Living Carbonomics: Tracking Footprint and Storage Dynamics Above and Below Ground

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Abstract
Human-caused disturbances to the equilibrium of carbon dioxide in Earth's systems are the primary cause of the ongoing increase in global temperatures and the growing occurrence of climate extremes. By combining aboveground and belowground carbon storage, net primary production (NPP), and individual carbon footprint within the study area, this study seeks to evaluate carbon dynamics holistically. By measuring 1) the circumference at breast height (CBH) of tree trunks, 2) the height of shrubs or saplings as inputs for allometric equations to determine biomass, and 3) the mass of herbaceous components, aboveground carbon storage was assessed using the Non-Standard Site Carbon Cycle Protocol. In order to incorporate carbon sequestration rates across time, net primary productivity (NPP) was evaluated by periodic vegetation growth assessments, while belowground carbon storage was calculated using soil bulk density and organic carbon content, along with soil characterization, star-pattern soil moisture and depth profile soil moisture protocols. The international standard ISO 14064-1:2006 for greenhouse gas quantification and reporting was used to gather and evaluate personal carbon footprint data.

The overall carbon storage, including projected belowground storage, ranged from 25,115 to 37,920 kg. Additionally, NPP in carbon storage increased by 202 g C/m^2 compared to a previous measurement, corresponding to the rise in vegetation biomass. During this period, personal carbon footprint rose to 41,557 kilograms of CO_2e, exceeding total carbon storage. These findings highlight the need for integrated personal and ecological strategies to reduce carbon emissions and mitigate climate change.

Research Questions:

- What is the carbon storage capacity of large tree species, shrubs, saplings, and herbaceous plants in the study area?
- Is there any correlation between the age, height, and diameter at breast height (DBH) of trees and their carbon storage capacity?
- What is the relationship between vegetation biomass and its carbon storage potential?
- How does the Net Primary Productivity (NPP) of vegetation in the yard correlate with its biomass and carbon storage capacity?
- How do aboveground and belowground carbon storage contributions vary across ecosystems and measurement methodologies?
- How does the household's carbon footprint compare to the ecosystem's capacity to store carbon, and what are the main contributors to the carbon footprint?

Hypotheses:

- We hypothesize that large tree species will store the most carbon, followed by shrubs and saplings, with herbaceous plants storing the least carbon.
- We believe that there is a positive relationship between the age of trees, their height, and their diameter at breast height (DBH) and carbon storage capacity. The older and larger the tree is, the higher carbon storage capacity it has.
- There is a high tendency that carbon storage capacity and vegetation biomass are positively correlated.
- Similarly, it is highly possible that the Net Primary Productivity (NPP) of the vegetation in our yard increases in accordance with its biomass.
- We hypothesize that aboveground carbon storage mainly results from mature trees while dense herbaceous vegetation significantly contribute to belowground carbon storage.
- We forecast that soil carbon storage contributes as much as vegetation carbon storage at the residence.

- We postulate that our personal carbon footprint will significantly exceed the vegetation's capacity to store carbon, with electricity consumption being the primary contributor to this imbalance.

Introduction and Review of Literature:

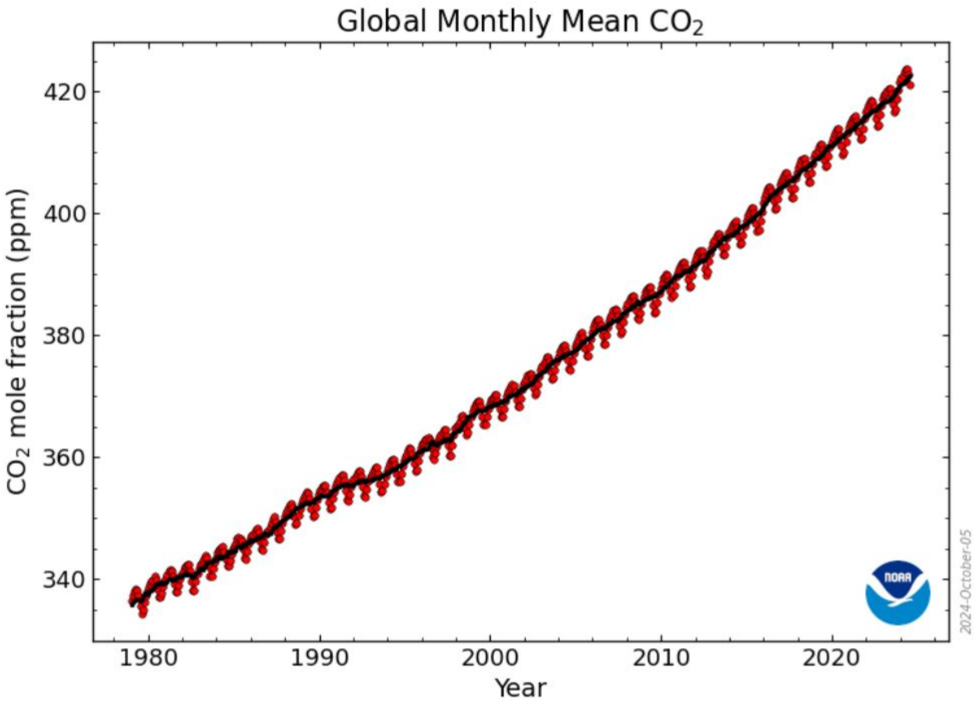
Carbon embeds in every element of life. The most common recognition of carbon is carbon dioxide, which living species release while breathing out. Plants use carbon dioxide as an expansion agent during photosynthesis to produce their nutrients by facilitating mineral and gas circulation in the soil. They separately store carbon and release oxygen. Hence, carbon is a medium between plants and living animals. Despite its necessity for life, a myriad of excessive carbon in certain form elements, e.g., carbon dioxide, threatens the ecosystem.

Human activities, especially during an industrialization era, induce more carbon dioxide into the atmosphere, mainly driven by the outstrip of fossil fuel consumption to natural processes' removal capabilities. People burn fossil fuels aggressively, which plants store carbon that is pulled out of the atmosphere through photosynthesis over millions of years for energy in much shorter periods of time. As a release of fossil fuels has outpaced natural processes' removal at a much faster rate, inevitably rooting for an increase in greenhouse gases.

Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor, fluorinated gases, and ground-level ozone are examples of greenhouse gases. They trap heat in the sky like a blanket, which leads to extreme weather events including heat waves, drought, flooding, and wildfires as well as continuously rising global temperatures. The infrared light that is transferred from the sun's surface to the Earth can be trapped, absorbed, and re-emitted by this group of gases in the atmosphere. This energy is released by them as heat. The blanket will get thicker as GHG levels rise, making air fluxes on Earth worse.

The latest high record of carbon dioxide concentrations in the atmosphere peaked at 426.91 parts per million (PPM) in June 2024 at NOAA's Mauna Loa Observatory, as compared to the previous peak at 424 PPM in May 2023 and the 2023 annual average carbon dioxide at 421.08 PPM. The annual peak has been steadily rising since measurements began in 1958. Extending the record back even further with ice cores, carbon dioxide concentrations are the highest they have been in at least 800,000 years. "The cause of that warming trend over the last 50 to 60 years is dominated by our changes to greenhouse gases, particularly carbon dioxide and methane," said Gavin Schmidt, director of NASA's Goodard Institute for Space Studies in New York City. (Colbert A. and Younger S., 2024)

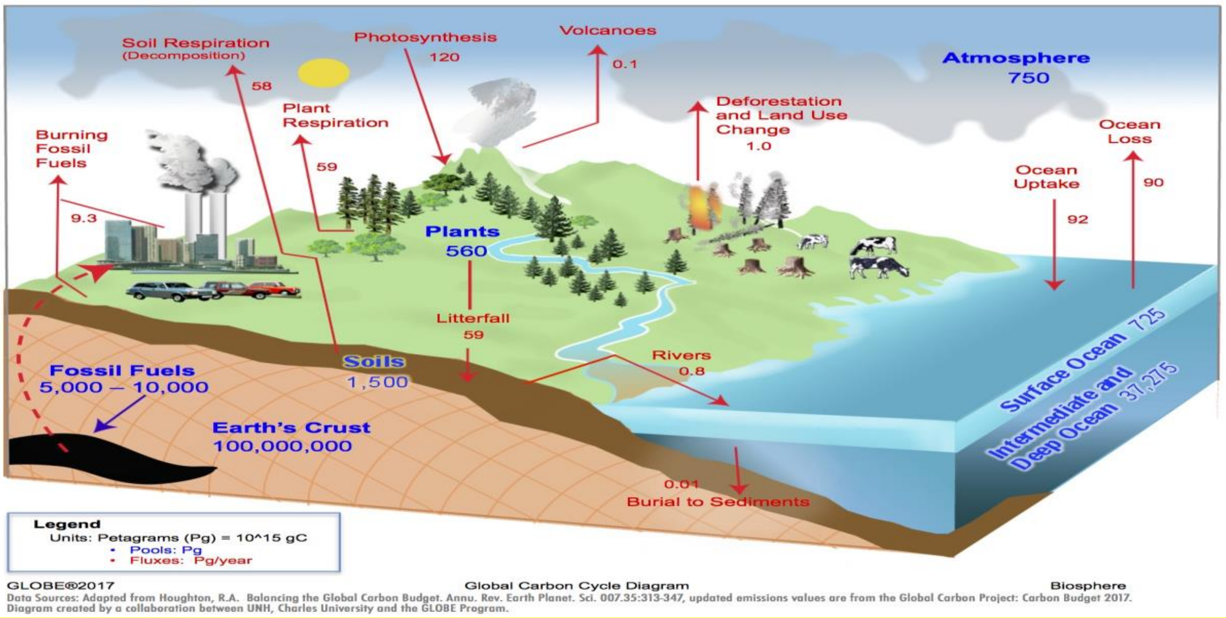
Figure1 Global Monthly Means since 1980



Source NOAA

Carbon sinks—terrestrial ecosystems including grasslands, wetlands, and forests—as well as oceans are essential for absorbing and storing carbon dioxide from the atmosphere. "Carbon sinks, both on land and in the ocean, are essential because they help absorb and store approximately 55 percent of human-induced carbon emissions each year," stressed Corinne Le Quere, Director of the Tyndall Centre in the United Kingdom, which carries out climate change research and chairs the Global Carbon Project. Kenward (2011). However, in recent years, the rate of greenhouse gas emissions into the atmosphere has outpaced the capacity of natural sinks to absorb and store them. The sudden rise in temperature and the disturbance of the natural environment are proven to be the cause.

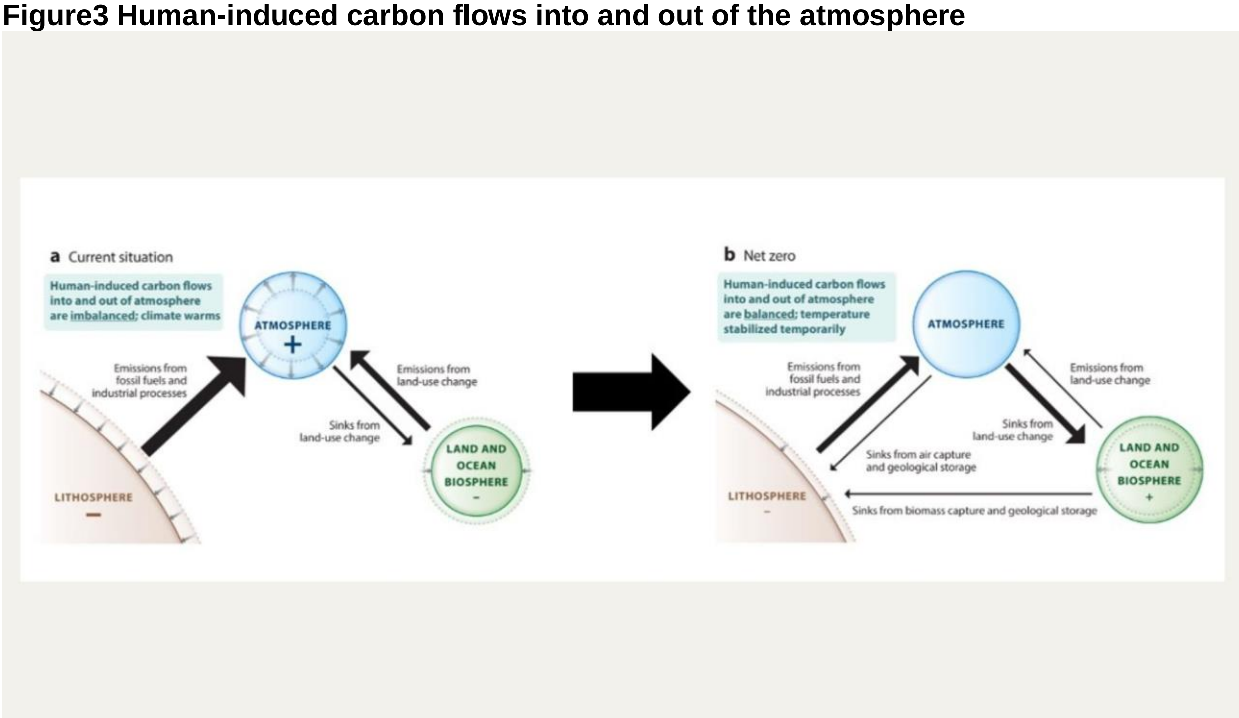
Figure2 Global carbon cycle diagram



Source Globe.gov

Without any stringent measures, it is unlikely that we can achieve our cap limit on a rise in the average global temperature at 1.5 degrees Celsius and reach net-zero greenhouse gas emissions by the year 2050 under the Paris Agreement. (Myles R. Allen et al., 2022). We should be aware of the extent of our own carbon footprint so that we can find ways to mitigate it to low-moderate levels, if possible, to an eventual onset of our carbon footprint.

Figure3 Human-induced carbon flows into and out of the atmosphere



Source Myles R. Allen, et al. (2022). Net Zero: Science, Origins, and Implications. Annual Review of Environment and Resources, Vol 47:849-887

Nitcha Thachuen and colleagues (2022) discovered that Darawittayalai School's trees have carbon storage abilities of roughly 418,706.45 kilograms of carbon, in the equivalent of 5,300 kilograms per rai (or 1,600 sq. m.). The presence of Rain Tree (Albzia saman (Jacq.) Merr.), a native forest tree with high carbon sequestration potential at Darawittayalai School, is a main contributor to carbon absorption at Darawittayalai School, outpacing the carbon storage in trees in the deciduous forest. Not only that, as they are fast-growing trees, they can relatively sequester carbon in large quantities over the same planting period to other tree species. The carbon sequestration of a tree depends on a tree's biomass and the carbon density within the biomass to a lesser extent. According to the findings, a high value for the amount of carbon sequestered in trees at Darawittayalai School resulted from a tree with high biomass that can sequester carbon in large quantities. With landscape specialists full of agricultural knowledge, Darawittayalai School unleashed full potential in plant selections and soil maintenance.

Priyada Saratthana and Thanyarat Sapson (2023) state that the resin tree and the Indian oak tree contain the highest average circumference increase, with the resin tree demonstrating the highest carbon sequestration growing in high soil moisture and organic matter content. While the nutrient content in the soil (NPK) is significantly low, rubber trees, with their deep root systems, can efficiently absorb nutrients from the soil for growth, giving the resin tree the best growth and the highest carbon sequestration when compared to other prominent tree species in the school. They recommended for schools nationwide to consider planting resin trees, as each resin tree can sequester 925.32 kilograms of carbon per year.

Sangay Choden and Yeshey (2024) reveal that the carbon sequestration varies with the number of plant species within Pelrithang Higher Secondary School, Sarpang, Bhutan. In addition, large trees have the highest biomass, letting them be the group that sequesters the most carbon in the area. On the school's total area of 133,547.3 square meters, the estimated carbon storage of plant species in the school is roughly 4,629.7 gC/m2, making the carbon sequestration in the plant species at 289.57 tons.

Kornwit Namuang, Tongta Reunrunwong, and Ittaya Yingnok concluded that higher soil organic matter makes the soil more suitable for growing plants at Phimai Wittayalai School. This is because soil organic matter positively affects soil porosity, bulk density, humidity, and nitrogen and phosphorus nutrient levels. In contrast, it tends to lower soil temperature and pH levels.

Chonradee Chuayruang, Siwaporn Plodkanthong, and Katathong Tanwetchakul found that rubber plant plots with intercropping have different soil characteristics, including humidity, temperature, pH levels, and nutrient content, compared to sole rubber plant plots. These differences affect the quantity of latex produced in these plots.

The exchange of carbon between soil, water, and Earth's living organisms is known as the carbon cycle. One of the fundamental elements, carbon, makes up around half of the organic tissues found in living organisms. The transfer of carbon dioxide (CO_2) from the atmosphere into living organisms is made possible by the process of photosynthesis in plants. However, this gas is released back into the environment by consumers who eat organic matter that contains stored carbon. According to the environmental system, if a plant's rate of photosynthesis is higher than that of animal and plant respiration, it will absorb more carbon from the atmosphere. A recent study that was published in the Proceedings of the National Academy of Sciences found that warmer weather tends to increase the amount of carbon that plants need to thrive. They absorb carbon dioxide from the atmosphere through the process of photosynthesis in their leaves and branches. (Dunning, 2018)

According to a global study by the US Forest Service, forests around the world absorb about 2.4 billion tons of carbon dioxide annually, and the National Aeronautics and Space Administration (NASA) asserts that "oceans act as a sink, absorbing around 30% of carbon emissions due to anthropogenic matters." However, the oceans' ability to absorb carbon may be limited by the rising environment.

To mimic carbon movements through the intricate carbon cycle of the Earth, we employ the 1-box model, where each box represents a carbon pool and arrows indicate the flux or movement of carbon. The picture below illustrates the global carbon cycle, which shows the movement of carbon between the atmosphere, soil, and carbon reserves such as trees. (Globe Program, 2022)

<table>
<tr><th>Figure 4 A 1-box model</th><th>Figure 5 A "1-Box model" carbon cycle</th></tr>
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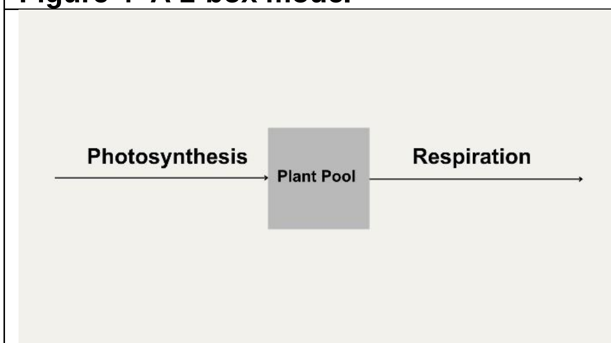

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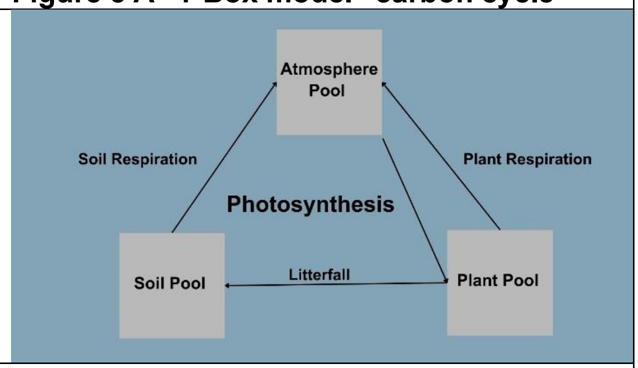

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<tr><td>Source Biosphere Carbon Cycle Introduction</td><td>Source Biosphere Carbon Cycle Introduction</td></tr>
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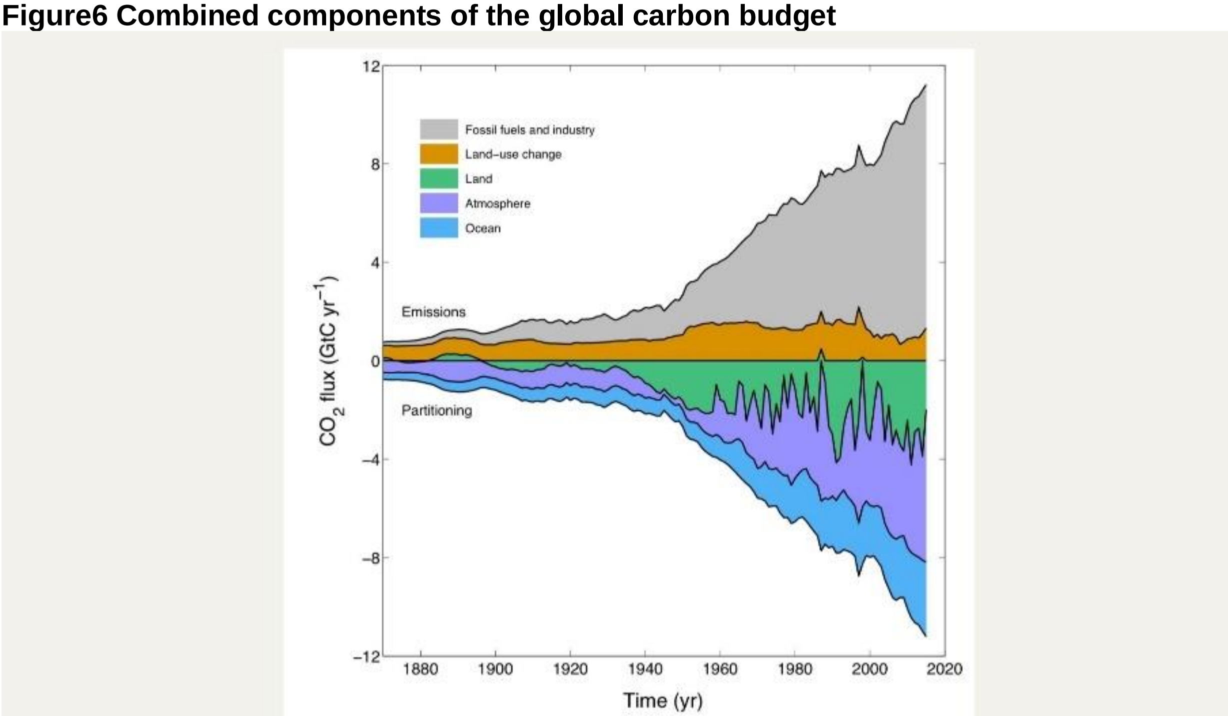
Figure6 Combined components of the global carbon budget



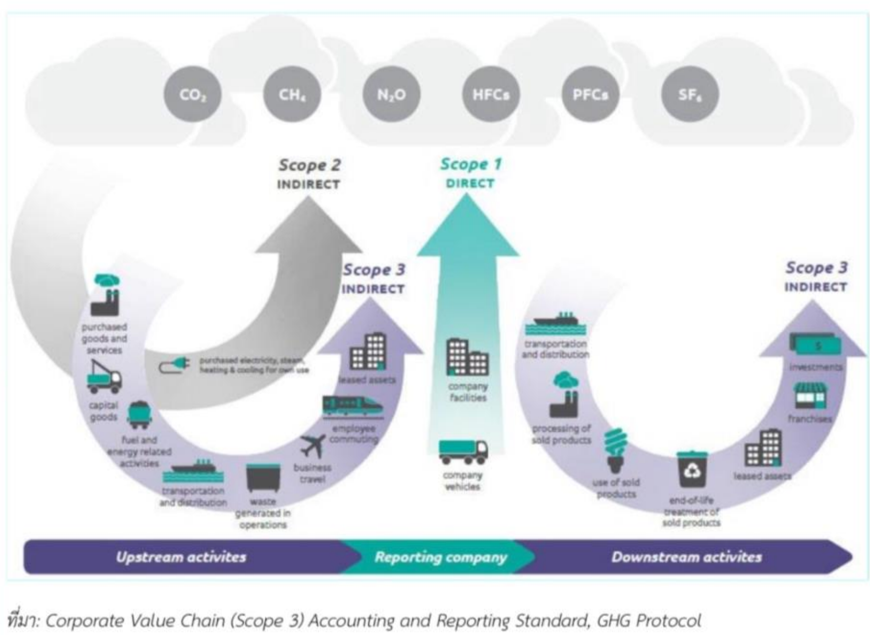
Source: Earth System Science Data, 8, 605-649,2016

Solutions to climate change must be understood in light of how ecosystems store and cycle carbon (The GLOBE Program, 2022). Hence, the Carbon Cycle Protocol under Biosphere is used to estimate carbon storage in vegetation, and the Pedosphere Protocol for belowground carbon storage on our site for this research.

The non-standard site carbon cycle protocol of GLOBE is used to measure the carbon cycle in our area. We summarize the total carbon quantity stored in plants into three groups: large trees, shrubs and saplings, and herbaceous. In addition, we use the Pedosphere Protocol to find belowground carbon storage by investigating soil bulk density and soil organic matter, which in turn translates into soil carbon storage.

To assess the carbon footprint, we classify activities based on the scope of greenhouse gas emissions and removals into three categories: direct emissions, energy indirect emissions, and other indirect emissions in accordance with the ISO 14064-1:2006 standard and use equations from the Intergovernmental Panel on Climate Change (IPCC) to calculate the carbon footprint.

Figure7 Classifying activities based on the scope of greenhouse gas emissions and removals Types 1, 2, and 3.



Source Corporate Value Chain (Scope3) Accounting and Reporting Standard, GHG Protocol

Type 1 (Scope 1), or direct greenhouse gas emissions, are actions that originate directly from sources that are under the entity's control. Examples include combustion in fixed sources (machinery) and combustion in mobile sources (mobile combustion). Energy Indirect Emissions, or Type 2 (Scope 2), are indirect greenhouse gas emissions resulting from energy use. This covers things like buying electricity or other energy sources. Other indirect greenhouse gas emissions from different activities outside of those listed in Types 1 and 2 are included in Type 3 (Scope 3).

Research Methods and Materials

Our land cover sample site is situated at 13.72411 Latitude, 100.503101 Longitude, with an elevation of 6 meters above sea level, covering 9,702 square meters. Classified as a Non-Standard Site, it exceeds 50% human interference, including residential and dwelling areas.

Equipment includes photographs, a smartphone with a GPS application, a compass, the Modified UNESCO Classification Guide (MUC Field Guide), a measuring tape, brown bags, grass clippers, pen and paper, a clinometer and a densiometer. Tool requirements for soil protocols: Soil color book, trowel, compass, meter stick, 15 quart-size sealable bags, 5 sampling PVC tubes, wood block, hammer, shovel and marker, auger, 2mm mesh sieve, graduated cylinder, rubber gloves, soil organic matter tool kits.

Protocols include the Land Cover Sample Site Protocol, along with the Biometry Carbon Cycle Protocols covering Tree Mapping, Tree Circumference, Shrubs/Sapling, and Herbaceous Vegetation. For belowground carbon storage, Soil Characterization Protocol, Star-Pattern Soil Moisture Protocol, Depth Profile Soil Moisture Protocol and Soil Bulk Density Protocol. Then, we find soil organic carbon (SOC), using the Walkley-Black method.

Additionally, the research adheres to the international standard ISO 14064-1:2006 Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. This standard is applied to determine emission factors for calculating carbon footprints.

Methodology

We performed a carbon cycle evaluation by collecting data about our land cover sample location using the guidelines of GLOBE's Land Cover Investigations. The chosen location, which is roughly 9,702 square meters in size and is located at coordinates of 13.72411 degrees north latitude, 100.503101 degrees east longitude, and an elevation of 6 meters above sea level, is categorized as a Non-Standard Site since it contains man-made structures.

Using Google Earth aerial images, we surveyed the region and determined the research site's length and width according to GLOBE's guidelines. In order to meet the requirements for satellite photography with a minimum pixel size of 30 meters by 30 meters and a resolution of at least 15 kilometers by 15 kilometers, we carefully selected a site that measured 99 meters by 98 meters. In order to get a certain pixel count of 10.7811 Landsat pixels, or 3.3 by 3.267 pixels, this choice was chosen. Given that approximately 50% of the area is covered by erected features for residential purposes, our study site falls into the category MUC91 of urban areas with residential land use, as defined by the Modified UNESCO Classification Guide (MUC Field Guide).

This research location is regarded as a "non-standard" site in accordance with the carbon cycle protocol. We measured latitude, longitude, and elevation above sea level using the built-in compass on our cellphones to find the area's midpoint. For accurate readings, our phones' GPS receivers made sure to align vertically. Five measurements were made, and the average was determined. We also separated the region into the north, east, south, and west quadrants. We counted steps from the leftmost to the rightmost point to compare the size of the aerial image with the actual area in order to verify the accuracy. The image and the on-ground distance have a 1 centimeter to 915.9 centimeter scale ratio. On the GPS Investigation Data Sheet form, we noted this information.

Figure8 Site selection and non-standard site set up (1)

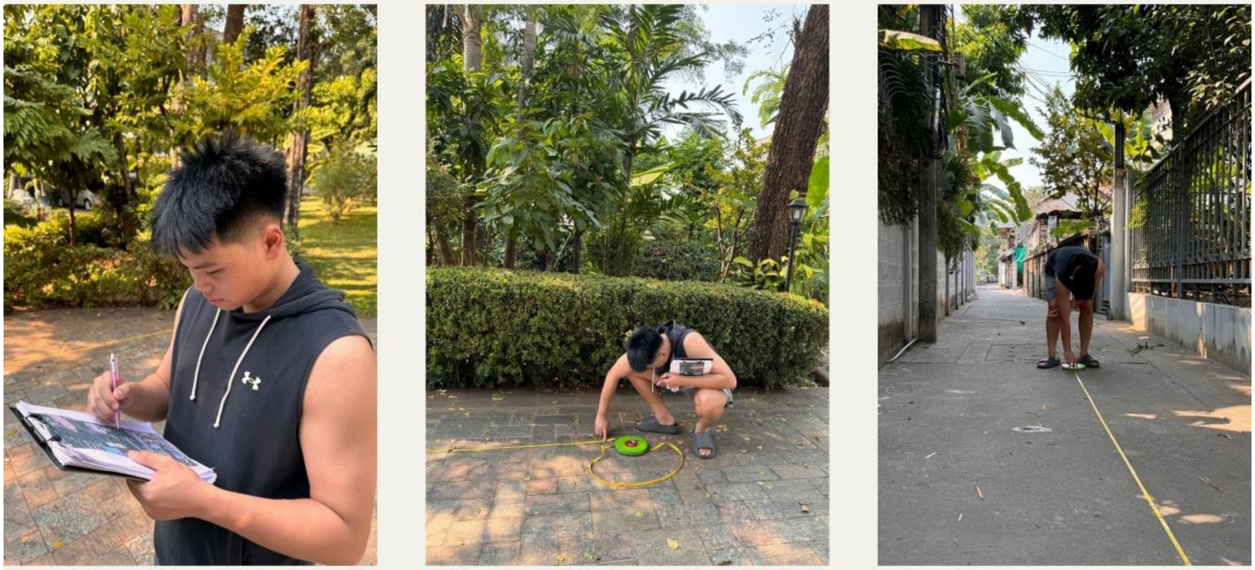
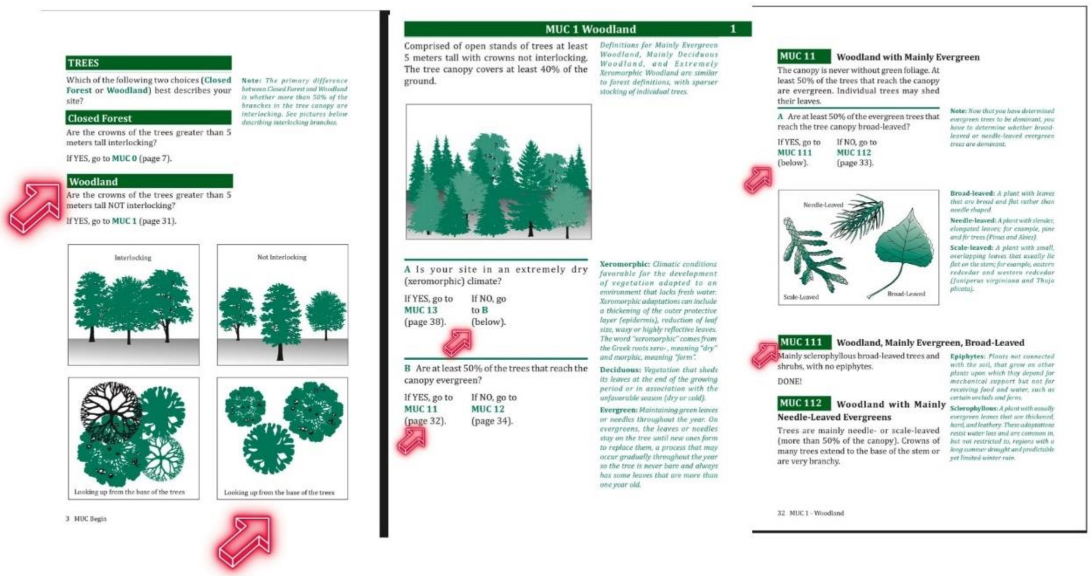


Figure9 Site selection and non-standard site set up (2)

To start the vegetation survey, we headed northwest and use the MUC Field Guide as a reference for identifying the species of trees. The trees at our study site fell into the woodland category given the fact that at least 40% of the area was blanketed by the canopies of the larger-than-5-meter trees, yet not-interlocking. In addition, at least 50% of the trees had green leaves all year round and the canopies of the trees were continuously green, fitting the categories MUC111: Woodland, Mainly Evergreen, Broad-Leaved and MUC1121: Woodland, Mainly Evergreen Needle-Leaved, Irregularly Rounded Crowns comprise the identified tree types at our study site.

Figure10 The selection of the land cover classification using the MUC Field Guide



TREES

Which of the following two choices (Closed Forest or Woodland) best describes your site?

Note: The primary difference between Closed Forest and Woodland is whether more than 50% of the branches in the tree canopy are interlocking. See pictures below describing interlocking branches.

Closed Forest

Are the crowns of the trees greater than 5 meters tall interlocking?

If YES, go to MUC 0 (page 7).

Woodland

Are the crowns of the trees greater than 5 meters tall NOT interlocking?

If YES, go to MUC 1 (page 31).

Interlocking

Not Interlocking

Looking up from the base of the trees

Looking up from the base of the trees

3 MUC Begin

MUC 1 Woodland 1

Comprised of open stands of trees at least 5 meters tall with crowns not interlocking. The tree canopy covers at least 40% of the ground.

Definitions for Mainly Evergreen Woodland, Mainly Deciduous Woodland, and Extremely Xeromorphic Woodland are similar to forest definitions, with sparser stocking of individual trees.

A Is your site in an extremely dry (xeromorphic) climate?

If YES, go to MUC 13 (page 38). If NO, go to B (below).

B Are at least 50% of the trees that reach the canopy evergreen?

If YES, go to MUC 11 (page 32). If NO, go to MUC 12 (page 34).

Xeromorphic: Climatic conditions favorable for the development of vegetation adapted to an environment that lacks fresh water. Xeromorphic adaptations can include a thickening of the outer protective layer (epidermis), reduction of leaf size, waxy or highly reflective leaves. The word "xeromorphic" comes from the Greek roots xero-, meaning "dry" and morphic, meaning "form".

Deciduous: Vegetation that sheds its leaves at the end of the growing period or in association with the unfavorable season (dry or cold).

Evergreen: Maintaining green leaves or needles throughout the year. On evergreens, the leaves or needles stay on the tree until new ones form to replace them, a process that may occur gradually throughout the year so the tree is never bare and always has some leaves that are more than one year old.

MUC 11 Woodland with Mainly Evergreen

The canopy is never without green foliage. At least 50% of the trees that reach the canopy are evergreen. Individual trees may shed their leaves.

A Are at least 50% of the evergreen trees that reach the tree canopy broad-leaved?

If YES, go to MUC 111 (below). If NO, go to MUC 112 (page 33).

Note: Now that you have determined evergreen trees to be dominant, you have to determine whether broad-leaved or needle-leaved evergreen trees are dominant.

Needle-Leaved

Scale-Leaved

Broad-Leaved

Broad-leaved: A plant with leaves that are broad and flat rather than needle shaped.

Needle-leaved: A plant with slender, elongated leaves; for example, pine and fir trees (Pinus and Abies).

Scale-leaved: A plant with small, overlapping leaves that usually lie flat on the stem; for example, eastern redcedar and western redcedar (Juniperus virginiana and Thuja plicata).

MUC 111 Woodland, Mainly Evergreen, Broad-Leaved

Mainly sclerophyllous broad-leaved trees and shrubs, with no epiphytes.

DONE!

MUC 112 Woodland with Mainly Needle-Leaved Evergreens

Trees are mainly needle- or scale-leaved (more than 50% of the canopy). Crowns of many trees extend to the base of the stem or are very branchy.

Epiphytes: Plants not connected with the soil, that grow on other plants upon which they depend for mechanical support but not for receiving food and water, such as certain orchids and ferns.

Sclerophyllous: A plant with usually evergreen leaves that are thickened, hard, and leathery. These adaptations resist water loss and are common in, but not restricted to, regions with a long summer drought and predictable yet limited winter rain.

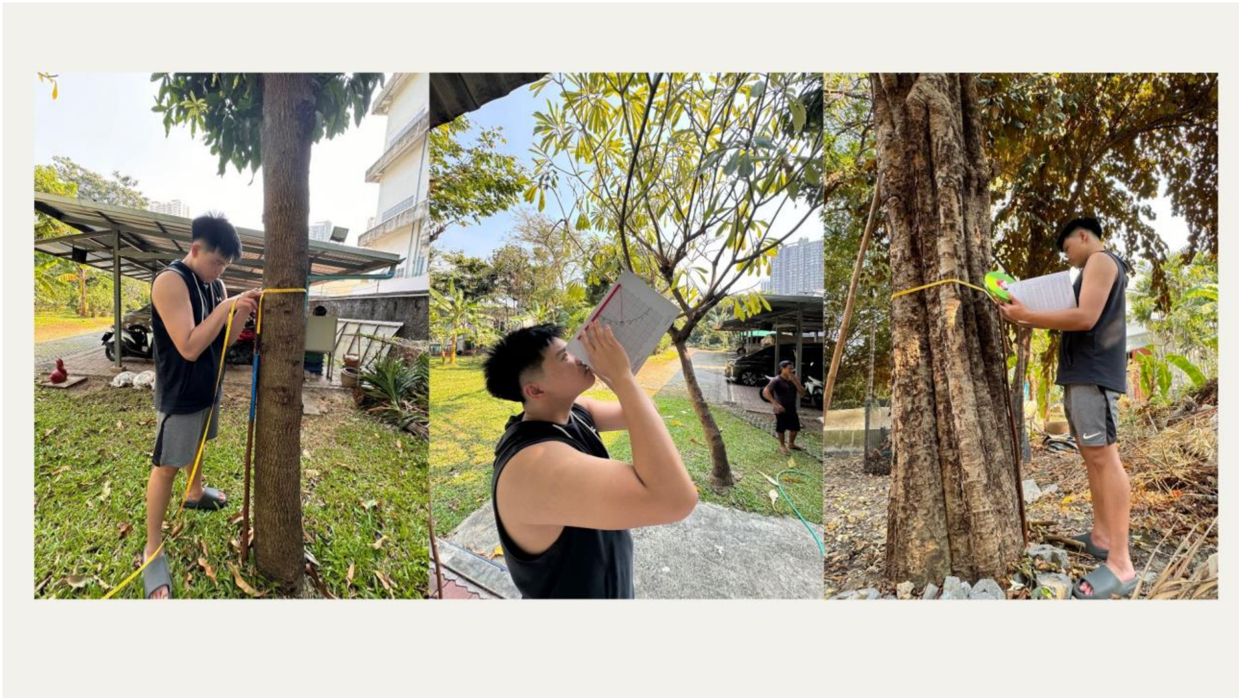
32 MUC 1 - Woodland

Source MUC Field Guide

Using our Google Earth photos, we were able to identify the tree crowns that were visible on the aerial map and compare them to the real tree that was present. We conducted tree mapping using the Biometry procedures, using the aerial map to identify and number the trees in each quadrant of the area. To identify the type of tree, we measured its circumference at breast height (Circumference at Breast Height) or 1.35 meters above the base.

The photosynthetic capacities of various species are influenced by differences in trunk shape, branching patterns, root structure, and leaf features. To identify the tree species, we used the iNaturalist application and spoke with tree experts. The GLOBE Carbon Cycle – Tree Data Sheet created for Non-Standard Sites users contained the collected data.

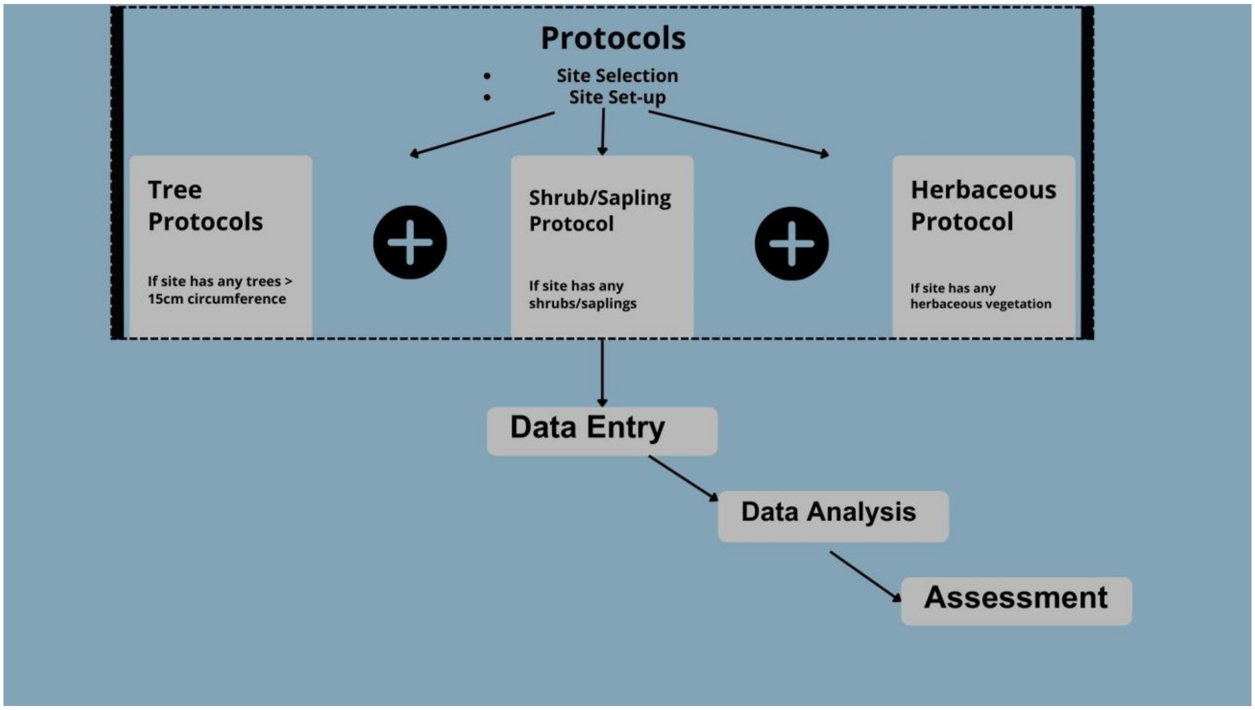
Figure11 Collecting tree data for tree protocols



Note: We attempted to record the height of the tallest tree at our research site using a simple method. We moved away from the tree and ensured that the reading angle was at 45 degrees from eye level to the top of the tree. Once we obtained this reading, we measured the distance from our standing point to the base of the tree and used trigonometry (Tangent) to determine the height of the tree.

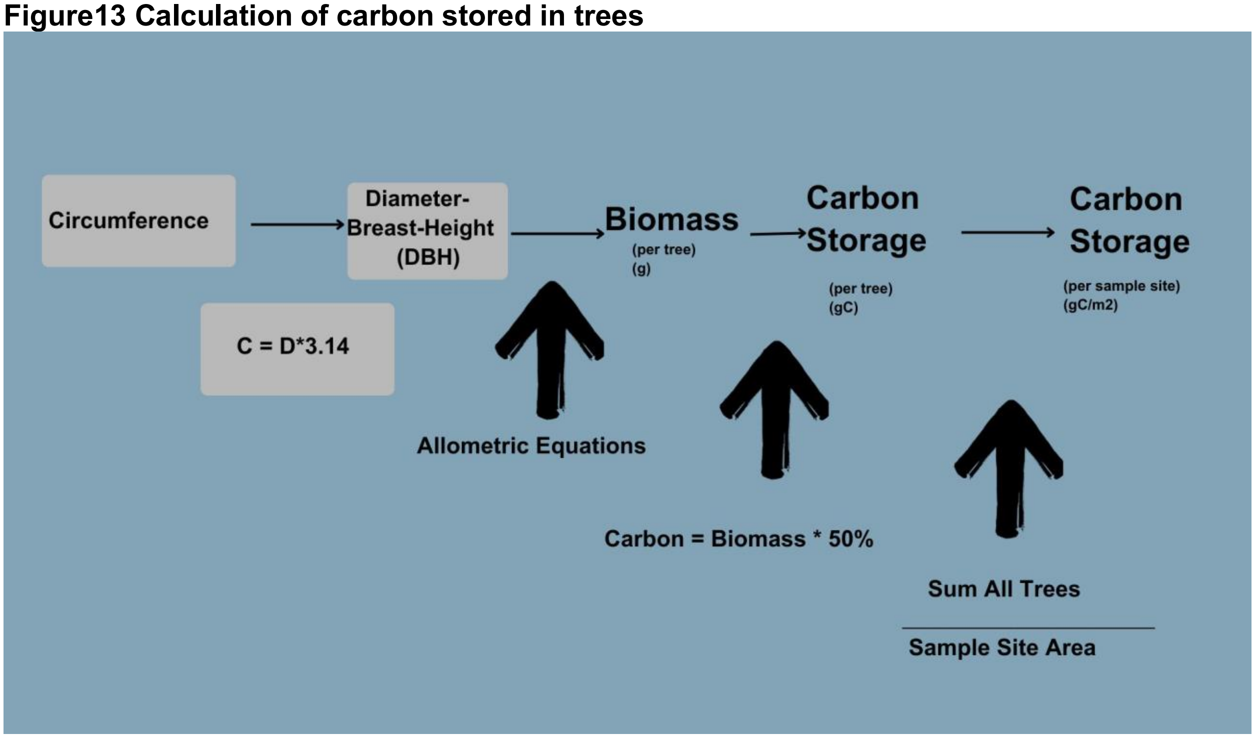
After gathering the circumference at breast height measurements of a total of 414 trees into the GLOBE database, aboveground carbon storage can be calculated as indicated below.

Figure12 Steps for carbon cycle measurement



Source GLOBE Program, 2022

Figure13 Calculation of carbon stored in trees

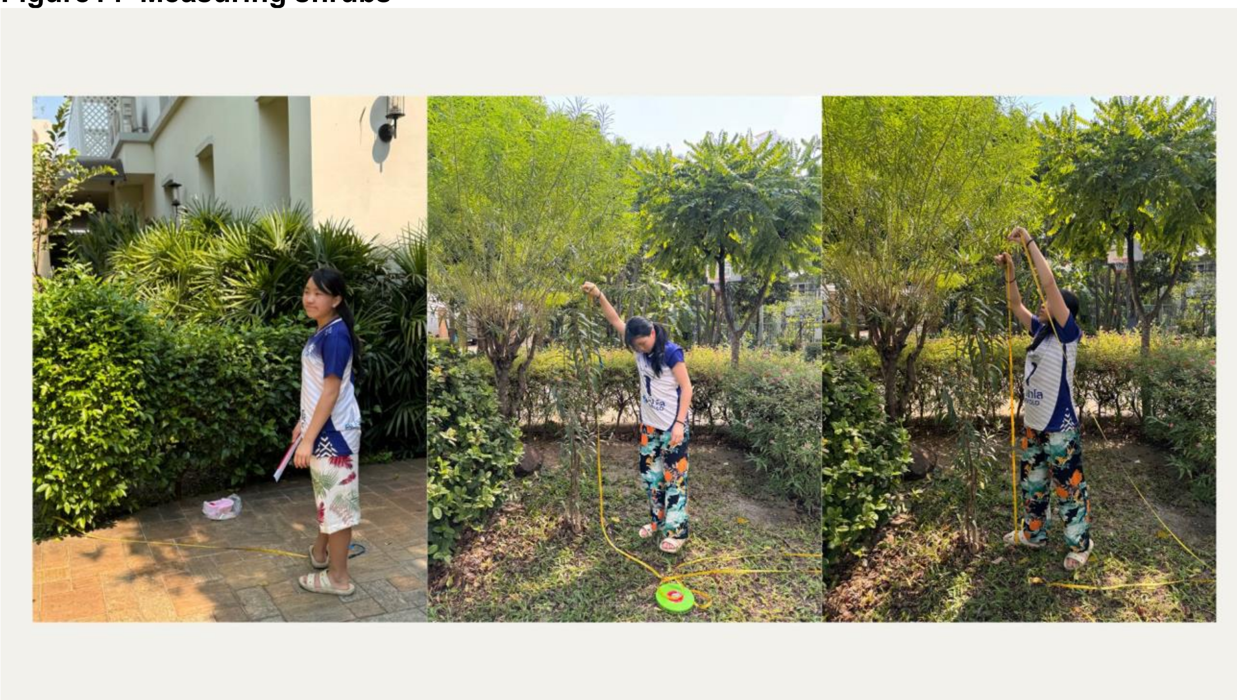


Source Globe Non-Standard Site Carbon Cycle Protocols

To estimate the biomass of large trees, we input the circumference values to find the diameter at breast height (DBH) as a variable in the allometric equation, which can be used to calculate the carbon storage in the trees. Since carbon storage is approximately 50% of the biomass, we can determine the total carbon sequestration in all the trees at our study site. (the Globe Program, 2022)

After having completed the tree protocols, we collected data for the non-standard shrub/sapling protocol to record the types of woody plants by measuring the length of the shrub's canopy by assessing the longest and shortest sides and the average height of the shrub with measurements in meters and identifying whether the plant is evergreen (E) or deciduous (D). The data is entered into the GLOBE database.

Figure14 Measuring shrubs



The surveyed region did not match the requirements for grass to be included in the GLOBE database because grassland made up less than 50% of the total area covered. However, using the Herbaceous Vegetation Measurements - Student Field Guide, we used a study design that incorporates herbaceous vegetation. In order to secure three sample sites, we closed our eyes and threw a beanbag once at each place during the data collection process. We then marked off a 1 x 1 m space around every beanbag. We used scissors to gather grass inside these specified zones. After that, the collected vegetation was put into separate brown paper bags that had coordinating labels on them. After that, the grass samples in these three bags were put somewhere dry. We began weighing the samples every day on the fifth day and kept track of the results. We found that if there was no change in weight for two days in a row, the grass sample was deemed totally dry. Six days were needed for the drying process. We were able to calculate the average biomass and estimate the amount of carbon stored in the area by recording the biomass data for the grass samples in the Graminoid Biomass Data Sheet.

Figure15 Data collection - Herbaceous

Soil Carbon Storage Approach
To estimate the soil carbon storage, we need to conduct soil characterization protocol, followed by star-pattern soil moisture protocol, depth profile soil moisture protocol, and soil bulk density protocol. Then, we find soil organic carbon (SOC) using the Walkley-Black method.

Soil Characterization protocol
Tool requirements for soil protocols: Soil color book, trowel, compass, meter stick, 15 quart-size sealable bags, 5 sampling PVC tubes, wood block, hammer, shovel and marker, auger, 2mm mesh sieve, rubber gloves, soil organic matter tool kits.

Preparation:
We selected our soil site to be away from any structure at least 5 meters and undertook soil characterization protocol, star-pattern soil moisture, and soil depth protocols at depths of 0-5 cm, 10 cm, 30 cm, 60 cm, and 90 cm and soil moisture gravimetric method. By measuring our site with a size of 2x2 meters. Using soil characterization protocol, we determine soil profile at the star-pattern soil moisture and soil depth protocols at predetermined depths. At the star-pattern soil moisture site, we selected spots #2, #3, and #10 for investigation. We raked grass covering the surface and dug vertically with a diameter of around 10 cm and marked our trowel with a marker to refer to our preferred depth while setting 0 cm at the surface of the profile.

Figure16 Our Star Pattern Soil Moisture

At each predetermined depth, we collected at least 100 grams of soil from each depth, removed all rocks, roots, and other debris using PVC pipes pushed into the side of the horizon. We then used a trowel to remove the pipe and the surrounding soil and placed it in a plastic bag with a detailed label indicating the location, weight, and soil characteristics. Our findings revealed that the soil at the surface, as well as at depths of 10 cm and 30 cm, was loamy and granular, resembling cookie crumbs. At depths of 60 cm and 90 cm, the soil was blocky and clayey. We weighed the soil samples in grams and recorded the measurements before drying them in a drying oven. When there was no change or less than a 0.1gram change in the soil weight, it was considered dried and ready for measuring soil organic matter.

We use a hard roller to gride dried soil sample and sieve it to get rid of unwanted components such as rocks, roots and transfer the rock-free, dry soil under the sieve to clean dry plastic bags, with label of date, site name, location, sample number, horizon number and top and bottom depth in cm. Now, we can measure sampling PVC pipe mass by weighing it and calculate its volume by using the formula:

Volume pipe = π * radius^2 * height

We weigh the roots or sticks that are left on top of the sieve and record this weight on the Bulk Density Data Entry Sheet. Not only that, we measure the volume of roots and sticks by adding them to the 50ml of water in a graduated cylinder. We read the level of the water and enter this value and the original volume of water on the Bulk Density Data Sheet. Here is the bulk density formula:

$$\text{Bulk Density (g/mL or g/cm}^3\text{)} = \frac{\text{Mass of dry soil (g)} - \text{Mass of rocks (g)}}{\text{Container volume (mL)} - \text{Volume of rocks (mL or cm}^3\text{)}}$$

Figure17 Soil Measurements

Soil organic carbon (SOC) is considered the largest terrestrial carbon pool, with organic matter often used as a proxy for estimating SOC. In other words, soil carbon storage refers to the carbon content that soil organic matter holds. We use chemical ingredients that can cause oxidation as a way to calculate. As a result, we apply the soil type method to estimate SOC stock, incorporating layer data to a 1-meter depth because most SOC mass in a soil column is concentrated at this depth (Chhara et al., 2003).

Our Soil Carbon Storage (SCS) estimate approach can be derived from 1) calculating the SOC density. SOC density represents the weight of organic carbon in the 1 cubic meter soil at the soil profile depth of 1.0 meter, while its density depends on soil genus. 2) using the Bemmelen factor to estimate the quantity of carbon in soil from the calculated SOC density and 3) multiplying the soil carbon density (SCD) by the area of each soil polygon. (Deng et al., 2010).

The equation of soil carbon density estimate is

$D_{SCDi} = p \times P_{SOCi} * B_f$

Where D_{SCDi} is the soil carbon density of the ith soil genera (kg.m -2); p is the average bulk density of soil (kg.m-3); P_{SOCi} is the percentage of organic matters of the ith soil genera (%); B_f is the Bemmelen factor (0.58).

Note that the Bemmelen factor derives from the fact that organic matter in soil contains around 58% carbon on average, or the factor 1.724 (e.g. 1/0.58) is commonly used to convert soil organic carbon (SOC) to soil organic matter (SOM).

Hence, we can estimate Soil Carbon Storage (SCS) as follows:

$M_{SCS} = \sum i \ D_{SCDi} \times A_i$

Where M_{SCS} is the amount of soil carbon storage and A_i is the area of the ith soil genera (square meter).

Note that soil bulk density is a measure of how dense and tightly packed a sample of soil is. We derive from measuring the mass of dry soil per unit of volume (g/mL or g/cm³). The structure of the soil peds, the tightness they are packed, the number of spaces or pores, and the composition of the soil particles determine the bulk density of soil. If the bulk density for a soil sample is less than 1.0, it has a very low density and may have a high organic matter content.

To find soil organic matter, we use the Walkley-Black method with the following steps:

1.We use 5 ml of potassium dichromate ($K_2Cr_2O_7$) to oxidize soil samples in a reacting bottle because it is a potent oxidizing agent that may convert organic carbon components in the soil, such as carbohydrates, proteins, and lipids, into carbon dioxide.
2.To speed up the oxidation process, we add 10 ml of sulfuric acid (H_2SO_4) as a catalyst. It makes it easier for the soil's organic materials to decompose into carbon dioxide. We wait for the reaction for fifteen minutes after introducing this catalyst.
3.To halt the oxidation reaction, we add 10 ml of distilled water to our sample and let it sit for half an hour. By ensuring that the final solution has a constant volume, the distilled water makes it possible to measure the amount of unreacted dichromate that remains precisely and dilute any excess chemicals.
4.Using a colorimetric reference chart, we compare the color of our 0.5 ml solution after dipping it into a tray. The percentage of soil organic matter would be provided by the outcome.

Figure18 A Colorimetric Reference Chart

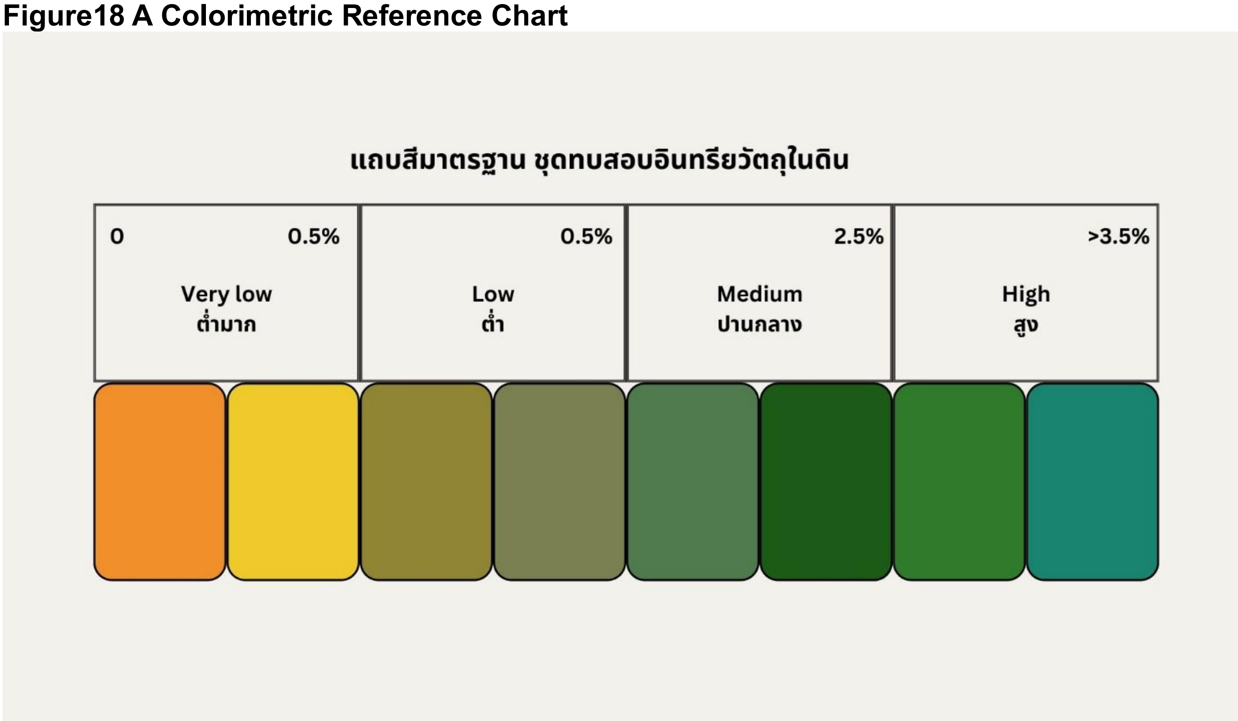
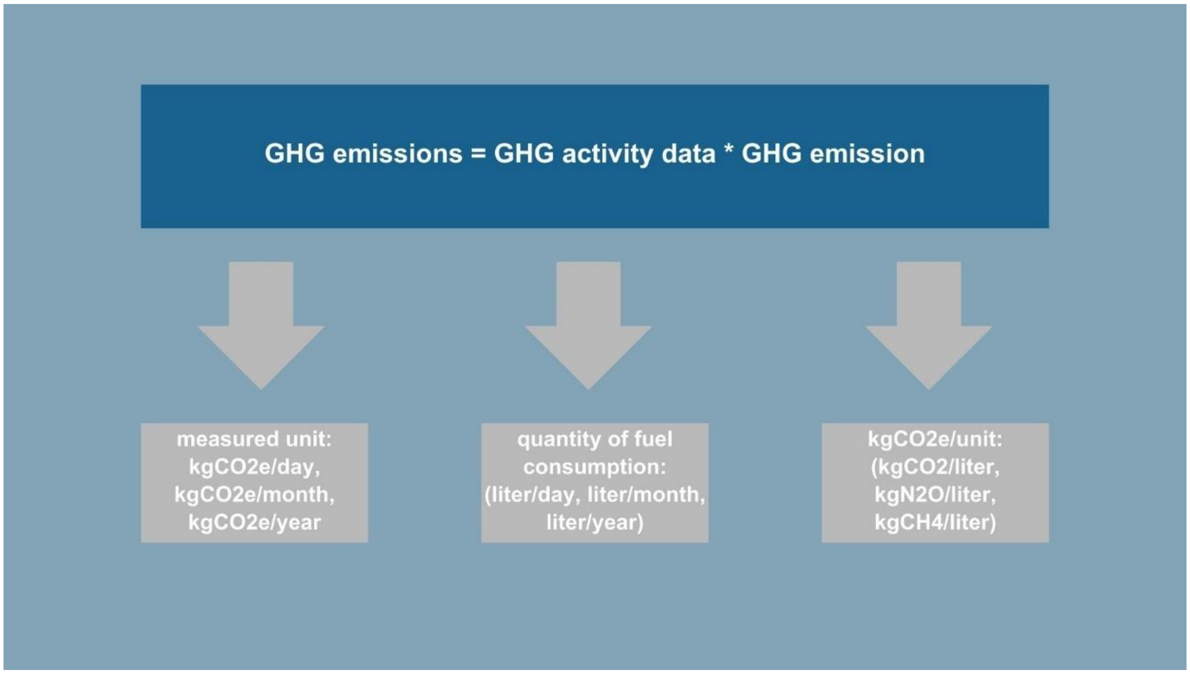


Figure19 Experiment with the Walkley-Black Method

Regarding carbon emissions, we gathered our activity data by classifying our sources of emissions, such as the amount of gasoline used in liters, the amount of energy used in kWh, and the distances traveled in kilometers (km). Tons of carbon dioxide equivalent (tons of CO_2e) are used to measure the amount of greenhouse gas emissions brought on by energy use. The activity data can be multiplied by emission factors to determine greenhouse gas emissions.

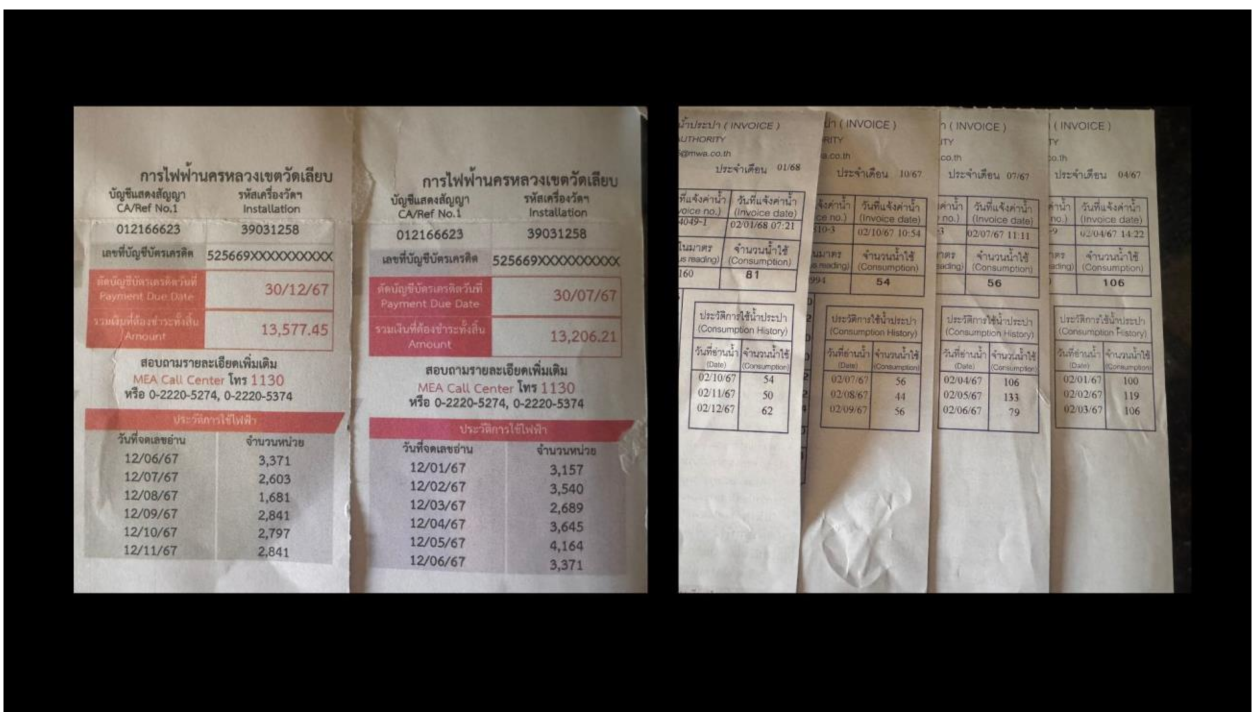
The data collection process for greenhouse gas emission activities involves two steps. The first step is to define the details of the gathered information to assess the quantity of greenhouse gas emissions. Define the specifics of the data collected in order to determine the amount of greenhouse gas emissions. Selecting the technique for gathering data is the second stage. Fuel receipts, power bills, and water bills are examples of the primary data we gather. We also use secondary data, such as surveys and statistical computations. For the evaluation and computation of greenhouse gas emissions, we collect and aggregate data over a one-year period. We use our most recent data to compare with previous data for comparison purposes.

Figure21 Calculating the quantity of greenhouse gas (GHG) emissions



Source ISO 14064-1:2006 Greenhouse gases – Part1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals

Figure22 Example of collecting data at the primary level - electricity and water bill



After collecting activity data for greenhouse gas emissions, the next step involves selecting greenhouse gas emission factors (EF). These factors convert activity data into greenhouse gas emission quantities, and we use the following:

Table23 Emission factors (EF) for greenhouse gas emissions, Types 1, 2, and 3.

Activity	Measured United	Scope of Work	GHG Emission (KgCO2e/unit)	Reference Source
Energy: Mobile Combustion		**Scope 1**		
Benzene	Liter		2.2376	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE
Electricity Usage		**Scope 2**		
Thailand Grid Mix Electricity	kilowatt - hour (kWh)		0.5813	Thailand Grid Mix Electricity LCI Database 2552 (2009)
Water Usage		**Scope 3**		
Thailand Metropolitan Water Authority	cubic meter (m3)		0.7948	Thailand Greenhouse Gas Management Organization
Air travel		**Scope 3**		
Domestic: Economy class	Passenger/ km		0.158	Defra, 2010
International short-haul flight: Economy class	Passenger/ km		0.0933	Defra, 2010
International long-haul flight: Economy class	Passenger/ km		0.0834	Defra, 2010
International short-haul flight: Business class	Passenger/ km		0.25	Defra, 2010
International long-haul flight: Business class	Passenger/ km		0.18	Defra, 2010

Source Citing data from the Emission Factor gathered from meteorological information for assessing the carbon footprint of the greenhouse gas management organization (private sector), updated as of April 30, 2013.

Table24 The method for calculating GHG emissions

Activities that are sources of GHG emissions	Method for calculating GHG emissions (kgCO2e)
Travel and transportation by vehicle type	Amount of fuel used in transportation (measured in fuel types) * GHGs emission factors by fuel type (KgCO2e/unit)
Usage of electricity imported from external sources (Energy Indirect Emission)	Electricity consumption (kWh) * GHGs emission factor (KgCO2e/kWh)
Usage of water (Other Indirect Emissions)	Water consumption (m3) * GHGs emission factor (KgCO2e/m3)
Air transportation (Other Indirect Emissions)	Number of passengers (passenger) * distance (km)* GHGs emission factor (KgCO2e/passenger-km)

Source ISO 14064-1:2006 Greenhouse gases – Part1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals

Results

After completing the study, we can utilize GLOBE's Non-standard Site Carbon Cycle Protocol to quantify the amount of carbon sequestered in the above-ground biomass of trees and shrubs/saplings at our research site and Pedosphere Protocols for appraising the carbon storage belowground. Our study team uses Microsoft Excel's Tree Biomass Analysis Template and Shrub/Sapling Biomass Analysis Non-Standard Template in conjunction with the Globe visualization system to examine the data. The following are the research's conclusions.

Table25 Summary of the carbon storage within the trees

	Unit	Oct-24	Jan-24
Plot aboveground biomass	g/plot	35,138,588	31,402,875
Plot aboveground carbon storage	**gC/plot**	**17,569,294**	**15,701,437**
Biomass	g/m2	3,622	3,237
Aboveground carbon storage	**gC/m2**	**1,811**	**1,618**

Table26 Summary of the carbon storage in the shrub/sapling in our site

	Unit	Oct-24	Jan-24
Deciduous Biomass	g/m2	1.7	1.4
Evergreen Biomass	g/m2	45.7	27.7
Total Biomass	**g/m2**	**47.4**	**29.1**
Carbon Storage - Shrub/sapling	**gC/m2**	**23.6**	**14.5**

Table27 Summary of the carbon storage in grass in our site

	Unit	Oct-24	Jan-24
Biomass: Grass in brown bag	g/m2	136	13
Brown bag	g	8	3
Net Biomass - Herbaceous	g/m2	31	10
Carbon Storage - Herbaceous	**gC/m2**	**15.5**	**5**

Figure28 The relationship between the circumference size of trees at breast height and aboveground biomass

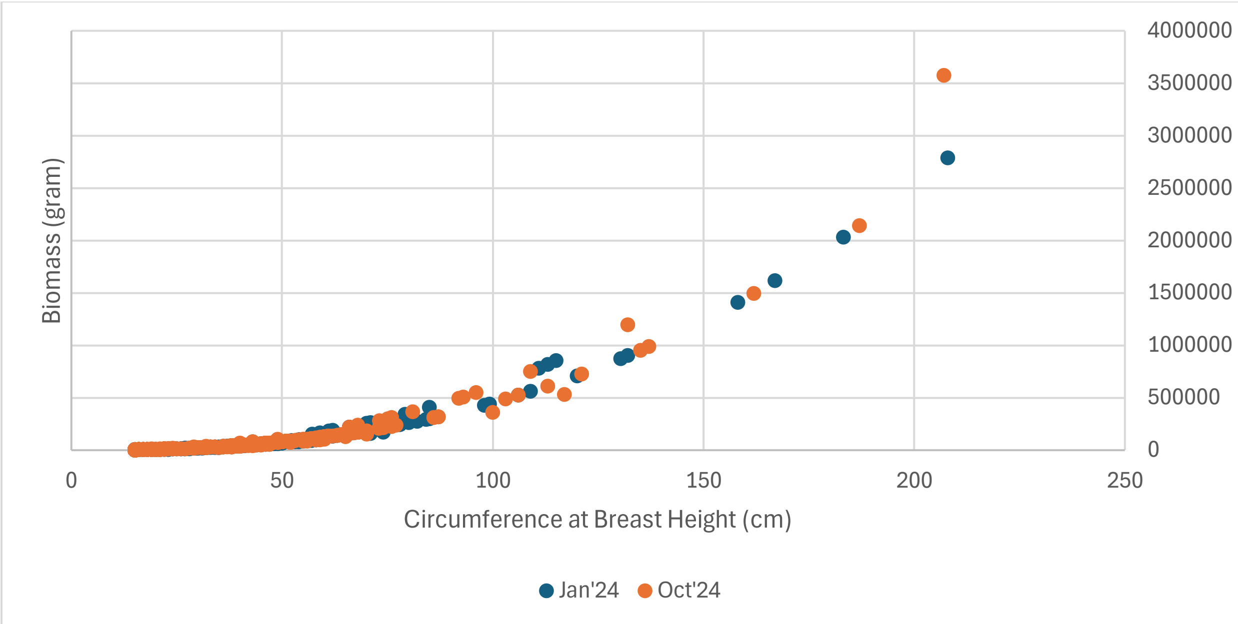


Figure29 The proportion of aboveground biomass in various parts of large trees

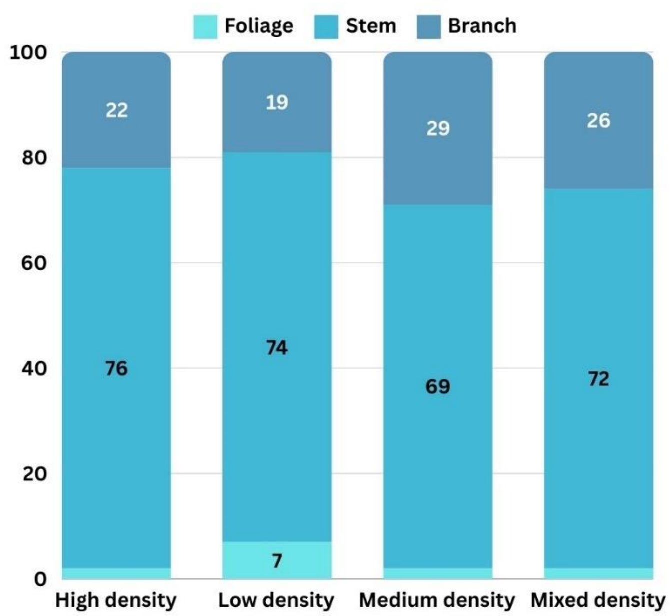


Figure30 The proportion of large trees in the area categorized by wood density

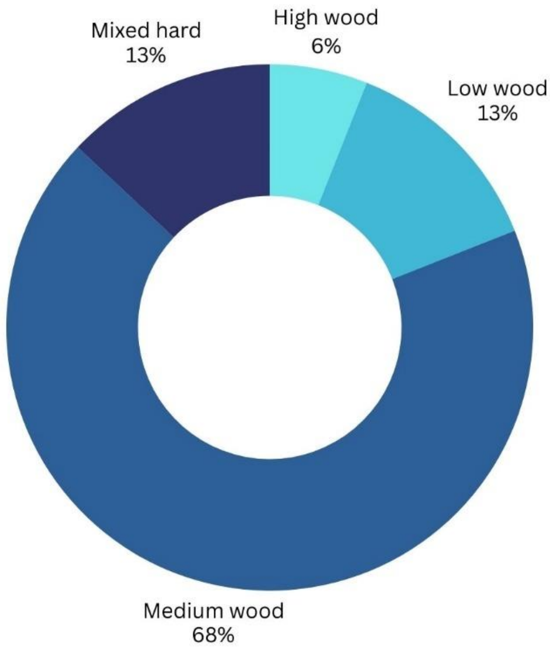


Figure31 Data analysis from the GLOBE Visualization System – Carbon Cycle

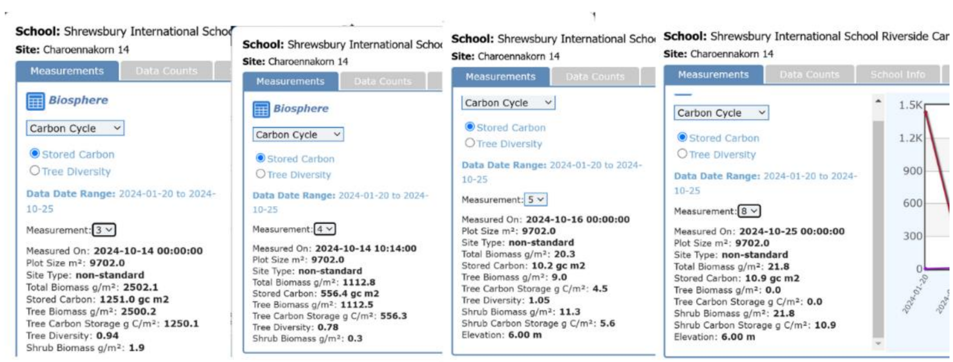


Figure32 Data analysis from the GLOBE Visualization System – Pedosphere

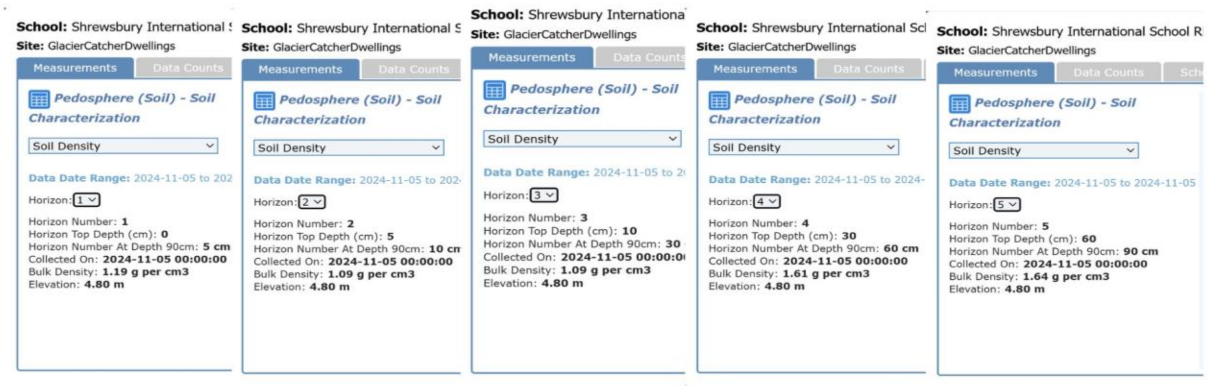
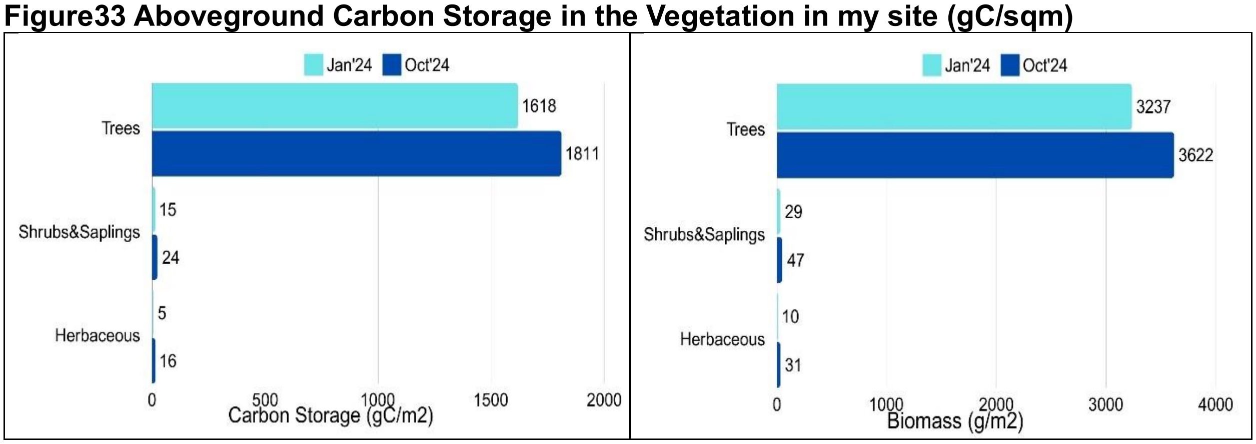


Figure33 Aboveground Carbon Storage in the Vegetation in my site (gC/sqm)



Calculating Net Primary Productivity (NPP)

Net Primary Production (NPP) measures the biomass produced by plants through photosynthesis, deducting the organic material that is used by plants in the process of respiration. It reflects the balance between the energy captured by photosynthesis and the energy lost through respiration. In our case, Net Primary Productivity (NPP) can indeed be calculated as the difference in biomass of trees over time.

NPP = Carbon Stored for Year2 – Carbon Stored for Year 1

Table34 Net Primary Productivity of the Site

	Oct’24	Jan'24	NPP
	gC/m2	gC/m2	gC/m2
Tree	1,811	1,618	193
Shrubs & Saplings	23.6	14.5	9
Herbaceous	15.5	5	11
Total - aboveground	**1834.5**	**1632.5**	**202**

Compared to our previous measurement in January 2024, net primary productivity (NPP) in carbon storage increased by 202 gC/m². The NPP shows an upward trend, reflecting the growing biomass of the vegetation across the site.

For belowground carbon storage, our findings show that the soil contains organic matter in very low (0-0.59%) and low (0.6-1.59%) ranges, as shown in the table. The average soil bulk density ranges from 1.10 to 1.64 g/cm³. Our total soil carbon storage ranges between 7,546 and 20,351 kg, contributing approximately 30-54% of the total carbon storage.

Table35 Soil Moisture – Depth Profile

	A	B	C	(A-B)/(B-C)		Pipe		
Depth	Mass of wet soil and container	Mass of dry soil and container	Mass of empty container	Soil Water Content	Mass of rocks	Container volume	**Volume of rocks**	**Bulk Density**
	(g)	(g)	(g)	(g/g)	(g)	(mL)	(mL or cm^3)	(g/mL or g/cm^3)
0-5cm	322.7	292	19.7	0.113	61.0	217.84	24.3	1.19
10 cm	341.7	276.3	19.7	0.255	76.7	217.84	38.7	1.10
30 cm	362	288.7	19.7	0.273	103.7	217.84	50.7	1.10
60 cm	359	339.7	19.7	0.060	56.7	217.84	36.7	1.61
90 cm	367.3	348	19.7	0.059	73.3	217.84	42.8	1.64

Table36 Estimation of Soil Carbon Storage

Depth	p = the average bulk density of soil	PSOCi = % of organic matters of the ith soil genera		Bf = the Bemmelen factor	Plantable areas	Soil Depth	Total Carbon Storage	Total Carbon Storage
	(g/mL or g/cm^3)	min	max		(cm)	(cm)	Min (kg)	Max (kg)
0-5cm	1.19	0	0.0059	0.58	17,373,000	5	-	354.44
10 cm	1.10	0.006	0.0159	0.58	17,373,000	5	331.09	877.39
30 cm	1.10	0.006	0.0159	0.58	17,373,000	20	1,324.92	3,511.05
60 cm	1.61	0.006	0.0159	0.58	17,373,000	30	2,924.14	7,748.96
90 cm	1.64	0.006	0.0159	0.58	17,373,000	30	2,965.77	7,859.28
Estimated Belowground Carbon Storage							**7,545.92**	**20,351.12**

On the aspect of carbon footprints, we delivered the details from calculations using the ISO14064-1 standard guidelines as follows:

Table37 Greenhouse gas emissions (CO2) – travel and transportation by vehicle type in the category of cars

Activities that are sources of GHG emissions - Travel and transportation by vehicles in the category of cars		
GHG Emissions Quantity (CO2) - Travel and Transportation by Vehicle Type (kgCO2)	=Quantity of gasoline used (liter/year) * Emission factor for GHG emissions from diesel use (combustion) (kgCO2/liter)	
Using Gasohol 95 (Fossil Fuel: Benzene 95%, Ethanol 5)	0.95	
EF - Travel and Transportation by Vehicle	2.2376	kgCO2/liter
Total Gasohol 95 used - 2024	3043.68	liter
GHG Emissions Quantity (CO2) - Travel and Transportation by Vehicle Type	6,470.01	kgCO2/year

Table38 Greenhouse gas emissions (CO2) – electricity use (Energy Indirect Emission)

Activities that are sources of GHG emissions - Imported electricity use (Energy Indirect Emission)		
GHG Emissions Quantity (CO2) - Electricity	= Quantity of electricity consumption (kWh) * GHG Emission Factor (KgCO2e/kWh)	
EF - Electricity consumption from external sources (Energy Indirect Emission)	0.5813	kgCO2e/kWh
Total Electricity Use - 2024	36,170	kWh/year
GHG Emissions Quantity (CO2) - Electricity - 2024	21,025.6	kgCO2e/year

Table39 Greenhouse gas emissions (CO2) – water (Other Indirect Emissions)

Activities that are sources of GHG emissions - Water use (Other Indirect Emissions)		
GHG Emissions Quantity (CO2) - Water	= Quantity of water consumption (cubic meter) * GHG Emission Factor (KgCO2e/kWh)	
EF - Water consumption	0.7948	kgCO2e/m3
Total Water Usage - 2024	961	m3
GHG Emissions Quantity (CO2) - Water - 2024	763.8	kgCO2e/year

Table40 Greenhouse gas emissions (CO2) – air travel (Other Indirect Emissions)

Activities that are sources of GHG emissions - Air travel (Other Indirect Emissions)		
GHG Emissions Quantity (CO2) - Air travel	= no. of passengers (passenger) * distance (km)* GHG Emission Factor (KgCO2e/passenger-km)	
EF - Domestic: Economy class	0.158	
EF - International short-haul flight: Economy class	0.0933	
EF - International long-haul flight: Economy class	0.0834	
EF - International short-haul flight: Business class	0.25	
EF - International long-haul flight: Business class	0.18	
Air travel 2024 - Details.		
Air travel activity of researcher #1:	**Distance traveled (km)**	**Classified as**
Bangkok - Sapporo (Business Class)	5070	Long-haul
Sapporo - Bangkok (Business Class)	5070	Long-haul
Bangkok - Taipei (Business Class)	2488	Short-haul
Taipei- San Francisco (Business Class)	10384	Long-haul
San Francisco - Taipei (Business Class)	10384	Long-haul
Taipei - Bangkok (Business Class)	2488	Short-haul
Bangkok - Trang (Economy Class)	445	Short-haul
Trang - Bangkok (Economy Class)	445	Short-haul
Bangkok - Chaing Mai (Economy Class)	573	Short-haul
Chaing Mai - Bangkok (Economy Class)	573	Short-haul
Air travel activity of researcher #2:	**Distance traveled (km)**	**Classified as**
Bangkok - Taipei (Business Class)	2488	Short-haul
Taipei- San Francisco (Business Class)	10384	Long-haul
San Francisco - Taipei (Business Class)	10384	Long-haul
Taipei - Bangkok (Business Class)	2488	Short-haul
Bangkok - Trang (Economy Class)	445	Short-haul
Trang - Bangkok (Economy Class)	445	Short-haul

Bangkok - Beijing (Economy Class)	3309.45	Short-haul
Beijing - Bangkok (Economy Class)	3309.45	Short-haul
Total traveled distance	71172.9	
GHG Emissions Quantity (CO2) - Air travel -2024	13,298	kgCO2e/year

Table41 Summary of carbon dioxide emission by researchers

Activities	2024	2023
CO2 - Transportation by car	6,470	7,321
CO2 - Electricity (Energy Indirect Emission)	21,026	20,112
CO2 - Water (Other Indirect Emission)	764	924
CO2 - Air travel (Other Indirect Emission)	13,298	2,601
Total Carbon Dioxide Emission (kgCO2/yr)	**41,557**	**30,959**

Figure42 Carbon dioxide (CO2) emissions proportion by activity type

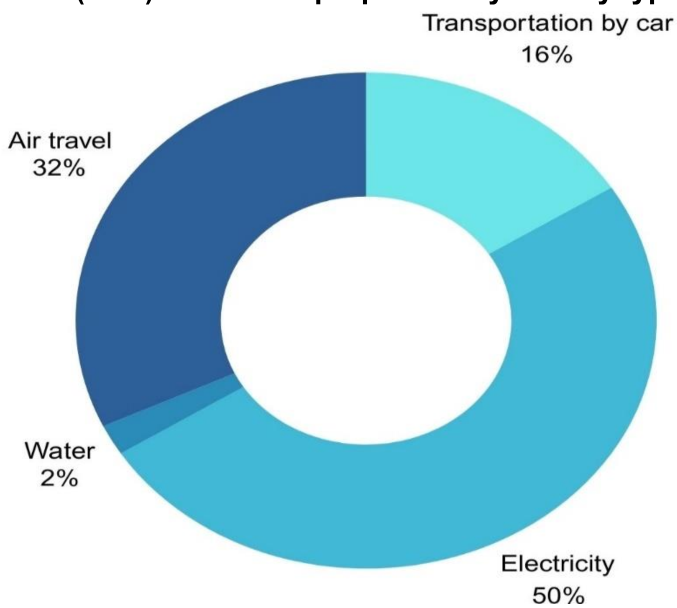
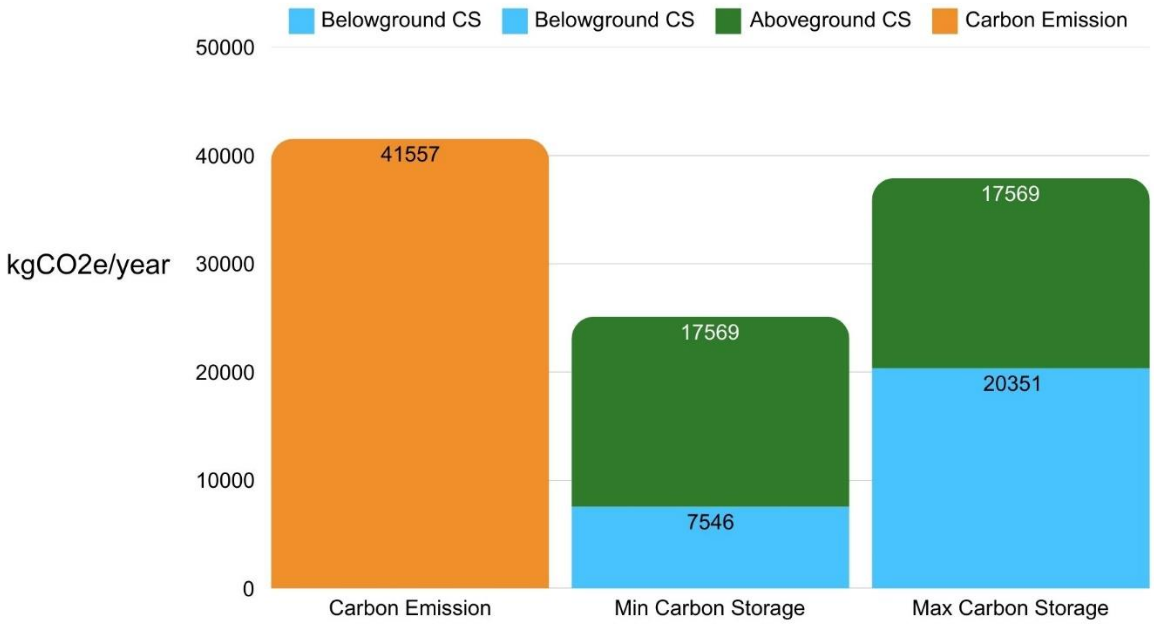


Figure43 The amount of carbon dioxide emissions compared to the amount of carbon sequestration in vegetation



Discussion

1. Our findings show that large trees have the most biomass, resulting in the greatest carbon storage capacity. Moreover, carbon storage depends on the density of vegetation. With plant knowledge and good selection, carbon storage capabilities can be maximized.
2. There is a positive correlation between a tree's age and girth size, indicating that older trees store more carbon because of their thicker trunks and greater height. Besides, our study showed that tree trunks store the most carbon above ground, followed by branches and leaves. It underscores how important it is to protect older trees in order to optimize their capacity to store carbon.
3. Carbon sequestration occurred the most in large trees (1,811 gC/sq.m.), preceding shrubs and saplings (23.6 gC/sq.m.) and herbaceous (15.5 gC/sq.m). These findings emphasize the need for effective plant management strategies that focus on both density and size to optimize carbon storage.
4. Total aboveground carbon sequestration was estimated at 17.6 * 10^6 gC (equivalent to 17,569 kilograms), aligning with previous studies in similar ecosystems and further validating the findings of carbon storage capacity in urban green spaces.
5. Net Primary Productivity (NPP) is positively correlated with both biomass and carbon storage capacity. It gives us a better understanding of how biomass growth translates into carbon storage over time.
6. Including both aboveground and belowground storage, the total combined carbon storage ranged from 25,115 to 37,920 kilograms, of which 30-54% is attributable to soil carbon storage. This highlights the important role of soil in total carbon storage. However, this amount is insufficient to offset the household’s carbon footprint, indicating a critical need for further reductions in emissions alongside enhanced carbon sequestration efforts.
7. Using ISO 14064-1:2006 standards and IPCC equations, the carbon footprint for 2024 was estimated at 41,557 kgCO2e/year, rising 34% from the previous measurement. This increase is primarily due to the carbon footprint associated with air travel.

8. Electricity consumption contributes the highest proportion (50%) to the carbon footprint, followed by air travel (32%), travel and transportation (16%), and water usage (2%). These findings emphasize the need to reduce energy consumption and travel-related emissions in order to mitigate the household's carbon footprint in addition to increasing carbon sequestration through plant growing and soil management.

Conclusions

This study provides a comprehensive view of carbon fluxes, both above ground in the form of carbon storage in trees, shrubs, saplings, and herbaceous plants, and below ground in the form of soil organic matter. It indicates that plant biomass has a strong relationship with its carbon sequestration potential, and that soil organic matter and soil bulk density are indicators of soil carbon storage. Additionally, biomass and carbon storage have a positive correlation with Net Primary Productivity (NPP). The higher NPP implies larger carbon sequestration over time.

Comparing the carbon storage potential of trees in different locations, the study finds that the trees at Darawittayalai School have the potential to store approximately 418,706.45 kilograms of carbon, averaging 5,300 kilograms per rai (1,600 m^2). The presence of native rain trees (Albizia sama) is a key contributor to a large pool of carbon storage, higher than carbon storage in deciduous forest trees. Similarly, carbon storage at Pelrithang Higher Secondary School in Bhutan has been calculated at 4,629.7 gC/m^2, which is around 2.5 times higher than the carbon storage of trees in this study. The older, organically grown trees in these locations (Darawittayalai School, founded 145 years ago, and Pelrithang, founded in 1981) are significantly older than the 16-year-old trees planted on our property, which likely affects the carbon sequestration capacity of our site.

The findings of Priyada Saratthana and Thanyarat Sapson (2023) suggest that resin trees, capable of sequestering 925.32 kilograms of carbon annually, could be valuable for enhancing carbon storage. These trees thrive in areas with high soil moisture and organic matter content, which support their growth. Given their deep roots and efficient nutrient extraction, resin trees are excellent candidates for improving carbon sequestration potential on our property. We plan to improve the soil conditions, mainly through fertilization, and introduce resin trees to enhance carbon storage on our property.

Our study also provides insight into the tree composition of the study area. In the study area, 68% of the trees were medium-density species like mango, foxtail palm, and pagoda trees, with an average age of at least 15 years. Additionally, 13% of the trees were low-density species, such as bananas, and another 13% were mixed-density species like Bayur trees, while 6% were high-density species like Asian bulletwood and Burmese ebony.

Although aboveground carbon storage plays a significant role in the study area due to the dense canopy and high biomass, belowground carbon storage cannot be overlooked. The soil in the research area has low organic content. Soil improvement, such as adding organic fertilizer at a minimum of 1 ton per rai, can enhance its carbon sequestration potential. Belowground carbon storage plays an important role in long-term carbon sequestration, even though the carbon storage in the research area is more significant in vegetation.

However, this combined storage is still insufficient to offset our household's carbon footprint, highlighting the need for integrated emission reduction strategies. We believe renewable energy sources, such as solar power, are essential for reducing our carbon footprint. Additionally, selecting airlines that use green fuels or offsetting carbon emissions will significantly reduce our air transportation footprint.

Owing to a lack of soil data, we can only compare aboveground carbon storage over time in this research. In our future research, we can improve the overall understanding of carbon movements as there will be soil information as a baseline for comparison.

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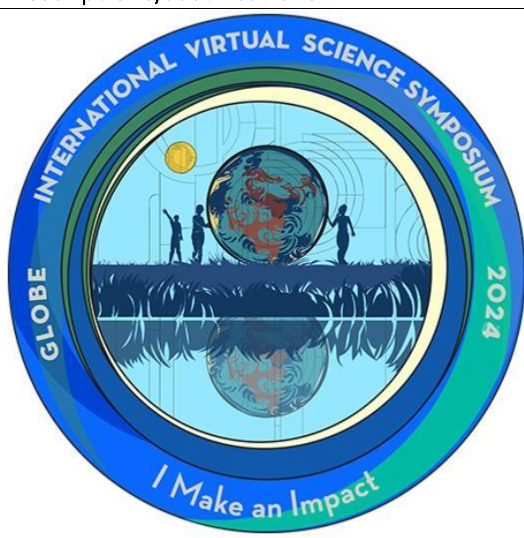
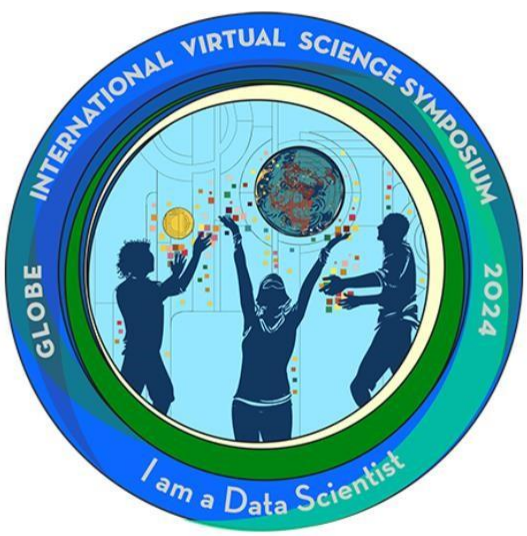
(Optional) Badge Descriptions/Justifications:

Badge Descriptions/Justifications:

	I MAKE AN IMPACT We can identify discrepancies between our carbon footprint and the carbon storage capacity of the vegetation and soil. We will take these opportunities to reduce emissions, enhance carbon sequestration, and change our way of living towards a low-carbon society.

	**I AM AN EARTH SYSTEM SCIENTIST** Our research effectively explores the interconnectedness of Earth's systems by investigating carbon sequestration, influxes, and flows through plant biomass using the biosphere protocol and soil organic matter through the pedosphere protocol.
	**I AM A DATA SCIENTIST** We conducted a comprehensive analysis, utilizing data from various sources, including the GLOBE Carbon Cycle, Biometry, and Pedosphere Protocols, while adhering to ISO 14064-1:2006 guidelines for calculating carbon footprints. This multidisciplinary approach enabled us to draw meaningful inferences about carbon storage both above and below ground at our site. By integrating diverse datasets and following industry standards, we demonstrated our proficiency as data scientists, emphasizing practical applications such as making recommendations for reducing the carbon footprint in line with our findings.

I AM A PROBLEM SOLVER

We are proposing an engineering solution to address a real-world problem by implementing renewable energy technologies, such as electric vehicles (EVs) and solar rooftop systems, to reduce our reliance on fossil fuels and decrease carbon footprints. Additionally, we plan to enhance carbon storage by planting high wood density vegetation and using organic fertilizers to improve soil quality on our site. To further reduce our environmental impact, we will prioritize traveling with green airlines that use sustainable aviation fuel (SAF) or offset their carbon emissions, further contributing to a reduction in our overall carbon footprint.