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Greening Healthcare Spaces: The Carbon Cost of Tree Loss in Public Healthcare Facilities

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Abstract
This study examines the environmental implications of landscape design decisions in Malaysian healthcare settings, with a focus on carbon storage loss resulting from the removal of mature trees. Centred on Hospital Taiping, a quantitative analysis involving tree inventories, carbon estimations, and site documentation identified a carbon loss of approximately 1.8 tonnes of CO_2 due to the replacement of green walls and ornamental shrubs. The findings reveal inconsistent, aesthetics-driven practices that neglect long-term ecological functions. This study highlights the urgent need for standardised landscape guidelines that integrate carbon accounting and mature tree preservation, thereby contributing to sustainable hospital development and national environmental resilience goals.

Keywords: Carbon sequestration, Healthcare environment, Green Infrastructure, Tree Inventory

1.0 Introduction

In the modern era, Malaysia's bustling cities and serene rural landscapes, where environmental consciousness is continually increasing, the concept of sustainable landscaping has gained significant traction. The inclination towards sustainable design represents a fundamental shift towards promoting a long-term ecological environment and health by minimising environmental impact through design. In the context of health institutions, traditionally seen as places of healing, hospitals are now viewed with a new and sustainable perspective, with the Ministry of Health (MOH) at the helm. Hospitals save lives and help protect the ecosystems that sustain human well-being. Integrating sustainable landscape design and green infrastructure within healthcare institutions is increasingly recognised for its multifaceted benefits, including enhanced patient well-being, improved air quality, passive cooling and greater energy efficiency (Bringslimark et al., 2009; Bowler et al., 2010). As the public sector increasingly embraces green initiatives aimed at safeguarding both the environment and public health and its inhabitants, Malaysia's hospitals are seizing the opportunity to lead the way in sustainable healthcare, actively addressing the interconnected challenges of climate change, pollution, and biodiversity loss (Abu Hassan & Mahmood, 2025). A well-planned hospital landscape incorporating mature trees and ecological functions can significantly contribute to carbon sequestration, passive cooling, and overall microclimatic balance. Globally, hospitals have begun adopting green landscape strategies to reduce environmental impacts, improve air quality, and support recovery through exposure to nature. However,

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implementing such a strategy in Malaysia has yet to make a global impact. It is still at a low level of development implementation, mainly due to gaps in clear sector-specific guidelines.

In Malaysia, although broader environmental policies such as the Green Building Index (GBI), Low Carbon City Framework (LCCF), and Green Technology Master Plan (GTMP) exist, these frameworks do not directly address landscape design in healthcare environments. Meanwhile, according to Abu Hassan and Mahmood (2025), the Sustainability Program by the Ministry of Health is a transformative initiative that incorporates planetary health principles into public hospitals and the core, which is the Carbon Neutral Healthcare Facilities Action Plan, where Ministry of Health's roadmap aims to achieve carbon neutrality in healthcare facilities as early as 2045. This action plan focuses on four key areas: (i) reducing greenhouse gas emissions through energy-efficient technologies; (ii) ensuring safe and comfortable environments for patients and staff; (iii) promoting green and smart building practices; and (iv) transitioning to renewable energy while conserving biodiversity. However, approaches related to the focus on natural resources, such as tree planting in healthcare institutions, have not received attention, although they can serve as advocates for energy and environmental awareness. Therefore, as a result, hospital landscape management practices vary widely, often depending on individual decision-makers or contractors. Without clear guidelines, landscaping often prioritises short-term aesthetics or function over long-term sustainability, leading to the removal and replacement of mature trees with high carbon storage, which offer far less ecological value.

This study aims to evaluate the environmental consequences of such landscape decisions, with a focus on their impact on carbon storage. Using selected public hospitals in Perak as case studies, the research highlights the need for more structured, long-term, sustainable landscape planning in healthcare environments. One such example is Hospital Taiping, where recent upgrades involved the removal of mature *Bucida molinetii* trees, which were replaced with green walls, ornamental plants, and hard landscape facilities. While these modifications addressed specific aesthetic and functional objectives, they simultaneously resulted in a measurable reduction in the site's overall carbon storage capacity. This situation reflects a broader trend in Malaysian healthcare infrastructure, where short-term landscape design considerations often outweigh long-term ecological sustainability. By assessing the environmental impact of landscape modifications in Malaysian public hospitals, with a specific focus on the loss of carbon storage that results from the removal of mature trees, it can seek to quantify and compare the carbon storage capacities of hospital landscapes before and after redesign efforts, using a case-based analysis rooted in site-specific data. Additionally, the study assesses the effectiveness of alternative landscape strategies, including sapling replanting and the integration of green walls, in compensating for this loss and restoring carbon sequestration functions. Ultimately, the study advocates for establishing structured and sustainable landscape design policies that emphasise the ecological value of mature trees and prioritise long-term environmental performance within healthcare environments.

2.0 Literature Review

2.1 Sustainable Landscape Design in Healthcare Facilities

Sustainable landscape design can be defined as crafting an ambience to fulfil a set of perspectives in an outdoor space that is practical and ecologically friendly towards the environment. Moreover, sustainable landscape design focuses on creating a space with multiple functionalities and minimising environmental impact by developing a healthy environment. This is achieved by involving oneself in designing, constructing, and maintaining landscapes to conserve natural resources and reduce environmental harm. Therefore, sustainable landscape design in healthcare facilities can be related to creating a healthcare environment that emphasises healthy, efficient, and environmentally friendly facilities that benefit patients and the environment. The application of landscape design in healthcare settings is rooted in its capacity to support healing, enhance patient recovery and improve staff well-being (Marcus & Sachs, 2014). According to Ismail et al. (2009), an absence of formal guidelines for landscape planning specific to healthcare institutions often results in ad hoc design changes that prioritise short-term aesthetics or functionality over long-term ecological performance. Healthcare facilities have begun integrating sustainable landscape elements, such as tree-lined courtyards, street planting, vertical gardens, therapeutic gardens, and shaded walkways, to reduce urban heat and promote natural ventilation.

2.2 The Role of Trees in Carbon Storage

Trees absorb carbon dioxide (CO_2) through photosynthesis, converting it into sugars and building their biomass, including wood, branches, and roots. The carbon in trees is stored in their biomass for as long as they live and even after they die. Therefore, trees are vital in a healthy green environment due to their ability to sequester atmospheric carbon dioxide through biomass accumulation. Large, mature trees store significantly more carbon and have a cooling effect than smaller, younger trees, emphasising the importance of preserving mature urban trees (Nowak et al., 2002; McPherson & Simpson, 2003). The statement has been supported by Stoffberg et al. (2010), who stated in their study that mature trees have a higher capacity for carbon storage than younger ones. Thus, the removal of mature trees can result in a significant loss of carbon sequestration due to the loss of biomass that stores carbon in the mature trees. Young trees have a limited capacity to sequester carbon during their early growth years and require substantial time to match the benefits of the trees they replace (Stoffberg et al., 2010). Altogether, the role of trees is significant in representing an effective natural tool for removing carbon dioxide (CO_2) from the atmosphere, helping to mitigate climate change, and promoting a healthy environment.

2.3 Green Walls and Alternative Green Features

As part of green environment strategies, vertical green walls and pocket landscape planting systems are increasingly being applied in space-constrained environments, such as healthcare facilities. Green infrastructure, which is defined as the connections between natural and semi-natural spaces, is one of the solutions being progressively implemented in healthcare environments. According to Perini and

Rosasco (2013), these approaches can provide insulation, shade, and cooling benefits, but often do not duplicate the carbon storage capacity of large canopy trees. Therefore, the decision to substitute mature trees with green walls should be thoroughly assessed in terms of its carbon impact and sustainability performance.

2.4 Policy and Governance Gaps

Malaysia's National Landscape Policy (2011) promotes urban greenery but lacks specific enforcement mechanisms or detailed standards for institutional landscape. This flaw is echoed by Teh et al. (2024), who emphasise that Malaysia has no specific regulations that directly govern landscaping activities. For example, in healthcare institutions, landscape upgrades are often made to meet green environmental standards. Still, they lack continuity in green infrastructure planning and overlook important ecological metrics such as carbon accounting and ecosystem resilience (Nor Atiah et al., 2020). Furthermore, challenges such as a lack of interagency coordination and weak enforcement mechanisms have led to inefficiencies in managing, developing, and protecting landscape assets, especially mature trees. These governance gaps hinder the adoption of sustainable landscape practices within public institutions, including healthcare facilities.

3.0 Methodology

This study employs a quantitative research design to assess the impact of hospital landscape modifications on carbon storage through a selected case study in Hospital Taiping in Perak. Recently, Hospital Taiping upgraded its green space by substituting mature trees with green infrastructure, including green walls, other planting systems, and hard landscape design. The methodology comprises three main components: tree inventory, carbon sequestration estimation and site-based visual documentation.

3.1 Site Selection

This study focuses exclusively on a selected green area in Hospital Taiping, Perak. The hospital was selected due to its recent redevelopment, which involved upgrading green spaces. Six (6) mature trees of Bucida molinetii were removed and replaced with green walls, shrub planting, and hardscape elements such as a concrete walkway and concrete seating. The study area is located in Hospital Taiping, Perak, near the entrance and front of the Clinical Service Block, with coordinates of 4.850769674186144, 100.73604269921252, and covers an area of 352 m² (Figure 1).

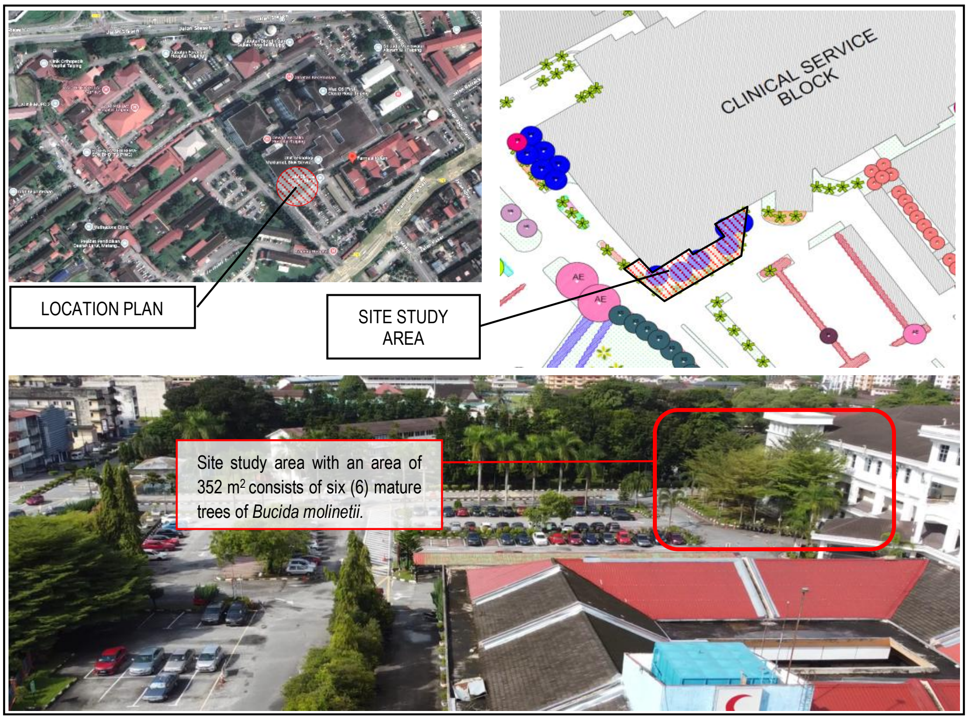

Fig. 1: Site Study Area
(Source: Authors, 2025)

3.2 Tree Inventory Classification and Carbon Storage Estimation

A comprehensive site inventory was conducted to record the perimeter of the study area and categorise trees before and after the landscape redesign. The data collected include the tree species involved, diameter at breast height (DBH), tree height and estimated carbon storage. Mature trees were categorised as having a DBH greater than 30 cm and estimated to be over 10 years old. This categorisation was supported by Nowak et al. (2002), who indicated that trees with DBH greater than 30 cm are typically considered mature, specifically in the context of biomass and carbon stock assessments (FAO Guidelines, 2000). Meanwhile, young trees have a

DBH of less than 15 cm, as defined in the Land of Wildlife categorisation (2015). Growth models indicate that many tree species reach a DBH of 15 cm within their first 10 years, supporting the classification of trees below this size as young. *Bucida molinetii* are mature trees in the study area, where the average DBH is approximately 40.78 cm. The above-ground biomass (AGB) for each tree and palm was estimated using the allometric equation proposed by Chave et al. (2005):

$$AGB = 0.0673 \text{ x } (\rho \text{ x } D^2 \text{ x } H)^{0.976}$$

Where ρ represents wood density (g/cm^3), D is DBH (cm), and H is height (m). Based on the Global Wood Density Database (Zanne et al.,2009), a 0.6 g/cm^3 wood density for *Bucida molinetii* was used, while for *Wodyetia bifurcata* palms, a wood density of 0.4g/cm^3 was applied following Dransfield et al. (2008) and IPCC guidelines (2006), which report lower densities typical of palms due to their fibrous structure. Carbon storage was derived by assuming that approximately 50% of the AGB is carbon, along with the estimation of total carbon storage for each tree. Table 1 presents the data collection on tree inventory and classification (before redesign), as well as the estimated carbon storage by individual planting identification. Table 2 displays the total carbon storage by clustering according to planting status.

Table 1. Planting Identification Data and Estimation of Carbon Storage

Planting ID	Species	Diameter Breast Height, DBH (cm)	Height (m)	Total AGB (kg)	Carbon Storage (kg)	Remarks
BM01	*Bucida molinetii*	40.5	11.5	608.81	304.41	Mature tree removed
BM02	*Bucida molinetii*	38.4	9.8	469.40	234.70	Mature tree removed
BM03	*Bucida molinetii*	39.0	10.7	527.14	263.57	Mature tree removed
BM04	*Bucida molinetii*	41.2	12.3	672.23	336.11	Mature tree removed
BM05	*Bucida molinetii*	45.4	13.2	870.45	435.23	Mature tree removed
BM06	*Bucida molinetii*	40.2	11.0	574.57	287.28	Mature tree removed
FP01	*Wodyetia bifurcata*	25.6	6.1	90.16	45.08	Palm trees are maintained.
FP02	*Wodyetia bifurcata*	23.5	5.4	67.73	33.86	Palm trees are maintained.
FP03	*Wodyetia bifurcata*	22.8	5.2	61.54	30.77	Palm trees are maintained.
FP04	*Wodyetia bifurcata*	29.3	7.0	134.20	67.10	Palm trees are maintained.
FP05	*Wodyetia bifurcata*	31.2	7.5	162.28	81.14	Palm trees are maintained.
FP06	*Wodyetia bifurcata*	25.0	6.2	87.45	43.73	Palm trees are maintained.
FP07	*Wodyetia bifurcata*	24.8	6.0	83.38	41.69	Palm trees are maintained.
FP08	*Wodyetia bifurcata*	26.2	6.8	104.88	52.44	Palm trees are maintained.

(Source: Authors, 2025)

Table 2. Total Carbon Storage by Status Planting

Planting ID	Species	Total AGB (kg)	Carbon Storage (kg)	Status Planting
BM01 – BM06	*Bucida molinetii*	3,722.60	1,861.30	Mature trees removed
FP01 – FP08	*Wodyetia bifurcata*	791.62	395.81	Palm trees are maintained

(Source: Authors, 2025)

4.0 Findings and Discussion

The findings from this study, which uses part of upgrading the green area in Hospital Taiping, Perak, as a case study, provide clear evidence of the environmental costs incurred due to unsustainable landscape design choices within Malaysian healthcare settings. Removing mature, high-sequestration value trees, primarily those of *Bucida molinetii*, and replacing them with lower carbon-storing elements, such as green walls, ornamental palms, and small shrubs, reveals a critical mismatch between landscape planning intentions and ecological outcomes. *Bucida molinetii* trees play a significantly greater role in carbon storage accumulation within the study area, highlighting their ecological importance and reinforcing the need for careful consideration before removing large canopy trees and mature trees in the Malaysian healthcare landscape.

Fig. 2: Before Tree Removal (left) and After Tree Removal and Redesign (right)
(Source: Authors, 2025)

4.1 Replacement with Green Infrastructure

Following the identification data presented in Table 1 and the recorded status of tree removal as outlined in Table 2, the site was subsequently redesigned to incorporate new green infrastructure elements. The redesign involved the installation of three (3) modular green walls comprising 216 individual plants: 72 each for *Schefflera arboricola, Phyllanthus myrtifolius*, and *Epipremnum aureum*, new shrub planting of four hundred (400) *Ficus microcarpa* 'Golden', new young tree planting consisting of eight (8) *Juniperus chinensis*, and maintaining eight (8) *Wodyetia bifurcata* palms. Small ornamental plants and green walls without measurable DBH, above-ground biomass (AGB) was estimated using standard approximate biomass values per plant (1-5 kg), consistent with IPCC (2006) guidelines and urban landscape biomass assessment approaches (Nowak et al., 2002; Perini et al., 2011). Table 3 presents the findings on the total carbon storage after the site study area was redesigned.

Table 3. Total Carbon Storage After Redesign

Planting ID	Species	Diameter Breast Height, DBH (cm)	Height (m)	Total AGB (kg)	Total Carbon Storage (kg)	Quantity (Nos)	Status Planting
FP01 - FP08	*Wodyetia bifurcata*	Avg: ~26.05	Avg: ~6.3	791.62	395.81	8	Palm trees are maintained.
GW01	*Schefflera arboricola*	N/A	N/A	180.0	90.0	72	Green Wall (New Plants)
GW02	*Phyllanthus myrtifolius*	N/A	N/A	108.0	54.0	72	Green Wall (New Plants)
GW03	*Epipremnum aureum*	N/A	N/A	57.6	28.8	72	Green Wall (New Plants)
SH01	*Ficus microcarpa* 'Golden'	N/A	0.5	2,000.0	1,000.0	400	New Shrub Planting
JC08	*Juniperus chinensis*	N/A	1.2	80.0	40.0	8	New Tree Planting
				After Redesigning - Total Carbon Storage (kg)	**1608.61**		

(Source: Authors, 2025)

4.2 Carbon Storage Loss from Mature Tree Removal

Removing six (6) *Bucida molinetii* trees, which are classified as mature with DBH ranging between 38.4 cm and 45.4 cm and overall height of the trees between 9.8 m and 13.2 m, caused a significant reduction in carbon storage capacity. Using standard allometric equations (Nowak et al.,2002; IPCC,2006), the estimated total loss of carbon storage by these six (6) mature trees (*Bucida molinetii*) after redesigning was approximately 1,861.30 kg. Table 4 illustrates the findings of the total loss of carbon storage before and after redesigning the landscape at Hospital Taiping, Perak.

Table 4. Results of Total Loss Carbon Storage (kg)

Planting ID	Status Planting ID	Total Carbon Sequestration (kg)	Quantity (Nos)	Total Carbon Storage (kg)- BEFORE redesigning	Total Carbon Storage (kg) - AFTER redesigning	TOTAL LOSS Carbon Storage (kg)
BM01-BM06	Mature tree removed	1,861.30	6	2,257.11		**648.50**
FP01-FP08	Palm trees are maintained	395.81	8		1,608.61	
GW01-GW03, SH01, JC08	New Planting	1,212.80	624			

(Source: Authors,2025)

4.3 Evaluating the Effectiveness of Green Infrastructure Replacement

Following the removal of mature *Bucida molinetii* trees, the green area at Hospital Taiping was redesigned, and various green infrastructure elements, including green walls, shrubs, young trees, and retained palms, were introduced. Although the replacement involved over 600 new plantings, the total estimated carbon storage was significantly reduced. The original mature trees stored approximately 1,861.30 kg of CO_2, while the new plantings collectively sequestered only about 1,212.80 kg of CO_2, a more than 34% reduction. The green walls, consisting of *Schefflera arboricola, Phyllanthus myrtifolius*, and *Epipremnum aureum*, contributed only 172.80 kg of CO_2, reflecting their limited carbon storage capacity. Shrubs (*Ficus microcarpa* 'Golden') and young trees (*Juniperus chinensis*) added 1,400.0 kg, underscoring the slow carbon accumulation in immature vegetation. Although the eight retained palms (*Wodyetia bifurcata*) stored 395.81 kg of carbon, they were unable to match the ecological functions of mature canopy trees.

These findings reaffirm that tree maturity is critical to adequate carbon storage. Replacing mature trees with decorative or small-scale greenery, often due to aesthetic or spatial constraints, compromises long-term environmental goals. This highlights the need for healthcare landscape policies emphasising ecological function, species selection, and carbon performance rather than superficial greening.

5.0 Conclusion & Recommendations

This study evaluated the environmental consequences of landscape design decisions in Malaysian healthcare facilities, specifically focusing on the carbon sequestration loss resulting from the removal of mature trees and the introduction of alternative green infrastructure and young trees. The research assessed how current hospital landscape redesign practices, particularly the replacement of mature trees with green walls, shrubs, and young trees, affect carbon storage capacity and overall ecological performance. The findings showed a marked drop in carbon storage after the landscape changes, as the new plantings stored only about 1,212.80 kg CO_2 compared to the original mature *Bucida molinetii* trees, which stored around 1,861.30 kg CO_2. This outcome reinforces the central hypothesis that tree maturity, rather than plant quantity, is critical in maximising carbon sequestration benefits within healthcare landscapes. The study also revealed that the absence of standardised guidelines or carbon-based criteria in hospital landscape planning leads to ad hoc, aesthetics-driven decisions, with green walls and young plantings offering far less ecological benefit than mature trees, undermining climate-responsive healthcare design.

In this study, several key recommendations emerge to support the advancement of sustainable landscape practices within healthcare environments. Firstly, there is an urgent need to develop national or institutional guidelines that specifically address sustainable landscape design in healthcare facilities. These guidelines should incorporate carbon accounting principles and prioritise the preservation of mature trees, which play a critical role in long-term carbon storage and environmental performance. Secondly, integrating tree inventory data and carbon sequestration metrics into the planning, upgrading and ongoing maintenance of hospital landscapes is essential to ensure informed decision-making that aligns with ecological goals. Lastly, further research is recommended to explore species-specific carbon sequestration capacities across different plant typologies, including trees, shrubs, and vertical vegetation systems, to build a robust, evidence-based foundation for future landscape planning and policy development. These measures collectively support the transition toward greener, more energy-efficient, and ecologically resilient healthcare environments.

In conclusion, achieving environmental sustainability in healthcare infrastructure requires green aesthetics and a science-based, policy-supported approach that recognises the long-term ecological value of mature vegetation, which is essential for meeting Malaysia's environmental and energy conservation goals. In this study, the 'loss of carbon storage' refers to the immediate reduction in carbon stock from tree removal. In contrast, 'loss of carbon sequestration potential' reflects the reduced future carbon absorption caused by replacing mature trees with smaller plantings.

Paper Contribution to Related Field of Study

This study contributes to sustainable landscape design by providing empirical evidence on the impact of landscape modifications on carbon sequestration in healthcare environments. The research highlights the ecological costs of poor landscape planning by quantifying the carbon loss resulting from the removal of mature trees and comparing the impact of the replacement planting. It emphasises integrating carbon accounting into landscape decision-making, specifically in institutional settings such as hospitals. The findings support the development of guidelines and frameworks for greener healthcare infrastructure, aligning environmental performance with health sector goals and offering a foundation for future research and policy implementation.

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