together without constructing an invalid numerical carbon balance. The framework distinguishes interventions that directly reduce emission sources from those that conserve vegetation carbon assets.

Limitations include five working days of traffic observations, the 365-day annualisation assumption, secondary emission factors and wood-density values, exclusion of trees with DBH < 21 cm and other carbon pools, the mismatch between zonal and species-based tree counts, and expert dependence in the ISM–MICMAC hierarchy. Longer traffic monitoring, harmonised vegetation inventories, repeated biomass measurements, and evaluation of implemented strategies are therefore required.

6. CONCLUSIONS

This study demonstrates an integrated campus-scale approach for linking mobility-related CO₂ emissions, mapped GOS, standing vegetation carbon stock, and policy prioritisation at UNP. Existing GOS covers 10.58 ha, accounting for 29.8% of the 35.51-ha campus area, while the vegetation census recorded 1,335 trees across 31 species. Campus mobility was strongly dominated by motorcycles, which accounted for 86.9% of recorded vehicle entries and contributed 68.5% of the annualised vehicular CO₂ estimate of 1,993.8 tonnes CO₂ year⁻¹.

The allometric assessment across 20 campus zones yielded a CO₂-eq standing vegetation carbon stock of 1,620.7 tonnes. Because this value represents carbon stored at the inventory date rather than an annual sequestration flux, it was not directly subtracted from annual vehicular emissions. Spatial mapping identified several campus areas requiring further evaluation for GOS expansion, while the ISM/MICMAC analysis identified institutional commitment to a green campus policy as the fundamental driver, followed by transport-management strategies and subsequent land- and infrastructure-based interventions.

The main contribution of this study is the integration of annual mobility-related emission pressure, spatial GOS distribution, field-derived vegetation carbon stock, and structured policy prioritisation within a unified spatial-environmental assessment framework while maintaining the temporal distinction between emission flow and carbon stock.

Future assessments should validate longer-term vehicle activity, harmonise the zonal and campus-wide vegetation inventories, and conduct repeated vegetation measurements to quantify temporal changes in carbon stock.

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