CARBON UNDER ONE ROOF: A HOUSEHOLD CARBON BUDGET

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ABSTRACT

THIS RESEARCH PRESENTS A THREE-YEAR, HOUSEHOLD-SCALE ASSESSMENT OF CARBON DYNAMICS BY INTEGRATING ABOVEGROUND VEGETATION CARBON, NET PRIMARY PRODUCTIVITY (NPP), BELOWGROUND SOIL CARBON STORAGE, AND HOUSEHOLD GREENHOUSE GAS EMISSIONS.

THE MEASUREMENTS INCLUDE:

1. CIRCUMFERENCE AT BREAST HEIGHT (CBH) OF TREE TRUNKS, THE HEIGHT OF SHRUBS OR SAPLINGS USED IN ALLOMETRIC EQUATIONS TO CALCULATE BIOMASS AND WEIGHING HERBACEOUS COMPONENTS FOR DETERMINING ABOVEGROUND CARBON STORAGE.
2. PERIODIC VEGETATION GROWTH ASSESSMENTS FOR EVALUATING NPP.
3. SOIL CHARACTERIZATION, STAR-PATTERN SOIL MOISTURE, DEPTH PROFILE SOIL MOISTURE, SOIL BULK DENSITY PROTOCOLS, AND ORGANIC CARBON CONTENT FOR CALCULATING BELOWGROUND CARBON STORAGE.

THE PERSONAL CARBON FOOTPRINT DATA IS GATHERED AND EVALUATED USING THE INTERNATIONAL STANDARD ISO 14064-1:2006 FOR GREENHOUSE GAS QUANTIFICATION AND REPORTING.

INTRODUCTION

HUMAN ACTIVITIES ARE ALTERING THE CARBON CYCLE, DRIVING A RISE IN GLOBAL TEMPERATURES.

GHGS ORIGINATE FROM ENERGY PRODUCTION, LAND USE, INDUSTRY, AND AGRICULTURE.

THESE GASES RETAIN HEAT BY ABSORBING AND RE-EMITTING INFRARED RADIATION.

HYPOTHESIS

- Aboveground carbon storage is dominated by large, mature trees, followed by shrubs and saplings, while herbaceous vegetation contributes least to carbon storage but supports ecosystem productivity.
- Vegetation biomass, carbon storage, and net primary productivity (NPP) are positively correlated, with greater biomass leading to increased carbon accumulation over time.
- Soil organic carbon represents a major component of total ecosystem carbon, increasing with depth and contributing substantially when fully quantified.
- Household greenhouse gas emissions exceed on-site vegetation and soil carbon storage, indicating that residential ecosystems alone cannot achieve household carbon neutrality.

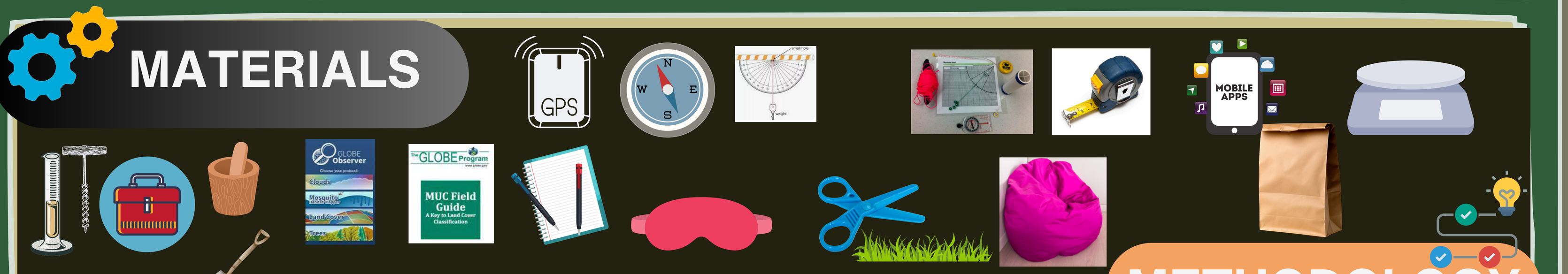
OBJECTIVE

TO QUANTIFY THE FIRST THREE-YEAR, HOUSEHOLD-SCALE CARBON BUDGET INTEGRATING NATURAL CARBON STORAGE, NPP, AND HOUSEHOLD GREENHOUSE GAS EMISSIONS.

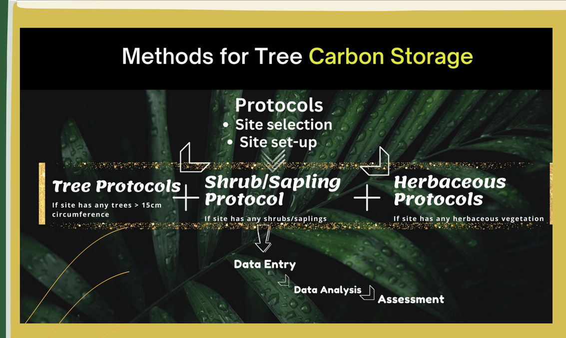
Research Questions

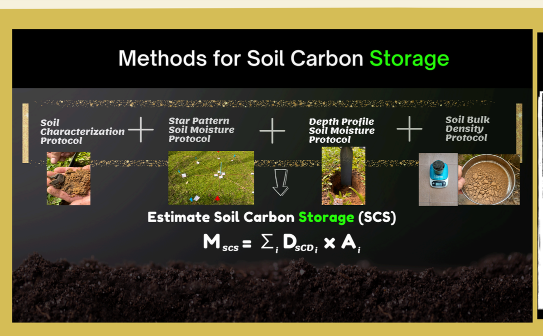
- How much carbon is stored in residential vegetation (trees, shrubs/saplings, and herbaceous plants)?
- How are vegetation biomass, carbon storage, and net primary productivity (NPP) related over time?
- How much carbon is stored in soil, and how does it vary with depth and soil properties?
- What is the relative contribution of soil carbon vs. vegetation carbon to total ecosystem storage?
- How does household carbon footprint compare with on-site vegetation and soil carbon storage?
- Can a residential ecosystem meaningfully offset household greenhouse gas emissions?

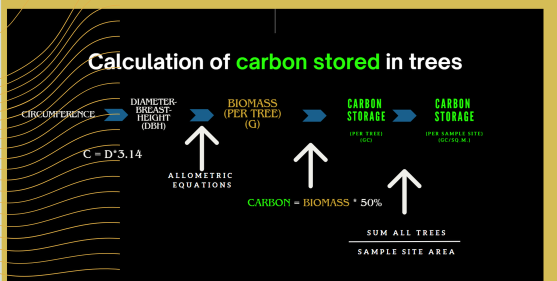
MATERIALS

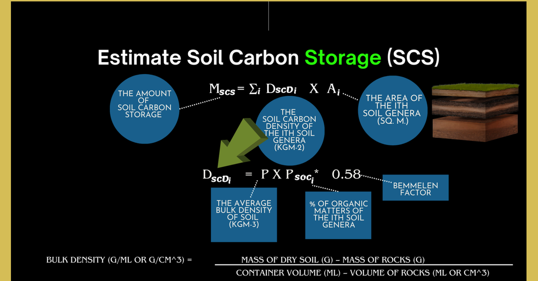


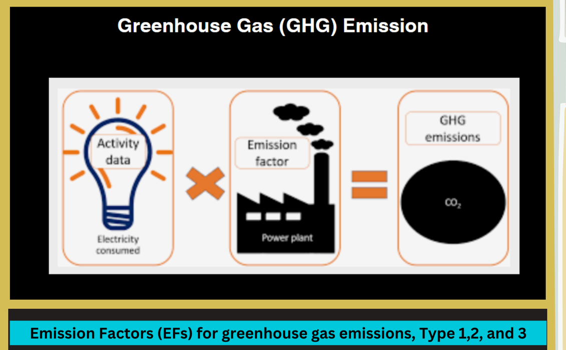
METHODOLOGY

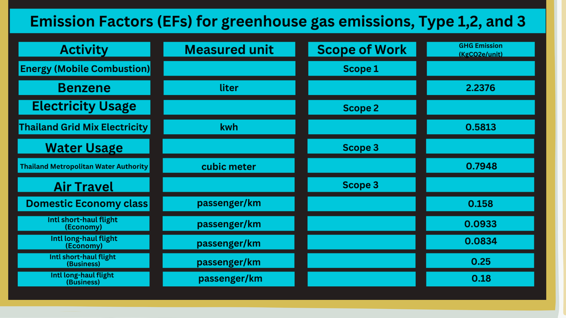










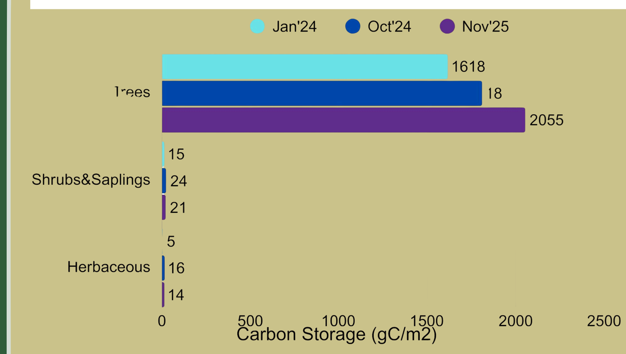


Emission Factors (EFs) for greenhouse gas emissions, Type 1,2, and 3

Activity	Measured unit	Scope of Work	GHG Emission (kgCO2e/unit)
Energy (Mobile Combustion)		Scope 1	
Benzene	liter		2.2376
Electricity Usage		Scope 2	
Thailand Grid Mix Electricity	kwh		0.5813
Water Usage		Scope 3	
Thailand Metropolitan Water Authority	cubic meter		0.7948
Air Travel		Scope 3	
Domestic Economy class	passenger/km		0.158
Intl short-haul flight (Economy)	passenger/km		0.0933
Intl long-haul flight (Economy)	passenger/km		0.0834
Intl short-haul flight (Business)	passenger/km		0.25
Intl long-haul flight (Business)	passenger/km		0.18

Data Summary

Carbon Storage Distribution across Vegetation Types



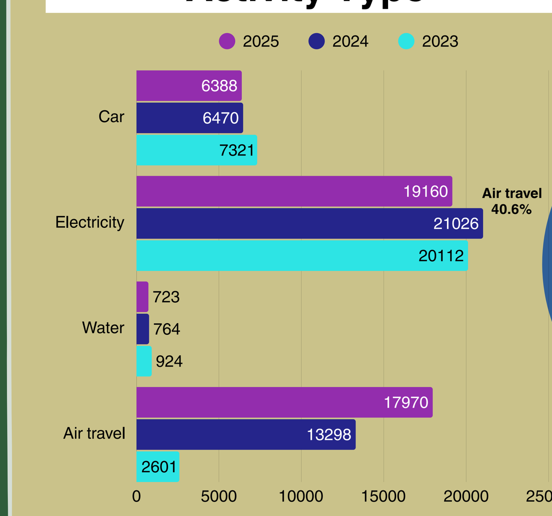
Net Primary Productivity by Vegetation Type

Type	Nov-25	NPP Yr3-Yr2	NPP Yr2-Yr1
	gC/m2	gC/m2	gC/m2
Trees	2,055	244	193
Shrubs & Saplings	21.2	-2.4	9
Herbaceous	14	-1.5	11
Aboveground - CS	2,090	240	213

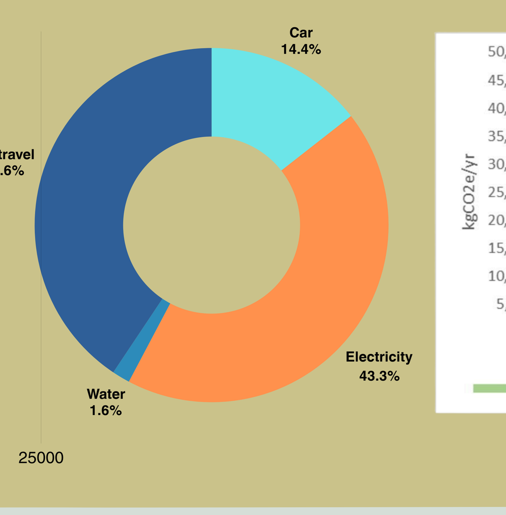
Estimation of Soil Carbon Storage

Depth	the average bulk density of soil = p (g/mL)	% of organic matters of the ith soil genera: Min	% of organic matters of the ith soil genera: Max	the Bemmelen Factor (Bf)	Plantable areas (cm)	Soil Depth (cm)	Total Carbon Storage: Min (kg)	Total Carbon Storage: Max (kg)
0 - 5 cm	1.19	0.0159	0.0250	0.58	17,373,000	5	1,433.43	2,389.06
10 cm	1.10	0.0159	0.0250	0.58	17,373,000	5	1,417.60	2,362.67
30 cm	1.10	0.006	0.0159	0.58	17,373,000	20	2,051.64	6,154.93
60 cm	1.61	0	0.0059	0.58	17,373,000	30	0	3,971.08
90 cm	1.64	0	0.0059	0.58	17,373,000	30	0	3,550.61
Estimated Belowground Carbon Storage							4,902.68	18,428.36

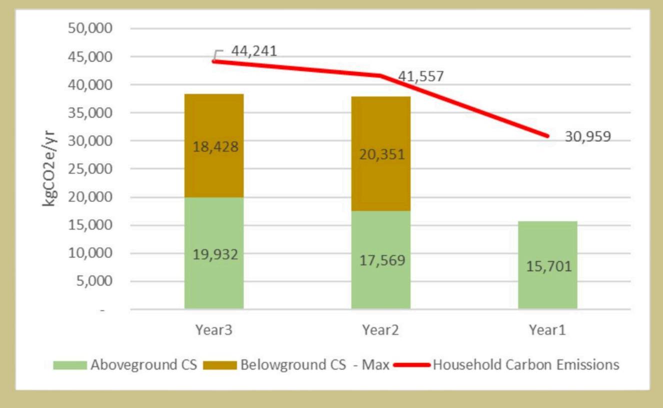
Household Emissions by Activity Type



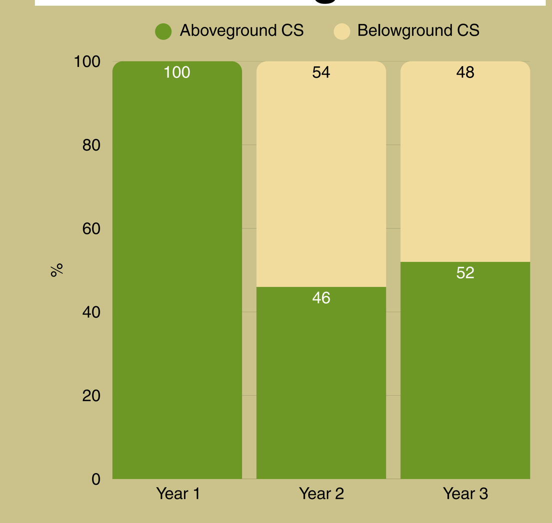
CO2 Emissions Proportion by Activity Type - 2025



Integrated Household Carbon Budget across Three Years



Soil vs. Vegetation



Conclusion

- Large, mature trees dominated aboveground carbon storage across all three years, storing substantially more carbon than shrubs, saplings, and herbaceous vegetation due to greater biomass and structural complexity.
- Vegetation biomass, carbon storage, and Net Primary Productivity (NPP) were positively related over time. Between Years 2 and 3, NPP increased by ~240 gC/m^2, driven primarily by continued growth in large trees.
- Shrubs and herbaceous vegetation exhibited negative NPP, likely due to pruning and biomass removal, highlighting how management practices influence net carbon gain.
- Belowground soil carbon constituted a major component of ecosystem carbon storage, contributing approximately 20–48% of total ecosystem carbon when measured across depth and mass.
- Soil organic carbon decreased with depth in concentration but increased in cumulative storage, emphasizing the importance of including deeper soil layers and bulk density in carbon assessments.
- Despite measurable carbon storage in vegetation and soil, household greenhouse gas emissions consistently exceeded ecosystem sequestration capacity across all three years.
- Residential ecosystems alone cannot offset household carbon emissions, underscoring the need to pair nature-based solutions with direct emission reductions.
- Household-scale nature-based solutions can complement climate action, but achieving net-zero requires prioritizing emission reductions alongside ecosystem carbon storage.

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