Green Secrets Unveiled: Probing Carbon Storage and Assessing Footprint in Living Spaces

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Abstract**:**

The increasing global temperature is a consequence of human-induced disruption to the balance of carbon dioxide in the world. The objective of this research is to assess and compare the aboveground carbon storage of plant species in the research area, utilizing the Non-Standard Site Carbon Cycle Protocol for measuring carbon dynamics. The measurements include 1) the circumference at breast height (CBH) for tree trunks and 2) the height of shrubs/saplings as independent variables in allometric equations, calculating biomass to determine aboveground carbon storage and 3) weighing herbaceous components. The results are then compared with the carbon footprint data using 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.

The research revealed that the plant density affects aboveground carbon storage capability. Total plant groups had a combined biomass of 3,275.8 g/m2 and an aboveground carbon storage capacity of 1,637.9gC/m2, equivalent to 15,701 kilograms of carbon stored in the research area. Meanwhile, the carbon footprint amounted to 30,802 kilograms of CO2e, highlighting the need for measures to reduce the carbon footprint, mitigate the impact, and work towards the goal of a low-carbon society.

Research Question and Hypothesis:

Research Questions:
How much carbon is stored in the vegetation at our home site?

How much carbon footprint do we produce?

Hypothesis:
We believe that large tree species should store the most carbon, followed by shrubs/saplings, and the lowest would be the group of herbaceous.

We propose that there is a positive relationship between the age of trees, their height, and diameter at breast height (DBH), indicating that older trees typically exhibit greater height and diameter.

We believe that there is a positive correlation between a tree's carbon storage capability and its biomass. This suggests that trees with greater biomass are likely to have a higher capacity for storing carbon.

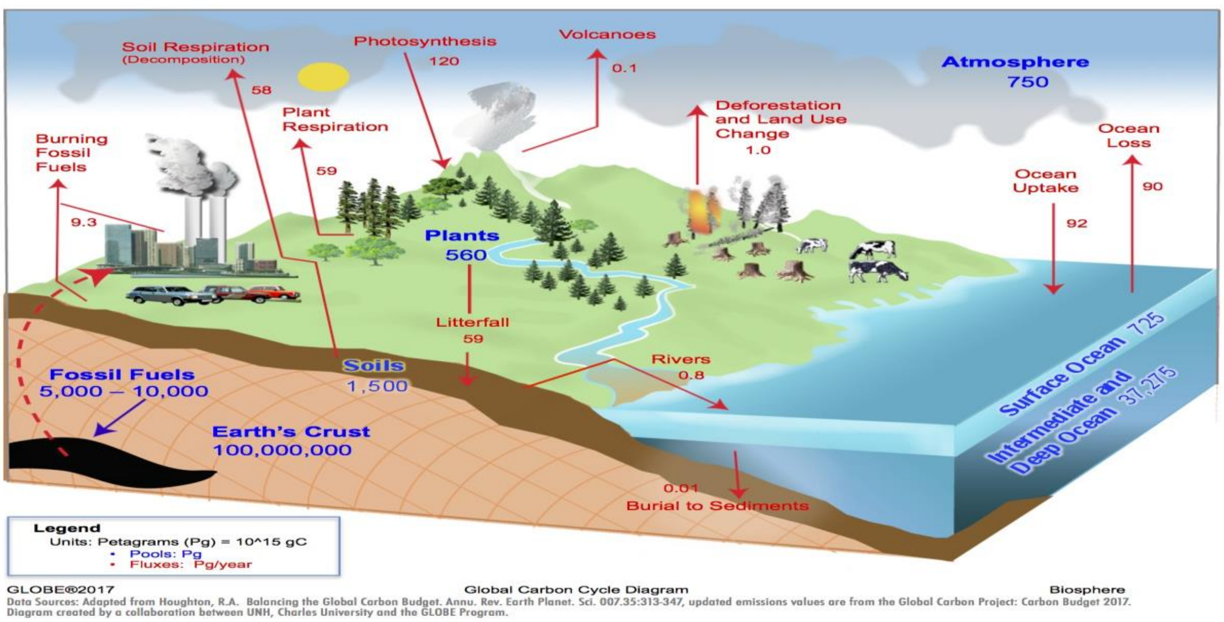
We hypothesize that our carbon footprint will significantly exceed the vegetation's capacity to store carbon and electricity is the main carbon footprint culprit.

Introduction and Review of Literature:

One of the most prevalent elements in our surroundings is carbon. When comparing carbon dioxide to other carbon oxides, it stands out as one of the most significant greenhouse gases. This is attributed to its crucial role as an expansion agent during photosynthesis in plants, facilitating mineral and gas circulation in the soil. Its presence is advantageous to all living things on Earth. However, despite its necessity for life, an excess of carbon dioxide can be detrimental to the ecosystem and the planet's climate.

If we compare the quantity of carbon dioxide in the atmosphere to water in a bathtub, burning fossil fuels can be likened to opening the faucet and letting water flow into the tub. Oceans and terrestrial ecosystems, such as forests, wetlands, and grasslands, which are known as carbon sinks, play a crucial role in storing and removing carbon dioxide from the atmosphere. Corinne Le Quere, Director of the Tyndall Centre in the United Kingdom, who conducts research on climate change and chairs the Global Carbon Project, emphasized, “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”. (Kenward, 2011)

Figure1 Global carbon cycle diagram

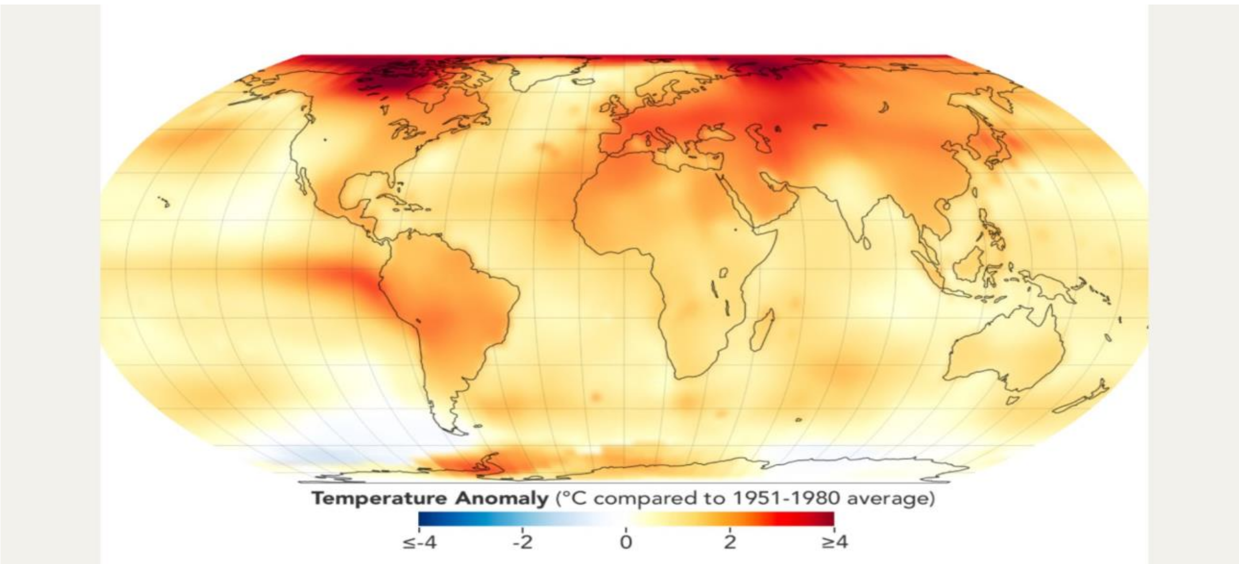


Source Globe.gov

Researchers are uncertain about the long-term viability of carbon sinks in completely eliminating the carbon generated by humans from the system, even though both the seas and forests contribute to absorbing more than half of the greenhouse gas (GHG) emissions caused by humans. Additionally, a significant amount of greenhouse gases remains present in the atmosphere, raising concerns about the feasibility and duration of ongoing carbon removal. NASA announced that 2023 was the hottest year on record, according to an analysis of annual global average temperatures by the Goddard Institute for Space Studies. The long-term rise in greenhouse gases is the primary driver. For more than 100 years, humans have been burning fossil fuels such as coal, gas, and oil to power everything from lightbulbs and cars to factories and cities. These actions, along with changes in land use, have led to a rise in greenhouse gases in the atmosphere.

Greenhouse gases act like a blanket trapping heat around the planet. The more of them you add, the thicker that blanket becomes, further heating Earth. In May 2023, carbon dioxide concentrations in the atmosphere peaked at 424 parts per million at NOAA's Mauna Loa Observatory, Hawaii. 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)

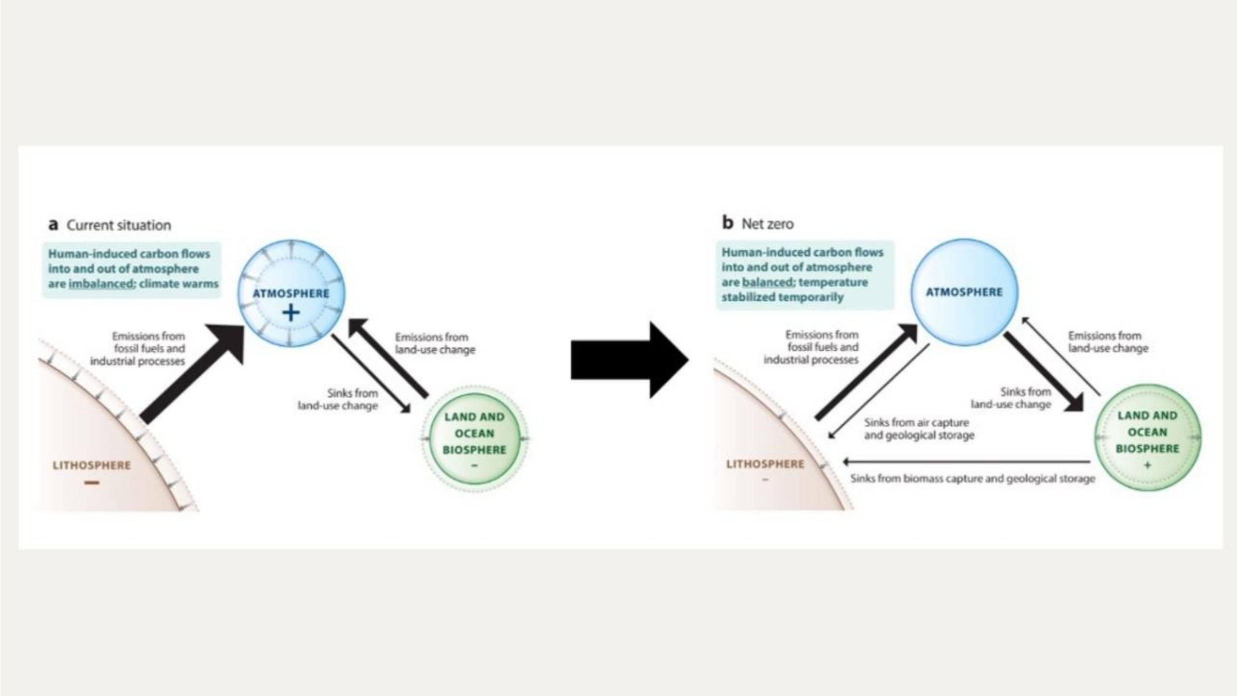
Figure2 Temperature anomaly (degree Celsius compared to 1951-1980 average)



Source gsfc.nasa.gov

Greenhouse gases (GHGs) are produced through the burning of bioenergy, chemical processes, land use, livestock farming, and the use of fertilizers and animal manure. Essentially, every dimension of life is connected to greenhouse gas emissions. These gases constitute a group in the atmosphere capable of trapping, absorbing, and re-emitting the infrared radiation transmitted from the sun's surface to the Earth. They release this energy in the form of heat. Greenhouse gases include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), fluorinated gases, water vapor, and ground-level ozone. We should be aware and expedite solutions before the global warming situation exceeds our capacity for mitigation. This aligns with the Paris Agreement, addressing climate change by limiting the average global temperature increase to no more than 1.5 degrees Celsius and setting a target for achieving net-zero greenhouse gas emissions by the year 2050. (Myles R. Allen, et al., 2022)

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

To prevent this, we need to concentrate on how we can keep moderate levels of carbon dioxide in the Earth's atmosphere. One solution we can adopt is to balance/maintain our carbon footprint.

Nitcha Thachuen and colleagues (2022) assert that the trees within Darawittayalai School have the ability to store approximately 418,706.45 kilograms of carbon, averaging 5,300 kilograms per 1 rai (or 1,600sq.m.). This surpasses the carbon storage in trees in the deciduous forest, attributed to the presence of Rain tree (Albzia saman (Jacq.) Merr.) at Darawittayalai School. These native forest trees are retained and possess high carbon sequestration potential. Fast-growing trees can sequester carbon in large quantities over the same planting period compared to other tree species. The carbon sequestration of a tree depends more on the biomass of that tree than the carbon density within the biomass. In other words, a tree with high biomass can sequester carbon in large quantities, resulting in a high value for the amount of carbon sequestered in trees at Darawittayalai School. Additionally, Darawittayalai School benefits from dedicated landscape specialists and agricultural knowledge, enabling the systematic selection of plant species and soil maintenance.

Priyada Saratthana and Thanyarat Sapson (2023) specify that the growth of prominent tree species in schools varies significantly in terms of average increase and statistical significance. Among the tree species, the Resin tree and the Indian Oak tree have the highest average circumference increase, with the Resin tree exhibiting the highest carbon sequestration. This is attributed to the presence of high soil moisture and organic matter content in the area where rubber trees are found. However, the nutrient content in the soil (NPK) is significantly low, as rubber trees, with their deep root system, can efficiently absorb nutrients from the soil for growth. This results in the Resin tree showing the best growth and the highest carbon sequestration when compared to other prominent tree species in the school. One Resin tree can sequester 925.32 kilograms of carbon per year. Therefore, it is recommended for schools nationwide to consider planting Resin trees to increase green areas and contribute to natural carbon sequestration.

Sangay Choden and Yeshey (2023) state that the carbon sequestration within Pelrithang Higher Secondary School, Sarpang, Bhutan, varies with the number of plant species in the area. Moreover, large trees have the highest biomass, making them the group that sequesters the most carbon in the school area. Calculations estimate that the biomass of plant species in the area is approximately 3,756 gC/m2, considering the school's total area of 133,547.3 square meters. This indicates that the carbon sequestration in the plant species in the area is approximately 5.02*10^8 gC.

The exchange of carbon between soil, water, and living things on Earth is known as the carbon cycle. One of the basic elements, carbon makes up around half of the organic tissues in living things. Through the process of photosynthesis, which occurs in plants, carbon dioxide (CO_2) is transferred from the atmosphere into living things. Carbon dioxide is transformed into organic molecules, which are stored forms of energy, during this process. In contrast, by consuming organic matter that contains stored carbon, consumers in ecosystems release this gas back into the atmosphere. One major cause of climate change is the rise in carbon dioxide emissions. Finding ways to reduce global warming will require an understanding of the potential for carbon sequestration in various natural systems.

Through the processes of photosynthesis and respiration in plants and animals, the biosphere affects the atmospheric concentration of carbon dioxide. Plant development is influenced by and contributes to the overall carbon balance when there is an equilibrium between the carbon dioxide released during respiration and the carbon dioxide taken up during photosynthesis. This is the ratio of carbon dioxide stored in living things to that which is available for free in the atmosphere.

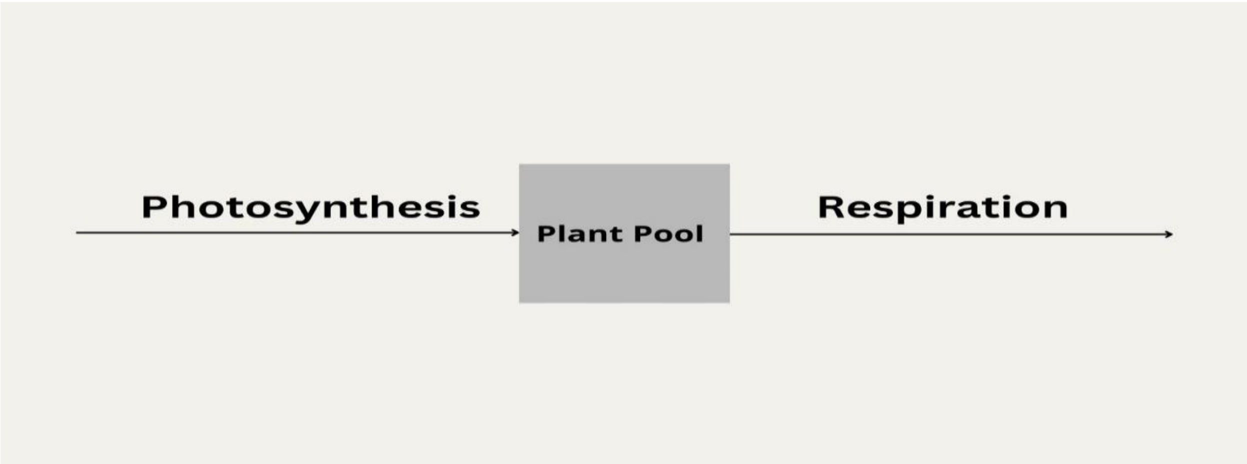
Plants will take up more carbon from the atmosphere if their rate of photosynthesis exceeds that of animal and plant respiration, as determined by the environmental system. According to a recent study that was published in the Proceedings of the National Academy of Sciences, plants often consume more carbon for growth when the weather is warmer. They use the process of photosynthesis in their leaves and branches to take up carbon dioxide from the atmosphere. (Dunning, 2018)

According to an international study conducted by the United States Forest Service, forests worldwide play a crucial role in absorbing carbon dioxide, approximately around 2.4 billion tons per year. This constitutes roughly one-third of the global greenhouse gas emissions resulting from the combustion of fossil fuels. Additionally, the National Aeronautics and Space Administration (NASA) states that "Oceans act as a sink, absorbing approximately 30% of carbon emissions generated by human activities. However, the warming climate may limit the oceans' capacity to absorb carbon further.”

To better understand how terrestrial ecosystems react to rising temperatures and concentrations of carbon dioxide (CO2), scientists gather data on the carbon cycle. This improves our understanding of the connection between soil surface temperatures and plant carbon sequestration. The carbon cycle is a very intricate system that is thought of as a model that focuses on examining important elements in order to help explain why the climate is changing and how it might change in the future.

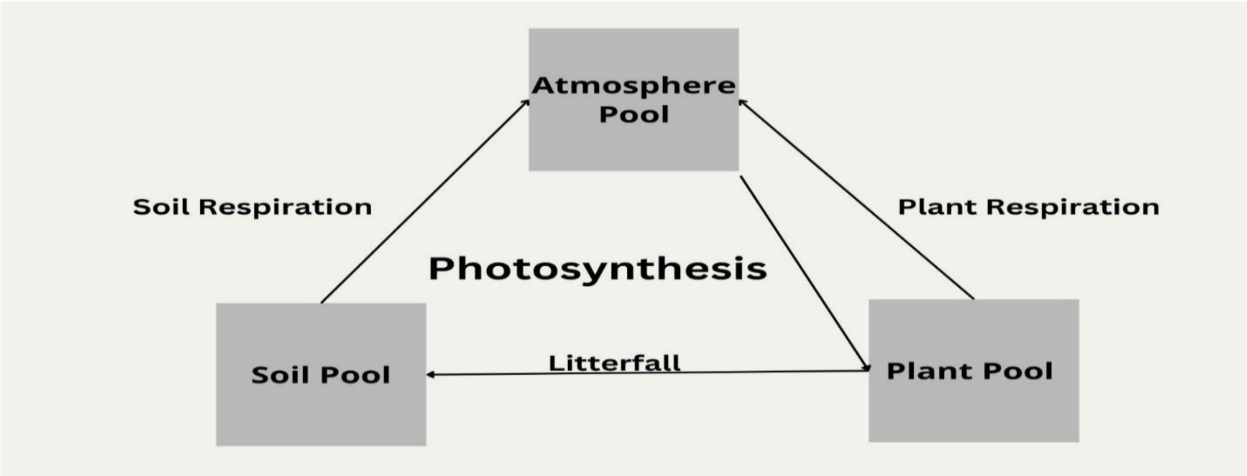
The idea makes use of a system called the "1-box model," in which every box is a carbon pool and arrows show the flux (or movement) of carbon. This method enables the simulation of carbon movements through the complex carbon cycle of the Earth. It explains ideas like input, output, and residence time and shows how these components might result in particular patterns of change over time. The global carbon cycle is depicted in the image below, showing how carbon moves between the soil, the atmosphere, and carbon reserves like trees. (Globe Program, 2022)

Figure4 A 1-box model



Source Biosphere Carbon Cycle Introduction

Figure5 A "1-Box models" carbon cycle



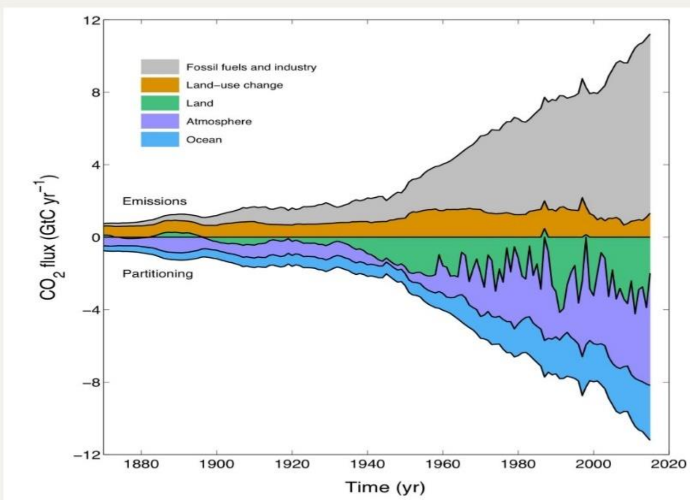
Source Biosphere Carbon Cycle Introduction

Carbon is the fundamental building block of living organisms, constituting approximately 45-50% of the total biomass. However, the carbon cycle is no longer in balance due to human activities, particularly those resulting from the burning of fossil fuels and changes in land use, including deforestation for agriculture, farming, and livestock. These activities have significantly increased the concentration of carbon dioxide (CO2) in the atmosphere, surpassing levels observed over the past 800,000 years by approximately 40%.

The carbon contained in fossil fuels is primarily responsible for the notable rise in greenhouse gas emissions. Burning these fuels, like fossil phosphates, releases carbon dioxide gas when the stored carbon reacts with oxygen. In a similar vein, when forests are destroyed and land use is changed, carbon contained in trees is released. Normally, natural sinks like rivers, marshes, forests, and seas absorb and store carbon dioxide, keeping the atmosphere's carbon dioxide equilibrium.

The rate at which greenhouse gases are being emitted to the atmosphere, however, has surpassed the ability of natural sinks to take up and store them recently. There is proof that the abrupt increase in temperature and the disruption of the natural environment.

Figure6 Combined components of the global carbon budget



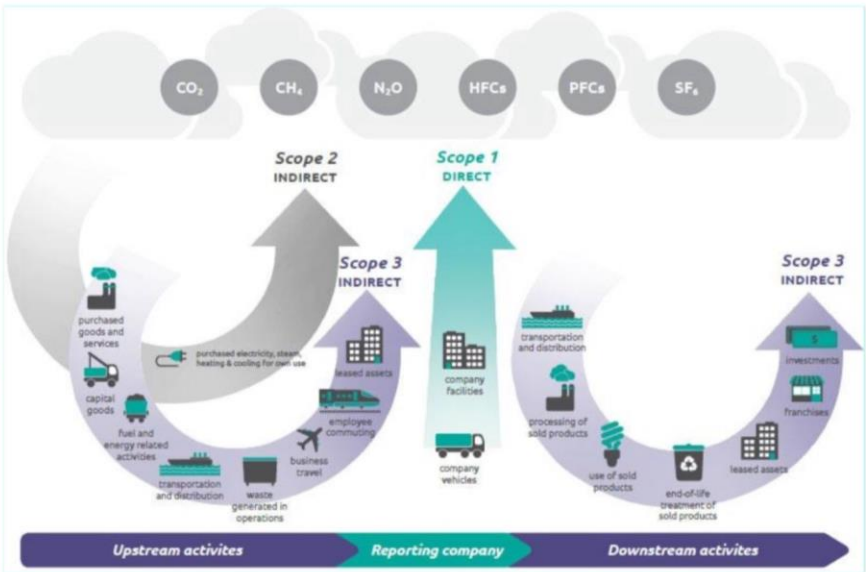
Source: Earth System Science Data, 8, 605-649,2016

Solutions to climate change must be understood in light of how ecosystems store and cycle carbon (The GLOBE Program, 2022). As a result, to estimate the amount of vegetation on my site for this research, we employ the Carbon Cycle Protocol under Biosphere, with a focus on carbon storage.

We utilize the Non-Standard Site Carbon Cycle Protocol of GLOBE to measure the carbon cycle in our area. Summarizing the total carbon quantity stored in plants into three groups: large trees, shrubs and saplings, and herbaceous.

We assessed the carbon footprint according to the ISO 14064-1:2006 standard, classifying activities based on the scope of greenhouse gas emissions and removals. It divides into three categories: Direct emissions, Energy indirect emissions, and Other indirect emissions. We used equations from the Intergovernmental Panel on Climate Change (IPCC) to calculate the carbon footprint due to climate change.

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



ที่มา: Corporate Value Chain (Scope 3) Accounting and Reporting Standard, GHG Protocol

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

Direct greenhouse gas emissions, also known as Type 1 (Scope 1), are activities that occur directly from sources under the control of the entity. Examples include combustion in mobile sources (Mobile Combustion) and combustion in stationary sources (machinery). For Type 2 (Scope 2), it involves indirect greenhouse gas emissions from the use of energy, referred to as Energy Indirect Emissions. This includes activities like purchasing electricity or other forms of energy. Type 3 (Scope 3) comprises other indirect greenhouse gas emissions from various activities beyond those specified in Types 1 and 2.

Research Methods and Materials:

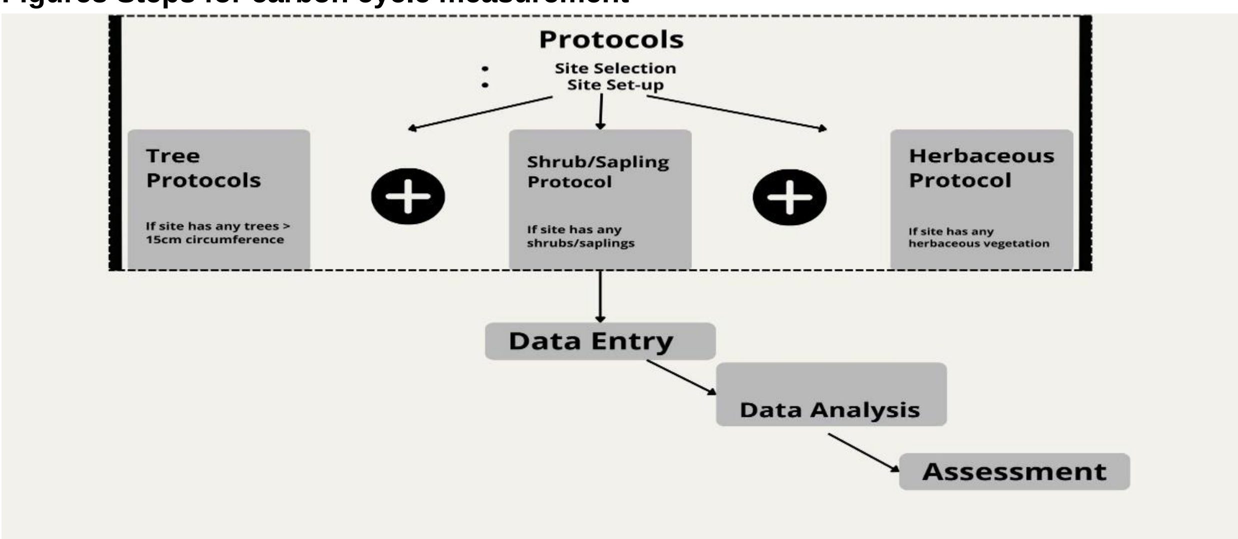
Our land cover sample site is situated at 13.72411 Latitude, 100.503101 Longitude, with an elevation of 6 meters above sea level, covering 9,702 square meters. Classified as a Non-Standard Site, it exceeds 50% human interference, including residential and dwelling areas.

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.

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. 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

Figure8 Steps for carbon cycle measurement



Source GLOBE Program, 2022

We conducted a carbon cycle assessment using the principles of GLOBE's Land Cover Investigations to gather information about our land cover sample site. This site, serving as the research base, is located at coordinates 13.72411 degrees north latitude, 100.503101 degrees east longitude, and an elevation of 6 meters above sea level. It covers an area of approximately 9,702 square meters. Classified as a Non-Standard Site, this research area includes human-built structures.

We initiated our observation by examining the surrounding area through aerial imagery sourced from Google Earth. We adhered to the specifications outlined by GLOBE, measuring the width and length of the designated area. To comply with the stipulated requirement for satellite imagery with a minimum pixel size of 30 meters by 30 meters and a resolution spanning at least 15 kilometers by 15 kilometers, we strategically chose a location measuring 99 meters by 98 meters. This selection was made to attain a specific pixel count of 10.7811 Landsat pixels, equivalent to 3.3 pixels by 3.267 pixels. Adhering to the Modified UNESCO Classification Guide (MUC Field Guide), our study site falls under the category MUC91: Urban area with residential land use, representing more than 50% of the area covered by constructed elements for residential purposes.

According to the carbon cycle protocol, this study site is considered a "non-standard" site. We utilized the built-in compass in our smartphones to navigate and locate the midpoint of the area, measuring latitude, longitude, and elevation from sea level. The GPS receiver in our phones ensured vertical alignment for accurate readings. We conducted measurements five times and calculated the average. Additionally, we divided the area into four quadrants: north, east, south, and west. To validate the accuracy, we compared the aerial image's size with the actual area by counting steps from the leftmost to the rightmost point. The scale ratio between the image and the on-ground distance was 1 centimeter: 915.9 centimeters. We recorded this data on the *GPS Investigation Data Sheet* form.

Figure9 Site selection and non-standard site set up (1)

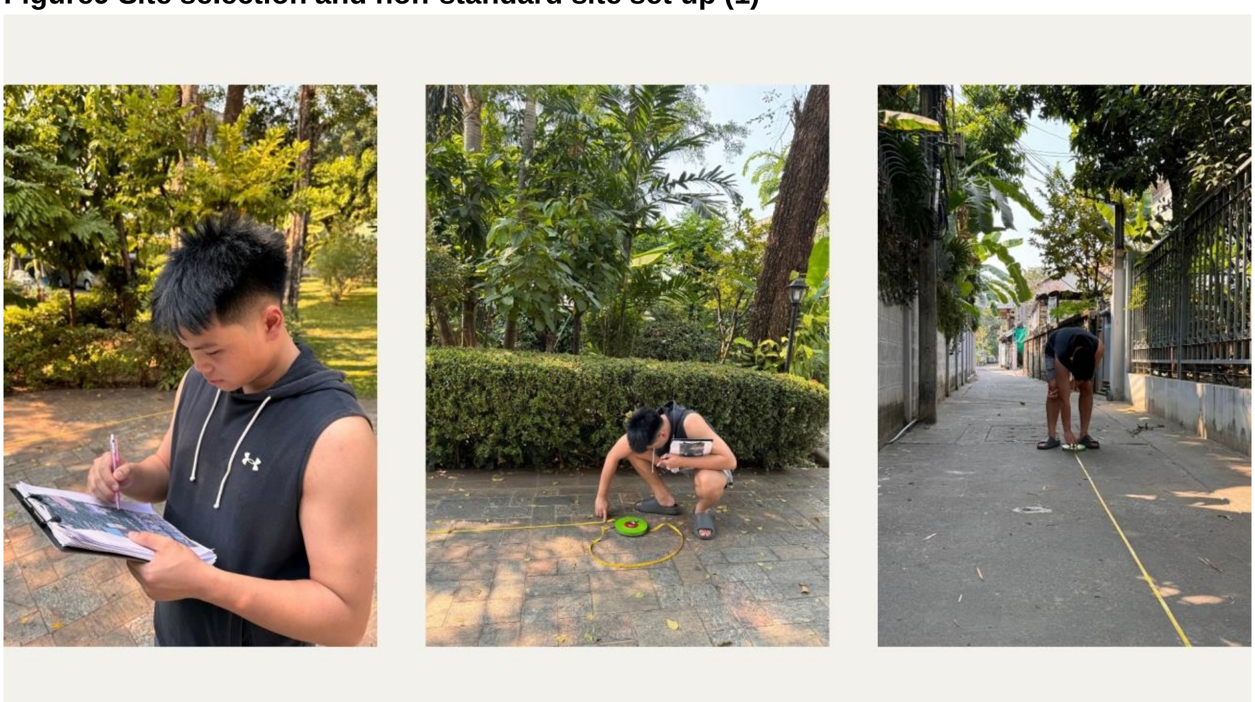
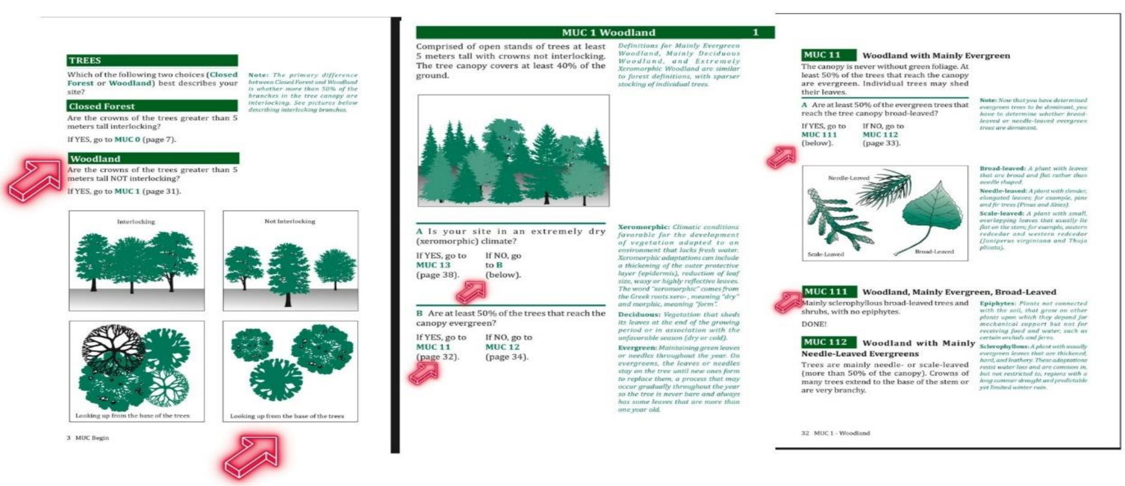


Figure10 Site selection and non-standard site set up (2)

After that, we headed northwest and started the vegetation survey in that region. We recognized the species of trees using the MUC Field Guide. The trees at our study site seemed to belong in the woodland category since at least 40% of the area was covered by the canopies of the larger-than-5-meter trees, which did not interlock. Furthermore, at least 50% of the trees had green leaves all year round, and the canopies of the trees were continuously green. 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.

Figure11 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!

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.

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.

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 the Biometry protocols, specifically tree mapping and tree circumference, we began by identifying the tree crowns visible on the aerial map from our Google Earth images and matching them with the actual trees on-site. We utilized the aerial map to locate trees in each quadrant of the area and assigned them numbers. Measuring the tree circumference was done at a height of 1.35 meters from the base or at breast height (Circumference at breast height) to determine the tree type.

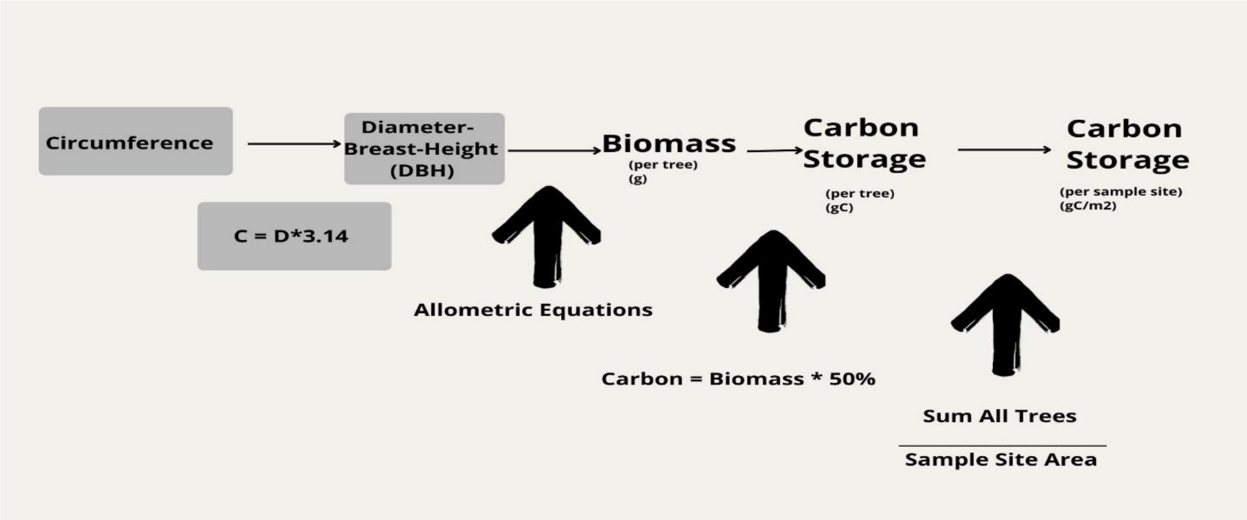
To identify the tree species, we consulted with tree experts and utilized the iNaturalist program. Different species exhibit variations in trunk shape, branching patterns, root structure, and leaf characteristics, impacting their photosynthetic capabilities. We recorded the gathered information in the *GLOBE Carbon Cycle – Tree Data Sheet* designed for Non-Standard Sites.

Figure12 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 entering the circumference measurements of the trees in centimeters, measured at breast height (Circumference at Breast Height), a total of 312 trees, into the GLOBE database, aboveground carbon storage can be calculated as indicated below.

Figure13 Calculation of carbon stored in trees

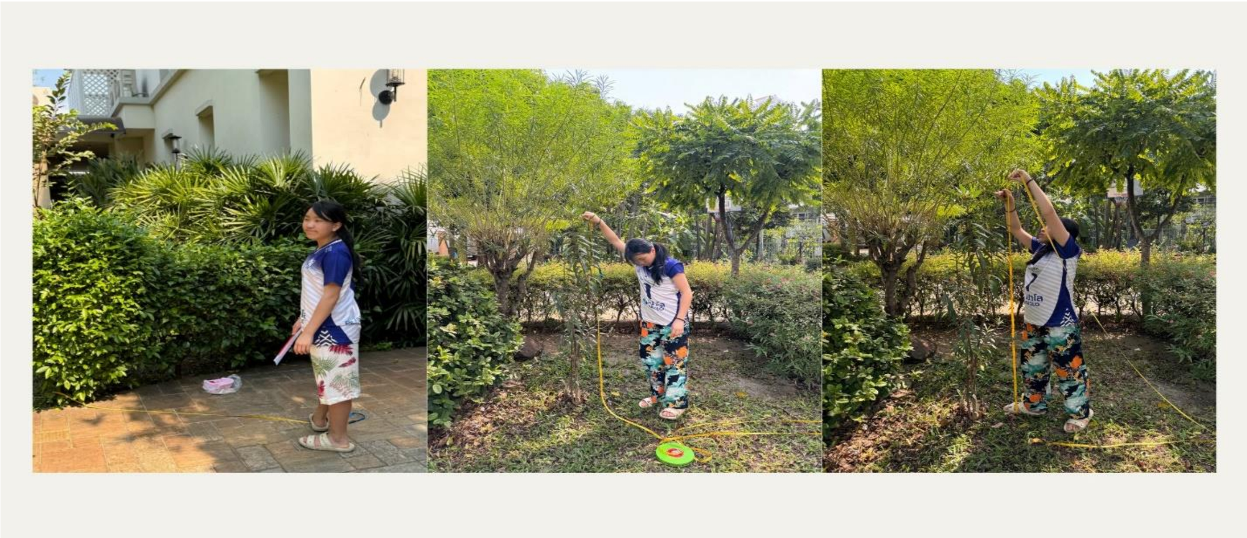


Source Globe Non-Standard Site Carbon Cycle Protocols

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)

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

Figure14 Measuring shrubs

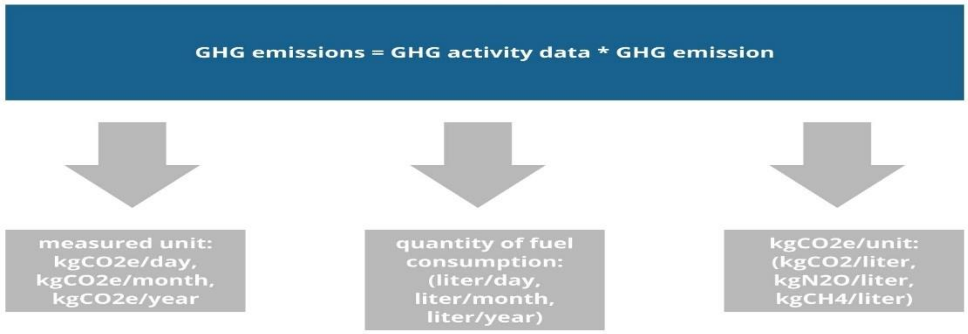


While the surveyed area did not meet the criteria for the inclusion of grasses in the GLOBE database (less than 50% of the area covered), we employed a study format that includes herbaceous vegetation, incorporating the *Herbaceous Vegetation Measurements – Student Field Guide*. The data collection process involved closing our eyes and tossing a beanbag once at each location, aiming to secure three sample sites. Subsequently, we delineated a 1*1 meter area around each beanbag. Within these designated areas, we collected grass using scissors. The gathered vegetation was then placed in distinct brown paper bags, each labeled with coordinates. The grass samples in these three bags were then placed in a dry location. Starting on the 5th day, we weighed the samples daily, recording the data. We observed that a grass sample was considered completely dry when there was no change in weight for two consecutive days. The drying process took six days. The biomass data for the grass samples were recorded in the *Graminoid Biomass Data Sheet*, allowing us to determine the average biomass and estimate the carbon storage in the area.

Figure15 Data collection - Herbaceous

For the collection of activity data related to greenhouse gas emissions, we gathered information from emission sources, including the volume of fuel consumed in liters, electricity usage in kilowatt-hours (kWh), and travel distances in kilometers (km). As for the quantity of greenhouse gas emissions resulting from energy use, it is expressed in tons of carbon dioxide equivalent (tons of CO_2e). The calculation of greenhouse gas emissions can be performed by multiplying the activity data by emission factors.

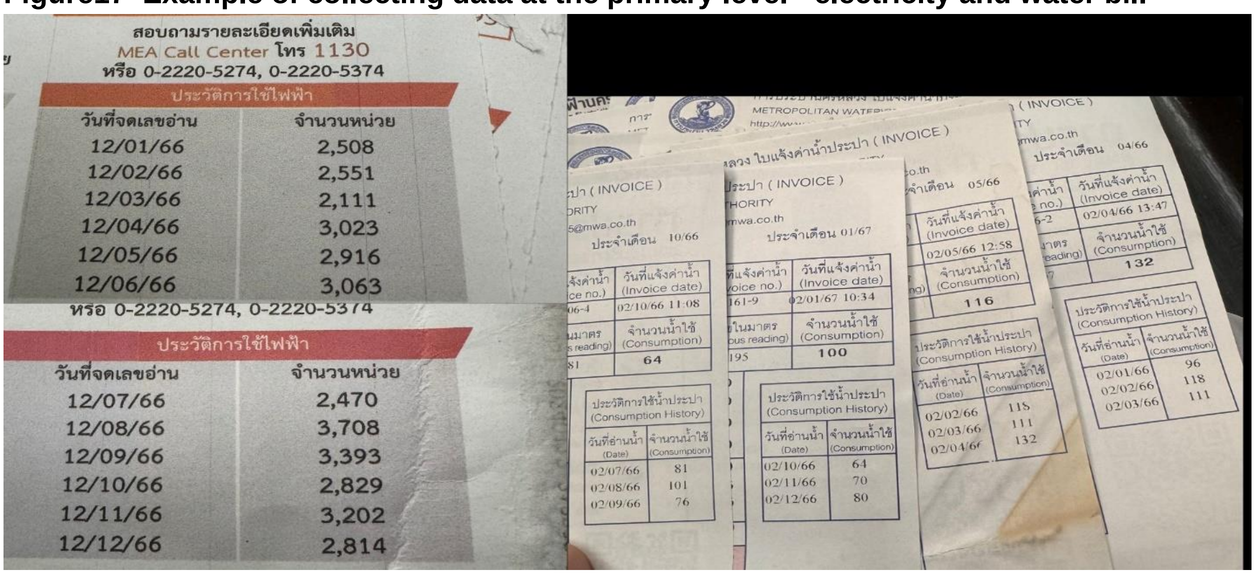
Figure16 Calculating the quantity of greenhouse gas (GHG) emissions



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

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. This involves collecting quantitative data such as volume in liters (liter) and electricity consumption in kilowatt-hours (kWh), as well as qualitative data such as fuel type. The second step is to choose the method of data collection. We collect data at the primary level, including fuel receipts, electricity bills, water bills, and utilize secondary data such as statistical calculations and surveys. We gather and compile data for the assessment and calculation of greenhouse gas emissions over a one-year period. This serves as a baseline year for future comparisons.

Figure17 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:

Table18 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**		
International short-haul flight (Economy class)	(passenger per km)		0.0933	Defra, 2010
International long-haul flight (Economy class)	(ppm)		0.0834	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."

The calculation of greenhouse gas emissions can be obtained by multiplying activity data by greenhouse gas emission factors (EF).

Table19 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. 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.

Table20 Summary of the carbon storage within the trees

	Unit	
Plot aboveground biomass	g/plot	31,402,875
Plot aboveground carbon storage	**gC/plot**	**15,701,437**
Biomass	g/m2	3,237
Aboveground carbon storage	**gC/m2**	**1,618**

Figure21 The relationship between the circumference size of trees at breast height and aboveground biomass

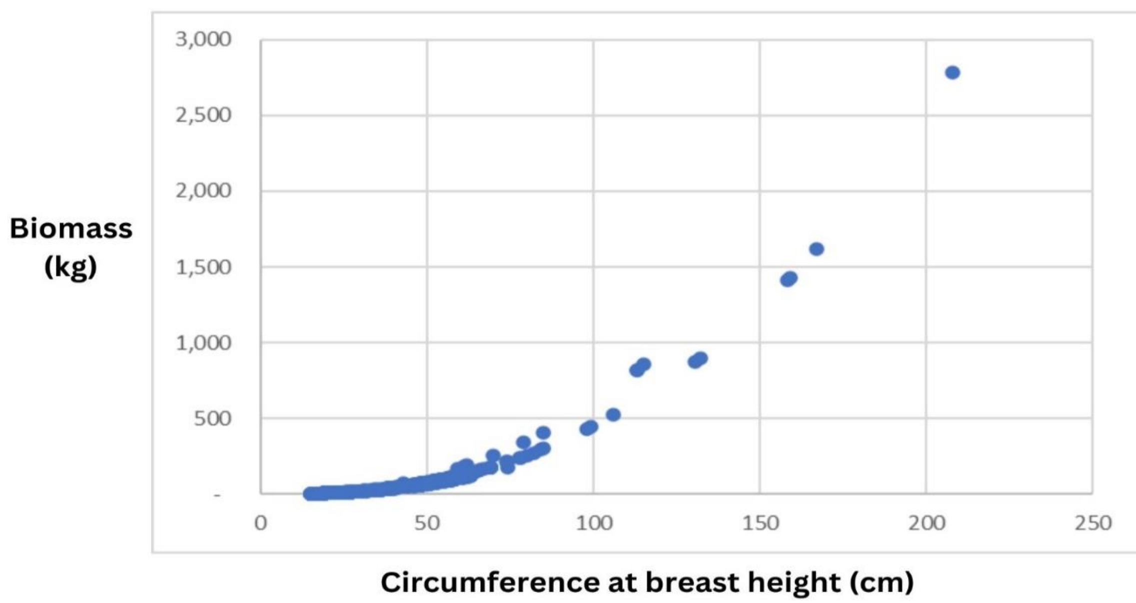


Figure22 The proportion of aboveground biomass in various parts of large trees

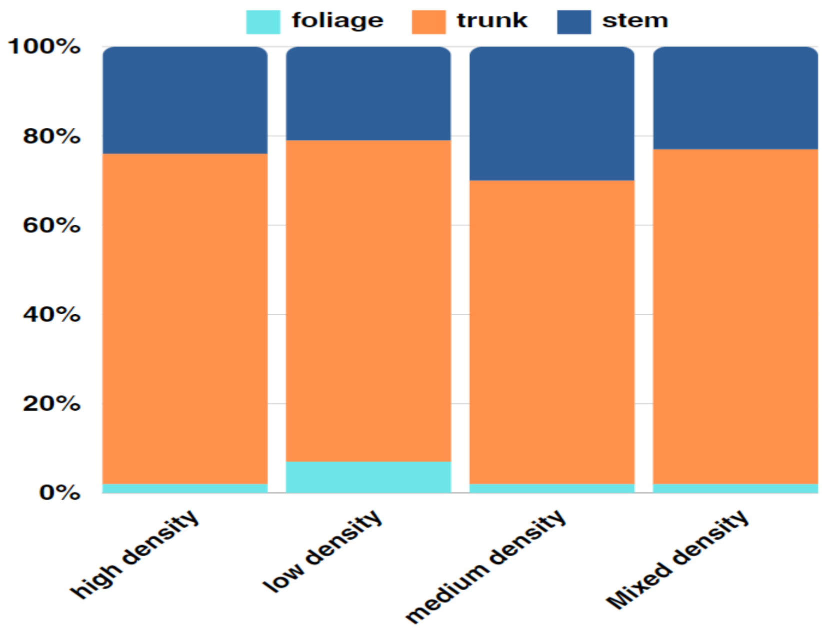


Figure23 The proportion of large trees in the area categorized by wood density

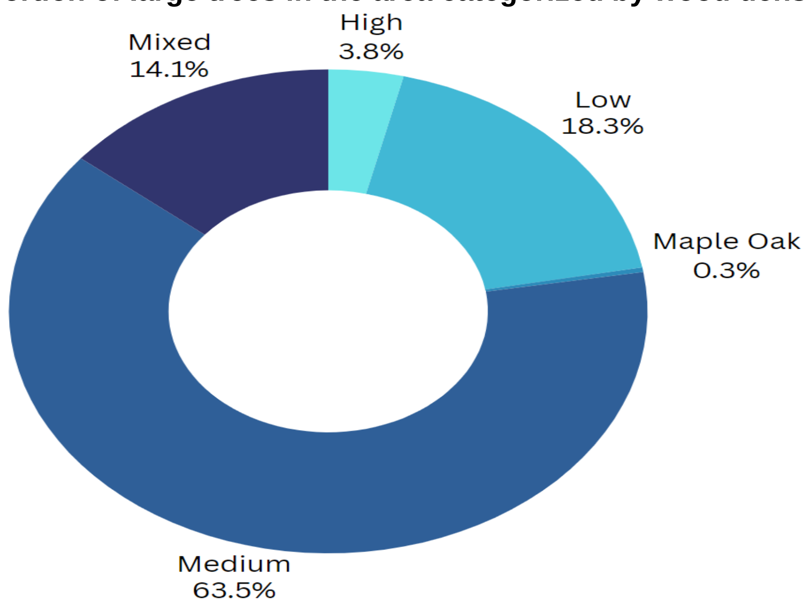


Table24 Summary of the carbon storage in the shrub/sapling in our site

	Unit	
Deciduous Biomass	g/m2	1.4
Evergreen Biomass	g/m2	27.7
Total Biomass	g/m2	29.1
Carbon Storage – Shrub/sapling	**gC/m2**	**14.5**

Table25 Summary of the carbon storage in grass in our site

	Unit	
Biomass: Grass in brown bag	g/m2	13
Brown bag	g/m2	3
Net Biomass - Herbaceous	g/m2	10
Carbon storage - Herbaceous	**gC/m2**	**5**

Figure26 Data analysis from the GLOBE Visualization System

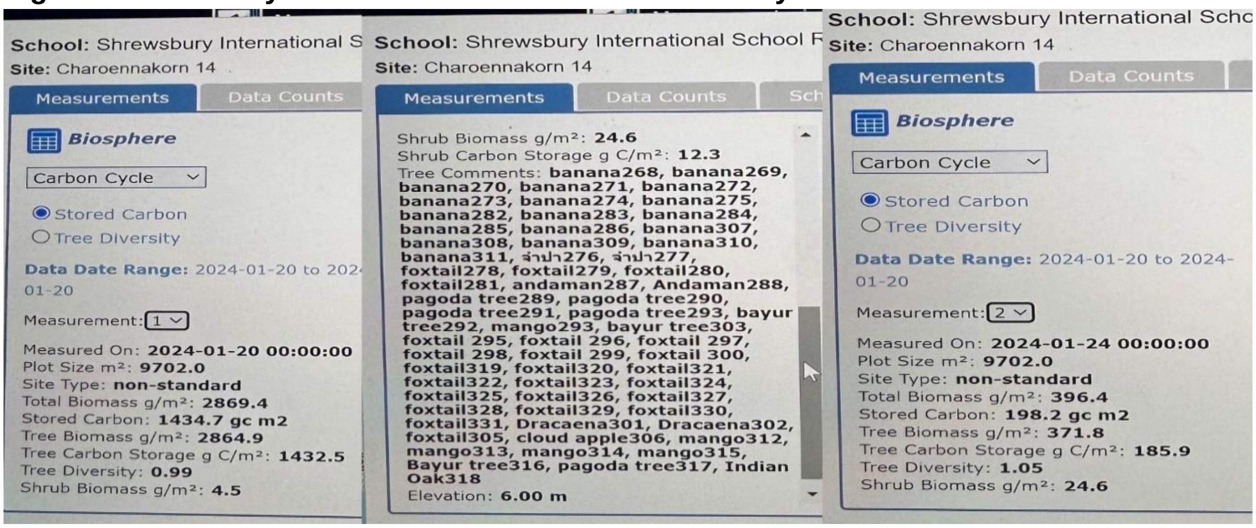
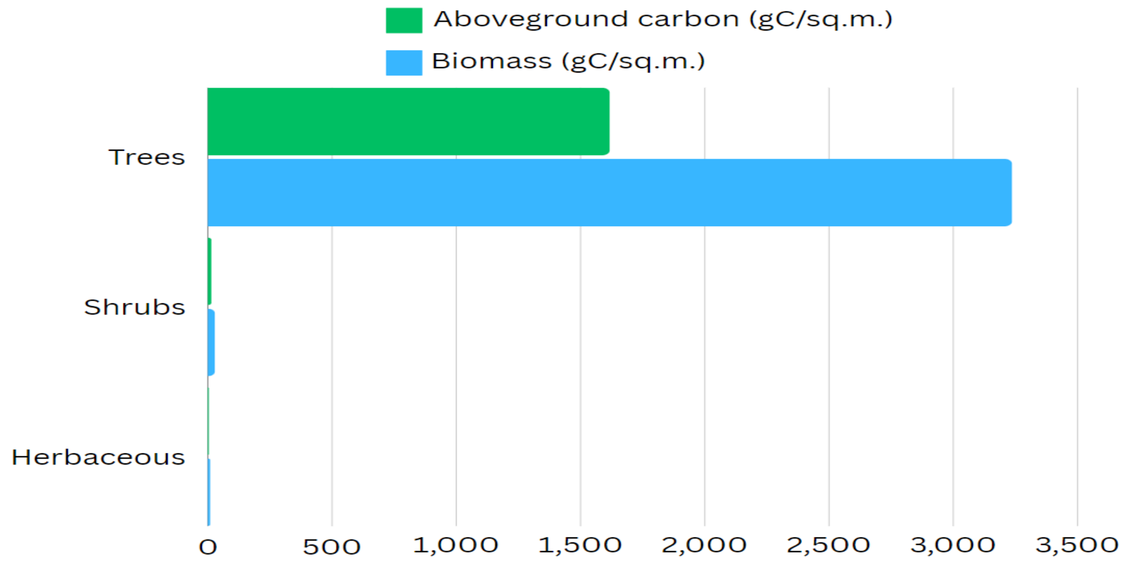


Table27 Greenhouse gas emissions (CO_2) – travel and transportation by vehicle type in the category of cars

Activities that are sources of GHG emissions - Travel and transportation by vehicles in the category of cars		
Fossil Fuel (Gasohol)		
- Volume	3,444.21	liter
- Gasohol	95%	%
Emission CO_2	**7,513.76**	**kg. CO_2e**
- Net Calorific Value $_{FOS}$	31.48	MJ/liter
- $EF_{CO2, FOS}$	69,300	kg.CO_2e/TJ
Global Warming Potential (GWP)	1.00	kg.CO_2e/kg.CO_2
Emission CH_4	**8.13**	**kg. CO_2e**
- Net Calorific Value $_{FOS}$	31.48	MJ/liter
- EF(CH_4)	3.00	kg. CH_4/TJ
Global Warming Potential (GWP)	25.00	kg.CO_2e/kg.CH_4
Emission N_2O	**19.39**	**kg. CO_2e**
- Net Calorific Value $_{FOS}$	31.48	MJ/liter
- EF(N_2O)	0.60	kg. N_2O/TJ
Global Warming Potential (GWP)	298	kg.CO_2e/kg.N_2O
GHG Emissions Quantity (CO2) - Travel and Transportation by Vehicle Type	**7,164.22**	**kgCO2/year**

Figure28 Summary of the carbon storage in the vegetation in my site (gC/sqm)



From calculations using the ISO 14064-1 standard guidelines for carbon footprint assessment, we obtained the following summary results:

Table29 Greenhouse gas emissions (CO2) – electricity use (Energy Indirect Emission)

Activities that are sources of GHG emissions - Imported electricity	**Calculations**	
GHG Emissions Quantity (CO2) - Electricity	= Quantity of electricity consumption (kWh) * GHG Emission Factor (KgCO2e/kWh)	
Total Electricity Unit	34,598	kWh/year
EF - Electricity consumption from external sources (Energy Indirect Emission)	0.5813	kgCO2e/kWh
GHG Emissions Quantity (CO2) - Electricity	20,111.82	kgCO2e/year

Table30 Greenhouse gas emissions (CO2) – water (Other Indirect Emissions)

Activities that are sources of GHG emissions – Water use	**Calculations**	
GHG Emissions Quantity (CO2) - Water	= Quantity of water consumption (cubic meter) * GHG Emission Factor (KgCO2e/kWh)	
Total water usage (m3)	1,163	m3
EF - Water consumption	0.7948	kgCO2e/m3
GHG Emissions Quantity (CO2) - Water	924.35	kgCO2e/year

Table31 Greenhouse gas emissions (CO2) – air travel (Other Indirect Emissions)

Activities that are sources of GHG emissions - Air travel (Other Indirect Emissions)	Calculations	
GHG Emissions Quantity (CO2) - Air travel	= no. of passengers (passenger) * distance (km)* GHG Emission Factor (KgCO2e/passenger-km)	
EF - International short-haul flight: Economy class	0.0933	kgCO2e/passenger-km
EF - International long-haul flight: Economy class	0.0834	kgCO2e/passenger-km
Air travel activity of researcher #1: Economy class	**Distance (km)**	**Classified**
Outbound		
Flying Thai airways: Bkk - Heathrow	9,580	Long haul
Flying British Airways: Heathrow - Reykjavik	1,893	Short haul
Inbound		
Flying play AirlineOG460 Reykjavik - Amsterdam	2,041	Short haul
Flying Turkish Airlines Amsterdam - Istanbul	2,213	Short haul
Flying Turkish Airlines Istanbul - Bangkok	7,554	Long haul
Air travel activity of researcher #2: Economy class		
Flying Air Asia: Bangkok - Phnom Penh	539	Short haul
Flying Air Asia: Phnom Penh - Bangkok	539	Short haul
Total air travel of the group	24,359	
GHG Emissions Quantity (CO2) - Air travel	2,601	kgCO2e/year

Table32 Summary of carbon dioxide emission by researchers

Activities		
CO2 - Transportation by car	7,164.22	kgCO2/year
CO2 - Electricity (Energy Indirect Emission) (kgCO2e)	20,111.82	kgCO2e/year
CO2 - Water (Other Indirect Emissions) (kgCO2e)	924.35	kgCO2e/year
CO2 - Air travel (Other Indirect Emissions) (kgCO2e)	2,601.41	kgCO2e/year
Total Carbon Dioxide Emission	**30,802**	**kgCO2e/year**

Figure33 Carbon dioxide (CO2) emissions proportion by activity type

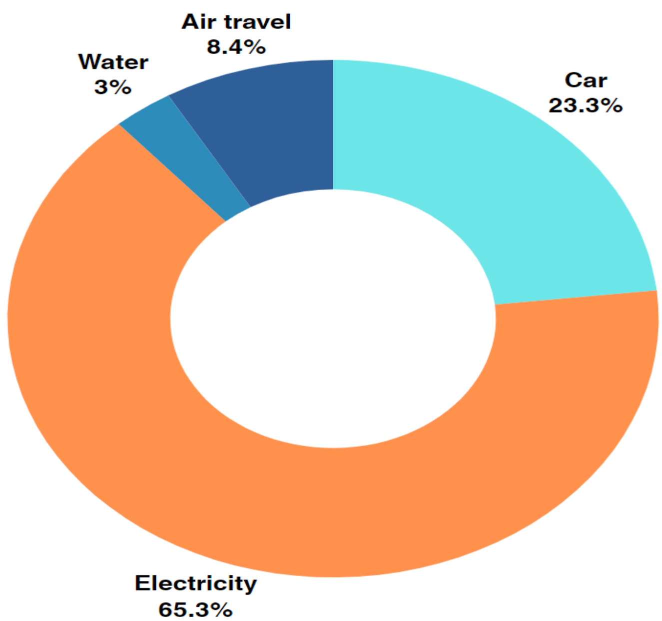
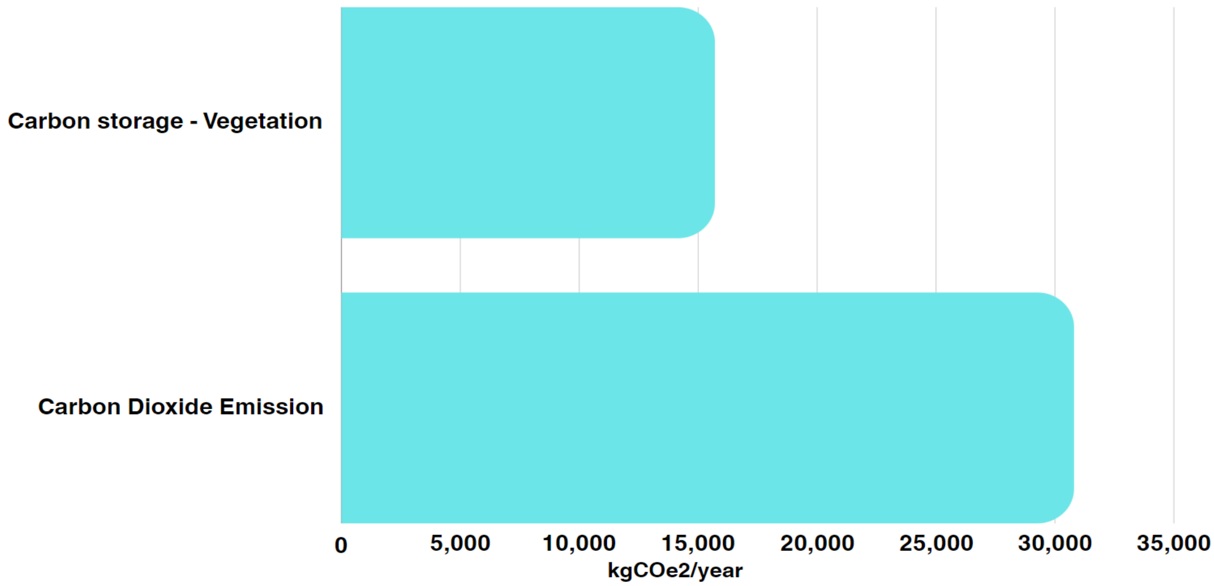


Figure34 The amount of carbon dioxide emissions compared to the amount of carbon sequestration in vegetation



From the above information, the conclusions drawn are as follows:

1. The denser the vegetation, the greater the carbon storage capacity, with large trees exhibiting the highest biomass and, consequently, the highest carbon storage.
2. There is a positive correlation between tree age and circumference size, indicating that older trees tend to be taller and have larger trunks, resulting in increased carbon storage. Trees with more branches and leaves show higher efficiency in aboveground carbon sequestration.
3. The majority of carbon storage aboveground occurs in tree trunks, followed by branches and leaves.
4. Large trees demonstrated the highest carbon sequestration capabilities in the area, equivalent to 1,618 gC/square meter, followed by shrubs/saplings with a carbon sequestration capacity of 14.5 gC/square meter and 5gC/square meter in grass.
5. Plant species significantly influence carbon sequestration capabilities.
6. From the data analysis, vegetation in the research area can store aboveground approximately 1,637.9gC/square meter. Therefore, the total aboveground carbon sequestration capacity of vegetation in the entire area is approximately 15.7*10^6gC or equivalent to 15,701 kilograms.
7. Large trees, shrubs/saplings and grass, receiving consistent care, contribute to stable carbon sequestration, with potential improvements as the plants mature.
8. Utilizing ISO14064-1:2006 standards and IPCC equations, the calculated carbon footprint is 30,802 kgCO2e/year, which is 1.96 times higher than the aboveground carbon sequestration capacity of woody plants.
9. Electricity consumption contributes the highest proportion (65%) to the carbon footprint, followed by travel and transportation (24%), air travel (8%), and water usage (3%).
10. Identified opportunities for reducing the carbon footprint include various measures to minimize environmental impact.

Discussion:

The research team measured the circumference of 312 large trees, each with a height not less than 5 meters and a circumference at breast height not less than 15 centimeters. According to the hypothesis, large trees have the highest carbon sequestration capabilities, followed by shrubs/saplings. The study found that as trees age, their height and circumference at breast height increase, leading to enhanced carbon sequestration. Additionally, a positive correlation was observed between the ability to sequester carbon and the biomass of plant species. Different plant species exhibited varying biomass, influencing their carbon sequestration capabilities.

Furthermore, there is a positive relationship between the ability to sequester carbon and the biomass of plant species. This implies that different plant species have varying biomass, which, in turn, affects their carbon sequestration capabilities. The research revealed that plant species with higher biomass have a greater capacity for aboveground carbon sequestration. The analyzed trees in the research area were at least 15 years old and represented a diversity of species, with approximately 64% being medium-density trees such as Pagoda tree, Foxtail Palm, and Mango. Low-density trees like Banana constituted 18.3%, mixed-density species like Bayur tree comprised 14.1%, and high-density trees like Asian bulletwood and Burmese ebony constituted 4.1% of all large trees.

Nitcha Thachuen and colleagues (2022) contend that the trees within Darawittayalai School have the capacity to store approximately 418,706.45 kilograms of carbon, averaging 5,300 kilograms per 1 rai (or 1,600 sq.m.). This surpasses the carbon storage in trees in the deciduous forest, attributed to the presence of the Rain tree (Albizia saman (Jacq.) Merr.) at Darawittayalai School. These native forest trees are retained and exhibit high carbon sequestration potential. Furthermore, the carbon storage at Pelrithang Higher Secondary School, Sarpang, Bhutan, estimated by Sangay Choden and Yeshey (2023), is 3,756 gC/m2. The carbon storage at these two schools far exceeds the capabilities of our vegetation by twice as much. I believe that both schools have been long-established, with most of the trees in these locations being naturally grown over a significant period. The trees on my site, cultivated and approximately 15 years old, are noticeably younger than those at Darawittayalai School (established 145 years ago) and Pelrithang Higher Secondary School (established in 1981), both with mature, naturally grown trees. The selection and youth of the planted trees on my site are expected to contribute to lower aboveground carbon storage.

The findings of Priyada Saratthana and Thanyarat Sapson (2023) are interesting that one Resin tree can sequester 925.32 kilograms of carbon per year. This is attributed to the presence of high soil moisture and organic matter content in the area where rubber trees are found. However, the nutrient content in the soil (NPK) is significantly low, as rubber trees, with their deep root system, can efficiently absorb nutrients from the soil for growth. This results in the Resin tree showing the best growth and the highest carbon sequestration when compared to other prominent tree species in the school. We consider to plant Resin trees on our site as a way to enhance an overall carbon storage.

To gain a deeper understanding of the carbon cycle, it is crucial to conduct repeated measurements and analyze temperature and rainfall data. These efforts will contribute to a comprehensive understanding of net primary production, which plays a significant role in carbon storage and absorption in the plant pool.

While the research results demonstrate the high carbon storage capacity of vegetation in the surveyed area, our carbon footprint is approximately twice the sequestration capacity. Hence, relying solely on existing vegetation or planting additional trees in the vicinity may not be sufficient. To effectively reduce our carbon footprint, it is crucial to implement additional measures. One such measure we consider necessary and efficient is transitioning the energy sources used in homes from fossil fuels to renewable energy, such as solar energy. Additionally, for transportation, considering electric vehicles instead of conventional cars can contribute to lowering our carbon footprint. This aligns with the goal of moving towards a Low-carbon Society. This research provides a baseline for future comparisons, enabling us to evaluate and review the effectiveness of the measures we implement.

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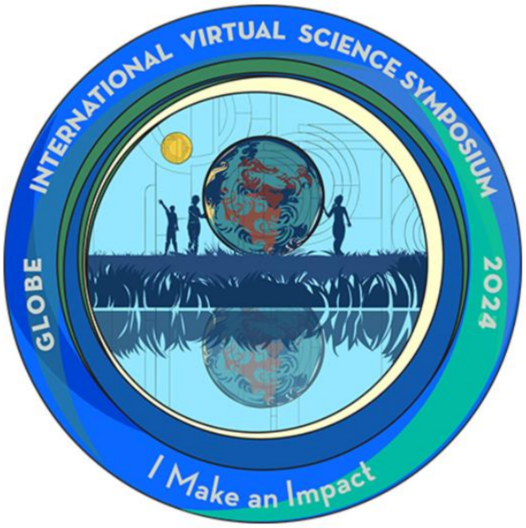
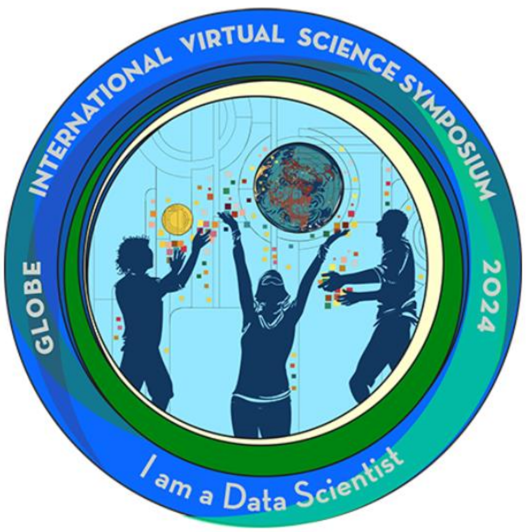
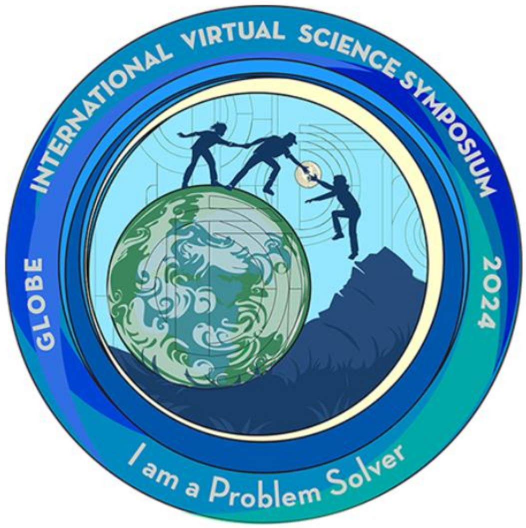
(Optional) Badge Descriptions/Justifications:

Badge Descriptions/Justifications:

	I MAKE AN IMPACT I can identify discrepancies between my carbon footprint and the carbon storage capacity of the vegetation, and I will take these opportunities to reduce emissions, enhance carbon sequestration, and change my way of living towards a low-carbon society.
	I AM A DATA SCIENTIST I engaged in a comprehensive analysis, utilizing data from various sources including GLOBE Carbon Cycle and Biometry Protocols, along with adhering to ISO 140640-1:2006 guidelines for calculating carbon footprint. This multidisciplinary approach allowed me to draw meaningful inferences about carbon storage in trees and shrubs/saplings at our site. By integrating diverse datasets and following industry standards, I showcased my proficiency as a data scientist, emphasizing practical applications such as making recommendations for reducing carbon footprint in alignment with the 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 on our site.