TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation		Expansion
AI	:	Artificial Intelligence
BC	:	Black Carbon
CO	:	Carbon monoxide
CO_2	:	Carbon dioxide
CO_2 e	:	Carbon Dioxide Equivalent
EV	:	Electric Vehicles
GCA	:	Gross Cropped Area
GHG	:	Greenhouse Gases
GIS	:	Geographic Information System
IPCC	:	Intergovernmental Panel on Climate Change
ITC	:	Industrial Training Centers
LED	:	Light Emitting Diode
LPG	:	Liquefied Petroleum Gas
LR	:	Likelihood Ratio
OHT	:	Over Head Tanks
R^2	:	Coefficient of determination
UNFCCC	:	United Nation Framework Convention for Climate Change
WBCSD	:	World Business Council for Sustainable Development
AGB	:	Above Ground Biomass
BGB	:	Below Ground Biomass
CF	:	Carbon Footprint
CFC	:	Chloro Fluoro Carbon

Abbreviation		Expansion
CH_4	:	Methane
CS	:	Carbon Sequestration
DBH	:	Diameter Breast Height
DIET	:	District Institute of Education and Training
EC	:	Elemental Carbon
FAO	:	Food and Agriculture Organization
GWC	:	Global Warming Commitment
ITI	:	Industrial training institutes
kg	:	Kilogram
KWH	:	Kilowatt Hour
LCA	:	Life Cycle Assessment
MJ	:	Metric Joule
MSW	:	Municipal Solid Waste
MT	:	Million Tons
OC	:	Organic Carbon
PES	:	Payment for Ecosystem Services
PM	:	Particulate Matter
t	:	Tonne
TANGEDCO	:	Tamil Nadu Generation and Distribution Corporation Ltd.
WRI	:	World Resources Institute

EXECUTIVE SUMMARY

The global challenge of climate change, driven by rising carbon emissions, has emphasized the importance of carbon sequestration as a mitigation strategy. In rural areas, where natural resources like trees are abundant, carbon sequestration plays a crucial role. This study investigates the carbon dynamics of Vembar South Gram Panchayat in Tamil Nadu, India, with a special emphasis on the palmyrah palm (Borassus flabellifer). These native, drought-resistant trees support local livelihoods and serve as critical carbon sinks. The study also explores the socio-economic factors influencing the community's willingness to expand palmyrah cultivation. A mixed-methods approach integrating primary and secondary data was employed to estimate emissions and sequestration levels. Carbon emissions were quantified using IPCC guidelines, considering household energy use, agriculture, and other community-level activities. Total biomass calculated using an allometric equation, was used to measure carbon sequestration by Palmyrah palms. The results indicated that households emerged as significant contributors, generating 3,675.98 tons of CO_2 e annually. Agriculture was the largest emission source, contributing 38,680.179 tons of CO_2 e per year, largely due to palm jaggery production, which involved biomass burning. Livestock farming emitted methane, while nitrous oxide from manure management further increased agricultural emissions. In addition, waste management and public electricity usage generated 2,659.11 tons of CO_2 annually, with open waste burning and electricity consumption across sectors contributing heavily to these emissions. On the other hand, the palmyrah palms in Vembar South sequestered an estimated 132,616 tons of CO_2 annually, making them an essential carbon sink. The overall carbon balance revealed that Vembar South operates as a net carbon sink, with total emissions of 45,015.26 tons of CO_2 annually, while sequestration from the palmyrah palms exceeds emissions by a significant margin of 194.6 per cent. These findings underscore the importance of preserving and expanding palmyrah cultivation to strengthen the village's carbon sink capabilities. The study also used a binary probit model to analyze socio-economic factors influencing the willingness to expand palmyrah cultivation. The results indicated that gender, occupation, and family size played key roles. Female landowners and individuals in non-agricultural occupations were more likely to support expansion, while larger families expressed reluctance due to resource constraints. Wealthier households, especially

those with greater income and land ownership, showed more interest in investing in palmyrah cultivation. In conclusion, Vembar South's status as a net carbon sink demonstrates the potential of combining natural carbon sinks with emission reduction strategies to achieve carbon neutrality in rural areas. Cleaner energy technologies, such as improved cookstoves and renewable energy, can further reduce emissions. Further, expanding palmyrah cultivation offers environmental and socio-economic benefits by fostering community involvement in carbon management.

1 INTRODUCTION

Over the past century, there has been a marked increase in global temperatures, driven primarily by human activities such as the burning of fossil fuels, deforestation and industrial processes. These activities have resulted in the accumulation of Greenhouse Gases (GHGs), including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), in the atmosphere. Among these gases, carbon dioxide (CO_2) is the most prominent contributor to global warming, intensifying the greenhouse effect and causing climate disruptions worldwide. CO_2 levels have surpassed 400 parts per million (ppm) in 2023, highlighting the urgency of addressing this issue (Leiter, 2024).

The consequences of climate change are becoming increasingly evident. Rising temperatures have triggered more frequent and severe heatwaves, floods, droughts and extreme weather events. The National Oceanic and Atmospheric Administration (NOAA) reported that U.S. weather and climate disasters cost over $1 billion each in recent years due to these intensified phenomena (He *et al.*, 2023).The melting of polar ice caps and rising sea levels threaten coastal communities and biodiversity, while disruptions to rainfall patterns jeopardize agriculture and food security. Climate-induced changes to ecosystems also impact species distribution, migration and survival, posing risks to biodiversity and human livelihoods.

Recognizing the need for coordinated global action, the Paris Agreement of 2015 marked a turning point in international climate efforts. Under this agreement, nations pledged to limit global temperature rise to well below 2°C above pre-industrial levels and to pursue efforts to restrict it to 1.5°C. The effectiveness of the Paris Agreement relies heavily on each country's Nationally Determined Contributions (NDCs), which outline their specific commitments to reduce emissions. As countries update their NDCs ahead of the global stocktake in 2023, it is essential to assess progress towards these commitments and enhance accountability within international climate governance (Skea *et al.*, 2022).

India has committed to ambitious climate goals under the Paris Agreement, aiming to reduce its emissions intensity by 33-35 per cent from 2005 levels by 2030. The country is also focusing on expanding its renewable energy capacity to 500 GW by 2030 as part of its National Action Plan on Climate Change. This transition is crucial for India as it seeks to balance economic growth with environmental sustainability (Urhan *et al.*, 2023). Meeting these targets requires significant reductions in GHG emissions across all sectors of society, including energy, transportation, agriculture and industry. This entails not only improving energy efficiency and transitioning to renewable energy sources but also transforming land-use practices to minimize emissions from deforestation and agricultural activities (Lamnatou *et al.*, 2023).

1.1 Carbon Neutrality

The concept of carbon neutrality achieving a balance between emissions and removals has emerged as a central framework for climate action. This approach recognizes that while reducing emissions is critical, some level of CO_2 emissions may remain unavoidable (Chen, 2021). Thus, carbon sequestration through forests, soils and technological solutions becomes essential to offset these emissions (Sedjo and Sohngen, 2012). The goal of carbon neutrality aligns with the broader objective of limiting global warming, ensuring the stability of earth's climate system and reducing the risks associated with climate change for future generations.

The path to carbon neutrality requires comprehensive policy reforms, technological innovations and behavioural changes at every level of society. As countries set ambitious emission reduction targets, the success of these efforts depends on collaborative global action and tailored local solutions (Vallejo *et al.*, 2018). Understanding the global climate crisis and the need for carbon neutrality sets the foundation for this research, which focuses on the role of rural environments and their contributions to carbon management and sustainable development.

1.2 The Role of Rural Environments in Climate Action

While urban areas often dominate discussions on climate change due to their high energy consumption, industrial activity and dense population, rural environments play an equally significant role in the global carbon cycle. Rural regions, covering nearly 80 per cent of the earth's inhabited land surface, function as both sources of emissions and natural carbon sinks, highlighting the need for their inclusion in carbon neutrality efforts. These areas are home to diverse ecosystems, agricultural landscapes and forests, all of which contribute to carbon fluxes the exchange of carbon between the atmosphere and the land.

Rural environments are often associated with agricultural emissions, including methane (CH_4) and nitrous oxide (N_2O) from livestock, rice cultivation and the use of synthetic fertilizers (Kebreab *et al.*, 2006). Additionally, activities such as fuelwood harvesting for cooking and traditional land-use practices contribute to carbon emissions. However, rural areas also offer considerable potential for carbon sequestration through afforestation, soil carbon storage and the preservation of native vegetation. Forested lands, particularly those managed by local communities, play a vital role in absorbing CO_2 from the atmosphere and stabilizing the climate (Aune *et al.*, 2004).

Given their dependence on natural resources, rural communities often have a unique knowledge and experience in managing local ecosystems. This provides an opportunity to integrate traditional ecological knowledge with modern carbon management strategies (Vierros, 2017). Additionally, promoting sustainable practices such as agroforestry, regenerative agriculture and efficient energy systems can help reduce emissions while enhancing carbon sequestration.

Addressing climate change in rural areas requires context-specific solutions that account for the socioeconomic conditions, cultural practices and resource constraints of these regions. Unlike urban settings, rural environments often face limited access to clean energy technologies, infrastructure and climate-related finance, which can hinder efforts to transition to low-carbon pathways (Konečný *et al.*, 2024). At the same time, these areas have the potential to become critical actors in the global effort toward carbon neutrality if empowered with the right policies and resources.

1.3 Role of Native Trees in Carbon Sequestration

Carbon sequestration, the process of capturing and storing CO_2 from the atmosphere, plays a critical role in mitigating climate change and achieving carbon neutrality. Local trees and forests are key natural carbon sinks, storing carbon in their biomass and soils while also offering environmental, social and economic benefits (Sedjo and Sohngen, 2012). Through photosynthesis, trees absorb CO_2 and convert it into organic matter, which is stored in their roots, trunks and leaves (Kirschbaum, 2003). This natural process makes forests and agroforestry systems essential components in offsetting greenhouse gas emissions.

In rural areas, native tree species such as Palmyrah palms serve as vital carbon sinks while also supporting livelihoods. Palmyrah palms, known for their adaptability to arid conditions, are well-suited for sustainable carbon management. These trees not only absorb significant amounts of CO_2 but also provide economic resources such as food, timber and non-timber products, making them invaluable for rural economies (Dey *et al.*, 2014). Local trees, which are naturally adapted to the environment, require minimal external inputs, are more resilient to climate variability and contribute to biodiversity by providing habitat for native species.

Preservation and expansion of tree cover through practices such as reforestation, afforestation and agroforestry enhance the carbon sequestration potential of local ecosystems. Beyond capturing carbon, trees improve soil quality by adding organic matter, increasing water retention and preventing erosion (Nave *et al.*, 2019). These environmental benefits make tree-based approaches to carbon management not only effective for climate mitigation but also crucial for improving agricultural productivity and ecosystem resilience.

1.4 Socio-Economic Benefits of Carbon Sequestration in Rural Areas

Carbon sequestration not only serves environmental goals but also offers significant socio-economic benefits, particularly in rural communities. These benefits extend beyond the direct environmental impact of reducing atmospheric carbon dioxide levels and include improving livelihoods, enhancing economic resilience, and contributing to sustainable rural development (Lal, 2004). One of the primary advantages is income generation for farmers. By participating in carbon sequestration projects such as reforestation or agroforestry, farmers can earn revenue through carbon credits, which can be traded on carbon markets (Smith *et al.*, 2008). This creates an additional income stream, incentivizing sustainable land management practices.

In addition to financial gains, carbon sequestration can significantly enhance agricultural productivity. Practices that sequester carbon, like agroforestry, improve soil fertility and water retention, leading to higher crop yields (Pretty, 2008). This directly benefits farmers by enhancing food security and increasing their income. Moreover, carbon sequestration efforts contribute to building climate resilience. Improved soil health and sustainable land management techniques make rural areas less vulnerable to climate-related risks such as droughts and floods, thereby stabilizing local livelihoods (Barker *et al.*, 2009).

Employment generation is another key benefit of carbon sequestration projects in rural areas. Activities like tree planting, forest management, and carbon monitoring provide job opportunities for local communities, fostering economic growth and skill development (World, 2008). Furthermore, these projects often contribute to biodiversity conservation, enhancing ecosystem services such as pollination and natural pest control, which improve agricultural outcomes and reduce the need for chemical inputs.

Diversifying livelihoods is another important socio-economic advantage. Carbon sequestration through agroforestry or other sustainable practices allows rural households to engage in multiple income-generating activities. Besides farming, communities can harvest timber, fruits, or non-timber forest products, which provide additional sources of revenue (McKinsey, 2009). These diverse income streams can help stabilize rural economies and reduce dependency on a single form of livelihood.

Moreover, community empowerment is often an outcome of carbon sequestration initiatives, as many projects are participatory in nature. Involving local communities in decision-making processes enhances social cohesion and equips residents with the knowledge and skills necessary to manage their land sustainably (Change, 2014). This empowerment leads to a stronger sense of ownership and responsibility for local environmental conservation efforts.

Health and environmental quality also improve as a result of carbon sequestration efforts. Sustainable land use reduces air and water pollution, benefiting the overall health of rural populations (Lal, 2004). Healthier environments lead to lower healthcare costs and improve the quality of life for rural communities. Finally, governments often support carbon sequestration projects through policy incentives, providing subsidies, technical assistance, or tax benefits. Such support can further bolster rural economic development while contributing to national sustainability goals (Smith *et al.*, 2008).

1.5 Balancing Emissions and Sequestration for Carbon Neutrality

The balance between emissions reduction and carbon sequestration is central to achieving carbon neutrality in rural areas. Carbon neutrality does not mean eliminating emissions altogether but rather ensuring that emissions are offset by the carbon sequestration potential of natural and managed ecosystems (McCaw, 2012). For rural communities, this balance can be achieved through a combination of sustainable land management, renewable energy adoption and the strategic planting of high-sequestration species like the palmyrah palm.

The process of balancing emissions and sequestration involves continuous monitoring and management. Tools such as remote sensing, carbon accounting models and field surveys are critical for assessing the carbon balance in rural environments. These tools allow for the accurate measurement of both emissions and sequestration over time, ensuring that rural villages are on track to meet their carbon-neutral goals (Lal, 2004; Ituen and Hu, 2023).

Furthermore, engaging rural communities in the management and monitoring of carbon sequestration efforts is essential for success. Community participation ensures that local knowledge is incorporated into carbon management strategies and fosters a sense of ownership over the carbon-neutral initiatives. This participatory approach also helps to align carbon sequestration efforts with the economic and social goals of the community, ensuring long-term sustainability (Negewo *et al.*, 2016).

Achieving carbon neutrality in rural villages is a complex but attainable goal. By focusing on both reducing emissions and enhancing sequestration, rural areas can contribute significantly to global climate change mitigation efforts. The role of species like the palmyrah palm, combined with sustainable agricultural practices and renewable energy adoption, presents a clear pathway toward balancing rural carbon emissions and sequestration.

1.6 Problem Focus

With the intensification of climate change and the rise in global temperatures, understanding the sources and sinks of carbon emissions has become important. While significant research has been conducted on carbon emissions and sequestration at national and urban levels, studies specific to rural villages remain limited. Furthermore, most existing literature has focused on large-scale forestry or agroforestry projects. However, there aren't many studies addressing the distinct potential of species like palmyrah palms, which are particularly suited to arid and semi-arid regions.

This study addresses these gaps by examining the balance between carbon emissions and sequestration in a rural village in Tamil Nadu, emphasizing the role of palmyrah palms in achieving carbon neutrality. By assessing both the emissions generated from rural household and agricultural activities and the sequestration potential of palmyrah palms, this research seeks to provide a nuanced understanding of carbon dynamics within rural Indian communities, thus contributing valuable insights to the field of carbon management.

Rural villages contribute significantly to carbon emissions through household energy use, primarily from biomass burning, agricultural practices and land-use changes like deforestation. These emissions, though individually small, collectively play a substantial role in regional carbon footprints. At the same time, rural areas hold immense potential for carbon sequestration through natural processes, especially through the cultivation of trees like palmyrah palms, which are well-suited to the local climate and possess high carbon sequestration capacity.

The core problem addressed by this study is the imbalance between carbon emissions and carbon sequestration in rural areas. To achieve carbon neutrality, it is essential to quantify the total emissions generated by households and agriculture, assess the carbon sequestration potential of the palmyrah palms and determine whether this balance can shift towards a carbon-neutral or even carbon-negative outcome. Additionally, the study aims to understand the community's willingness to accept and expand palmyrah cultivation, which is key to implementing effective, large-scale sequestration efforts. Ultimately, the study seeks to evaluate whether the village can become a carbon sink, contributing to global climate change mitigation efforts while improving local socio-economic conditions.

1.7 Objectives

The objectives of this study are as follows:

1. To quantify the household carbon emissions in the selected village of Thoothukudi district.
2. To estimate the carbon emissions from agricultural activities focussing major crops.
3. To estimate the carbon sequestration potential of Palmyrah palm in the selected village
4. To analyze the willingness to expand the Palmyrah plantations as a carbon sequestration strategy.
5. To assess the overall carbon balance scenario for the village.

1.8 Hypothesis

The hypothesis underlying this research are,

1. There exists potential for the village not only to achieve carbon neutrality but also to function as an even greater carbon sink by expanding Palmyrah cultivation, resulting in net negative carbon emissions.
2. There exist significant socioeconomic factors that shape and influence the potential for expanding Palmyrah palm cultivation in the village.

2 METHODOLOGY

To achieve the objectives of this study, a suitable methodology was designed, which includes sampling design, data collection methods and the specification of empirical models and analytical tools. This chapter offers a brief summary of the methodologies used. It describes the sampling framework for selecting the study area and respondents, identifies the data sources and types of data collected and outlines the analytical framework, including the quantitative tools employed for data analysis. These components are thoroughly discussed under the following headings.

2.1. Selection of the Study Area

2.2. Sampling Design

2.3. Study Period

2.4. Assessment Boundary

2.5. Method of Data Collection

2.6. Tools of Analysis

2.1 Selection of the Study Area

The study area was chosen with a focus on the high density of palmyrah palm trees, a crucial factor for analyzing carbon sequestration potential. Thoothukudi district was selected due to its substantial number of palmyrah palms, accounting for 5.19 crore out of the 8.59 crore in Tamil Nadu. Thoothukudi district comprises 14 blocks, of which, Vilathikulam block was selected because it has one of the largest areas under palmyrah cultivation accounting 719.99 hectares during 2022-23. In this block, Vembar village was selected for its significant area of 220.57 hectares under palmyrah cultivation. For our study, Vembar South Gram Panchayat was specifically selected, since it has an area with a dense concentration of palmyrah palms. This selection process ensured that the study could effectively measure carbon emissions and sequestration while also exploring the community's willingness to expand palmyrah cultivation towards a carbon-neutral village environment.

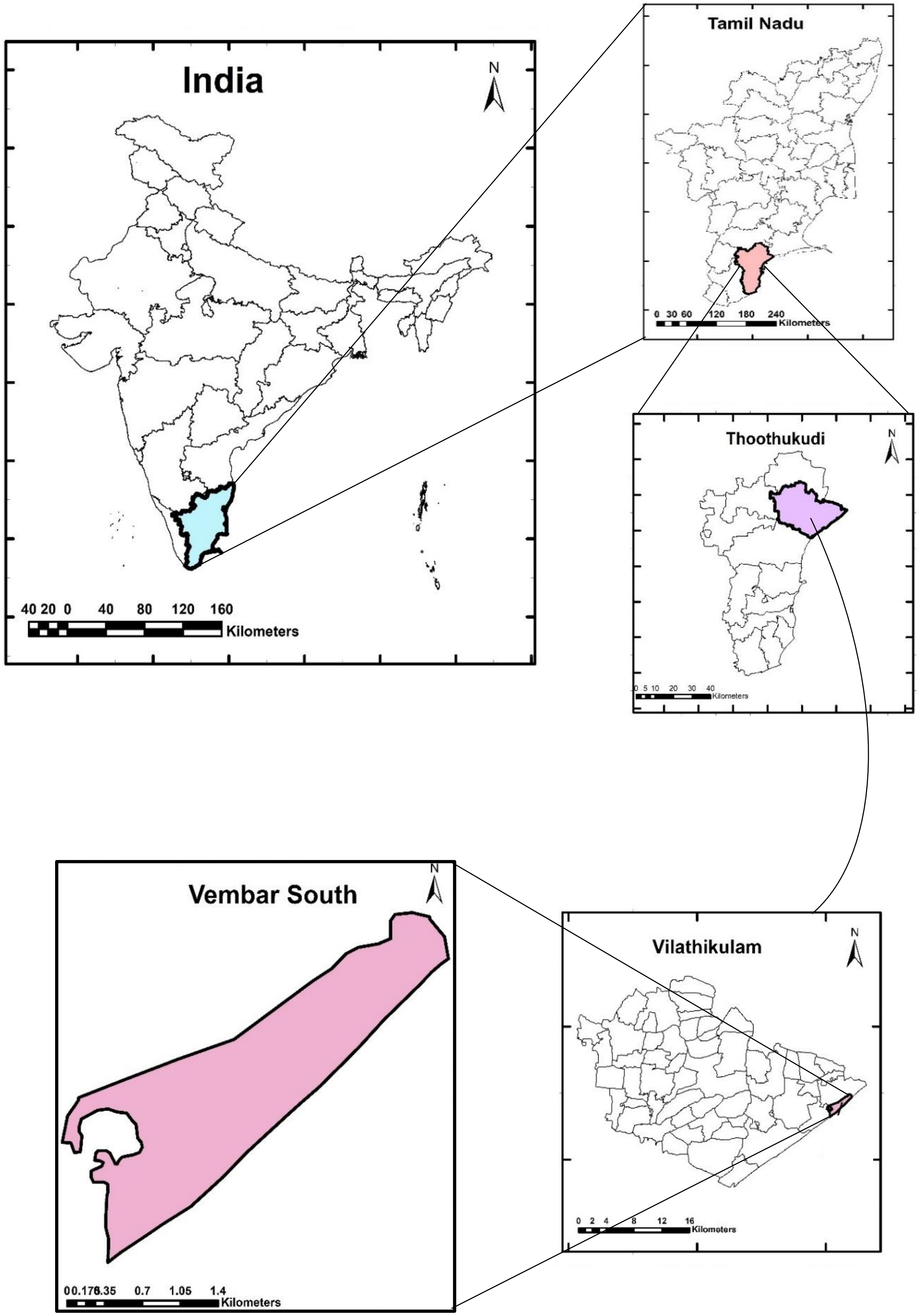

Figure 2.1. Map Showing the Study Area

Table 2.1. Block-wise area under Palmyra palm in Thoothukudi District of Tamil Nadu

(Area in hectares)

S.No.	Block	2021-22	2022-23
1	Udangudi	484.32	467.29
2	Alwarthirunagari	235.51	236.52
3	Tiruchendur	335.38	323.66
4	Karungulam	69.13	69.29
5	Srivaikundam	121.15	119.99
6	Thoothukudi	91.44	95.58
7	Sattankulam	530.04	532.11
8	Kovilpatti	6.84	5.86
9	Kayathar	3.20	4.36
10	Vilathikulam	705.55	719.99
11	Pudur	13.43	13.52
12	Ottapidaram	23.22	22.97

(**Source**: Block "G"- Return particulars of Thooothudi, 2022-23)

Table 2.2. Village-wise area under Palmyra palm in Thoothukudi District of Tamil Nadu

(Area in hectares)

S.No	Village	2022-23	S.No	Village	2022-23
1	A.Subramaiapuram	0	28	M Subramaniyapuram	0
2	Ariyanayagipuram	0	29	Melmanthai	0
3	Arunkulam	0	30	Manthikulam	21.12
4	Attankarai	51.88	31	Marthandanpatti	0.11
5	Ayanbommaiyapuram	0.04	32	Madharajapuram	0
6	Ayansengalpadai	0.02	33	Namasivayapuram	0
7	Chithavanaickenpatti	18.02	34	Nedunkulam	0.1
8	E.Velayuthapuram	2.00	35	Pallakulam	10.32
9	Guruvarpatti	0.2	36	Periyasamipuram	96.07
10	Jaminsengalpadai	0.09	37	Poosanoor	0.66
11	Jaminkarisalkulam	0.15	38	Puliyanulam	1.53
12	K Kumareddiapuram	0	39	S Kumaragiri	0
13	K Thangammalpuram	51.03	40	Sakkammalpuram	0.09
14	Kaloorani	0	41	Sivagnanapuram	0
15	Kamalapuram	0.06	42	Sivaperunkundram	46.2
16	Kannimarkuttam	0	43	Surangudi	3.43
17	Keela Vilathikulam 1	0.00	44	T Subbiahpuram	0
18	Keela Vilathikulam 2	0.01	45	Thathaneri	0.08
19	Koothaloorani	0	46	V Vedapatti	4.65
20	Kottanatham	0.44	47	Vaippar 1	0.74
21	Kulathur east	21.5	48	Vaippar 2	0.20
22	Kulathur North	50	49	Veerapandiyapuram	0.1
23	Kulathur South	85.19	50	Vellaiammalpuram	0
24	Kuralayampatti	0	51	Vembar	220.57
25	M Kodangipatti	0.39	52	Vilathikulam	2.55
26	M Kumarasakkanapuram	0	53	Virusampatti	0.64
27	M Shunmugapuram	27.43		Total	719.99

(**Source**: Village "G"- Return particulars of Vilathikulam, Thooothudi, 2022-23)

2.2 Sampling Design

A stratified random sampling method was employed for selecting sample respondents and 10 percent of households were covered from each hamlet to ensure comprehensive representation. The snowball method was employed to identify additional respondents, which facilitated the inclusion of a diverse range of respondents. For the assessment of carbon sequestration, palmyrah trees were sampled systematically by identifying 20 slots, each slot containing 25 trees. This approach allowed for detailed analysis across different tree clusters.

Table 2.3. Distribution of samples in the hamlets of Vembar Gram Panchayat

Name of Gram Panchayat	Name of the Hamlet	Total Number of Households	Number of sample households (10%)
Vembar South	Akkarai	56	6
	Matharasipuram	91	9
	Pachaiyapuram	152	15
	Subramaniyapuram	43	4
	Vaalasamuthirapuram	184	18
	Vembar South	1154	72
	Total	1680	124

2.3 Study Period

The primary data was collected and the sample respondents were surveyed during the month of April 2024 to May 2024.

2.4 Assessment Boundary

The assessment focused on all emissions and carbon sequestration within the physical boundary of Vembar South. This boundary included emissions from all households, agricultural activities, public services and communal areas within the village. However, the study excluded indirect emissions arising from the production of goods consumed by the village that occurred outside its limits. Emissions from activities beyond these geographical boundaries, such as transportation to external markets or external business-related activities were also excluded from the assessment.

2.5 Method of Data Collection

2.5.1 Primary Data

Primary data collection was conducted out through personal interviews and field observations. Households were surveyed to gather comprehensive data on household's socio-economic profile status including age, education, size of family, occupation, energy consumption, including the use of electricity, LPG, wood and kerosene, as well as information on public and private transportation. Additionally, the survey covered agricultural practices focusing on palmyrah palm cultivation and community perspectives on expanding palmyrah cultivation. Beyond household data, emissions from various sectors were collected, including value addition processes, shops and other local small-scale industries. The study also documented transportation emissions by assessing the types and usage of vehicles.

For palmyrah trees, the tree height and diameter at breast height was measured using Haga altimeter and Measuring Tape respectively.

2.5.2 Secondary Data

Secondary data collection for the study involved sourcing information from existing records and publications. Electricity usage data were obtained from the Soorangudi division, TANGEDCO which provided insights into energy consumption patterns in the village. Additional data on demographics, waste generation and other relevant local information were sourced from the gram panchayat records. General information, including demographic details, land utilization patterns, cropping patterns, agro-climatic conditions, rainfall and irrigation sources were collected from the District Statistical Office. Livestock census data were collected from District Veterinary department.

2.6 Tools of Analysis

2.6.1 Conventional analysis

The conventional analysis, which includes percentage and average analysis was employed to examine various socio-economic variables, including age, family size, farming experience, annual income, land ownership, gender, educational status, primary occupation and family type. This approach allowed for a comprehensive understanding of the demographic and economic characteristics of the sampled households.

2.6.2 Estimation of Carbon Dynamics

2.6.2.1 Selection and Classification of Carbon Sources and Sinks

The classification of carbon sources and sinks in this study was methodically designed to provide a thorough evaluation of Vembar South's carbon emissions and sequestration dynamics. The selection process was based on the relevance of each source or sink to the village's socio-economic activities and environmental conditions, while also taking into account the availability of reliable data. The carbon sources were categorized into three distinct groups based on their origin and nature of emissions. Moreover, emissions were further stratified by scope distinguishing direct emissions (Scope 1) from localized activities such as household energy consumption and agricultural processes, indirect emissions (Scope 2) arising from the use of purchased electricity and all other indirect emissions (Scope 3), which encompass emissions embedded in the production and supply chain of goods, as defined by the World Resources Institute and WBCSD (2004). Notably, Scope 3 emissions were excluded, in accordance with the study's assessment boundaries. Table 2.4 provided a detailed breakdown of the carbon sources and sinks within the geographical boundary of Vembar South which were considered for the present study. Scope 1 emissions referred to direct emissions from activities under the immediate control of village households and public services, while Scope 2 emissions were indirect emissions from the consumption of purchased energy, particularly electricity.

Table 2.4. Classification of Carbon Sources and Sink

Category	Source	Sub-source	Greenhouse Gases Involved	Classification
Carbon Sources				
Household	Cooking & Heating	LPG	CO_2, CH_4, N_2O	Direct Emissions (Scope 1)
		Fuelwood	CO_2, CH_4, N_2O	Direct Emissions (Scope 1)
		Kerosene	CO_2, CH_4, N_2O	Direct Emissions (Scope 1)
		Electricity	CO_2	Indirect Emissions (Scope 2)
	Transportation	Two-wheeler	CO_2	Direct Emissions (Scope 1)
		Four-wheeler	CO_2	Direct Emissions (Scope 1)
		Public transport by Bus	CO_2	Direct Emissions (Scope 1)
Agriculture	Value addition (Palm jaggery production)	Fuelwood	CO_2, CH_4, N_2O	Direct Emissions (Scope 1)
	Livestock		CH_4, N_2O	Direct Emissions (Scope 1)
Public and Other Services	Waste Management	Open Burning	CO_2	Direct Emissions (Scope 1)
	Electricity	Public lighting, schools, etc.	CO_2	Indirect Emissions (Scope 2)
Carbon Sink				
Natural Vegetation	Palmyrah palms		CO_2 Sequestered	Natural Sink

2.6.2.2 Estimation of carbon footprint

The carbon emissions for this study were calculated using the Emission Factor Approach as outlined in the 2019 IPCC guidelines. This method provided standardized emission factors that account for CO_2, CH_4 and N_2O emissions across various activities. Household emissions were calculated based on energy consumption data, particularly focusing on fuel types used for cooking and heating. Biomass combustion (primarily from firewood) was a significant source of emissions and the respective emission factors provided by the IPCC were applied to estimate the release of CO_2 and CH_4.

Electricity consumption data were collected through household surveys and cross-verified with records from the local electricity provider and emissions were computed using India-specific grid emission factors. Transportation-related emissions were estimated by considering vehicle usage patterns, fuel types and distances travelled, with corresponding emission factors applied.

Agricultural emissions, particularly those arising from palm jaggery production and livestock management were assessed using sector-specific emission factors. Methane and nitrous oxide emissions from livestock were calculated by taking into account the number and type of animals, as well as manure management practices. The carbon emissions from palm jaggery production were calculated based on biomass (fuelwood) usage during the production process.

Other sources of emissions, such as waste incineration and electricity consumption for public facilities (e.g., street lighting, schools) were also incorporated into the overall emissions profile. These were estimated using a combination of direct observations and community records, in accordance with the IPCC's guidelines for waste management and public energy consumption. The total emissions from all sources were then aggregated to quantify the total carbon footprint of Vembar South, that helps to provide a holistic understanding of the village’s emissions profile.

2.6.2.3 Estimation of Carbon Sequestration

The carbon sequestration potential of the palmyra palms in Vembar South was calculated by measuring the tree height and Diameter at Breast Height (DBH). These measurements were collected from randomly selected trees in the village. To assess the carbon stock available in palmyrah palms, 20 sample slots were selected from the village by covering 25 trees from each slot was randomly selected and measurements on diameter at breast height (DBH) and the height of the trees were collected. The DBH was measured using a measuring tape and expressed in centimetres (cm), while the height of the trees was measured using a Haga altimeter and expressed in meters (m) (Yasin *et al.*, 2021).

2.6.2.3.1. Tree Biomass Estimation

The tree biomass was estimated using a non-destructive sampling method. Both above-ground biomass (AGB) and below-ground biomass (BGB) were estimated.

a) Above Ground Biomass (AGB)

The above ground biomass of tree includes the whole shoot, branches, leaves, flowers and fruits. It is calculated using the following formula:

$$\text{AGB (kg tree}^{-1}) = 0.0673 \text{ x } (\text{ H x } \rho \text{ x } D^2)^{0.976}$$

Where ρ = Wood density (kg/m^3)

D = Diameter of the tree in meters

H = Height of the tree in meter

For palmyra palms, the standard average value for wood density is assumed to be 0.870 gm/cm^3 (Zanne *et al.,* 2009).

b) Below Ground Biomass (BGB)

Below ground biomass includes all biomass of the root system, which weighs about 20 per cent as much as the above-ground biomass of the tree (De Villiers *et al.*, 2014).

$$\text{BGB (kg tree}^{-1}) = \text{AGB (kg tree}^{-1}) \text{ x } 0.20$$

c) Total Biomass

Total biomass is the sum of the above-ground and below-ground biomass.

$$\text{Total Biomass (kg tree}^{-1}) = \text{BGB (kg tree}^{-1}) + \text{AGB (kg tree}^{-1})$$

2.6.2.3.2. Estimation of Carbon Stock

The carbon stock was estimated by converting the total biomass to carbon content. It is generally assumed that 49.86 per cent of the biomass is carbon (Rajadurai *et al*., 2021).

$$\text{Carbon Stock (kg tree}^{-1}) = \text{Total Biomass(kg tree}^{-1}) \text{ x } 0.4986$$

2.6.2.3.3. Estimation of CO_2 Sequestered

The CO_2 equivalent was estimated by converting the carbon stock to CO_2. The conversion factor used is 3.67, representing the molecular weight ratio of CO_2 to carbon (44/12).

$$\text{CO}_2 \text{ sequestered (kg tree}^{-1}) = \text{Carbon Stock(kg tree}^{-1}) \text{ x } 3.67$$

2.6.2.4 Estimation of Net Carbon Emission

The net carbon balance was determined by evaluating the total carbon emissions in relation to the carbon sequestered by Palmyrah palms and other natural processes. The formula employed to calculate the net carbon balance is as follows:

$$\text{Net Carbon Emissions} = \text{Total Carbon Emissions} - \text{Total Carbon Sequestration}$$

This overall net carbon balance offers valuable insights into whether the village functions as a net carbon source or sink. If the total carbon sequestration surpasses emissions, the village is classified as a net carbon sink, thereby positively contributing to climate change mitigation efforts. Conversely, if emissions exceed sequestration, it signifies a net carbon source, underscoring the necessity for additional emissions reduction or improved sequestration initiatives. This balance serves as a crucial basis for evaluating the feasibility of achieving carbon neutrality at the village level.

2.6.3 Binary Probit Model

In this study, the factors influencing the willingness of landowners to expand Palmyrah palm cultivation in their fields were analyzed using a Probit regression model. The Probit model was selected due to its suitability for analyzing binary outcome variables, where the dependent variable is either 0 (not willing to expand) or 1 (willing to expand).

2.6.3.1 Model Specification

The Probit model is a type of regression used when the dependent variable is binary. It models the probability that a certain event occurs, based on the cumulative normal distribution function. In this study, the event of interest is whether or not the landowner is willing to expand Palmyrah palm cultivation. The Probit model is specified as follows:

$$P(Y = 1 \mid X) = \Phi(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k)$$

Where;

$P(Y = 1 \mid X)$	:	Probability that the landowner is willing to expand Palmyrah palm cultivation, given the set of independent variables.
$\Phi(.)$	:	Cumulative distribution function of the standard normal distribution.
β_0	:	Intercept term.
$\beta_1, \beta_2, \dots, \beta_k$	:	Coefficients corresponding to the independent variables $X_1, X_2, \dots, X_k$.

2.6.3.2 Determinant of Willingness to Expand the Number of Palmyrah Palms

The analysis incorporated a variety of socio-economic variables hypothesized to influence the willingness to expand Palmyrah palm cultivation are given in Table 2.5.

Table 2.5. Determinant of Willingness to Expand the Palmyrah Palms

Independent Variables	Measurement Units	Description	Variable Definition
Age (X1)	Years	Represents the age of the landowner	Continuous variable
Gender (X2)	Binary (0 or 1)	Gender of the landowner	Male = 1, Female = 0
Education (X3)	Binary (0 or 1)	Educational status of the landowner	Illiterate = 0, Literate = 1
Primary Occupation (X4)	Binary (0 or 1)	Primary occupation of the landowner	Agriculture = 1, Others =0

Independent Variables	Measurement Units	Description	Variable Definition
Family Type (X5)	Binary (0 or 1)	Family type of the landowner	Nuclear Family = 1, Joint Family = 0
Family Size (X6)	Numbers	Number of family members in the household	Continuous variable
Experience in Occupation (X7)	Years	Experience in the primary occupation	Continuous variable
Annual Income (X8)	Rupees	Annual income of the landowner	Continuous variable
Land Ownership (X9)	Hectares	Amount of land owned by the landowner	Continuous variable

2.6.3.3 Calculation of Marginal Effects

In addition to estimating the coefficients of the Probit model, the marginal effects were calculated to better understand the impact of each independent variable on the probability of willingness to expand Palmyrah palm cultivation. The marginal effect provides insight into how a one-unit change in an independent variable affects the probability of the dependent variable being 1, holding all other variables constant.

$$\text{Marginal Effect} = \phi(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k) \times \beta_i$$

Where:

$\Phi(.)$ represents the probability density function of the standard normal distribution.

β_i is the coefficient of the independent variable of interest.

3 DESCRIPTION OF THE STUDY AREA

This chapter provides essential context for research by detailing the geographic, environmental and socio-economic characteristics of the location where the study is conducted. This information is crucial as it helps readers understand the specific conditions under which the research was carried out, allowing them to assess the relevance, applicability and limitations of the study's findings. This section outlines factors such as climate, vegetation, topography, population demographics and land use patterns of the Thoothukudi district.

3.1 Geopolitical Location

Thoothukudi district, located in the southern part of Tamil Nadu, covers a geographical area of 4,707 square kilometers. The district lies between 8°08'N to 9°23'N latitude and 77°30'E to 78°20'E longitude. It is bordered by Virudhunagar and Ramanathapuram districts to the north, the Gulf of Mannar to the east, Tirunelveli district to the west and the Bay of Bengal to the southeast. The topography of the district is characterized by its coastal plains, with a few isolated hills. The region's elevation varies, with the coastal plains near sea level and the interior regions slightly elevated.

3.2 Administrative Setup

Thoothukudi district is administratively divided into ten taluks: Eral, Kayathar, Thoothukudi, Srivaikuntam, Tiruchendur, Kovilpatti, Vilathikulam, Sathankulam, Ottapidaram and Ettayapuram. The district has 3 Revenue Divisions, 10 Taluks, 480 Revenue Villages, 12 Blocks, 1 Corporation, 3 Municipalities, 18 Town Panchayats and 403 Village Panchayats. The district has Six Assembly Constituencies and One Lok Sabha Constituency. The administrative setup and administrative framework of the Thoothukudi district are presented in Table 3.1 and Table 3.2 respectively.

Table 3.1. Administrative Setup of Thoothukudi District

S.No.	Administrative Division	Numbers
1.	Revenue Divisions	3
2.	Taluks	10
3.	Revenue Firkas	41
4.	Revenue Villages	480
5.	Municipalities	3
6.	Panchayat Unions (Blocks)	12
7.	Town Panchayats	18
8.	Village Panchayats	403

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

Table 3.2. Administrative Framework of Thoothukudi District

Corporation	Municipalities	Panchayat Unions	Town Panchayats
Thoothukudi	1. Kovilpatti 2. Kayalpattinam 3. Tiruchendur	1. Thoothukudi 2. Srivaikundam 3. Karungulam 4.Alwarthirunagari 5. Tiruchendur 6. Udangudi 7. Sattankulam 8. Kovilpatti 9. Kayathar 10. Vilathikulam 11. Pudur 12. Ottapidaram	1. Alwarthirunagari 2. Author 3. Arumuganeri 4. Eral 5. Ettayapuram 6. Kadambur 7. Kalugumalai 8. Kanam 9. Kayathar 10. Nazareth 11. Perungulam 12. Pudur 13. Sattankulam 14. Sawyerpuram 15. Srivaikundam 16.Thenthirupperai 17. Udankudi 18. Vilathikulam

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.3 Demographic Pattern

According to the Census 2011, the district had a population of 1,750,176 people, among which 49.42 percent were female and 50.58 percent were male. The sex ratio and the population density of the district were 1,023 female per 1,000 male and 369 persons per square kilometer, respectively. About 50.10 percent of the district's total population resided in urban areas, while the remaining 49.90 percent lived in rural areas. The literacy rate of the district was 86.16 percent, with male and female literacy rates at 91.14 percent and 81.10 percent, respectively. Literacy was higher in urban areas (91.84 percent) compared to rural areas (80.60 percent).The demographic information of the Thoothukudi district is presented in Table 3.3, Table 3.4.

Table 3.3. Demographic Description of Thoothukudi District

S. No	Particulars	Numbers	Percent to the total population
1	Total Population	1750176	100
	i) Male	865021	49.42
	ii) Female	885155	50.58
2	Total Rural and Urban Population		
	i) Rural	873374	49.90
	ii) Urban	876802	50.10
3	Total Literates	1349697	86.16
	i) Male	703106	52.09
	ii) Female	646591	47.91
4	Population Density / km^2	369	
5	Sex ratio (Female per 1000 male)	1023	
6	Child Sex Ratio	963	
7	Number of Households	462010	

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

Table 3.4. Population by Age Groups

S.No.	Age Groups	Persons	Percentage to total
1.	0-14	428475	24.5
2.	15-59	1120799	64
3.	60 and above	199194	11.4
4.	Age not stated	1708	0.10
	Total	1750176	100

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.4 Distribution of Working Population

The district total labour force comprises about 7,48,095 persons, making up 42.74 percent of the total population. Among them, 63.64 percent were engaged in other types of work, 26.82 percent were agricultural labourers, 12.12 percent were marginal workers, 6.49 percent were cultivators and 3.06 percent were household industrial workers as provided in Table 3.5.

Table 3.5. Occupational Distribution of Workforce in Thoothukudi District

S. No	Industrial Category	Numbers	Percentage to Total Workers	Percentage to Total Population
1.	**Main workers**	657447	87.88	37.56
	a) Cultivators	48515	6.49	2.77
	b) Agricultural labourers	200644	26.82	11.46
	c) Household industry workers	22863	3.06	1.31
	d) Other workers	476073	63.64	27.20
	Marginal workers	90648	12.12	5.18
	Total workers	748095	100.00	42.74
2.	**Non-workers**	1002081		57.26
Total population		1750176		100.00

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.5 Climate

The district experiences a tropical climate, characterized by high temperatures and moderate humidity. The climate is predominantly hot and dry, with summer temperatures ranging from 23.6°C to 34.9°C. The district is prone to high temperatures during the summer months from March to June, followed by a more moderate climate during the monsoon and winter seasons.

3.6 Rainfall Distribution

The district receives an average annual rainfall of approximately 570.1 mm, which is below the state average. The distribution of rainfall is uneven, with the coastal regions receiving more rainfall compared to the interior areas. The southwest monsoon contributes significantly to the annual precipitation, with the northeast monsoon providing additional rainfall during the latter part of the year.

Table 3.6. Season-wise Rainfall Distribution in Thoothukudi District

S.No.	Season	Rainfall (mm)	Rainfall (%)
1.	Southwest Monsoon (Jun-Sep)	120.1	21.07
2.	Northeast Monsoon (Oct-Dec)	308.9	54.18
3.	Winter (Jan-Feb)	22.2	3.89
4.	Summer (Mar-May)	118.9	20.86
	Total	570.1	100.00

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.7 Soil Type

The predominant soil types in the Thoothukudi district include red loam, laterite, black soil, sandy coastal alluvium and red sandy soil. Table 3.7 provides a detailed distribution of these soil types across the district.

Table 3.7. Distribution of Soil Types in Thoothukudi District

S. No.	Soil Type	Places in District
1.	Red Loam	Udangudi, Kayathar, Sattankulam
2.	Lateritic Soil	Srivaikuntam, Tiruchendur
3.	Black Soil	Kovilpatti, Kayathar, Vilathikulam, Thoothukudi and Ottapidaram
4.	Sandy Coastal Alluvium	Tiruchendur
5.	Red Sandy Soil	Udangudi, Sattankulam, Srivaikuntam, Karungulam, Ottapidaram, Vembar

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.8 Land Use Pattern

Table 3.8 illustrates the land utilization pattern in the Thoothukudi district for the year 2022-23. According to the table, Thoothukudi has a total geographical area of about 4.71 lakh hectares. Of this, approximately 44.77 percent (12.11 lakh hectares) is used for cropping (net sown area), 16.27percent for non-agricultural purposes, 4.63 percent as current fallow land, 13.16 percent as other fallow land and another 8.14 percent as cultivable waste land.

Table 3.8. Land Utilization Pattern in the Thoothukudi District

S. No.	Land Classification	Area (ha)	Percentage to Total Geographical Area
1.	Forest	11012	2.34
2.	Barren and Uncultivable uses	19685	4.18
3.	Land put to Non-agricultural uses	76583	16.27
4.	Cultivable Waste Land	38306	8.14
5.	Permanent Pastures and Other Grazing Land	5060	1.07
6.	Miscellaneous Tree Crops and Groves	25567	5.43
7.	Current Fallows	21818	4.63
8.	Other Fallows Land	61935	13.16
9.	Net Area Sown	210758	44.77
10.	Total Geographical Area	470724	100.00
11.	Area Sown more than once	3154	
12.	Gross Cropped Area	213911	
Cropping Intensity (%)		101.49	

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.9 Operational Landholdings

The operational landholding patterns in the Thoothukudi district is presented in Table 3.9. The table showed that the majority of farmers were categorized as marginal farmers, with operational areas of less than 1 hectare, totaling approximately 194,263 hectares (48.25 percent). In contrast, large farmers hold a minimal portion of the land, accounting for only 0.05 percent of the total farm holdings, with an operational area of 5,898 hectares.

Table 3.9. Operational Landholding Patterns in Thoothukudi District

S.No.	Land Holders Classification	Size of Holdings (ha)	Number of Holdings	Operational Area (ha)
1.	Marginal	< 1	114667 (64.71)	47496 (20.36)
2.	Small	1.1 - 2.0	31861 (17.98)	45497 (19.50)
3.	Semi -medium	2.1 - 4.0	19529 (11.02)	54118 (23.19)
4.	Medium	4.1 - 10.0	9379 (5.29)	54901 (23.53)
5.	Large	> 10.0	1768 (1.00)	31318 (13.42)
Total			177204 (100.00)	233331 (100.00)

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23

Figures in parentheses indicates percentage to the total)

3.10 Source of Irrigation

Table 3.10 provides information on the various sources of irrigation in the Thoothukudi district during the study period (2022-23). It shows that wells are the primary source of irrigation, with open wells accounting for 44.36 percent of the gross irrigated area, canals contributing 29.49 percent and followed by tanks contributing for about 22.08

percent of the gross cropped area, making up about 95.97 percent of the gross cropped area. The irrigation intensity of the district is noted to be 17.11 percent.

Table 3.10. Sources of Irrigation in Thoothukudi District

Source	Gross Area Irrigated (ha)	Percent to Total Gross Area Irrigated
I Surface Water:		
1. Canals		
i) Government Canals ii) Private Canals	10792	29.49
2. Tanks		
i) Large	3476	9.50
ii) Small	4603	12.58
II Ground Water:		
1. Private Tube Wells & bores	1491	4.07
2. Open Wells	16232	44.36
Total	23162	100.00
Irrigation intensity (%)	17.11	

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.11 Cropping Pattern

The cropping pattern in Thoothukudi district predominantly features food crops, occupying 89.94 percent of the total Gross Cropped Area (GCA) of 213,911 hectares. Cereals are the most significant category, covering 74.89 percent of the GCA, with maize as the leading crop at 23.38 percent, followed by paddy (6.00 percent), sorghum (3.86 percent) and cumbu (4.18 percent). Pulses also play a vital role, constituting 34.06 percent of the area, primarily with black gram (26.51 percent) and green gram (7.53 percent). Other notable crops include spices and condiments (8.24 percent), fresh fruits (4.77 percent) and vegetables (3.52 percent). Non-food crops account for 10.06

percent of the GCA, with fibre crops (4.00 percent) and palmyrah (1.22 percent) being the most prominent. The cropping pattern of Thoothukudi District is given in Table 3.11.

Table 3.11. Area under Major Crops in Thoothukudi District

S.No.	Crop	Area (ha)	Percentage Share to GCA
A.	**Cereals**		
1.	Paddy	12833	6.00
2.	Sorghum	8254	3.86
3.	Cumbu	8948	4.18
4.	Maize	50005	23.38
5	Kudhiraivali	52	0.02
	Total cereals	160196	74.89
B.	**Pulses**		
1.	Black gram	56702	26.51
2.	Green gram	16115	7.53
	Total pulses	72849	34.06
C.	**Total oilseed crops**	10576	4.94
D.	**Spices & condiments**		
	Chilli	14403	6.73
	Other Spices & condiments	3220	1.51
	Total Spices	17623	8.24
E.	**Sugar crops**		
	Palmyrah palm	2612	1.22
	Sugarcane	4	0.00
	Total sugar crops	2616	1.22

S.No.	Crop	Area (ha)	Percentage Share to GCA
F.	**Fresh fruits**		
	Banana	8648	4.04
	Other fresh fruits	1558	0.73
	Total Fresh Fruits	10206	4.77
H.	**Citrus fruits**	11260	5.26
I.	**Dry fruits**	417	0.19
	Total Fruits	11677	5.46
J.	**Vegetables**	7524	3.52
K.	**Fibre crops**	8562	4.00
M.	**Drugs &narcotics crops**	60	0.03
N.	**Fodder crops**	1215	0.57
O.	**Flowers**	383	0.18
P.	**Misc. Non-food crops**	636	0.30
Non-food crops		21516	10.06
Food crops		192387	89.94
Gross Cropped Area (GCA)		213911	100.00

(**Source**: Seasons and crop report, 2022-23)

3.12 Livestock

The livestock population of Thoothukudi District, as presented in Table 3.12, shows that poultry constitute the largest proportion, with 38.31 percent of the total livestock population. Goats follow at 30.33 percent, sheep at 15.20 percent and cattle at 9.45 percent. Pigs represent a minimal portion at 0.11 percent. The total poultry population in the district is 504,526 birds.

Table 3.12. Livestock Population of Thoothukudi District

S.No.	Particulars	Number	Percentage
1	Cattle	124466	9.45
2	Sheep	200264	15.20
3	Goats	399427	30.33
4	Pigs	1415	0.11
5	Poultry	504526	38.31
	Total	1317100	100.00

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.13 Agricultural Machinery and Implements

Table 3.13 presents the agricultural machinery and implements in Thoothukudi district. The data reflects efforts to modernize agriculture by promoting the use of various tools, equipment and machinery. The district has a total of 54 pieces of agricultural machinery, including 10 tractors, 24 power tillers, 1 power weeder, 3 multi-crop threshers, 2 cultivators, 8 rotavators, 1 mould board plough, 7 power sprayers and 1 baler. These figures indicate the district's commitment to enhancing agricultural productivity through mechanization.

Table 3.13. Agricultural Machinery and Implements in Thoothukudi District

S.No.	Particulars	Quantity in Numbers
1	Tractor	10
2	Power Tiller	24
3	Power weeder	1
4	Multi crop Thresher	3
5	Cultivator	2
6	Rotavator	8
7	Mould Board Plough	1
8	Power Sprayer	7
9	Baler	1
	Total	54

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.14 Infrastructure Facilities

3.14.1 Educational Institutions

Table 3.14 presents the educational institutions in Thoothukudi district. The district has 27 Arts and Science Colleges and various professional education institutions, including 1 Medical College, 10 Engineering Colleges, 1 Agricultural College, 1 Law/Physical Education College, 1 Fisheries College, 13 B.Ed. colleges, 7 Teacher Training Institutes, 5 Nursing Colleges/Schools, 1 DIET, 9 Polytechnics, 4 ITIs and 10 ITCs. There are also 23 Pre Primary Schools, 130 Nurseries, 1,055 Primary Schools, 300 Primary with Middle Schools, 73 High Schools, 128 Matriculation Schools and 158 Higher Secondary Schools.

Table 3.14. Educational Institutions in Thoothukudi District

S.No.	Educational Institution	Counts in number
1.	Arts and Science Colleges	27
2.	Colleges for Professional Education	
a.	Medicine (Allopathy)	1
b.	Engineering and Technology	10
c.	Agriculture	1
e.	Law / Physical Education	1
f.	Fisheries College	1
g.	B.Ed. colleges	13
h.	Teacher Training Institute	7
i.	Nursing College / Schools	5
j.	DIET/Polytechnics	1/9
k.	I.T.I / ITC	4/10
3.	Pre-Primary Schools/Nursery	23/130
4.	Primary Schools	1055
5.	Primary with middle school	300
6.	High Schools	73
7.	Matriculation Schools	128
8.	Higher Secondary Schools	158

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.14.2 Banking Institutions

Table 3.15 presents the banking institutions in Thoothukudi district. The district has a total of 128 Public Sector Bank branches, 74 Private Sector Bank branches, 25 Primary cooperative banks and 37 Regional Rural Banks. These institutions provide comprehensive banking services across the district.

Table 3.15. Banking Institutions in Thoothukudi District

S.No.	Banking Institution	Counts in number
1.	Public Sector Bank Branches	128
2.	Private Sector Bank Branches	74
3.	Primary Co-operative Banks	25
4.	Regional Rural Banks	37

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

3.14.3 Transport

Thoothukudi district's transport infrastructure given in Table 3.16, includes 162 km of national highways and 2305.114 km of state highways, along with an extensive network of local roads. It supports a significant vehicle fleet, with 8,298 commercial and 34,036 non-commercial vehicles. The district has 160.85 km of broad gauge railway tracks with 21 stations, enhancing connectivity. Additionally, Thoothukudi hosts a major seaport and an airport, providing vital maritime and air transport links. This robust infrastructure facilitates the district's economic and social activities.

Table 3.16. Transport Infrastructure in Thoothukudi District

S.No.	Transport particulars	Length
A)	Road Length	(in Km)
1.	National Highways	162.0
2.	State Highways	2305.114
3.	Corporation and Municipalities Road	747.66

S.No.	Transport particulars	Length
4.	Panchayat Union and Panchayat Road	3023.39
5.	Town Panchayat and Townships Road	465.82
B)	Registered Motor Vehicles	(in Numbers)
1.	Commercial	8298
2.	Non-Commercial	34036
C)	Railway Length	
1.	Route Length	(in Km)
	i. Broad Gauge	160.85
2.	Number of Railway Stations	21
D)	Seaport	1
E)	Airport	1

(**Source**: District Statistical Handbook, Thoothukudi District 2022-23)

4 RESULTS AND DISCUSSION

The current study investigated balance between carbon emissions and sequestration in Vembar South. The research covered a broad range of sources contributing to emissions, including household energy use, agricultural practices and other village-level activities, while also examining the potential for carbon sequestration, particularly through Palmyrah palms. To achieve the specific objectives outlined, primary data were collected from these different sectors and methodologies were applied to estimate both emissions and sequestration rates. The findings from the analysis are presented and discussed in the following sections, providing a detailed breakdown of emissions by category and evaluating the net carbon footprint of the village. This comprehensive approach not only highlights the primary drivers of emissions, but also underscores the influence of socio-economic factors on increasing the number of Palmyrah palms.

4.1. General Characteristics of Sample Respondents

4.2. Estimation of Village Carbon Footprint

4.3. Estimation of Carbon Sequestration by Palmyrah Palms

4.4. Estimation of Net Carbon Emission

4.5. Estimation of Influence of Socio-Economic Factors on Increasing the Number of Palmyrah Palms

4.1 General Characteristics of Sample Respondents

This section presents a comprehensive analysis of the demographic and socio-economic characteristics of the sample respondents, based on data collected from 124 households. The findings provide critical insights into the age distribution, gender, family type, family size, educational status, primary occupation, farming experience, land holdings and annual income of the respondents.

4.1.1 Age Distribution of Sample Respondents

Age profile of respondents significantly influence attitudes and behaviours toward carbon emissions, sequestration practices and community participation in sustainability initiatives. Different age groups might have distinct levels of awareness and experience related to environmental issues, affecting their willingness to participate in sustainability initiatives. Respondents were classified into four distinct age categories *viz.*, below 35 years, 36 to 45 years, 46 to 55 years and above 55 years. Table 4.1 provides a detailed breakdown of the age distribution among the sample respondents.

Table 4.1. Age Profile of Sample Respondents

S. No.	Age (Years)	No. of Sample Respondents	Percentage
1.	Below 35	35	28.23
2.	36 to 45	25	20.16
3.	46 to 55	37	29.84
4.	Above 55	27	21.77
Total		124	100.00

It could be observed from Table 4.1 that the majority of respondents (29.84 percent) were aged between 46 and 55 years, followed by those aged below 35 years (28.23 percent). Additionally, 20.16 per cent of respondents were aged between 36 and 45 years, while 21.77 per cent were aged above 55 years. This distribution highlights a diverse age range among the respondents, with significant representation across different age brackets.

4.1.2 Gender Distribution

The details of gender distribution of sample respondents are given in Table 4.2. Gender is also an important demographic factor that could significantly influence perspectives and engagement in maintaining the environmental sustainability. Gender roles often affect involvement in community initiatives and could shape attitudes toward environmental practices.

Table 4.2. Gender Composition of Sample Respondents

S.No.	Gender	No. of Sample Respondents	Percentage
1.	Male	82	66.13
2.	Female	42	33.87
Total		124	100.00

From Table 4.2, the results of the study indicates that majority of the respondents were male accounting for 66.13 percent, while female accounted for 33.87 percent. The predominance of male respondents might reflect broader societal norms and power structures within rural communities, where men often had greater access to resources and decision-making roles. This gender disparity could influence the findings, as male perspectives might dominate discussions on carbon management practices. Conversely, the under-representation of female voices limited our understanding of the critical role women play in sustainable practices and community engagement. Women often possess valuable knowledge regarding local resources and environmental stewardship, which is essential for developing effective carbon neutrality initiatives. Addressing these disparities is essential for achieving a comprehensive understanding of carbon emissions and sequestration in rural village environments.

4.1.3 Family Structure of Sample Respondents

Family structure of sample respondents are presented in Table 4.3 and it is essential for contextualizing the social dynamics that might influence carbon emissions and sequestration practices. Different family types could shape resource management and decision-making processes in rural environments.

Table 4.3. Family Type of Sample Respondents

S.No.	Family Type	No. of Sample Respondents	Percentage
1.	Nuclear Family	105	84.68
2.	Joint Family	19	15.32
Total		124	100.00

Table 4.3 reveals that a significant majority of respondents (84.68 percent) belong to nuclear family, while only 15.32 per cent are part of joint families. This predominance of nuclear families suggested a trend towards more individualized living arrangements in the rural village context. The prevalence of nuclear families might influence carbon management practices in various ways. For instance, nuclear families might prioritize immediate needs and resources differently than joint families, which typically had larger support networks and shared responsibilities (Nixon *et al.*, 2023). This difference could affect collective actions related to carbon emissions and sequestration strategies, as nuclear families might have less communal input in decision-making processes. The family type of respondents highlighted the structural dynamics that might play a major role in shaping their environmental behaviours. Recognizing these differences is essential for developing targeted interventions aimed at promoting carbon neutrality in rural village environments.

4.1.4 Family Size of Sample Respondents

The family size of sample respondents are provided in Table 4.4. Family size could play a significant role in shaping resource consumption, decision-making processes and collective actions related to emissions and environmental concern.

Table 4.4. Family Size of Sample Respondents

S.No.	Category (Numbers)	No. of Sample Respondents	Percentage
1.	Less than 4	57	45.97
2.	5 to 7	56	45.16
3.	Above 7	11	8.87
Total		124	100.00

It is inferred from Table 4.4 that nearly half of the respondents belong to families with fewer than four members (45.97 percent), while a similar proportion consists of families with 5 to 7 members (45.16 percent). Only a small fraction, 8.87 percent, reported having more than seven family members. This distribution highlighted the predominance of smaller family sizes within the community, which might have implications for resource management and carbon emission practices. Families with fewer members often had distinct consumption patterns and approaches to resource management compared to larger families. For instance, those in smaller households might prioritize individual responsibilities, potentially leading to less collective action in sustainability efforts (Shao *et al.*, 2024). On the other hand, families with more members might experience a balance between shared resources and individual roles, which could enhance community engagement in initiatives aimed at achieving carbon neutrality (Sun and Lu, 2023).

4.1.5 Educational Status of Sample Respondents

The educational status of respondents is a critical factor in understanding their awareness in carbon emission and sequestration practices. Education could influence individuals' knowledge of environmental issues and their willingness to adopt sustainable practices. The educational status of the sample households was analyzed and the results are presented in Table 4.5.

Table 4.5. Educational Status of Sample Respondents

S.No.	Category	No. of Sample Respondents	Percentage
1.	Illiterate	22	17.74
2.	Primary Education	54	43.55
3.	Secondary Education	25	20.16
4.	Higher Secondary Education	10	8.06
5.	Graduate	13	10.48
Total		124	100.00

Among the sample respondents, 17.74 per cent are illiterate, while 43.55 per cent had completed primary education. Secondary education was completed by 20.16 per cent of respondents and only 8.06 per cent had attained higher secondary education. A small proportion, 10.48 percent, hold graduate degrees. This distribution indicated a predominance of lower educational attainment levels, which might impact knowledge and attitudes towards carbon management practices. The findings suggest that a significant portion of the respondents, particularly those with only primary or no formal education, might lack awareness about emissions from household and agriculture and its management practices. This knowledge gap could hinder effective engagement in initiatives aimed at achieving carbon neutrality. In contrast, those with higher education levels might be better equipped to understand and advocate for sustainable carbon management practices within their communities. Educational status of respondents provides valuable insights into the potential challenges and opportunities for promoting carbon management strategies.

4.1.6 Primary Occupation

The primary occupations of respondents are critical for understanding the socio-economic dynamics within the rural village, particularly in relation to carbon emissions and sequestration practices. Different occupations contribute uniquely to the carbon footprint of the community, influencing both resource use and environmental impact. The different primary occupations of the sample respondents are presented in Table 4.6.

Table 4.6. Primary Occupations of Sample Respondents

S.No.	Primary Occupation	No. of Sample Respondents	Percentage
1.	Palm Tappers	34	27.42
2.	Fishermen	48	38.71
3.	Salt mine workers	18	14.52
4.	Others	24	19.35
Total		124	100.00

Table 4.6 reveals that the majority of respondents was engaged in fishing, with 38.71 per cent identifying as fishermen. This indicated a significant reliance on aquatic resources for livelihoods in the area. Following this, palm tappers constituted 27.42 per cent of the respondents, highlighting the importance of palm cultivation in the local economy. Salt mine workers represented 14.52 per cent of the sample, reflecting another critical sector for income generation. Lastly, the category of "Others," which included various occupations such as mechanics, wage workers, office employees and those in petty shops which accounted for 19.35 per cent of respondents. Understanding the primary occupations of respondents was essential for analyzing carbon emissions and sequestration practices in the village. The predominant reliance on fishing and palm tapping influenced land and resource management strategies, which were critical in the context of carbon neutrality. For instance, practices related to sustainable fishing and the management of palm resources had significant implications for carbon sequestration efforts. Furthermore, recognizing the diversity in occupations allowed for the development of tailored interventions that addressed the specific needs and practices of each occupational group,

promoting more effective sustainable carbon management practices. The distribution of occupations among respondents underscored the importance of economic activities in shaping environmental outcomes. The presence of a majority working in other sectors suggests that many individuals are adapting to changing economic conditions. However, this shift also highlights the need for training programs that develop skills relevant to both agricultural and non-agricultural sectors. By enhancing skills across various fields, the community could ensure sustainable livelihoods for its members and reduce vulnerability to economic shocks.

4.1.7 Occupational Experience of Sample Respondents

The total sample consisted of 124 respondents was categorized into three, those with less than 10 years, those with 10 to 30 years and those with more than 30 years of experience. The occupational experience of the sample respondents is presented in Table 4.7.

Table 4.7. Occupational Experience of Sample Respondents

S.No.	Occupational Experience (Years)	No. of Sample Respondents	Percentage
1.	Less than 10	43	34.68
2.	10 to 30	42	33.87
3.	Above 30	39	31.45
Total		124	100.00

Among the sample respondents, 43 respondents (34.68 percent) reported having less than 10 years of occupational experience. This indicated a notable presence of relatively new professionals within the sample. In comparison, 42 respondents (33.87 percent) fell within the 10 to 30 years of experience, suggesting a significant segment of the workforce with moderate experience. Lastly, 39 respondents (31.45 percent) had more than 30 years of experience.

4.1.8 Landholding Pattern of Sample Respondents

The landholdings of respondents play a crucial role in evaluating their potential contributions to carbon emissions and sequestration in rural village environments. The distribution of land ownership could significantly influence agricultural practices within the community. The distribution of landholdings among the sample respondents are detailed in Table 4.8.

Table 4.8. Landholdings of Sample Respondents

S.No.	Landholdings	No. of Sample Respondents	Percentage
1.	Marginal (< 1.0 ha)	18	14.52
2.	Small (1.0 – 2.0 ha)	9	7.26
3.	Medium (2.1 – 4.0 ha)	4	3.23
4.	Large (> 4.0 ha)	3	2.42
5.	Other Occupation	90	72.58
Total		124	100.00

In addition, 18 respondents (14.52 per cent) had marginal landholdings of less than 1.0 hectare, while 9 respondents (7.26 per cent) fell into the small landholding category, owning between 1.0 and 2.0 hectares. These groups might have limited capacity for extensive agricultural activities or carbon management initiatives. Only a small number of respondents reported medium (3.23 per cent) and large landholdings (2.42 per cent), indicating a concentration of land ownership among a few individuals in the community. This distribution is critical for understanding the dynamics of land use and its implications for carbon emissions and sequestration strategies in rural village environments.

4.1.9 Annual Income of Sample Respondents

The annual income of respondents is a critical factor in assessing their economic capacity and potential involvement in carbon emissions and sequestration initiatives. Understanding income distribution provides insights into the socio-economic dynamics that might influence environmental practices within rural communities. The distribution of annual income of the sample respondents are displayed in Table 4.9.

Table 4.9. Annual Income of Sample Respondents

S.No.	Annual Income (Rs.)	No. of Sample Respondents	Percentage
1.	Less than 1,00,000	82	66.13
2.	1,00,001 – 3,00,000	37	29.84
3.	Above 3,00,000	5	4.03
Total		124	100.00

It could be observed that the majority of sample respondents (66.13 percent), reported an annual income of less than ₹1,00,000, followed by 37 respondents (29.84 percent) fell within the income range of ₹1,00,001 to ₹3,00,000, suggesting a moderate level of economic stability among this segment. However, only 5 respondents (4.03 percent) reported an annual income above ₹3,00,000, highlighting a concentration of wealth among a small fraction of the population. Overall, the distribution of annual income among the respondents was essential for understanding the socio-economic context in which carbon emissions and sequestration strategies were evaluated in rural village environments.

4.2 Estimation of Village Carbon Footprint

Estimating the carbon footprint of Vembar South panchayat involved a comprehensive assessment of various contributing factors, such as households, agricultural practices and other community-level operations. This analysis aimed to quantify the total greenhouse gas emissions produced by Vembar South, providing a clear picture of its environmental impact.

4.2.1 Estimation of Carbon Footprint of Households

The estimates of carbon emissions from households in Vembar South revealed significant contributions from various sources, particularly cooking & heating and transportation. The source-wise household carbon emissions from Vembar South are given in Table 4.10. As shown in Table 4.10, the use of Liquefied Petroleum Gas (LPG) resulted in an emission of approximately 685.473 tons of CO_2 e annually. Fuelwood contributed even more significantly, accounting for around 1,226.859 tons of CO_2, alongside minor emissions of methane (CH_4) about 0.329 tons and nitrous oxide (N_2O) about 0.044 tons. Kerosene usage added about 4.787 tons of CO_2e, while electricity consumption across households accounted for approximately 981.160 tons of CO_2 annually. Transportation also played a notable role, with two-wheelers contributing 385.551 tons of CO_2, four-wheelers adding 264.509 tons and transportation availed through buses accounting for 106.822 tons.

Table 4.10. Household Carbon Emissions by Source in Vembar South

Particulars			Average Emission per Household (kg/year)			Overall Emission (t/year)		
			CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Household	Cooking & Heating	LPG	406.455	0.019	0.004	682.844	0.032	0.006
		Fuelwood	730.273	0.196	0.196	1226.859	0.329	0.044
		Kerosene	2.840	0.00012	0.00002	4.772	0.00020	0.00004
		Electricity	584.024	-	-	981.160	-	-
	Transportation	Two wheelers	229.494	-	-	385.551	-	-
		Four wheelers	157.446	-	-	264.509	-	-
		Bus	63.585	-	-	106.822	-	-
Total			2174.117	0.215	0.199	3652.517	0.361	0.050

The aggregated total household emissions amount to approximately 3,675.975 tons of CO_2 e annually. These findings highlighted that fuelwood usage as the major source of emissions within households, followed by electricity consumption.

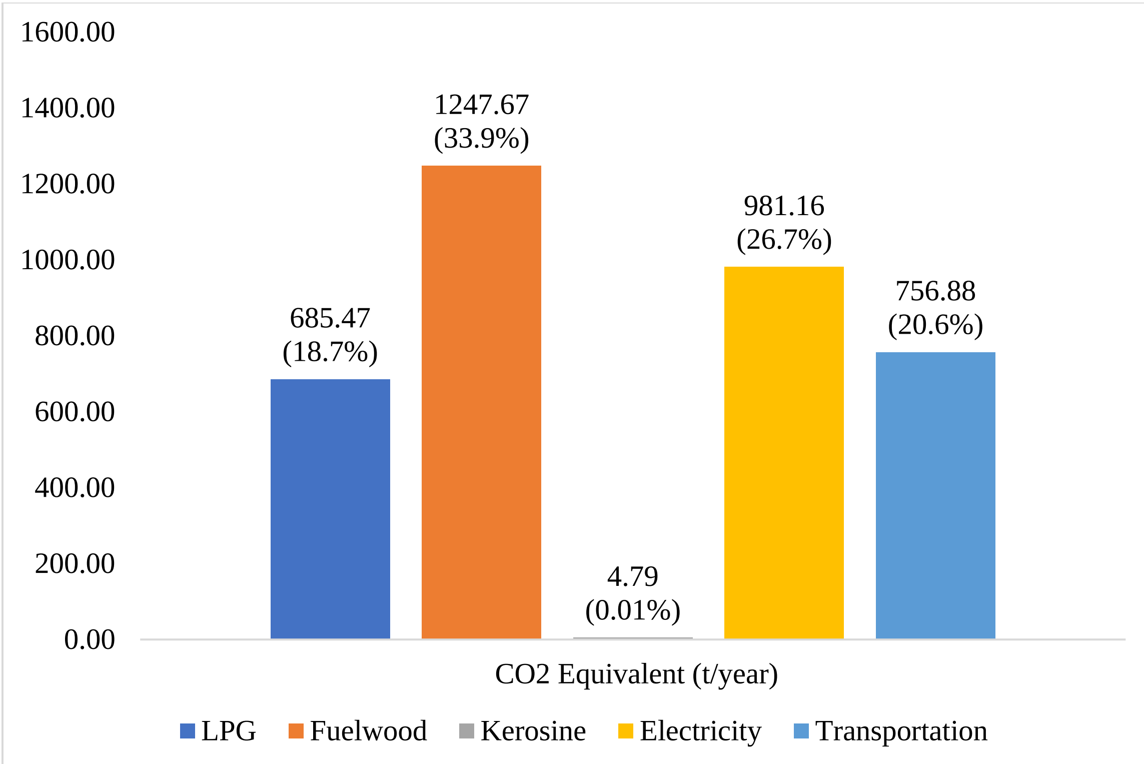

Figure 4.1. Annual household carbon emission from Vembar South

Figure 4.1 illustrates that fuelwood usage was the primary contributor to household emissions, followed by electricity and LPG, while kerosene had lower emission contributions. Transportation contributed comparatively less to overall household emissions than Cooking & Heating. The significance of household energy consumption as a contributor to global carbon emissions could not be overstated. It accounted for nearly three-quarters of total emissions (Druckman and Jackson, 2016). In developing countries like India, biomass fuels used in household stoves were a major source of greenhouse gas emissions due to their thermal inefficiency and incomplete combustion products (Smith *et al.*, 2000). Similarly, estimation of carbon emissions in Pakistan revealed that domestic vehicles were the largest contributors to household emissions, followed by electricity consumption and cooking and heating fuel use (Khan and Siddiqui, 2017). These findings emphasized the need for targeted mitigation strategies focused on household energy consumption.

4.2.2 Estimation of Carbon Emission from Agriculture

Agricultural activities in Vembar South were predominantly characterized by palm jaggery production, which stood out as a major source of carbon emissions in this region. As depicted in Table 4.11, value addition accounted for approximately 38,522.120 tons of CO_2 e annually due to the combustion of fuelwood used in traditional jaggery-making methods that utilized open-hearth furnaces. These practices were not only energy-intensive but also released harmful pollutants into the atmosphere.

The high emissions associated with traditional biomass burning for palm jaggery production highlighted the environmental costs and significantly contributed to the increased greenhouse gas emissions. Additionally, livestock emissions contributed approximately 5.62 tons of CH_4 annually through enteric fermentation and manure management processes. While livestock emissions were relatively small compared to those from fuelwood combustion for jaggery production, they represented an important component of agricultural emissions that could be mitigated through improved livestock management practices (Gerber *et al.*, 2013). The results indicated that agriculture, particularly biomass burning for jaggery production, was a major contributor to emissions in Vembar South.

Transitioning to clean combustion devices for jaggery production could significantly reduce emissions from this agricultural activity (Tyagi *et al.*, 2022). By adopting more efficient technologies and practices within agriculture, Vembar South could mitigate its carbon footprint while promoting sustainable development towards carbon neutral village.

Table 4.11. Emissions from Agricultural Activities in Vembar South

Particulars		Average Emission per Household (kg/year)			Overall Emission (t/year)		
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Agriculture	Fuelwood used for palm jaggery production	22547.334	6.039	0.805	37879.521	10.146	1.352
	Livestock	-	-	-	0.000	5.624	0.002
Total		22547.334	6.039	0.805	**37879.521**	**15.770**	**1.354**

4.2.2.1 Estimation of Livestock Emissions

In Vembar South, the emissions from livestock were significant contributors to greenhouse gases, particularly methane (CH_4) and nitrous oxide (N_2O) and its emissions were summarized in Table 4.12. Among the livestock, cattle were the largest emitters of methane primarily due to enteric fermentation which produces the highest methane emissions of 2709 kg, , followed by goats 1850 kg and sheep 600 kg annually. Pigs contribute minimally to methane emissions, generating only 24 kg/year, while poultry have negligible emissions. In terms of nitrous oxide, cattle also lead with 1.6254 kg/year from manure management, whereas sheep and goats shown no significant emissions. Overall, the total methane emissions from all livestock amount to 158.058 CO_2 e annually. This data underscores the importance of livestock management in mitigating greenhouse gas emissions, suggesting that improving livestock diets and manure handling practices could significantly reduce their emission and its environmental impact.

Table 4.12. Annual Emission Estimates from Livestock in Vembar South

S. No.	Livestock	Count	CH_4 emission (Kg/year)		N_2O emission (Kg/year)
			Enteric Fermentation	Manure Management	
1.	Cattle	63	2709	239.4	1.6254
2.	Sheep	120	600	24	0
3.	Goat	370	1850	81.4	0
4.	Pig	24	24	96	0.1776
5.	Poultry	172	0	0	0.43
Total			**5183**	**440.8**	**2.233**

4.2.2.2 Estimation of Emissions from Palm Jaggery Production

The value addition process through Palm jaggery production was another significant source of carbon emission in Vembar South due to its reliability on fuelwood for energy-intensive production methods. The average emission per household from this process was estimated CO_2 at around 22.55 t/year accounting to an overall emission of approximately 37,879.521 tons/year as shown in Table 4.13. This substantial contribution underlined the need for cleaner production technologies that could significantly reduce reliance on traditional biomass fuels while maintaining economic viability for local palm jaggery producers.

Table 4.13. Estimation of Emissions from Palm Jaggery Production in Vembar South

S.No.	Particulars	Annual Wood Usage (Kg)	CO_2 emission (t/year)	CH_4 emission (Kg/year)	N_2O emission (Kg/year)
1.	Average Household Emission	12905	22.55	6.04	0.81
2.	Overall Emission	21680129	**37879.52**	**10146.30**	**1352.84**

4.2.3 Estimation of Emissions from Other Activities in the Vembar South

In addition to household and agricultural sources, Vembar South had notable emissions from other village-level operations such as waste management and public electricity consumption. The results of the emissions from various community activities are presented in Table 4.14. Waste management practices resulted in approximately 950.91 tons of CO_2 annually due to open burning methods commonly employed for municipal solid waste disposal. Public electricity consumption added another significant layer to the community's carbon footprint; accounting for around 1,708.198 tons of CO_2 per year from various facilities such as schools and street lighting.

Furthermore, public electricity consumption was categorized *viz.,* small-scale industries, government schools and hospitals, places of worship, agriculture used, commercial activities, industrial use and village panchayat overhead tanks/street lights which accounted for 35.03, 13.30, 15.82, 6.15, 207.45, 1,360.49 and 69.96 tons of CO_2 emission respectively. The total CO_2 emission from public electricity consumption across these sectors amounted to 1,708.198 tons when combined with waste generation contributions leading to an overall total emission of 2659.108 tons annually.

Table 4.14. Emissions from Various Community Activities in Vembar South

S.No.	Particulars		Quantity per Annum	CO_2 emission (t/year)
1.	Waste Generation (Kgs)		819750	**950.910**
2.	Electricity (KWH)	Small scale industry	43790.00	35.032
		Govt. Schools & Hospitals	16620.00	13.296
		Place of worship	19775.00	15.820
		Agriculture	7691.60	6.153
		Commercial	259312.60	207.450
		Industrial	1700614.70	1360.492
		Village panchayat OHT/Street lights	87444.00	69.955
	Subtotal		2135247.90	**1708.198**
Total				**2659.108**

The findings of our study aligned with Sharma *et al.* (2019) and Kumari *et al.* (2019) indicating that open burning of Municipal Solid Waste (MSW) was a significant source of air pollutants and greenhouse gases in developing countries like India. Open burning contributed substantially to various pollutant emissions including CO_2, CO, particulate matter and volatile organic compounds (Wiedinmyer *et al.*, 2014). Projections suggested that greenhouse gas emissions from India's waste management sector could increase significantly without comprehensive mitigation strategies in place (Manuja *et al.*, 2018). Effective approaches such as diverting organic waste from landfills and improving wastewater management practices could play a crucial role in reducing these emissions while enhancing overall environmental sustainability.

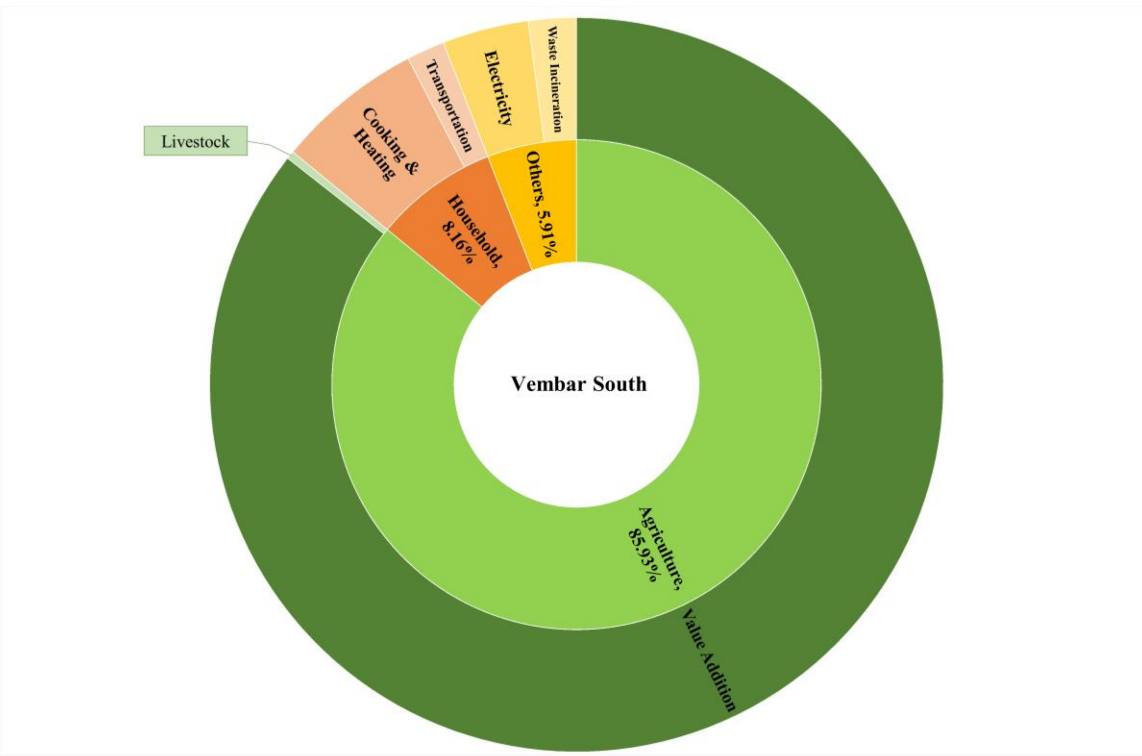

Figure 4.2. Carbon Emissions from Vembar South

The results indicated that emissions from Agriculture contributed about 85.93 per cent, followed by household emissions and other community-level activities contributed about 8.16 and 5.91 per cent respectively. This summary in Figure 4.2 highlighted the need for comprehensive strategies aimed at reducing these emissions across all sectors.

4.3 Estimation of Carbon Sequestration by Palmyrah Palms

The carbon sequestration potential of Palmyrah palms in Vembar South was substantial, playing a critical role in offsetting carbon emissions. With a total population of 165,431 trees, each capable of sequestering approximately 801.64 kg of CO_2 annually, the overall sequestration potential reached about 132,616.60 tons of CO_2 per year, as indicated in Table 4.16. This significant capacity for carbon storage highlighted the importance of maintaining and potentially expanding Palmyrah populations as part of local climate mitigation strategies. Palmyrah palms were not only vital for carbon sequestration but also contributed to soil conservation and provided livelihoods through products like palm jaggery. These trees thrive in the semi-arid climate of Vembar South, showcasing remarkable adaptability and resilience during adverse climatic conditions. Their long lifespan further enhanced their role as effective carbon sinks compared to other tree species. The results indicated that Palmyrah palms exhibit comparable or even higher sequestration potential than other commonly planted species such as neem (Noor *et al.*, 2020; Sivaji *et al.*, 2023).

4.3.1 Descriptive Statistics of Palmyrah Palm Trees Growth Parameters

The descriptive statistics of Palmyrah palm trees growth parameters are shown in Table 4.15. The growth parameters measured for the Palmyrah palms included height and diameter at breast height (DBH), which were crucial for estimating biomass and carbon sequestration potential. The maximum height recorded among these trees is 15.56 m, while the minimum height was noted at 0.23 m. This range indicated a diverse population that could influence overall biomass estimates and carbon storage capabilities. The mean height of the Palmyrah palms was approximately 7.46 m, with a standard deviation recorded at 4.74 m. These metrics reflected the variability within the population, which was essential for understanding how different tree sizes contributed to total carbon sequestration. The DBH measurements also played a significant role in determining the biomass and carbon stock; thus, accurate assessments were vital for effective management strategies aimed at enhancing carbon storage. The diameter at breast height (DBH) also showed variability, with a maximum measurement of 48.76 cm and a minimum of 22.29 cm, resulting in an average DBH of approximately 32.12 cm. This information is vital for calculating biomass and understanding the growth dynamics of the Palmyrah palm population.

Table 4.15. Descriptive Statistics of Palmyrah Palm Trees Growth Parameters

S.No.	Particulars	Height (m)	DBH (m)
1.	Maximum	15.56	48.76
2.	Minimum	0.23	22.29
3.	Mean	7.46	32.12
4.	Standard Deviation	4.74	9.50

4.3.2 Estimation of Carbon Sequestration Potential

To effectively estimate CO_2 sequestration within this palmyrah palm ecosystem, several parameters were considered. The total number of trees present was counted at 1,65,431. The average tree height stood at about 7.47 m and the average DBH was measured at approximately 32.14 cm. The above-ground biomass per tree was calculated to be 365.70 kg, while below-ground biomass per tree measures around 73.14 kg. This led to an estimated total biomass per tree of about 438.84 kg, with a corresponding carbon stock per tree calculated at 218.63 kg. Overall, the total CO_2 sequestered amounts to approximately 132,616 t/year by considering all trees in the population as shown in Table 4.16. This substantial figure illustrated the critical role that Palmyrah palms play not only in carbon sequestration but also in supporting local ecosystems through soil conservation and providing livelihoods through products like palm jaggery.

Table 4.16. Estimation of Carbon Sequestration Potential

S.No.	Parameters	Units	Values
1.	Number of trees	Count	165431.25
2.	Tree Height	Metres	7.470
3.	DBH	Centimetre	32.141
4.	Above Ground Biomass	Kgs/tree	365.700
5.	Below Ground Biomass	Kgs/tree	73.140
6.	Total Biomass	Kgs/tree	438.840
7.	Carbon Stock	Kgs/tree	218.630
8.	CO_2 Sequestered per tree	Kgs/tree	801.643
9.	Total CO_2 sequestered	t/year	132616.804

The high sequestration potential presented an opportunity for scaling up Palmyrah cultivation as a climate mitigation strategy. These findings highlighted the importance of Palmyrah palms as a natural solution to combat climate change while simultaneously supporting local livelihoods and ecosystems. By focusing on conservation and sustainable management practices, Vembar South could enhance its capacity for carbon sequestration and contribute positively to global efforts aimed at reducing greenhouse gas emissions. This dual benefit positioned the community as a potential model for other rural areas seeking sustainable development pathways that aligned economic growth with environmental stewardship. The strategic management of Palmyrah palms not only could enhance their ecological benefits but also promote social and economic resilience within the community, making them an invaluable asset in addressing climate change challenges effectively.

4.4 Estimation of Net Carbon Emission of Vembar South

The net carbon balance for Vembar South was a critical indicator of the village's environmental sustainability, revealing whether it acts as a carbon sink or source. By comparing total carbon emissions against the amount of carbon sequestered, it was evident that the village functions as a net carbon sink. This meant that the total sequestration of approximately 1,32,616.60 tons of CO_2 per year surpassed the combined emissions from households, agriculture and other activities, which total around 45,015.262 tons of CO_2 equivalent annually. This positive net balance was illustrated in Figure 4.3, which provided a visual representation of the relationship between emissions and sequestration.

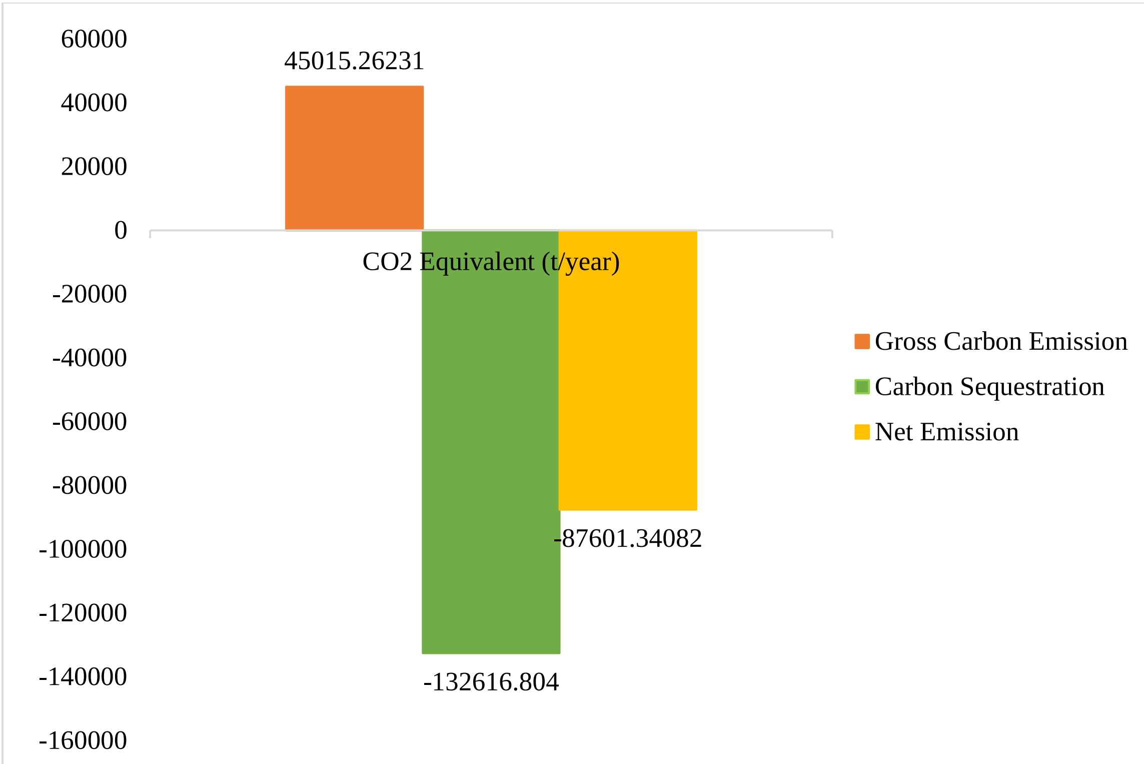

Figure 4.3. Net Carbon Emission of Vembar South

Household emissions, primarily from cooking and heating, accounted for a significant portion of the total emissions. Agricultural practices, particularly palm jaggery production, contributed substantially due to their dependence on fuelwood and traditional combustion methods. Additionally, emissions from waste management and public electricity consumption further added to the overall carbon footprint of Vembar South.

The findings implies that Vembar South had successfully implemented strategies that not only reduce emissions but also enhanced its capacity for carbon sequestration through the preservation and cultivation of Palmyrah palms. This dual approach positioned the village as a potential model for other rural areas aiming for carbon neutrality. However, while the current status as a carbon sink was promising, there remained opportunities for further reductions in emissions. Implementing cleaner cooking technologies could significantly lower household emissions by reducing reliance on traditional biomass fuels, which were often inefficient and polluting. Promoting renewable energy sources within agricultural practices could also play a crucial role in minimizing emissions associated with farming activities. Furthermore, improving waste management practices would be essential for reducing greenhouse gas emissions from waste disposal methods like open burning. By adopting more sustainable waste management strategies such as composting organic waste and recycling materials the village could further decrease its carbon footprint.

The expansion of Palmyrah palm populations represented another avenue for enhancing carbon sequestration capacity. Such an initiative would not only bolster the village's role as a carbon sink but also provide additional ecological benefits, including improved soil health and biodiversity. Vembar South's net carbon balance illustrated its potential as a model for sustainable rural development that aligns economic growth with environmental sustainability. By continuing to focus on reducing emissions while enhancing carbon sequestration efforts through Palmyrah palms and other strategies, the village could contribute positively to global climate change mitigation efforts while fostering resilience against future environmental challenges. This holistic approach emphasized the interconnectedness of ecological health and community well-being, underscoring the importance of sustainable practices in achieving long-term environmental goals.

4.5 Estimation of Influence of Socio-Economic Factors on Increasing the Number of Palmyrah Palms

The expansion of Palmyrah palm cultivation in Vembar South is influenced by various socio-economic factors. Understanding these factors was essential for developing strategies to promote the growth of this valuable resource. The results from the probit regression analysis and marginal effects provided insights into how different socio-economic variables affected the willingness to expand Palmyrah palm cultivation.

4.5.1 Results of Probit Model Regression

A probit regression analysis was conducted to examine the socio-economic factors influencing the willingness to expand palmyrah palm cultivation. The detailed results of this analysis are provided in Table 4.17.

Table 4.17. Binary Probit Results of Willingness to Expand Area under Palmyrah Palm

Variables	Coefficient	Standard Error	p-value
Age	-0.0392	0.0426	0.358
Gender	-2.4911**	1.0963	0.023
Education	-0.9768	1.1939	0.413
Primary occupation	-2.8751**	1.3834	0.038
Family type	0.9812	2.0107	0.626
Family size	-0.8891**	0.4269	0.037
Experience in occupation	0.1035*	0.0565	0.067
Annual income	0.00002**	0.00001	0.034
Land ownership	1.3492*	0.7492	0.072
Constant	4.4747	2.9707	0.132
Log likelihood	-9.9443		
Pseudo R^2	0.5493		
Prob > Chi^2	0.0039		
LR Chi^2 (9)	24.26		
Number of observations	34		

**, * indicates significance at 5% and 10% levels respectively

The regression model was designed to evaluate how different variables, including gender, primary occupation, family size, experience in occupation, annual income and land ownership, impact the likelihood of expanding palmyrah palm cultivation. These variables were selected based on their potential influence on agricultural decision-making processes. The analysis revealed that gender, primary occupation, family size, experience in occupation, annual income and land ownership had significant influence on willingness to expand area under palmyrah palm.

Gender negatively influenced the Willingness to Expand by 2.3 per cent. This suggested that female landowners were more inclined to expand palmyrah palm cultivation compared to male landowners, reflecting gender-specific differences in decision-making. It was likely that female landowners were more open to expansion, perhaps due to varying priorities or resource management strategies within households.

Primary occupation negatively influenced the Willingness to Expand by 3.8 per cent. This indicated that individuals primarily engaged in agriculture were significantly less likely to expand palmyrah cultivation than those engaged in non-agricultural occupations. This could be due to the demands and risks associated with agricultural work, where expanding into palmyrah cultivation might not be perceived as a viable or profitable investment for those already involved in other agricultural activities.

Family size negatively influenced the Willingness to Expand by 3.7 per cent. This result suggested that larger families were less willing to expand palmyrah cultivation, likely due to the need to allocate resources to support a larger household. In such cases, the financial or labor demands of expanding cultivation might be seen as too great a burden for families with more members, especially if there were competing needs, such as education or healthcare.

Experience in occupation, though marginally significant, showed positively influenced the Willingness to Expand by 6.7 per cent. This finding implied that individuals with more experience in their respective occupations are somewhat more inclined to expand palmyrah cultivation. The positive relationship between experience and expansion might be attributed to the fact that more experienced individuals had accumulated the knowledge, skills and resources necessary to take on the risks associated with expansion. However, the marginal significance suggested that other factors might also play a role in moderating this relationship.

Annual income was found to be positively associated with the willingness to expand by 3.4 per cent. This finding reflected the general notion that households with higher incomes had more financial flexibility and were, therefore, more likely to invest in expanding agricultural activities, including palmyrah cultivation. Wealthier households might be better able to absorb the costs associated with expansion, such as purchasing additional land, equipment, or labour.

Lastly, land ownership exhibited a positive, though less significant, relationship with the willingness to expand by 7.2 per cent. Households that owned larger tracts of land were more likely to expand palmyrah cultivation, as they had the physical resources necessary to accommodate such growth. The slightly lower level of significance for this variable suggested that while land ownership is important, other factors such as income, occupation, or family size might moderate its impact on expansion decisions.

Overall, the probit model's performance was robust, the model was a whole is statistically significant. Additionally, the Pseudo R-squared value suggested that the socio-economic variables included in the model explained a considerable proportion of the variation in willingness to expand palmyrah cultivation. This high explanatory power underscored the importance of considering multiple socio-economic dimensions when analyzing agricultural decision-making processes.

4.5.2 Willingness to Expand Area under Palmyrah Palm Cultivation

While the probit regression coefficients provided valuable insights into the direction and significance of each variable, the marginal effects offered a more intuitive interpretation by showing the specific changes in the probability of the outcome to expand palmyrah cultivation for a unit change in each predictor variable. These marginal effects are detailed in Table 4.18.

Table 4.18. Results of Willingness to Expand Area under Palmyrah Palm

Variables	Marginal effects	Standard Error	p-value
Age	-0.0063	0.0065	0.337
Gender	-0.4019***	0.1195	0.001
Education	-0.1576	0.1864	0.398
Primary Occupation	-0.4639***	0.1721	0.007
Family Type	0.15832	0.3212	0.622
Family Size	-0.1434***	0.0537	0.008
Occupational Experience	0.0167**	0.0074	0.025
Annual Income	0.000004***	0.000001	0.004
Land ownership	0.2177**	0.2177	0.036

***, **indicates significance at 1% and 5% levels, respectively

One of the most notable findings was the significant effect of gender on the willingness to expand palmyrah cultivation. The results indicated that male landowners had approximately 40 percent less probability to expand palmyrah cultivation than female landowners. This gender disparity in decision-making might reflect broader societal patterns, where male landowners prioritized other forms of agricultural investment or face different socio-cultural expectations compared to female landowners. The findings of the study aligned with Meijer *et al.* (2015), which highlighted that while men often dominate agricultural decision-making, but joint decision-making with women could lead to better outcomes, such as higher tree densities and more sustainable land-use practices. This suggested that empowering women in agricultural households could had positive implications for the expansion of palmyrah cultivation.

The primary occupation also had significant influence on Willingness to Expand palmyrah cultivation. The results suggested that individuals whose primary occupation was agriculture were about 46 percent less probability to expand palmyrah cultivation compared to those in non-agricultural sectors. This result was particularly striking, as it implied that households already engaged in agricultural activities might perceive palmyrah cultivation as less beneficial or too risky compared to their current agricultural ventures. It might also reflect resource constraints or a focus on staple crops over long-term investments in tree-based agriculture. This result was consistent with the findings of Euler *et al.* (2016) that non-agricultural households exhibited a stronger willingness to adopt and expand oil palm cultivation. The reluctance of agricultural households to expand palmyrah cultivation might stem from competing demands for labor and resources or from the perception that palmyrah cultivation offered lower returns compared to staple crops or other agricultural activities.

Family size also played a significant role in shaping expansion decisions. The results revealed that each additional family member reduces the probability of expanding palmyrah cultivation by about 14 percent. Larger families might face resource limitations, as they need to prioritize immediate household needs such as food security and education, take precedence over long-term investments in agricultural expansion, which typically required upfront investment and might not provide immediate returns. This suggested that household size could act as a constraint on agricultural innovation and expansion. This finding was consistent with Mingorría *et al.* (2014), who observed that larger families often prioritize subsistence crops over expansion in uncertain environments, where stability is valued over growth.

Experience in occupation showed a significantly positive marginal effect. This result suggested that for each additional year of experience, the probability of expanding palmyrah cultivation increases by 1.67 percent. Although this effect was modest, it reflected the importance of accumulated knowledge and expertise in influencing the willingness to engage in agricultural expansion. More experienced individuals were likely to have a deeper understanding of the benefits and challenges associated with expanding cultivation, making them more willing to take on the risks of expansion. This finding aligned with the work of Euler *et al.* (2016), who found that more experienced household heads were more likely to expand oil palm plantations in Sumatra.

The annual income had a marginal but significant positive effect on willingness to expand area under Palmyrah palm cultivation. While the effect size might seem minimal, it highlighted the fact that even small increases in income could had a positive influence on the likelihood of expanding palmyrah cultivation. This finding underscored the role of economic resources in shaping agricultural decisions, particularly in rural contexts where financial capital could be a limiting factor. This result was consistent with the findings of Jayathilake *et al.* (2023), who reported that higher household income levels positively correlated with plantation expansion. Wealthier households had greater access to financial resources, which allowed them to invest in the necessary inputs such as land, labour and equipment that were required for expanding the area under palmyrah cultivation.

Finally, the land ownership had a significant positive influence on Willingness to Expand the palmyrah palm cultivation. This suggested that for each additional hectare of land owned, the probability of expanding palmyrah cultivation increased by approximately 22 percent. This result emphasized the importance of land availability in agricultural expansion, as larger landholdings provided the physical space and resources necessary for expansion of palmyrah palm. This finding was consistent with Aromolaran *et al.* (2022), who found that larger landholdings were associated with greater willingness to expand agricultural activities in Nigeria.

Interestingly, the analysis did not find significant effects for other variables, such as age, education and family type. While these factors might not be relevant in the specific context of the study area, they might still be important in other regions. Yaseen *et al.* (2023) found that age and education were significant predictors of oil palm adoption in Northeast Thailand. This suggested that the influence of these variables might be context-dependent and could vary based on the specific socio-economic conditions of different regions.

These marginal effects offered a clear understanding of the factors that influence the willingness to expand palmyrah cultivation. They highlighted the complex interplay between socio-economic characteristics and agricultural decision-making, with certain variables such as gender, occupation and land ownership having particularly strong effects on the likelihood of expansion. These findings underscored the importance of understanding the specific socio-economic dynamics of agricultural households when developing policies or interventions aimed at promoting sustainable agricultural growth. By considering these factors, policymakers could better tailor their efforts to support households that are willing to expand palmyrah cultivation and other tree-based agricultural practices.

5 SUMMARY AND CONCLUSION

Climate change, driven by increasing carbon emissions, poses a significant global challenge and rural areas have a unique role in mitigating its effects. While urban areas are often highlighted in discussions on carbon emissions, rural regions also contribute substantially to global carbon cycles through agricultural practices, energy consumption and other local activities. Simultaneously, rural regions offer valuable natural carbon sinks through their forests and tree species, which can offset some of these emissions. This study focused on quantifying carbon emissions and sequestration within a rural village, Vembar South, in Tamil Nadu, India, to assess its potential for achieving carbon neutrality.

The study's central focus was the balance between carbon emissions and sequestration in rural environments, specifically the role of Palmyrah palms, a species native to the region and known for its carbon storage potential. The research aimed to explore whether Vembar South, with its high density of Palmyrah palms, could serve as a model for rural carbon neutrality through a combination of emission reduction and enhanced sequestration.

The following objectives were defined for the research:

1. To quantify the household carbon emissions in the selected village of Thoothukudi district.
2. To estimate the carbon emissions from agricultural activities focussing major crops.
3. To estimate the carbon sequestration potential of Palmyrah palm in the selected village
4. To analyze the willingness to expand the Palmyrah plantations as a carbon sequestration strategy.
5. To assess the overall carbon balance scenario for the village.

This study addressed the pressing issue of balancing rural carbon emissions with the natural sequestration capacity of native species, with the goal of contributing valuable insights toward climate change mitigation efforts.

5.1 Sampling Framework

The research adopted a mixed-method approach, integrating both quantitative and qualitative methods for data collection and analysis to address the research objectives comprehensively. The study was conducted in Vembar South, located in the Vilathikulam block of Thoothukudi district in Tamil Nadu. The choice of this location was based on the high density of Palmyrah palms, which play a crucial role in carbon sequestration, alongside the traditional agricultural and household practices that contribute to carbon emissions. A proportional sampling technique was used to select households from different hamlets in Vembar South. A total of 124 households were surveyed of the total population. In addition, 500 Palmyrah palms were systematically evaluated to estimate their carbon sequestration potential.

5.2 Data Collection

Household data were collected through personal interviews, covering energy consumption patterns, fuel usage (such as LPG, firewood and kerosene) and transportation habits. The survey also gathered demographic information, including age, education, occupation and family size. For Palmyrah palms, the height and diameter of trees were measured using Haga altimeter and measuring tape respectively.

Relevant secondary data were obtained from local government records, including electricity consumption statistics from the Tamil Nadu Generation and Distribution Corporation (TANGEDCO) and agricultural data from the District Statistical Office. These data sources provided crucial context for understanding the broader carbon dynamics within the village.

5.3 Analytical Tools

Carbon emissions were calculated using the Emission Factor Approach, following the 2019 IPCC guidelines. This included emissions from household energy use, transportation and agricultural practices. Biomass equations were employed to estimate the carbon storage capacity of the Palmyrah palms. These equations considered the tree height, diameter at breast height (DBH) and growth characteristics. The study focused on direct emissions (Scope 1) and electricity-related indirect emissions (Scope 2). Scope 3 emissions, such as those from the production of goods consumed by the village, were excluded.

5.4 *Major Findings of the study*

5.4.1 Household Carbon Emissions

Households in Vembar South contribute significantly to carbon emissions, particularly through cooking and heating practices. The predominant use of firewood for cooking resulted in annual emissions of 1,226.86 tons of CO_2. Additionally, the use of LPG for cooking contributed 682.844 tons of CO_2, while electricity consumption, although more efficient, added 981.160 tons of CO_2 per year. Transportation-related emissions from bus travel, two-wheelers and four-wheelers added 756.88 tons of CO_2 annually.

5.4.2 Agricultural Emissions

Agricultural practices, particularly palm jaggery production, were found to be a major contributor to carbon footprint in Vembar South. The traditional burning of biomass (fuelwood) for jaggery production emitted approximately 38,522.120 tons of CO_2 e annually. In addition to this, livestock farming contributed to methane (CH_4) emissions from enteric fermentation and manure management accounted for 2709, 1850 and 600 kg/year from cattle, goat and sheep respectively. Pigs and poultry contribute minimal methane emissions. Overall, methane emissions from all livestock were about 5,183 kg/year and total nitrous oxide emissions were 440.8 kg/year. While livestock emissions were relatively smaller compared to jaggery production, they still represented a significant source of emissions in the agricultural sector.

5.4.3 Emissions from Other Community Activities

In addition to household and agricultural emissions, Vembar South produced significant emissions from waste management and public electricity consumption, totalling approximately 2,659.108 tons of CO_2 annually. Waste management through open burning contributed 950.91 tons of CO_2, while public electricity consumption across sectors such as industries, schools and street lighting added 1,708.198 tons of CO_2 per annum.

5.4.4 Carbon Sequestration by Palmyrah Palms

The Palmyrah palms serve as a significant source of carbon sink which has sequestered an estimated amount of 132,616 tons of CO_2 annually. Furthermore, a 20 per cent increase in the Palmyrah palm population could have potentially enhanced sequestration by an additional 26,523 tons of CO_2 each year. This makes them a key factor in offsetting the carbon emissions generated by household and agricultural activities. Moreover, the study explored the potential for expanding Palmyrah cultivation, which could further enhance the village's carbon sequestration capacity.

5.4.5 Carbon Balance in Vembar South

When comparing the total carbon emissions generated by the village with the carbon sequestration provided by Palmyrah palms, a carbon balance was established. The total sequestration of approximately 132,616.60 tons of CO_2 per year exceeded the combined emissions from households, agriculture and other activities, which amounted to around 45,015.262 tons of CO_2 equivalent annually. This indicates that the village is already a net carbon sink, sequestering more carbon than it emits. This positive net balance highlighted the village's effective strategies in reducing emissions while enhancing carbon sequestration through the preservation and cultivation of Palmyrah palms.

5.4.6 Socio-Economic Factors Influencing Sequestration

The study found that socio-economic factors such as gender, primary occupation, family size, experience, annual income and land ownership played a crucial role in determining the community's willingness to expand Palmyrah cultivation. Notably, female-headed households were more likely to expand cultivation, highlighting the potential benefits of empowering women in agricultural decision-making. Households primarily engaged in agriculture were less inclined to expand, possibly due to competing demands and perceptions of lower returns from palmyrah compared to staple crops. Larger family sizes showed a reluctance to expand due to immediate resource needs, while more experienced individuals were more open to take expansion risks. Higher-income households demonstrated a greater willingness to invest in palmyrah cultivation and those with larger landholdings were more likely to pursue expansion. Interestingly, age, education and family type did not show significant effects on this context, suggesting that these factors may vary regionally. Overall, the study emphasized the complex interplay of socio-economic factors in agricultural expansion decisions, underscoring the need for tailored policies to support sustainable growth in palmyrah cultivation.

5.5 Conclusion

Based on the findings of the research, the following conclusions can be drawn:

- Households in Vembar South contribute significantly to carbon emissions, particularly through the use of firewood and LPG for cooking, as well as electricity consumption.
- Agricultural practices, especially palm jaggery production are the major contributors to the village's carbon footprint due to the reliance on biomass burning.
- Palmyrah palms serve as an essential carbon sink, with the potential to offset a substantial portion of the village's carbon emissions. Expanding Palmyrah cultivation could further enhance carbon sequestration.
- Vembar South is already a net carbon sink, with its current sequestration potential exceeding its total emissions. However, further reductions in emissions and expanded sequestration could move the village toward complete carbon neutrality.
- Socio-economic factors, such as gender, primary occupation, family size, experience, income and land ownership, influence the community's engagement in carbon sequestration practices, highlighting the need for targeted interventions to ensure equitable participation.

5.6 Recommendations

- **Promoting Clean Energy**

To reduce household carbon emissions, encourage the adoption of cleaner energy sources. Key actions include:

- **Subsidizing LPG or alternative clean energy solutions** to transition households away from firewood, thereby reducing CO_2 emissions and improving air quality.
- **Implementing community-based renewable energy systems** like solar-powered cookstoves or small-scale solar grids, which can provide reliable energy for cooking and lighting.

- **Optimizing Agricultural Practices**

Agriculture is a significant emission source; optimizing practices can reduce this footprint. Recommended actions include:

- **Improving efficiency in fuelwood use** for jaggery production by providing access to modern stoves or biogas, which will cut down CO_2 emissions from inefficient biomass burning.
- **Encouraging low-emission livestock management practices** such as improved feed that can lower methane emissions from cattle and other livestock.

- **Expanding Palmyrah Plantation**

Given the high carbon sequestration potential of Palmyrah palms, expanding cultivation could enhance carbon capture:

- **Incentivize landowners** through subsidies or a carbon credit program to cultivate additional Palmyrah palms.
- **Partner with local agricultural organizations** to provide training and resources for Palmyrah plantation maintenance, optimizing growth and health for maximum carbon sequestration.
- **Utilize Palmyrah byproducts** (such as jaggery and other goods) to generate income and community interest, thereby strengthening local economies alongside environmental goals.

- **Improving Waste Management**

To mitigate emissions from waste, promote eco-friendly waste management practices:

- **Establish community composting programs** to manage organic waste and reduce methane emissions from traditional open burning.
- **Implement waste segregation** and recycling systems to encourage responsible waste disposal and reduce carbon emissions from landfills.
- **Introduce awareness programs** on sustainable waste practices, which can foster community engagement in maintaining a cleaner environment.

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