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CARBON BALANCE ATTRIBUTION AND STORAGE IN KHON KAEN UNIVERSITY, THAILAND

*Watchara Pattanawiwattanaporn[1] and Choopong Thongkumsamut[2]

[1,2] Program in Integrated Research for Design, Faculty of Architecture, Khon Kaen University, Thailand

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ABSTRACT: Effective terrestrial ecosystem management is essential for enhancing carbon sequestration and achieving carbon neutrality. University towns, characterized by dynamic land use and high per capita emissions, pose challenges to ecosystem stability. This study investigates land use and land cover changes (LULCC) at Khon Kaen University, Thailand—a large university city emitting over 88,000 tons of CO_2 equivalents annually—with emissions projected to reach 105,000 tons by 2040 without intervention. Utilizing Sentinel-2 satellite imagery from 2019 to 2023, we applied remote sensing classification and carbon sequestration models to assess land use dynamics and forecast ecosystem carbon stock over 22 years. Five land categories were classified: forest, agriculture, built-up areas, waterbodies, and bare land. Results indicate a slight increase in forest and agricultural areas (4.51% and 0.41%, respectively), contrasted by a 26.98% rise in built-up land. Current green spaces offset only 0.45% of the university's total emissions. However, approximately 32% of underutilized land presents an opportunity for rehabilitation, potentially increasing sequestration by 1,575.91 tons CO_2 equivalents annually. The findings support strategic land use planning, emphasizing forest conservation and ecosystem restoration as viable approaches to enhance carbon sinks. When combined with emission reduction initiatives across operational scopes, Khon Kaen University has the potential to meet its carbon neutrality target within the projected timeline.

Keywords: Carbon Neutrality, University City, Carbon Emission, Carbon Storage

1. INTRODUCTION

Achieving carbon neutrality is a critical step in combatting climate change and limiting global warming to safe levels. The Intergovernmental Panel on Climate Change (IPCC) has stated that reaching net zero emissions by around 2050 is necessary to meet the goals of the Paris Agreement and keep global warming below 1.5 degrees Celsius [1]. Carbon neutrality demonstrates a commitment to protecting the environment and preserving the Earth's ecosystems. By reducing greenhouse gas emissions, we can minimize the negative impacts on natural resources, wildlife, and fragile ecosystems.

Higher Education Institutes (HEIs) have recognized the importance of taking responsibility for climate change and have been actively involved in various initiatives to address this global issue. As centers of learning and research, universities have the potential to contribute significantly to tackling climate change through education, collaboration, and innovation. However, universities also have the potential to make a positive impact by reducing their emissions and promoting sustainable practices. HEIs, as large organizations with significant operations, have their own greenhouse gas emissions footprints. These emissions can come from various sources, including energy consumption, transportation, waste management, and buildings. For example, the University of Melbourne reported emitting approximately 200,000 metric tons of carbon dioxide equivalent in 2019 [2].

To recognize their impact, HEIs have a responsibility to reduce their greenhouse gas emissions. Many HEIs have committed to sustainability goals and initiatives, aiming to minimize their carbon footprint and promote sustainable practices. Some universities have joined initiatives like the "Race to Zero" campaign, which rallies leadership and support from businesses, cities, and universities to achieve net-zero emissions [3].

There are several strategies that HEIs can adopt to reduce their greenhouse gas emissions:

a. Energy efficiency and renewable energy: Implementing energy-efficient practices and investing in renewable energy sources such as solar or wind power can significantly reduce emissions from energy consumption [4]. Universities can also consider energy-saving measures in buildings, including efficient lighting, insulation, and smart energy management systems.
b. Sustainable transportation: Encouraging sustainable transportation options for students, staff, and faculty, such as promoting public transit, cycling, and walking, can help reduce emissions from commuting and campus transportation [4].
c. Waste management: Implementing recycling programs, composting organic waste, and reducing waste generation can minimize emissions associated with waste disposal [4].
d. Sustainable campus operations: Adopting sustainable practices in campus operations,

including green procurement, water conservation, and responsible resource management, can contribute to emission reductions [2].

e. Sustainable land management: Land management refers to the practices and activities implemented to utilize and protect land resources sustainably. It involves decisions and actions to optimize land use, conserve biodiversity, and manage natural resources effectively. Proper land management can help maintain or enhance the carbon sink potential of ecosystems.
f. Curriculum integration: Integrating sustainability and climate change topics into various disciplines and educational programs can help raise awareness and empower students to become sustainability leaders [2].

Evaluation of carbon sink potential is closely related to land use and land cover. Land use refers to the human activities and purposes for which land is utilized, while land cover describes the physical and biological features of the Earth's surface. The type of land use and land cover greatly influences the carbon storage and absorption capacity of an area, thereby affecting the overall carbon sink potential. Sentinel-2's spectral data can be used to quantify above-ground biomass and vegetation indices, which are essential indicators for assessing carbon sinks. By analyzing changes in these indicators over time, it is possible to estimate the carbon sequestration potential of different land cover types [4]. To forecast land use change and carbon sink using Sentinel-2 data, it is necessary to employ remote sensing techniques, including image classification, change detection, and time series analysis. These techniques, coupled with ancillary data and models, can provide valuable insights into the dynamics of land use change and carbon sink at a regional or global scale.

2. RESEARCH SIGNIFICANCE

This study highlights the critical role of land use management in advancing carbon neutrality within university cities. By integrating Sentinel-2 satellite data with carbon sequestration models, it provides an accurate assessment of land cover dynamics and ecosystem carbon storage at Khon Kaen University. The findings reveal the limited offset capacity of existing green spaces but also identify underutilized land with high potential for rehabilitation. This evidence-based approach supports targeted interventions such as forest conservation, afforestation, and sustainable land restoration. The study contributes to climate mitigation strategies, offering a replicable framework for other academic institutions and urban ecosystems worldwide.

3. MATERIALS AND METHODS

3.1 Study Area

Khon Kaen University is located in Khon Kaen, a city in northeastern Thailand. The university's main campus is situated in the northwestern part of Khon Kaen, with the following geographic coordinates: Latitude 16° 26' 48.16" N and Longitude 102° 49' 58.80" E.

The university is home to seventeen faculties, three academic support centers, two academic service centers, a hospital, and a research institute, covering a wide range of disciplines and areas of study. The campus spans approximately 900 hectares and is set in an attractive park-like environment.

As of 2023, the university has a student population of 38,071 and employs 11,445 staff members.

3.1.1 Survey of Biodiversity and Forest Assessment

A comprehensive biodiversity and forest resource assessment was conducted within Khon Kaen University to characterize the structural and compositional attributes of its forest ecosystem. The survey aimed to quantify species diversity, evaluate forest stand structure, and determine the predominant forest type, which is essential for campus ecological management and long-term sustainability planning [5-6].

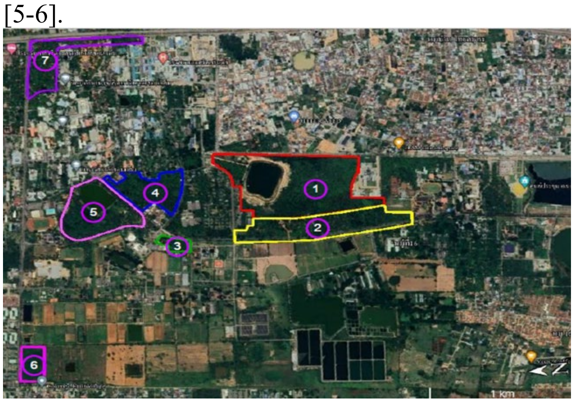

Fig.1 KKU's forest map

Field data were collected by establishing sampling plots, each measuring 40 × 40 meters, with at least two plots allocated to each forest density category derived from Normalized Difference Vegetation Index (NDVI) analysis. A purposive sampling strategy was employed to ensure spatial representation across heterogeneous vegetation conditions throughout the campus. Within each plot, all perennial tree species were identified, and individuals with a diameter at breast height (DBH) ≥ 4.5 cm and a height > 1.3 m were measured in accordance with standard forest inventory protocols [7].

Fig.2 Sample layout of plots in conservation forest areas.

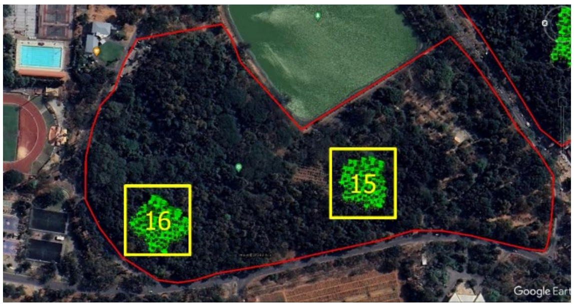

Fig.3 Monitored survey plots.

Analysis of species composition and stand structure revealed that the university's forested areas are predominantly classified as Dry Dipterocarp Forest (DDF), locally known as Pa Teng Rang, a forest type commonly found in seasonal tropical regions of Northeast Thailand [8]. This forest type is characterized by open canopy structures, dominance of Dipterocarpus species, and adaptation to nutrient-poor soils and pronounced dry seasons. The classification not only reflects the ecological heritage of the area but also informs future forest management, biodiversity conservation, and carbon sequestration planning for the university.

3.1.2 KKU Greenhouse Gas Emission Assessment

In 2023, the total greenhouse gas (GHG) emissions of Khon Kaen University were estimated at approximately 80,000 metric tons of carbon dioxide equivalent (tCO_2e) per year. Without the implementation of effective mitigation strategies, these emissions are projected to rise to 105,000 tCO_2e per year by 2027. The 2023 emissions profile comprised Scope 1 (direct emissions from on-campus fuel combustion and university-owned vehicles) at 12%, Scope 2 (indirect emissions from purchased electricity) at 65%, and Scope 3 (other indirect emissions, including commuting, waste disposal, and purchased goods) at 23%. This distribution highlights the predominance of electricity-related emissions in the university's carbon footprint, emphasizing the need for targeted interventions in energy efficiency, renewable energy adoption, sustainable mobility, and carbon offsetting.

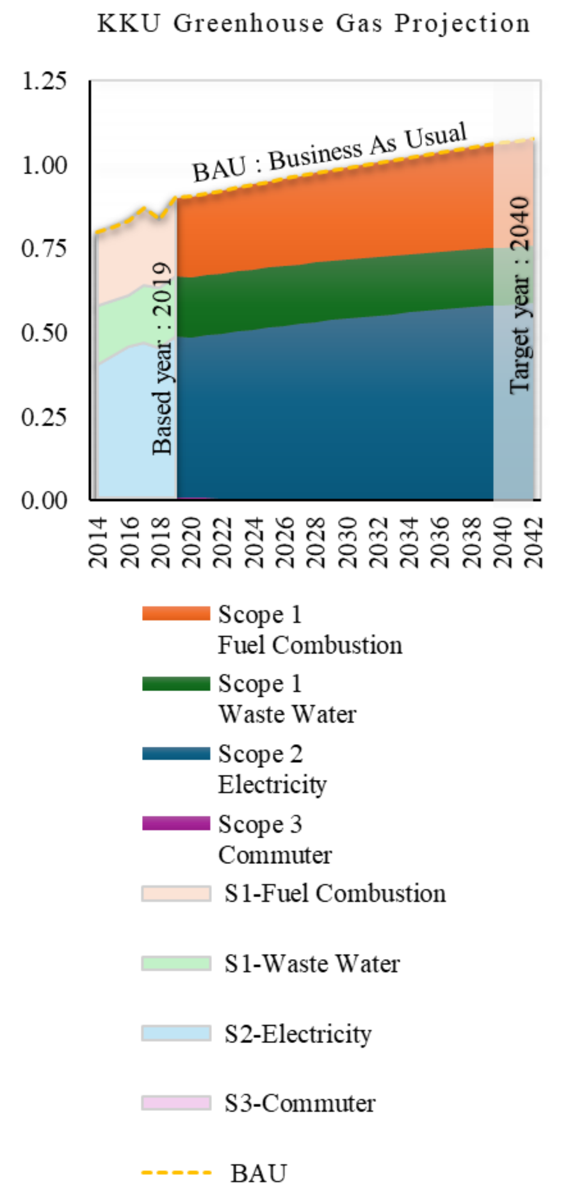

Fig.4 KKU's Greenhouse Gas Inventory and Forecasting.

Khon Kaen University (KKU), one of the largest academic institutions in Northeast Thailand, is ideally positioned to lead in climate change mitigation and sustainable campus operations. Its expansive campus features a variety of facilities, including academic buildings, laboratories, residential areas, and extensive green spaces and forests.

These elements offer both challenges and opportunities for reducing greenhouse gas (GHG) emissions across all operations. By utilizing its resources and infrastructure, KKU can adopt innovative strategies to enhance sustainability and serve as a model for other institutions in the region, promoting environmental stewardship and addressing climate change effectively.

a. Energy efficiency (Scope 2): HVAC retrofits, LED + controls, building commissioning, lab ventilation optimization.
b. On-site renewables: PV rooftop/ground, solar hot water, BESS for peak shaving.
c. Procurement: green power (market-based Scope 2), RECs/PPAs.
d. Mobility: EV fleet, shuttle/bike infrastructure, parking pricing, telepresence.
e. Refrigerants: low-GWP replacements, leak detection, recovery.
f. Waste & water: organics diversion, anaerobic digestion, wastewater upgrades.
g. Purchasing & construction: low-carbon concrete/asphalt, steel with EAF, circularity.
h. Nature-based removals: campus forest restoration (Dry Dipterocarp context), urban trees.

Integrating nature-based solutions (NBS) with technological mitigation measures positions KKU to achieve deep decarbonization while delivering ecosystem services that extend beyond GHG accounting. As highlighted by Griscom et al. (2017), natural climate solutions can contribute up to one-third of cost-effective mitigation potential by 2030, making them a critical complement to engineered solutions in institutional net-zero strategies.

3.2 Land Use and Land Cover Change Analysis

This study presents an integrated analysis of Land Use and Land Cover Change (LULCC) using satellite remote sensing and digital image processing techniques, with a particular focus on monitoring changes in forested and agricultural landscapes. The primary objective was to classify and assess spatial and temporal land cover dynamics to support evidence-based environmental planning, sustainable land management, and climate change mitigation strategies.

Sentinel-2A imagery from the European Space Agency's (ESA) Copernicus program was employed as the primary data source. Together with its twin satellite, Sentinel-2B, this mission provides global coverage through Multispectral Instruments (MSI) capturing high-resolution (10–60 m) imagery across 13 spectral bands, spanning the visible, near-infrared (NIR), and shortwave infrared (SWIR) regions. These spectral capabilities are particularly suited for environmental monitoring, vegetation health assessment, and change detection [9-10].

The analysis covered a five-year period (2019–2023). Three key spectral bands—Band 3 (green), Band 4 (red), and Band 8 (near-infrared)—were selected for classification due to their sensitivity to chlorophyll absorption and vegetation reflectance properties [11-12]. Land cover was classified into five major categories: (1) Forestry Land, (2) Agricultural Land, (3) Water Bodies, (4) Built-up Land, and (5) Bare Land. These classes were selected to facilitate consistent monitoring of land use changes and to provide a robust basis for environmental decision-making [13].

To effectively evaluate vegetation density and assist in land use classification, we employed the Normalized Difference Vegetation Index (NDVI), a widely used spectral index.

The NDVI calculated by Eq. (1)

$$NDVI = \frac{(NIR + RED)}{(NIR - RED)} \tag{1}$$

Where NIR represents the near-infrared reflectance (Band 8 in Sentinel-2) and RED represents the red reflectance (Band 4 in Sentinel-2).

NDVI values range from -1 to 1. Higher values, NDVI values range from −1 to +1, with higher values indicating dense, healthy vegetation typical of intact forests or well-managed croplands, and lower values representing sparse vegetation, bare soil, or built-up areas.

This NDVI-based approach enables the detection of phenological trends in agriculture and the identification of forest canopy changes over time. In the context of Khon Kaen University, it supports the integration of remote sensing data with ground-based forest assessments for estimating biomass and carbon sequestration potential, particularly within the Dry Dipterocarp Forest ecosystems that characterize much of the campus landscape [14-15]. This integrated methodology strengthens the scientific basis for the university's carbon neutrality planning and its broader environmental sustainability objectives.

To quantify the change in each land use class over the study period, we calculated the percentage change (ΔA) in area using Eq. (2)

$$\Delta A = \frac{(A_{final} - A_{initial})}{A_{initial}} \times 100\% \tag{2}$$

where $A_{initial}$ is the area of a specific land use class in the initial year (2019) and A_{final} is the area of the same land use class in the final year (2023).

This formula enabled us to accurately quantify the percentage increase or decrease in each land use category over the specified study period. By applying this method, we gained detailed insights into the dynamics of land use changes, providing a comprehensive overview of how various categories evolved.

Table 1. Spectral Bands for the Sentinel-2 sensors

Sentinel-2 bands	Sentinel-2A		Spatial resolution (m)
	Central wavelength (nm)	Bandwidth (nm)	
Band 1 – Coastal aerosol	442.7	21	60
Band 2 – Blue	492.4	66	10
Band 3 – Green	559.8	36	10
Band 4 – Red	664.6	31	10
Band 5 – Vegetation red edge	704.1	15	20
Band 6 – Vegetation red edge	740.5	15	20
Band 7 – Vegetation red edge	782.8	20	20
Band 8 – NIR	832.8	106	10
Band 8A – Narrow NIR	864.7	21	20
Band 9 – Water **vapor**	945.1	20	60
Band 10 – SWIR – Cirrus	1373.5	31	60
Band 11 – SWIR	1613.7	91	20
Band 12 – SWIR	2202.4	175	20

3.3 Carbon Sequestration

Carbon sequestration is the process of capturing and storing carbon dioxide. The amount of carbon sequestered varies based on the ecosystem type, such as forests, grasslands, or wetlands, and their specific features, like the type of plants, soil makeup, and climate conditions.

Forest ecosystems represent a critical component of the global biosphere, providing indispensable ecological services, including the regulation of atmospheric carbon dioxide through sequestration. The role of these terrestrial biomes in mitigating the effects of anthropogenic climate change is paramount, as they function as the largest land-based carbon sinks. Through the process of photosynthesis, forests absorb CO_2 and store it as carbon in various pools, including above-ground biomass (trunks, branches, leaves), below-ground biomass (roots), and soil organic matter. The integrity and extent of these forests are thus directly linked to the planet's capacity to maintain climatic equilibrium, making their conservation and sustainable management a global priority. The efficiency of carbon sequestration, however, is not uniform across all forest types, with distinct variations dictated by species composition, climate, and ecological condition.

Here is the value of carbon sequestration rates for different ecosystems used in this study:

3.3.1 Forests

The carbon sequestration capacity of dry dipterocarp forests, a prevalent ecosystem in mainland Southeast Asia, has been quantified through empirical research in Thailand, which indicates a storage potential ranging from approximately 94.38 to 101.56 tons of carbon per hectare per year [16-18]. This data is particularly relevant to the context of Khon Kaen University, where the campus forest is predominantly characterized as a young dry dipterocarp forest of moderate density. Given that the forest is not fully mature and its density is moderate, it would not be expected to achieve the maximum sequestration potential observed in older, high-density stands. Therefore, the selection of a conservative value from the established range is scientifically justified for this study. This approach provides a robust and realistic baseline for assessing the current carbon stock of the university's forest and its contribution to regional climate mitigation efforts. In this study, the average rate of above-ground carbon sequestration is 94.38 metric tons of carbon dioxide per hectare per year.

3.3.2 Agricultural land

Depending on the farming practices used, agricultural land can contribute to carbon sequestration. Practices such as agroforestry, cover cropping, and conservation tillage can enhance carbon sequestration in agricultural soils. The carbon sequestration rate of farming systems can range from 3.90 to 19.53 metric tons of carbon dioxide per hectare per year, but it can vary widely depending on management practices [19-20]. In this study, we use 3.90 metric tons of carbon dioxide per hectare per year to calculate the carbon sequestration.

3.4 Data Processing

This study leverages the capabilities of SNAP (Sentinel Application Platform) and ENVI (Environment for Visualizing Images), two powerful and widely recognized software tools specifically designed for the analysis and processing of remote sensing imagery.

For individuals interested in obtaining Sentinel-2 data products, the Copernicus Open Access Hub is the most authoritative and comprehensive resource available. This hub operates as a sophisticated ground processing system, delivering a diverse array of Sentinel data products. Among these offerings is the high-resolution imagery captured by the Sentinel-2 satellites, which provide valuable insights for various applications, including environmental monitoring, land use classification, and disaster management. Users can access a wide range of data formats and processing levels tailored to their specific needs, making the Copernicus Open Access Hub an essential tool for researchers and professionals in the field.

To ensure optimal analysis, it is crucial to preprocess the Sentinel-2 imagery prior to any examination (Fig.5). This preprocessing may encompass several essential steps, such as applying radiometric and atmospheric corrections to improve image clarity, performing orthorectification to rectify any spatial distortions, and calibrating the imagery to enhance its overall quality. These meticulous processes are vital for extracting accurate and reliable information from the images (Fig.6).

To perform image classification using the SNAP toolbox, you can choose from a range of advanced algorithms such as Support Vector Machines (SVM), Maximum Likelihood, Random Forest, and Artificial Neural Networks (ANN). These methods allow for the accurate classification of various land use categories in Sentinel-2 imagery, including forests, agricultural land, water bodies, and urban areas. The process involves preprocessing the imagery, selecting features, and fine-tuning the algorithm to achieve optimal results, supporting effective environmental monitoring and land cover analysis.

Once the classification is completed, export the classified image from SNAP to a format compatible with ENVI. Visualize the classified image in ENVI to examine the land use categories and their spatial distribution (Fig.7).

Fig.6 Sentinel-2 band composite image

Fig.5 Sentinel-2 image for the area of Khon Kaen University

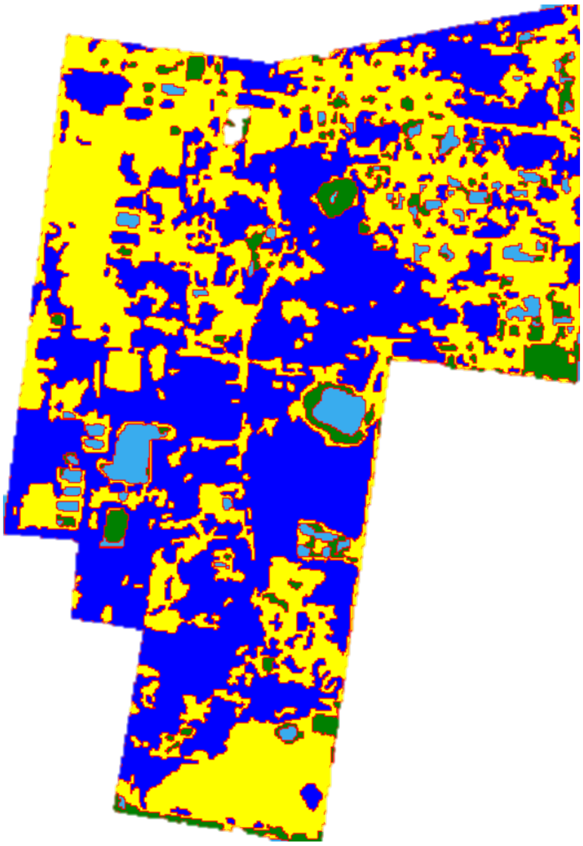

Fig.7 Classification Results

4. RESULT AND DISCUSSION

This study investigates the spatiotemporal dynamics of Land Use and Land Cover Changes (LULCC) within Khon Kaen University (KKU) between 2019 and 2023, with a particular emphasis on their implications for carbon sequestration potential and the institution's carbon neutrality objectives. Using Sentinel-2A multispectral imagery from the European Space Agency's Copernicus programme, land cover was classified into five categories: Forestry Land, Agricultural Land, Built-up Land, Water Bodies, and Bare Land. The classification process employed a supervised algorithm—Support Vector Machines (SVM)—validated through ground-truthing and accuracy assessment via a confusion matrix, with metrics including overall accuracy (OA) and the Kappa coefficient (κ).

The results reveal notable land cover transformations over the five-year period, characterized by an accelerated urbanization trend on the campus. Although forestry areas exhibited a modest increase of 4.51% and agricultural land expanded by 0.41%, the Built-up Land category experienced a substantial increase of 26.98%. Such expansion imposes ecological pressures, potentially reducing the campus's capacity for long-term carbon sequestration [14].

Green space analysis indicates that existing forestry areas contribute to an annual sequestration equivalent to only 0.45% of KKU's total greenhouse gas (GHG) emissions, which were estimated at 88,000 tCO_2e in 2023. Carbon sequestration was estimated using Eq. (3), the general biomass-to-carbon conversion formula.

$$C_{seq}=A\times B\times CF\times \frac{44}{12} \quad (3)$$

where C_{seq} is the annual CO_2 sequestration (tCO_2 yr^{-1}), A is the forested area (ha), B is the average aboveground biomass (t/ha), CF is the carbon fraction (default IPCC Tier 1 value = 0.47), and 44/122 is the molecular weight ratio of CO_2 to C [1]

A key finding is the identification of underutilized Bare Land (brownfield), accounting for approximately 34.90% of KKU's total land area. These sites represent a strategic opportunity for ecological restoration. Scenario modelling suggests that converting this land into dedicated dry dipterocarp forest plantations—aligned with the regional forest typology—could yield an additional sequestration potential of 29,019.96 tCO_2 yr^{-1}.

The integration of remote sensing classification outputs with carbon sequestration modelling provides a robust decision-support tool for strategic campus land-use planning. This evidence underpins the development of a comprehensive land use master plan prioritizing forest conservation, afforestation of brownfield areas, and ecosystem restoration, which, when coupled with institution-wide emission reduction measures, could enable KKU to meet its carbon neutrality target within the projected timeframe.

The methodological approach and findings have broader applicability for Higher Education Institutions (HEIs) seeking to operationalize land-based mitigation strategies within their carbon neutrality frameworks, particularly in tropical and subtropical contexts.

Table 2. LULCC Analysis Result

		2023						
	Change Area (Hectare)	Waterbody	Build-Up Land	Forrest Land	Bare Land	Agriculture	Class Total	Percent
	No Change	24.53	82.83	140.91	290.76	281.10	820.13	93.08%
2018	Waterbody	5.80	-	-	-	-	5.80	0.66%
	Build-Up Land	-	30.60	-	-	-	30.60	3.47%
	Forrest Land	-	-	6.66	-	-	6.66	0.76%
	Bare Land	-	-	-	16.72	-	16.72	1.90%
	Agriculture	-	-	-	-	1.15	1.15	0.13%
	Class Total	30.33	113.43	147.57	307.48	282.26	881.08	
	Percent	3.44%	12.87%	16.75%	34.90%	32.04%	0.12%	
	Increasing Rate	19.14%	26.98%	4.51%	5.44%	0.41%		

Table 3. Carbon Sequestration Calculation

Carbon Sequestration (metric tons of carbon dioxide equivalent)		
	Forest Land	Agriculture
Previous	33,248.19	1,096.29
Changed	1,571.43	4.49
Total	34,819.61	1,100.78
Total Carbon Sequestration	35,920.39	

5. ACKNOWLEDGMENTS

Reforestation and afforestation are widely recognized as effective, nature-based climate solutions for mitigating atmospheric carbon dioxide concentrations. These approaches involve either restoring degraded or deforested lands (reforestation)

or establishing forests on lands that have not previously supported tree cover historically (afforestation). Both practices enhance the global carbon cycle by creating or expanding forest ecosystems capable of absorbing atmospheric CO_2 through photosynthesis and storing it in aboveground biomass, belowground biomass, dead organic matter, and soil carbon pools.

However, sequestration rates are highly context-dependent, influenced by regional biophysical variables such as climate regime, edaphic (soil) conditions, and floristic composition. Forest type also plays a critical role; for instance, dry dipterocarp forests typical of Northeast Thailand may exhibit slower biomass accumulation rates compared to moist evergreen systems but still provide significant long-term carbon storage and biodiversity benefits.

When integrated into institutional carbon neutrality strategies, reforestation and afforestation offer co-benefits beyond carbon storage, aligning with the United Nations Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action) and SDG 15 (Life on Land). For higher education institutions such as Khon Kaen University, the spatial availability of underutilized lands (e.g., brownfields) provides a unique opportunity to deploy these measures as cost-effective, land-based climate mitigation solutions with long-term environmental and educational value.

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