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Bending the Curve

Emissions Report of Mandede

Emissions, natural sequestration and net-zero calculations in Project Mandede

September 2025

Prepared by:

Centre for Sustainable Development

Net Zero -Climate Resilient Village project: Mandede.

GHG Emissions Report of Mandede village

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1. Executive Summary

The Mandede project sets out a framework to transform the village into a **sustainably developed, net-zero, and climate-resilient community**. A comprehensive baseline survey of 120 households was conducted across six thematic areas: Water, Energy, Livelihood-Agriculture, Waste, Health-Education, and Natural environment, gathering detailed data on domestic fuel consumption, electricity usage, transportation, and agricultural practices including livestock and fertiliser use.

Key Findings and Achievements:

- **Baseline Emissions:** For the fiscal year 2022-2023, the total baseline greenhouse gas (GHG) emissions in Mandede were recorded at **2481.74 tCO_2e/Yr**.

- **Natural Carbon Sequestration:** Mandede possesses a significant natural capacity for carbon sequestration. Its natural vegetation and cultivated areas contribute to an approximate annual total sequestration rate of **5,159 tCO_2e/yr**. This is based on calculations using IPCC Tier-1 methodology, considering the village's 621.84 hectares of natural vegetation and 279.79 hectares of cultivation.

- **Interventions and Emission Reductions:** From Year 1 to mid-Year 3, various initiatives were implemented to reduce GHG emissions. These include the deployment of household solar panels, Eco STPs, Nirdhur Chulhas, solid waste management system and biogas plants to reduce emissions from manure, LPG, and firewood.

  Several other interventions, like solar street lights, solar water pumps and climate resilient agriculture are planned to take place in the remaining part of the third year. **However, these interventions and their impacts have not be included in this report.**

- **Impact of Interventions:** These interventions have led to a reduction in projected emissions:
  - **FY 2023-24:** Total emissions were **3% lower** than baseline growth.
  - **FY 2024-25:** Total emissions were **5% lower** than baseline growth.
  - **FY 2025-26:** Total emissions are estimated to be **7% lower** than baseline growth. The total GHG emissions with interventions for FY 2025-26 are projected to be **2727.83 TCO_2e/Yr**.
  - **The highest reduction is expected only after the completion of climate resilient agriculture.** This will reduce the paddy field emissions, which have not been addressed by our interventions so far.

Achieving Net-Zero Status: Based on the IPCC definition, a Net-Zero Village balances annual GHG emissions produced within its boundaries with an equivalent amount of GHG removals or offsets.

We confidently state that Mandede is a Net-Zero Village. With the interventions, the total annual GHG emissions are projected to be **2727.83 tCO_2e/Yr by FY 2025-26**, which is significantly lower than the village's total natural sequestration capacity of **5,159 tCO_2e/yr**.

The project's interventions are effectively "bending the curve" of emissions.

2. Introduction

The ‘Net-zero and Climate Resilient Village’ pilot project at Mandede defines a framework to transform a village into a sustainably developed, net-zero and climate-resilient village, and to pilot these efforts at the village Mandede.

We conducted a baseline survey in the village, with a detailed questionnaire and an on-ground house-level survey. We collected data from 120 households in Mandede village in six thematic areas: Water, Energy, Livelihood-Agriculture, Waste, Health-Education, and Natural environment.

Table 1 The sectors and sub-sectors considered for emission calculation

Sectors and sub-sectors	Scope 1	Scope 2	Scope 3	Data used
1. Electricity consumption				
Household Electricity		Yes		Primary
Commercial/ Institutional Electricity		Yes		Primary
Agricultural electricity (Irrigation)		Yes		Primary
All backup for electricity*	Yes			Primary
2. Fuel consumption				
LPG Consumption	Yes			Primary
Firewood for cooking	Yes			Primary
Firewood for heating	Yes			Primary
Firewood for other uses**	Yes			Primary
3. Transportation all fuel				
All Private vehicles#	Yes			Primary
All Commercial vehicles##	Yes			Primary
Tractor and earth moving equipment	Yes			Primary + estimates
4. Agricultural Data				
All Livestock*#	Yes			Primary
Fertilizers and Chemicals			Yes	Primary + estimates
Manure in open	Yes			Primary
Paddy field emissions	Yes			Primary + estimates
5. Other Scope 3 emissions				
Travel out of Mandede			Yes	Estimates
Supply chain for goods and services			Yes	Estimates

*Backup for electricity – Diesel Generators, Kerosene, others
** Firewood for other uses – cemetery, brick kilns, others
# Private Vehicles - 2w, 3w and 4w
All Commercial Vehicles - 3w, 4w and Multi wheeled
*# All Livestock – Cattle, buffaloes and goats

3. Methodology and reference sources

The emissions and net-zero assessment for Mandede village has been prepared using globally recognized methodologies to ensure scientific robustness, consistency, and transparency. The calculations for greenhouse gas (GHG) emissions are based primarily on the **Greenhouse Gas (GHG) Protocol** developed by the **World Resources Institute (WRI)**. The calculations for natural sequestration of carbon are based on the **2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 (Agriculture, Forestry and Other Land Use - AFOLU)**. Additional guidance and data sources have been referenced to ensure alignment with national reporting frameworks and local ecological conditions.

System Boundary Definition

The geographic boundary for this assessment is defined by the **water catchment area** surrounding Mandede village. This boundary reflects hydrological connectivity, ecosystem integrity, and administrative relevance. It encompasses all forested areas, cultivated lands, and associated soil carbon pools where carbon fluxes are interrelated and where management or natural processes influence sequestration potential.

Reference Sources

1. **World Resources Institute – Greenhouse Gas Protocol**

   The GHG Protocol provides comprehensive standards for calculating emissions across sectors. For Mandede village, the **Calculation Tools and Guidance** sections were used to define activity data, emission factors, and accounting procedures relevant to land use and agriculture.

   Source: https://ghgprotocol.org/calculation-tools-and-guidance

2. **2019 Refinement to the 2006 IPCC Guidelines – Volume 4: Agriculture, Forestry and Other Land Use (AFOLU)**

   The IPCC guidelines provided the framework for estimating carbon stocks and fluxes in forests and cultivated lands. Default factors, growth models, and assumptions were adapted to the local context with adjustments for canopy cover, old-growth proportions, and land-use distribution. The refinement's guidance on **biomass carbon stock**, **soil organic carbon**, and **non-CO_2 emissions** was incorporated into sequestration estimates.
   Source: https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

3. **Additional References**

   IPCC Special Report on Climate Change and Land (2019): Provided supplementary insights on sustainable land management, soil carbon dynamics, and mitigation pathways.
   https://www.ipcc.ch/srccl/

   FAO Global Forest Resources Assessment (2020): Offered reference data for forest carbon stocks and trends, particularly relevant for tropical regions such as India. https://www.fao.org/forest-resources-assessment/en/

MoEFCC National Inventory Reports (India): Used for cross-referencing regional emission factors and sectoral data.

https://moef.gov.in/

Emission Factors and Assumptions

- **Forest sequestration factor:** Derived from IPCC Tier-1 default growth rates (1.2 tC/ha/yr), adjusted by local canopy cover (60%) and old-growth proportion (30%), resulting in an effective rate of **0.54 tC/ha/yr**.
- **Cultivated land sequestration:** Based on soil organic carbon, crop residue, and agroforestry contributions, with a default rate of **1.56 tC/ha/yr**, applied to 279 ha under mixed cultivation.
- **Conversion factor:** 1 tonne of carbon (tC) is equivalent to **3.667 tonnes of CO_2 (tCO_2e)**.
- **Time horizon:** Annual sequestration is projected for a three-year period under constant land-use conditions, with assumptions that no major disturbances (e.g., forest fires, land conversion) occur during the period.

Uncertainty and Limitations of this report

The calculations are based on primary data and in some cases, estimations superimposed on primary data.

- The 'Other Scope 3 emissions' (Refer to Table 1) are made on estimations that are based on demographic data. The estimations, assumptions and calculations have been done in good faith, and are subject to errors.
- In absence of 3-year data for calculating the actual natural sequestration of Mandede watershed, we have relied on the use of **Tier-1 default factors from the IPCC guidelines.** These guidelines introduce uncertainty, since we apply global averages to local conditions. However, we have ensured that local forest and vegetation conditions are used based on primary data collected from Mandede.
- **Canopy cover and old-growth percentages** were derived from field surveys but are subject to measurement variability.
- **Soil carbon estimates** are based on assumptions regarding crop management, residue handling, and soil texture; periodic monitoring is advised to refine these values.

This methodology ensures that Mandede village's net-zero framework is grounded in scientifically endorsed approaches while accommodating local ecological realities. The integration of WRI's GHG Protocol and IPCC's refined guidelines provides a robust structure for measuring, reporting, and improving the village's contribution to climate mitigation efforts.

4. Mandede Emissions data

4.1 Domestic Fuel Consumption

4.1.1 LPG Consumption

The following table represents the total annual LPG consumption in the village. Out of 120 householdssurveyed, 70 households have LPG connection and remaining are fully dependent on firewood for theirenergy requirements related to cooking & heating.

Table 2: LPG consumption of Mandede village in 2022-2023

	Consumption
No of households with LPG connection	70
No of LPG cylinders needed by the village annually	245
The standard size for a domestic LPG (kg)	14.2

Data Source: Primary survey conducted in June -July 2023.

4.1.2 Firewood Consumption

The following table represents the firewood consumption of the village. According to the observationand primary data collected, we find that every household is highly dependent on firewood.

Table 3: Firewood consumption of Mandede village in 2022-2023

	Consumption (Kg)
Average firewood consumption per household per day	3.5
Total firewood consumption per day in village (120 Households)	420
Total firewood consumed per year by 120 households	**153,300**

Data Source: Primary survey conducted in June -July 2023.

Assumptions:
All 120 households use firewood for some or the other purpose, cooking, heating, irrespectiveof their LPG availability.

4.2 Electricity Consumption

The following table gives the latest numbers for sector wise electricity consumption in the village. Thelatest emission-factors offered by Ministry of Power (Ministry of Power 2022) are considered.

Table 4 depicts the usage of electricity for 1 month, for 9 months of other season and 3 months of summer *(Twice the regular usage)* and the yearly consumption.

Table 4: Electricity consumption of Mandede village in 2022-2023

ConsumptionType	Monthly Units (kWh)	9 months (kWh)	3 months (kWh)	Annual (kWh)	As percent of total
Industrial	108	972	648	1620	0.7%
Residential	3748	33,732	22,488	56,220	24%
Agricultural (common water)	343	3087	2058	5145	2%
Municipal	5	45	30	75	0.3%
Agri-water pumps	712			171,056	73%
Total Annual consumption of electricity in Mandede				234,121	**100%**

Data Source: MSEDCL 2022.

Assumptions:

- For around 9 months of the year, the village has almost steady electricity usage.
- During summer & and some part of the farming season, the village has twice the regular electricity usage.
- During around 8 months of the year, the village actively employs its agricultural water pump, operating it for approximately eight hours each day. However, for approximately four months, encompassing the monsoon and a portion of the winter season, the village refrains from utilizing its agricultural water pump.

Table 5: Backup electricity consumption of Mandede village in 2022-2023

Other Electricity	Annual Requirement	
Usage of Grid Electricity annually in Hours	7512	Hrs
Usage of Backup annually in Hours	1248	Hrs
Diesel required for genset running for 1248 hours annually	12480	Kg

Data Source: Primary survey conducted in June -July 2023.

Assumptions:

- There is power cut in the village for 1248 hours annually, 1 day every week on average.
- As a backup, the villagers use Genset; and other options like candle, lanterns, and their emissions are assumed to be replaced by a diesel-genset in this study.

4.3 Transportation (CNG, Petrol, Diesel)

This table provides the fuel consumption for scope 1 emissions in the Mandede from Diesel, Petrol, CNG and LPG. Currently, the village does not have public transport.

Table 6: Transportation fuel consumption of Mandede village in 2022-2023

Vehicle Type	Annual Distance (km)	Estimation buffer	Annual usage (Days)	Vehicle Average Km/L	Fuel used L	Density (kg/L)	Fuel Consumed (Kg)
2W	157,680	20%	365	30	5256	0.74	3889.44
4W	25,295	10%	365	15	1686	0.83	1399.62
Agri-vehicles	17,550	30%	90	4	4387	0.83	3641.62

Data Source: Primary survey conducted in June -July 2023.

Assumptions:

a) 2W travels for 10km; 4W for 7kms and Agri-vehicles for an average of 30kms per day. This is averaged out estimation from the primary survey data.
b) The mileage is assumed as follows: 2W – 30 km/l; 4W - 15 km/l; Agri-vehicles 4 km/l
c) 2W run on petrol, all 4W and Agri-vehicles run on Diesel.
d) An estimation buffer of 20%, 10% & 30% are considered to increase the confidence level.

4.4 Agriculture Data (Livestock)

The following table represents the emissions caused by the livestock in the village. (Mahadeswara Swamy 2006) which are more relevant to Indian economy bases the emission factors of our analysis.

Table 7: Livestock emissions of Mandede village in 2022-2023

Animal	CO2 Emission Factor kg CO_2e/year	Cattle population Number	Emissions Kg of CO_2e
Buffalo	60	46	2760
Cow	90	47	4230
Bull	105	29	3045
Dog	1.5	24	36
Cat	0.5	28	14
Hen	0.3	70	21
Duck	0.3	7	2.1
Goat	30	6	180
	Total emissions in KG		**10288.1**
	Total emissions in tons		**10.2881**

Data Source: Primary survey conducted in June -July 2023.

4.5 Fertilizer usage Data

The following table represents the scope 3 emissions caused by the use of fertilizers in the village. The emission factor for the respective fertilizer is taken from SimaPro software for LCA assessment.

Table 8: Emissions from Fertilizers of Mandede village in 2022-2023

Fertilizer	Consumption Kg per year	Emission factor Kg CO_2e/kg of product	Emissions Kg CO_2e emissions
Urea	500	1.68	840
DAP	3750	1.6	6000
Sagarika	100	1.6	160
Weed side	50	1.36	68
Pesticides	5	1.36	6.8
Fungicide	2	1.36	2.72
Rat killer	250	1.36	340
		Total emissions in KG	**7417.52**
		Total emissions in tons	**7.41**

4.6 Other Scope 3 Emissions

Table 9: Other activities that contribute to Scope 3 emissions in 2022-2023

Category	Emissions Kg CO2e emissions
Travel out of Mandede, Supply chain for goods & services	800,000
Total Scope 3 Emissions CO2e	807,410
Total Scope 3 Emissions tons CO2e	**807.41**

5 Emissions Calculations

Paddy field emissions
Methane, a hydrocarbon is a significant GHG. Among all the anthropogenic sources of methane emissions, the agriculture sector, specifically flooded Paddy cultivation contributes 12% of global methane emissions and 1.5% of total greenhouse gasses (IPCC 1996). The principal crop of Mandede village is paddy in the Kharif season and multiple other crops in the Rabi. As these crops vary every season, and a significant portion of the fields are left uncultivated in Rabi, we have only considered flooded paddy cultivation in Kharif season for calculating the paddy field emissions. The IPCC guidelines for paddy fields with continuous flooding and no organic interventions recommend an average methane emission factor of 1.3 to 1.5 kg CH_4 per hectare per day. This rate will vary with local water management practices, soil type, and temperature.

Assumptions in Mandede's paddy field emission calculations:

1. Rice variety cultivated: We assume Indrayani rice, which is cropped the most in Mandede.
2. Standard Methane Emissions from Paddy Fields: We use a conservative value of 1.4 kg CH_4/ha/day.
3. Area under paddy cultivation: We use a highest possible value of 265 hectares, considering that the 279.7 hectares of cultivation have 5% farm bunds with trees.
4. Duration of emissions: We assume flood irrigation for 120 days as an average.

Calculations of the Paddy field emission in Mandede:

Total Methane Emissions (CH_4) = (1.4kg CH_4/ha/day × 265 ha × 120days) / 1000
Total Methane Emissions (CH_4) = 44.52 tons CH_4/year

Conversion to CO_2 equivalent:
Methane has a Global Warming Potential (GWP) of 25 over 100 years.
CO_2 equivalent emissions = 44.52 tons CH_4× 25 = 1,113 tons CO_2e

Table 10: Scope 1 Emissions in Mandede village in 2022-2023

Scope 1 Fuel and agricultural emissions	FY 2022-2023			
	Emission Factor TCO_2E/MT[1]	Kg	Tons	Emissions TCO_2E/Yr
LPG	2.993	3479	3.47	10.39
CNG	2.7	0	0	0
Petrol	3.147	3889.44	3.88	12.21
Diesel	3.253	5041.25	5.04	16.40
Firewood	1.9	153300	153.30	291.27[2]
Backup Electricity	3.252	12480	12.48	40.58
Manure	Variable			12.8[3]
Livestock	Variable		10.28	10.28
Paddy field emissions				1113
			Total Emissions	**1506.93**

Table 11: Scope 2 Emissions in Mandede village in 2022-2023

Scope 2 Electricity use	FY 2022-2023			
	Share % of Total	kWh 1 Unit = 1kWh	Consumption MWh	Emissions TCO_2E/Yr[4]
Industrial	0.70%	1620	1.62	1.15
Residential	24.0%	56220	56.22	40.19
Agricultural	2.00%	5145	5.145	3.67
Municipal	0.30%	75	0.075	0.05
Irrigation Pumps	73.0%	171056	171.056	122.30
				167.37

5.1 Baseline Emissions in Mandede

This is the baseline emissions table, before the start of Project Mandede. This data is used as the baseline, in all further calculations in this report.

[1] Carbon emission factors based on emission factors published by GHG Protocol / WRI - https://ghgprotocol.org/calculation-tools-and-guidance, Refer Annexure-1 for more details.
[2] CO_2 emissions from the biomass-combustion are often excluded from the reported emissions, as they are assumed to be balanced by the uptake of carbon when the biomass-feedstock is grown, resulting in zero net emissions over a short period of time. To avoid confusion, these emissions are often reported separately alongside the emissions due to fossil fuel combustion. Here, for the same of simplicity and to account for emissions due to incomplete combustion of the wood + any unaccounted biomass-combustions on farms, crematories etc., these emissions are considered with 100% factor in the total emissions,
[3] CO_2 emissions from manure in open from livestock is calculated as per "2006 IPCC Guidelines for National Greenhouse Gas Inventories"
[4] Weighted Average Emission Factor for Indian Grid as per 2021-22 is 0.715 $TCO_2E/YR/MWh$.

Table 12: Total Emissions in Mandede village in 2022-2023, without any interventions.

Scope	Baseline Emissions TCO_2e/Yr
1	1506.93
2	167.39
3	807.41
Total	**2481.74**

Projected growth in Emissions in Mandede, without any interventions

Table 13: Estimated growth in Emissions in Mandede without any interventions.

Scope	Baseline Emissions FY 2022-2023 TCO_2e/Yr	FY2023-24 TCO_2e/Yr	FY2024-25 TCO_2e/Yr	FY2025-26 TCO_2e/Yr
1	1506.93	1589.81	1681.22	1782.09
2	167.39	176.60	186.75	197.96
3	807.42	851.83	900.81	954.85
Total	**2481.74**	**2618.23**	**2768.78**	**2934.91**

Assumption: Rural rate of growth considered as follows. The basis for this assumption is the economic growth data supplied on the Ministry of Statistics and Program Implementation website of the Government of India[5].

FY2023-24	FY2024-25	FY2025-26
5.5%	5.75%	6%

[5] Based on growth data https://www.mospi.gov.in/sites/default/files/press_release/NAD_PR_30may2025.pdf

6 Natural Carbon Sequestration Calculations

Even as economic activities emit greenhouse gases, the natural and agricultural vegetation is busy sequestering the gases.

The natural vegetation of Mandede is mainly moist deciduous/semi-evergreen. As per IPCC, the natural forest type of Mandede is TaWa, tropical moist deciduous with old growth and secondary regeneration. The Dominant species composition comprises of *Ficus racemosa, Mangifera indica, Ficus amplissima, Tamarindus indica, Syzygium cumini, Careya arborea, Albizia procera, Acacia auriculiformis*.

The total site area for Mandede village is approximately 922 hectare. Sixty one sampling units of 10 m X 10 m i.e. hectare each were sampled covering approximately 0.07% of the total site area. Sample size and sampling locations ensured adequate representation of the variation in vegetation types observed across the site.

Table 14: Total area and No. of quadrats sampled

Land Class	Area (hectares)	No. of sample quadtrats
Natural vegetation	621.84	31
Cultivation	279.79	15
Open areas	2.79	5
Others	17.58	Nil
Total area of Mandede	**922**	

A limitation for this study was the mapping of open areas. Open areas, scrubs and abandoned fields were not easily mappable with the current available satellite imagery. Therefore, some number of areas from cultivation (especially abandoned fields) might also be a part of the defined "Open Area". However, this does not impact the total Carbon stock.

6.1 Methodology

6.1.1 Fixing the natural boundary for natural sequestration capacity of Mandede village

The critical question is how do we define the boundary for natural sequestration? A scientifically sound boundary is essential for consistency, reporting, and aligning with IPCC principles.

The IPCC defines boundaries based on geographical units, ecosystem types, or administrative areas, depending on data and governance relevance. IPCC encourages clear documentation of the **system boundary**, including what is and isn't covered. The use of a watershed-based boundary is consistent with **land-based mitigation approaches**, where hydrology, land cover, and management practices jointly influence carbon dynamics.

Based on these recommendations, we used the following criteria for selecting the natural boundary of Mandede:

a) Ecosystem integrity – Identify areas where biomass, soils, and wetlands are ecologically connected and dominantly accessible to the villagers of Mandede, than any other village
b) Administrative clarity – Do the revenue boundaries, forest compartments, or water catchment lines overlap? If yes, then we use the largest area among the three.

c) Materiality – Include lands that contribute significantly to sequestration — such as forests, croplands and common lands

For Mandede village, the **natural sequestration boundary should be the village's defined water catchment area**, as it best reflects ecological processes, governance structures, and data availability. This boundary is scientifically defensible, aligns with IPCC's requirements for system delineation, and ensures that sequestration accounting is meaningful, transparent, and replicable.

6.1.2 Calculating Carbon Stock of Mandede's vegetation

Preliminary site surveys were conducted to understand existing land use types, vegetation cover, accessibility etc. Based on these observations three main land classes i.e. Natural vegetation, Cultivation and Open areas were identified.

Sampling design: Above ground carbon as well as below ground carbon were estimated using suitable methods for each component. Components measured to estimate Above Ground Biomass (ABG) were trees, shrubs, herbs, grasses, leaf litter and deadwood. Components measured to estimate Below Ground Biomass (BGB) were soil samples.

A (statistically significant) sample size was calculated based on the total site area. The primary sampling units were 10m X 10m quadrats. Quadrat locations were first mapped ensuring adequate representation of all land classes. Final quadrat locations were decided on-site, based on accessibility.

Land class wise Carbon stock for trees, shrubs, soil and HGLD (leaf litter, herbs, grasses, dead wood) is given below

Table 15: Carbon Stock for trees & shrubs, soil and HGLD by Land-class wise

Land Class	Area Ha	Trees & Shrubs Tons	Soil Tons	Herbs, Grasses, Leaf Litter, Dead Wood (HGLD) Tons	Total Carbon Tons
Natural Vegetation	621.84	293,769.97	22,020.28	916.46	316,706.71
Cultivation	279.79	66,717.49	7784.88	357.24	74,859.61
Open Area	2.79	9.01	75.5	1.89	86.4
Others	17.58	NA	NA	NA	NA
For total area of Mandede	**922**				**391,652.72**

Note: These numbers have been computed by averaging and extrapolating the respective quadrat data to area of the land class.

6.1.3 Calculating Carbon Sequestration rate per hectare per annum

Carbon sequestration estimates for forested land were developed using the IPCC 2006 Guidelines for National Greenhouse Gas Inventories, Volume 4 (AFOLU), applying Tier-1 growth factors for tropical moist forests. The reference document used for Mandede is 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 (Agriculture, Forestry and Other Land Use). The guide is available here https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html .

Since we do not have a 3-year data of vegetative growth in Mandede, we had to employ Tier-1 methodology to calculate the Carbon stock and Carbon sequestration per hectare per year at Mandede. Once we get 3-year data, we will rework these estimates by Tier-3 methodology of IPCC guidelines. Tier-1 estimates carry high uncertainty as they rely on generalized biomass growth rates and not site-specific increments.

6.1.4 Mandede's Carbon Stock and Sequestration

Refer to Annexure 2 for terminology, definitions, IPCC Tier-1 methodology and calculations. Table 16 presents the Carbon Stock and Sequestration rate of Mandede's vegetation, by Land Use category.

Table 16: Carbon stock and sequestration in Mandede

Land Use category in Mandede	Area Ha	Carbon stock, Tons	Total sequestration rate tCO_2e/yr
Natural Vegetation	621.84	316,706.71	1231
Cultivation	279.79	74,859.61	3928
Open Area	2.79	86.4	-
Others	17.58	NA	NA
For total area of Mandede	**922**		**5159**

We keep the annual sequestration constant at 5159 tCO_2e/yr. This is commonly used when we project over short time periods of 1 to 5 years.

Note:
The sequestration values presented for cultivated land, including paddy fields, are based solely on CO_2 uptake from soil organic carbon and biomass, in accordance with Tier-1 methodology. They do not account for methane and nitrous oxide emissions typically associated with wetland cultivation. Therefore, the net GHG balance for paddy fields may be higher than indicated here, and we strongly recommend field-based assessments for a more accurate representation of Mandede.

7 Interventions in Mandede

Our goal is to make Mandede a Net-Zero village. Towards this end, we undertook several interventions, which resulted in reduction of GHG emissions. The interventions and their reduction impacts are presented in Table 17.

Table 17: Intervention type and their impact in reduction of CO_2 emissions.

		Year 2023-24		**Year 2024-25**		**Mid of Year 2025-26**	
Initiatives	**Annual Emission reduction per unit TCO_2e/YR[6]**	**Number of Initiatives**	**Total Reductions TCO_2e/Yr**	**Number of Initiatives**	**Total Reductions TCO_2e/Yr**	**Number of Initiatives**	**Total Reductions TCO_2e/Yr**
HH Solar Panel 170W	0.17			10	1.7	2	0.34
HH Solar Panel 1kW	1.20					17*	20.4
Eco STP	25.16			1	25.16	1**	25.16
Nirdhur Chulha	1.19	70	83.3				
Solid waste management	0.043					1	0.04
Solar street light 30W LED	0.11						
Solar water pump 3HP	1.68						
Biogas leading to Manure related Emissions reduction	0.425			21	8.93	These are planned activities for FY 25-26. Emissions reduction not taken in this calculation	
Biogas leading to LPG related emission reduction	0.15			21	3.15		
Biogas leading to Firewood related emission reduction	1.19			21	24.99		
		Total for year	**83.30**		**63.93**		**45.94**

Note:

* In the current FY 2025-26, 10 HH solar panels are being installed. There is budget for 7 more.
** There is a budget for making 1 EcoSTP.

[6] Based on IPCC Emissions factors and guidelines & Central Electricity Authority

7.1 Emissions before and after interventions

Following table compares over a 3-year period the emissions growth without any interventions and the emissions with year wise interventions listed in Table 18.

Table 18: Emissions before and after interventions.

		FY2023-24		FY2024-25		FY2025-26	
	Baseline Emissions (TCO_2E/YR)	**Baseline growth**	**After Interventions**	**Baseline growth**	**After Interventions**	**Baseline growth**	**After Interventions**
Scope 1	1506.93	1589.81	1506.51	1681.22	1530.91	1782.09	1597.56
Scope 2	167.39	176.60	176.60	186.75	185.05	197.96	175.42
Scope 3	807.42	851.83	851.83	900.81	900.81	954.85	954.85
Total	**2481.74**	**2618.23**	**2534.93**	**2768.78**	**2616.77**	**2934.91**	**2727.83**
Reduction in Emissions			**3%**		**5%**		**7%**

Assumption: Rural rate of growth[7] considered is as follows

FY2023-24	FY2024-25	FY2025-26
5.5%	5.75%	6%

[7] https://www.mospi.gov.in/sites/default/files/press_release/NAD_PR_30may2025.pdf

8 Is Mandede Net-Zero?

IPCC Sixth Assessment Report (AR6) glossary definition of net zero emissions (IPCC, 2021) is as follows:

> *Net zero greenhouse gas emissions Condition in which metric-weighted anthropogenic greenhouse gas (GHG) emissions are balanced by metric-weighted anthropogenic GHG removals over a specified period. The quantification of net zero GHG emissions depends on the GHG emission metric chosen to compare emissions and removals of different gases, as well as the time horizon chosen for that metric.*
>
> ***IPCC AR6 Annexure VII Page 2240[8].***

Defining Net-Zero for Project Mandede (based on the IPCC principles)

A Net-Zero Village is a rural community in which the annual greenhouse gas (GHG) emissions produced within its boundaries are balanced by an equivalent amount of GHG removals or offsets, such that the net balance of emissions equals zero.

This balance is achieved through:

- Reducing emissions from energy use, agriculture, waste, and transport by adopting sustainable practices and technologies;
- Enhancing natural carbon sinks such as forests, soils, and agroforestry systems to absorb and store carbon; and
- Where necessary, offsetting residual emissions through certified external measures consistent with international standards.

In the case of Mandede village, the system boundary is the village territory and its managed ecosystems

Based on this definition, we can confidently state that Mandede is a Net-Zero Village. Here is the summary of the emissions and sequestration:

Table 19: Is Mandede Net-Zero?

Sr No	Head	Emissions & Sequestration TCO_2e/Yr		
		2023-24 with interventions	2024-25 with interventions	2025-26 with interventions
1	Total GHG emissions in Mandede (From Table 18)	2534.93	2616.77	2727.83
2	Total natural sequestration in Mandede boundary (From Table 16)	5159.00	5159.00	5159.00

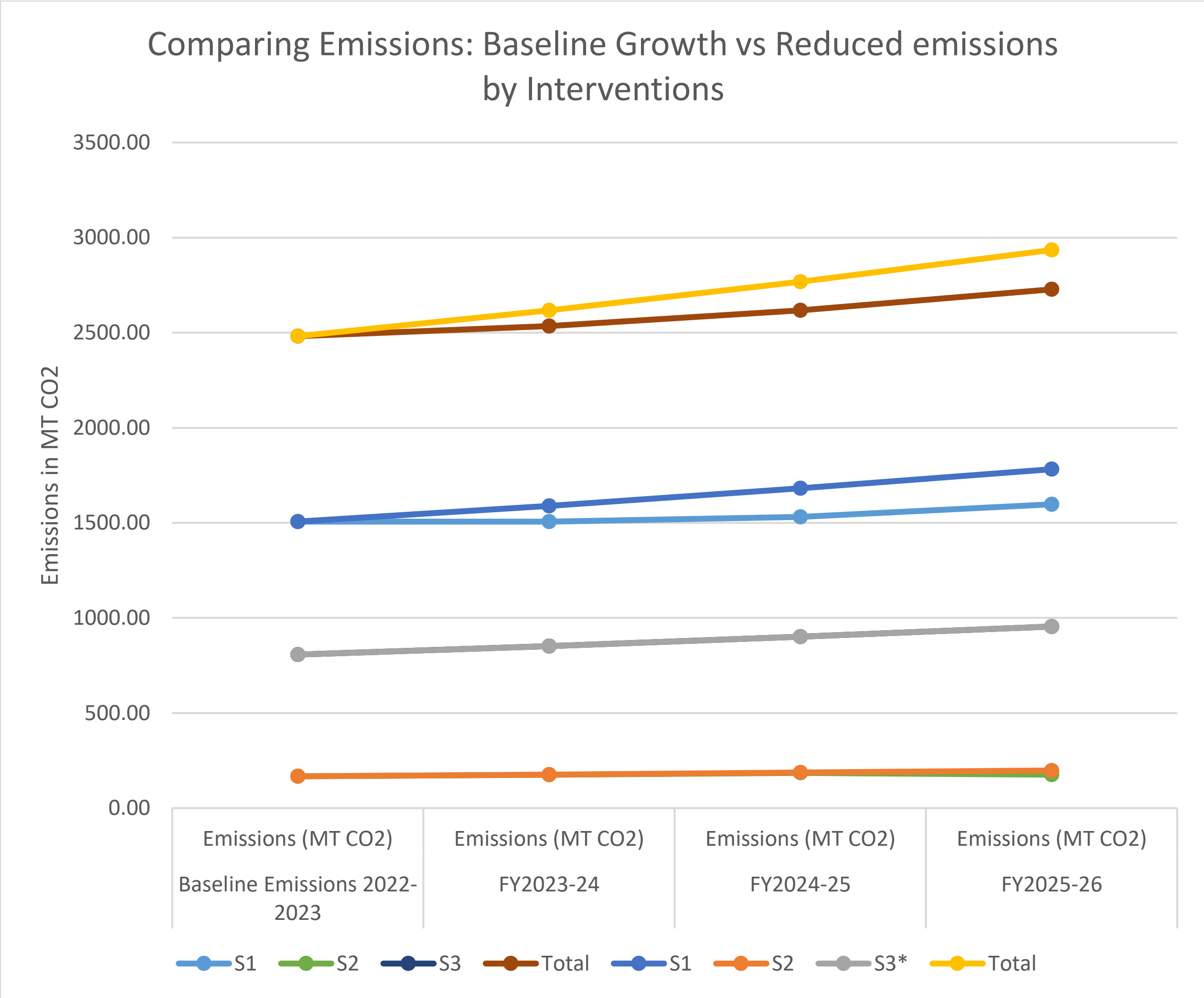
Notwithstanding the natural sequestration capacity of Mandede, our interventions are bending the curve (Figure 1).

[8] Available here https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_AnnexVII.pdf

How we bent the curve

Figure 1 shows the graph of emissions over a 3-year period. The steeper sloping curves represent the emissions if no interventions are done in Mandede, and the lesser sloping lines represent the reduced emissions after the interventions are completed.

Figure 1: Bending Mandede's Emissions Curves



Annexure-1
Emission Factors used in Calculations

Table 20: Emission factors for transport fuels

Fuel	Emission factor unit	CO_2	CH_4	N_2O
Petrol/Gasoline	kg/US gallon	8.599	0.00450	0.000435
	kg/Litre	2.272	0.00119	0.000115
	kg/kg or MT/MT	**3.058**	**0.00160**	**0.000155**
Diesel	kg/US gallon	10.131	0.00144	0.000260
	kg/Litre	2.676	0.00038	0.000069
	kg/kg or MT/MT	**3.217**	**0.00046**	**0.000083**
1 US gallon = 3.78541 Litre *Density of Petrol/Gasoline: 0.7429 kg/Litre* *Density of Diesel: 0.832 kg/Litre*				

Table 21: Emission factor estimation

Fuel	Emission factor (in MT/MT)			CO_2 equivalent (in MT/MT)			CO2e (MT/MT)
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	
Petrol/Gasoline	3.058	0.00160	0.000155	3.0577	0.04768	0.042315	**3.147695**
Diesel	3.217	0.00046	0.000083	3.2167	0.01371	0.022659	**3.253067**
LPG	2.985	0.00024	0.000005	2.9846	0.00715	0.001365	**2.99**
Natural Gas	2.693	0.00024	0.000005	2.6928	0.00715	0.001365	**2.701317**
Wood/wood waste	1.747	0.00468	0.000062	1.7472	0.13946	0.016926	**1.90359**

Global warning potential (100 years) (As per IPCC Sixth Assessment Report):

1. CO_2: 1
2. CH_4: 27. According to IPCC AR6, this number is for fossil-based methane emissions. Chapter 7 of the AR6 report mentions that methane from fossil sources contributes additional fossil CO_2 to the atmosphere. In contrast, biogenic methane (e.g., from paddy field agriculture of Mandede) replaces CO_2 that has been recently removed from the atmosphere. Thus, for methane emissions from Mandede's paddy fields the soil uptake and removal of partially oxidized products are equivalent to a sink of atmospheric CO_2. Research suggests that climate impact of non-fossil methane emissions may be less than that of fossil methane, due to the potential for carbon sequestration in soils and the shorter-term nature of biogenic carbon cycles. AR6 does not provide a specific GWP value for non-fossil methane emissions. For Mandede calculations, we have taken a GWP for methane as 25.
3. N_2O: 273

Annexure 2
Natural Carbon Sequestration Calculations

Natural carbon sequestration refers to the process by which ecosystems, such as forests, soils, and wetlands, absorb carbon dioxide (CO_2) from the atmosphere and store it in organic matter. This storage occurs primarily in plant biomass (trunks, branches, roots, and leaves) and in soils through accumulated organic material. Forests **sequester carbon annually through growth** and **hold large long-term stocks** of carbon in standing biomass and soils.

When a Mandede resident chops wood from the forest to use in her chula, she allows the stored carbon to be released back into the atmosphere as a byproduct of combustion.

We have used the IPCC method in the Agriculture, Forestry and Other Land Use (AFOLU) Sector to estimate greenhouse gas emissions and removals. The reference document used for Mandede is 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 (Agriculture, Forestry and Other Land Use). The guide is available here https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

Key Terms used

1. **Carbon Stock:** The total quantity of carbon stored in a given location at a point in time. In forests, the main carbon pools are:
    a. *Above-ground biomass (AGB):* stems, branches, foliage.
    b. *Below-ground biomass (BGB):* roots.
    c. *Dead wood and litter:* standing dead trees, fallen logs, leaf litter.
    d. *Soils:* organic matter within the soil profile.
2. **Carbon Sequestration (Flow or flux):** The annual increase in carbon stored, expressed as tonnes of carbon (tC) or tonnes of carbon dioxide equivalent (tCO_2e) per hectare per year. It represents the *flow* of carbon into the stock.
3. **Carbon Fraction (CF):** A default value (≈0.47) used to convert dry biomass into its carbon content.
4. **Root: Shoot Ratio (R):** The ratio used to estimate below-ground biomass from measured or estimated above-ground biomass.
5. **Conversion Factor (C → CO_2):** To express results in CO_2 terms, the molecular weight ratio of 44/12 = 3.667 is applied.
6. **Unit conversions:** 1 acre = 0.4047 ha; 1 tC = 3.667 tCO_2.

IPCC Guidelines

The **Intergovernmental Panel on Climate Change (IPCC)** provides internationally accepted methods for estimating greenhouse gas (GHG) emissions and removals from land use, land-use change, and forestry. The authoritative references are the **2006 Guidelines for National Greenhouse Gas Inventories** and the **2019 Refinement**[9].

The IPCC defines three methodological "tiers":

- **Tier 1:** Uses global default values provided by the IPCC. This method is transparent, requires minimal data, and is suitable when local measurements are unavailable. For estimating the carbon sequestration at Mandede, we use Tier 1 calculations. This is because we have carbon stock data only for 2 years. We need Carbon stock data for at least 3 years to derive the rate of change of Carbon.
- **Tier 2:** Uses country-specific values (e.g., data from the Forest Survey of India).
- **Tier 3:** Employs detailed field measurements, permanent plot inventories, or advanced dynamic models for the highest accuracy.
- These measurements are currently being done at Mandede. We have data of 2 years.

Mandede Calculation Framework (Tier 1)

At Tier 1, annual change in carbon stock (ΔC) is estimated as:

EQUATION 2.1 Annual carbon stock changes for the entire AFLOU sector estimated as the sum of changes in all land-use categories Δ

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{O}$$

Where ΔC = carbon stock change in each of the land-use categories: AFOLU = Agriculture, Forestry and Other Land Use FL = Forest Land; CL = Cropland; GL = Grassland; WL = Wetlands; SL = Settlements; OL = Other Land.

And each of the ΔC_{LU} term represents the change in above-ground biomass, below-ground biomass, dead wood, litter, and soil carbon, respectively. In practice, Tier 1 methods often focus on live biomass (AGB + BGB) because dead wood, litter, and soils are assumed stable or change slowly. Based on GIS and ground truthing on 61 sample plots, we estimated the Land use per category in hectares.

Table 22: Carbon stock in Mandede

Land Use category in Mandede	Area (Hectares)	Carbon stock (Tons)
Natural Vegetation:	621.84	316,706.71
Cultivation:	279.70	74,859.61
Open Area:	2.78	86.4
Others	17.58	Nil
Total area of Mandede	**922**	

[9] https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

As the Open Area is the most likely candidate for changes, and our current calculation shows its average carbon stock as 30 tons/acre, we did not take up sequestration calculations for this.

Assumptions in natural sequestration calculations

The assumptions made for Mandede's natural sequestration are highly conservative, which follows our principle 'to err on the side of caution'. Thus the conservative values will yield a conservative estimate of natural sequestration.

1. **Mandede Forest type:** Moist deciduous/semi-evergreen (Eastern foothills, Western Ghats, Maharashtra)
   Predominant Species: *Ficus racemosa, Mangifera indica, Ficus amplissima, Tamarindus indica, Syzygium cumini, Careya arborea, Albizia procera, Acacia auriculiformis*
2. We assumed a canopy cover of 60% in the forest areas. This is a conservative estimate, since satellite imagery shows a dense canopy cover.
3. We assumed 30% old-growth trees in the forest area. This is a conservative estimate, since our sample plots record a higher number of old-growth trees.
4. No major disturbances (harvest, fire, disease, land-use change) and canopy cover/species composition remain the same.

A. Calculations for Natural Vegetation

We measured the carbon stock using GBH method. This included the Above-ground biomass (AGB) + Below-ground biomass (BGB). The Carbon Stock was computed by actual measurements of girth of trees by GBH method, on 31 sample plots of natural vegetation on the slopes of Mandede. Thus, the carbon stock in one standing hectare of Mandede forest is calculated as follows:

C = Stock / Area

C_F = 315,790 / 621.84 = **508** tons per hectare of **forest**

C_C = 74,859.61 / 279 = **267.03** tons per hectare of **cultivation** land

The measured stock includes **above-ground biomass (AGB)** and **below-ground biomass (BGB)**.

Step 1: The default Tier-1 growth growth is 1.2 tC/ha/yr.

We need to adjust this for 60% canopy cover and 30% old growth trees in Mandede's forests:

(60×30)/ (100×40) =1800/4000 = 0.45

Thus, the adjustment factor is **0.45**.

Step 2 — Apply the factor to the default Tier-1 growth

Default = 1.2tC/ha/yr x 0.45 = 0.54tC/ha/yr

Step 3 — Convert to CO_2 equivalent

CO_2 equivalent = 0.54 × 3.667 = 1.98 tCO2e/yr

Step 3 — Calculate the total forest sequestration

Total forest sequestration = 1.98 × 621 hectares = 1231 tCO2e/yr

B. **Calculation for Mandede Cultivated area**

The calculation of carbon sequestration for cultivated land was done using the **IPCC 2006 Guidelines for National Greenhouse Gas Inventories, Volume 4 (Agriculture, Forestry and Other Land Use, AFOLU)**, applying **Tier-1 default values** for annual cropland and perennial systems. These were adjusted to reflect local land use composition (70% paddy, 25% mango, 5% mixed farm bund trees). For mango plantations, empirical values reported for Indian orchards around 10 years of age were applied.

Please note that IPCC Tier-1 guidance notes large uncertainties around these defaults. However, in absence of a minimum 3-year data on carbon stock, it is not possible to calculate the actual rate of sequestration in Mandede.

Key inputs & assumptions

1. **Land mix (area-weight):** 70% paddy, 25% mango plantation (average tree age ≈ 10 yr), 5% mixed farm-bund trees.
2. **Carbon stock based on 15 quadrat sampling sites:** 266 tC/hectare
3. **Tier-1 defaults:** IPCC cropland/perennial defaults (annual cropland ≈ 4.7–5.0 tC/ha/yr; perennial tropical moist ≈ 2.6 tC/ha/yr)[10].
4. **Mango (10-yr orchard):** literature for Indian mango orchards indicates **~3.0 tC/ha/yr** for average 10-year trees in humid to sub-humid conditions[11].

Calculation per hectare

- **Paddy (Tier-1 default 4.7 tC/ha/yr)** × (1 − 0.10 straw removal) = **4.23 tC/ha/yr** (effective)
  Paddy: 70% × 4.23 = **2.961 tC/ha/yr**
- **Mango (empirical for ~10 yr): 3.0 tC/ha/yr**

  Mango: 25% × 3.00 = 0.750 tC/ha/yr
- **Farm-bund trees (perennial default, tropical moist): 2.6 tC/ha/yr**

  Mixed Farm bund trees: 5% × 2.60 = 0.130 tC/ha/yr

Total per hectare = **2.961 + 0.750 + 0.130 = 3.841 tC/ha/yr**

Per hectare in tCO_2e: 3.841 × 3.667 = 14.08 tCO_2e/ha/yr

So 14.08 tCO_2e /ha/ yr x 279 hectares = **3928.32 tCO_2e/yr**

Total natural sequestration in Mandede = 1231 + 3928 = 5159 tCO_2e/yr

[10] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch05_Cropland.pdf?utm_source=chatgpt.com

[11] https://www.researchgate.net/publication/334693937_Biomass_production_and_carbon_stocks_estimate_in_mango_orchards_of_hot_and_sub-humid_climate_in_eastern_region_India?utm_source=chatgpt.com

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10. All definitions and meanings for the terms used in this report are taken from the IPCC Sixth Assessment Report (AR6), Annexure VII: Glossary https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_AnnexVII.pdf

The **Centre for Sustainable Development**, with the support of **Praj Industries Limited**, has initiated the '**Project Mandede: Net Zero and Climate Resilient Village development**'.

This project aims to demonstrate how net-zero and climate resilent village development can be achieved with an ecological approach. Our planning is based on a systems thinking approach, where we examine the interconnectedness and relations between the local ecology, economy and society, and then search for root causes.

In this project we are working on six themes: Water, Energy, Waste and sewage, Livelihoods, Health and Social aspects and the Natural environment.

Project Mandede is an amalgamation of Science, Technology and Social engineering.

Supported by:

Praj Industries Limited, Pune

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