Tamil Nadu Green Climate Company

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Tamil Nadu Climate Change Mission

VIRUDHUNAGAR

DISTRICT DECARBONISATION ACTION PLAN

VASUDHA FOUNDATION
Green ways for a good earth!

Credit

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“Tamil Nadu has always led the nation in showing how growth and responsibility can go hand in hand. We are steadily building on our actions toward becoming a Net-Zero economy well before 2070. These District Decarbonisation Action Plans take this commitment deeper by bringing climate action closer to the people, to our villages, towns, and industries. When every district and every citizen joins hands, Tamil Nadu will demonstrate how sustainability can take root in local action and collective responsibility.”

Thiru M.K.Stalin

Honourable Chief Minister of Tamil Nadu

“For Tamil Nadu, economic progress and environmental care go hand in hand and they are central to how we plan and govern. These District Decarbonisation Action Plans reflect our commitment to ensuring that development also builds climate resilience. They will guide each district to grow responsibly, aligning prosperity with the health of our land, air, and water. This is how we see the future of Tamil Nadu where fiscal discipline, environmental stewardship, and people’s well-being move forward together.”

Thiru Thangam Thennarsu

Honourable Minister for Finance,
Environment and Climate Change, Tamil Nadu

“ The District Decarbonisation Action Plans strengthen Tamil Nadu’s commitment to integrating climate priorities into development planning. They bring together policy, people, and business to act on shared goals of resilience and sustainability. This approach reflects our focus on turning data and collaboration into practical outcomes that safeguard our environment and support inclusive growth. This is where the strength of Tamil Nadu truly lies, in turning science and policy into action that uplifts people and protects nature. ”

Tmt. Supriya Sahu, I.A.S.

Additional Chief Secretary to Government, Environment, Climate Change & Forest Department, Tamil Nadu

"The District Decarbonisation Action Plans reflect Tamil Nadu's participatory and bottom-up approach to climate action. They combine data, local experience, and cross-sector coordination to help districts plan and act with clarity. Through collaboration between departments, industries, and communities, TNGCC is working to ensure that every local effort contributes meaningfully to the state's long-term climate goals."

Thiru A.R. Rahul Nadh, I.A.S.

Director, Department of Environment and Climate Change, Tamil Nadu

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List of Abbreviation

2W	Two Wheeler
3W	Three Wheeler
4W	Four Wheeler
AES	Aggressive Effort Scenario
AFOLU	Agriculture, Forestry and Other Land Use
AMRUT	Atal Mission for Rejuvenation and Urban Transformation Scheme
ANR	Assisted Natural Regeneration
AWD	Alternate Wetting and Drying
BAU	Business as Usual
BCS	Baseline Case Scenario
BFS	Blast Furnace Slag
BLDC	Brushless Direct Current
BOD	Biochemical Oxygen Demand
BPKP	Bharatiya Prakritik Krishi Paddhati
BUR	Biennial Update Report
CCTV	Closed Circuit Television
CCU	Carbon Capture and Utilization
CFL	Compact Fluorescent Lamp
CGWB	Central Ground Water Board
CH_4	Methane
CMMK-MKS	Chief Minister's Manniyur Kaathu Mannuyir Kappom Scheme
CO^2	Carbon Dioxide
COD	Chemical Oxygen Demand
COP	Conference of Parties
CPP	Captive Power Plant
DEWAT	Decentralised Wastewater Treatment
DFCs	Dedicated Freight Corridors
DJF	December-January-February
ECBC	Energy Conservation Building Code
EP	Energy Productivity
EV	Electric Vehicle

FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
FO	Furnace Oil
FOG	Fats Oils and Grease
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIM	Green India Mission
GJ	GigaJoule
GOBARd-han	Galvanising Organic Bio-Agro Resources Dhan
GRIHA	Green Rating for Integrated Habitat Assessment
GWh	Gigawatt Hour
HGV	Heavy Goods Vehicles
HSD	High Speed Diesel
HT	High Tension
ICM	Indian Carbon Market
IEA	International Energy Agency
INCCA	Indian Network on Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IRES	India Residential Energy Survey
JJM	Jal Jeevan Mission
KAVIADP	Kalaignarin All Village Integrated Agriculture Development Programme
KNMT	Kalaignarin Nagarpura Mempattu Thittam
$ktCO_2e$	Kiloton Carbon Dioxide equivalent
LED	Light Emitting Diode
LPA	Local Planning Area
LPG	Liquified Petroleum Gas
LT	Low Tension

LULUCF	Land Use, Land Use Change and Forestry
MAM	March-April-May
MES	Moderate Effort Scenario
mbgl	Meters Below Ground Level
MITRA	Mega Integrated Textile Regions and Apparel Parks
MLD	Million Liters per Day
MMM	Multi Model Mean
MORTH	Ministry of Road Transport and Highways
MTEE	Market Transformation for Energy Efficiency
MTPA	Million Tonnes per Annum
MW	Mega Watt
N_2O	Nitrous Oxide
NADP	National Agriculture Development Programme
NAP	National Afforestation Program
NAPCC	National Action Plan on Climate Change
NATCOM	National Communications
NBP	National Bio Energy Programme
NDC	Nationally Determined Contributions
NDDP	Net District Domestic Product
NEMMP	National Electric Mobility Mission Plan
NFHS	National Family Health Survey
NGT	National Green Tribunal
NMSA	National Mission for Sustainable Agriculture

NSM	National Solar Mission
OCEMS	Online Continuous Emission / Effluent Monitoring System
ODF+	Open Defecation Free
PAT	Perform Achieve and Trade
PJ	Peta Joule
PLF	Plant Load Factor
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PNG	Piped Natural Gas
PV	Photovoltaic
RCP	Representative Concentration Pathways
RPO	Renewable Purchase Obligation
SBM	Swachh Bharat Mission
SCM	Smart Cities Mission
SEEP	Super Efficient Equipment Programme
SRI	System of Rice Intensification
STP	Sewage Treatment Plant
SWM	Solid Waste Management
TANSEED	Tamil Nadu Startup Seed Grant Fund
TANSIM	Tamil Nadu Startup and Innovation Mission
TNGCC	Tamil Nadu Green Climate Company
TNPCB	Tamil Nadu Pollution Control Board
TPD	Tonnes per Day
TSS	Total Suspended Solids
UGD	Underground Drainage
ULBs	Urban Local Bodies
ZLD	Zero Liquid Discharge

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Preamble

The District Decarbonisation Action Plan for Virudhunagar aims to guide the district toward a low-carbon, climate-resilient, and economically inclusive future. As an industrial and agricultural hub in a semi-arid region, Virudhunagar requires tailored strategies that integrate climate science, energy modelling, and local realities.

Grounded in historical emissions analysis, climate projections, and sectoral assessments, the plan outlines mitigation and carbon sequestration strategies across industry, transport, power, agriculture, buildings, and waste. It presents three scenarios—Business as Usual (BAU), Moderate Effort Scenario (MES), and Aggressive Effort Scenario (AES)—with the potential to reduce emissions by up to 85 percent by 2050, while aligning with state and national climate targets.

Some mitigation measures such as industrial electrification, energy-efficient retrofits, fertiliser reform, and adoption of clean transport—may involve transitional costs. However, these are outweighed by long-term gains in energy security, job creation, public health, and ecosystem restoration. For example, shifting from fossil-based captive power to renewables and promoting electric mobility can reduce emissions while boosting industrial competitiveness and air quality.

The plan emphasises nature-based solutions, such as agroforestry, social forestry, and improved forest management. Repurposing fallow and barren land to enhance carbon sinks not only enables annual CO_2 sequestration but also improves soil health, restores degraded ecosystems, supports biodiversity, and enhances water retention. Though these interventions may require upfront investments and community engagement, they offer long-term co-benefits including livelihood support and climate resilience.

Conversely, a business-as-usual approach may seem cost-effective in the short term but risks intensifying climate vulnerabilities like water stress, extreme heat, and declining agricultural productivity. The plan takes a forward-looking approach by advocating systemic decarbonisation, sustainable resource use, and climate-informed governance.

By aligning economic growth with ecological sustainability, the Action Plan positions Virudhunagar as a district-level model for climate action—advancing Tamil Nadu's decarbonisation goals and contributing to India's net-zero ambition.

This report provides a comprehensive decarbonisation and climate action plan of Virudhunagar, including infographics on the need for climate resilience and decarbonisation in the district in an easy-to-understand manner. It also includes ready to implement projects for near term, sectoral interventions elaborated in a decadal plan.

Executive Summary

The Virudhunagar district, located in the southwest region of Tamil Nadu, is home to 21.5 lakh people and is a hub of industrial activities. The district is known for cement manufacturing IPPU in Alangulam and Thulukkapatti, as well as its textile industry which is based in Rajapalayam and is further supported by the PM Mega Integrated Textile Regions and Apparel Park (MITRA) in the Kumaralingapuram village. These, alongside the other industrial subsectors, are supported by a robust network of 41,604 Micro, Small and Medium Enterprises (MSMEs) that supply raw material and offer allied services. While the economy of Virudhunagar is industry-led, contributing 45 percent of Gross Value Added (GVA), the district still retains a distinct rural character with 53 percent of land used for agriculture which also employs 66.3 percent of its population.[1]

Virudhunagar district experiences semi-arid climatic conditions with high inter-annual climate variability, making it particularly vulnerable to climate change impacts. Virudhunagar faces high climate vulnerability due to rising temperatures (up to 2.8°C by 2090) and erratic monsoon patterns under RCP 8.5. Historical data show increasing trends in heatwaves and extreme rainfall, heightening risks to agriculture, industry, and public health.

The very industries that define Virudhunagar's economic profile also pose a challenge of Greenhouse Gas (GHG) emissions in the district. In 2022, cement manufacturing and industrial energy including captive power plants accounted for 37 percent (1023 ktCO_2e) and 21 percent (592 ktCO_2e) of Virudhunagar's total gross emissions (2790 ktCO_2e). Witnessing a rapid expansion, road transport contributed to 17 percent (471 ktCO_2e), followed by emissions from livestock at 9 percent (252 ktCO_2e), building at 7 percent (201 ktCO_2e) and other sources.

Land-based sequestration was estimated at 171 ktCO_2e in 2022, with agroforestry and social forestry interventions on fallow and wastelands offering considerable scope to enhance carbon removals and further reduce the district's overall emissions footprint.

Low Carbon and Resilient Pathways for Virudhunagar

As the district's economy and population continue to grow, total greenhouse gas (GHG) emissions are expected to rise due to increasing energy demand across the industrial, building, and agriculture sectors, along with emissions from livestock, cropland activities, and waste.

Under the **Business as Usual (BAU)** scenario, total emissions are projected to reach **3535 ktCO$_2$e by 2050**, driven by both **energy-related** and **non-energy-related** sources.

Emissions from the energy sector (excluding IPPU) are estimated to grow by 22 percent, rising from 1290 ktCO$_2$e in 2022 to 1574 ktCO$_2$e in 2050. This increase is primarily attributed to rising industrial activity, fuel consumption for cooking, and road transport.

Simultaneously, emissions from Agriculture, Forestry and Other Land Use (AFOLU) and the Waste sector are projected to increase by 21 percent, from current levels to 578 ktCO$_2$e in 2050. The livestock sub-sector will be the largest contributor within this category, with emissions expected to reach 339 ktCO$_2$e. Aggregate and non-CO$_2$ sources on land, such as rice cultivation, agricultural soils, and biomass burning, will also grow, from 87 ktCO$_2$e in 2022 to 115 ktCO$_2$e in 2050.

Conversely, waste sector emissions are projected to decline from 138 ktCO$_2$e in 2022 to 124 ktCO$_2$e in 2050, mainly due to a significant reduction in solid waste emissions—dropping from 27 ktCO$_2$e to just 2 ktCO$_2$e.

Emission Reduction Opportunities

Significant mitigation potential exists across both energy and non-energy sectors:

- Energy sector emissions can be reduced by up to 86 percent through: (a) Transition from LPG to PNG and electric cookstoves in buildings, (b) Increased uptake of electric vehicles (EVs) in transport, (c) Electrification of industrial heating processes and (d) Replacing diesel pumps and tractors in agriculture with solar or electric alternatives.
  These efforts are strongly supported by enabling policies such as the Tamil Nadu Electric Vehicle Policy 2023, Tamil Nadu Industrial Policy 2021, and the PM-KUSUM scheme.
- In the waste sector, deploying centralised sewage treatment systems (e.g., activated sludge process), septic tanks with Fecal Sludge Treatment Plants (FSTPs) at Gram Panchayat cluster level, and Decentralised Wastewater Treatment Systems (DEWATS) could collectively reduce emissions by 91 ktCO$_2$e.
- Adoption of Zero Liquid Discharge (ZLD) technologies and improved sludge waste treatment could further abate 8.7 ktCO$_2$e by 2050.
- In the livestock sector, implementing balanced rationing, methanogen-suppressing feed additives, and manure management practices could yield an estimated reduction of 93 ktCO$_2$e, equivalent to 28 percent of projected livestock emissions in 2050.

Together, these interventions offer a clear pathway to significantly reduce emissions across sectors, supporting the district's transition to a low-carbon, climate-resilient future.

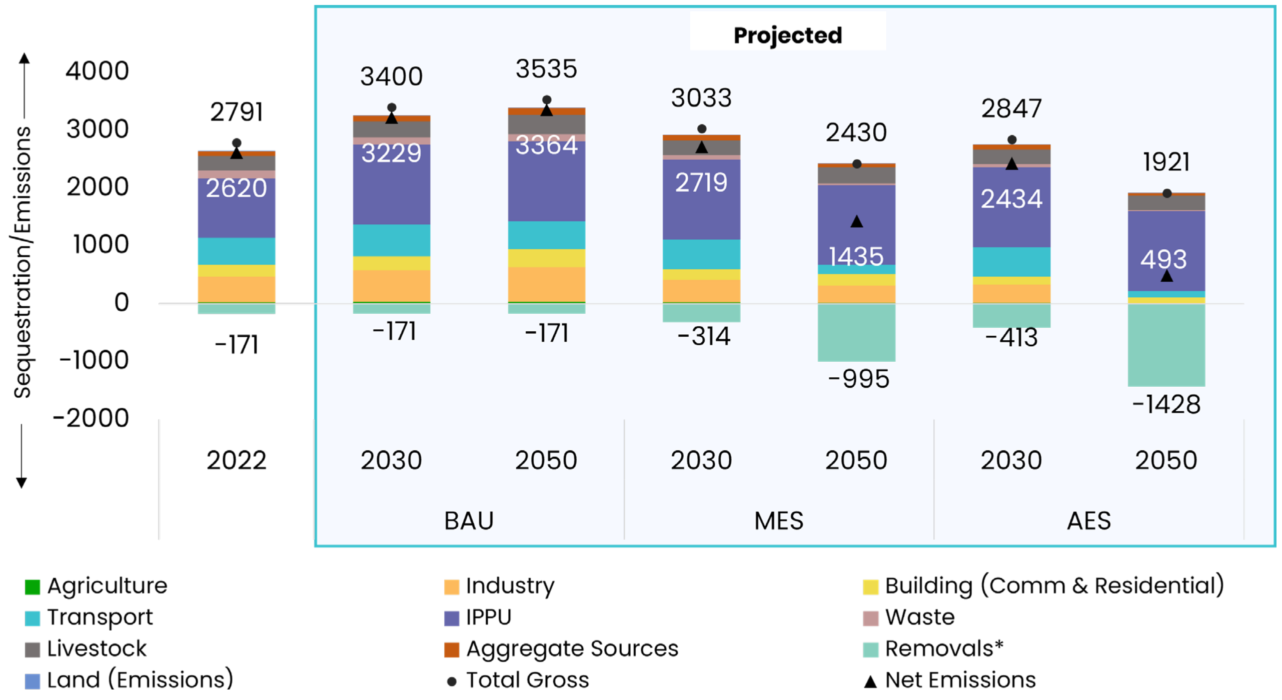


Figure ES1: GHG emissions in Virudhunagar in 2022 (actual), 2030 and 2050 (projections) under BAU, MES and AES

Implementation of the Decarbonisation Plan

Implementing this decarbonisation plan calls for a phased approach, prioritising high-impact and readily implementable projects in the short to medium term, particularly those that can be advanced by 2030. These initiatives are high-priority actions that are well-suited for near-term implementation, deliver developmental co-benefits alongside decarbonisation, and serve as foundational steps in advancing the district's transition toward a low-carbon future. Details on each project, including specific targets, implementation costs, and associated mitigation potential are as below:

Electrification of Road Transport: Virudhunagar's vehicle stock of 5.2 lakh 2-wheelers, ~5000 3-wheelers, ~47500 4-wheelers, ~3000 buses, and ~12700 heavy-good vehicles (trucks, trolleys) is significantly relied on fossil fuels (diesel, petrol, natural gas), as evident from less than 0.5 percent penetration of electric vehicles in total stock in 2022. As the economy grows, the mobility needs are expected to increase. Adding 200 electric buses to the vehicle stock by 2030 can abate 3.4 $ktCO_2e$ 1% of the gross emissions. Awareness generation over time can further nudge commuters to adopt public transport. A 10 percent shift of commuters from private vehicles to public buses is expected to result in need avoidance of ~18000 4W and abatement of ~46 $ktCO_2e$ by 2050.

Interventions	Departments	Expected Cost (Rs. Crores)	Available Finance
Addition of 200 electric buses by 2030	Tamil Nadu State Transport Corporation (TNSTC) and State Transport Department	360[2]	Rs. 55 crore available under PM E-DRIVE[3] with a supplementing Rs. 20 crore under TN EV Policy 2023[4] Furthermore, the Rs. 70 crore allocation made by SPCB to TN Transport Corporation[5] can be explored.

Replacing Diesel Pumps with Solar Pumps: Agriculture in Virudhunagar showcases heavy reliance on diesel pumps for irrigation purposes. As many as 330 diesel pumpsets in the district contribute 6 $ktCO_2e$ each year. Replacing them with solar/electric pumps by 2030 could completely abate these, negating 0.2% of the gross emissions directly.

Interventions	Departments	Expected Cost (Rs. Crores)	Available Finance
Replacing the existing 330 diesel pump with solar/electric pumps	Department of Agriculture	11.55	Rs. 10 crore available under PM KUSUM[6], at the rate of Rs. 0.0314 per 5HP pump

Promoting Energy Efficiency in Buildings: Electricity consumption in commercial buildings and public/street lights stood at 304 GWh in 2022, and is expected to double to nearly 614 GWh under BAU 2050. By replacing 8.5 lakh incandescent and CFL lights with LEDs and converting 80,000 street lights to smart LED systems by 2030, about 30-40% of energy demand can be avoided, saving 28 ktCO_2e of emissions. By replacing 11 lakh incandescent bulbs with LED by 2050, the total annual mitigation potential could reach 35 ktCO_2e.

Interventions	Departments	Expected Cost (Rs. Crores)	Available Finance
Replacing 8.5 lakh incandescent lights with LED by 2030	Commissionerate of Municipal Administration, Directorate of Town Panchayats	13	Some allocations may be available under Street Lighting National Programme, but major coverage would only be possible through municipal finance.
Converting 80,000 street lights to smart LED systems by 2030		25	

RE Installation for Abating Scope 2 Emissions Across Sectors: The entire decarbonisation plan for Virudhunagar hinges on the district's capacity to transition from fossil based to renewable energy based grid electricity through an additional RE capacity integration of 3GW in addition to the existing 0.7 GW RE capacity. This RE based electricity will be essential for powering various electrification measures suggested in the plan over short, medium and long term and could abate 4384 ktCO_2e of Scope 2 emissions by 2050. To achieve this, potential assessment is required to be conducted immediately for rooftop solar, utility scale, wind, floating solar and other technologies.

Interventions	Departments	Expected Cost (Rs. Crores)	Available Finance
Potential assessment for 3GW of additional RE capacity integration (in addition to existing RE capacity of 0.7 GW) by 2030, and subsequent installations	Tamil Nadu Green Energy Corporation Limited (TNGECL) and State Energy Department	16,500	Partial coverages under different RE schemes/policies, subjective to assessment results

Agro/Social Forestry in Fallow and Barren Lands: Virudhunagar district, with its dry plains and scattered hillocks, contains sizable stretches of fallow and underutilised lands of 258044 hectares. These lands offer significant potential for agro and social forestry interventions. By implementing targeted programs of social forests, agro forests and horticulture plantations with native species, an annual carbon sequestration potential of 193 ktCO_2e can be leveraged by 2030, offsetting gross emission by 6%, apart from supporting soil conservation, rural livelihoods and improving overall biodiversity of the region. The initiative will contribute to improving the district's green cover, reduce heat stress, and create long-term resilience against climate change.

Interventions	Departments	Expected Cost (Rs. Crores)	Policies/Funding Schemes
Social and agro forestry in 35,163 ha of barren/fallow lands by 2030	Forest Department, Municipal Administration Department, Horticulture Department	492	Sub-Mission on Agro Forestry (SMAF), Green Tamil Nadu Mission, Green India Mission, State Compensatory Afforestation Fund Management and Planning Authority Fund (CAMPA), Trees Outside Forests in India initiative by MoEFCC and Government of Tamil Nadu

Further, expanding agro/social forestry over an additional 105489 ha has the potential to mitigate 1238 ktCO_2e by 2050, offseting gross emissions by 35%.

Enhancing Domestic Wastewater Treatment: To overcome the risk of untreated discharge while also reducing the strain on existing infrastructure, the proposed intervention aims to achieve 100 percent treatment of domestic wastewater by 2040, thereby targeting a reduction in projected GHG emissions from 112 ktCO_2e under BAU to 21 ktCO_2e annually.

Emission Reduction Potential: **~90 ktCO_2e/year** by 2040 mitigating gross emissions by 2.61%.

Interventions	Departments	Expected Cost (Rs. Crores)	Policies/Funding Schemes
▸ Urban: raise centralised capacity to ≈ 171 MLD (≈ 20% surplus for peak flow) by 2040 ▸ Rural: add ≈ 171,200 households connected to septic-tank + 39 FSTPs. ▸ Advanced DEWATS for campuses >2,500 m², resorts, restaurants etc	Municipal Administration Department, Tamil Nadu Water Supply and Drainage Board, Rural Development and Panchayat Raj Department, Tamil Nadu Pollution Control Board	547	Government initiated with possibilities for gap funding through private, CSR, Swachh Bharat Mission, Tamil Nadu Urban Development Project. Namakku Namae Thittam, Kalaignar Nagarpura Mempattu Thittam

Livestock Emission Reduction through Improved Feed and Manure Management: Livestock is the dominant source of emissions within the AFOLU (Agriculture, Forestry and Other Land Use) sector in Virudhunagar, contributing approximately 74 percent of total AFOLU emissions (excluding land). This initiative aims to reduce methane and nitrous oxide emissions from livestock by promoting balanced rationing, methanogen-suppressing feed additives, and improved manure management practices, thereby enhancing productivity and reducing the sector's climate impact. By 2030, emissions are expected to decrease from 277 ktCO_2e under BAU to 251 ktCO_2e in AES.

Emission Reduction Potential: ~**26 ktCO_2e/year** by 2030, mitigating gross emissions by 0.76%.

Interventions	Departments	Expected Cost (Rs. Crores)	Policies/Funding Schemes
Balanced rationing introduced in 30% and improved feed supplements like Harit Dhara and Tamrin plus in 25% of livestock . 30% reduction in manure management emission through GOBAR dhan scheme	Environment and Climate Change Department, Animal Husbandry Department	161	Farmer driven with possibilities of Government funds as subsidies under various schemes like Balanced Ration programme National Livestock Mission,NABARAD funded biogas projects

Further, balanced rationing introduced in 90%, improved feed supplements like Harit Dhara and Tamrin plus in 75% of livestock and 90% reduction in manure management emission through GOBAR dhan scheme by 2050 could mitigate 93 ktCO_2e/year, mitigating gross emissions by 2.64%.

Climate-Smart Rice Cultivation Programme: Rice fields are a significant source of methane (CH_4) emissions due to continuous flooding practices. The AWD method, which involves periodic drying of fields instead of continuous inundation, can significantly lower these emissions without compromising yield. This project proposes district-wide awareness, training, demonstration, and input support to scale up AWD in rice-growing areas of Virudhunagar.

Emission Reduction Potential: ~**4 ktCO_2e/year** by 2030 mitigating gross emissions by 0.13%.

Interventions	Departments	Expected Cost (Rs. Crores)	Policies/Funding Schemes
Scale up Multiple Aeration Water Regime (AWD method) from ~20% of rice-growing areas to 27% by 2030	Agriculture department, Environment and Climate Change department,Krishi Vigyan Kendras (KVKs)	62	Farmer driven with possibilities of Government funds as subsidies under various schemes

Further, scaling up Multiple Aeration Water Regime (AWD method) from ~20% of rice-growing areas to 77% by 2050 could mitigate 42 ktCO_2e/year, mitigating gross emissions by 1.18%.

Financial incentives and allocations made available under AMRUT 2.0, Swachh Bharat Mission, Tamil Nadu Industrial Policy 2021, National Biogas Programme, National Mission for Waste to Wealth, PM KUSUM, TN EV Policy 2023, National Mission for Sustainable Agriculture, Pradhan Mantri Krishi Sinchayee Yojana, National Afforestation Mission, Green India Mission, Green Tamil Nadu Mission, Compensatory Afforestation Fund Management and Planning Authority and other such policies/schemes are a few other schemes that could support these initiatives.

Key Sectoral Insights

The developed pathways focus on key emitting categories, exploring a range of distinct interventions aimed at reducing emissions while ensuring that the transition aligns with ongoing programmes and schemes at both the state and central levels. The pathways explore three emission scenarios for Coimbatore through 2050: Business as Usual (BAU), Moderate Effort Scenario (MES), and Aggressive Effort Scenario (AES) (Figure ES2).

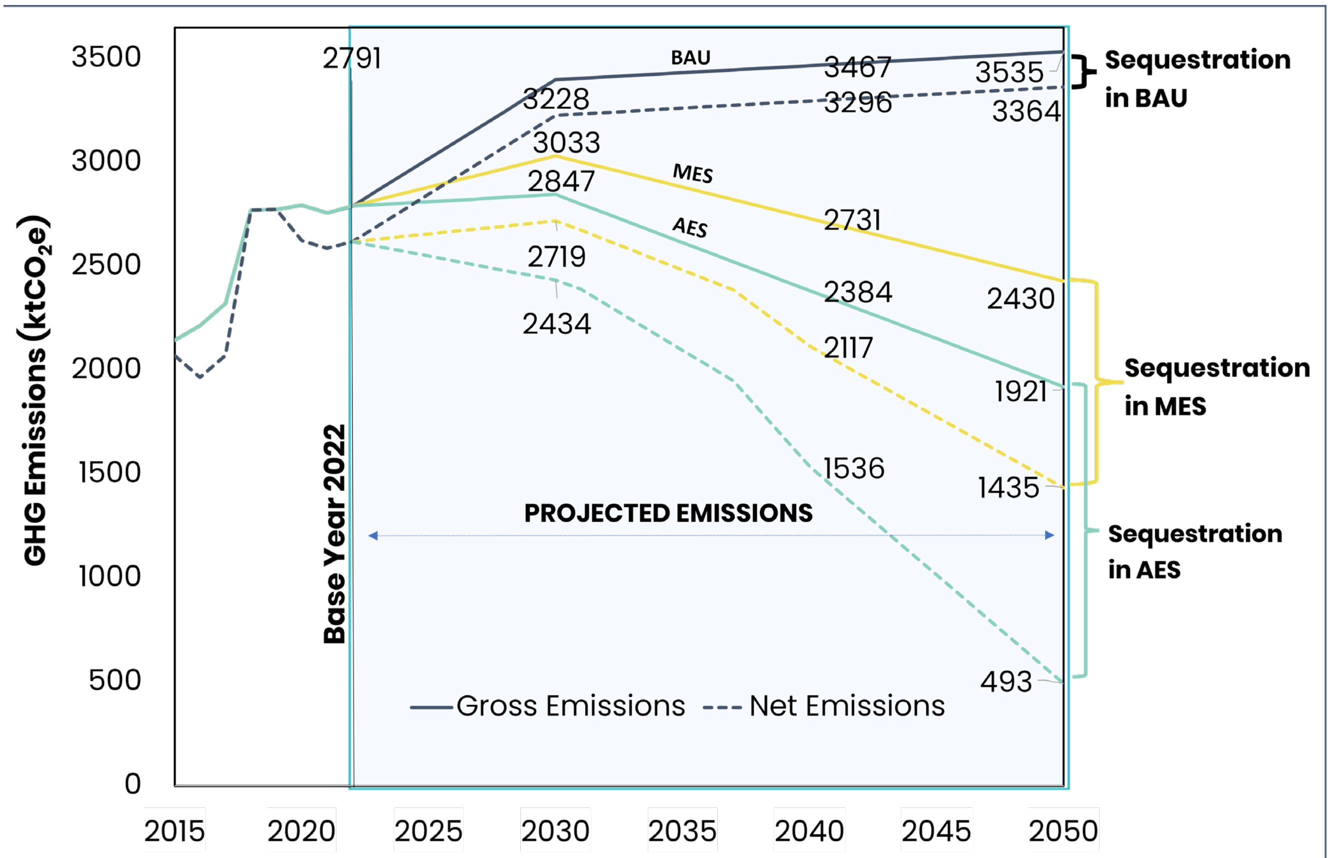


Figure ES2: Economy wide GHG emissions in Virudhunagar under BAU and emission abatements under AES scenario by 2050

(Source: Authors' analysis)

Harnessing mitigation strategies suggested in the plan could enable the district to abate ~85 percent of its emissions by 2050. However, achieving carbon neutrality in the district would require the complete decarbonisation of hard-to-abate cement industries.

Gross GHG emissions in BAU are projected to reach 3,535 ktCO_2e by 2050 from 2,791 ktCO_2e in 2022, driven primarily by industrial growth and increased energy demand in buildings and transport sectors. Virudhunagar could abate 3020 ktCO_2e of these emissions (85% reduction) through higher electrification of the transport fleet and industrial processes, use of renewable sources to replace fossil fuel based captive generation, waste management, and higher sequestration among other strategies.

The net emissions of 493 ktCO_2e in 2050 will primarily come from IPPU emissions, which will require technological solutions such as carbon capture etc. However, the techno-economic feasibility of these solutions is yet to be explored at a larger scale in India.

Deep electrification and energy efficiency initiatives across end use sectors will lead to reduction of final energy consumption, making them key drivers of a sustainable energy future.

Virudhunagar's energy demand is projected to rise from about 29 PJ in 2022 to around 48 PJ by 2050 under BAU. Through energy efficiency measures, deep electrification (particularly in industry and transport), and fuel switching in buildings from LPG to PNG, total energy demand can be reduced to roughly 37 PJ in the AES 2025 scenario—about a 23 percent drop compared to BAU 2050. This shift is driven by higher EV adoption in transport (replacing gasoline and diesel vehicles) and electric furnaces in industry (replacing fossil-fueled processes), which together reduce fossil fuel consumption and improve overall system efficiency.

Deep electrification of end use sectors resulted in higher electrical energy consumption in AES over BAU—approximately 24 PJ in BAU 2050 to over 32.3 PJ in the AES scenario—while the contribution from fossil fuels such as diesel, gasoline, coal, and petcoke has declined.

Further, in the BAU 2022, electricity accounted for ~30 percent of the total energy mix. This share is expected to increase to 50 percent by 2050 due to current market dynamics and initiatives such as electric vehicle adoption, increased electricity use in the building sector, and electrification of agricultural pump sets etc. However, under the AES, the electricity share in the energy mix will rise further to 88 percent due to near complete electrification of the transport fleet, and higher electrification in industries.

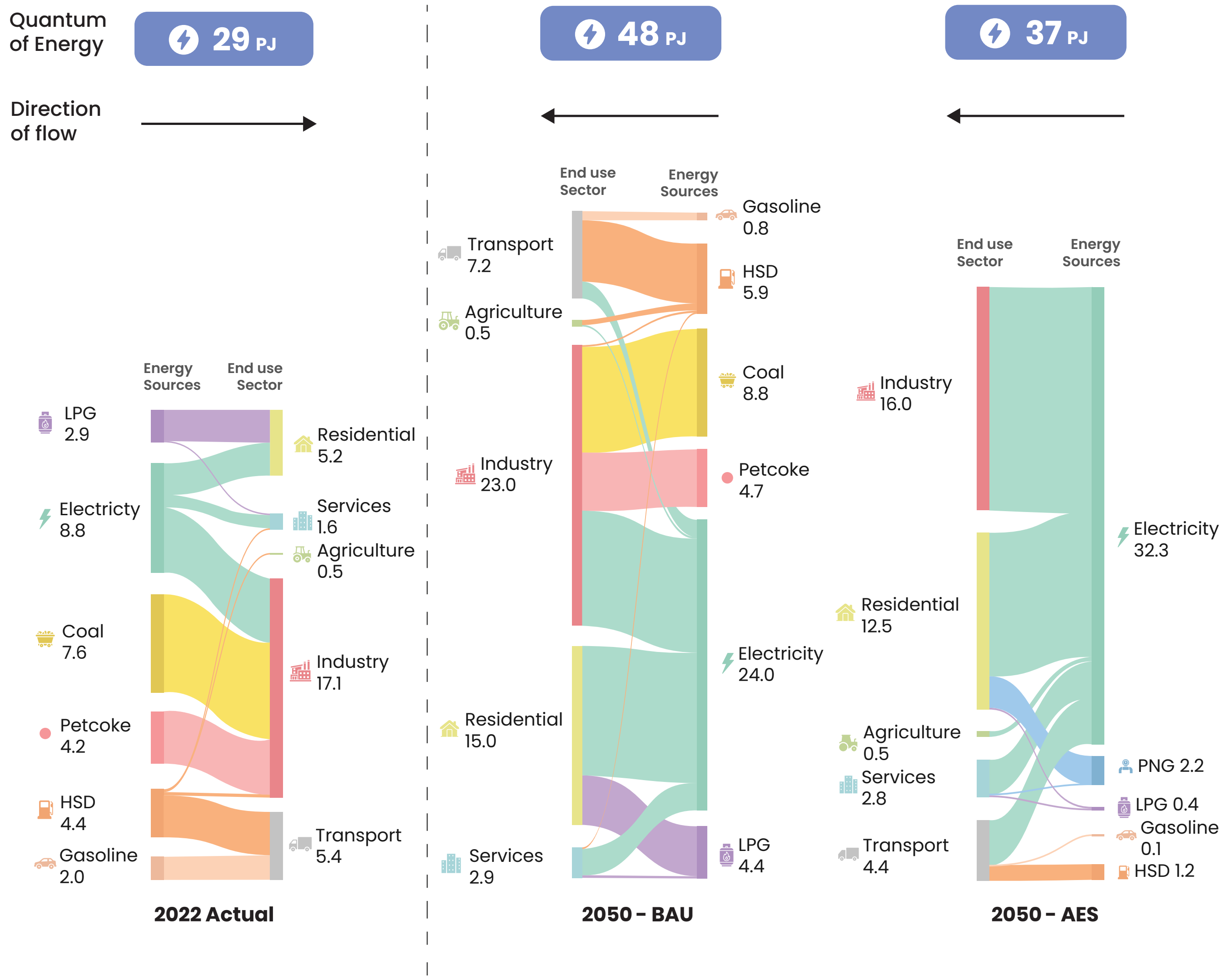


Figure ES3: Energy sources and respective end-use sectors flow diagram in Virudhunagar across 2022 (actual) and 2050 (both BAU and AES scenarios)

(Source: Authors' analysis)

Decarbonisation of hard-to-abate cement sector will play a crucial role in reducing emissions in the district

The GHG emissions from the industries in the district, including the captive power plant emissions and Industrial Processes and Product Use (IPPU) emissions, are expected to increase from 1615 ktCO_2e in 2022 to 1985 ktCO_2 in 2050 under BAU. Majority of these emissions are from cement production. At present, the cement production capacity in Virudhunagar is 2.4 MTPA, which is planned to increase to 3.1 MTPA with an inclusion of 0.7 MTPA RAMCO plant by 2027. Apart from this, Virudhunagar is a textile hub as well. Recently, PM Mega Integrated Textile Regions and Apparel Parks (MITRA) has been inaugurated in Kumaralingapuram village of district to further boost textile sector.

A 100 percent replacement of fossil fuels with clean fuels (such as green hydrogen for firing in Kiln) for heating, energy storage for power backups, electrification of heating processes, and replacing fossil fuel based CPPs with RE can fully decarbonise the industrial sector by abating 748 ktCO_2e of projected emissions in 2050.

Further, adopting Carbon Capture and Utilisation (CCU), as the technology and market matures in the future, would enable the district to abate the process emissions in the cement sector, driving it closer to becoming carbon neutral.

Road transport electrification is critical to mitigate the transport sector's GHG emissions

After Industries, road transport is the second highest GHG emitter in the energy sector, contributing 471 $ktCO_2e$ or 36.5 percent of energy related emissions in 2022. Despite projections of higher EV penetration in new vehicle sales owing to policy and market dynamics, diesel run vehicles will marginally increase emissions to 483 $ktCO_2e$ by 2050. A further push towards achieving 100 percent penetration of EVs in new sales of two-wheelers, three-wheelers, and four-wheelers and 80 percent penetration in heavy goods vehicles will further abate the GHG emissions. This will contribute to the reduction of ~78 percent of projected GHG emissions by 2050, with only 107 $ktCO_2e$ remaining. Due to the fleet electrification, an additional 513 GWh of electricity will be required by 2050 to power these vehicles.

Role of Behavioral Interventions in Road Transport: Non-motorised transport and smart traffic systems can further curtail emissions over and above the projected abatement. Using public transport for inter-city and intra-regional movement can result in 45 percent reduction in emissions in comparison to private vehicles in Virudhunagar. Assuming that 10 percent commuters in Virudhunagar shift from 4W cars to buses, this behavioral change could reduce GHG emissions by ~46 $ktCO_2e$ by 2050. Such a shift could also avoid the need for around~ 18,000 four-wheelers on the road, replaced with an addition of ~800 buses additionally smart traffic systems can reduce 25 percent of signal emissions by reducing idle time at intersection.

Electricity consumption in the district is expected to triple by 2050 compared to current level

Electrification across sectors, higher space cooling needs, and economic growth in the district are expected to increase the district's electricity demand from 2,278 GWh to 7,488 GWh by 2050. Industrial deep electrification would increase industrial electricity demand to 3080 GWh by 2050, almost 41 percent of the total electricity demand of the district. (Figure ES4a) A drastic increase in electricity demand is projected in the transport sector due to higher EV adoption, increasing its share in total electricity mix from nil in 2022 to 11.6 percent in AES 2025 (Figure ES4b).

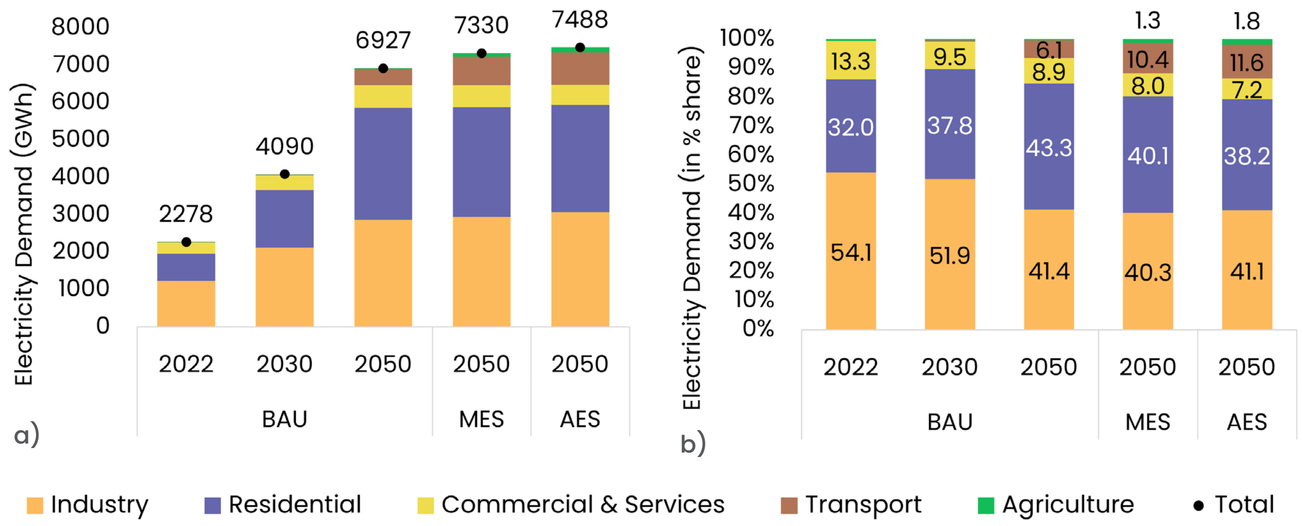


Figure ES4a: Electricity demand projections across sectors and scenarios in GWh
ES4b: Electricity demand projections across sectors and scenarios in percentage share of total

(Source: Authors' analysis)

Residential demand for electricity is projected to increase from 728 GWh to 3,002 GWh by 2050, with that for space cooling accounting for 61 percent of it, at 1845 GWh by 2050. By maintaining a temperature setting of 26°C, it is possible to save up to 60 percent of the electricity required for space cooling, compared to operating air conditioners at 18°C.

Role of Behavioral Interventions in Building Sector: Setting the AC to a higher temperature (around 24–26°C) is both comfortable and energy-efficient. A conservative increase in the temperature setting by 2°C from 24°C to 26°C could reduce electricity demand by approximately 120 GWh. Additionally, smart lighting solutions can prevent 40 percent of lighting electricity usage or 98 GWh in Virudhunagar district.

Decarbonising electricity sector would require holistic assessment and implementation of various renewable energy sources

Over and above the Scope 1 GHG emissions, which have been analysed in the plan, the electricity consumption related GHG emissions (Scope 2 emissions) contribute to almost 736 ktCO_2e and could increase to 4383 ktCO_2e by 2050 in absence of decarbonisation measures. To meet this demand from renewable sources, an additional equivalent capacity of 3 GW (in addition to 0.7 GW solar capacity) is required. Therefore, there is a need for exhaustive and holistic assessment of various solar energy sources such as utility scale PV plants, rooftop solar, floating solar, and agri-photovoltaic solar, bio energy, and wind energy in the district.

In the latest 'Solar PV Potential of India: Ground Mounted' assessment report published in September 2025, the National Institute of Solar Energy (NISE) has estimated a potential of ground-mounted solar capacity of 24 GW in the Virudhunagar district. This is highest in Tamil Nadu at 10% of the total State potential. The potential assessment is based on a dynamic land use modeling that identify 10% of total wasteland with high irradiance and adequate grid access as feasible site for deployment of ground mounted solar in the district. Realising this potential in medium to long term will make the district carbon neutral from electricity standpoint, and support the state's vision of achieving net zero by 2070. Refer to Annexure for more details.

Enhancing ecosystems in Virudhunagar to achieve the dual benefits of carbon sequestration and water resilience

Developing 1,407 km^2 barren, fallow, and cultivable waste lands into agroforestry, social forestry, and afforestation projects can boost carbon sequestration by 1,237.7 ktCO_2e per year by 2050. The Sanjeevi Malai Hills restoration project serves as a model, showcasing the potential of community-driven afforestation, soil conservation, and biodiversity restoration. Scaling similar projects across Virudhunagar's degraded landscapes can significantly enhance carbon sequestration and promote ecological balance and biodiversity (Figure ES5). This also plays a critical role in recharging groundwater, which the district heavily relies on for its water needs. As a drought prone region with no access to perennial rivers and dependent solely on the monsoons, there is an urgent need for effective water conservation and groundwater recharge measures.

Decarbonising the non-energy sector would drive the district towards carbon neutrality

As of 2022, total non-energy emissions (excluding IPPU) in Virudhunagar stood at 477 ktCO_2e (~17% of total emissions), primarily led by livestock (53%, 252 ktCO_2e) and waste (29%, 138 ktCO_2e). In BAU, the total non-energy emissions are projected to increase by 100 ktCO_2e to 578 ktCO_2e (~16% of total emissions) by 2050, again with predominant contributions from livestock (59%, 339 ktCO_2e) and waste (21%, 124 ktCO_2e). Meanwhile, the emissions from aggregate sources and non-CO_2 emission sources on land, which includes emissions from rice cultivation, agriculture soil and biomass burning in cropland, increased from 87 ktCO_2e (~18% of non-energy emissions) in 2022 to 115 ktCO_2e (~20% of non-energy emissions) in 2050.

One third of projected non-energy emissions in 2050 can be abated by targeted interventions in livestock management—balanced rationing and feed additives to control methanogens, manure management—and waste sector.

In AES, through introduction of balanced rationing (90% of livestock), improved feed supplements, methanogen inhibiting substitutes (75% of livestock), and manure management practices, 93 ktCO_2e of emissions from livestock category can be abated by 2050. Similarly, efficient waste management through centralised treatment for urban, septic tanks for rural and fecal sludge treatment plants at Firka level, effluent treatment plants with continuous monitoring systems for industrial wastewater, zero liquid discharge, composting organic waste, reuse etc. can abate 101 ktCO_2e by 2050 from the largely static waste sector.

Half of the projected emissions from aggregate sources and non-CO_2 emission sources from land can be abated by adoption of sustainable agriculture practices.

Replacing synthetic fertilisers and urea with organic fertiliser and nano urea and increasing the percentage of multiple aeration in the rice cultivated area would help to reduce the emissions from the agriculture sector. Under AES, increasing the multiple aeration for rice cultivation from 20% to 77% and transitioning 75% of agriculture area to organic fertiliser will reduce 42 ktCO_2e and 24 ktCO_2e of emissions respectively by 2050.

Additionally, scaling carbon sequestration through green space restoration (Sanjeevi Malai and other forest area) in Virudhunagar would help convert 61% of barren, fallow, and cultivable waste lands into agroforestry, social forestry, and other afforestation projects, and could boost carbon sequestration by 1238 ktCO_2e/year by 2050. The Sanjeevi Malai Hills restoration project serves as a model, showcasing the potential of community-driven afforestation, soil conservation, and biodiversity restoration. Scaling similar projects across Virudhunagar's degraded landscapes can significantly enhance carbon sequestration and promote ecological balance and biodiversity (Figure ES5).

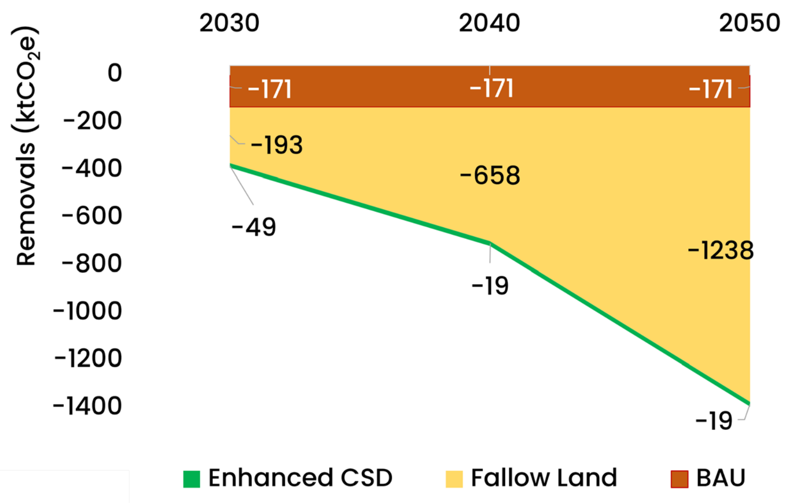


Figure ES5: Carbon sequestration potential in Virudhunagar

(Source: Authors' analysis)

Communities have a catalytic role to play in operationalising decarbonisation of Virudhunagar in a sustainable manner

Strategies for decarbonising Virudhunagar could be made sustainable by rooting them within community groups, with community members – particularly women, youth and other marginalised groups acting as anchors of these solutions. In doing so, local ownership of energy and climate solutions can be instilled and local livelihoods generated.

Table ES1: Models of community engagement in Virudhunagar's decarbonisation

S.no	Intervention	Scope of Community Engagement			Models of Engagement
		Low	Medium	High	
1.	**Green Space Restoration & Sequestration**	✗	✗	✓	**Community-led Forestry & Other Models** **Description:** Community led WADI, agroforestry, social forestry and other sequestration models. Most feasible for community engagement. **Lever Point**: Women SHGs, individual farmers and groups supported by Krishi Vigyan Kendras (KVKs) *Example: Tamil Nadu Tree Cultivation in Private Lands Project (TNPP) engaged farmers for market linked agroforestry*
2.	**Electrification of Road Transport**	✗	✗	✓	**Women E-Rickshaw Ecosystem** **Description:** Provides (additional) livelihoods to women while challenging social norms. In addition to e-rickshaw drivers, women can also be trained on repair and allied services. **Lever Point:** Udyam Sakhis under SRLM *Example: Women E-Rickshaws in UP supported by UPSRLM under 1 Million Jobs by 2027 vision*
3.	**Clean Energy in Agriculture and Buildings**	✗	✗	✓	**Community-led Decentralised RE/Solar Systems** **Description:** Irrigation and solar energy solutions (including installation and maintenance) managed by community members, particularly women SHGs. Generates additional livelihoods while ensuring local ownership of DRE assets. **Lever Point:** Women SHGs, Farmer Producer Organisations under NABARD/SFAC/Khadi Commission *Example: Women SHGs as Irrigation Service Providers piloted in Bihar, Solar Saheli Project piloted in Madhya Pradesh, Rajasthan, Uttar Pradesh, Bihar, Odisha and SHG Solar Power Initiative in Telangana*

S.no	Intervention	Scope of Community Engagement			Models of Engagement
		Low	Medium	High	
4.	**Decarbonisation of Industrial Sector**	✔	✖	✖	**Decarbonisation of MSME Value Chain** **Description:** EVs for transportation of goods from one factory/unit to another, and further to market; training of youth on green jobs; generation of additional jobs through need for repair/maintenance and allied services.Preferential interest rates to women owned green enterprises. **Lever Point:** Women and youth run e-rickshaws can be linked; Safai Sathis and other formal waste management groups; DLBCs for identifying aspiring women entrepreneurs *Examples: Saamuhika Shakti Programme in Bangalore, Karnataka focused on promoting micro entrepreneurship among women waste pickers. NEPRA in Indore also promotes decent work for waste pickers in a business set-up.*
5.	**Waste Management**	✖	✖	✔	**Community-led Waste Management** **Description:** Decentralised waste management, covering waste collection, segregation and processing (if any), owned and managed by local community groups (non-entrepreneurial). Women from disadvantaged communities could play a leading role in this. **Leverage:** Local Safai Sathi Groups *Example: Ecogram Project in Bangalore. Earth5R, a social enterprise in Mumbai, links green entrepreneurship with community driven waste models.*

Virudhunagar's decarbonisation strategy pivots on renewable energy integration, electrification of key sectors, and enhancement of natural carbon sinks. By implementing these measures, the district can significantly reduce its GHG emissions and enhance resilience – contributing its share to Tamil Nadu's decarbonisation goals.

Why Should Virudhunagar Transition Towards a Low-carbon, Climate Resilient Future?

DISTRICT HIGHLIGHTS

~41,000 MSMEs
Concentrated in textile, fireworks, paper and paper products and cement manufacturing

Fireworks and matches manufacturing hub

47% of GDDP
is contributed by the service sector, and 29% by industries

CLIMATE PROFILE

1,243 mm
Annual rainfall

18.9°c to 37.6°c
Annual temperature range

0.2°c to 2.8°c
Projected increase in maximum summer temperature by 2090

Drought, Heat-stress and Forest Fire Risks

Projected increase in rainfall by 2090

10% – 43%
in SW monsoon

18% – 51%
NE monsoon rainfall

GHG EMISSIONS (2022)

2,791 $ktCO_2e$
Gross emissions

2,620 $ktCO_2e$
Net emissions

Key Contributors
% of gross emissions

37%
Cement production (IPPU)

21%
Industrial energy

17%
Road transport

(-171) $ktCO_2e$
Annual sequestration

TRANSFORMATION POTENTIAL

Blended Finance and Community-Ownership Models

Robust Public Transport Ecosystem
for sustainable and shared intra-city mobility

(-1,428) $ktCO_2e$
Annual sequestration potential

1,614 $ktCO_2e$ Annual Mitigation Potential

Electrification of Heating Processes

Climate-resilient Multifunctional Green Spaces

Low-Carbon Interventions and Ecosystem-Livelihood Co-benefits

Blue-Green Ecosystem

-1,428 $ktCO_2e$*

Intervention

- Enhance the carbon stock density of existing forest cover
- Agroforestry in waste/fallow lands
- Restoration of Sanjeevi Malai

Resilience & Co-benefits

- Strengthens heat and drought resilience.
- Enhances water security and soil health
- Promotes biodiversity conservation and ecological balance
- Enables integrated water and agriculture efficiency management

Economics and Livelihood Improvement

- Promotes green jobs and local entrepreneurship
- Strengthens farmers' institutions and support market access.
- Supports livelihood opportunities for women and youth

Industrial Decarbonisation

749 $ktCO_2e$*

Intervention

- Electrify heating processes in industries
- Replace all diesel and coal based captive power plants with renewable energy

Resilience & Co-benefits

- Boosts energy access and health outcomes
- Improves air, water and soil

Economics and Livelihood Improvement

- Improves efficiency & operational performance
- Minimises supply chain disruption
- Skilling and reskilling of workforce for RE based O&M

Sustainable Public Transport

99 $ktCO_2e$*

Intervention

- Addition of 2000 intra-city electric buses by 2050
- Promotion of non-motorised transport and public bicycle sharing infrastructure

Resilience & Co-benefits

- Resilient transport access
- Cooler cities and cleaner air

Economics and Livelihood improvement

- Boosts sustainable mobility
- Green jobs, especially for women
- Better health, last-mile access

NMT: Non-motorised Transport; PBS: Public Bike Sharing; * denotes mitigation potential

What Does Climate-resilient Development Deliver?

- Reduced heatstress risks and improved health infrastructure.
- Strengthened market access for climate-smart and low carbon produce.
- Decent work and improved health outcomes, especially for factory workers
- Supports climate-informed planning and governance
- Enables water management through restoration, rejuvenation of water bodies and efficient urban and industrial water management.
- Bankable green projects | Access to global climate finance | Green jobs | Livelihood security

Virudhunagar's
Path to Decarbonisation

Virudhunagar's path to decarbonisation hinges on electrified transport, clean energy, and enhanced sequestration with additional scope to decarbonise hard-to-abate industries.

Total Net Emissions (2022): 2,620 ktCO_2e

- **Annual Growth in Emissions (2005 to 2022): 3.7%**
- **Per Capita Emissions (2022): 1.21 tonnes CO_2e per capita**
- **Emission Intensity Reduction in 2022 w.r.t 2005: 57%**

INDUSTRIES

AMP: 748 ktCO_2e
21.19% of Gross Emissions

Shifting from the current **~87 MW** fossil-based captive power generation to an equivalent **105 MW** renewable energy capacity by 2040

AMP: 146 ktCO_2e emissions

Replacing fossil fuel-based heating with **electricity-based heating** by 2050

AMP: 602 ktCO_2e emissions

- Adopting material substitution **(LC3 and fly ash)** to reduce process emissions without compromising cement strength
- Exploring **carbon capture utilisation (CCU)** systems

TRANSPORT

AMP: 376 ktCO_2e
10.64% of Gross Emissions

100% penetration of electric **2W and 3W by 2035,** electric **4W and bus by 2040**, and **80%** of **electric trucks and trolleys** in new sales by 2050

Installation of **~475 charging stations** and development of allied infrastructure such as metering and grid infrastructure, to support fleet electrification by 2050

Stock of EVs in 2050

E-2W	**~6.8 lakh**
E-3W	**7,000**
E-4W	**2.6 lakh**
E-buses	**5,200**
E-trucks & trolleys	**11,000**

CARBON SEQUESTRATION

ASP: -1,428 ktCO_2e
40.4% of Gross Emissions

Restoration of Sanjeevi Malai

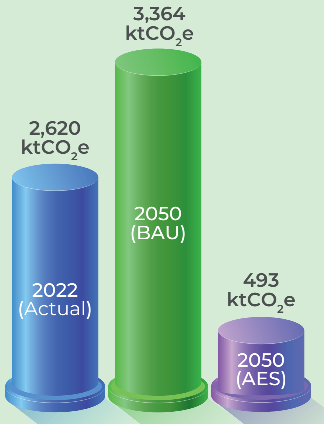
- Plantation of mixed species and assisted **natural regeneration**
- Encourage social forestry, participation of local communities, regular maintenance and monitoring

- Repurposing **1,40,653** ha of barren/fallow lands to horticulture, agro/social forestry
  ASP: -1,237 ktCO_2e/yr by 2050
- Enhance carbon stock density by 5% from the existing **~82.25 tCO_2/ha to 86.76 tCO_2/ha** through reforestation/ afforestation and sustainable forest management
  ASP: -19 ktCO_2e/yr by 2050
- Maintaining the current rate of forest cover increase and existing carbon stock density **ASP: -171 ktCO_2e/yr**

Increasing green spaces through **climate resilient bioparks, urban forests and floating gardens** can help reduce the heat stress

*AMP stands for annual mitigation potential

**ASP stands for annual sequestration potential



Decarbonisation interventions can abate ~2,871 $ktCO_2e$ of projected emissions by 2050

AMP: CO2 **194 $ktCO_2e$**
5.49% of Gross Emissions

AGRICULTURE

- **90% balanced rationing** and **75% methanogen** inhibiting feed additives for livestock by 2050 **AMP: 93 $ktCO_2e$**
- Increase multiple aeration water regime from **20% to 77%** for rice cultivation by 2050 **AMP: 42 $ktCO_2e$**
- Replace existing **~330 diesel pumps** with off-grid solar pumps by 2030, and electrifying **~3000 tractors and tillers** by 2050 **AMP: 35 $ktCO_2e$**
- Replace synthetic nitrogen fertiliser and urea with **75% organic fertiliser** and **25% nano-urea** by 2050 **AMP: 24 $ktCO_2e$**
- **39** mini weather monitoring stations (rainfall and temperature)
- Capacity building to promote sustainable modernisation

AMP: CO2 **4,384 $ktCO_2e$** (Scope 2)

ELECTRICITY

Electricity consumption: **2,278 GWh (2022)**
Led primarily by:

50% Industrial Sector	35% Residential Sector

Deep electrification is expected to increase electricity demand by **three-fold** from 2,278 GWh (2022) to 7,488 GWh (2050)

Potential assessment for integration of additional **~3GW renewable energy** capacity and installation from 2040 onwards, till 2050

WASTE

AMP: CO2 **179.27 $ktCO_2e$**
5.07% of Gross Emissions

- Improved wastewater treatment by 2040 **AMP: 91 $ktCO_2e$**
  - Urban: **171 MLD** centralised sewage treatment and **100% UGD connection**
  - Rural: Twin pit septic tanks for **1.9 lakh households** and **39 FSTPs** at Firka level
- Biogas plant (livestock waste) of **30,000 m^3/day** by 2050 **AMP: 64 $ktCO_2e$**
- Generate electricity through a **3 MW** biodegradable waste-to-energy plant by 2030, **AMP: 14 $ktCO_2e$**
- Setting up of ETPs and continuous treated effluent monitoring system for **2 MLD industrial wastewater** by 2050 **AMP: 9 $ktCO_2e$**
- 100% segregation at source and processing of municipal solid waste with zero landfilling through **39 rural and 15 urban recycling centres** and **15 urban composting** units **AMP: 1.27 $ktCO_2e$**

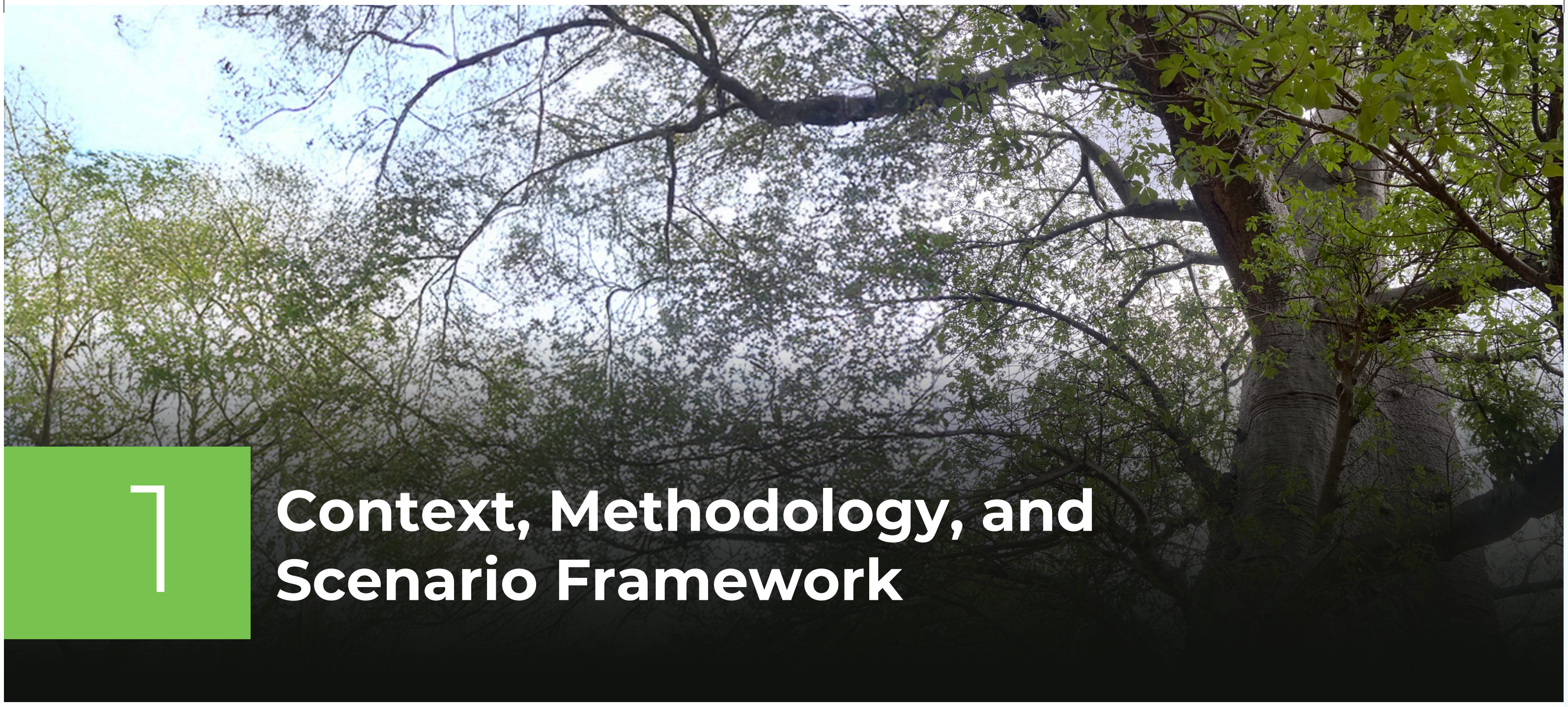
BUILDINGS

AMP: CO2 **195 $ktCO_2e$**
5.52% of Gross Emissions

Urban green cover, reflective roofing, and cool surfaces can reduce ambient temperatures by **1–2°C** and lower cooling energy demand by **5 – 15%**

Residential	Cooking	Commercial
Replace existing incandescent, CFL with **11 lakh LED bulbs**, **7 lakh BLDC fans** and other EE equipments (by 2030) Adopt **~7.5 lakh 3-5 star ACs** by 2030 Save 7-12% electricity demand for space cooling against inefficient electrical system	Transitioning from LPG to PNG, and gradual adoption of **~1.7 lakh electric cook stoves** **Save: 60% cooking emissions by 2050**	**100% electrification of the service sector** including replacement of **high-speed diesel (HSD)** in commercial DG sets (by 2035)

Scope 2 emissions are indirect GHG emissions from purchase of energy (electricity, steam, heat etc)



1 Context, Methodology, and Scenario Framework

At the 26th Conference of Parties (COP26) in November 2021, India made a bold commitment to achieving net-zero greenhouse gas emissions by 2070, signalling its strong resolve to combat climate change.[7] This ambitious pledge marks a significant milestone in India's journey toward sustainable development and reflects the country's determination to play a leading role in global efforts to reduce carbon emissions.

Complementing the national agenda, the role of sub-national entities is essential to realising this vision. As India advances its national decarbonisation plan, active participation from states and regions is critical in achieving a carbon-neutral and resilient future.

Tamil Nadu has emerged as a pioneer in climate action, demonstrating leadership through various initiatives aimed at mitigating carbon emissions. In this regard, the Government of Tamil Nadu has established the Tamil Nadu Green Climate Company (TNGCC) to promote renewable energy, sustainable infrastructure, climate-resilient agriculture, forest conservation, and climate adaptation strategies.

TNGCC follows a dual approach—pursuing carbon neutrality at the state level while formulating bottom-up strategies to decarbonise specific districts. In line with this strategy, Virudhunagar has been identified as a key district for targeted decarbonisation efforts.

In support of this initiative, Vasudha Foundation, in collaboration with TNGCC, has developed a targeted decarbonisation strategy for Virudhunagar. This comprehensive study offers a detailed analysis of Virudhunagar's current and historical emissions, energy landscape, and projected future energy trajectory, while presenting an all encompassing decarbonisation plan across various scenarios under consideration.

Methodology

Climate Variability (Temperature and Rainfall in the Region) Analysis and Projections: Historical climate data and climate models under RCP 4.5 and RCP 8.5 scenarios[8] are used to project future changes in temperature and rainfall. The projections show changes in rainfall, temperatures, and heatwaves.

Historical GHG Emission Inventory: To determine the historical greenhouse gas (GHG) emissions of the district, the methodology outlined by the Intergovernmental Panel on Climate Change (IPCC) for GHG emission inventory has been adopted[9]. This approach typically involves collating data from various sectors contributing to emissions, such as energy, agriculture, forestry, and waste, and applying emission factors and activity data to calculate overall GHG emissions.

Energy Demand and Emissions Projection: A bottom-up energy system model was used, which projects energy demand and emissions from 2022 to 2050 in five-year intervals. The model tracks the transformation of primary energy to meet end-user energy demand across sectors such as residential, services, agriculture, transportation, and industry. Emissions from rice cultivation, fertiliser use, wastewater, and solid waste were also projected , along with assessing the potential for carbon sequestration from forestry.

The model utilises inputs from the district statistical handbook, census data, electricity feed: The district's historical GHG emissions were estimated using the IPCC methodology, which involves collecting sectoral data (energy, agriculture, forestry, and waste) and applying relevant emission factors and activity data to calculate total emissions.

Sectoral GHG Emissions Abatement and Sequestration Potential Assessment: This assessment includes imploring strategies to minimise the emissions and maximise sequestration through afforestation.

Scenario Framework

The scenarios analysed in this study have been designed keeping in view the different operational and technological parameters. These parameters vary depending on system level efficiency, fuel switching, behavioural changes, improving existing forest cover, waste management practices and land utilisation etc. The studied scenarios in this report are:

Business As Usual (BAU): The BAU scenario projects demand and supply growth based on current policies and historical trends. In this scenario, improvements in energy efficiency, fuel switching, and sequestration remain constant at current levels. Electrification is limited to road transport, with no changes in cooking fuel use or waste management practices. This scenario will be used as the reference scenario upon which the decarbonisation scenarios will be built.

Moderate Effort Scenario (MES): MES evaluates the impact of current national policies and targets on emissions reduction (i.e., India's NDC). This scenario makes moderate assumptions on various sectoral emission abatement interventions. For the energy sector, it entails partial electrification of the transport sector, fuel switching in buildings, industry and transport sector. For other sectors, the scenario sets moderate decarbonisation targets for categories such as waste treatment, fertiliser use, and enhancing carbon sequestration.

Aggressive Effort Scenario (AES): AES outlines an aggressive strategy to achieve decarbonisation of the district by 2050, prioritising energy security and substantial emission reductions. It emphasises on widespread electrification, implementing energy efficiency measures, and adopting robust strategies for waste management, optimising fertiliser usage, and enhancing carbon sequestration through afforestation and sustainable land-use practices. Behavioural change induced by public and private campaigns, awareness and capacity building is also accounted for under the aggressive scenario, and is expected to accelerate decarbonisation efforts through environmentally sustainable lifestyle choices at individual level.

Assumptions under each of the above mentioned scenario are further explained in Table 1.1.

Table 1.1: Assumption tree considered under this study

Sector	Sub-Sector Disaggregation	Demand Driver	Scenario-BAU	MES	AES
Agriculture (Energy)	Irrigation	Annual increase in water consumption* and fuel demand	▸ 2022 shares of electrified, diesel, and solar pump sets remain unchanged through 2050. ▸ Fossil fuel-based tractors and tillers in operation retained until 2050.	Conversion of 100 percent of diesel pumpsets to off-grid solar pumps by 2030	
	Agricultural Machinery			Electrifying 50 percent of tractors and tillers by 2050	Electrifying 100 percent tractors and tillers by 2050
Buildings (Residential, Commercial, and cooking)	Residential Appliances & Lighting	GSDP growth leading to higher spend capacities, Higher temperature led space cooling needs	▸ Current level of EE to continue till 2050 ▸ Stock out of Conventional Lighting by 2030	3 Star Appliances to cut down energy demand by 7-8 percent by 2050	5 Star Appliances to cut down energy demand by 11-12 percent by 2050
	Cookstoves	GSDP Growth, Population Growth	LPG as a major fuel for cookstoves, only 8 percent cookstoves electrified by 2050	Shift in composition to LPG (40 percent), PNG (30 percent) and electricity (30 percent)	Shift in composition to electricity (50 percent), PNG (45 percent) and LPG (5 percent)
	Commercial Buildings, Public Lighting, Miscellaneous Services	Commercial Development in the District, leading to increase in electricity and fuel consumption	Electricity consumption in commercial buildings and public lighting to increase by 4.8 percent and 3.7 percent respectively by 2050	▸ Replacement of street lights with LED by 2030 ▸ 50 percent electrification for back-up supply through commercial DG sets, and solarisation of commercial buildings by 2050	▸ Replacement of street lights with LED by 2030 ▸ 100 percent electrification for back-up supply through commercial DG sets, and solarisation of commercial buildings by 2050

Sector	Sub-Sector Disaggregation	Demand Driver	Scenario-BAU	MES	AES
Transport	Road Vehicles	Annual growth in vehicle demand*	▸ 100 percent EV share in new sales of 2W, 3W and 4W by 2050 ▸ 20 percent and 60 percent EV share in new sale of Heavy Goods Vehicles (trucks, trolleys etc) and Buses in new sales by 2050	▸ 100 percent electrification of 2W, 3W, 4W and buses ▸ 50 percent electrification of HGVs	▸ 100 percent electrification of 2W, 3W, 4W and buses ▸ 80 percent electrification of HGVs
Industry	Cement, Textile, Metals and others	Annual industrial growth* leading to increased energy demand	Current growth and emission rates from fuel consumption to continue till 2050	Substitution of coal with renewable energy (green hydrogen and others), waste heat recovery systems etc.	Industrial emissions, except IPPU, are reduced to zero due to deep decarbonisation strategies.
Waste	Solid Waste Disposal	Increase in population and per capita waste generation	Current growth	0 percent solid waste sent to landfills/ dumpsite by 2030	
	Industrial Wastewater	Annual industrial growth	Current MLD to be the same as 2050	60 percent treatment by 2050	80 percent treatment by 2050
	Domestic Wastewater	Increase in population	Current growth	100 percent treatment by 2050	100 percent treatment by 2040

Sector	Sub-Sector Disaggregation	Demand Driver	Scenario-BAU	MES	AES
Carbon Sequestration			Existing sequestration to be same till 2050	▸ Repurposing 30-40 percent of total 258044 ha of barren/fallow lands to horticulture, agro/social forestry ▸ Enhancing Carbon Stock Density by 3 percent from existing ~82.25 t/h to 84.76 t/ha	▸ Repurposing 50-60 percent of total 258044 ha of barren/fallow lands to horticulture, agro/social forestry ▸ Enhancing Carbon stock Density by 5 percent from existing ~82.25 t/ha to 86.76 t/ha
Agriculture	Agriculture Soils	Increase in net sown area and fertiliser demand to enhance productivity	Current growth	Substituting nitrogen fertiliser and urea with 50 percent organic fertiliser and 50 percent nano- urea by 2050	Substituting nitrogen fertiliser and urea with 75 percent organic fertiliser and 25 percent nano-urea by 2050
	Rice Cultivation	Increase in net sown area	Current growth	Increase in multiple aeration water regime from 20 percent to 60 percent for rice cultivation by 2050	Increase multiple aeration water regime from 20 percent to 77 percent for rice cultivation by 2050
	Livestock	Increase in livestock population	Current growth	60 percent Balanced rationing, 45 percent methanogen inhibiting feed additive and 60 percent manure management by 2050	90 percent Balanced rationing, 75 percent methanogen inhibiting feed additive and 90 percent manure management by 2050.

*Historical growth rates are assumed to continue

Detailed assumptions considered in the assessment have been discussed in the individual sections in subsequent chapters.

Stakeholder Engagements

As part of the formulation of this Virudhunagar District Decarbonisation Action Plan, extensive stakeholder consultations were conducted with key line departments across Virudhunagar district to ensure a data-driven and context specific approach. Preliminary discussions were held with the officials from the electricity, forest, industries, agriculture, horticulture, transport, disaster management, town and country planning and urban local bodies with dynamic support from the Environment Climate Change and Forests Department and the District Administration.

These consultations facilitated collection and validation of data required for developing the district's GHG Inventory while also fostering a clear understanding of the prevailing challenges, ongoing initiatives and potential opportunities which can be explored in the relevant sectors. The draft Decarbonisation Plan, prepared keeping in mind these insights and gathered data, was subsequently presented to the District Administration and Heads of Departments (HoDs) of the respective line departments for review. Based on the received recommendations and feedback the plan was further refined and tailored to reflect the ground realities and align with the current and upcoming initiatives.

This collaborative approach ensured that all key stakeholders are well-aware of the proposed sectoral strategies aligned with the district's broader vision of progressing towards carbon neutrality, thereby creating a sense of shared responsibility and enabling smooth and coordinated action to support effective implementation of the proposed interventions across the district.

The details of the departments and officials consulted during the preparation of the action plan are presented below,

Data Collection for GHG Inventory preparation and preliminary discussions

Involved gathering sector-specific activity data using standardized templates tailored for energy, waste, transport, agriculture, and industrial processes. Preliminary discussions were held with key departmental stakeholders to clarify data requirements, address gaps, and ensure consistency and completeness in reporting formats.

Date	Department	Designation of the Person Consulted
06.08.2024	Tamil Nadu Power Distribution Corporation (TNPDCL), Virudhunagar Electricity Distribution Circle (VEDC)	Superintending Engineer and Executive Engineer/General
	District Industries Centre	General Manager
	Agriculture	Joint Director
	Forest - Srivilliputhur Megamalai Tiger Reserve (SMTR)	Deputy Director
09.08.2024	Economics and Statistics	Deputy Director
	District Administration	Personal Assistant (General) to Collector
	Water Resources, Virudhunagar	Executive Engineer, Vaippar
	Tamil Nadu Pollution Control Board (TNPCB)	District Environment Engineer
18.09.2024	District Administration	Personal Assistant (Agriculture) to Collector
	TNPCB	District Environment Engineer
	TNPDCL, VEDC	Superintending Engineer
	District Town and Country Planning	Deputy Director

19.09.2024	District Industries Centre	General Manager
	Regional Transport Office, Virudhunagar	Regional Transport Officer
	Virudhunagar Municipality	Commissioner
	Tourism	Tourist Officer
	Horticulture Department	Deputy Director
	Disaster Management	Tahsildar
20.09.2024	Animal Husbandry Department, Rajapalayam	Assistant Director
	Rajapalayam Municipality	Commissioner
	Water Resources, Rajapalayam	Executive Engineer, Upper Vaippar
	Regional Transport Office, Srivilliputhur	Regional Transport Officer
	Sivakasi Corporation	Assistant Commissioner

Data Collection for GHG Inventory Preparation and Preliminary Discussion

Involved gathering sector-specific activity data using standardized templates tailored for energy, waste, transport, agriculture, and industrial processes. Preliminary discussions were held with key departmental stakeholders to clarify data requirements, address gaps, and ensure consistency and completeness in reporting formats.

Date	Department	Designation of the Person Consulted
18.07.2025	District Administration	District Collector
	Virudhunagar Municipality	Commissioner
	Rajapalayam Municipality	Commissioner
22.07.2025 and 23.07.2025	Forest - SMTR	Deputy Director
	Agriculture	Joint Director
	Horticulture	Deputy Director
	TNPCB	District Environment Engineer
	District Industries Centre	General Manager
	TNPDCL	Executive Engineer/General

2 District Profile

Virudhunagar district, located in the southwestern part of Tamil Nadu, was officially established on 15 March, 1985, following its separation from the combined *Ramanathapuram* district. It covers an area of 4,243 square kilometres and is divided into three revenue divisions and nine taluks. The district shares boundaries with Kerala to the west, *Madurai* and *Sivagangai* districts to the north, *Ramanathapuram* to the east, and *Tirunelveli, Thoothukudi*, and *Tenkasi* districts to the south.[10]

Demography

Virudhunagar exhibits notable demographic trends, with a higher female population compared to the national average, reflecting progress in gender equality. However, challenges in education and healthcare persist despite the improved literacy rates.

Table 2.1: Important demographic indicators of Virudhunagar (Census 2011)

Total Population	Population Density (Person per sq. km)	Urban Population	Rural population	Sex Ratio
19,42,288	458	9,80,226	9,62,062	1007

The demographic landscape is expected to evolve significantly. Overall, the district's total population is forecasted to grow by 11 percent between 2021 and 2050, with an annual growth rate of 0.41 percent, which remains below the national average of 0.61 percent. As per the 2011 Census, around 50.47 percent of the population of Virudhunagar district resides in urban areas, while the remaining 49.53 percent lives in rural areas. The urban population is projected to grow by 22 percent, while the rural population is expected to decline by 8 percent. Additionally, the number of households is anticipated to rise by 16.85 percent, reaching 7,30,926 (7.3 lakh) by 2050.

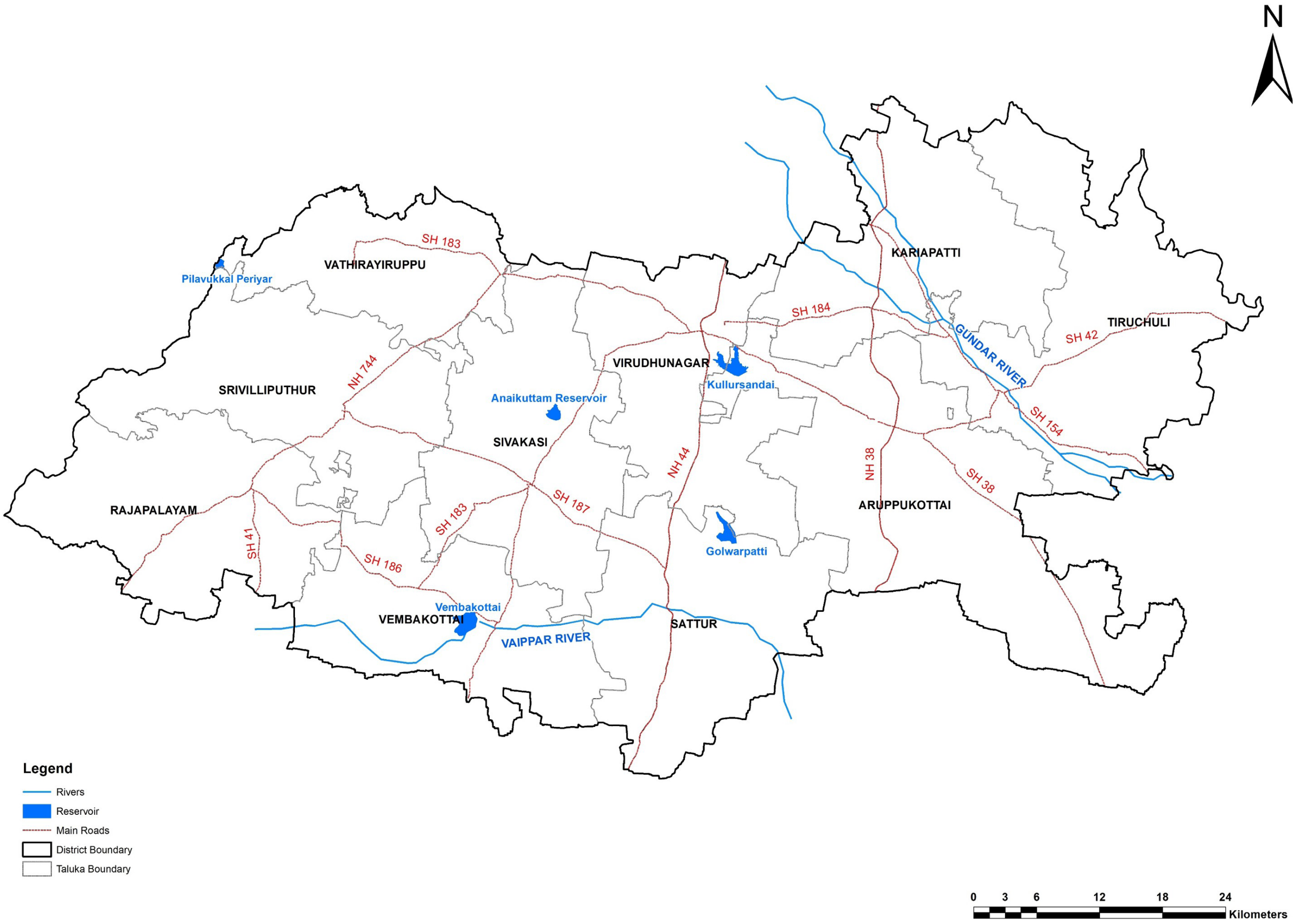


Figure 2.1: Geographical map of Virudhunagar

Topography and Climate

Virudhunagar is characterised by semi-arid climatic conditions and mostly plain topography, with some hilly terrain in the western region. The Western Ghats form a natural boundary along the district's western edge, particularly in the Srivilliputhur and Rajapalayam taluks. In contrast, the black soil plains dominate the areas of *Sivakasi, Virudhunagar, Sattur, Aruppukkottai, Tiruchuli,* and *Kariapatti*. The district lies in two major river basins: *Vaippar* and *Gundar*.

Water Resources

Virudhunagar district has no access to the sea as it is covered by land on all sides. The major part of Virudhunagar district falls in the Vaippar - Gundar river basin. Vaippar, Arjuna River, Gundar, and Deviar are the important rivers. The drainage pattern, in general, is dendritic. All the rivers are seasonal and carry substantial flows during the monsoon period. In 2021-22, the pre-monsoon water level in the district ranged from 5 to 10 meters below ground level (mbgl), while the post-monsoon water level ranged the same from 5 to 10 mbgl.

2.1 Land and Other Natural Resources Profile

2.1.1 Natural Resources (Forests and Biodiversity, Mining, Wetlands)

The land use pattern in Virudhunagar is diverse, consisting of agricultural lands, forests, wetlands, built-up areas, and barren land. The majority of the land is dedicated to agriculture, while forests are concentrated in the northwestern parts. Geologically, the district is predominantly covered by black soil with Precambrian rocks, including charnockite and crystalline limestone, along with residual hills.[11]

Currently, only 6.24 percent of the district is covered by forests, whereas ideally, it should account for 33 percent.[12] Approximately 73 percent of Virudhunagar's area is cultivable. Fallow land constitutes 1.65 lakh hectares, making up 39 percent of the total area, while uncultivated yet arable land amounts to 9,400 hectares or 2.2 percent in 2022-23. Areas used for purposes like tree crops but not counted as net sown land make up 0.48 percent.

Land designated for non-agricultural use covers 70,511 hectares, or 16.62 percent, while land unsuitable for cultivation spans 4,525 hectares (1.07 percent). The district also has 804 hectares of village commons and grazing land, representing 0.14 percent of the total area. The net sown area is 32.3 percent of the district's total, with a cropping intensity of 1.05, consistent with the previous year.[13] (Figure 2)

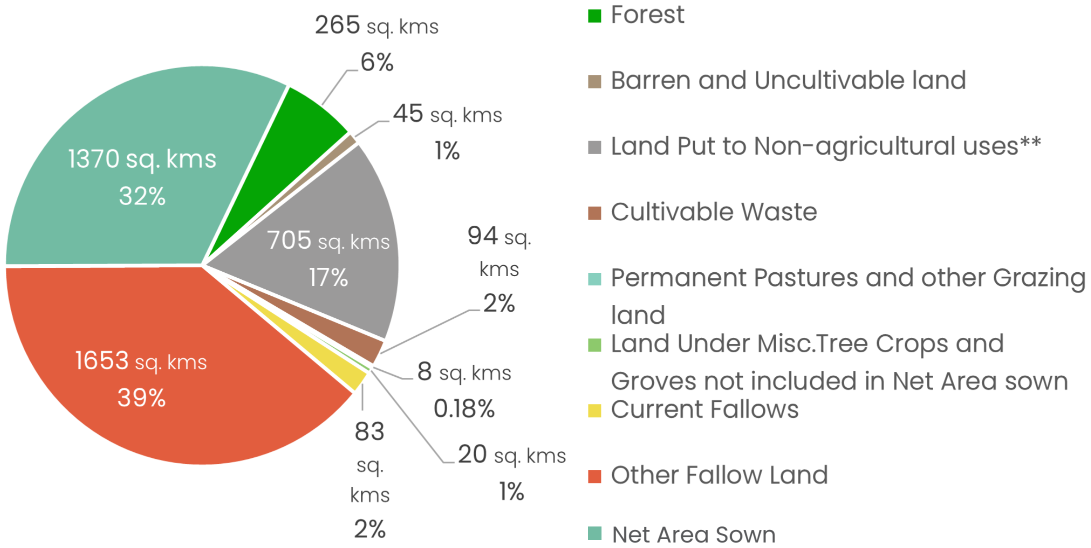


Figure 2.2: Land classification of Virudhunagar (District Statistical Handbook, 2022-23)

The Virudhunagar district covers a total geographical area of 4,243.23 sq. km, and area under forest cover accounts for 352.94 sq. km (FSI, 2023), which makes up 8.32 percent of the total geographical area. Comparison of land use pattern between 2013 and 2023 depicts a 56 percent expansion in forest land. Built-up area has also responded to the population growth and industrial development, increasing by 47 percent over the decade. These increases are adjusted with reductions in other categories, particularly a 11 percent reduction in waste land, 5 percent reduction in scrubland and 4 percent reduction in area under cultivation among others.

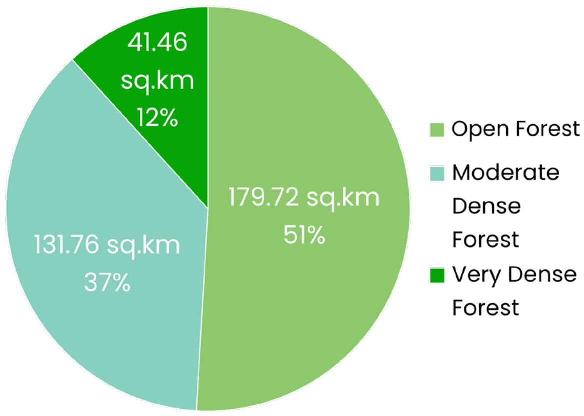


Figure 2.3: Density-wise classification of forest land in Virudhunagar

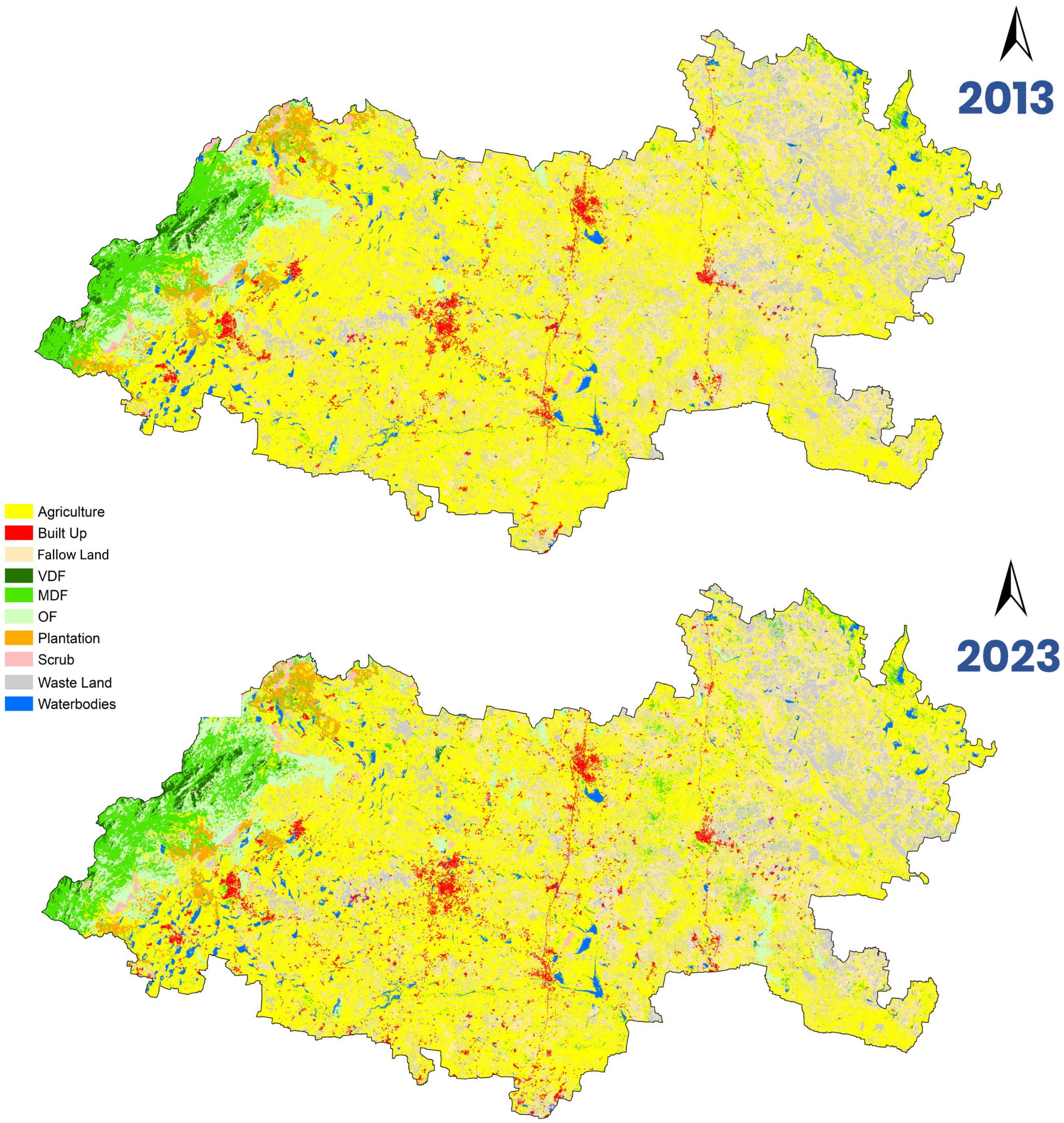


Figure 2.4: Land use map of Virudhunagar

(Source: LISS III and IV satellite imageries for 2013 and 2023, Authors' analysis)

Table 2.2: Land use pattern of Virudhunagar

Land use/ land cover categories (sq km)	Agricul-ture	Built up land	Fallow land	Very dense forest (VDF)	Mod-erate dense forest (MDF)	Open forest (OF)	Plan-tation	Scrub land	Waste land	Water bodies
Year 2013	2332.01	74.68	676.23	28.18	217.79	134.65	60.97	22.95	640.09	67.90
Year 2023	2247.08	109.78	667.55	25.14	238.04	182.45	56.57	21.79	629.06	77.99
Change %	**- 3.64**	**47.00**	**-1.28**	**-10.7**	**9.30**	**35.50**	**-7.22**	**-5.05**	**-11.03**	**14.86**

2.1.2 Biodiversity and Wetlands

Wetlands in the district cover around 290.71 sq. km, accounting for 6.89 percent of the district's total land area. Virudhunagar district has a diverse array of ecosystems and wildlife hotspots. Ayyanar Falls and Sastha Koil Waterfalls situated at the base of the Western Ghats, serve as a vital water source for the diverse inhabitants of the surrounding forests.

Virudhunagar district hosts several important biodiversity hotspots, with the Vembakottai Reservoir—fed by various distributaries of the Vaippar River—being one of them. The Srivilliputhur Wildlife Sanctuary is a major ecological asset, extending into the area around the Kovilar Dam, where elephants can often be seen along forested riverbanks. Other significant sites include the Sanjeevi Mountain, renowned for its medicinal flora, and Shenbaga Thoppu, a forested region rich in endemic species. Spanning an area of 480 square kilometres, the sanctuary is home to the endangered Grizzled Giant Squirrel, as well as a wide array of birds, mammals, reptiles, and butterflies. The rich wildlife includes tigers, leopards, Nilgiri Tahr, various deer species, langurs, macaques, and sloth bears. Over 100 species of birds have been recorded here, including the majestic Great Indian Hornbill.

2.2 Economy

Economically, the district is at a developing stage with its Gross District Domestic Product (GDDP) at constant prices for 2022-23 estimated at INR 30,94,758 lakh – a contribution of 2.13% of Tamil Nadu's economy. Based on 2022-23 GVA at constant price of Virudhunagar service sectors (including trade, repair, financial and other services) and manufacturing are the largest contributors to the district's Gross Domestic Value Addition at 47% and 29% respectively. The district is particularly known for fireworks, matchbox production, textile manufacturing, and printing industries, with Sivakasi being a major industrial hub. With population growth and industrial development driving the need for more buildings and living spaces, construction is emerging as yet another crucial economic sector in the district. Agriculture, despite being a primary occupation and employing 66.3% of the population, contributes only 7.3% to the district's GVA. (Fig 2.2)[14]

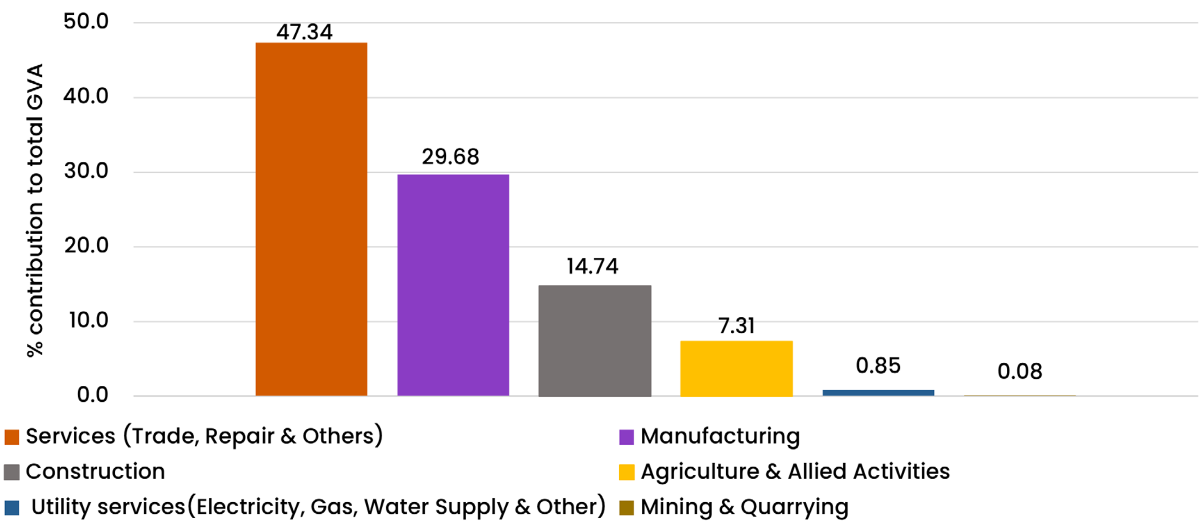


Figure 2.5: Sectoral contribution of Virudhunagar (in GVA)

2.2.1 Transport and Other Infrastructure

Road Connectivity

Virudhunagar district has a road length of 5399 km of which 4764 km is surfaced road and around 635 km is unsurfaced road. The district is enclosed by three significant National Highways: Chennai to Kanyakumari, Chennai to Sengottai, and Chennai to Tuticorin.

Railway Connectivity

Virudhunagar district also has an extensive railway network, encompassing 11 stations and a track length of 240 km, that ensures the accessibility of the region (District Handbook, 2022-23).

2.2.2 Industry

Virudhunagar is renowned for its diverse range of industrial clusters concentrated in and around the blocks of Virudhunagar, Sattur, Rajapalayam, Srivilliputhur, and Aruppukottai. Based on 2023 data from the District Statistical Department, there are around 2561 registered factories and 4606 registered small-scale industries in the district.

A significant share of India's match production and fireworks production, amounting to 70 percent and 90 percent respectively, takes place in the Sivakasi and Sattur taluks of Virudhunagar district. Sivakasi is renowned for its fireworks and as an industrial hub specialising in printing technology. In the vicinity of Sivakasi, there are currently 488 fireworks manufacturers, 3989 match work facilities, 380 printing presses, 82 offset printing presses, and 20 paint production companies in operation. Rajapalayam is another significant industrial town in the district, known for hosting numerous spinning mills and ginning factories. There are approximately 26 mills operational in the district, with a notable concentration in the Rajapalayam/Aruppukottai regions. The district is also a notable production centre for surgical cotton, and bandage cloth, and a diverse range of cotton yarns. Limestone, granite, and sand constitute the primary economically valuable minerals found within the district. The district houses two cement factories situated in Alangulam and Thulukkapatti.

To boost the district's industrial sector, a mini-tidel park has been announced for Virudhinagar under the TN State Budget 2025-26 and is expected to create 6600 jobs.

2.2.3 Agriculture

Agriculture is the primary occupation, employing 66.3 percent of the population. However, the district faces economic challenges in agriculture, largely due to drought-prone conditions and dependence on well irrigation. Major crops cultivated include paddy, millets, cereals, cotton, groundnut, and various grains.

In 2022-23, the gross cultivated area in the district was 1,44,447 hectares, with a net cultivated area of 1,36,989 hectares. Cultivation covered 34 percent of the district's total geographical area, of which 42 percent was irrigated. Maize was the primary crop, with significant areas also dedicated to paddy, cholam, cotton, pulses, and groundnut. Additionally, 329 hectares in Rajapalayam taluk were used to grow cardamom. (Figure 2.6).

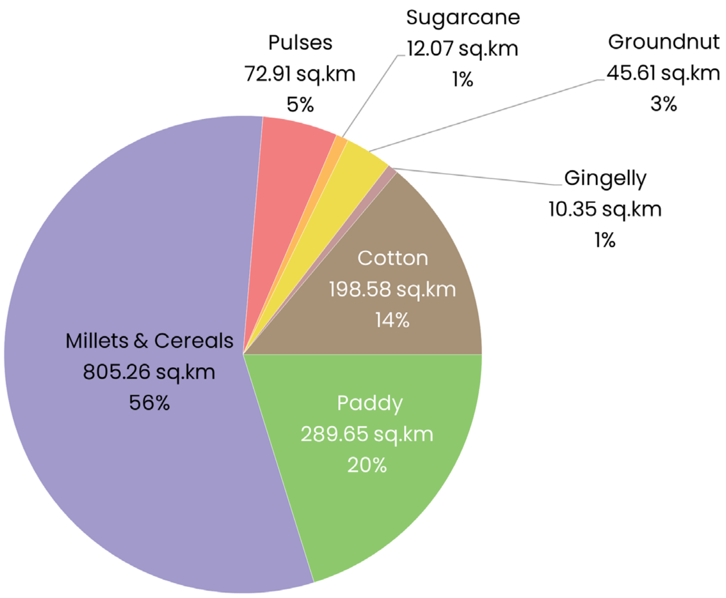


Figure 2.6: Distribution of principal crop-wise area of Virudhunagar (District Statistical Handbook, 2022-23)

2.3 Power Sector

Virudhunagar has a total of 700 MW of installed power capacity. The district harnesses renewable energy for electricity generation, with an installed capacity of 685 MW in solar power, 10 MW in biopower by ETA Power Gen Pvt Ltd, and an additional 5 MW in biopower by Sripathi Paper and Board P Ltd. The district instantaneous demand is 740 MW and sustained peak demand is 669 MW in 2021-22.

Virudhunagar's total electricity consumption in 2022 stood at 2,085 GWh (2278 GWh including captive power consumption) led predominantly by the industrial sector at 1,040 GWh, which represented 50 percent of the total electricity consumption. This was followed by the domestic sector 728 GWh or 35 percent of the total. The commercial and services sector consumed approximately 304 GWh, making up 15 percent of the total electricity usage. The agriculture sector consumed 12 GWh, accounting for 0.6 percent of the total electricity consumption. Transport usage was the lowest, at 0.32 GWh, contributing just 0.02 percent to the total. (Figure 2.7)

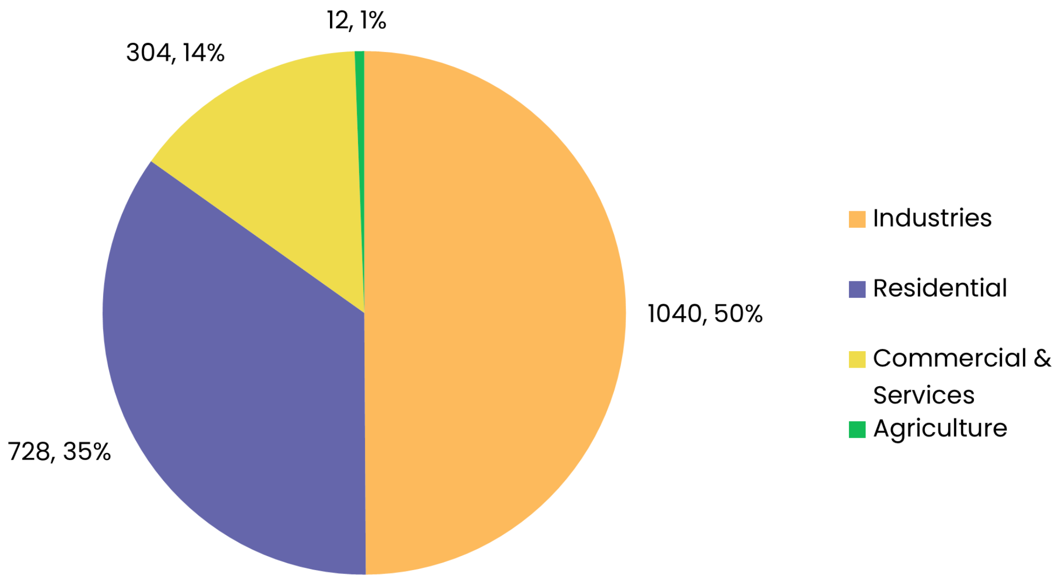


Figure 2.7: Sector-wise power consumption distribution of Virudhunagar (excluding CPP) (2021-22)

SOURCE: TANGEDCO

2.4 Waste Management

In 2023, the total solid waste generated from the 15 Urban Local Bodies (ULBs) in the district was 188 tonnes per day (TPD). The solid waste generated in the district is being fully collected and processed across the ULBs of the district.

Virudhunagar district comprises a total of 348 wards, with door-to-door waste collection services being provided in all of them (100percent coverage). Additionally, waste source segregation is practiced in 328 of these wards. Out of 15 ULBs, 14 ULBs are Open Defecation Free (ODF+). In Virudhunagar district, there are two operational Sewage Treatment Plant (STPs), in Virudhunagar and Rajapalayam, with a combined installede capacity of 29 Million Liters Per Day (MLD).

3 Climate Variability, Projections and Vulnerability

Virudhunagar experiences a hot, dry climate with low humidity and a subtropical climate. The mean maximum summer temperatures (March-April-May) range from 30°C to 35°C, with May being the hottest month in the district. The winter temperature (December-January-February) ranges from 18°C to 22°C, with January being the coldest month. The district receives the highest rainfall during the northeast monsoon (October to December)[15], with an average rainfall of 401 mm (1951-2020). The southwest monsoon (June to September) contributes around 231 mm of rainfall.

This chapter focuses on historical climate information (1986-2005) and projects climate for a future period using global climate models. Precipitation and temperature are used as the key climate variables for this analysis. The simulations of precipitation and temperature have been used for 1986 to 2005 (historical period) while projections have been considered over four different epochs 2021-2040 (2030s), 2041-2060 (2050s), 2061-2080 (2070s) and 2081-2100 (2090s) under medium (RCP4.5) and high (RCP8.5) emission scenarios.[16]

3.1 Temperature

Variability

Maximum Temperature

- The variability in maximum temperature in the summer months (March-April-May) shows a significant increasing trend which has accelerated in the last decade (Figure 3.1).
- The mean percentage of warm days shows a significant increasing trend (Figure 3.2) in the district.

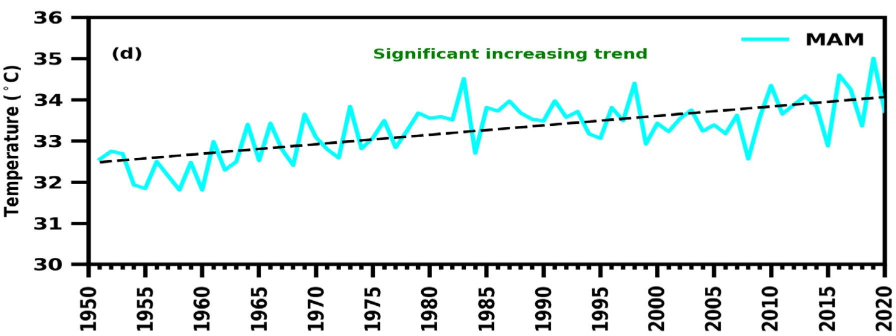


Figure 3.1: Inter annual variability of maximum temperature (°C) over Virudhunagar for 1951-2020

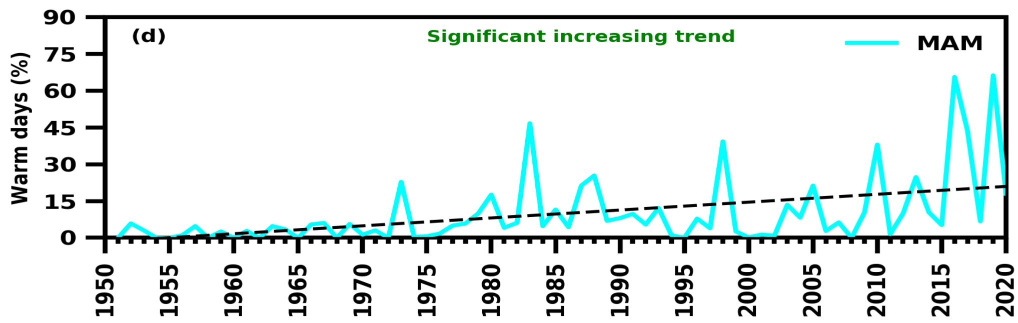


Figure 3.2: Inter annual variability of warm days (%) over Virudhunagar for 1951-2020

Minimum Temperature

- The year-to-year variability in minimum temperature indicates a significant increase in the mean minimum temperature from 1951 to 2020 (Figure 3.3).
- The mean percentage of cold days has decreased in recent decades (Figure 3.4).

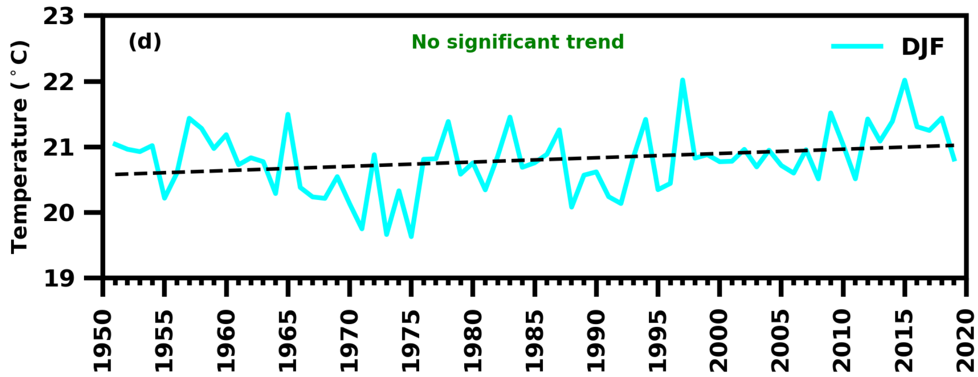


Figure 3.3: Inter annual variability of minimum temperature (°C) over Virudhunagar for 1951-2020

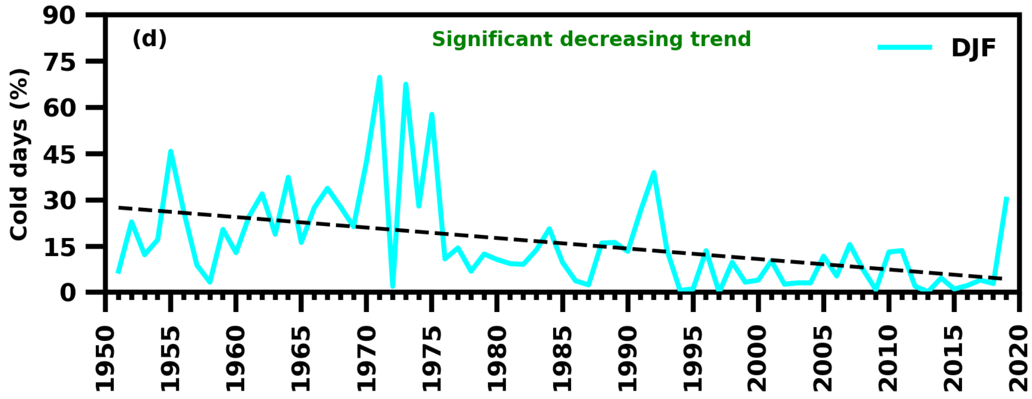


Figure 3.4: Inter annual variability of cold days (%) over Virudhunagar for 1951-2020

Projections

Analysis has been carried out for projected changes in maximum and minimum temperatures on a monthly scale during the summertime (MAM) and wintertime (DJF), respectively.

Maximum Temperature

- The projections show that the maximum temperatures may increase by 0.1°C-1.1°C under RCP4.5 and 0.2°C-2.8°C under RCP8.5 over the district (Figure 3.5).[17]

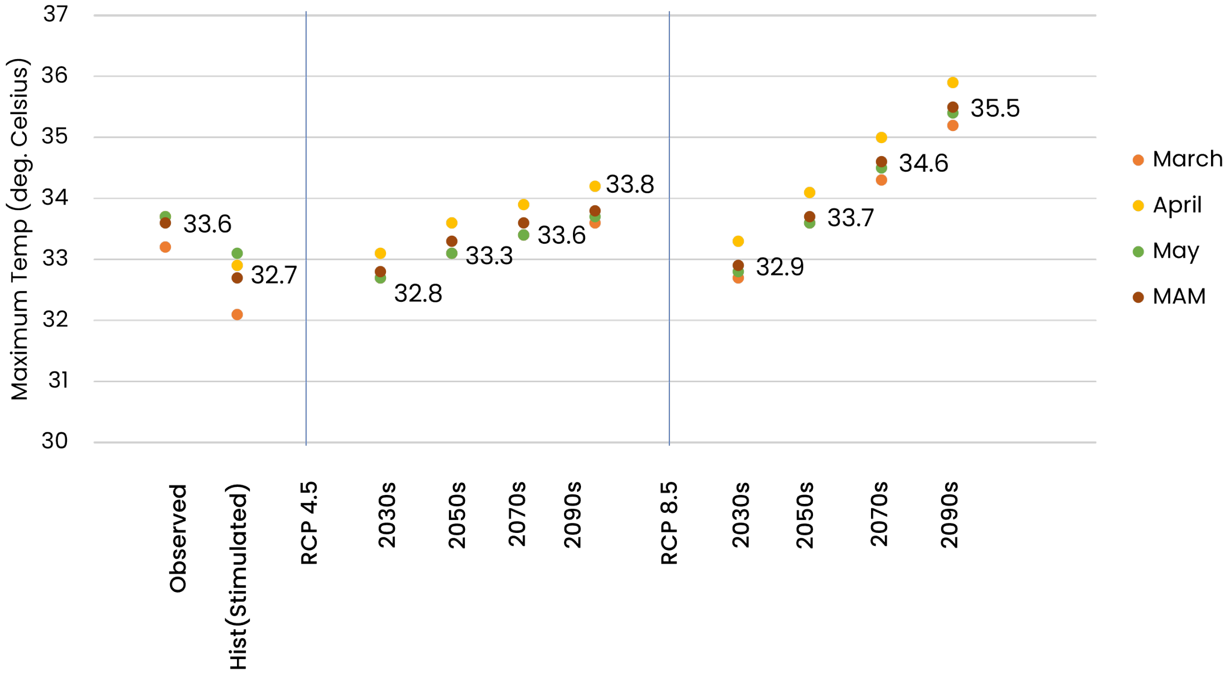


Figure 3.5: Observed, simulated, and projected monthly and seasonal maximum in Virudhunagar

(The change in maximum temperature is based on MAM, which is observed to be 32.7°C under historical estimates, 32.8–33.8°C under RCP4.5, and 32.9–35.5°C under RCP8.5)

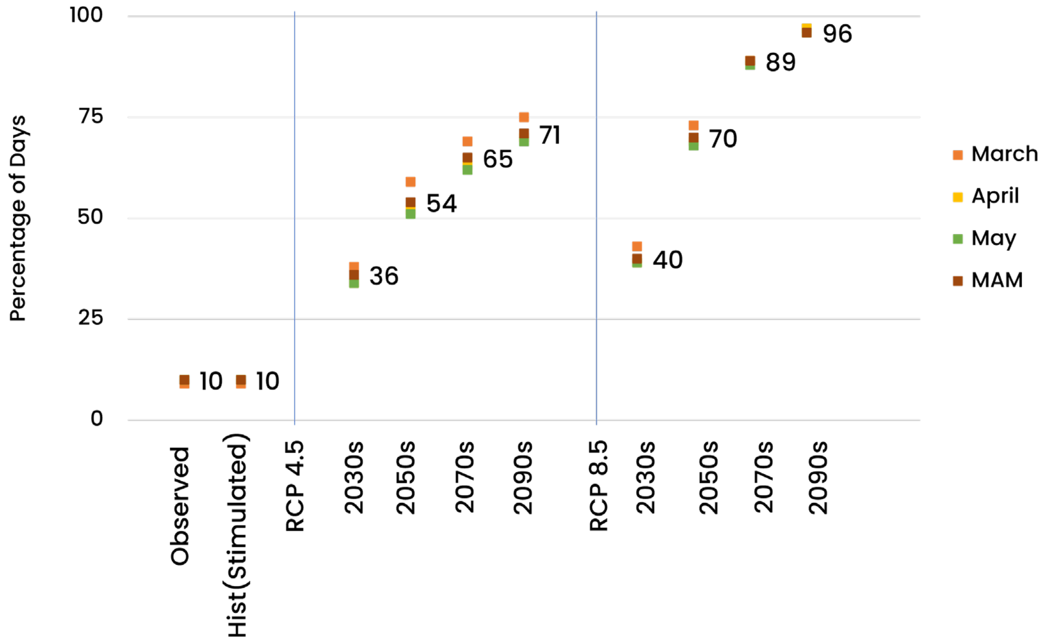


Figure 3.6: Observed, simulated, and projected percentage of warm days in Virudhunagar

- The percentage of warm days is projected to increase by the end of the century compared to the present climate (Figure 3.6).
- The HWDI[18] does not show an increase in RCP4.5 scenario, however, it may increase by 0-7 days per season in RCP8.5 by the end of the 21st century (Figure 3.7).
- The HWFI[19] is also expected to increase in the range of 15-44 days in RCP4.5, and the intensity is more pronounced in RCP8.5, projected to increase in the range of 17-77 days towards the end of the century (Figure 3.7).

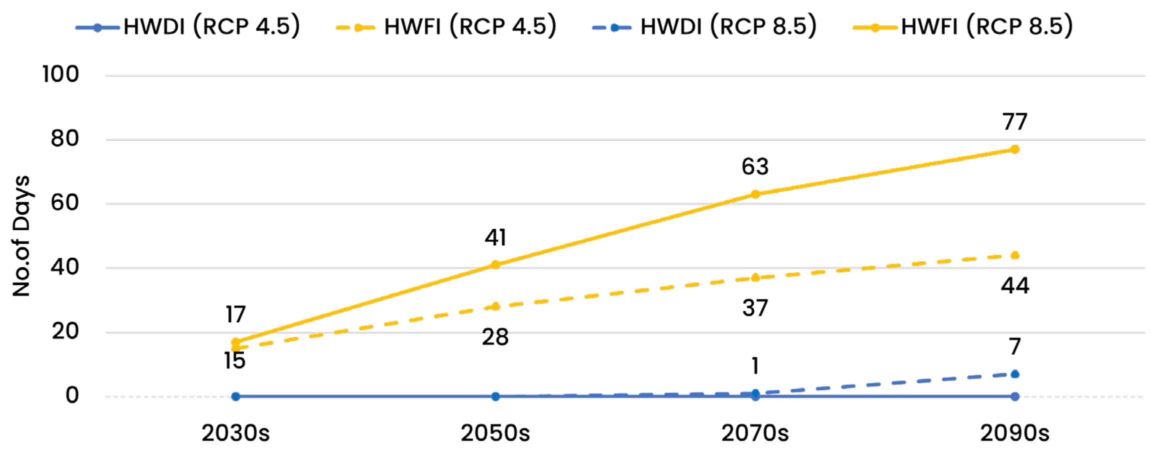


Figure 3.7: Simulated and projected seasonal temperature extremes in Virudhunagar

Minimum Temperature

- Minimum temperatures in the winter season are projected to increase by 0.7°C-1.7°C under RCP4.5 and 0.9°C-3.3°C under RCP8.5 emission scenarios (Figure 3.8).[20]
- This projected warming trend is accompanied by a decrease in the percentage of cold days across all time periods (Figure 3.9).

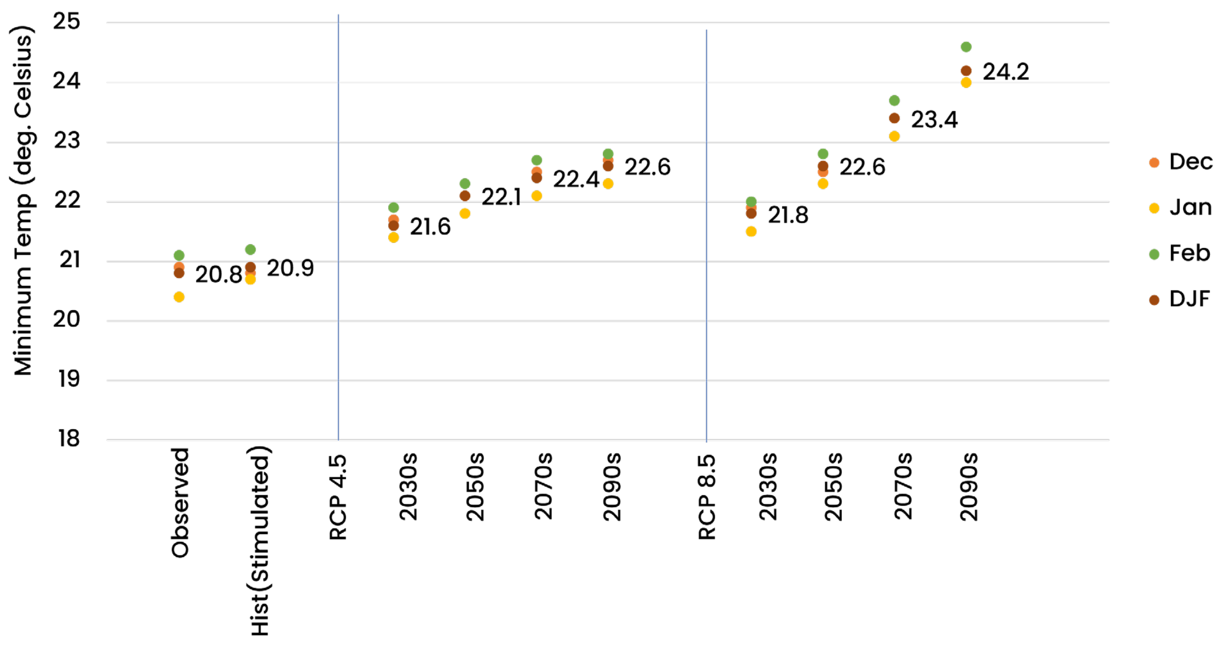


Figure 3.8: Observed, simulated, and projected monthly and seasonal minimum temperature in Virudhunagar

(The change in minimum temperature is based on DJF, which is observed to be 20.9 °C under historical estimates, 21.6 °C-22.6°C under RCP 4.,5 and 21.8°C-24.2°C under RCP 8.5)

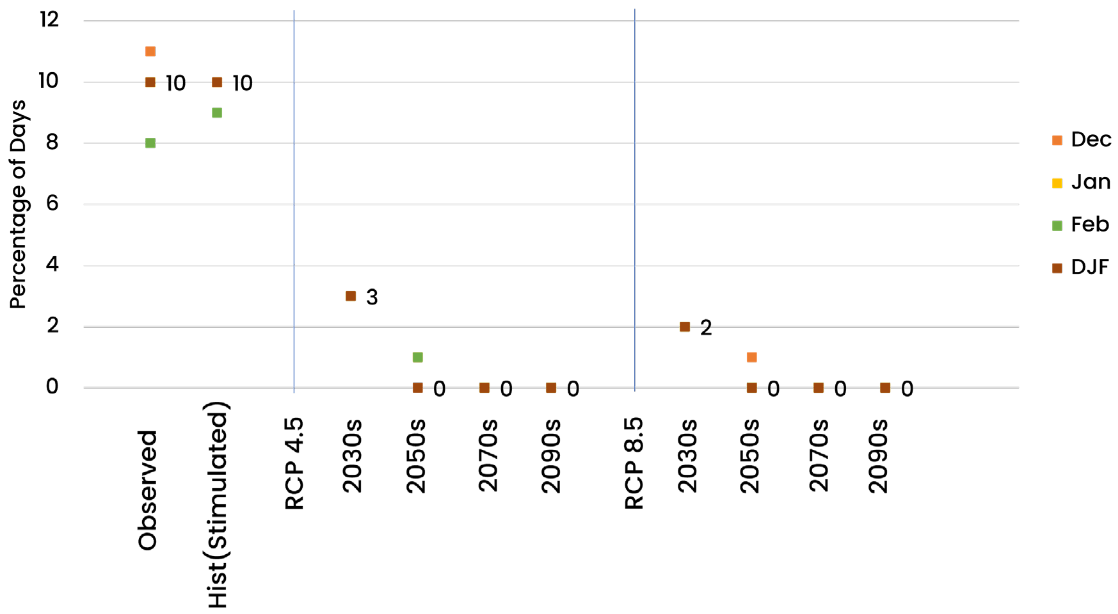


Figure 3.9: Observed, simulated, and projected percentage of cold days in Virudhunagar

3.2 Precipitation

Variability

Southwest Monsoon

- The rainfall shows no significant trend for June-July-August-September period (Figure 3.10).
- The number of rainy days does not show a significant trend for the period (Figure 3.11).

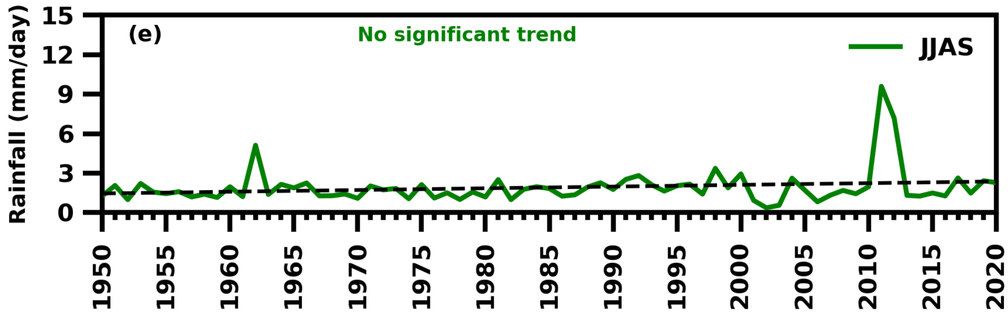


Figure 3.10: Inter annual variability of southwest monsoon rainfall (mm/day) over Virudhunagar for 1951-2020

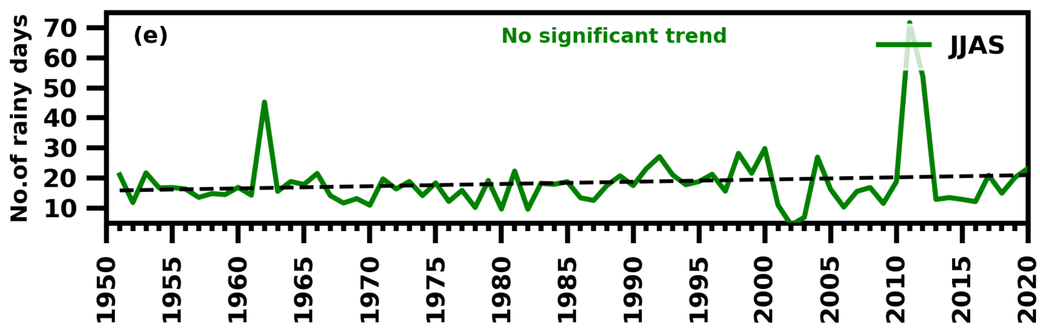


Figure 3.11: Inter annual variability of number of rainy days during southwest monsoon over Virudhunagar for 1951-2020

Northeast Monsoon

- The rainfall shows no significant trend for October-November-December period (Figure 3.12).
- It is observed that the variability in rainy days is higher in October and November. A decreasing trend is observed in October and the entire northeast monsoon season (Figure 3.13).

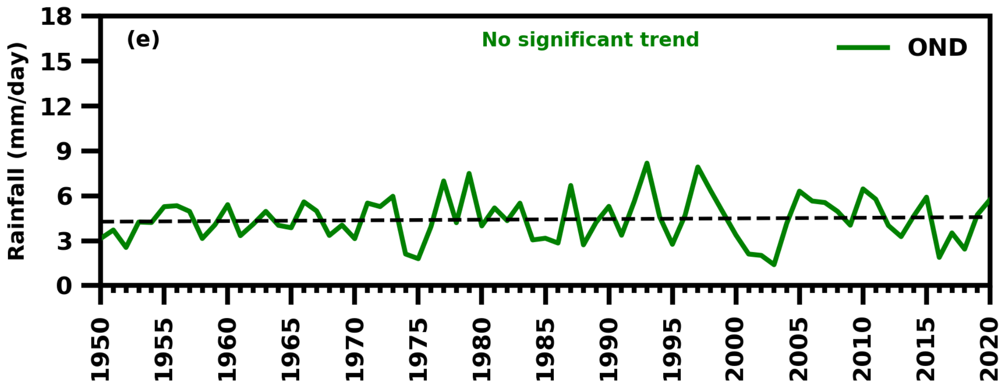


Figure 3.12: Inter annual variability of northeast monsoon rainfall (mm/day) over Virudhunagar for 1951-2020

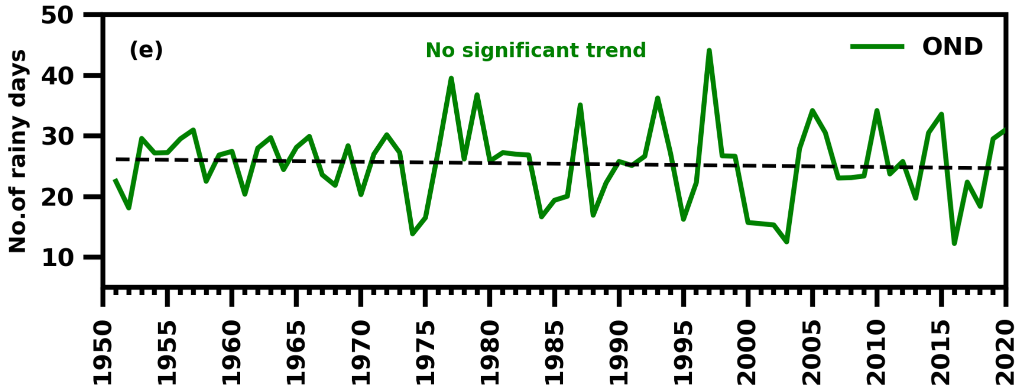


Figure 3.13: Inter annual variability of number of rainy days during northeast monsoon over Virudhunagar for 1951-2020

Projections

Southwest Monsoon

- During the southwest monsoon period (June-July-August-September), the precipitation may increase between 13 percent to 27 percent under RCP 4.5 and 10 percent to 43 percent under RCP 8.5 emission scenarios (Figure 3.14).
- The number of rainy days is projected to increase mainly during July & August in the southwest monsoon season under both RCP4.5 and RCP8.5 emission scenarios (Table 3.1).

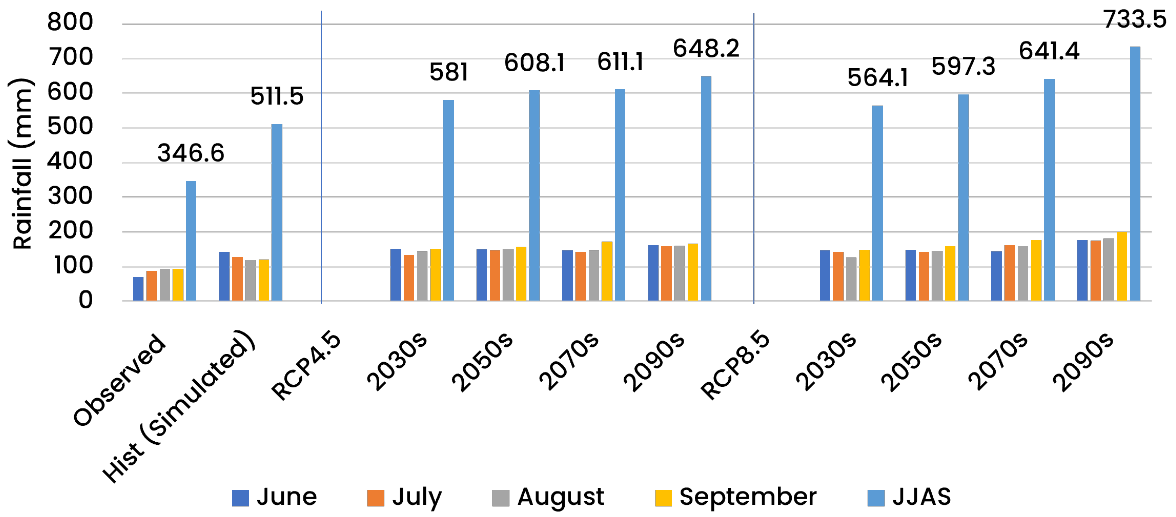


Figure 3.14: Observed (1986-2005), simulated (1986-2005) and projected mean monthly and southwest monsoon rainfall (mm) for Virudhunagar

Table 3.1: Observed (1986-2005), simulated (1986-2005), and projected mean number of rainy days (rainfall > 2.5 mm) during southwest monsoon months and season as a whole for Virudhunagar

Obs.	Hist. (Simulated)	RCP 4.5	2030s	2050s	2070s	2090s	RCP 8.5	2030s	2050s	2070s	2090s
19	32		41	42	41	43		39	40	41	44

- There may be a slight projected decrease in the number of consecutive dry days during both the southwest monsoon season in the future under RCP 4.5 and RCP 8.5 scenarios (Figure 3.15).
- The 1-DAY highest rainfall amount during the southwest monsoon season increases from ~69 to ~79 mm under the RCP4.5 and from ~71 to ~94 mm under the RCP8.5 scenarios (Figure 3.16).
- The 5-DAY cumulative highest precipitation amount during the southwest monsoon is also projected to increase from ~130 to ~146 mm under the RCP4.5 and from ~127 to ~172 mm under the RCP8.5 scenarios (Figure 3.16).

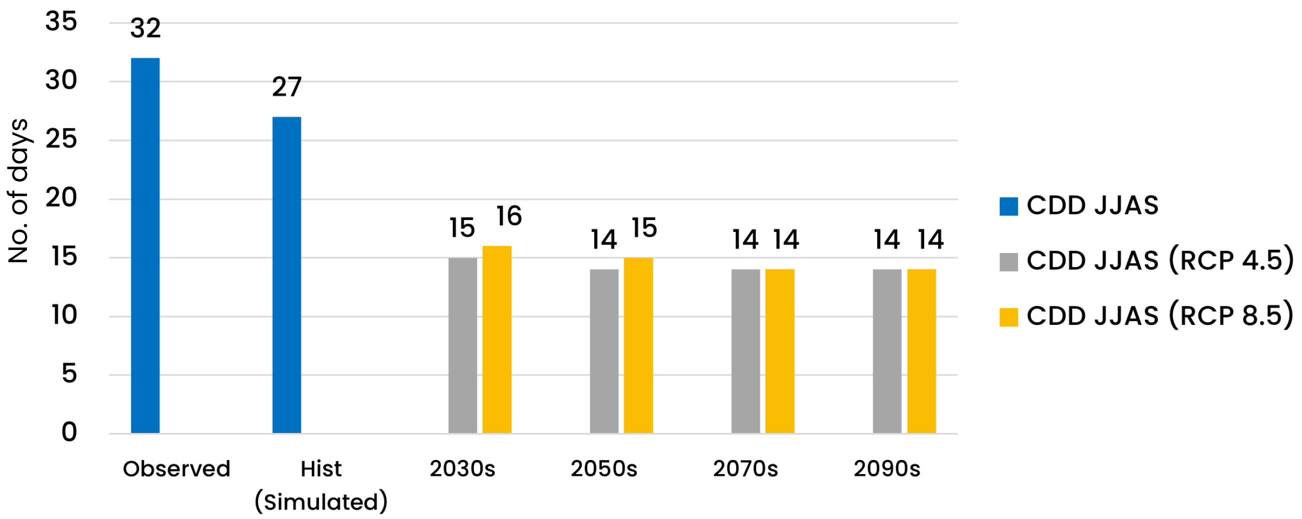


Figure 3.15: Simulated and projected seasonal (JJAS) precipitation extremes (CDD) for Virudhunagar

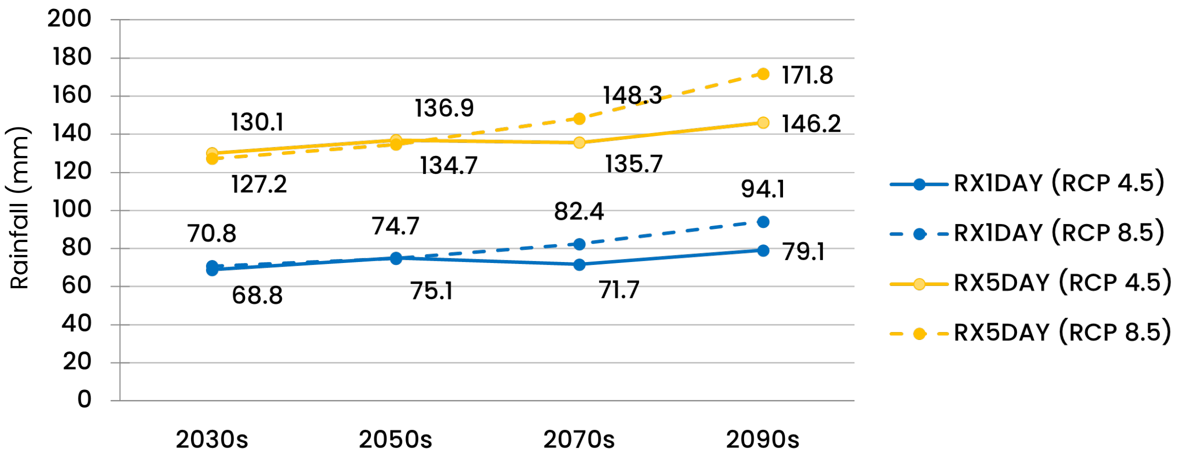


Figure 3.16: Simulated and projected seasonal (JJAS) precipitation extremes (RX1 and RX5) for Virudhunagar

Northeast Monsoon

- During the northeast monsoon period (October-November-December), the precipitation may increase between 8 percent to 27 percent under RCP 4.5 and 18 percent to 51 percent under RCP 8.5 emission scenarios.
- The rainy days for this season are projected to increase by the end of the century under both RCP4.5 and RCP8.5 scenarios (Table 3.2).

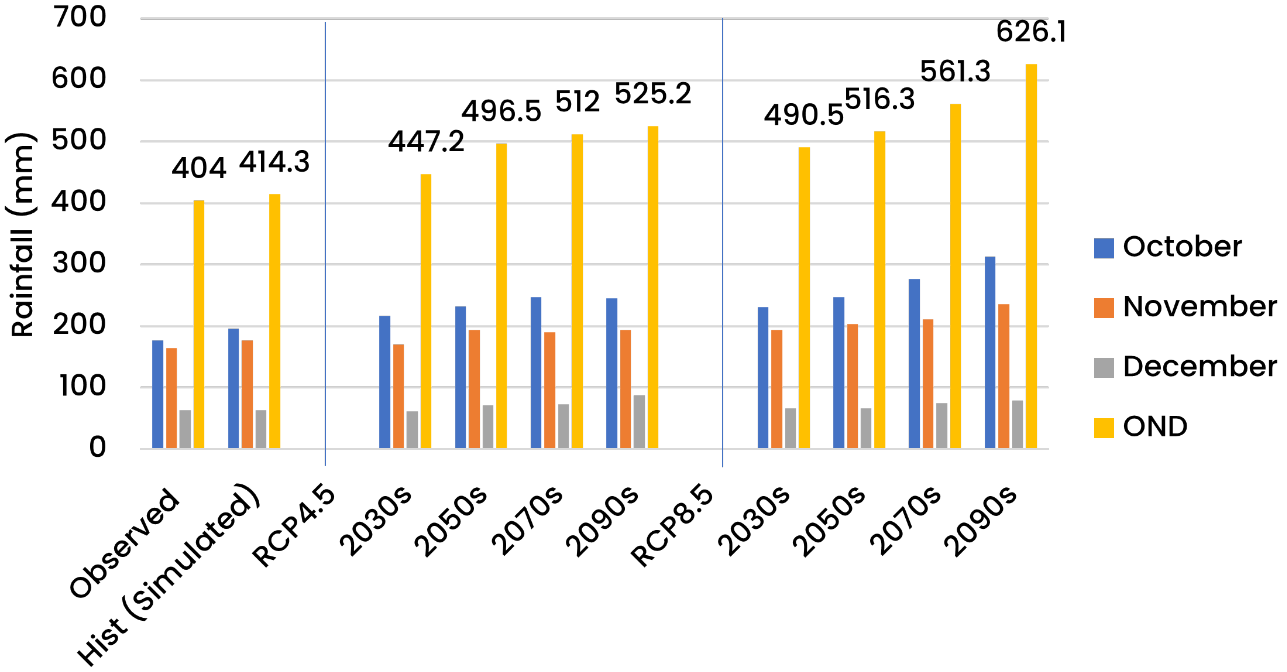


Figure 3.17: Observed (1986-2005), simulated (1986-2005) and projected mean monthly and northeast monsoon rainfall (mm) for Virudhunagar

Table 3.2: Observed (1986-2005), simulated (1986-2005) and projected mean number of rainy days (rainfall > 2.5 mm) during northeast monsoon months and season as a whole for Virudhunagar

Obs.	Hist. (Simulated)	RCP 4.5	2030s	2050s	2070s	2090s	RCP 8.5	2030s	2050s	2070s	2090s
25	22		33	34	36	36		33	34	35	38

- There may be a slight projected decrease in the number of consecutive dry days during both the northeast monsoon season in the future under RCP 4.5 and RCP 8.5 scenarios (Figure 3.17).
- The 1-DAY highest rainfall amount during the southwest monsoon season increases from ~52 to ~54 mm under the RCP4.5 and from ~101 to ~114 mm under the RCP8.5 scenarios (Figure 3.18).
- The 5-DAY cumulative highest precipitation amount during the southwest monsoon is also projected to increase from ~110 to ~125 mm under the RCP4.5 and from ~157 to ~182 mm under the RCP8.5 scenarios (Figure 3.19).

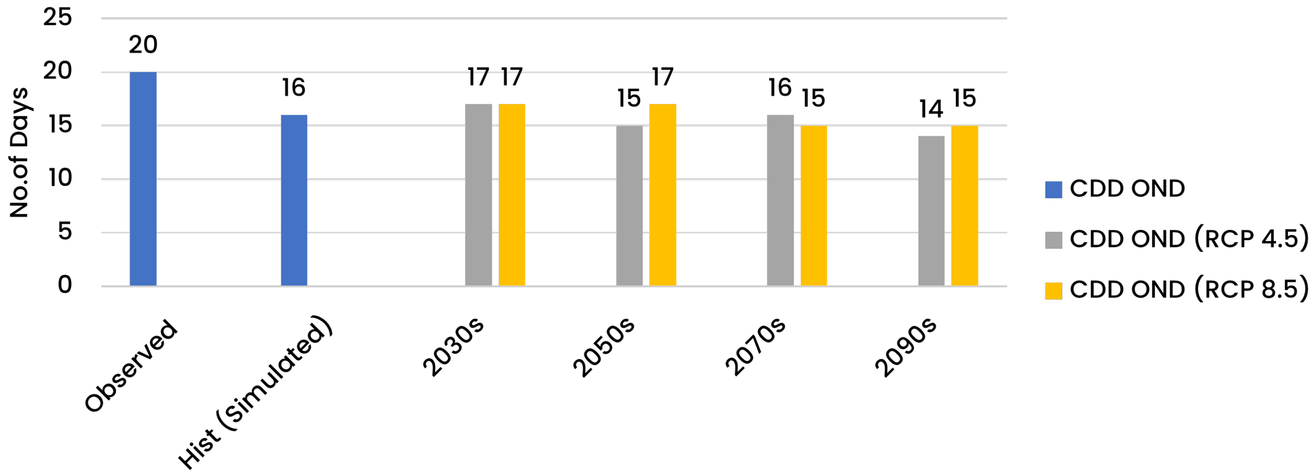


Figure 3.18: Simulated and projected seasonal (OND) precipitation extremes (CDD) for Virudhunagar

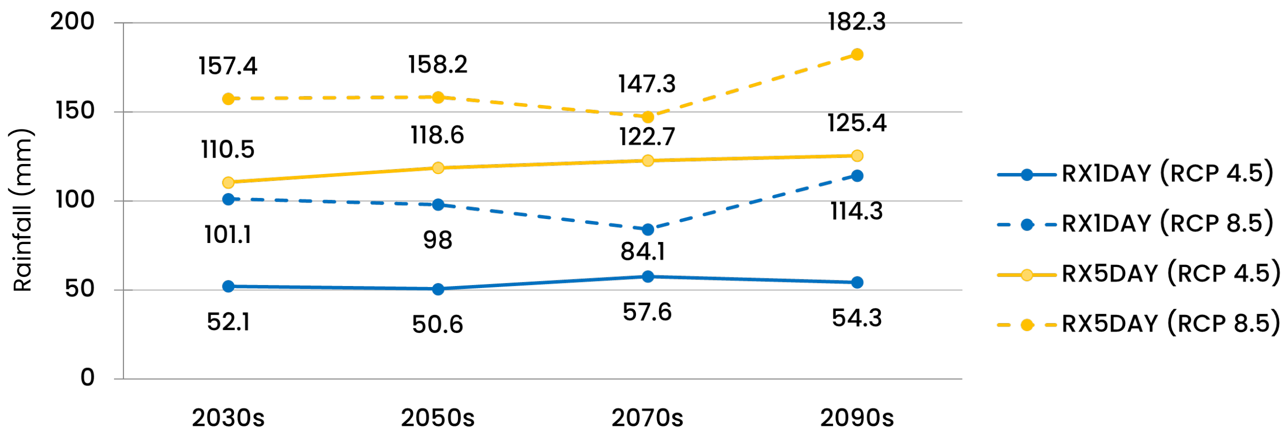


Figure 3.19: Simulated and projected seasonal (OND) precipitation extremes (RX1 and RX5) for Virudhunagar

3.3 Climate Vulnerabilities[21]

Drought

Virudhunagar district faces frequent droughts due to low and erratic monsoon rainfall, especially during the summer months from April to July. The district lacks access to perennial rivers and other reliable water sources, making it heavily dependent on groundwater. Overuse of this limited resource has led to scarcity, and the available groundwater is often not potable. Even minor changes in annual rainfall can result in hydrological drought.

About 66.3 percent of the population in Virudhunagar depends on agriculture and related activities. Most of the cultivable land is rain fed, offering limited irrigation options for both landowners and agricultural laborers during much of the year.

Droughts are complex and difficult to predict, and they often trigger secondary hazards such as forest fires. Forest fires typically occur during April and May, when dry leaves become fuel for fires. These events damage biodiversity and increase carbon emissions.

To address drought, the district administration has taken steps like supplying drinking water through tankers, installing deep water hand pumps, and restoring traditional water sources. However, a more robust and long-term strategy focused on water conservation and sustainable resource management is essential.

Floods

Although Virudhunagar is primarily drought prone, it does experience flood like situations during the monsoon. The seven rivers that flow through different parts of the district, mostly originate in the Western Ghats. Along with several rivulets and seasonal streams, these rivers receive sudden surges of water during heavy rainfall or cloudburst like situation in the hills. Nine villages located along the banks of these rivers are particularly vulnerable to these flash floods.

The district receives most of its rainfall during the Northeast Monsoon (October to December). While the likelihood of large-scale flooding is low, continuous rainfall and strong winds often damage both the kaccha and pucca houses. In 2022, 141 huts were reported as fully or partially damaged.

Climate projections suggest that rainfall during the Northeast Monsoon could increase by 8 percent to 27 percent under RCP 4.5 and 18 percent to 51 percent under RCP 8.5 by the end of the century. Additionally, the number of rainy days is expected to rise under both scenarios. This underscores the urgent need to manage flash flood risks, especially in the vulnerable areas.

Heat Waves

While heat wave conditions are occasional in the district, both maximum and minimum temperatures, as well as the number of warm days have been steadily increasing since 1950. With further temperature rise projected, the threat of heat stress cannot be ignored.

This is especially concerning for vulnerable groups. A large portion of the district's population belongs to Scheduled Castes, who primarily depend on agriculture and small to medium scale industries for their livelihood. To address this growing challenge, and to build resilience, it is essential to foster sustainable agriculture, ensure safer working conditions in the MSMEs, and strengthen social safety nets.

4 GHG Profile

Key Findings

- GHG emissions increased from 1416 $ktCO_2e$ in 2005 to 2620 $ktCO_2e$ in 2022, with a CAGR of ~4 percent, driven largely by a sharp rise of 699 $ktCO_2e$ in 2018 due to increased pet coke usage in industrial energy the transition of forest land from carbon sink to a net emitter.
- The energy sector was the largest emitter at 1,290 $ktCO_2e$ (49% of total emissions), followed by Industrial Processes and Product Use (IPPU) at 1,023 $ktCO_2e$ (39%), Agriculture, Forestry and Other Land Use (AFOLU) at 169 $ktCO_2e$ (6.4 percent net, after 171 $ktCO_2e$ sequestration), and waste at 138 $ktCO_2e$ (5%).
- Cement production (IPPU) was the single largest contributor, accounting for 37 percent of emissions, followed by road transport (17%), industrial energy (16%), livestock (9%), and residential energy (6%) in 2022.
- Energy sector emissions rose significantly from 414 $ktCO_2e$ (29% of total) in 2005 to 1,290 $ktCO_2e$ (49%) in 2022, overtaking IPPU as the top contributor after 2017, with road transport and industrial energy emerging as the major sub-sectors.
- IPPU emissions, dominated by cement production (99.98%), increases from 590 $ktCO_2e$ in 2005 to 1023 $ktCO_2e$ in 2022.
- AFOLU sector emissions decreased from 304 $ktCO_2e$ (22%) in 2005 to 169 $ktCO_2e$ (6%) in 2022. This reduction is primarily attributed to land-based carbon sequestration, which offset 171 $ktCO_2e$.
- Waste emissions grew from 109 $ktCO_2e$ in 2005 to 138 $ktCO_2e$ in 2022, with domestic wastewater contributing 72 percent, solid waste disposal 20 percent and industrial wastewater 8 percent.

The greenhouse gas (GHG) emissions of the Virudhunagar district have been estimated for the period from 2005 to 2022, accounting for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The emissions estimated are of Scope 1[22] type and reported in terms of CO_2 equivalent as per the Second Assessment Reports[23] (AR2) of the IPCC.

The inventory follows the broad guidelines provided by the Intergovernmental Panel on Climate Change (IPCC), specifically the 2006 and 2019 guidelines, and aligns with the approach and methodology of GHG inventory development followed by the Government of India in NATCOM[24] and BUR[25] reports.

The data and information used for the development of the Inventory were sourced exclusively from government agencies, including various line departments of the Government of Tamil Nadu and from national organisations such as the Central Electricity Authority, the Petroleum Planning and Analysis Cell amongst others. The data source is as detailed in the Annexure 2.

4.1 Summary of GHG Profile of Virudhunagar District

The emission of the greenhouse gases, namely CO_2, methane and nitrous oxide, in Virudhunagar accounted for 2620 ktCO_2e in 2022. The energy sector emitted 1290 ktCO_2e, while the Industrial Processes and Product Use (IPPU) sector contributed 1023 ktCO_2e. Agriculture, Forestry and Other Land Use (AFOLU) sector emitted 169 ktCO_2e, despite the land category sequestering 171 ktCO_2e, and the waste sector contributed 138 ktCO_2e. The category and gas wise emissions and their percentage contribution is as detailed in Table 4.1.

Table 4.1: Sector-wise and gas-wise GHG emissions (2022)

Sector	GHG Sources and Sink Categories	CO_2 (kt)	CH_4 (t)	N_2O (t)	ktCO_2e	Contribution
ENERGY	Captive Power Plants	145	2	2	146	6%
	Industrial Energy	445	14	3	446	17%
	Road Transport	462	99	23	471	18%
	Commercial	26	2.71	0.13	27	1%
	Residential	174	14	0.35	174	7%
	Agriculture	26	4	0.2	26	1%
	Energy Total	**1278**	**136**	**29**	**1290**	**50%**
AFOLU	**Aggregate Sources and Non-CO_2 Emission Sources on Land**	-	**2626**	**102**	**87**	**3%**
	Agriculture Soil	-	-	98	31	1%
	Biomass burning in cropland	-	140	4	4	0.2%
	Rice Cultivation	-	2486	-	52	2%
	Land	**-171**	-	-	**-171**	-
	Agricultural Land	-0.05	-	-	-0.05	-
	Forest Land	-171	-	-	-171	-
	Other Land	0.14	-	-	0.14	0.01%
	Settlements	-0.06	-	-	-0.06	-
	Livestock	**-**	**11977**	**3**	**252**	**10%**
	Enteric Fermentation	-	11200	-	235	9%
	Manure Management	-	777	3	17	1%
	AFOLU total	**-171**	**14603**	**105**	**169**	**6%**
IPPU	**Mineral Industry**					
	Cement Production	1023	-	-	1023	39%
	Non-Energy Products from Fuels and Solvent Use					
	Lubricant Use	0.22	-	-	0.22	0.01%
	IPPU Total	**1023**	-	-	**1023**	**39%**
Waste	Solid Waste Disposal	-	1294	-	27	0.23%
	Domestic Wastewater	-	3420	91	100	4%
	Industrial Wastewater	-	538	-	11	0.42%
	Waste Total	-	**5252**	**91**	**138**	**5%**
Total Emissions		**2130**	**19991**	**225**	**2620**	

4.2 Economy-wide Emissions

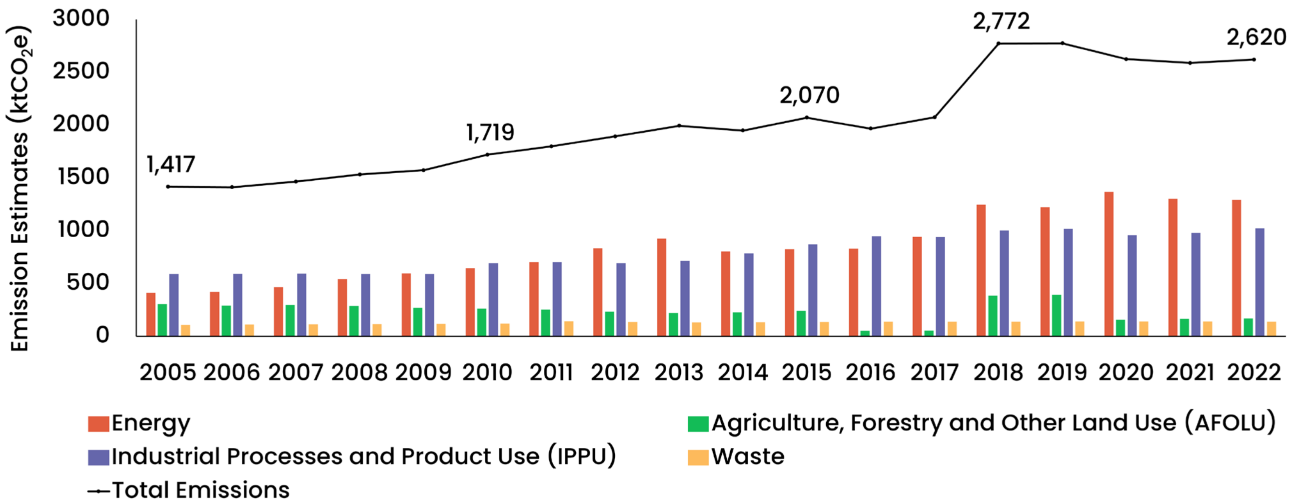


Figure 4.1: Economy-wide emissions of Virudhunagar (2005 to 2022)

The total GHG emissions from Virudhunagar increased from 1,417 $ktCO_2e$ in 2005 to 2,620 $ktCO_2e$ in 2022 at a CAGR of ~4 percent (Figure 4.1). The Industrial Processes and Product Use (IPPU) sector was the biggest contributor during the period 2005 to 2017, and the energy sector thereafter. The emissions rose sharply from 2073 $ktCO_2e$ in 2017 to 2772 $ktCO_2e$ in 2018. (Figure 4.1) This increase can be attributed to higher emissions from the AFOLU and energy sectors, driven by sudden increase in the pet coke usage in the industrial energy category and the forest category becoming an emitter in 2018.

Emissions from the energy sector increased from 414 $ktCO_2e$ (~29% of the total emissions) in 2005 to 1290 $ktCO_2e$ (~49% of the total emissions) in 2022 and it was the major contributor to districts' total economy-wide emissions in 2022. The IPPU sector emitted 590 $ktCO_2e$ contributing to 42 percent of the total emissions in 2005 and 1023 $ktCO_2e$ contributing to 39 percent in 2022. The AFOLU sector emitted 304 $ktCO_2e$ contributing to 21 percent of the total emissions in 2005 and 169 $ktCO_2e$ contributing to 7 percent in 2022. Emissions from the waste sector increased from 109 $ktCO_2e$ in 2005 to 138 $ktCO_2e$ in 2022.

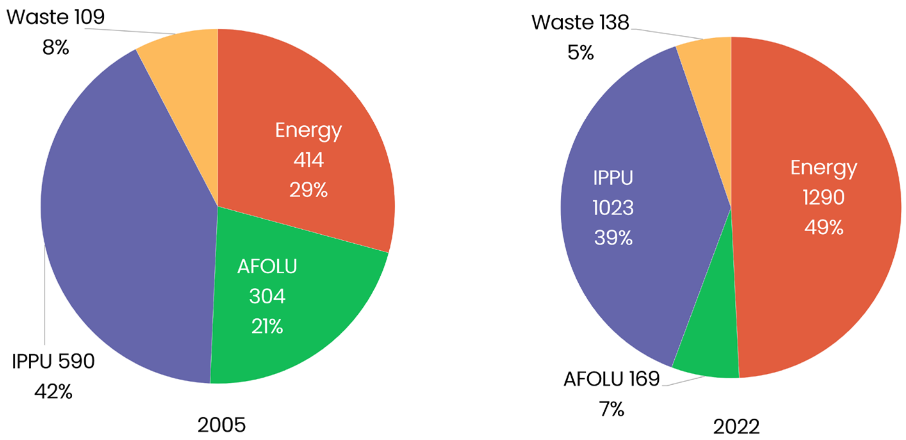


Figure 4.2: Sector-wise contribution ($ktCO_2e$) and percentage share in economy-wide GHG emissions of Virudhunagar

4.3 Key Category Analysis

Figure 4.3 highlights the primary sources of greenhouse gas (GHG) emissions in the Virudhunagar District for 2022. Cement production emerged as the largest contributor, accounting for approximately 37 percent of total emissions, followed by road transport (17%), industrial energy (16%), livestock (9%), and residential energy (6%).

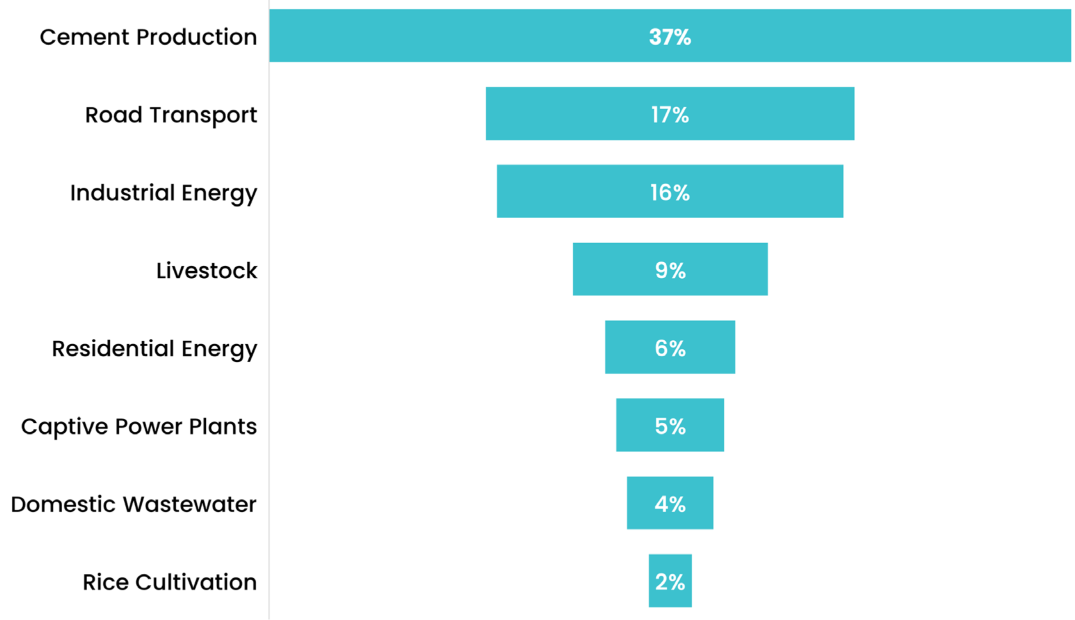


Figure 4.3: Key category analysis for Virudhunagar (2022)

4.4 Sector-wise Emission Trends

4.4.1 Energy Sector

In 2022, emissions from the energy sector, encompassing fossil fuel combustion across captive power plants, road transport, industries, commercial, residential, and agriculture sectors, amounted to 1,278 kilotonnes of CO_2, 0.14 kilotonnes of CH_4, and 0.03 kilotonnes of N_2O. These emissions equate to 1,290 kilotonnes of CO_2 equivalent (Figure 4.4.1), a significant increase from 414 kilotonnes of CO_2 equivalent recorded in 2005.

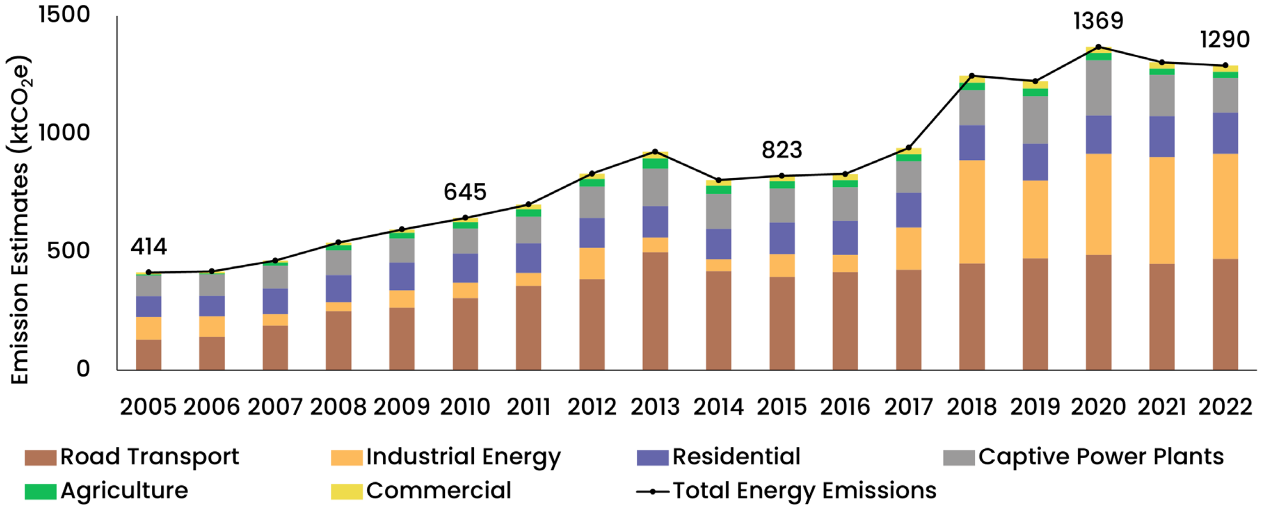
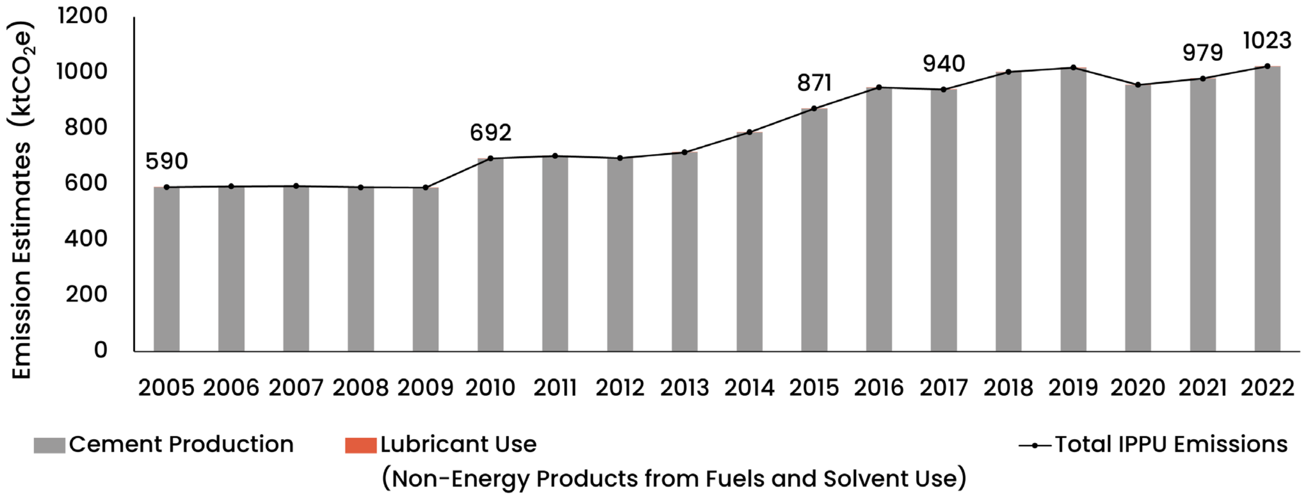


Figure 4.4.1: GHG emissions of energy sector for Virudhunagar (2005 to 2022)

4.4.2 Industrial Processes and Product Use (IPPU) Sector



**Estimated emissions from lubricant use (non-energy products from fuels and solvent use) is marginal throughout the time period*

Figure 4.4.2: GHG emissions of IPPU sector for Virudhunagar (2005 to 2022)

In Virudhunagar, emissions from the Industrial Processes and Product Use (IPPU) sector in 2022 were almost exclusively from cement production (99.98%), with lubricant use accounting for the remaining 0.02 percent. While the IPPU sector's share of total economy-wide emissions decreased significantly from 42 percent in 2005 to 39 percent in 2022.

4.4.3 Agriculture, Forestry and Other Land Use (AFOLU) Sector

Emissions from the Agriculture, Forestry and Other Land Use (AFOLU) sector arise from Livestock (enteric fermentation and manure management); Land; and the Aggregate Sources & Non-CO_2 Emissions Sources on Land. The sub-sector 'Aggregate Sources & Non-CO_2 Emission Sources on Land' includes emissions from Rice Cultivation, Agriculture Soils and Biomass Burning in Cropland.

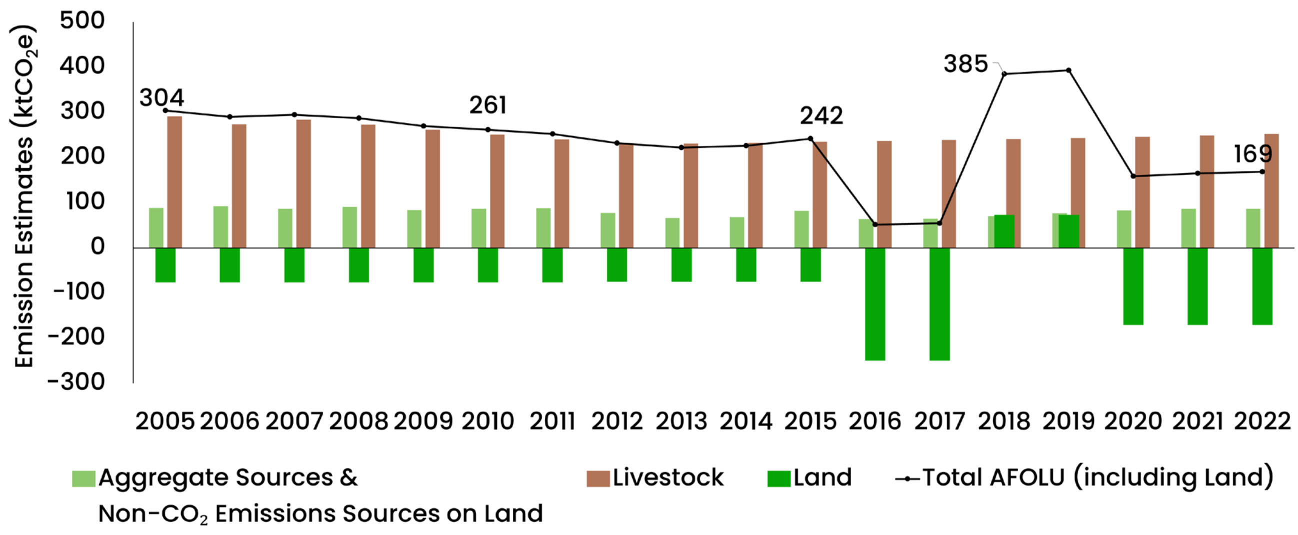


Figure 4.4.3(a): GHG emissions of AFOLU sector for Virudhunagar (2005 to 2022)

The AFOLU sector represented 6 percent of the total economy-wide emissions of Virudhunagar in 2022 and decreased by 0.6 times from 304 ktCO_2e in 2005 to 169 ktCO_2e. The land category contributed to carbon removal of around 76 ktCO_2e and during 2005 to 2015 and 249 ktCO_2e during 2016 to 2017. It was an emitter in 2018-2019, emitting around 73 ktCO_2e, leading to a steep increase in the total AFOLU emissions. From 2020 to 2022, the land category contributed to a carbon removal of 171 $ktCO_2e$ (Figure 4.4.3 (a)). Emissions from Aggregate Sources & non-CO_2, and livestock categories were static throughout the reference period and contributed 26% and 74%, respectively to the total AFOLU emissions in 2022.

In the total AFOLU emissions excluding land, Enteric Fermentation accounted for ~69 percent, followed by Rice Cultivation contributing to ~15 percent and Agriculture Soils accounted for ~9 percent respectively in 2022.

In the Aggregate sources & non-CO_2 category, Rice Cultivation was the major contributor, with its emission decreasing from 56 $ktCO_2e$ in 2005 to 52 $ktCO_2e$ in 2022. The emissions from Agricultural Soils increased from 29 $ktCO_2e$ in 2005 to 31 $ktCO_2e$ in 2022 while the emissions from Biomass burning in Cropland was negligible throughout the reference period accounting to around 3 $ktCO_2e$. (Figure 4.4.3(b))

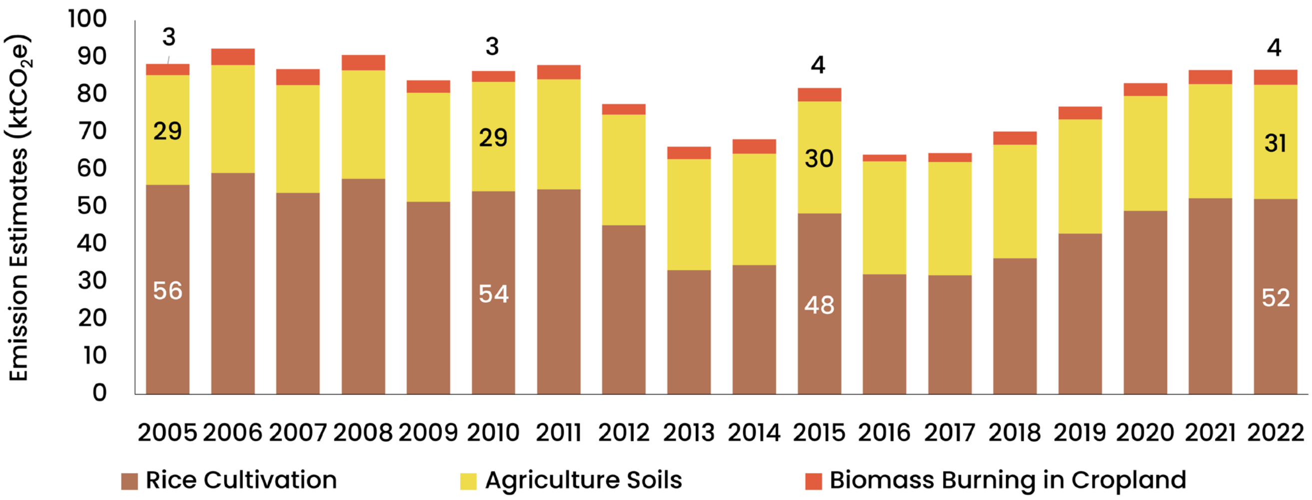


Figure 4.4.3(b): GHG Emissions from Aggregate sources & non-CO_2 category (2005 to 2022)

4.4.4 Waste Sector

In Virudhunagar district, the waste sector contributed ~5252 tonnes of CH_4 and 91 tonnes of N_2O accounting to 138 $ktCO_2e$ of emissions in 2022, compared to 109 $ktCO_2e$ in 2005 (Figure 4.4.4(a)). Domestic Wastewater, Solid Waste Disposal and Industrial Wastewater categories respectively contributed 72 percent, 20 percent, 8 percent (Figure 4.4.4(b)). The year 2011 saw a surge in emissions from industrial wastewater as a result of increased meat production.

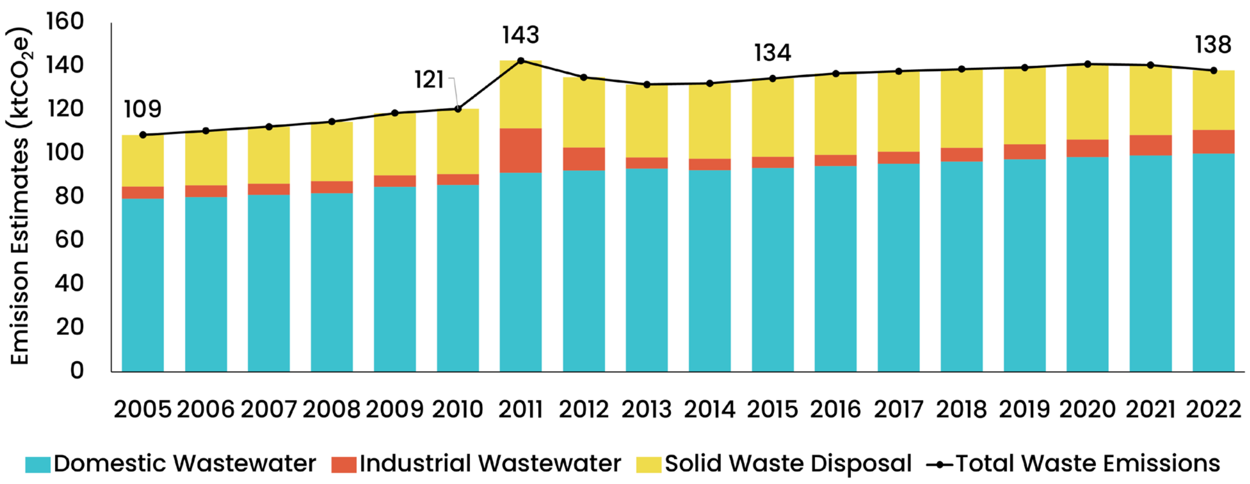


Figure 4.4.4(a): GHG emissions estimates of waste sector for Virudhunagar (2005 to 2022)

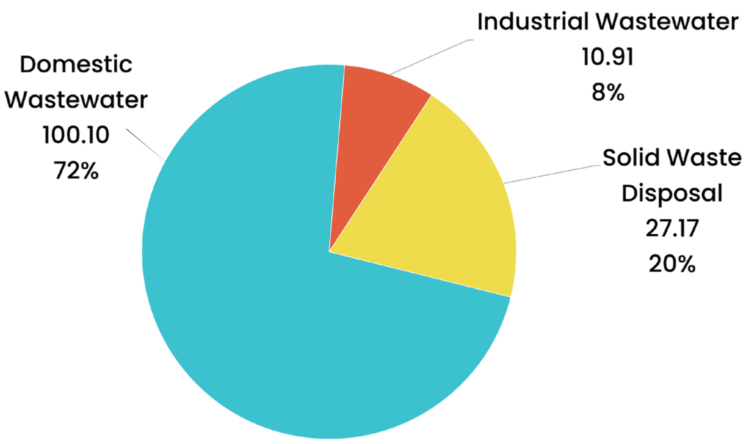


Figure 4.4.4(b): Sub-sector emissions (ktCO_2e) and percentage share in total waste sector emissions (2022)

Of the 100 ktCO_2e from the domestic wastewater category, ~62 ktCO_2 eq was emitted from urban domestic wastewater (62%) and 38 ktCO_2e from rural domestic wastewater (38%) (see Figure 4.4.4(c)). Within the Industrial Wastewater category, emissions from meat processing contributed 71 percent, paper and pulp contributed 27 percent, followed by dairy which contributed ~2 percent and fish processing contributed ~0.1 percent as illustrated in Figure 4.4.4(d).

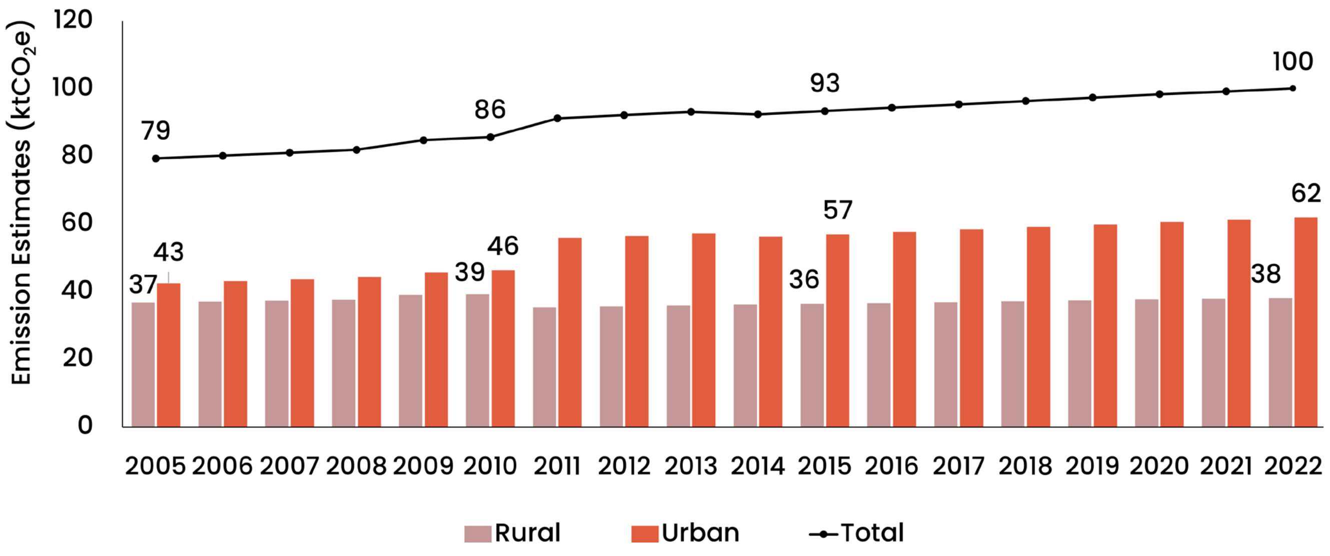


Figure 4.4.4(c): Area-wise GHG emissions estimates for domestic wastewater (2005 to 2022)

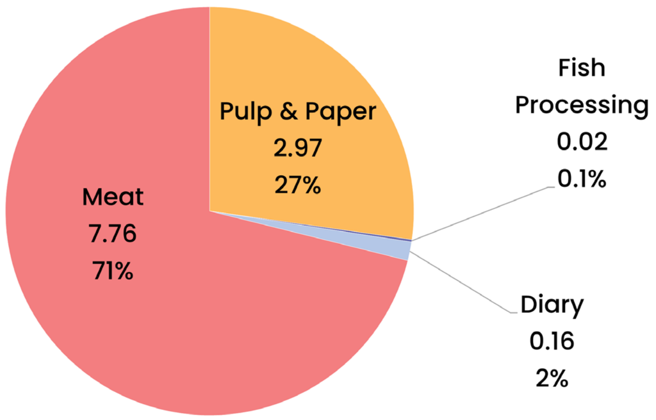


Figure 4.4.4(d): Category-wise emissions (ktCO_2e) and percentage share in total industrial wastewater emissions (2022)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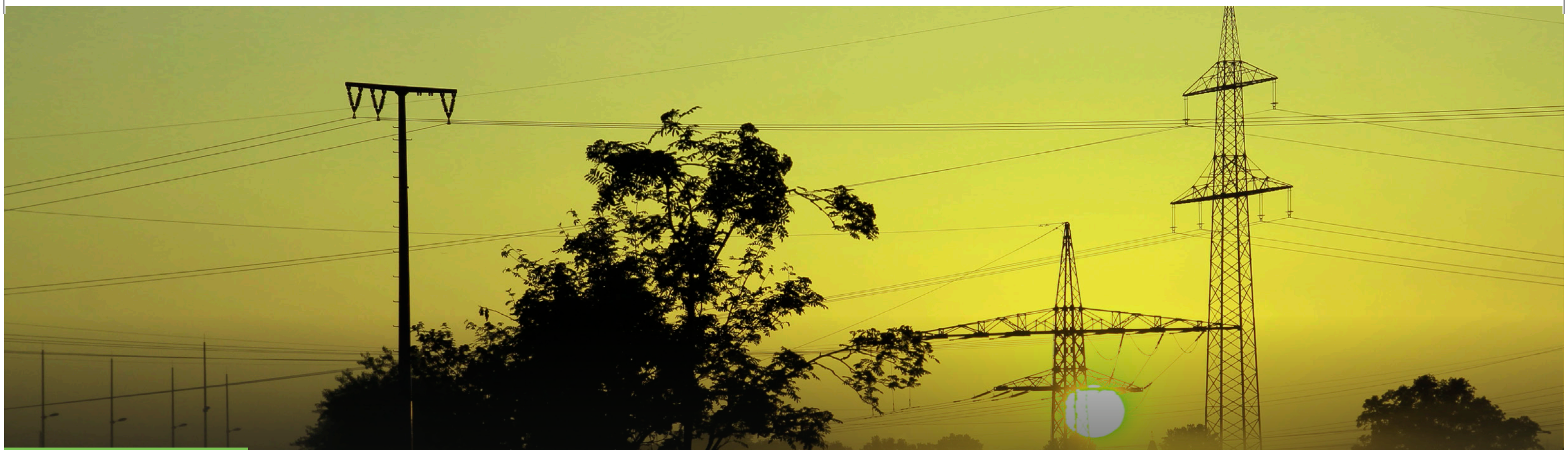


5 Deep Dive into District's Energy and Non-energy Sectors (AFOLU, Waste) and Projections to 2050

Key Findings

In the Business As Usual (BAU) scenario, energy demand is projected to grow by 64 percent between 2022 and 2050, rising from 29 PJ in 2022 to 48 PJ by 2050. Energy use in the industrial sector alone accounts for 62 percent of this consumption (17 PJ).

Electrification of the road transport fleet and industrial heating, along with higher space cooling requirements, would to increase electricity demand threefold from 2,278 GWh in 2022 to 7,488 GWh by 2050.

GHG emissions in the IPPU sector, particularly in the hard-to-abate cement industry, which contributed 39 percent of total GHG emissions in 2022, are projected to rise by 2050 due to the expansion of the cement plants. As technology matures and the market develops further, carbon capture utilisation could potentially reduce GHG emissions.

In the residential sector, LPG in cooking is a major source of GHG emissions (307 ktCO_2e), and can be abated by fuel switching to PNG and electricity.

Livestock contribute 74 percent of AFOLU emissions (excluding land). Under the BAU scenario, and are projected to increase from 252 kt CO_2e in 2022 to 339 kt CO_2e by 2050.

District's current forest cover is 352.94 sq km (8 percent of the total geographical area), with carbon stock density declining from 87.26 tonnes/ha in 2015 to 82.25 tonnes/ha in 2021. Interventions proposed in the pathways could increase sequestration from the current 170.8 kt CO_2e/year (BAU) to 995 kt CO_2e/year under MES and 1428 kt CO_2e/year under AES through agro/social forestry initiatives in the land classified as barren, waste, or fallow.

This chapter examines the anticipated energy mix in Virudhunagar district for 2050, considering both primary energy sources and final energy consumption. By analysing current and projected consumption and production patterns, it aims to evaluate how various energy sources and policy measures are likely to shape the district's energy profile in the years ahead. For instance, the state's EV policy[26] is set to transform the transport sector, while the PM KUSUM scheme promotes solar-powered irrigation, reducing dependence on diesel.

Further, this chapter also covers other key GHG emitting sectors such as waste, agriculture, livestock, land use change, carbon sequestration, and industrial processes and product use (IPPU). It outlines potential interventions for mitigating GHG emissions from wastewater, methane and nitrous oxide emissions from agricultural practices and livestock. Opportunities to enhance carbon sinks through afforestation and agro-forestry are discussed, along with a brief assessment of IPPU emissions from select industrial activities relevant to the district.

The energy sector discussed in the chapter focuses on five key sectors: electricity usage, road transport, heavy and small industries, buildings, and cooking in both residential and commercial segments. It also outlines the methodology used to project future energy demands. Finally, the chapter presents aggregate findings on projected energy requirements and related GHG emissions from the energy sector. The energy consumption and emissions projections in this chapter serve as the basis for the three decarbonisation scenarios discussed in Chapter 1.

Limitations to the Study:

1. While the demand projections are based on robust, sector-specific methodologies, certain sectors lack sufficient data. In such cases, projections have been made using estimated growth rates derived from the most reliable available data.
2. In addition to primary data collected from district offices in Virudhunagar, the analysis relied on secondary data sources at national and international levels, particularly where necessary data was unavailable or not maintained in the required format. The energy and sectoral projections were guided by well-founded assumptions to ensure consistency despite data constraints.

However, the following data limitations were identified:

- **Agriculture:** The available data on crop production, irrigation requirements, groundwater usage, and water storage infrastructure over the past 10 to 15 years in the district is currently insufficient.
- **Transport:** There is no available data on railway transportation; therefore, it is excluded from the transport sector in our projections.
- **Industrial Production and Capacity:** Data on the production and installed capacity of industries within the district is limited.
- **Residential:** There is no specific data on the exact number of electric appliances used by residential end-user customers in the Virudhunagar district. Therefore, appliance penetration rates have been estimated based on macro-level survey data from a nearby district, Tirunelveli.

5.1 Energy Sector

Demand forecasting at a sub-sectoral level, concentrating on specific end-use applications, is essential for gaining insights into future growth areas such as appliance penetration, industrial production, and vehicle ownership etc. For electricity distribution companies, such forecasting exercises support medium- to-long-term planning for power procurement. This section describes the methodology and metrics employed to estimate sectoral energy demand by 2050.

5.1.1 Building Sector

The building sector in Virudhunagar is a predominant energy consumer. The district's energy demand with respect to buildings is typically categorised into four key sub-sectors: cooling, heating, cooking, and appliances. While cooking is largely driven by Liquefied Petroleum Gas (LPG), fuelwood, the other sub-sectors mainly rely on electricity.

Residential Buildings

In 2022, residential electricity demand in Virudhunagar district was 728 GWh, accounting for 32 percent of the district's electricity consumption. This demand was primarily driven by space cooling, appliances, and lighting. Overall, the district's residential electricity demand increased annually by 5.54 percent from 2012-13 to 2021-22.[27]

Methodology for Projection

The methodology for demand projections is based on robust secondary data sources to estimate electricity consumption across various appliance categories in the residential sector of Virudhunagar district. Household appliance penetration data is derived from the National Family Health Survey (NFHS) Tamil Nadu reports for 2005-06, 2015-16, and 2019-21. Table 5.1.1 presents the appliance penetration rates for key appliances such as electric fans, refrigerators, air conditioners/coolers, and washing machines.

The annual growth rates of these appliances between 2005, 2016, and 2021 were analysed to project household appliance penetration up to 2050. For lighting devices, including incandescent bulbs, CFLs, CFL tubes, LEDs, and LED tubes, household penetration data was obtained from the India Residential Energy Survey (IRES)[28] of 2020. As a household penetration survey was not conducted specifically for the Virudhunagar district, data from the nearest available district, Tirunelveli, was used. Iinformation on annual hours of usage and wattage for different appliances was retrieved from various secondary literature.

Table 5.1.1: Residential appliance penetration (number per household) in 2021 in Virudhunagar

Category	Penetration (per household)			
	2021	2030	2040	2050
Lighting	3.16	3.55	3.77	4
Electric fan	0.96	0.97	1	1
Refrigerator	0.54	1	1	1
Air conditioner/ cooler	0.12	0.45	1	1
Washing machine	0.25	0.39	0.65	1

The role of energy efficiency in evaluating residential electricity consumption was also assessed. In the BAU scenario, current energy efficiency levels are assumed to continue. Annual energy savings for appliances such as fans, refrigerators, air conditioners, and washing machines are computed based on energy efficiency indicators (star labels) of these appliances. Decarbonisation scenarios assume higher efficiency levels, with applications rated 3 stars and above.

Results

Figure 5.1 shows the residential electricity consumption by appliance category in Virudhunagar district. Overall, residential electricity consumption is projected to increase to ~3000 GWh by 2050.

By 2050, space cooling—which includes the use of ceiling fans and air conditioners—is projected to account for 83.5 percent of total residential electricity consumption in Virudhunagar. This significant share is attributed to the energy-intensive nature of cooling appliances. In comparison, appliances such as refrigerators, washing machines, and motors are expected to consume 9.6 percent of residential electricity. Cooking-related electricity usage is anticipated to constitute 3.6 percent of the residential sector's total, while lighting is projected to contribute 3.3 percent to overall residential electricity consumption in 2050.

In MES, electricity savings of 188 GWh could be achieved in the residential sector by 2050 due to energy efficiency measures such as adoption of star rated air conditioners, refrigerators and appliances. In AES, electricity savings of 322 GWh could be achieved in the residential sector by 2050 due to energy efficiency measures. These projections highlight the need for targeted energy efficiency measures and strategic planning to manage the growing electricity demand in the residential sector of Virudhunagar district.

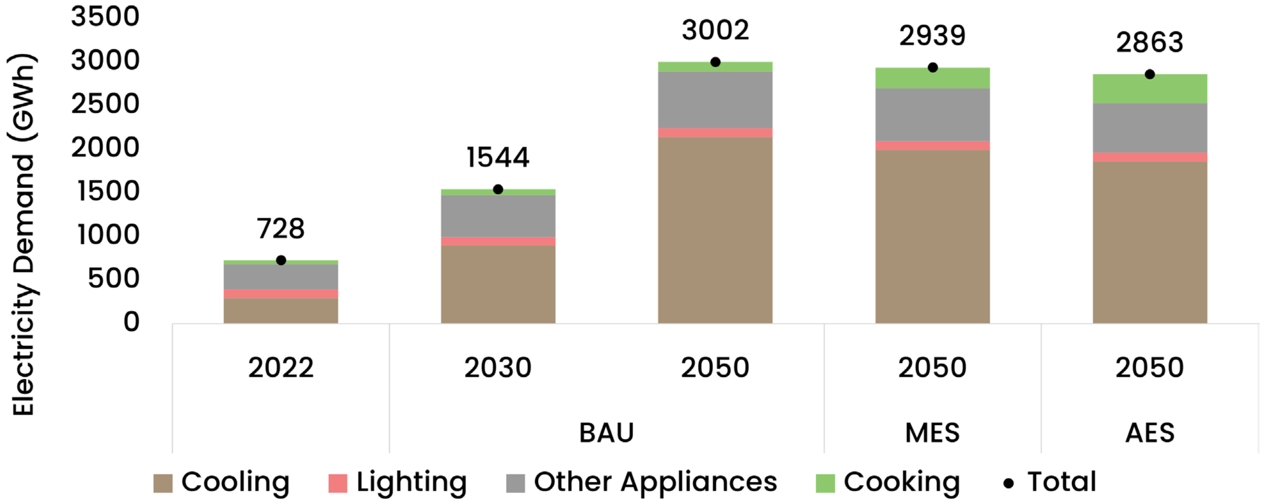


Figure 5.1: Electricity consumption (GWh) in residential sector in Virudhunagar

Commercial Buildings and Public Services

The commercial building sector in Virudhunagar comprises finance, retail, education, healthcare, hospitality (hotels and restaurants), and religious activities. Energy consumption in this sector primarily relies on electricity, LPG, and diesel. In 2022, the electricity demand for commercial buildings through low-tension (LT) feeders was 147.3 GWh, while public lighting and waterworks consumed 66.94 GWh, and miscellaneous activities accounted for 93.26 GWh.

The HT feeder load has experienced a consistent growth in electricity demand, with annual growth of 10.7 percent between 2004-05 to 2022-23. In 2022, the electricity demand through HT feeders was recorded at 27.5 GWh. This demand is projected to increase in proportion to the continued commercial development in the district.

The electricity demand projections for the commercial sector are developed using a time series regression model (FB Prophet), which analyses the past 15 years of data for LPG, High-Speed Diesel (HSD), and electricity consumption (HT & LT feeder).

Under the BAU scenario, the total electricity consumption from commercial buildings, public lighting, and miscellaneous categories in the district is projected to reach 616 GWh by 2050. Electricity consumption in commercial buildings is expected to increase by 4.8 percent by 2050, while public lighting and miscellaneous categories are anticipated to see a 3.7 percent rise in electricity demand over the same period. In terms of GHG emissions, the sector emitted 27 $ktCO_2e$ in 2022, which is expected to increase to 45 $ktCO_2e$ by 2050.

In the MES, GHG emissions could drop 28 percent as compared to BAU, to 32 $ktCO_2e$ by 2050. In the AES scenario, 100 percent of the energy currently supplied by HSD is expected to be replaced by electricity, and a 60 percent replacement of LPG by PNG by 2050 could achieve a GHG emissions reduction of nearly 78 percent, limiting emissions to 10 $ktCO_2e$ by 2050.

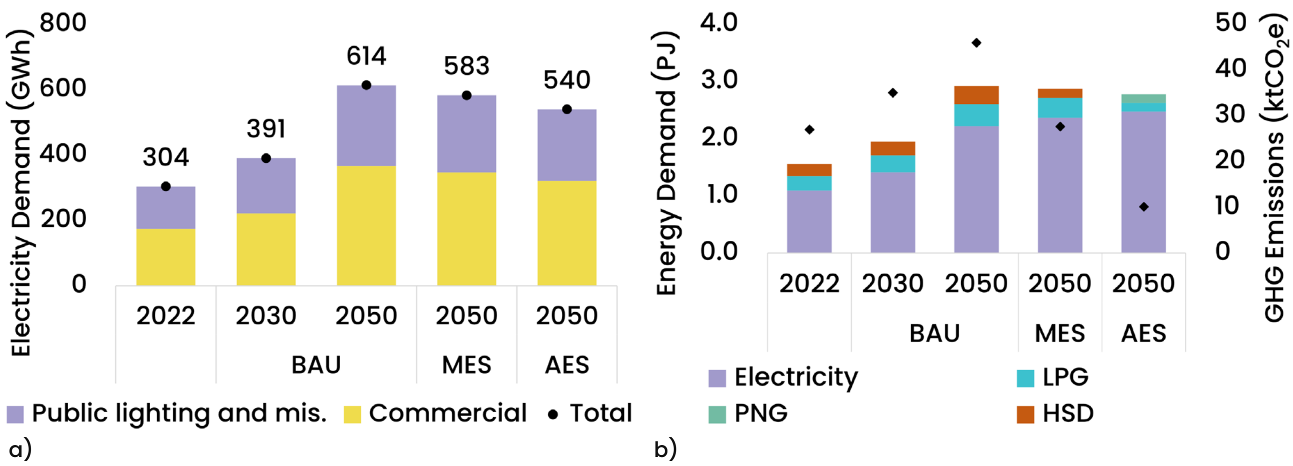


Figure 5.2 (a): Electricity demand in commercial building, (b) Energy and emissions in commercial buildings and public services in Virudhunagar

Cooking Sector

The cooking sector constitutes a significant portion of residential energy consumption. Projections for cooking energy demand in the residential sector were based on district-specific per capita cooking fuel consumption data. In 2021-22, LPG consumption in the district was 53.29 kt in the residential sector and 4.51 kt in the commercial sector. Between 2004-05 and 2022, LPG consumption grew at an annual rate of 7.6 percent. Historically, residential LPG usage accounted for approximately 92 percent of the district's total LPG consumption, with the commercial sector making up the remainder. These proportions are assumed to remain unchanged. As kerosene usage in cooking has declined significantly from 2005 to 2022, future projections exclude kerosene and fuelwood.

Under the BAU scenario, 92 percent of cooking energy demand is met by LPG and 8 percent is met by electricity. Owing to population growth, the GHG emissions from the residential sector are further estimated to increase from 174 $ktCO_2e$ in 2022 to 262.4 $ktCO_2e$ by 2050.

In the MES and AES scenario, PNG is expected to replace LPG usage after 2030 as a result of policy push for installation of new PNG pipelines in the district. Penetration of electric cookstoves is also expected to increase from 6 percent in BAU to 30 percent under MES and 50 percent under AES due to policy and market shifts. Electric cookstoves, including induction and infrared models, offer a significant advancement in cooking technology by providing a clean, efficient, and safe alternative to traditional biomass and even LPG. They eliminate indoor air pollution, offer precise thermal control, and reduce fire hazards. In Tamil Nadu, as of 2021, about 17 percent of households had adopted some form of electric cooking, a rate matched only by Delhi among Indian states.This adoption is driven by government campaigns like "Go Electric," which promote the benefits of electricity-based cooking, and is supported by relatively high urbanisation and awareness in the state.

In MES, GHG emissions can be reduced by 40 percent to 158.5 ktCO_2e in 2050. In the AES scenario, GHG emissions are expected to reduce to 103.4 ktCO_2e by the same year, achieving a 61 percent reduction compared to the BAU projection for 2050.

Box Item 1: Promoting Piped Natural Gas (PNG) over Liquified Petroleum Gas (LPG) will enhance handling efficiency

Piped natural gas (PNG) offers an uninterrupted supply through pipelines, eliminating the need for LPG cylinder storage and refilling. Compared to LPG, PNG has lower handling losses and is often more economical, with metered billing options. PNG primarily consists of methane (CH_4), which burns more cleanly and completely, producing minimal CO_2 emissions. Methane has a higher hydrogen-to-carbon ratio, leading to less incomplete combustion. Whereas LPG, composed of propane (C_3H_8) and butane (C_4H_{10}), generates higher CO_2 emissions due to its molecular structure and lower hydrogen-to-carbon ratio.

PNG emits approximately 11-15 percent less CO_2 compared to LPG, depending on appliance efficiency and combustion conditions. The CO_2 emission factor for LPG is 63.1 tCO_2/TJ, while for PNG 56.1 tCO_2/TJ, according to the Indian Network on Climate Change Assessment (INCCA).

In lieu of these benefits, the Indian Oil Corporation Limited (IOCL), authorised by the Petroleum and Natural Gas Regulatory Board (PNGRB), is expanding the City Gas Distribution network to add additional 86.55 lakh domestic PNG connections across nine districts of Tamil Nadu (11th round) namely, Virudhunagar, Thoothukudi, Tirunelveli, Kanyakumari, Madurai, Dharmapuri, Krishnagiri, Theni and Tenkasi. The plan is in early implementation. This contributes towards the 2.28 crore PNG connections target across Tamil Nadu under the TN City Gas Distribution Policy 2023.

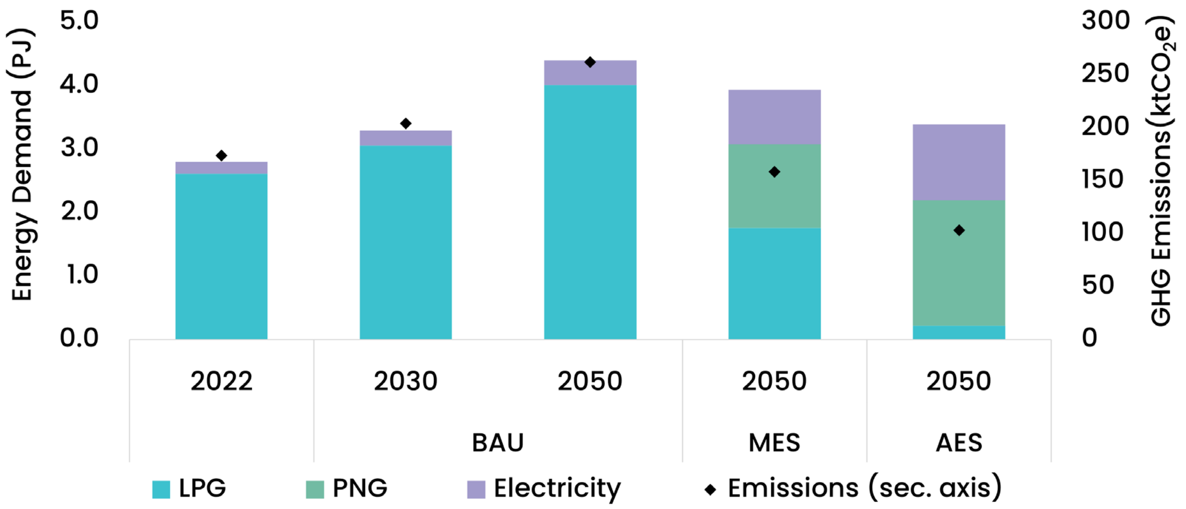


Figure 5.3: Energy requirement and emissions in cooking sector in Virudhunagar

Aggregate Results of Building Sector

Figure 5.4 (a) and (b) illustrate the total energy demand met by sector and fuels types, together with its GHG emissions buildings accounts for approximately 40 percent of the district's total electricity supplied. The aggregate electricity consumption in buildings is projected to increase by 3.6 times, from 1 TWh in 2022 to 3.6 TWh by 2050. With adoption of energy-efficient appliances, econversion of liquid fuels to electricity, and substitution of LPG with PNG, an estimated energy savings of 12.1 percent can be achieved by 2050.

In the BAU, the total energy demand in the building sector is expected to more than triple, increasing from 6.9 PJ in 2022 to 17.74 PJ by 2050. Under the MES, the total energy demand could reach approximately 16 PJ, while in the AES, it is expected to decline further to 15 PJ by 2050. Further, in AES, electricity is anticipated to account for 87 percent of the total energy share, and the remaining 13 percent is met by PNG, with phaseout of HSD by 2050.

Building-related GHG emissions under the BAU scenario are projected to increase from 201 $ktCO_2e$ in 2022 to 307.2 $ktCO_2e$ by 2050. However, with the implementation of GHG mitigation interventions suggested earlier, emissions could be significantly reduced to 120.1 $ktCO_2e$ by , comprising 103 ktCO2e from residential cooking and 17 ktCO2e from commercial cooking. This substantial reduction can be achieved through two major interventions: **Fuel Mix Transformation** and **Energy Efficiency Improvements**. The fuel mix transformation includes transitioning to an electricity-dominated system, phasing out high-emission fuels such as HSD, and switching from LPG to cleaner PNG. Energy efficiency improvements focuses on adopting energy-efficient appliances, implementing building management systems to optimise energy use, and enhancing operational practices for improved energy performance. These strategic interventions demonstrate the substantial potential for decarbonising the building sector reduce GHG emissions by up to 61 percent compared to the BAU scenario.

An additional ~208 GWh of projected electricity demand in 2050 and 147 $ktCO_2e$ of Scope 2 emissions can be abated over and above the abatement in aggressive efforts scenario through behavioural interventions of temperature control and smart lighting in the building sector.

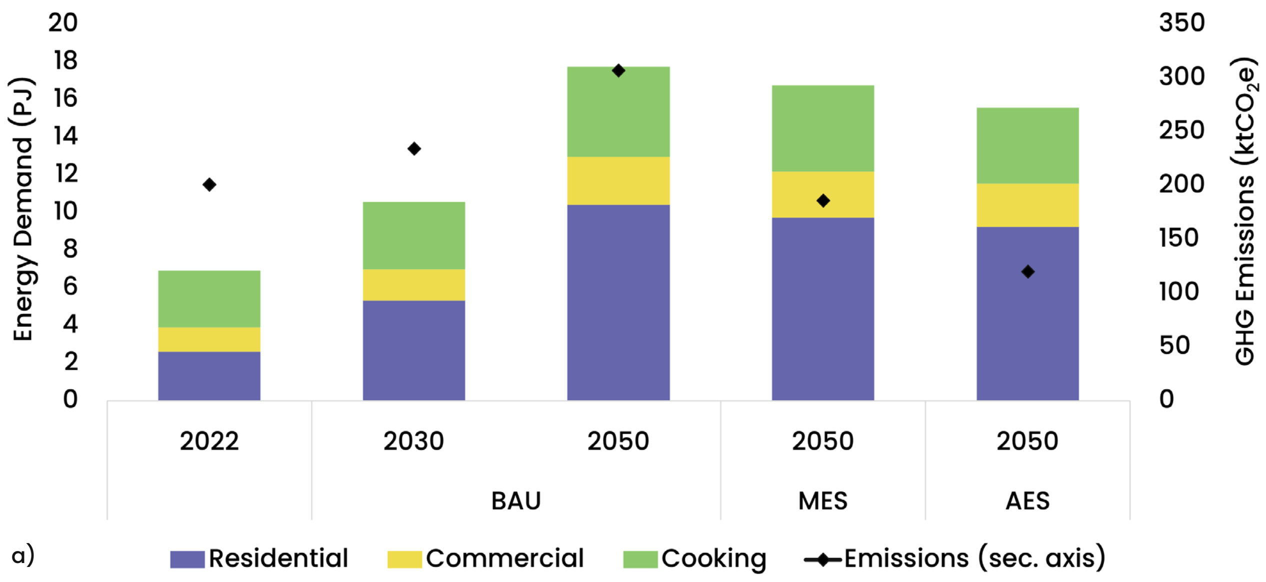


Figure 5.4 (a): Aggregate energy requirement and emissions in buildings sector in Virudhunagar

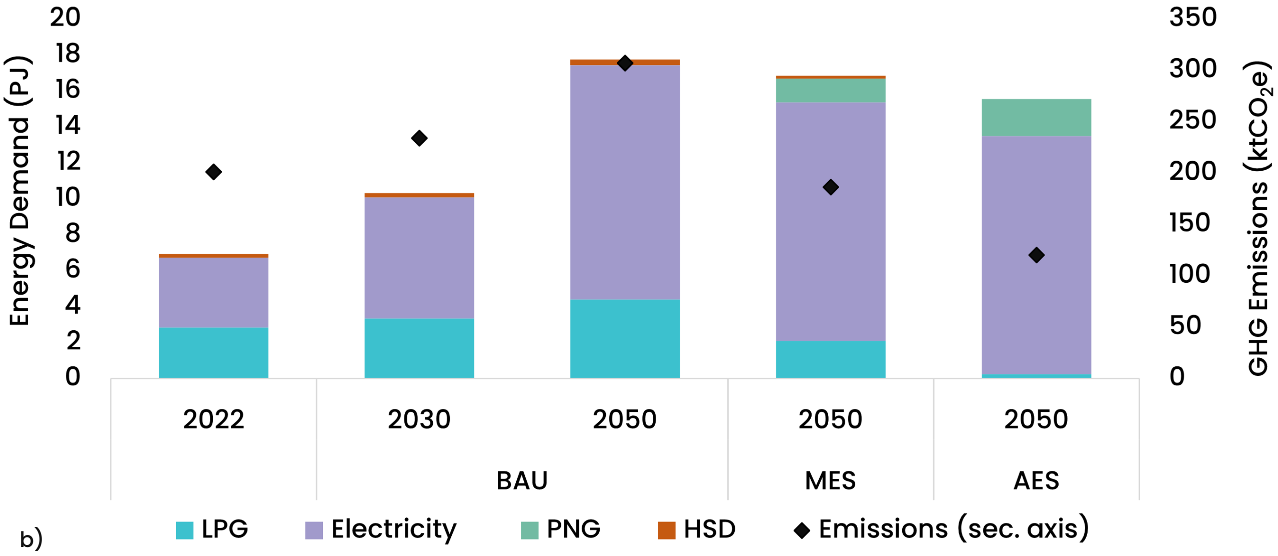


Figure 5.4 (b): Aggregate energy demand met by various fuels and emissions in Virudhunagar

Key Interventions to Decarbonise the Building Sector

Promote High-Efficiency Appliances and Cooling Solutions: Encourage adoption of 3-5-star rated cooling appliances, approx 7 lakh BLDC fans and 7.5 lakh air conditioners, gradually through incentives coupled with awareness campaigns to drive their market demand. Adopting high-efficiency appliances can save up to 322 GWh of electricity or 11 percent of the residential consumption by 2050.

166 $ktCO_2e$ of Decarbonisation Potential by 2050

Stakeholders: Individual Users, Bureau of Energy Efficiency (Central - for enforcement), Tamil Nadu Energy Development Agency and TANGEDCO (State policies and subsidies)

Encourage Renewable Energy Integration: Increase penetration of rooftop solar in residential buildings by 2030. Assessment of potential, door to door campaigning, and low cost financing for households can enable this uptake.

Solar Rooftop: Mandate or incentivise the installation of solar photovoltaic (PV) on commercial buildings, aiming to meet at least 30 percent of their electricity demand from on-site renewables by 2030. This could be covered under ECSBC/GRIHA standards compliance for both existing and new commercial buildings.

Battery Storage: Promote the replacement of diesel generators with battery storage systems to improve power backup, manage supply interruptions, and enhance grid reliability.

Potential of RE integration in further abating building emissions needs to be assessed.

Stakeholders: Individual Users and Commercial Entities (for adoption), State Energy Department / Tamil Nadu Energy Development Agency (potential assessment and subsidies), Private Project Developers and Financiers

Public Lighting and Infrastructure Upgrades to Smart LED Lighting: Fast-tracking the replacement of ~11 lakh incandescent and CFL lights with LED-based lights and converting ~80,000 public street lighting to smart LED systems by 2030, could result in a 30-40 percent reduction in energy consumption. Explore adaptive lighting solutions that adjust based on usage patterns and time of day to enhance energy savings.

35 $ktCO_2e$ of Decarbonisation Potential by 2050
Stakeholders: Individual Users (for adoption) and Urban Local Bodies (implementation)

Promoting Cleaner Fuels for Cooking in Residential and Commercial Buildings:

Accelerate PNG Infrastructure Development and Subsidise Initial Connections: Increase PNG share to 40-50 percent in residential cooking by 2050 by including credit-linked instalment mechanisms to boost new initial connection charges.

Promote High-Efficiency Electric Cooking Appliances: Subsidise induction and electric cookstoves for approximately 74,000 units by 2030 and around 1.4 lakh units by 2050, with support from the National Energy Cooking Program (NECP). Installing a biogas plant of approx 30,000 m^3/day capacity, considering 50% realization of total potential of 60,000 m^3/day of the district.

195 $ktCO_2e$ of Decarbonisation Potential by 2050
Stakeholders: Individual Users, Public/Private Developers, PNGRB, EESL

Box Item 2: Setting ACs to 26°C can save 6.5 percent of space cooling demand by 2050

Temperature control (setting AC temperature at 26°C) can save Virudhunagar an upwards of ~120 GWh out of 1845 GWh of the projected electricity consumption in space cooling in 2050 and abate scope 2 emissions of ~84 $ktCO_2e$ over and above the energy efficiency measures. Residential demand for electricity is projected to increase from 728 GWh to 3,002 GWh by 2050, with that for space cooling accounting for 61 percent of it, at 1845 GWh by 2050. By maintaining a temperature setting of 26°C, it is possible to save up to 60 percent of the electricity required for space cooling, compared to operating air conditioners at 18°C. Currently, commercial buildings commonly set their ACs between 18°C and 21°C. Setting an AC to very low temperatures (like 18–21°C) doesn't make it cool faster or better — the compressor works the same way. According to ASHRAE comfort standards, 25°C with proper humidity and air movement is enough to make people feel cool and comfortable. So, setting the AC to a higher temperature (around 24–26°C) is both comfortable and energy-efficient. A conservative increase in the temperature setting by 2°C from 24°C to 26°C could reduce electricity demand by approximately 120 GWh.

5.1.2 Transport Sector

Transport in Virudhunagar predominantly relies on road transport, similar to the trend observed across Tamil Nadu. Road transport is a significant contributor to GHG emissions in the energy sector. Consequently, this analysis focuses on the main source of transport-related emissions in the district, and strategies to mitigate related GHG emissions.

Road Transport:

As of August 2024, the vehicle composition in Virudhunagar included a predominance of two-wheelers and a significant presence of diesel-powered vehicles, particularly in the heavy duty segment. According to the Tamil Nadu Statistical Handbook (2022), Virudhunagar accounts for 1 percent of the state's two-wheelers, three-wheelers, buses, and Heavy-Goods Vehicles (HGVs) like buses and trucks. Further, electric vehicles (EVs) currently represent a minimal share of the overall vehicle stock, indicating a significant reliance on fossil fuels.

To assess the decarbonisation potential of the transport sector in Virudhunagar, a stock model was developed using historical vehicle ownership data from the Tamil Nadu Statistical Handbook, Ministry of Road Transport and Highways (MORTH) yearbook and the VAHAN dashboard. The model projects vehicle ownership from 2024 to 2050 across various segments, including two-wheelers(2W), three-wheelers (3W), cars, buses, trucks (HGV), and others.

Table 5.1.2 (a): Total road transport service demand projection in BAU, vehicle category-wise

Year	2W	3W	4W	BUS	HGV	Others
2022	5,20,012	5,012	47,357	2,883	12,663	19,221

(Source: Statistical Handbook 2017-18, VAHAN Dashboard)

Table 5.1.2 (b): Projection of road transport service demand EV, vehicle category-wise

Scenario	Year	2W	3W	4W	BUS	HGV	Others
BAU	2022	520	16	67	1	3	1
	2030	25,241	227	6,718	130	167	235
	2050	6,49,640	6,889	1,49,030	2,776	2,788	6,958
MES	2050	6,78,158	7,164	2,55,405	4,055	7,563	15,434
AES	2050	6,78,158	7,164	2,55,405	5,201	10,677	19,225

The model incorporates several operational assumptions, including the annual kilometeres driven across all vehicle segments, fuel efficiency, the average retirement age of vehicles,[29] and vehicle saturation per 1,000 people. These variables serve as inputs for the **Gompertz growth model**[30], which is used to forecast the number of vehicles. This forecast is then utilised to calculate year-on-year fuel consumption and, ultimately, to estimate greenhouse gas (GHG) emissions.

Table 5.1.2 (c): Electric vehicle new sales in different scenarios

Vehicle category	BAU			MES	AES
	2022	2030	2050	2050	2050
2W	1%	30%	100%	100%	100%
3W	1%	30%	100%	100%	100%
4W	0%	30%	70%	100%	100%
BUS	0%	30%	65%	100%	100%
HGV	0%	7%	20%	50%	80%
Others	3%	10%	40%	85%	95%

To explore pathways for reducing transport emissions, three scenarios were developed, reflecting varying levels of EVs adoption and their impact on energy consumption and emissions from 2022 to 2050.

The BAU scenario projections take into account the momentum built by policy shifts and fiscal incentives under Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) Phase-I Scheme (2015), FAME-II (2019) and the Electric Vehicle Policy of Tamil Nadu (2019; 2023). These incentives along with the behavioural shifts resulted in a 8-fold increase in the new registrations of electric vehicles in India, and a 20-fold increase in that in Tamil Nadu between 2019-20 and 2023-24 which was led predominantly by two-wheelers (2W) and three-wheelers (3W).[31]

By 2030, the penetration of electric two-wheeler (2W), three-wheeler (3W), four-wheeler (4W) and e-buses in new sales is projected to increase to 30 percent, to further increase to 100 percent for 2W and 3W, 70 percent for 4W and 65 percent for e-buses by 2050. Through full and effective implementation of the existing schemes, further development and maturity of allied infrastructure for electric mobility, MES anticipates 100 percent electrification of buses and 50 percent electrification of HGVs, while the AES projects even greater progress, with almost all buses and other segments electrified.

Box Item 3: EV share in new registration is expected to grow in future years, similar pattern observed in other states

The table below showcases showcases the vehicle category-wise EV share as a percentage of total vehicle registrations in each category for the year 2023-24. Kerala, Karnataka, and Maharashtra exhibit strong EV penetration in the 2-wheeler segment. Similarly, the 3-wheeler segment is dominated by Uttar Pradesh, where a remarkable 82.4 percent of new registrations are electric. Meanwhile, Kerala, Maharashtra, and Tamil Nadu maintain a balanced EV share in this segment.

In the Light Motor Vehicle category (LMV), mostly the 4 wheelers, states like Kerala, Maharashtra, Karnataka, and Tamil Nadu are experiencing an increasing growth in EVs registration. In Maharashtra, 28 percent of the new registration in HPV category were electric.

Category-wise share of EVs (%) in new registration in Indian states, year 2023-24

EV Category	Karnataka	Kerala	Maharashtra	Tamil Nadu	Uttar Pradesh
2 Wheeler	11.6	**13.5**	10.1	6.0	2.1
3 Wheeler	9.0	15.6	15.2	12.3	**82.4**
HPV (Buses)	22.6	12.3	**28.0**	5.6	0.0
LMV (Cars)	3.1	**5.4**	2.4	2.3	1.1

Figure 5.1.2 (a) highlights the total projected energy demand in the vehicle segment growing from 5.5 PJ to 7.2 PJ in 2050 in BAU. Energy requirements decrease in alternative scenarios due to the penetration of efficient EVs, which replace high-energy-intensive internal combustion vehicles. Thus, energy demand reduces from 7.2 to 4.4 PJ by 2050. Figure 5.1.2 (b) shows that electricity demand from the electrification of the road transport fleet is projected to rise to 424 GWh in the BAU scenario by 2050, with the majority of this consumption attributed to 4-wheelers and heavy-duty vehicles.

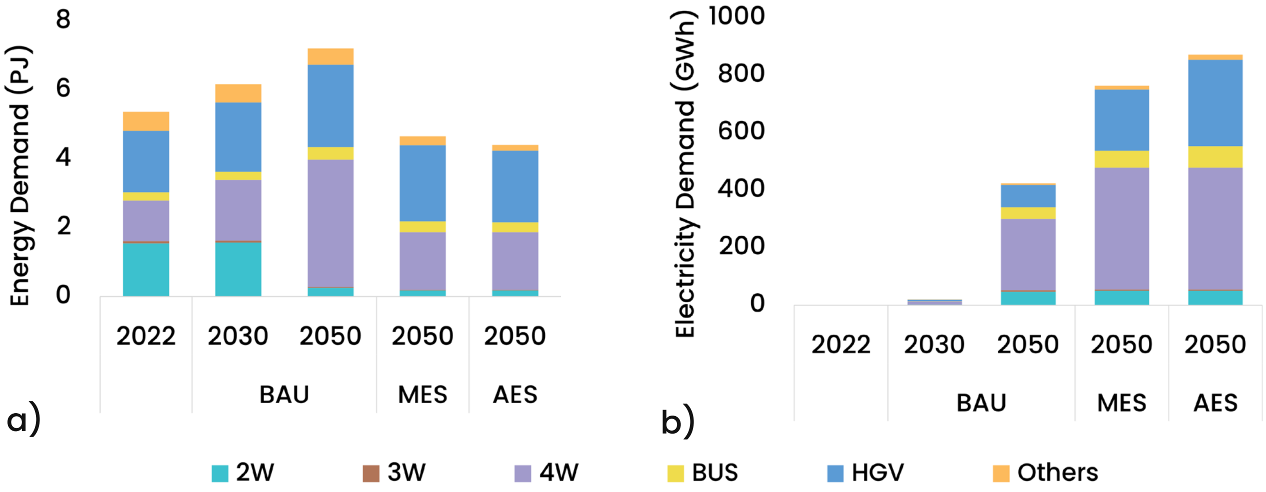


Figure. 5.1.2 (a): Energy demand (PJ) in vehicle segment, (b) road transport electricity (GWh) consumption

The projected GHG emissions under the BAU scenario are estimated to reach 483 ktCO_2e by 2050. Under the MES, emissions are expected to decrease to 161 ktCO_2e, reflecting a significant reduction driven by increased adoption of electric vehicles. In the AES, emissions are further reduced to 107 ktCO_2e, representing the most substantial decline due to more aggressive electrification strategies and improved fuel efficiency across vehicle segments.

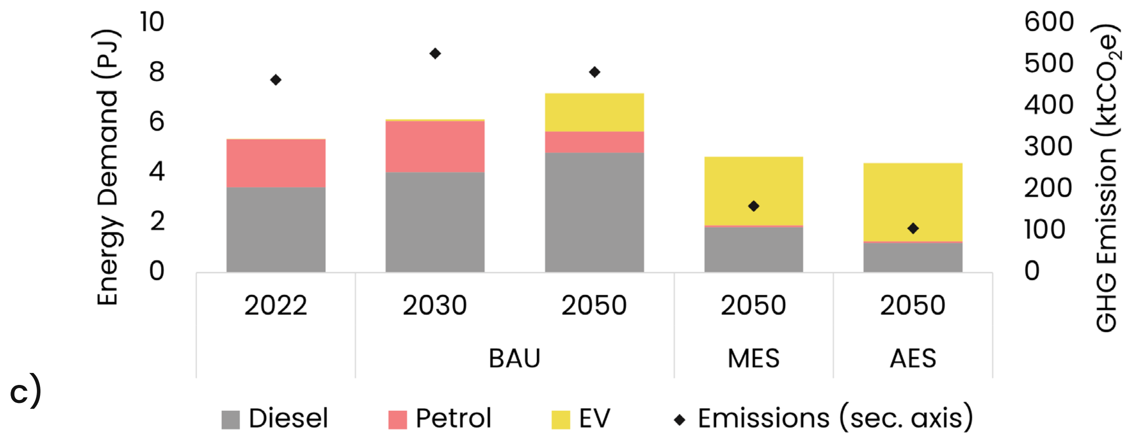


Figure 5.1.2(c): Energy demand and GHG emissions in different scenarios based on fuel used

Key Interventions to Decarbonise the Road Transport

Prioritise Two-Wheeler and Three-Wheeler Electrification: With 5,20,012 two-wheelers and 5,012 three-wheelers dominating the current fleet, out of which only 0.1 percent and 0.3 percent respectively are electric, electrification efforts in this segment can be expedited in alignment with the State EV Policy. The district should target 100 percent electrification of 2W and 3W, to the total stock of 5 lakh electric 2W and ~7500 electric 3W by 2050.

Scale Charging Infrastructure: The analysis projects electricity demand reaching 425 GWh by 2050 under BAU scenario. Augment electricity distribution infrastructure, focusing first on urban areas where 2W/3W adoption will be highest. Increase capital investment in public charging points at bus bays, fuel stations, parking lots, malls. At least 475 new charging stations should be targeted by 2050.

Accelerate Bus Fleet Transition: Electrification of intra-city public and private buses needs to be prioritised. Given the potential for electrification of public buses and the high upfront costs involved, it is crucial to adopt innovative financing mechanisms, such as the OPEX (operational expenditure) model.

376 $ktCO_2e$ of Decarbonisation Potential by 2050

Stakeholders: Individual Users, State Transport Department (policies/subsidies), RTO (monitoring and progress), Local Businesses (repair and allied services), Industry (tech availability and infrastructure)

Box Item 4: Policy directions exist that can accelerate decarbonisation of road transport in Virudhunagar

Virudhunagar can benefit from Tamil Nadu's initiatives to push electricity mobility. Under the TN Electric Vehicle Policy 2023,

- The State Government has announced incentives up to Rs. 5000 for procurement of e-cycles, Rs.30,000 for e-2W, Rs. 40,000 for e-3W, Rs. 1,50,000 for e-4W and Rs. 10,00,000 for e-buses. In addition, a 100 percent road tax has been exempted, and registration charges and permit fees waived for electric vehicles in the State till 31.12.2025.
- Furthermore, to promote EV supply, electricity tax on EV manufacturing has been exempted for the period of five years and a 100 percent reimbursement of SGST is being offered on a minimum investment of Rs. 50 crores and generation of at least 50 jobs.
- A total investment of Rs. 50,000 crore in EV manufacturing and generation of 1.5 lakh new jobs is targeted under the policy. It also targets increasing the share of electric buses to 30 percent of the fleet by 2030.

Further extension of the timeline under EV policy could be explored.

Promoting non-motorised transport (bicycle, cycle rickshaw, push scooters etc) for shorter distances (3.5-4 km) can complement these efforts in abating GHG emissions of the transport sector. Over and above the projected abatement potential, behavioural interventions such as use of smart traffic systems at intersections and using public transport for inter-city and intra-regional movement could curtail 25 percent of emissions at traffic lights and 45 percent of emissions vis-a-vis private vehicles respectively.

5.1.3 Agriculture Sector

The agricultural production in Virudhunagar district encompasses a variety of crops such as paddy, groundnut, cotton, millets, pulses, and cereals, which cover around 80 percent of the gross sown area. In 2022-23, agricultural electricity consumption in the district was 12.2 GWh[32]. The electricity consumption is driven by water pumping requirements driven by each cropping season. The analysis relies on 10-year crop production pattern and water requirement of Tamil Nadu. Projections for agricultural crop production until 2050 were based on historical crop production and crop yield data.

Currently, 42 percent of the total sown area is irrigated, with 60 percent of this irrigation supported by wells and 40 percent by tanks.[33] The average depth of water in Virudhunagar is 7.22 metres below ground level.[34,35] The number of electrified pump sets rose from 39,011 in 2020-21[36] to 2,40,574 in 2022-23.[37]

The electricity requirements for irrigation were projected based on water needs per hectare for major crops. Under the BAU scenario, 98.5 percent of irrigation pumps operate on grid electricity, 0.83 percent use diesel, and the remaining are solar-powered. In this scenario, the shares of electrified, diesel, and solar pump sets in 2022 remain unchanged until 2050. Additionally, diesel -based tractors and tillers are expected to remain operational through 2050. Diesel-powered groundwater pumping used for irrigation and agricultural machinery, such as tractors and tillers used for land preparation, are projected to increase GHG emissions from 26 $ktCO_2e$ to 35 $ktCO_2e$ by 2050.

The PM-KUSUM scheme aims to reduce diesel usage by promoting the electrification and solarisation of irrigation pumps. Under the MES, all diesel-based irrigation pumps are replaced with solar pumps under the PM-KUSUM scheme by 2030, and 50 percent of agricultural machinery is electrified. This could lower GHG emissions to 22 $ktCO_2e$ by 2050, with electricity consumption reaching 93 GWh. In the AES, achieving a 100 percent replacement of diesel pumps with solar pumps and complete electrification of agricultural machinery could fully abate energy-based sectoral emissions to by 2050, with an estimated electricity requirement of 134 GWh.

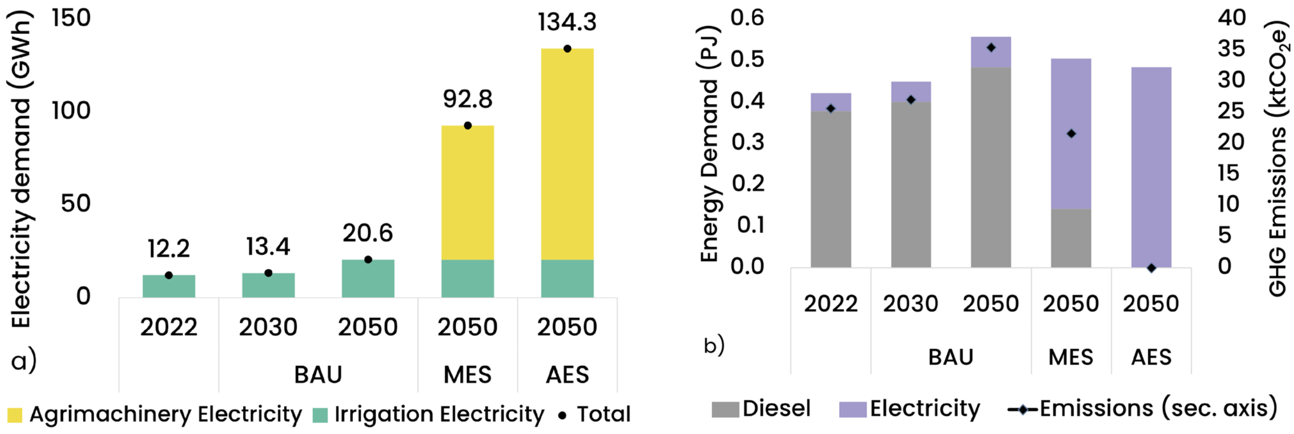


Figure 5.1.3: (a) Electricity demand (GWh) in agriculture sector, (b) Energy requirement (PJ) and GHG emissions ($ktCO_2e$) in agriculture sector in Virudhunagar

Key Interventions to Decarbonise Energy in Agriculture

Promotion of Renewable Energy Solutions:

- **Solar-Powered Irrigation Systems:** Replace ~330 existing diesel pump sets with solar pumps by 2030, in convergence with the PM-KUSUM scheme.
- **Agrivoltaics[38]:** Explore potentials for Implementing agri-voltaic systems that allow for the dual use of land for both agriculture and solar energy production. This can be done through detailed assessment of crop diversity in the district and viability assessment.[39]

Transitioning from Diesel Agro Machineries to Electric Agro Machineries: Promote electric tractors by targeting at least 30 percent of new tractor sales to be electric by 2035, supported by tailored financing solutions from agricultural banks and financial institutions. Additionally, transition all 8,000 projected diesel-based tractors and tillers to electric by 2050.

35 $ktCO_2e$ of Decarbonisation Potential by 2050

Stakeholders: Individual Farmers/Farmer Producer Organisation (FPO)/Water User Associations, State Agriculture and Energy Department, TANGEDCO

5.1.4 Industrial Sector

Virudhunagar comprises 41,604 Micro, Small and Medium Enterprises, which represents 3 percent of all MSMEs in Tamil Nadu. Virudhunagar district is a significant industrial hub, with specialised clusters spread across its various blocks. Rajapalayam is renowned for its spinning mills and cotton production, while Sivakasi and Sattur are leaders in the match, fireworks, and printing industries. Kadiyapatti is home to major enterprises of the TVS group, and Alangulam, Uppathur, and Thulukkapatti are prominent for cement production. Dhalavaipuram in Rajapalayam is also a centre for garment manufacturing and rice mills.[40]

Approximately 50 percent of the electricity demand in Virudhunagar district is consumed by the industrial sector. In 2021-22, the industrial sector's electricity consumption was 1,040 GWh. Large industries in the district use electricity from both mixed feeders and dedicated high-tension (HT) feeder lines (11 KV). Therefore, projections for industrial electricity demand were made separately for HT and low-tension (LT) industries.

In 2021-22, the electricity consumption from LT feeders was 263.4 GWh, with an annual growth rate of 3.3 percent since 2004-05. Whereas, the total electricity consumption through the HT-I feeder was 777 GWh. A time series regression model (FB Prophet) was applied to this historical data, effectively capturing trends, seasonality, and the impact of the COVID years for future projections. Based on the observed growth rate, it is projected that the HT-I feeder will cater to nearly 2000 GWh of electricity by 2050. The total electricity demand, including both HT and LT feeders, is expected to reach 2593 GWh by 2050 under the BAU scenario.

The total electricity demand in the industrial sector is projected to increase to 2,952 GWh under the MES and to 3,080 GWh under the AES by 2050.

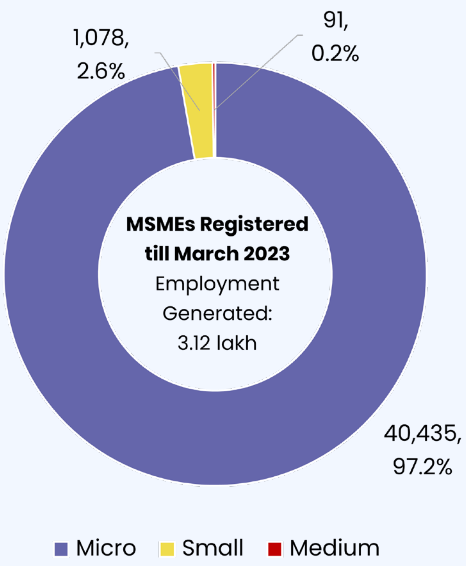
GHG Emissions

In the Industrial sector, chemical, textile, and metal industries contribute to majority GHG emissions. The sector used fuels such as coal, petcoke, FO, and bitumen from 2004-05 to 2022. Time-series regression has been applied to forecast future fuel consumption. Under the BAU scenario, GHG emissions from these fuels in the industrial sector, which amounted to 446 ktCO_2e in 2022, are projected to rise to 603 ktCO_2e by 2050.

However, with available decarbonisation options, such as renewable electricity-based systems, green hydrogen, and biomass could limit GHG emissions in the industrial sector to 301 ktCO_2e in the MES. In the AES, the full adoption of all decarbonisation technologies would reduce GHG emissions to nearly zero by 2050.

Box Item 5: Decarbonising industries in Virudhunagar requires a value-chain approach

Virudhunagar's industrial sector is dominated by textile, fireworks and cement industries, and supported by a deep network of micro, small and medium enterprises that provide raw materials, transportation and other services throughout the value chain. These MSMEs are critical for sustenance of the large industries, and equally important for local employment generation. Considering that 97 percent of these enterprises are micro in nature, a category known to witness higher representation from women and youth, MSMEs in Virudhunagar are also engines of change in improving gender equity outcomes in the district. These factors make a holistic, value-chain approach to decarbonisation of the industrial sector – highest emitter in Virudhunagar - a moral and economic imperative.



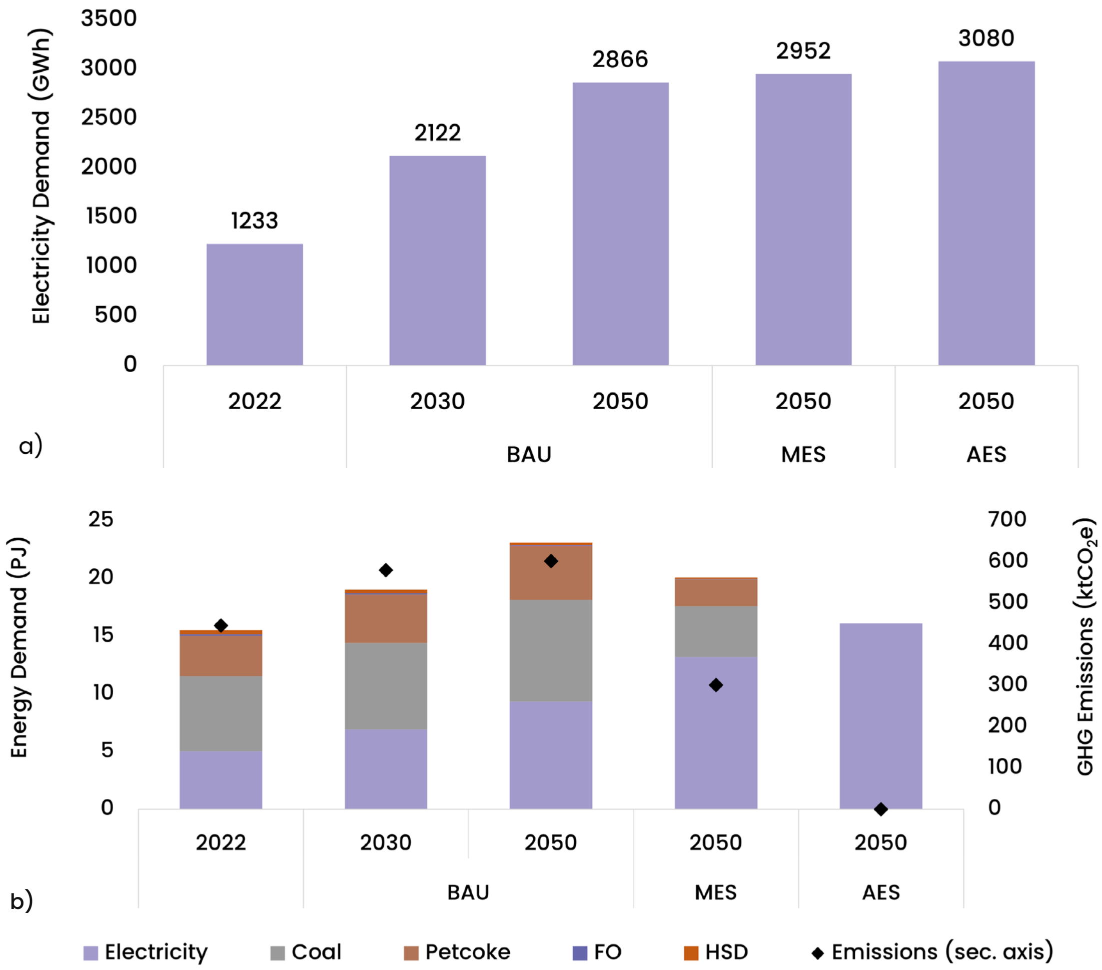


Figure 5.1.4 (a): Total electricity demand in industrial sector (in GWh) under different scenarios (b): energy and emissions in industrial sector in Virudhunagar

Box Item 6: Textile MSMEs can act as first movers towards a holistic industrial decarbonisation

Textile is one of the major MSME segments in Virudhunagar. By acting as early adopters of clean energy and energy efficient solutions, they can lead the way for a holistic industrial decarbonisation.

About 52 percent of all emissions in textile manufacturing accrue to fabric processing and finished material production (WRI 2021; Vasudha 2025). Heating, particularly steam for dyeing, treatment and conditioning of fabric, represents a significant portion of these emissions. Traditional boilers use coal and firewood to generate heat. These boilers also pose a significant health hazard as factory workers are required to consistently manage heat output – increasing their exposure to pollutants and extreme temperatures. Low-load boilers and various other solutions have been tested as alternatives but risks remain. With electrification of the heating process, these emissions and risks can be completely avoided as industries transition from fossil fuel to electric steam boilers, thermal oil boilers or heat pumps, and the need for human intervention in maintaining consistent heat output is reduced.

Another 24 percent of emissions take place during raw material extraction (cultivation of cotton and other fibres), which can be abated by using electric tractors and replacing diesel pumps with solar pumps for irrigation, as well as by preserving the soil structure and nutrient profile through regenerative agricultural practices.

The remaining emissions at raw material processing (15%) and tailoring/sewing (9%) stages can be reduced/avoided through electrification of equipment (dryers, hydraulic press etc). EVs for transportation of goods from one unit to another can supplement these efforts. Further, renewable energy integration for day time usage and to replace grid electricity throughout the process along with adoption of energy efficient appliances can abate Scope 2 emissions in textile MSMEs.

Decarbonising Textile Industry

Each Step of the Way

Interventions

01 Production & Procurement of Raw Material

Raw Material Production (Cotton, Jute etc.)

Collection & Transportation of Raw Material/Fibre

Regenerative Soil Management
No/reduced till farming, precision nutrients and water use to preserve soil quality

Solar Pumps for Irrigation
towards eliminating diesel use and subsequents emissions

E-Tractors/Trucks
for collecting and transporting raw materials from sources to factories/units

02 Raw Material Processing & Spinning

Processing of Fibre

Solar/Electric Dryers
to replace conventional coal/biomass based dryers used to remove moisture from fibers

Electric Hydraulic Systems
to replace diesels balers and pressers; scope to capture braking eergy by pairing with regenerative drives

03 Fabric Manufacturing

Dyeing & Yarn Making

Fabric Processing

Electric Heat/Cooling Systems
to replace coal/firewood run steam boilers and humidifiers

**Potential of retrofitting existing setups by switching to biofuels/bioCNG or biomass briquettes for heating/drying in case where new RE installations are economically unviable or are applicable in long run.*

Tailoring & Garment Manufacturing

E-Autos & Other EVs
to transport material from one unit to another at various stages of textile manufacturing

Decarbonising Scope 2 Emissions

RE Integration

- RE based electricity for own consumption either through the Green open access or power markets.
- Installation of Solar rooftop systems.

Enhancing Energy Efficiency
through adoption of 5 star appliances and other energy efficient equipments throughout the processes

5.1.5 Captive Power Plants (CPP)

Almost all industries in Virudhunagar operate captive power plants (CPPs) to meet their electricity needs[41]. These industries span sectors such as textiles, papers, automobiles. Diesel and coal are the primary fuels used in these CPPs. According to the Central Electricity Authority (CEA), as of 2018-19, the total installed capacity of steam-based CPPs was 134.5 MW, while diesel-based CPPs had a capacity of 128 MW.

Due to unavailability of an active number of captive power plants in the district from 2018-19, the plant capacity (MW), electricity generation (GWh) and GHG emissions ($ktCO_2e$) are assumed to remain unchanged in the future.

The average plant load factor (PLF) for steam-based CPPs is approximately 15 percent, while for diesel-based CPPs, it is 0.8 percent. For this analysis, it is assumed that the installed capacity of fossil fuel-based CPPs will remain unchanged in the future. Under the BAU scenario, CPP-related GHG emissions are constant from 146 $ktCO_2e$ in 2022 to 2050. In MES and AES, replacing all diesel and coal-based CPPs with renewable energy sources, such as solar and wind, by 2050 would reduce CPP-related GHG emissions to zero.

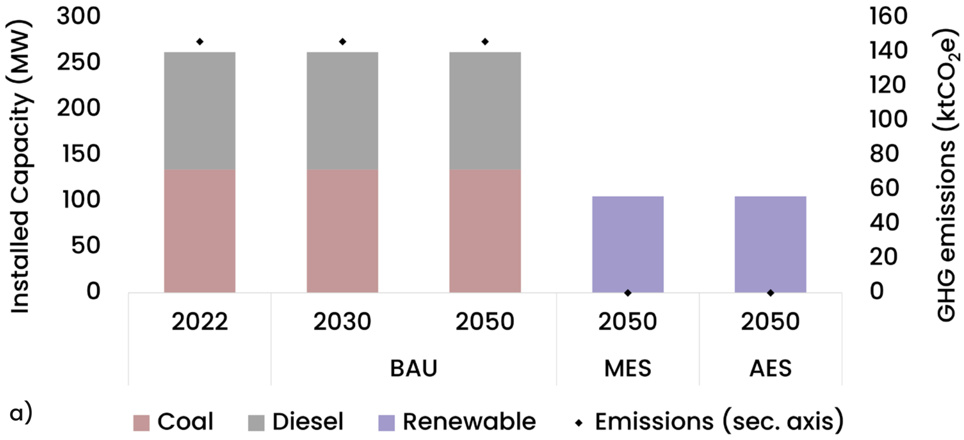


Figure 5.1.5 (a): Installed fossil fuel-based CPP and related emission in Virudhunagar under BAU, MES and AES

Box Item 7: Green hydrogen plasma generator offers a zero-emission solution for industrial heating processes

Industries that rely on extremely high process temperatures—such as those involved in cement production, metal treatment, and ceramic firing—are increasingly moving away from fossil fuels to embrace cleaner, carbon-neutral solutions. One emerging approach gaining attention is the use of plasma generators powered by green hydrogen. These systems utilise hydrogen derived from renewable energy sources like wind and solar to produce intense heat without emitting carbon dioxide during operation.

In this process, green hydrogen is fed into a plasma torch, where it is ionised by an electric arc, resulting in generating exceptionally high thermal heat. This heat can be efficiently transferred to industrial units like furnaces or kilns, replacing conventional carbon-based fuels such as coal, petroleum coke, or natural gas. Consequently, plasma systems fueled by renewable hydrogen not only slash CO_2 emissions but also significantly reduce pollutants like nitrogen oxides and sulfur dioxide.

Despite their promise, the widespread implementation of these systems hinges on several factors: adequate production of green hydrogen, affordable and efficient electrolyzers, dependable infrastructure for hydrogen logistics, and continuous innovations in plasma torch engineering. Addressing these technical and logistical hurdles will be critical to establishing plasma-based hydrogen heating as a scalable, zero-emission alternative for heavy industry.

The advantages of this method are substantial. First, since green hydrogen combustion yields only water vapor, the process eliminates direct carbon emissions. Second, the absence of fossil fuels in combustion creates a flue gas dominated by CO_2 from material reactions like calcination, simplifying and reducing the cost of carbon capture efforts.

Real-world validation is already underway. Projects such as Heidelberg Materials' ELECTRA initiative are testing plasma-heated kilns, while Cemex has partnered with HiiROC to investigate plasma-driven hydrogen generation. Although challenges remain in making the technology commercially viable at scale, its potential to dramatically reduce industrial emissions is clear. With continued progress, hydrogen-powered plasma heating—complemented by efficient carbon capture—can help the cement sector meet climate goals and contribute to a more sustainable infrastructure future.

Key Interventions to Decarbonise the Industrial Sector

- First and foremost, a comprehensive assessment needs to be made on the potential of RE integration in industries, including use of rooftop solar and other clean and zero emission technology (such as green hydrogen based plasma generators) to replace fossil fuel consumption – especially for heating in industries.
- Replace 100 percent of diesel and coal-based CPPs with renewable energy sources (solar, wind) by 2050 through market based power procurement (Open access or power exchange route) or RE based captive power.

748 ktCO_2e of Decarbonisation Potential by 2050

Stakeholders: Primarily Industries with support/incentives from TEDA/TANGEDCO, DICs

- Energy audits conducted in the Virudhunagar industries indicate that various technical interventions can result in electricity savings of 7–11 percent. Therefore, it is essential to implement the recommendations provided in these audits to achieve the potential energy savings.

In the long term, carbon capture technologies could be implemented to mitigate process emissions, particularly in cement manufacturing plants within the district.

5.1.6 Aggregate Results across the Scenarios

Electricity

Overall, under the BAU scenario, total electricity consumption in the district is projected to more than triple between 2022 and 2050, reaching 6,927 GWh. In contrast, the AES projects a higher electricity consumption of 7,488 GWh due to greater electrification of the transport fleet, and deeper electrification of industrial processes.

In 2022, the industrial sector was the largest consumer of electricity, accounting for nearly 54 percent of the total consumption, equivalent to 1,233 GWh. Over the coming decades, a shift in the sectoral shares of electricity consumption is anticipated. By 2050, the industrial sector's share is projected to decrease slightly to 42 percent, despite an overall increase in absolute electricity demand.

By 2050, electricity demand in the residential sector is expected to surpass that of the industrial sector. Currently, the residential sector consumes 728 GWh of electricity, contributing approximately 35 percent of the total demand. Meanwhile, the transport sector is forecasted to experience the fastest growth, with its share rising significantly from 0.01 percent in 2022 to 6.1 percent by 2050.

The commercial sector's share of electricity demand in the district is expected to decline from 14 percent to 9 percent, although its absolute consumption is projected to nearly double to 614 GWh under BAU. Energy saving measures under AES will reduce this to 540 GWh in 2050.

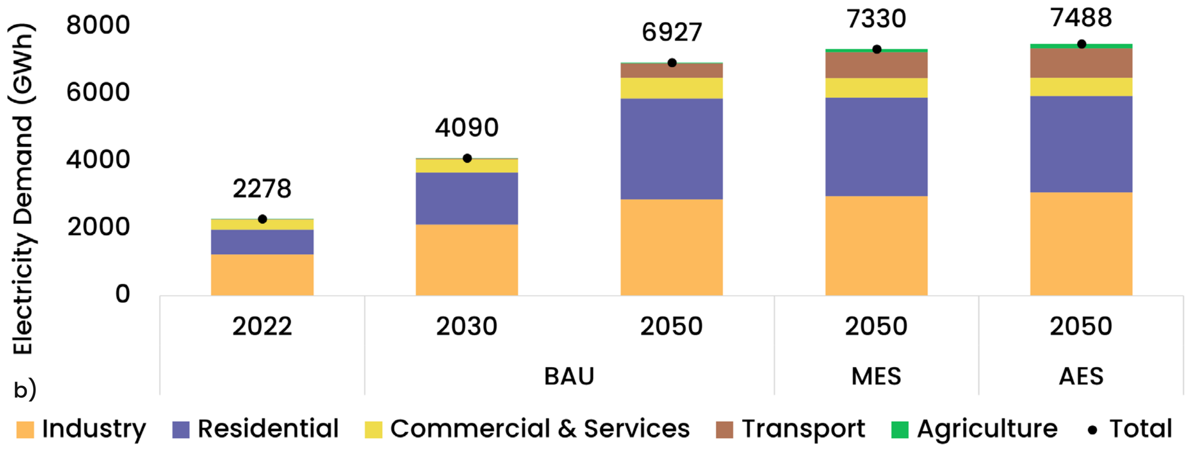


Fig 5.1.5 (b): Electricity demand across the scenarios

(Source: Authors' analysis)

Total Sectoral Energy Use in the District

Total sectoral energy use is the sum of energy consumed across different economic/social sectors (e.g., residential, commercial, industrial, transportation). It breaks down how much energy each part of the economy uses. Figure 5.1.5 (c) illustrates the TPEC disaggregated across these demand sectors.

In the BAU scenario, total sectoral energy use is projected to grow to 48 PJ by 2050 from 29 PJ. The Industrial sector currently holds the largest share of the total energy supply in Virudhunagar, contributing nearly 62 percent of the total energy demand in 2022, primarily due to the use of high-calorific-value fuels like coal, petcoke, and diesel. The second largest energy intensive sector in Virudhunagar is the transport sector. However, the transport sector's share in energy demand is projected to decline from 29 percent to 15 percent by 2050, despite a slight increase in absolute energy consumption.

The building sector, which accounted for approximately 23 percent of energy demand in 2022, primarily for LPG in cooking, appliances and space cooling, is projected to become the second largest energy-intensive sector with a share of 30 percent by 2050. This increase is driven by growing demand for space cooling and cooking energy. The agricultural sector's share of energy demand is less than 2 percent in the BAU scenario by 2050.

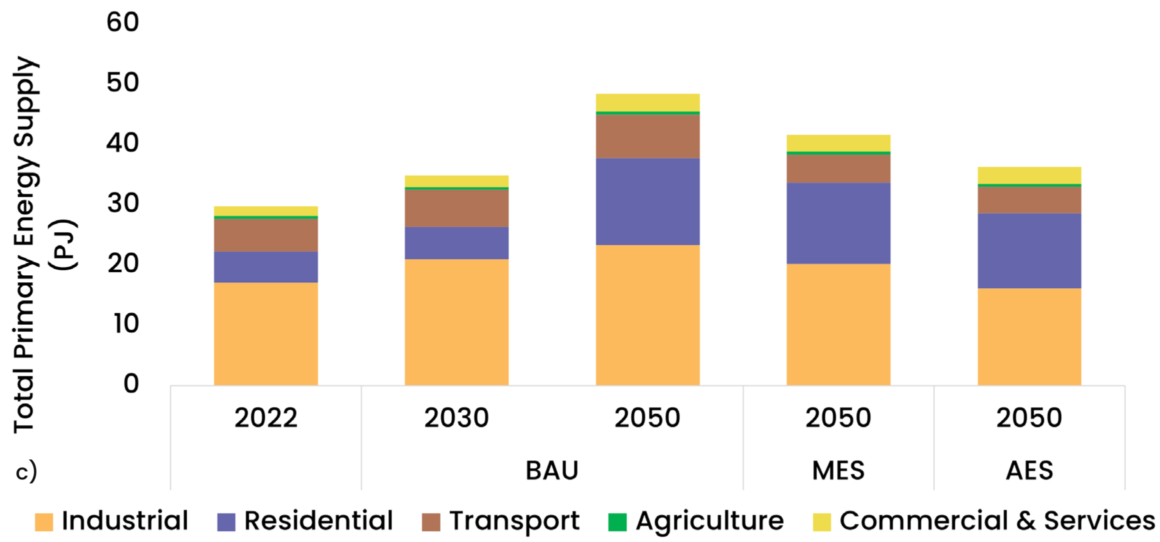


Figure 5.1.5(c): Total primary energy supply across the scenarios

(Source: Authors' analysis)

Emissions from the Energy Sector

Figure 5.1.5 (d) illustrates the projected total GHG emissions from the energy sector up to 2050. GHG emissions from this sector are expected to increase from 1,290 $ktCO_2e$ in 2022 to 1,574 $ktCO_2e$ by 2050.

The transport sector is the largest GHG emitter in 2022, accounting for approximately 37 percent of the total emissions, i.e.471 $ktCO_2e$. However, with the increasing adoption of energy-efficient EVs, its share is projected to decline to 32 percent, with emissions increasing slightly to 483 $ktCO_2e$ by 2050.

The industrial energy sector is the second-largest GHG emitter, contributing about 35 percent of the total emissions in 2022 i.e. 446 $ktCO_2e$. Emissions from this sector are projected to increase marginally to 602 $ktCO_2e$ by 2050.

The building sector (residential and commercial combined) contributed around 16 percent of the total GHG emissions in 2022, i.e. 201 $ktCO_2e$. This share is projected to rise to approximately 22 percent, with emissions increasing to 307 $ktCO_2e$ by 2050.

The captive power plant (CPP) sector also holds a significant share of emissions, at 146 $ktCO_2e$ in 2022, which is projected to increase to 210 $ktCO_2e$ by 2050 due to its reliance on fossil fuels, primarily HSD and coal. The agricultural sector's GHG emissions are 26 $ktCO_2e$ in 2022, accounting for 2 percent of the total. These are projected to rise to 62 $ktCO_2e$, with a share of 4.5 percent, by 2050. Under alternate scenarios, the industrial, agricultural, and CPP sectors are projected to achieve full decarbonisation by 2050.

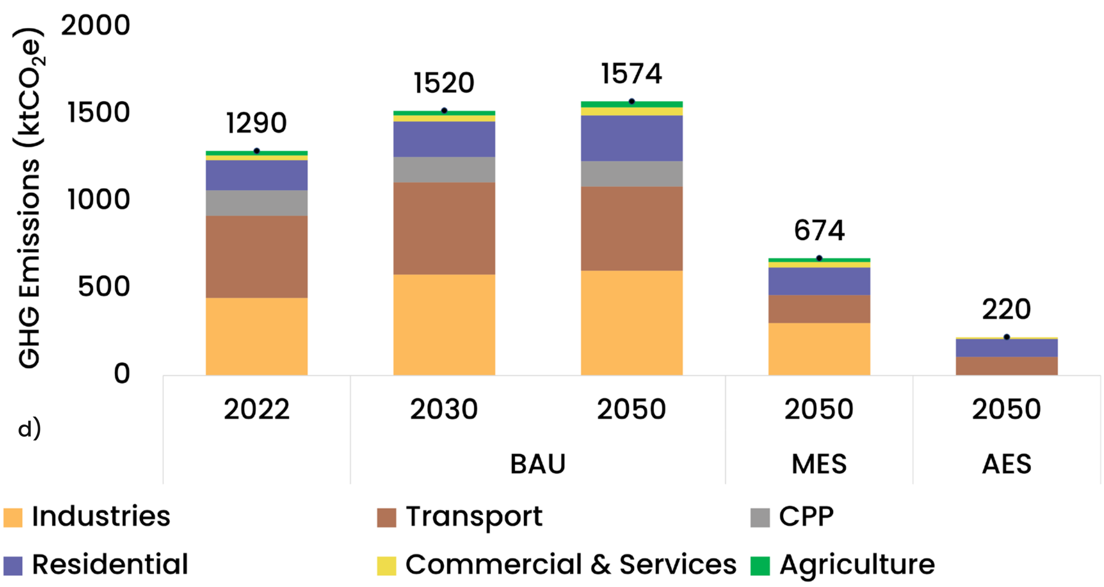


Figure 5.1.5 (d): GHG emissions in the energy sector across the scenarios

(Source: Authors' analysis)

Box Item 8: Renewable energy integration is key to curb Scope 2 emissions by 2050

Emissions reported in previous sections are from fossil fuel combustion to meet energy demand across sectors in Virudhunagar. These GHG emissions from the source qualify as scope 1 emission. Additionally, Over and above the Scope 1 GHG emissions, which have been analysed in the plan, the electricity consumption related GHG emissions (Scope 2 emissions) contribute to almost 736 $ktCO_2e$ in 2022 and could increase to 4,383 $ktCO_2e$ by 2050 in absence of decarbonisation measures. To meet this demand of 7,488 GWh from renewable sources, an additional equivalent capacity of 3 GW (in addition to 0.7 GW solar capacity) is required. Therefore, there is a need for exhaustive and holistic assessment of various solar energy sources such as utility scale PV plants, rooftop solar, floating solar, and agri-photovoltaic solar, bio energy, and wind energy in the district.

5.2 Industrial Processes and Product Use (IPPU) Sector

The IPPU sector contributed 1,023 ktCO_2e of GHG emissions in Virudhunagar in 2022, with the majority of these emissions arising from the cement industry. The cement industry is the most energy-intensive sector within the industrial sector of Virudhunagar. A significant portion of both thermal and electrical energy is consumed in key processes, including crushing, milling, reheating, clinkering, and grinding. Over 75 percent of the energy used in cement manufacturing comes from thermal energy sources, primarily coal and petcoke, which are also a major contributor to CO_2 emissions.[42]

The analysis indicates that coal remains the dominant thermal energy source for the cement industry and is expected to maintain its share of energy consumption through 2050 under the BAU scenario. Virudhunagar district has two large-scale cement manufacturing plants: RAMCO Cements, R.R. Nagar[43] , with an annual capacity of 2 MTPA, and TANCEM Alangulam[44], with an annual capacity of 400 kTPA. Additionally, a grinding unit owned by Dalmia Bharat Green Vision in Uppathur, with a capacity of 2.5 MTPA in Phase I and 5 MTPA in Phase II is expected to be commissioned soon.[45]

Since RAMCO Cements and TANCEM Alangulam are integrated cement plants, they are the primary focus of this analysis. In 2021-22, their annual cement production was 1.67 MT and 0.276 MT, respectively (source: TNPCB). RAMCO Cements' production capacity is projected to expand to 2.7 MTPA after 2030. [46]Additionally, five micro cement manufacturing plants operate in the district, each producing 20–50 tonnes of cement per day.

Key parameters in the cement industry—such as the clinker-to-cement ratio[47], thermal energy consumption per tonne of clinker (GJ/tonne), and coal requirements per tonne of cement production[48] —were used as the basis for analysis.[49] Using cement production data provided by TNPCB, the specific coal consumption was calculated, and CO_2 emissions per tonne of cement production were estimated for the year 2021-22. The plant utilisation factors for 2021-22 were 0.84[50] and 0.69[51], respectively, and it is assumed that the utilisation factor for these plants will reach 0.8 by 2050.

Total CO_2 emissions from cement production are divided into two categories: fuel combustion emissions and process emissions. Fuel combustion, primarily involving coal and pet coke during preheating, co-processing, precalcining, and clinkering, contributes 33–35 percent of total CO_2 emissions. The remaining 65–67 percent of CO_2 emissions are categorised as process emissions, primarily from the chemical decomposition of limestone into lime during calcination, as well as physical transformations in the rotary kiln where pre-calcined meal converts into clinker.

A time series regression analysis was conducted on coal and petcoke consumption data and extrapolated for future years, correlating it with plant utilisation factors and projected cement production levels. By aggregating CO_2 emissions from fuel combustion and process-related emissions, total CO_2 emissions from the cement sector were calculated.

In 2022, Greenhouse Gas (GHG) emissions from the IPPU sectors were 1,023 ktCO_2e, and under a business-as-usual (BAU) scenario, they are projected to increase to 1,383 ktCO_2e by 2050. This increase is driven by Ramco Cement's planned capacity expansion from 2 MTPA to 2.7 MTPA by 2027-28. The cement industry is considered a hard-to-abate sector because process emissions are inherent in the chemistry of traditional Portland cement production. Reducing these emissions requires approaches that either alter the chemistry, capture the CO_2 before it is released, or both.

Additionally, **Carbon Capture and Utilisation (CCU)** is a well-known method capable of capturing approximately 90 percent of process emissions. However, the high energy requirements to operate post-combustion CCU systems in the cement industry, along with significant capital and operational costs, make retrofitting such technologies economically unfeasible at present. The cost of capturing CO_2 from low-concentration flue gases is currently estimated to be in the range of US$ 60-120 per tonne of CO_2.[52] In Virudhunagar alone, capturing 1,383 ktCO_2e would require a capital investment of approximately US$ 83-165 billion.

Globally, there are about 21 CCUS facilities with a combined capacity to capture approximately 40 million tonnes per annum (MTPA) of CO_2—only about 0.1 percent of the 40 gigatonnes per annum (GTPA) of global annual greenhouse gas emissions.[53] With continued technological advancements, the cost of amine-based CCU—currently at a Technology Readiness Level (TRL) of 8–9 and recognised as a mature technology for the cement industry—is expected to decrease, making retrofitting economically viable in the near future.

Implementing CCU will also require an additional 1,106 - 1,660 GWh of energy per year, translating to an additional power capacity requirement of 505–758 MW, ideally supplied by renewable energy sources.

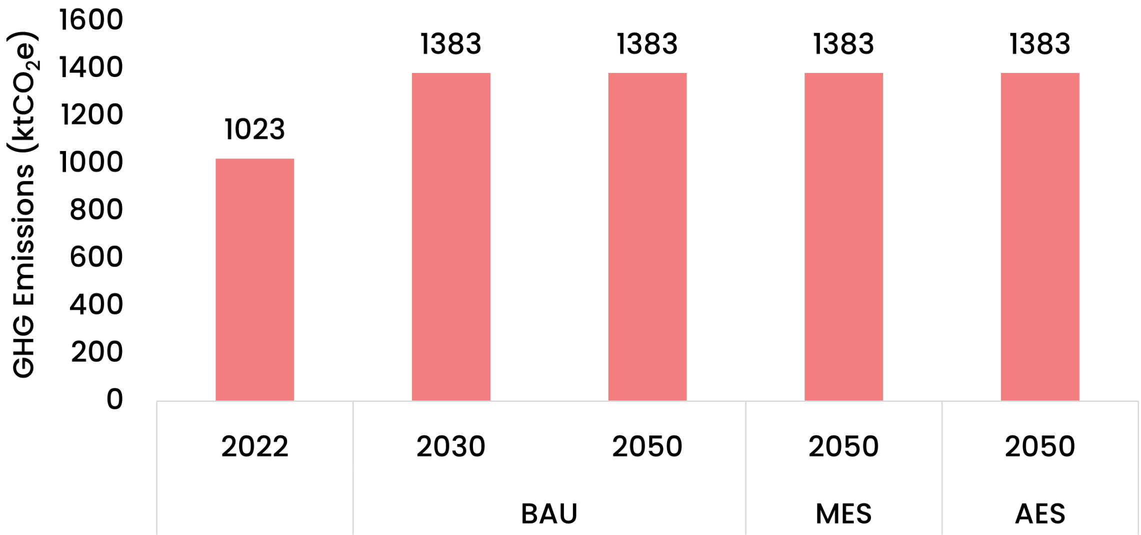


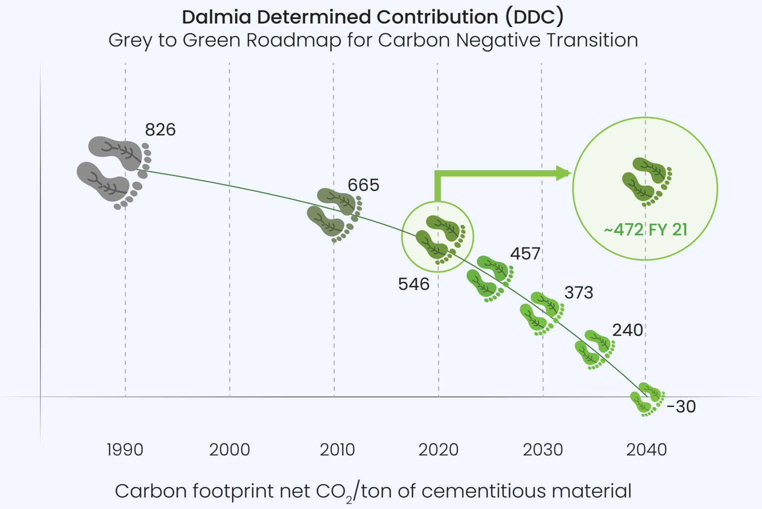
Figure 5.2.1: GHG emissions by IPPU in Virudhunagar

The use of carbon capture technology could abate 90–95 percent percent of these emissions. The AES scenario considers the implementation of carbon capture in cement industries but in the longer term (post-2040).

Box Item 9: Dalmia Cement's Carbon Negative Roadmap 2040

Dalmia Cement stands as a pioneering example of successful decarbonisation in the traditionally hard-to-abate cement sector, transforming it into a possible-to-abate industry. The company has demonstrated that clean and green is profitable and sustainable while expanding from 9 MT capacity (3 plants) in FY '11 to 38.5 MT (17 plants) in FY'23. Their carbon negative roadmap, first committed to in 2018, includes ambitious targets:

- Achieving 100 percent renewable power usage by 2030 under their fossil-free electricity initiative (RE 100).
- Doubling energy productivity by 2030 (EP 100).
- Completely replacing fossil fuels with renewable biomass, hazardous waste, hydrogen, and Municipal Solid Waste by 2035.
- Carbon Capture and Utilisation (CCU) to make value added products; Carbon Sequestration and adoption of other advanced green technologies by 2040.



The company has already reduced its carbon footprint to a net 472 kg CO_2/ton of cementitious material in FY'21 through various innovative measures. These include optimal utilisation of industrial wastes from steel, thermal power, and aluminium industries, becoming India's largest producer of Portland Slag cement, implementing state-of-the-art technologies for energy efficiency, monthly GHG footprint monitoring, accelerating alternative fuel use in cement kilns, and integrating renewable energy sources like solar and waste heat recovery from kiln off-gases. This comprehensive approach demonstrates how systematic decarbonisation strategies can be successfully implemented in the cement industry while maintaining business growth and profitability. [54]

Additional Efforts to Reduce Cement Sector Emissions:

In Virudhunagar, Tamil Nadu, incorporating alternative materials like fly ash and blast furnace slag in cement production can significantly reduce its environmental footprint. By substituting traditional Portland cement clinker, these alternatives lower the required thermal energy and CO_2 emissions. Fly ash, when used to replace 25 percent of Portland cement clinker, can save up to 15 percent in thermal energy, due to lower need for kiln heating. Similarly, blast furnace slag cement (BFS), when replacing 65 percent of the clinker requirement can reduce energy demand by roughly 36 percent per ton[55], given BFS's inherent reactivity and lower energy-intensive processing.

This approach not only reduces energy intensity of cement production, but also imparts resource efficiency and reduces its carbon footprint. Going forward, reuse and recycled raw material for cement production would aid in imparting sustainability within the value chain.

5.3 Projection of Emissions from Non-energy Sectors

5.3.1 Livestock

The GHG emissions from livestock management contributed ~74 percent of the total AFOLU emissions (excluding land). Enteric fermentation and manure management respectively accounted for 93 percent and 7 percent of total livestock emissions. Under BAU, the GHG emissions are projected to increase from 252 ktCO_2e in 2022 to 339 ktCO_2e in 2050 (Figure 5.3.1).

The emissions from the livestock management could be significantly reduced through the implementation of balanced rationing[56] and feed additives[57] to control methanogens[58] and through manure management. By 2050, in MES, emissions are expected to decrease from 339 ktCO_2e under BAU to 280 ktCO_2e and to 245 ktCO_2e in AES . The decadal implementation is as detailed in Annexure 3.

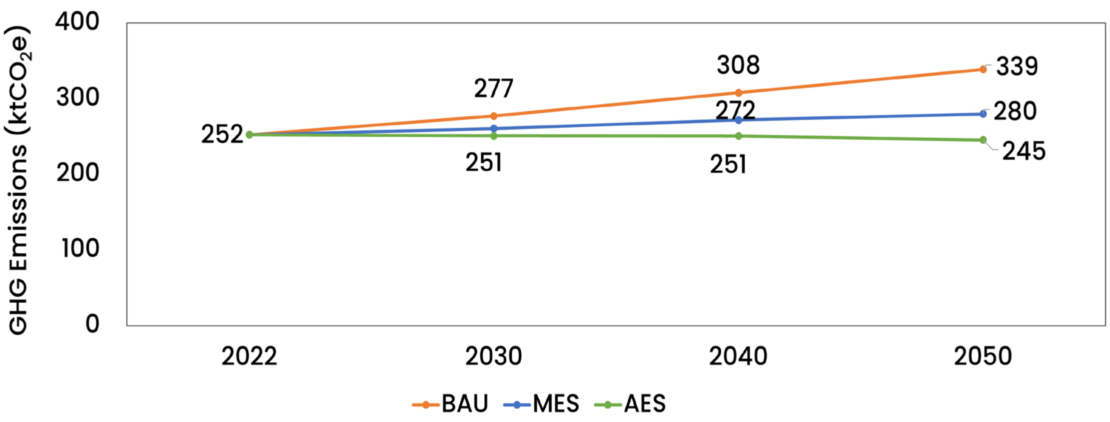


Figure 5.3.1: Projected emissions from livestock under various scenarios

Other Interventions

- Use of improved feed supplements for suppressing methanogens.
- Promote better/efficient manure management practices, like biogas production from cattle manure by endorsing Gobar-Dhan scheme[59].
- Promote non-cattle (sheep, goat, donkey) dairy products.
- Encourage and subsidise large-scale cattle farming with advanced feed and manure management.
- Training and promotion of balanced rationing, such as Ration Balancing Programme- initiative of National Dairy Development Board.
- Promote aerobic management of cattle manure such as composting or direct application to the soil.

Box Item 10: Climate resilient livestock management

Climate resilience of livestock management involves adopting strategies and practices that help livestock and farming systems withstand, adapt to, and recover from the impacts of climate change. Extreme heat and increasing atmospheric CO_2 levels affect livestock by impacting their feed, water availability, growth and reproduction, apart from increasing the susceptibility to vector-borne diseases.

Interventions:

- Select or develop livestock breeds that are naturally more resilient to extreme weather conditions, such as heat-tolerant or drought-resistant breeds. Indigenous breeds often have traits that make them more adapted to local climates.
- Provide shade, ventilation, and cooling systems (such as fans or sprinklers) in animal housing to reduce heat stress. Properly designed shelters can significantly lower the risk of heat-related illnesses and improve animal welfare.
- Implement water conservation practices and efficient water use strategies, such as rainwater harvesting, to ensure a reliable water supply for livestock during droughts.
- Integrate trees into grazing areas (silvopasture) to provide shade, reduce heat stress, and improve forage availability. Trees also contribute to soil and water conservation.
- Enhance disease surveillance and monitoring to detect and respond to emerging health threats, which may become more prevalent due to changing climates, such as vector-borne diseases.
- Adopt better grazing practices in pastures and hygienic environments
- Ensure complete nutrition requirement is met through the feed by implementing balanced rationing related schemes.
- Periodic veterinary camps to prevent spread of diseases
- Consider livestock insurance to mitigate financial losses due to climate-related events such as drought, floods, or disease outbreaks.

Provide support for alternative livelihoods, such as algae culture, fish farming, etc., in case livestock farming becomes unsustainable due to severe climate impacts.

5.3.2 Agriculture Soils

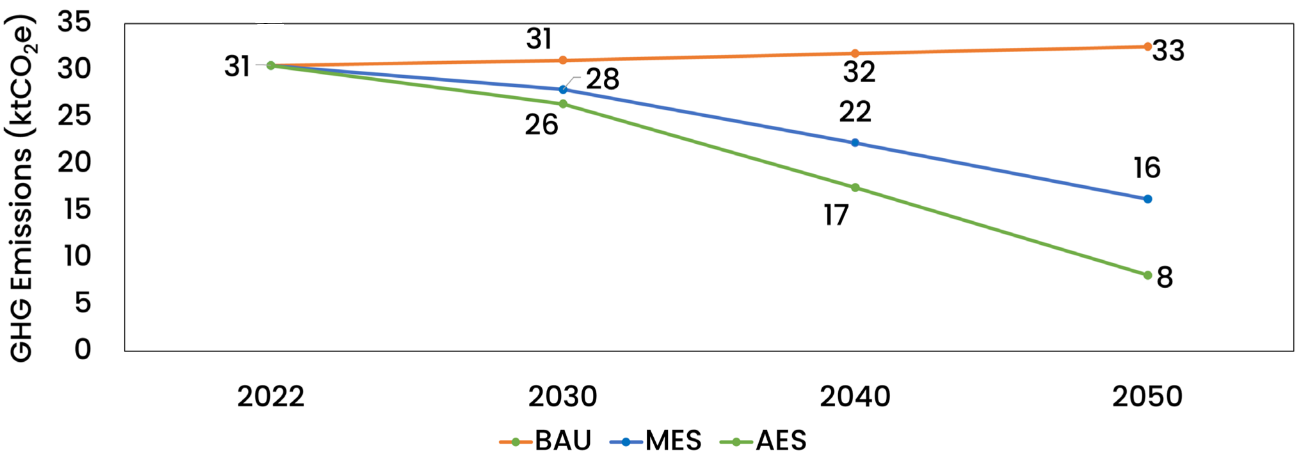


Figure 5.3.2: Projected emissions from agriculture soils under various scenarios

Emissions from the Agriculture Soils category mainly arise due to the use of synthetic nitrogen fertilisers and urea, and are projected to increase from 31 ktCO_2e in 2022 to 33 ktCO_2e in 2050. Nitrogen fertiliser consumption is projected[60] to increase from 10 kt in 2022 to 11 kt in 2050, while Urea consumption is projected[61] to decrease from 11 kt in 2022 to 9 kt in 2050.

Substitution of organic fertilisers and nano urea can potentially reduce the GHG emissions arising from the use of synthetic fertilisers. Nano fertiliser[62] has the potential to regulate the release of nitrogen (N) for an extended period (20 days) in comparison to the conventional urea fertiliser (9 days). The slow and steady release of nitrogen assists in the reduction of nitrous oxide emission by 50 percent in nano-fertiliser fertilised soils.[63]

Adoption of organic farming practices can not only decrease GHG emissions but can increase yield over the long-term. Shift to organic farming can contribute significantly towards the improvement of soil health by increasing soil nutrient mineralisation, microorganism abundance, diversity as well as soil physical properties. Farmer support including strengthened extension services with easy access to inputs, together with the development of robust markets for organic produce, certification and branding is recommended, to incentivise farmers to take up organic farming.[64]

In MES, an emission reduction of 50 percent from 33 ktCO_2e in BAU to 16 ktCO_2e by 2050 is estimated by replacing 50 percent of total nitrogen and urea by organic fertiliser and nano urea to meet the remaining urea requirement .

In AES, an emission reduction of 75 percent from 33 ktCO_2e in BAU to 8 ktCO_2e by 2050 is estimated by replacing 75 percent of total nitrogen and urea by organic fertiliser and nano urea to meet the remaining urea requirement. See Annexure 3 for the details on organic fertiliser and nano urea substitution .

Decarbonisation strategies for agricultural soils include precision nitrogen management, use of organic fertilisers, cover cropping, and conservation tillage to reduce emissions and enhance soil carbon. Promoting bio-pesticides and 'Zero Budget Natural Farming' practices further supports low-emission farming. Additionally, encouraging the use of decision support tools can improve nutrient and input efficiency.

25 ktCO_2e of Decarbonisation Potential by 2050

Stakeholders: Individual Farmers/Farmer Producer Organisation (FPO), Agriculture department, Horticulture Department, Environment and Climate Change Department

5.3.3 Rice Cultivation

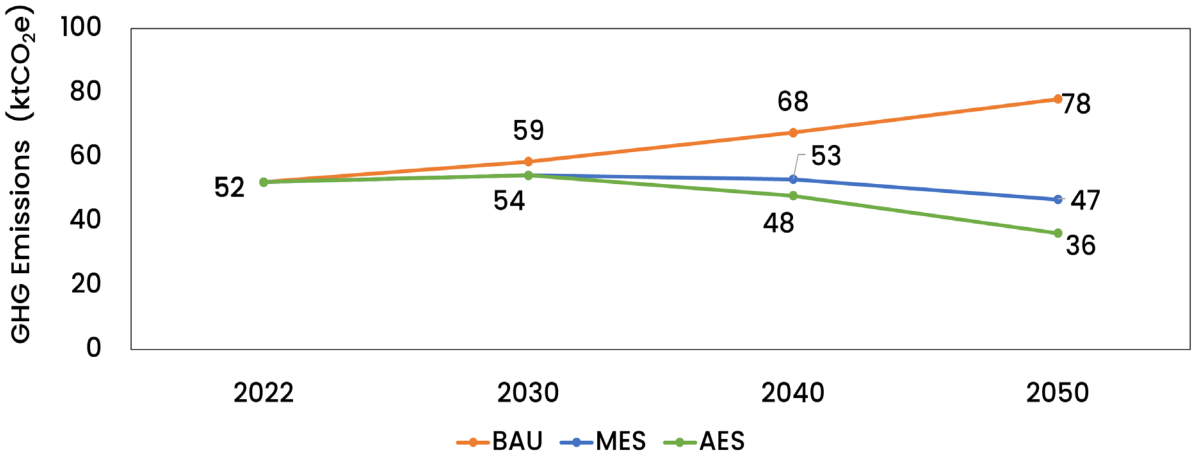


Figure 5.3.3: Projected emissions from rice cultivation under various scenarios

Paddy cultivation is one of the significant sources of methane emissions in the agriculture sector. Methane emissions arise due to anaerobic decomposition of organic materials in flooded paddy fields. The rice cultivation water regimes followed in Virudhunagar district is assumed to be the same as that for Tamil Nadu which is continuous flooding (30%), single aeration (43%), Multiple aeration (20%), upland (1%), rainfed drought prone (3%), rainfed flood prone (1%) and deep water (1%).

Emissions from rice cultivation are projected[65] to increase by 1.5 times from 52 ktCO_2e in 2022 to 78 ktCO_2e in 2050 in the BAU scenario. These could be reduced by promoting multiple aeration water regime over the more prevalent single aeration and continuous flooding. The methane emission factor for multiple aeration (18 kg CH_4/ha) is 9 times lower than that of continuous flooding (162 kg CH_4/ha) and 4 times lower than single aeration (66 kg CH_4/ha).

Aeration results in reduced methane emissions by:

- Reducing the activity of the methane emitting microorganisms in the top soil as well.
- Promoting the growth of methane metabolising micro-organism.

The details of the water regime recommended under MES and AES are as described in Annexure 3.

In MES, where multiple aeration is recommended in 60 percent of the cultivated area by 2050, emissions are projected to decrease from 78 ktCO_2e to 47 ktCO_2e. In AES, with 77 percent of the rice cultivation following multiple aeration water regime, by 2050, emissions are projected to decrease from 78 ktCO_2e to 36 ktCO_2e (Figure 5.3.3).

In addition, it is also recommended to:

Practice System of Rice Intensification (SRI) which presents an efficient approach to address methane emissions through a nature-centric method. It promotes aerobic soil conditions by employing Alternate Wetting and Drying (AWD). This technique permits the soil to come into contact with oxygen, effectively neutralising methanogens. Additionally, SRI has demonstrated the ability to increase aerobic bacteria, specifically methanotrophs, which actively consume methane. Moreover, the technique has the potential to enhance rice yield by 36-49 percent with about 22-35 percent less water than conventional transplanted rice.[66]

Direct Seeded Rice, which also serves as an effective strategy for mitigating methane emissions in rice cultivation. This method minimises methane release by eliminating the need for raising nurseries, puddling, and transplanting. In contrast to traditional transplanted paddy cultivation, the system doesn't maintain standing water.[67]

42 ktCO_2e of Decarbonisation Potential by 2050

Stakeholders: Individual Farmers / Farmer Producer Organisation (FPO) , Agriculture department, Environment and Climate Change department

Box Item 11: Harnessing Virudhunagar's waste-to energy potential can save 160 GWh of electricity demand, abating 136 ktCO_2e GHG emissions by 2050

Virudhunagar, with its large livestock population, holds significant potential for biogas production, to an estimated 30,000 m³/day of biogas (from a potential of 60,000 m³/day at 50% efficiency). This can contribute to clean energy, including compressed biogas (CBG), and mitigate 32 ktCO_2e of greenhouse gas emissions annually.

As an agricultural area, the district also produces substantial crop residues (an estimated 3,44,109 tonnes per year) from crops like paddy, maize, and cotton. These residues can be converted into electricity through biomass power plants, with the potential to generate 34–50 MW of electricity, yielding 90–130 GWh of energy per year and offsetting 63–90 ktCO_2e of greenhouse gas emissions. Furthermore, Virudhunagar's municipal waste offers another avenue for power generation; in 2022, the district processed about 90 tons of biodegradable waste daily, which could power a 3 MW plant, generating roughly 13 GWh of energy annually and reducing emissions by approximately 14 ktCO_2e.

Collectively, the utilisation of these waste streams present a robust pathway for Virudhunagar to enhance clean energy generation, improve waste management, and significantly reduce its carbon footprint.

Box Item 12: Promoting Sustainable Agriculture in Virudhunagar District

Virudhunagar's semi-arid agro-climatic conditions and declining groundwater levels are impacting traditional farming practices. The district's key crops include rainfed pulses, cotton, millets, oilseeds, and paddy in irrigated pockets like Aruppukottai, Kariapatti, and Tiruchuli. With rising climate risks, sustainable and climate-resilient farming methods are essential for livelihood security, soil health, and greenhouse gas (GHG) mitigation—especially methane emissions from paddy fields.

Priority Interventions

Reducing Methane Emissions in Paddy Cultivation

- Promote Alternate Wetting and Drying (AWD) irrigation in paddy-growing villages in Aruppukottai and Narikudi to reduce standing water time and methane generation.
- Introduce System of Rice Intensification (SRI) method to reduce water use, improve yield, and lower methane emissions.
- Encourage Direct-seeded Rice (DSR) as an alternative to traditional transplanting where feasible.
- Promote use of organic amendments (e.g., biochar, compost) instead of urea to reduce methane formation.
- Train farmers under Krishi Vigyan Kendra (KVK) programs on methane-reducing field practices.

Crop Diversification & Climate-Resilient Varieties

- Encourage shift from water-intensive paddy to drought-tolerant pulses and millets (e.g., Kodo millet, pearl millet) in moderately irrigated zones.
- Promote climate-resilient crop varieties developed by Tamil Nadu Agricultural University (TNAU) suited for the district's dry conditions.

Soil Health & Organic Farming

- Implement the Soil Health Card Scheme for tailored nutrient management.
- Promote vermicomposting, bio-fertilisers, and green manuring with support from the Tamil Nadu Organic Certification Department (TNOCD).
- Reduce dependency on synthetic nitrogen fertilisers to limit indirect N_2O emissions.

Agroforestry & Trees Outside Forests (TOF)

- Promote integration of native species like *Pongamia pinnata, Azadirachta indica* (Neem), and *Tamarindus indica* in farmlands.
- Encourage field bund plantations and live fences under MGNREGA and National Agroforestry Policy to enhance carbon sequestration and income.

Farmer Institutions & Market Access

- Strengthen Farmer Producer Organisations (FPOs) for input procurement, aggregation, and access to Electronic National Agricultural Market (e-NAM).
- Establish rural collection centres and support marketing of low-carbon produce (e.g., organic cotton, millets).

Climate Risk Management & Insurance

- Enrol farmers in Pradhan Mantri Fasal Bima Yojana (PMFBY) for climate risk insurance.
- Collaborate with India Meteorological Department (IMD) and KVK Aruppukottai for tailored weather advisories.

Women and Youth in Resilient Farming

- Engage Self-Help Groups (SHGs) in seed banks, nursery development, and organic input production.
- Promote skill-building and climate-smart entrepreneurship among rural youth through National Rural Livelihoods Mission (NRLM).

5.3.4 Waste Sector

The Waste sector contributed 5 percent to the economy-wide emissions of the Virudhunagar district in 2022. Within the Waste sector, the largest contributor is the domestic wastewater category (~72%), followed by Solid Waste Disposal (~20%) Industrial Wastewater (~8%) and Under BAU, the emissions from the Waste sector are projected to increase from 138.17 in 2022 to 124.20 ktCO_2e for 2050. Reportedly, Virudhunagar has almost 100 percent door to door collection and 94.25 percent waste segregation at source.

Domestic Wastewater Treatment

The characteristics of domestic wastewater and the associated GHG emissions vary depending on factors such as economic status, community food intake, water supply status, treatment systems and climatic conditions of the area. The GHG emissions from the wastewater management are estimated to increase from 100.1 ktCO_2e in 2022 to 111.8 ktCO_2e in 2050 under BAU , resulting from ~280 million litres per day (MLD) wastewater (at a BOD of 350 mg/L[68]) based on the projected population. As of May 2025, the centralised treatment capacity of Virudhunagar district is 34.15 MLD (21.85 MLD in Rajapalayam and 7.65 MLD in Virudhunagar) and 4.65 MLD in Sattur [69], with a utilisation of 14.9 MLD (9.6 MLD in Rajapalayam and 3.8 in Virudhunagar) and 1.5 MLD in Sattur. Additionally two FSTPs of 0.04 and 0.03MLD is also operational. Further, STP of capacity 13.25 MLD in Arupukottai and FSTP of 0.04 MLD is under construction in Sivakasi.[70] In addition to this, a treatment capacity of ~171 MLD (~20 percent excess) is recommended for urban and 125 MLD for rural areas for effective wastewater management and recycling by 2050. For urban areas, centralised sewage treatment[71] such as the activated sludge process[72] is suggested, while onsite treatment[73] such as septic tanks along with FSTPs[74] Gram Panchayat cluster level is recommended for rural areas in Virudhunagar. Additionally, advanced decentralised wastewater treatment (DEWAT) is recommended for spaces >2500 m2 and other isolated facilities such as resorts, restaurants, etc.

MES aims at treating 100 percent of wastewater by 2050, thereby reducing the projected GHG emissions from 111.8 ktCO_2e under BAU to 21 ktCO_2e and an ambitious target of 100 percent treatment by 2040 is set for AES. The decadal plan is detailed in the Annexure 3. The recommended wastewater treatment plan contributes to several state and national programs towards improving public health and especially to the targets set by honourable NGT in OA-673[75]. Treated wastewater could be promoted for use in irrigation, industrial use, cooling etc.

91 ktCO_2e of Decarbonisation Potential by 2050

Stakeholders: Commissionerate of Municipal Administration, Tamil Nadu Water Supply and Drainage Board, Tamil Nadu Pollution Control Board, Rural Development and Panchayat Raj Department

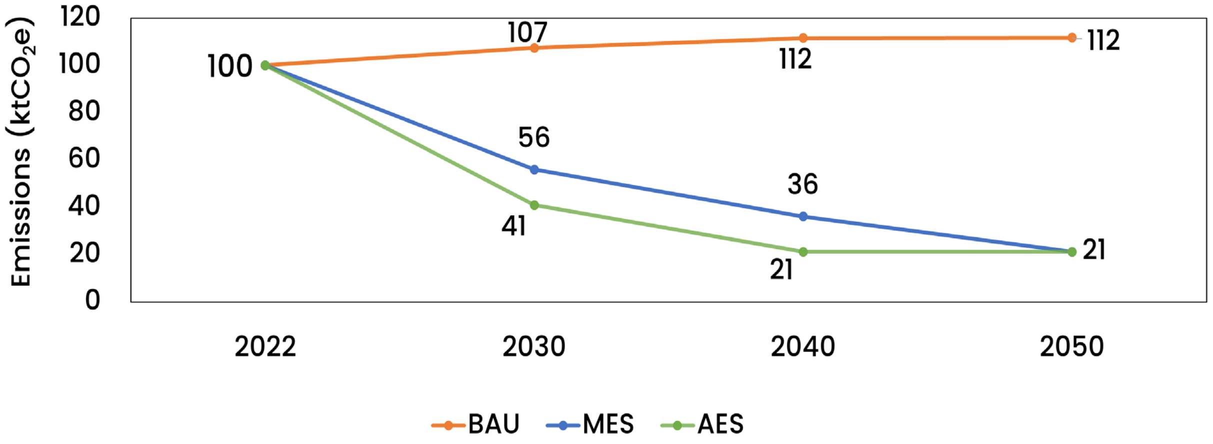


Figure 5.3.4. (a): Projected emissions from domestic wastewater under various scenarios

Industrial Wastewater Treatment

In 2022, industrial wastewater emissions from meat processing, fish processing, paper and pulp and dairy production in Virudhunagar district accounted for 11 $ktCO_2e$. The MES scenario targets a 60 percent wastewater treatment rate by 2050, which will reduce GHG emissions from 11 $ktCO_2e$ to 4 $ktCO_2e$. While AES scenario aims for an 80 percent treatment rate by 2050, further lowering emissions to 2 $ktCO_2e$. Based on the production data, meat, pulp and paper, dairy, fish processing produced 1.01, 0.33, 0.30, 0.01 MLD respectively in 2022.

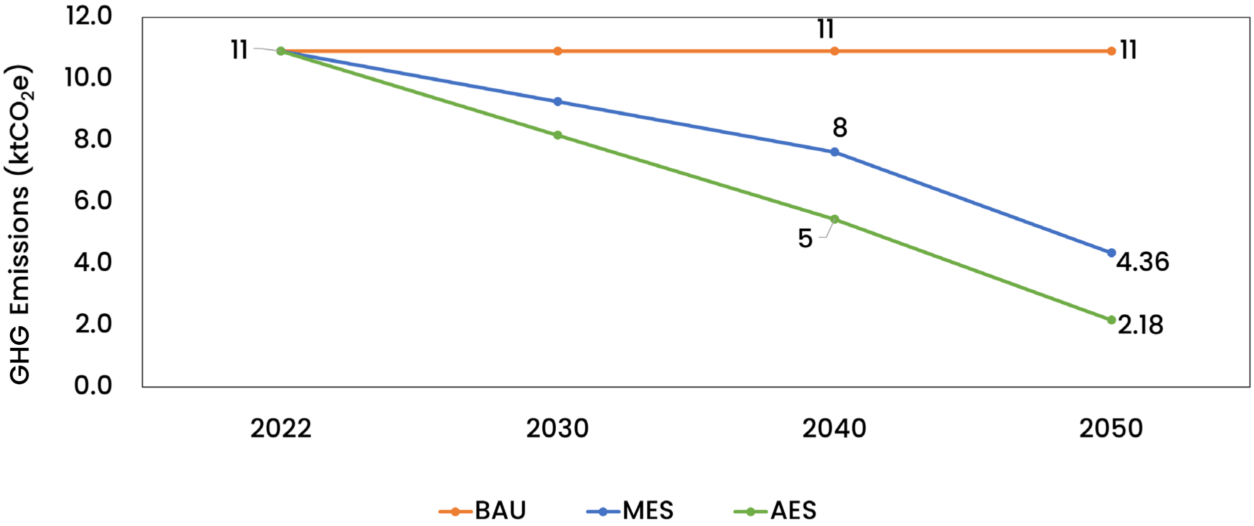


Figure 5.3.4(b): Projected emissions from industrial wastewater under various scenarios

9 $ktCO_2e$ of Decarbonisation Potential by 2050

Stakeholders: Environment and Climate Change Department, Tamil Nadu Pollution Control Board

Box Item 13: Domestic Wastewater Management

Virudhunagar district is home to different types of industries like cement, matches and fireworks apart from a large number of spinning mills and paper mills. The district population is almost equally divided in its urban and rural areas which stresses the importance of waste management in rural areas along with cities and towns.

Interventions for Domestic Wastewater Management:

- Set up adequate Decentralised Wastewater Treatment facilities (DEWAT) at remote housing entities (resorts/camping grounds/homestays).
- Increase household connections to Underground Drainage (UGD) in urban areas and promote septic tank based wastewater treatment for remote houses.
- Ensure Faecal Sludge Treatment Plant (FSTP) facility at GP cluster level.
- Ensure that untreated wastewater is not discharged into rivers/lakes and other water bodies.
- Periodic scouting of the water body periphery to check the discharge of untreated wastewater and penalising the violators.
- Ensure Underground Drainage (UGD) connection within the township to respective STP to avoid ground and surface water body contamination.
- Zero discharge policy[76] for commercial and residential entities in the township boundary.
- Promote non-potable usage of treated wastewater (gardening, parks, golf courses, car wash).
- Regular water quality testing and monitoring to ensure the treatment standards.
- Regulations for the use of treated water discharged from the STPs.

Box Item 14: Industrial Wastewater Management

Virudhunagar district is home to different types of industries like cement, matches and fireworks apart from a large number of spinning mills and paper mills. The pulp and paper industries alone generated around 330 KLD of industrial wastewater in the year 2023. Additionally, around 36 percent of the registered fireworks units lack waste identification systems. This creates challenges in collection, segregation and management of municipal solid waste and industrial hazardous waste.

Interventions for Industrial Waste Water Management:

- Adopt Zero Liquid Discharge process by the industries.
- Increase the Effluent Treatment Plants with higher capacities and also sludge waste treatment.[77]
- Encouraging installation of Online Continuous Emission / Effluent Monitoring System (OCEMS) in the industries.
- Dedicated RE powered recycling unit for water in each factory.
- Alternate technologies consuming less water can be explored for the paper mills.

Meat Processing Industry:

- Mandating pre-treatment of wastewater from meat / poultry processing plant.
- Sludge management and disposal.
- Installation of monitoring/instrumentation mechanisms to ensure the reduction of BOD, COD, Total Suspended Solids (TSS) and Fats, Oils and Grease (FOG) to permissible levels before sewer discharge.
- Electrification of process heat using induction, radiative heating or heat pumps.

Dairy Industry:

- Limit the milk and milk product losses during loading / unloading from tankers.
- Electrification of process heat.
- Avoid leakage inside the plant during processing.
- Adopt treatment techniques for controlling dissolved impurities, odour and suspended particles before discharge.
- Onsite treatment to reduce FOG to avoid issues in sedimentation tanks.
- Adopt proper sludge disposal techniques for biological treatment plants.

Box Item 15: Integrated Water Resource Management in Virudhunagar District

Virudhunagar district lies in the semi-arid zone of Tamil Nadu, where annual rainfall is both low (700–800 mm) and highly variable. The district is heavily dependent on groundwater for both drinking and agriculture, but declining water tables, inefficient irrigation, and climate-induced stress threaten long-term water and food security. Agricultural regions like Tiruchuli, Narikkudi, Kariapatti, and Aruppukottai blocks are especially vulnerable to hydrological drought due to poor surface water availability and over extraction of aquifers. Integrated water and agricultural planning is essential for resilience.

Water-Smart Agriculture and Irrigation Efficiency

- Scale-up micro-irrigation systems (drip and sprinkler) for crops like cotton, millets, and groundnut, especially in the PMKSY–Per Drop More Crop priority blocks like Narikkudi and Tiruchuli.
- Conduct water budgeting at village level under Atal Bhujal Yojana pilot activities, involving Farmer Producer Organisations (FPOs) and Water User Associations (WUAs).
- Rehabilitate and interlink ayacut tanks and traditional irrigation canals in blocks like Sattur, Srivilliputhur, and Rajapalayam, to reduce groundwater overdependence.
- Promote agroforestry and farm pond models that increase water retention, biodiversity, and soil health.

Reviving Traditional Water Systems and Watersheds

- Rejuvenate ancient water bodies like Anaikuttam Tank, Ayyanar Koil tank, and Periyakulam by desilting, bund restoration, inlet-outlet maintenance, and vegetative fencing.
- Scale up watershed development in undulating and drought-prone villages under Jal Shakti Abhiyan and MGNREGS, integrating trenching, bunding, and reforestation.

- Restore and protect ooranis (village ponds) and temple tanks especially in semi-arid hamlets for dual use drinking water and cattle use.
- Establish check dams and recharge wells in dry streams (e.g., tributaries of Arjuna and Vaippar rivers) for enhancing shallow aquifer recharge.

Efficient Urban and Industrial Water Management

- Enforce Zero Liquid Discharge (ZLD) in fireworks and dyeing industries in Sivakasi and Rajapalayam to avoid groundwater contamination.
- Promote greywater recycle and reuse and decentralised wastewater treatment systems in urban households, schools, and institutions.
- Encourage dual plumbing and water-efficient fixtures in housing colonies and government buildings under ECSBC (Energy Conservation and Sustainable Building Code).

Safe Drinking Water and Public Health Measures

- Ensure regular water quality testing (especially for nitrates and fluorides) in rural drinking water sources through Village Water and Sanitation Committees (VWSCs) under Jal Jeevan Mission.
- Install RO plants or water kiosks in fluoride-affected habitations in Watrap, Sattur, and Kariapatti blocks.
- Promote safe sanitation and greywater recycling in all Gram Panchayats (GPs) through WaSH (Water, Sanitation and Hygiene) campaigns.

Data, Governance and Community Engagement

- Develop a district water security plan integrating rural and urban demands, surface and groundwater potential, and climate vulnerability.
- Map all minor irrigation structures using GIS and MIS platforms under State WRIS (Water Resources Information System).
- Empower women and youth via Water User Committees (WUCs), FPOs, and Eco Clubs to take stewardship of local water bodies.
- Use mobile-based citizen science platforms for reporting tank water levels, rainfall, and water quality.

Nature-Based Blue-Green Infrastructure

- Develop blue-green corridors in Virudhunagar and Sivakasi municipalities, including constructed wetlands, bioswales, and rain gardens to reduce runoff and recharge aquifers.
- Integrate urban sponge infrastructure (e.g., infiltration trenches, green rooftops) in AMRUT 2.0 projects to reduce urban water stress and flooding.

Solid Waste

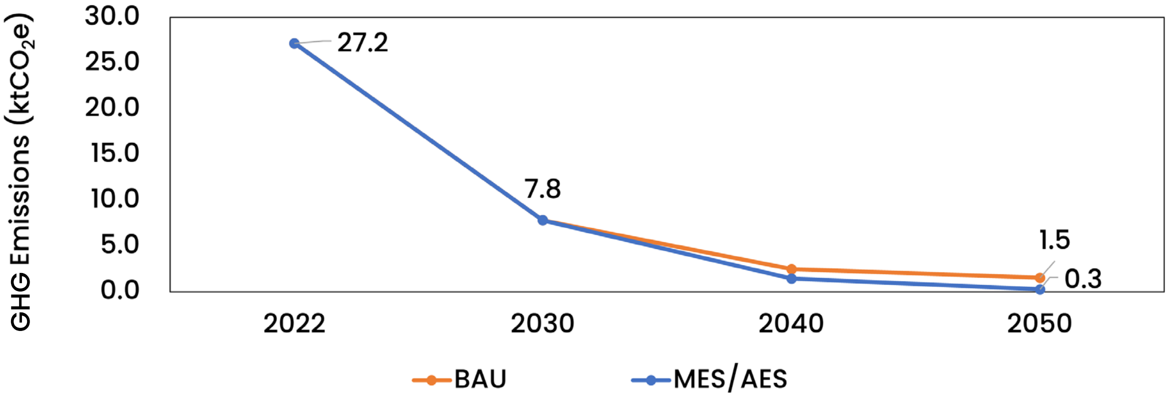


Figure 5.3.4 (c): Projected emissions from solid waste under various scenarios

1.2 $ktCO_2e$ of Decarbonisation Potential by 2050

Stakeholders: Commissionerate of Municipal Administration, Tamil Nadu Pollution Control Board, Rural Development and Panchayat Raj Department

The GHG emissions from solid waste are projected to decrease from ~27 $ktCO_2e$ to ~1.5 $ktCO_2e$ between 2022 and 2050 in the BAU scenario since the Virudhunagar district currently has 100 percent of door to door collection and 94.25 percent of source segregation of municipal solid waste.[78] With Virudhunagar district segregating and managing 100 percent of the municipal solid waste, promoting compositing, recycling, reuse and recovery, and zero landfilling of organic waste by 2030 in MES/AES, GHG emissions from solid waste could be reduced from 1.5 $ktCO_2e$ to just 0.3 $ktCO_2e$ by 2050.

The solid waste management could be further strengthened as detailed in the box item below

Box Item 16: Solid Waste Management

Virudhunagar district is home to different types of industries like cement, matches and fireworks apart from a large number of spinning mills and paper mills. The district population is almost equally divided in its urban and rural areas which stresses the importance of waste management in rural areas along with cities and towns. The urban areas generate close to 160 TPD of solid waste. Additionally, around 36 percent of the registered fireworks units lack waste identification systems. This creates challenges in collection and management of municipal solid waste.

Interventions for Solid Waste Management:

- Encourage 100 percent segregation and collection of waste at source at both rural and urban areas.
- Ensure adequate placement and management of waste collection bins, segregation centres.
- Install community waste bins with sensors to monitor volume and optimise routes of waste collection vehicles.
- Encourage and promote decentralised, community based composting, vermi-composting and biogas plants at residential and commercial entities (hotels/resorts/homestays).

- Set up and incentivise dry waste collecting centres at village/panchayat level.
- Incentivise the informal sector and build public-private partnerships for segregation, collection and disposal of waste.
- Develop waste management knowledge banks, theme centres, and audio/visual promotions.
- Promote resource utilisation and entrepreneurship focusing on waste reuse, recycle and recovery.
- Facilitate and conduct behaviour change communications workshops on appropriate disposal of solid waste
- Facilitate infrastructure creation for waste to energy plants.
- Promote Biomining of legacy waste at the administrative level.
- Facilitate cleaning of dumpsites and encourage development of eco parks.
- Promote zero waste, zero carbon footprint, organic thematic centres (restaurants/ home stays).

Special events (fares, celebrations):

- Develop a special waste management plan for large religious festivals or events that attract massive crowds.
- Set up additional waste disposal and management facilities during peak times.
- Waste management outsourcing or through PPP mode.
- Ensure strict regulation, surveillance and penalty for violators.
- Set up onsite composting units for biodegradable waste like flowers, leaves, and food waste. Install biogas plants to convert organic waste into energy.
- Ensure waste management plan before event permission sanction.

5.3.5 Enhancing Carbon Sequestration Potential in Virudhunagar

The total GHG emissions of Virudhunagar were 2,620 $ktCO_2e$ in 2022. The sector of 'Land Use, Land Use Change and Forestry' (LULUCF) removed 170.8 $ktCO_2e$. For effective decarbonisation of the district, along with the measures to reduce the GHG emissions, efforts to enhance the carbon sequestration are very pertinent.

If the existing forest cover of 352.94 square kilometeres and the current carbon stock density of 82.25 t/ha are preserved without any deforestation, forest fires, or land degradation, the removals are projected at 170.70 $ktCO_2e$ by the year 2050 under a BAU scenario. This projection assumes that no significant changes occur in land use practices or forest management. To offset the GHG emissions of the district, strategies for enhancing land based sequestration are suggested.

Land Use Carbon Sequestration: Virudhunagar has a forest cover of 8 percent (significantly lower than Tamil Nadu's average forest cover of 20.62 percent) and the area under the forest cover has increased from 306.50 sq.km in 2005 to 352.94 sq. km in 2021. However, the carbon stock density of Virudhunagar forests (i.e; Tamil Nadu's Carbon Stock Density) has decreased from 87.26 tonnes/hectare in 2015 to 82.25. tonnes/hectare in 2021[79]. In addition to this, 2,58,044 hectares of land is barren or fallow or cultivable waste land or land put to non- agricultural uses accounting to 61 percent of the total geographical area (Annexure 4).

Interventions for enhancing sequestration potential of land and blue carbon:

The projected carbon sequestration of Virudhunagar (170.8 ktCO_2e) could be enhanced to 995 ktCO_2e/year under MES and 1428 ktCO_2e/year under AES through following interventions:

1. Promoting social and agroforestry in land classified as barren or fallow, land put to non-agricultural uses or cultivable waste land

Out of the total geographical area, 2,58,044 hectares of land is either barren, fallow, cultivable waste, or used for non-agricultural purposes, making up 61 percent of the total geographical area. These land areas are well-suited for agroforestry practices[80]. To implement these agroforestry practices and increase carbon sequestration, two scenarios are suggested in phases across 2030, 2040, and 2050.

- MES considers the conversion of 30% to 40% of the total fallow land area (2,58,044 hectares) with a median of ~92166 ha, into agro and social forests and is projected to sequester approximately 811 ktCO_2e by the year 2050.
- AES, on the other hand, expands this vision by considering 50% to 60% of the same land area, with a median of 140653 ha, and is anticipated to achieve a carbon sequestration potential of around 1238 ktCO_2e within the same time frame.

For developing the agro/social forestry in 2026 activities focusing on laying the groundwork — identifying suitable native species, preparing nurseries, stakeholder coordination, approvals and securing planting sites are proposed. From 2027, plantations could be rolled out progressively across the district, integrating fallow and under-utilised land, with institutional mechanisms, irrigation facilities and building capacity. The programme could include protective measures such as fencing, maintenance systems, survival monitoring along with value chain development and impact assessment. Carbon sequestration is expected to gradually increase from 2028 as trees mature, with benefits compounding over time.

Categories of land under non-agriculture uses, barren and uncultivable land, fallow lands other than current fallow and current fallow that are suitable for agro/social forestry and horticulture interventions have been identified based on expert inputs, historic trend and literature review. In addition to this, the possible site for plantations, reforestation, and enhancing green cover have also been mapped through spatial analysis and is as represented in the map below. These areas represent high potential for enhancing carbon sequestration, restoring ecological function, and supporting sustainable land use practices.

However, it is important to note that these mapped areas are indicative in nature and serve as a preliminary planning tool. Prior to implementation, detailed on-ground verification and ecological assessments are essential to validate site suitability. Such field surveys should evaluate soil characteristics, existing vegetation, slope stability, land tenure, and proximity to water sources, among other factors, thereby ensuring that plantation activities are context-sensitive, ecologically appropriate, and aligned with long-term sustainability goals.

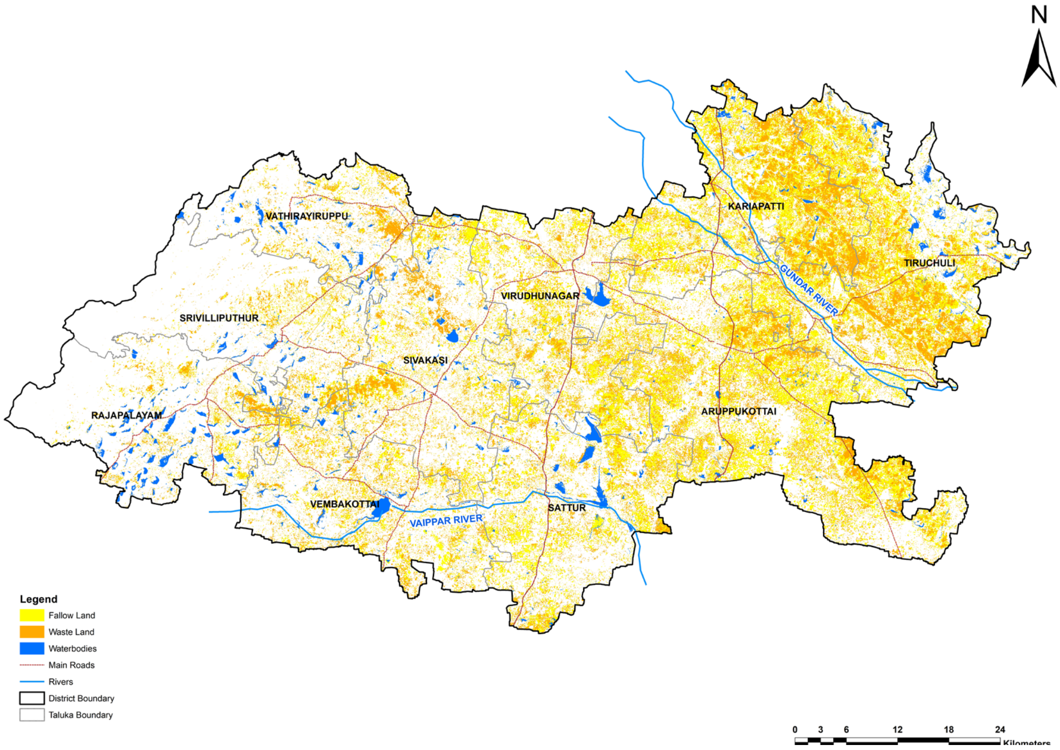


Figure 5.3.5: Fallow and wasteland areas suitable for agro/social forestry intervention

2. Enhancing Carbon Stock Density

- In 2021, the carbon stock density of the Virudhunagar forest was measured at 82.25 tons per hectare (t/ha), compared to 87.26 t/ha in 2015. To reach carbon stock densities near the 2015 level by 2050, two scenarios have been proposed: MES aims for a 3 percent increase from 82.25 t/ha to 84.76 t/ha, while AES targets a 5.5 percent increase from 82.25 t/ha to 86.76 t/ha. Achieving these targets could potentially sequester 12.97 $ktCO_2e$ in MES and 19.45 $ktCO_2e$ in AES (detailed in box item below).

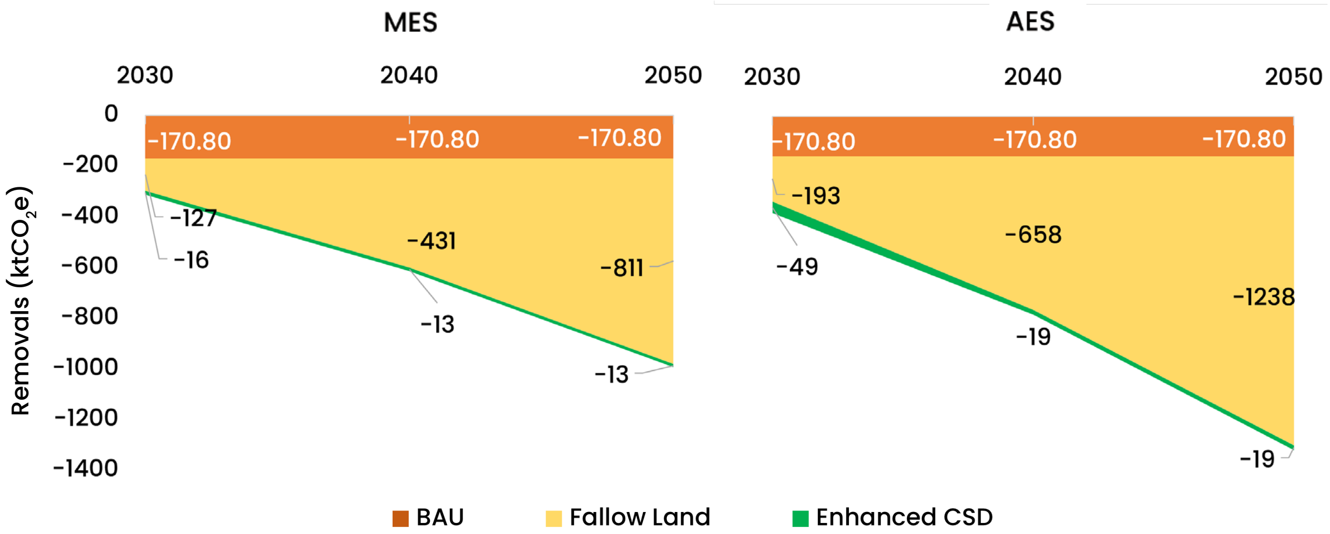


Figure 5.3.6: Enhancing carbon sequestration potential under various scenarios

1428 $ktCO_2e$ of Decarbonisation Potential by 2050

Stakeholders: Environment and Climate Change Department, Forest Department, Commissionerate of Municipal Administration, Horticulture Department

Box Item 17: Social Forestry

Social forestry in fallow and waste lands is a community-centred approach to managing forests that integrates social, economic, and environmental objectives. Active participation of local communities in the planning, implementation, and management of forest resources is essential. Along with the social benefits such as food security, community empowerment, cultural preservation, health and nutrition benefits, social forestry could effectively contribute towards enhancing biodiversity, soil health, microclimate regulation, carbon sequestration, water conservation, pollution reduction and improve mental health of the citizens.

- Encourage community/farm/village forests.
- Involve local communities in decision-making processes related to forest management, ensuring that their needs and knowledge are respected and utilised.
- Involve schools and academic institutions, especially children and young adults.
- Training and support to effectively manage forest resources and engage in sustainable practices.
- Analyse soil type, fertility and water availability and choose appropriate species.
- Promote tree diversity and opt for trees that offer multiple benefits, such as timber, fruit, fodder, or nitrogen fixation.

Increasing tree cover outside the forest area. In addition to agroforestry, measures such as planting avenue trees and implementing social forestry in upcoming towns, municipalities can increase the carbon uptake along with shade, oxygen and pollutant absorption benefits.

Box Item 18: Sanjeevi Malai Restoration

Sanjeevi Malai, also known as Kothankulam Reserved Forest, is a unique 278-hectare forest near Rajapalayam LPA. It holds both cultural and ecological significance, but is under threat due to rapid urbanisation, human activities, and rising temperatures, leading to frequent forest fires. Due to frequent forest fires in the region and deforestation activities, the district lost more than 3 hectares of tree cover between the years 2010-2023[81]. Sanjeevi Malai restoration could potentially sequester 33,116 tCO_2e/year by 2041, with an average annual sequestration of 1,840 tCO_2e/year. Further details on restoration of Sanjeevi Malai can be accessed from the 'Action Plan for Decarbonisation Pathways in Rajapalayalam' document.

Box Item 19: Safeguarding Forest Ecosystems for Climate Resilience and Carbon Sequestration in Virudhunagar

Reforestation and Afforestation: Planting trees in deforested or degraded forest patches by selecting native species adapted to the local climate and ecosystem, controlling invasive species and ensuring regular maintenance and monitoring.

- Improved Forest Management: Implementing sustainable forest management practices such as minimising forest degradation through selective logging, protecting old-growth forests, and promoting natural regeneration; preventing forest degradation activities such as illegal logging and forest fires, promote sustainable collection of forest produce.
- Wetlands within and outside forests must be protected for their huge potential in acting as a carbon sink.
- Enhancing green cover by increasing the trees outside the forests.
- Create, Enhance and Maintain Riparian zones.
- Monitor and remove encroachment of forest land.
- Use of satellite imagery and modern technology to identify encroachment, illegal construction and plantations.
- Mark and place appropriate boundaries for the forest lands.
- Mark traversing hours for the roads that overlap with ecological sensitive zones.
- Install strategic check-points.
- Formalise eco-tourism activity by issuing permits for trekkers and develop water, solid waste and wastewater managed camping grounds.
- Educate the communities in sustainable farming and carbon farming practices.

Frequent forest fires are encountered in the district due to the prevailing high temperature and dryness. The district has lost approximately 630 hectares of forest area due to forest fires from 2009 to 2023 which is 1.3 percent of the total forest area of the district.

- Strategic controlled burning, where patches of the grassland is burnt at regular intervals in high forest fire susceptible zones to avoid spreading of fire across a big area, would reduce the burn extent.
- Install strategic watch stations and CCTV cameras to monitor wildfires.
- Formalise protocol for fire control and ensure immediate access to fire extinguishing equipment.
- Establish protocol for use of helicopters for dousing bigger fires across forests and sholas.
- Ground mapping and integration of Remote Sensing technology to identify fire prone areas in forest.
- Develop a forest fire forecasting system and coordinate with efficient ground patrolling for early detection.
- Screening of pilgrims to Sathuragiri hills and prohibiting inflammable materials that pose risk of possible fires.
- Placing dedicated waste collection bins along the pilgrim pathway in the hills.
- Place appropriate warning boards for pilgrims to keep forest area free from inflammable materials.
- Explore the possibilities of drone systems for extinguishing forest fires in deep forest areas.

6 Aggregate Scenario Results and Key Insights

This chapter analyses GHG emission projections from 2022 to 2050 across three scenarios: BAU, MES, and AES. The energy sector emerges as the primary driver of GHG emissions growth, with the industrial sector, particularly industries with captive power plants (CPP), contributing approximately 46 percent of energy-related emissions, followed by the transport sector at around 37 percent. The AFOLU sector plays a vital role in offsetting GHG emissions, with sequestration showing significant improvement in both the MES and AES scenarios.

6.1 GHG Emissions Across Scenarios

Table 6.1: GHG emissions by category of source

S.No.	Sector	GHG Emissions ($ktCO_2e$) in year 2022	GHG Emissions ($ktCO_2e$) in 2050		
			BAU	MES	AES
I	*Agriculture*	*26*	*35*	*22*	*0*
II	*Industry*	*446*	*602*	*301*	*0*
III	*Commercial*	*27*	*45*	*32*	*10*
IV	*Residential*	*174*	*262*	*158*	*103*
V	*Captive Power Plant*	*146*	*146*	*0*	*0*
VI	*Transport*	*471*	*483*	*161*	*107*
A	Total Energy	1290	1574	674	220
I	*Cement Industries*	*1023*	*1383*	*1383*	*1383*
B	Total IPPU	1023	1383	1383	1383
I	*Aggregate Sources*	*87*	*115*	*67*	*48*
II	*Livestock*	*252*	*338*	*280*	*245*
III	*Land*	*-171*	*-171*	*-995*	*-1428*
C	Total AFOLU	169	283	-648	-1134
I	*Domestic Wastewater*	*100*	*112*	*21.22*	*21.22*
II	*Industrial Wastewater*	*10.91*	*10.91*	*4.36*	*2.18*
III	*Solid Waste Disposal*	*27*	*1.53*	*0.26*	*0.26*
D	Total Waste	138	124	26	24
E	Net Emissions (A+B+C+D)	2620	3364	1435	493
F	Gross Emissions	2791	3535	2430	1921

(Source: Authors' analysis)

In the BAU scenario, total net GHG emissions are projected to increase from 2620 $ktCO_2e$ in 2022 to 3364 $ktCO_2e$ by 2050, reflecting a 28 percent rise. This increase is primarily driven by the energy sector, which contributes approximately 47 percent of the growth, and by industrial processes and product use (IPPU), accounting for around 41 percent. Emissions from waste and other sectors remain relatively minor. The energy sector generates the highest emissions at 1574 $ktCO_2e$, followed by IPPU at 1383 $ktCO_2e$, AFOLU (Agriculture, Forestry, and Land Use) at 283 $ktCO_2e$, and waste at 124 $ktCO_2e$, resulting in total net emissions of 3364 $ktCO_2e$[82].

MES scenario, emissions from the energy sector declined to 674 $ktCO_2e$, while waste sector emissions were reduced to 26 $ktCO_2e$. Within the AFOLU sector, the land category acted as a net sink of 995 $ktCO_2e$, whereas aggregate sources and the livestock category together emitted 347 $ktCO_2e$, resulting in a net AFOLU sink of 648 $ktCO_2e$. With IPPU emissions which continue as such, this results in total net emissions of 1,435 $ktCO_2e$.

The AES represents the most aggressive decarbonisation approach, focusing on fuel switching in the industrial, transport, and residential sectors. In this scenario, energy sector emissions further decrease to 220 $ktCO_2e$ and waste emissions reduce to 24 $ktCO_2e$,while IPPU remain to be remain at 1383 $ktCO_2e$. In the AFOLU sector, land sequestration increases to 1,428 $ktCO_2e$ while emissions from livestock and aggreagte sources together reduce to 293 $ktCO_2e$, resulting in a net AFOLU sink of 1,134 $ktCO_2e$, leading total net emissions to 493 $ktCO_2e$.

6.2 Sectoral Emissions in BAU 2022 to 2050

Figure 6.1 illustrates the increase in gross greenhouse gas (GHG) emissions from 2,791 $ktCO_2e$ in 2022 to around 3,535 $ktCO_2e$ by 2050 under a BAU scenario, representing an increase of about 21 percent. Significant contributions to this growth primarily come from IPPU (360 $ktCO_2e$), industrial fossil fuel consumption (156 $ktCO_2e$), LPG cooking (106 $ktCO_2e$), livestock emissions (86 $ktCO_2e$), aggregate sources (28 $ktCO_2e$), transport fuel (12 $ktCO_2e$), and diesel pumpsets and tractors (9 $ktCO_2e$). However, emissions from solid waste decrease even under the BAU scenario due to stringent waste management practices implemented in the district. The main reasons for the rise in emissions include increased fossil fuel consumption (coal, petcoke) in industrial processes, higher process emissions resulting from the expansion of RAMCO cement plant capacity, and growing LPG demand for cooking driven by population growth toward 2050. Additionally, livestock emissions rise due to a projected increase in livestock population.

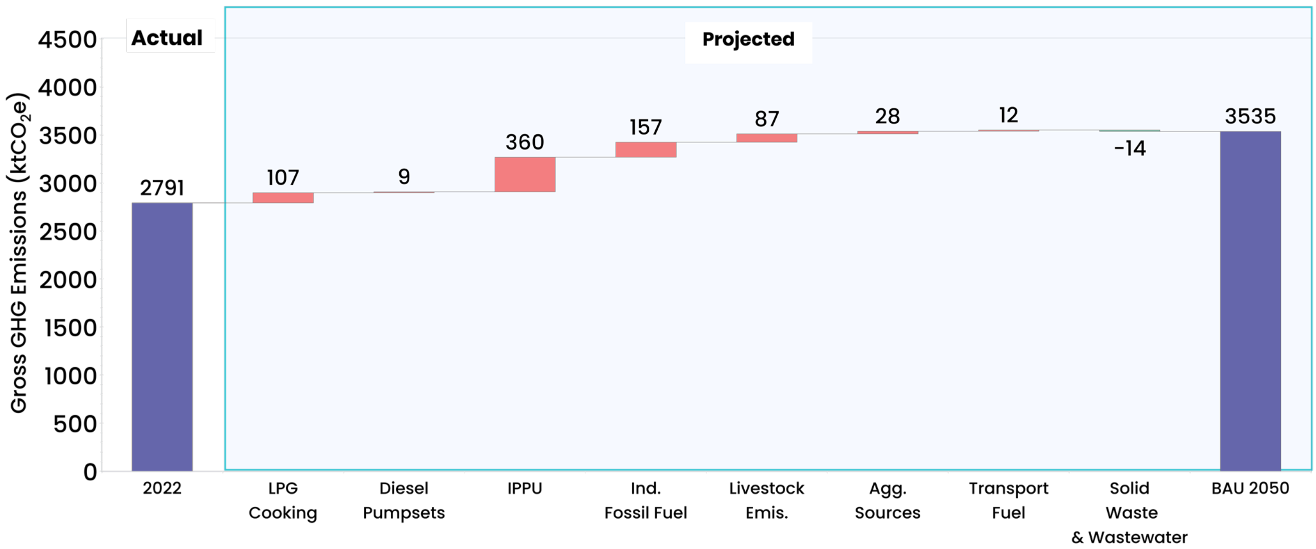


Figure 6.1: Sectoral emissions contribution in BAU scenario (2022-2050) in Virudhunagar

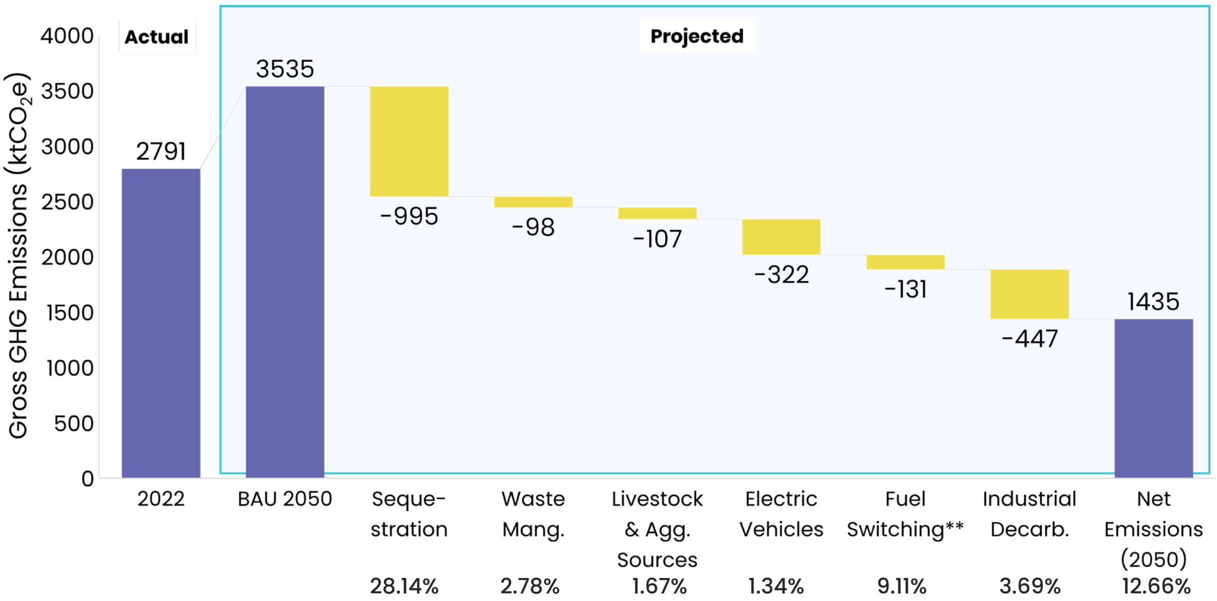
6.3 Pathways to Decarbonise Virudhunagar

6.3.1 Emission Reduction under Moderate Effort Scenario (MES)

Figure 6.2 illustrates the greenhouse gas (GHG) emissions mitigation measures under the MES. Starting from a baseline of 2,790 $ktCO_2e$ gross emissions in 2022, emissions are projected to rise to 3,535 $ktCO_2e$ by 2050 under a business-as-usual (BAU) scenario without intervention. However, the implementation of targeted mitigation measures leads to a significant reduction, bringing net emissions down to 1,435 $ktCO_2e$ by 2050.

The most substantial contribution to these reductions comes from carbon sequestration (995 $ktCO_2e$), highlighting its critical role in emission reduction strategies. Other key measures include the adoption of clean technologies in industry, including captive power (447 $ktCO_2e$), electrification of the transport fleet (322 $ktCO_2e$), fuel switching to cleaner energy sources (130 $ktCO_2e$), and improved waste management, along with reductions from livestock and other aggregated sources.

This integrated approach demonstrates the effectiveness of combining land-based sequestration, renewable energy deployment, electrification, and sustainable practices across sectors to offset emissions—aligning with ambitious climate targets. Further reductions are possible under the AES scenario.



***Electrification of tractors & tillers, & partial shift to PNG and electric cooking*

Figure 6.2: GHG emissions mitigation interventions in Virudhunagar. Progress under MES by 2050

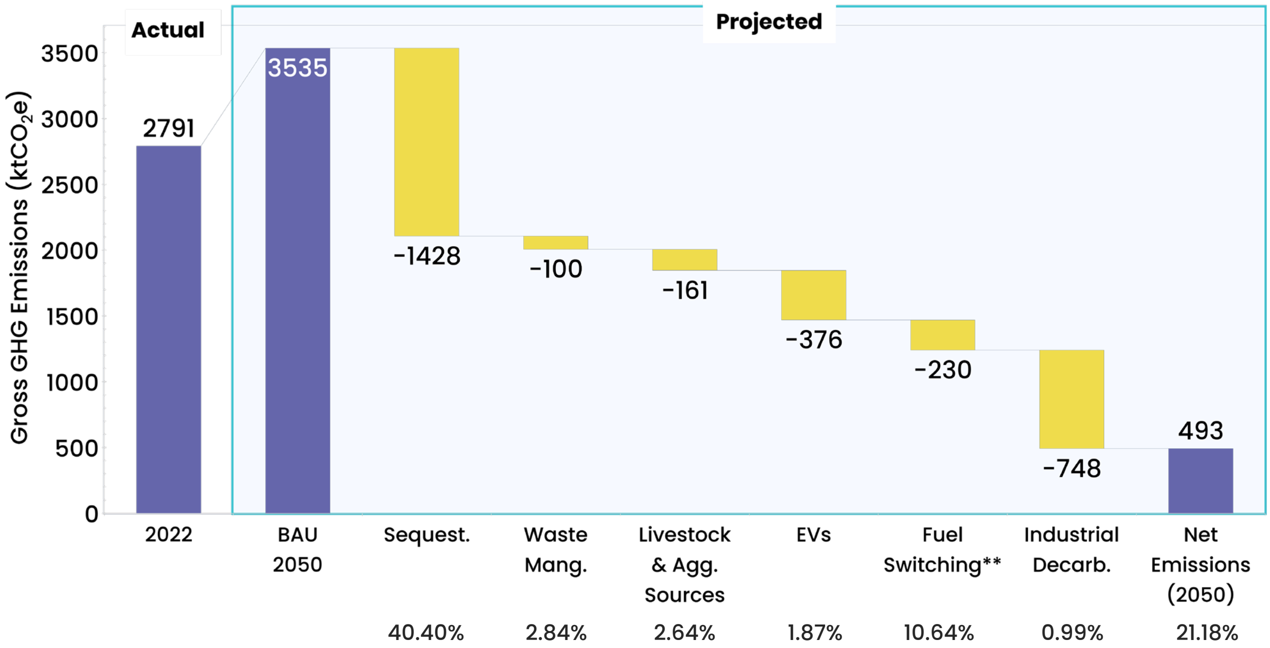
Source: Authors' Analysis

6.3.2 Emission Reduction under Aggressive Effort Scenario (AES)

Figure 6.3 illustrates greenhouse gas (GHG) emissions mitigation measures under the AES. The implementation of targeted actions results in a significant reduction in emissions, with net emissions dropping to 493 $ktCO_2e$ by 2050. The largest contribution to this reduction comes from carbon sequestration (1,428 $ktCO_2e$), highlighting its vital role in emission mitigation strategies.

Additional reductions are achieved through the adoption of clean technologies in industry, including captive power (748 $ktCO_2e$), electrification of the transport fleet (377 $ktCO_2e$), fuel switching to cleaner energy sources (229 $ktCO_2e$), improved waste management, and other sources such as livestock and aggregate emissions.

This integrated approach demonstrates the effectiveness of combining land-based sequestration, renewable energy deployment, deep electrification, and sustainable practices across sectors to achieve substantial emission reductions aligned with ambitious climate targets.



***Full electrification of agro machinery, and partial electric cooking*

Figure 6.3: GHG emissions mitigation interventions in Virudhunagar. Progress under AES by 2050

Source: Authors' Analysis

6.3.3 Leveraging Non-CO_2 Mitigation for Deep Decarbonisation

Non-CO_2 pollutants such as methane, nitrous oxide (N_2O),black carbon, and hydrofluorocarbons (HFCs) have high global warming potential, significant impacts on health and ecosystems, and their mitigation holds immense potential for achieving rapid, near-term climate benefits. These pollutants must be prioritised alongside CO_2 mitigation. In Virudhunagar, targeted Non-CO_2 mitigation—such as reducing methane and N_2O—offers a potential reduction of 260 $ktCO_2e$ by 2050. Moreover, interventions to reduce black carbon could further enhance the mitigation potential. In addition to climate benefits, non-CO_2 action often delivers strong developmental co-benefits, including improved air quality, public health, and agricultural productivity.

6.4 Key Interventions to Decarbonise the District

Decarbonisation of Industrial sector, particularly cement manufacturing, is necessary to decarbonise Virudhunagar

A major electricity consumer and emitter in the district, the industrial sector in Virudhunagar and particularly cement production needs to be decarbonised on priority. Electrification of heating processes through green hydrogen and other means, renewable energy based captive power generation and circular economy practices could completely abate 748 $ktCO_2e$ of projected emissions by 2050. Decarbonising the IPPU sector, which is projected to contribute 1383 $ktCO_2e$ of GHG emissions in 2050 will require carbon capture and similar technological solutions. The techno-economic feasibility of these are yet to be explored in India. Complementary efforts in decarbonising the textile sector, supported by PM MITRA, can further supplement these efforts.

Fuel switching from fossil fuel to clean sources could significantly reduce carbon footprint of the residential and commercial sector

Adopting ~1.7 lakh electric cookstoves to reduce LPG consumption in cooking and using cleaner alternatives like solar energy and biofuels for power backup in buildings can lower buildings carbon footprint by 63 percent from 307 ktCO_2e to 113 ktCO_2e by 2050.

Replacement of ICE vehicles with electric vehicles holds the key to decarbonise road transport

Full electrification of 2W, 3W, 4W and buses and partial electrification of Heavy Goods Vehicles (trucks, trolleys)[83] could save the district 71 percent of sectoral emissions, from 483 ktCO_2e to 107 ktCO_2e by 2050. To achieve this, the district will have to invest in development of allied infrastructure for electric mobility, including installation of charging stations.

Agriculture sector could further save 35 ktCO_2e of emissions by 2050, through prioritising solarisation of existing ~330 diesel pumps and electrification of ~8000 tractors and tillers.

Decarbonising electricity sector and energy efficiency measures in buildings will abate Scope 2 GHG emissions

Electrification of the road transport fleet, industrial decarbonisation, and increased demand for space cooling are expected to increase electricity consumption in the district. Electricity consumption is projected to rise fourfold, from 2,085 GWh in 2022 to 7,488 GWh by 2050. Out of this, 3,002 GWh will be required for space cooling needs alone, driven by higher temperature as per RCP 8.5 scenario. To meet this demand through renewable energy, an additional equivalent capacity of 3 GW will be required. Therefore, a comprehensive assessment of the resource potential across various renewable energy sources—such as solar rooftops, utility-scale solar, wind energy, agro-photovoltaics, and others—is essential. Adopting energy-efficient appliances, insulation, rooftop solar, and smart technologies will curb emissions, ease grid pressure, and support decarbonisation efforts.

Improving waste management and converting waste to energy can mitigate 178 ktCO_2e by 2050

Waste sector emissions projected at 124 ktCO_2e by 2050 could be reduced to 24 ktCO_2e by implementing measures such as 100 percent source segregation and processing of municipal solid waste with zero landfilling, comprehensive domestic wastewater management through 100 percent UGD connections, centralised STPs in urban areas, septic tanks with FSTPs in rural areas, and improved industrial wastewater management.

About 90 TPD of **municipal waste** could further generate ~13 GWh annually, mitigating 14 ktCO_2e emissions through municipal solid waste and Refuse Derived Fuel (RDF) based projects. Similarly, 3,44,109 tonnes of **annual crop residues** could generate 34–50 MW of power, producing 90–130 GWh and reducing 63–90 ktCO_2e emissions. **Livestock waste** could also produce 30,000 m^3/day of biogas, enabling compressed biogas (CBG) production and mitigating 32 ktCO_2e annually.

Agriculture soil and livestock management, and enhancement of sequestration potential (incl. through agroforestry) are other key drivers

Virudhunagar's carbon sequestration could be enhanced from 170.8 ktCO_2e to 1,428 ktCO_2e by 2050 by repurposing fallow/barren/wastelands as social/agroforestry and enhanced carbon stock density. Rice cultivation emissions, projected to rise from 52 ktCO_2e in 2022 to 78 ktCO_2e by 2050, could potentially reduce to 36 ktCO_2e by expanding multiple aeration water regimes from 20 percent to 77 percent . Livestock emissions, expected to grow from 252 ktCO_2e in 2022 to 339 ktCO_2e by 2050, can be reduced to 245 ktCO_2e through balanced rationing, adoption of methanogen-inhibiting feed additives, and improved manure management practices.

Box Item 20: Behavioural interventions will drive deeper abatement, over and above key interventions suggested in the plan

Behavioural interventions will result in avoided demand, efficient consumption wherever unavoidable and mindful decision making regarding choice of fuel, materials and use of appliances. This is over and above key interventions suggested in the plan for decarbonising Virudhunagar.

In Building Sector

- Setting ACs at 26°C in Virudhunagar could save ~120 GWh of electricity and abate 84 ktCO_2e of scope 2 emissions by 2050, beyond standard energy efficiency measures. Space cooling is projected to account for 61 percent (1845 GWh) of residential electricity demand, which is expected to rise from 728 GWh to 3002 GWh by 2050. Commercial buildings currently set ACs too low, causing unnecessary energy use, while 25–26°C ensures comfort with better efficiency.
- **Smart lighting solutions using motion/occupancy sensors and daylight integrators** can prevent idle running of utilities and save the district 40 percent electricity in lighting or 98 GWh out of ~245 GWh of projected electricity consumption in lighting in residential and commercial buildings by 2050, further abating 69 ktCO_2e of GHG emissions (scope 2).

In Transport Sector

- **Smart traffic systems** that optimise signal timings based on real-time traffic data, reduce idle time at intersections and minimise stop-and-go traffic can save up to 25 percent of emissions at traffic lights and intersections.[84]
- **Using public transport for inter-city and intra-regional movement** can result in 45 percent reduction in emissions in comparison to private vehicles in Virudhunagar.[85,86] Assuming that 10 percent commuters in Virudhunagar shift from 4W cars to buses, this behavioral change could reduce GHG emissions by ~46 ktCO_2e by 2050. Such a shift could also avoid the need for around~ 18,000 four-wheelers on the road, replaced with an addition of ~800 buses.
- Non-motorised Transport (bicycle, cycle rickshaw, push scooters etc) for shorter distances (3.5-4 km), supported with development of sidewalks, pedestrian zones, and safe crosswalks for walkers and cyclists, can further avoid unnecessary emissions.

Box Item 21: Strengthening heat resilience in Virudhunagar district through climate-smart cooling and public health interventions

- Rising temperatures in Virudhunagar district pose a growing concern, with maximum temperatures projected to increase by 0.1°C by 2030 and 1.1°C by 2090 under the RCP4.5 scenario, and by 0.2°C and 2.8°C under the RCP8.5 scenario, respectively. As a predominantly dry zone that already experiences high temperatures for much of the year, this warming trend is likely to exacerbate heat stress, especially in urbanising and densely populated areas. Further, with a significant population dependent on MSMEs for their livelihood, building heat resilient is of priority. In this context, the widespread adoption of passive and sustainable cooling techniques emerges as a critical strategy to improve thermal comfort, reduce electricity demand, and enhance the district's overall climate resilience.

Built Environment and Cooling Infrastructure

- Enforce Energy Conservation and Sustainable Building Code (ECSBC) and Indian Green Building Council (IGBC) norms in all new residential, commercial, and public buildings, especially in fast-growing urban centres like Virudhunagar town, Aruppukkottai, and Rajapalayam.
- Incentivising the retrofitting of existing buildings—including government offices, hospitals and schools—to incorporate passive cooling features such as improved cross ventilation, thermal insulation, and shaded courtyards.
- Establish park pockets, urban forests and community gardens in settlements like Sivakasi Municipality, using native drought-resistant species like Neem (*Azadirachta indica*) and Pungan (*Pongamia pinnata*).
- Promote cool roofing techniques (e.g., lime-based reflective coatings) in low-income housing clusters and MSMEs across Watrap and Srivilliputhur.
- Develop green-blue infrastructure such as bio-parks in Virudhunagar town, incorporating rain gardens, butterfly parks, and urban ponds to enhance thermal comfort and aquifer recharge.
- Leverage lakes and local tanks (e.g., Anaikuttam Tank) as passive cooling buffers in land use planning.
- Encourage rooftop gardens and Agro-Photovoltaics (Agro-PV) in rooftop solar installations, especially on industrial rooftops in Sivakasi.

Public Health Measures to Address Heat Stress

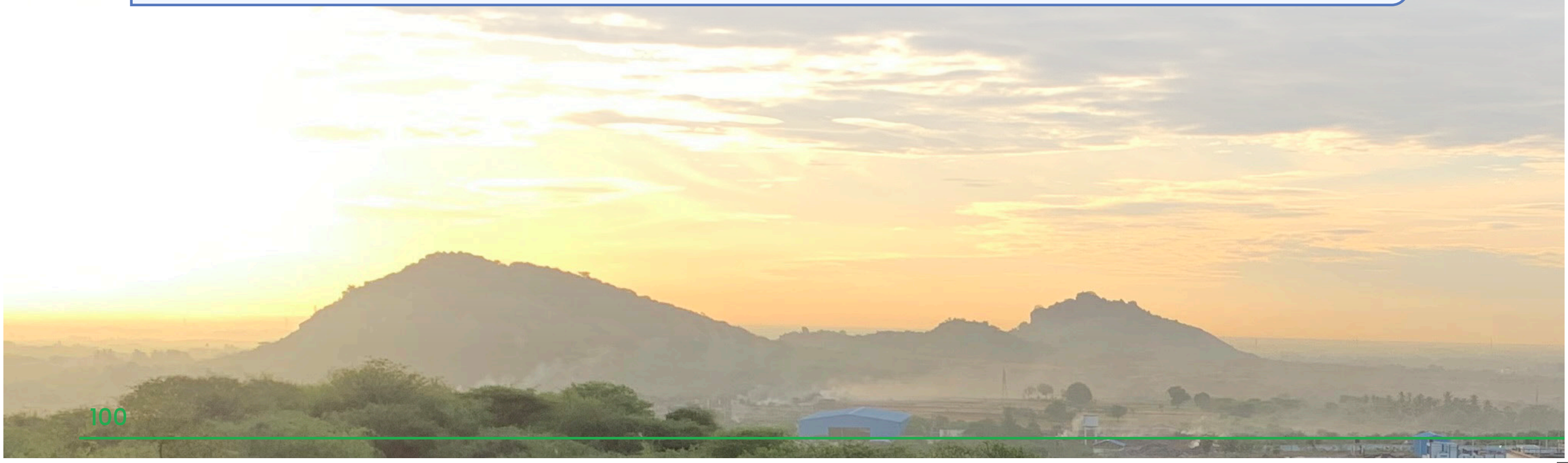
- Implement district-wide early warning systems, public alerts via radio and mobile SMS, and community outreach in urban slums and rural habitations like Pudur, Kariapatti, and Vembakottai.
- Establish cooling shelters in public spaces such as community halls in Aruppukkottai and libraries in Rajapalayam, equipped with water stations and fans.
- Train Primary Health Centre (PHC) staff across the district, especially in rural blocks like Tiruchuli and Narikkudi, to detect and treat heat-related illnesses including dehydration, heat stroke, and respiratory distress.
- Ensure hydration through free public water kiosks, especially in market areas and bus stands of Virudhunagar and Sivakasi.
- Engage SHGs and school eco-clubs to promote water conservation, heat and mosquito awareness, and lead public campaigns on heat-related health in urban and rural areas.

Vector-borne & Zoonotic Disease Resilience

- Establish climate-linked surveillance systems in collaboration with District Health Society, tracking mosquito populations and diseases like dengue and chikungunya, particularly after monsoons.
- Reduce vector breeding grounds through community-led solid waste management and desilting of local waterbodies like Periyakulam and Thiruthangal Tank.
- Organise veterinary camps in rural blocks like Sattur and Kariapatti to prevent spread of zoonotic diseases from livestock and stray animals.
- Implement one health approach—coordinating health, veterinary, and environment departments to pre-empt zoonotic outbreaks.

Health, Disaster Preparedness, and Infrastructure

- Integrate climate-health planning in district-level disaster preparedness strategies, supported by District Collectorate, Virudhunagar.
- Build climate-resilient health infrastructure (e.g., solar-powered PHCs) and deploy mobile health units in remote areas such as Vembakottai during emergencies.
- Promote the PM-E-DRIVE Scheme by introducing electric ambulances and e-rickshaws for patient transport, particularly in dense localities with limited access.
- Strengthen air quality monitoring by installing a continuous Air Quality Index (AQI) station in Sivakasi, given its high industrial emissions.
- Develop green corridors and shaded walking/cycling routes along major roads in Rajapalayam and Aruppukkottai.
- Encourage industries and commercial establishments to ensure workplace thermal comfort, conduct regular health check-ups, and organise employee wellness campaigns.

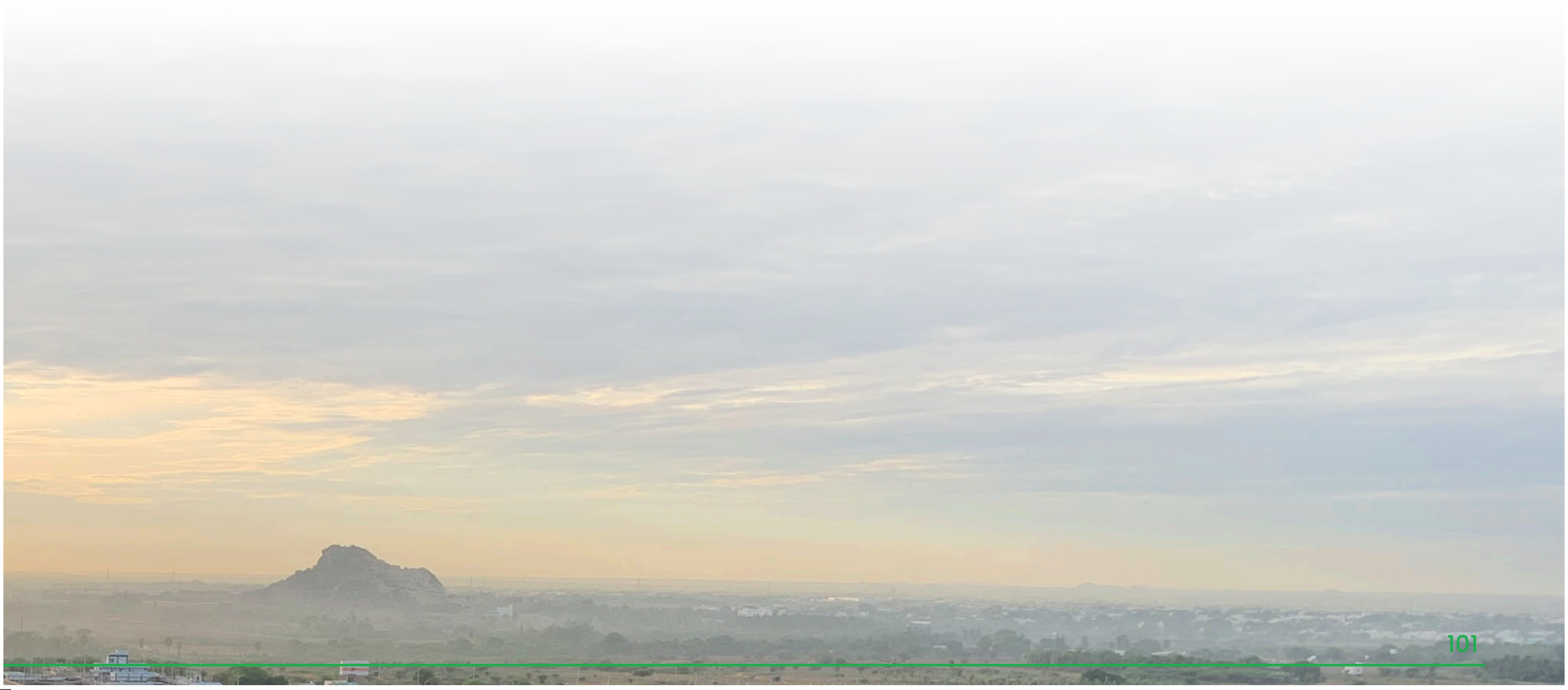


7 Financing Decarbonisation for Virudhunagar

Table 7.1 outlines the key interventions for achieving decarbonisation in Virudhunagar by 2050, along with corresponding short-term, medium-term, and long-term targets, and projected GHG emission reduction potential. These strategies encompass key emitting sectors, including energy, industry, waste management, sustainable urban development and carbon sequestration.

The implementation of these interventions could be supported through strategic alignment of resources with existing government schemes and policies aimed at promoting industrial decarbonisation, sustainable waste management, and other climate-resilient practices. Leveraging public-private partnerships (PPPs) can further enhance the scalability and effectiveness of implementation of these initiatives.

Annexure 5 provides an overview of relevant Central and State government policies, programs, and funding mechanisms that could be mobilised to finance the proposed interventions. These policies offer opportunities for financial convergence, enabling efficient resource utilisation and fostering an enabling environment for achieving Virudhunagar's long-term decarbonisation goals.



Virudhunagar Decarbonisation Plan

The decadal target and the activities along with their mitigation potential, cost estimate, and supporting policies are as detailed in the table below:

Table 7.1: Key short, medium and long term interventions

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
A	**Waste Management**										
A.1	Domestic Wastewater Management	Set up adequate centralised wastewater treatment plants for urban	Government initiated with possibilities for gap funding through private, CSR	Facility to treat 135 MLD of wastewater	66 (1.95%)	Facility to treat addditional 20 MLD of wastewater	90 (2.61%)	Additional maintenance	91 (2.56%)	Swachh Bharat Mission-AMRUT 2.0, Kalaignarin Nagarpura Mempattu Thittam (KNMT), Tamil Nadu Urban Development Project (TNUDP) III, Namakku Namae Thittam	Commissionerate of Municipal Administration, Tamil Nadu Water Supply and Drainage Board, Tamil Nadu Pollution Control Board
A.2		Enhancing decentralised treatment	Market/ household driven with possibilities of Government subsidies	Retrofitting unsanitary septic tanks and unlined hole in the ground with leach pit or twin-pit septic tanks at household level for 1,34,750 households		Retrofitting unsanitary septic tanks and unlined hole in the ground with leach pit or twin-pit septic tanks at household level for 57,750 households		Additional maintenance			

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
A.3		Setting up Fecal Sludge treatment plant (FSTP) at firka level	Government or private initiative	20 FSTPs for 20 firkas		19 FSTPs for remaining 19 firkas		Additional maintenance			
A.4		Increase household connections to underground drainage,	Government initiated and funded	60 percent Households to be connected with UGD		100 percent Households to be connected with UGD		Additional maintenance			
A.5	Industrial Wastewater Management	Setting up of Effluent Treatment Plants (ETP) and Contionous Effluent Treatment Plants (CETPs) along with continous treated effluent monitoring system	Market/ industry driven with possibilities of Government funds for industrial areas developed by the Government	Facility to treat 2 MLD	3 (0.08%)	Maintenace and additional facilities as per requirement	5 (0.16%)	Maintenace and additional facilities as per requirement	9 (0.25%)	Tamil Nadu Industrial Policy 2021	Environment and Climate Change department, Tamil Nadu Pollution Control Board

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
A.6	Solid Waste Management	Dry waste recycling centre	Government or private initiative	1. 20 recycling centres for 20 firkas at village level 2. 1 recycling centre per 1 lakh population (total 10 recycling centres))	0	1. 19 recycling centres for 19 firkas at village level 2. Additional 5 recycling centre (total 15 recycling centres)	1.04 (0.03%)	Maintenace and additional facilities as per requirement	1.27 (0.04%)	Swachh Bharat Mission, Solid Waste Management Rules 2016	Commissionerate of Municipal Administration, Tamil Nadu Pollution Control Board, Rural Development and Panchayat Raj department
A.7		Composting Centres	Government or private initiative	10 composting centre (1 per 1 lakh population)		5 additional composting centre (total 15)		Maintenace and additional facilities as per requirement			
A.8		Stakeholder capacity building and awareness generation for holistic and sustainable waste management	Government initiated with possibilities for gap funding through private, CSR	Ongoing initiative		Ongoing initiative		Ongoing initiative			

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
	Total Mitigation Potential				**69 (2.03%)**		**96.04 (2.8%)**		**101.27 (2.85%)**		
B	**Green Spaces & Carbon Sequestration**										
B.1	Restoration and Conservation of Existing Forest Area and Tree Cover	Maintaining the current carbon stock densities to ensure the carbon sequesteration of -170.8 $ktCO_2e$ per year	Government initiated with possibilities for gap funding through private, CSR	Strengthening protection around existing reserved forest areas with additional measures of protection like: strengthening the fencing; eliminating encroachment; levying penalty on defaulters; etc.	170.8 (5.02%)	Strengthening protection around existing reserved forest areas with additional measures of protection like: strengthening the fencing; eliminating encroachment; levying penalty on defaulters;etc.	170.8 (4.93%)	Strengthening protection around existing reserved forest areas with additional measures of protection like: strengthening the fencing; eliminating encroachment; levying penalty on defaulters;etc.	170.8 (4.83%)	Compensatory Afforestation Fund Management and Planning Authority Fund (CAMPA), Nagar Van Yojana, Rashtriya Krishi Vikas Yojana (RKVY), National Afforestation Programme, Sub-mission on Agroforestry (SMAF) - Har Medh Par Ped Scheme ; Kalaignarin All Village Integrated Agriculture Development Programme (KAVIADP) National Agriculture Development Programme (NADP) ; CCUS Policy	Forest Department, Environment and Climate Change Department, Commissionerate of Municipal Administration

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
B.2		Promoting social and agroforestry in land classified as barren or fallow, land put to non-agricultural uses of cultivable waste land	Private driven for private lands and Government initiated for Government lands with possibilities for gap funding through private, CSR	Social and agroforestry in 35,163 ha of land (~14 percent of 2,58,044 ha) In the subsequent years, continuous monitoring and maintenance of the plantations need to be undertaken	193 (5.69%)	Social and agroforestry in 49,228 ha of land (~19 percent of 2,58,044 ha) In the subsequent years, continuous monitoring and maintenance of the plantations need to be undertaken	658 (18.97%)	Social and agroforestry in 56,261 ha of land (~22 percent of 2,58,044 ha) In the subsequent years, continuous monitoring and maintenance of the plantations need to be undertaken	1,238 (35.02%)	Tamil Nadu Climate Change Mission ; Green India Mission; Green Tamil Nadu Mission; Trees Outside Forests in India' initiative by MoEFCC and Governemnt of Tamil Nadu;	
B.3		Enhancing Carbon stock density in Sanjeevi Malai etc	Government initiated with possibilities for gap funding through private, CSR	Enhancement of carbon stock density by ~2 percent increase from 82.25 t/ha to 83.75 t/ha	49 (1.43%)	Enhancement of carbon stock density by ~4 percent increase from 82.25 t/ha to 85.26 t/ha	19 (0.56%)	Enhancement of carbon stock density by ~5 percent increase from 82.25 t/ha to 86.76 t/ha	19 (0.55%)		
	Total Mitigation Potential				**413 (12.14%)**		**848 (24.56%)**		**1,428 (40.04%)**		

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e/yr$) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e/yr$) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e/yr$) (Percentage to BAU Gross Emissions)	Target			
C	**Sustainable Agriculture Practices**										
C.1	Promote Modern Cultivation Techniques to Optimise Agricultural Inputs and Maximise Outputs	Use of organic fertiliser and compost in place of urea in agricultural production	Farmer driven with possibilities of Government funds as subsidies under various listed schemes	15 percent agriculture area transitioned to organic fertiliser	4.66 (0.14%)	45 percent agriculture area transitioned to organic fertiliser	14.31 (0.41%)	75 percent agriculture area transitioned to organic fertiliser	24.39 (0.69%)	National Mission for Sustainable Agriculture, Chief Minister's Manniyur Kaathu Mannuyir Kappom Scheme (CM MK MKS), National Mission on Natural farming	Agriculture department, Horticulture department, Environment and Climate Change department, Animal Husbandry department
C.2		Use of nano urea in place of urea in agricultural production	Farmer driven with possibilities of Government funds as subsidies under various kisted schemes	30 percent of urea requirement met through nano urea		55 percent of urea requirement met through nano urea		25 percent of urea requirement met through nano urea			

	Key Inter-vention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approxi-mate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Cen-tral Govt.	Depart-ments
			Descrip-tion of Financing the Activ-ity (to be read with color codes)	Target	Approxi-mate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approxi-mate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
C.3		Capacity building pro-grammes can be conducted through Kri-shi Vigyan Kendra for creating awareness on climate resilient practices	Govern-ment initiated with possi-bilities for gap fund-ing through private, CSR	Can be an ongoing initiative		Can be an ongoing initiative		Can be an ongoing initiative		National Innova-tions in Climate Resilient Agri-culture (NICRA), Paramparik Krishi Vikas Yojana	
C.4		Establish local net-work of mini weather monitoring stations to moni-tor rainfall and tem-perature as well as to be able to forecast extreme weather conditions	Govern-ment or private initiative	20 mini weather monitoring stations	NA	19 mini weather monitoring stations	NA	Additional mainte-nance		Krishi Decision Support System, Agricultural In-frastructure Fund (AIF)	

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e$/yr) (Percentage to BAU Gross Emissions)	Target			
		- this can help inform farmers of appropriate sowing, harvesting and irrigation timings									
C.5	Emission Reduction from Rice Cultivation	Increase the percentage of multiple aeration in the rice cultivated area	Farmer driven with possibilities of Government funds as subsidies under various schemes as listed	Increase in multiple aeration from 20 percent to 27 percent	4 (0.13%)	Increase in multiple aeration from 20 percent to 51 percent	20 (0.57%)	Increase in multiple aeration from 20 percent to 77 percent by 2050	42 (1.18%)	Chief Minister's Manniyur Kaathu Mannuyir Kappom Scheme (CM MK MKS)	

	Key Intervention	Activity/ Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Approximate AMP in 2050* ($ktCO_2e/yr$) (Percentage to BAU Gross Emissions)	Policies/Fiscal Measures by State and Central Govt.	Departments
			Description of Financing the Activity (to be read with color codes)	Target	Approximate AMP in 2030* ($ktCO_2e/yr$) (Percentage to BAU Gross Emissions)	Target	Approximate AMP in 2040* ($ktCO_2e/yr$) (Percentage to BAU Gross Emissions)	Target			
C.6	Livestock Management	feed inputs for livestock - Tamarin plus and Harit Dhara and balanced rationing to reduce methane emissions from enteric fermentation. Implementation of GOBARdhan scheme for manure management	Farmer driven with possibilities of Government funds as subsidies under various schemes as listed	Balanced rationing introduced in 30 percent and improved feed supplements like Harit Dhara and Tamrin plus in 25 percent of livestock . 30 percent reduction in manure management emission through GOBAR dhan scheme	26 (0.76%)	Balanced rationing introduced in 60 percent and improved feed supplements like Harit Dhara and Tamrin plus in 50 percent of livestock . 60 percent reduction in manure management emission through GOBAR dhan scheme	57 (1.65%)	Balanced rationing introduced in 90 percent and improved feed supplements like Harit Dhara and Tamrin plus in 75 percent of livestock . 90 percent reduction in manure management emission through GOBAR dhan scheme	93 (2.64%)	Balanced Ration Programme (BRP) GOBAR dhan scheme	
	Total Mitigation Potential				**34.66 (1.03%)**		**91.31 (2.63%)**		**159.39 (4.51%)**		

Purely Government Backed / Investment	Market Driven	Partially backed by Government

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
Interventions to Mitigate Scope 1 Emissions									
A	**Decarbonising the Energy Sector**								
A.1	Shift from Fossil-Fuel to RE based Captive Power Generation	Replacing/tying up PPAs from existing 262 MW fossil-fuel based Captive Power Plants (CPPs) to equivalent renewable energy capacity of ~105 MW (solar, wind and GH2) by 2050.	40% of the existing tied up capacity (equivalent RE capacity 40 MW)	5 (1.62%)	55% additional capacity (equivalent RE capacity ~60 MW)	129 (3.72%)	5% of the balance (equivalent RE capacity 5 MW)	146 (4.13%)	- 100% electricity tax exemption for 5 years on power generated and consumed from captive sources - Concessions on land purchase or lease through reduced stamp duty available under Tamil Nadu Industrial Policy 2021
A.2	Use of Electric Cookstove in Cooking	Adoption of ~1.4 lakh electric cookstoves in residential cooking by 2050	0.7 lakh	77 (2.27%)	0.2 lakh	91 (2.63%)	Remaining 0.5 lakh	137 (3.88%)	Potential of covering 0.7 lakh electric cookstoves (worth 13.3 crores) under National Efficient Cooking Program (NECP) which provides cookstoves at a low cost.
A.3	Use of Biogas using Waste (Livestock waste, Food Scaps etc)	Installing a biogas plant of approx 30000 m3/day capacity, considering 50% realisation of total potential of 60000 m3/day of the district	40%	22 (0.64%)	Additional 10%	26 (0.75%)	50%	58 (1.64%)	Potential of coverage of 10 small biogas plants of 25 m3/day capacity (worth Rs. 0.07 crores) by 2026 under National Biogas Programme. Higher coverage subject to scheme extension.

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
A.4	Replacement of diesel pumps with solar pumps for irrigation	Conversion of 330 diesel pumpsets to off-grid solar pumps by 2030	100%	6 (0.16%)	NA	6 (0.17%)	NA	6 (0.17%)	Potential of covering 330 solar pumps worth ~INR 10 crore (Rs. 314,088 per 5HP pump) under PM KUSUM (Component B)
A.5	Use of EV tractor and tillers for agriculture land preparation	Electrifying ~8000 tractors and tillers by 2050	1480	5 (0.16%)	3760	19 (0.55%)	2760	29 (0.82%)	-
A.6	Replacement of HSD by Biodiesel in Diesel Generator for Backup Supply / Renewable based Backup Supply Support	"Replacement of HSD by Biodiesel in Diesel Generator for Backup Supply / Renewable based Back-up Supply Support a. Exploring biodiesel availability production in the district (assessment) b. Pilot implementation of bio-diesel use in commercial DG sets / RE based backup supply support c. Using biodiesels in all the DG sets in the districts"	To be assessed						
B	**Shift to Electric Mobility**								

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
B.1	Shift to Electric 2-Wheeler	Increasing the share of EV in 2W sales to achieve 100% penetration (upto ~5 lakh EV 2W) by 2050	1 lakh	10.41 (0.31%)	Additional 2 lakh	32 (0.92%)	Additional 2 lakh	50.3 (1.38%)	The current market price of EV 2W are comparable with the ICE counterparts, hence market dynamics will decide the pace of 2W EV sales. However, a sum of Rs. 50 crore (Rs. 50 crore + Rs. 0.3 crore) is available under current center and state policies (PM E-DRIVE Scheme 2024 and TN EV Policy 2023) for 1,00,000 2W EVs. Higher coverage is possible subject to scheme extension.
B.2	Shift toElectric 3-Wheeler	Increasing the share of EV in 3W sales to achieve 100% penetration (~7500 EV 3W) by 2050	1000	1 (0.03%)	2701	1.9 (0.05%)	3463	4 (0.11%)	The current market price of EV 3W are comparable with the ICE counterparts, hence market dynamics will decide the pace of 3W EV sales. However, a sum of Rs. 3.75 crore (Rs. 0.75 crore + Rs. 3 crore) is available under current center and state policies (PM E-DRIVE Scheme 2024 and TN EV Policy 2023) for 1000 3W EVs.

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
B.3	Shift to Electric 4-Wheeler	Increasing the share of EV in 4W sales to achieve 100% penetration (upto ~2 lakh EV 4W) by 2050	0.25 lakh	14.95 (0.44%)	Additional 1 lakh	64 (1.85%)	Additional 0.75 lakh	103 (2.91%)	Maximum incentive of up to Rs. 1.5 lakh per 4W commercial vehicle is available under TN EV Policy 2023 for a maximum of 3000 vehicles per year.
B.4	Shift toElectric Buses	Increasing the share of EV buses in sales and achieving 100% penetration (upto ~2000 EV buses) by 2050	200	16 (0.47%)	Additional 1100	76 (2.19%)	Additional 500	99 (2.8%)	"The current market price of e-Buses are comparable with the ICE buses, hence market dynamics will decide the pace of e-Buses sales. However, a sum of Rs. 75 crore (Rs. 55 crore + Rs. 20 crore) is available under current center and state policies (PM E-DRIVE Scheme 2024 and TN EV Policy 2023) for 200 e-Buses."
B.5	Shift to Electric Heavy Goods Vehicles (HGVs)	Increasing the share of electric Heavy Goods Vehicles (trucks, trolleys) in sales to achieve 80% penetration (upto ~2000 EV HGVs) by 2050	100	5 (0.16%)	Additional 1200	93	Additional 500	120 (3.4%)	-

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
B.6	Creation of EV Charging infrastructure	Installation of ~475 charging stations in total by 2050	39	NA	166	NA	270	NA	Incentives worth Rs. 1 lakh for slow charging and Rs. 10 lakh for fast charging stations are available under TN EV Policy 2023 and further coverage under PM E-DRIVE subject to scheme extension.
C	**Decarbonisation of the Industry**								
C.1	Exploring Electrification of Heating Processes in Industries to Reduce Fossil Fuel Consumption (Furnace Oil, HSD etc)	Fully Electrified kiln via plasma generator for heating in industries in place of fossil fuel based heating by 2050	40% of the target	237 (6.97%)	20% additional achievement	363 (10.47%)	Remaining 40% of the target	603 (17.06%)	-
Total Scope 1 Mitigation Potential ($ktCO_2e$)			**1355 (38.34%)**		**901.2 (25.99%)**		**1355 (38.34%)**		

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
Interventions to Mitigate Scope 2 Emissions (Electricity Sector)									
a	Addition of Renewable Energy (RE) Capacity to Meet the Domestic Electricity Demand at District Level	- Additional RE capacity integration of ~3 GW (in addition to existing RE capacity of 0.7 GW) a. Potential Assessment for various RE sources including rooftop solar, utility scale, wind, floating solar, agro PV and others) b. Installation as per assessment	NA	0	1 GW of the RE capacity target	1,533	~2 GW of remaining capacity	4,384	- Subsidy maximum up to Rs. 78,000 for rooftop system under PM Surya Ghar Muft Bijli Yojana
b	Energy Efficiency Improvements	Installation of ~7.5 lakh 3/5 star EE ACs in residential spaces to replace old/inefficient ACs	3 lakh	50	4.08 lakh	143	0.46 lakh	154	
		Installation of 3/5 star EE refrigeration units up to a total of 7 lakh by 2050	6.5 lakh	6	0.5 lakh	7	0.00	8	
		Replacing existing ~11 lakh incandescent bulbs and CFL bulbs and CFL tubelights with LED in residential space by 2030	8.5 lakh	2	2.5 lakh	6	NA	10	
		Replacing ~0.8 lakh street lights with LED lights by 2030	100%	25	NA	25	NA	25	
		Adoption of ~7 lakh BLDC fan by 2050	6.3 lakh	2	0.6 lakh	4	0.1 lakh	4	

	Key Intervention	Activity/Target	Short Term (till 2030)		Medium Term (2030-40)		Long Term (2040-50)		Incentive under Central/State Schemes and Policies
			Target	AMP in 2030 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2040 ($ktCO_2e$/yr)	Additional Target	Cumulative AMP in 2050 ($kTCO_2e$/yr)	
C	Utilising Biodegradable Waste to Generate Electricity	Installation of waste to energy plant of 3 MW (the plant will require ~90 tons waste per day) by 2030	100%	14	NA	14	NA	14	Potential for covering 3MW project worth INR. 6 crore (Rs.2 crore/MW) under National Mission for Waste to Wealth (Policy for Promotion of City Composting)
Total Scope 2 Mitigation Potential ($ktCO_2e$)			**85.3**		**1,718.1**		**4,586**		

*AMP = Annual Mitigation Potential

Note: Percentages denote AMP as a share of respective BAU emissions.

Purely Government Backed / Investment	Market Driven	Partially backed by Government

8 Monitoring and Evaluation

Monitoring and Evaluation (M&E) is essential for ensuring effective implementation, tracking progress, and assessing impacts on resilience and sustainability of the Virudhunagar Decarbonisation Plan, In a shifting climate landscape, a robust M&E framework provides structure to evaluate success, address new challenges, and guide data-driven improvements. This section outlines measurable indicators to monitor outcomes, optimise resources, and align actions with Virudhunagars's climate resilience goals, supporting continuous, community-focused adaptation. This section also identifies key stakeholders and institutions to be engaged in the monitoring and evaluation process.

Suggested Indicators

The Table 8.1 provides indicators across key themes of the decarbonisation plan. The indicators provided as part of this plan are not exhaustive, and should be updated periodically to better reflect the outcomes achieved as part of the implementation of climate action suggestions.

Indicators can be against an established baseline (year when the implementation starts) and then progress of the implementation can be measured annually or bi-annually as per decision of the Monitoring committee.

Table 8.1: Probable list of indicators for monitoring and evaluation

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
Transport Sector	Achieve a zero-emission public and private transportation system by 2050 • Promote electric vehicle (EV) adoption and set up EV charging stations • Electrify public transportation (buses, 3W, 4W passenger vehicles)	Number of EV registered per Vehicle Category OR % Penetration of EV in the New sales	100% penetration of electric vehicles in new sales of 2W, 3W, 4W, and bus by 2050. 80% penetration of electric vehicles in new sales of HGVs (trucks, trolleys) by 2050.

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
Electricity	Transition to 100% Renewable Energy in the district through potential assessment and installation of rooftop solar, agro photovoltaic, captive RE etc.	Annual new RE capacity addition	3 GW of new and additional renewable energy capacity built by 2050
Agriculture	Transition to Solar pumps: Replace 100% of diesel pumps with decentralised solar pumps under PM KUSUM scheme. Electrification of agro-machinery (tractors and tillers)	Percentage of Electric Tractors in New Sales Number of farmers benefiting from solar pumps installation by total/New Number of pumps installed	100% conversion of existing 330 diesel pumpsets to off grid solar by 2030 Electrification of 8000 tractors and tillers by 2050
Industry	Electrify commercial heating systems in sectors Promote shift from fossil fuel to RE based captive power generation	Renewable energy capacity addition	Transition to 100% electrified heating systems by 2050 ~105 MW of renewable energy capacity to run Captive Power Plants in industries.
Buildings	Shift to Energy Efficient residential appliances. Adoption of LED based lighting Replacement of Diesel generators by clean source of electricity backup Mandate energy efficiency retrofits in commercial buildings	Number of five star rated appliance sales in new appliance sales. % Penetration of 3-5 star ACs, Fans and Bulbs in new sales in the district % of electric cookstoves in the total stock in the district Number of DG sets replaced with electricity based alternatives Number of residential/ commercial buildings installing rooftop solar. Number of Households purchasing Electric or Induction Cooking.	**Long term:** 100% adoption of super efficient appliances in households. More than 50% adoption of electric cooking. 100% commercial buildings adopt building retrofits.

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
Solid Waste Management	Ensure 100 percent segregation and collection of waste at source	Percentage of households (urban+rural) from where segregated waste is collected	Efficient waste collection and processing, increased recycling, and enhanced sanitation services contribute to cleaner and healthier communities, and reduce emissions by preventing waste to reach landfills
		Percentage of commercial and institutional/ administrative establishments from where segregated waste is collected	
		Number of EVs in use for waste collection	
		Percentage of collected dry waste recycled/ processed (urban+rural)	
		Percentage of collected wet waste processed (urban+rural)	
		Number of waste collection bins installed at strategic locations	
		Number of operational e-waste collection points established	
		Percentage of localities covered under monthly collection of e-waste	

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
	Management of Organic Waste 1. Setting up of waste management facilities 2. Encourage and promote composting, vermi-composting and biogas plants at residential and commercial entities (hotels/resorts/ homestays). 3. Facilitate and conduct Behaviour Change Communications workshops on proper disposal of solid waste	Number and installed capacity of composting centres established	
		Compost sold	
		Number and installed capacity of vermicomposting plants	
		Capacity of waste management plants (TPD)	
		Number and installed capacity of biogas plants	
Solid Waste Management	Management of C&D waste	Number of C&D collection and transfer stations	
		Total installed capacity of C&D waste management plants (TPD)	
		Amount of recycled material sold/reused (concrete, ceramics, iron, wood, etc,.)	
	Management of Legacy waste	Quantity of legacy waste in all the identified dumpsited underwent remediation	
		Number of eco parks	
	Waste management through circular economy	Dry waste being processed out of total dry waste collected	
		Total dry waste collected and capacity of dry waste processing facility	
		Number of waste management based entrepreneurship supported	

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
Water and Wastewater Management	Management of water bodies 1. Marking and bund construction around the boundaries of the water bodies. 2. Restoration of wetlands 3. Restoration and softscaping of lakes	Wastewater nalahas emptying into water bodies and Interception and Diversion (I&D) works undertaken	Improved water access, groundwater conservation, and rejuvenated water bodies support sustainable water management and resilience. Reduced GHG emissions from wastewater, and enhanced sanitation services contribute to cleaner and healthier communities
		Water quality assessment test for the lakes	
		Amount spent on lake restoration/ dredging	
		Number of employment generated for lake restoration/ dredging	
		Number of wetlands rejuvenated/restored	
		Number of lakes restored, dredged and softscaping carried out	
Water and wastewater management	Groundwater management 1. Construction of rainwater harvesting structures (RwH) across commercial and residential buildings 2. Construction of RwH in PRI buildings 3. RwH in all suitable tourist accommodations	Number of public buildings (Government offices, government schools, institutes, etc.) having functional rainwater harvesting mechanism	
		Number of PRI buildings having functional rainwater harvesting mechanism	
		Percentage of public/PRI buildings covered with RwH mechanism	
		Number of hotels/lodges/ guest houses with RwH structures	
		Number of new buildings with RwH structures	

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
	Wastewater management 1. Enhancing stormwater infrastructure 2. Enhancing domestic wastewater management infrastructure 3. Enhancing industrial wastewater management infrastructure	Percentage (length) of roads with proper storm water drain coverage	
		Number of silt traps installed at outfall point of drains	
		Number of trench grates installed along the curb of the road in residential and civil line area	
		Number of households connected to sewage system	
		Percentage of households connected to drainage/ sewage network	
		Capacity of installed, operational, and maintained STPs	
		No. of DEWATS installed in the villages within the planning area	
		Capacity of installed, operational, and maintained ETPs	
		Number of rural households with septic tank and FSTP	
Tourism	Incorporate sustainable waste management awareness with tourism activities	Number. of capacity building workshops organised for hospitality professionals (waste, management)	Increased sustainability practices in hospitality, including water management, waste management and energy efficiency, enhance eco-friendly tourism experiences.
		Number of 'Swacchta Saarthis' deployed at key locations	
		Number of hotels/ lodges/rest houses with IEC material on waste segregation and disposal displayed	
		Number of solar water kiosks installed and operational at public places	
		Percentage of hotels/ lodges/guest houses with sustainable infrastructure (ECBC compliant,etc.)	

Category	Proposed Interventions	Broad Suggested Indicators	Broad Anticipated Outcomes
Sustainable Agriculture	Increased use of organic fertilisers, promoting balanced rationing for livestock and alternate wetting and drying of paddy fields	Quantity of nano urea and organic fertilisers used annually (in tonnes)	Increased sustainability Enhanced crop productivity Improved soil quality Reduced Emissions
		Quantity of improved feed supplements incorporated in the livestock diet (in tonnes)	
		Annual productivity of crops	
		Agriculture area affected by extreme weather events (Hectare) and change in production of crops (tonnes)	
		Area of cultivated rice under multiple aeration and System of Rice Intensification	
Enhancing Carbon Sequestration	1. Promoting social and agroforestry 2. Enhancing Carbon stock density through reforestation and afforestation.	Percentage increase in tree cover in the planning area since baseline year	Expanded green cover, enhanced carbon sequestration leading to reduced GHG emissions, improved biodiversity conservation, and increased urban green spaces for environmental and social benefits.
		Number of trees planted/ plantation activities carried out	
		Number of plants survived	

9 Conclusion and Way Forward

Virudhunagar's journey towards achieving carbon neutrality by mid-century presents a transformative opportunity to align its industrial, transport, and other energy sectors with sustainable development principles. This decarbonisation plan lays a comprehensive foundation for mitigating greenhouse gas emissions while fostering economic growth in the district. By adopting key strategies, such as transitioning to renewable energy, promoting energy efficiency, electrifying the transport sector, and implementing carbon capture technologies, Virudhunagar can significantly reduce its emissions across multiple sectors.

As an industrial hub, Virudhunagar's decarbonisation efforts will necessitate targeted measures, such as the implementation of carbon capture and utilisation (CCU) technologies. However, the economic feasibility and practical applicability of such technologies need to be thoroughly evaluated. Given the current constraints, widespread adoption of CCU is likely to be achievable only in the long term.

The success of this plan hinges on **robust implementation, continuous stakeholder engagement, and sustained collaboration** between government agencies, industries, and local communities. For the implementation of this plan, a dedicated **project management unit (PM**U) could be formed which will monitor and provide the implementation support for the overall execution of the plan.

Further, the decarbonisation plan should be **reviewed and updated periodically** to incorporate the latest advancements in technology, changes in policy frameworks, and evolving socio-economic conditions. This will ensure that the strategies remain relevant and aligned with the district's long-term vision.

A **central repository of energy, emissions, and progress-related data** should be established to enable transparent monitoring and tracking. The availability of real-time, granular data will facilitate informed decision-making and course corrections where necessary. This will also enhance accountability among stakeholders.

By implementing measures/interventions in the decarbonisation plan, Virudhunagar can establish itself as a model for district-level decarbonisation in India. The plan's holistic approach, combined with adaptive strategies and collaborative efforts, will enable the district to balance economic growth with environmental sustainability, ensuring a thriving and resilient future for its residents.

Annexures

Annexure 1

Methodology of Climate Variability

Climate variability refers to variations in the mean state of the climate parameters (temperature, rainfall, etc.) and other statistics (such as standard deviations, statistics of extremes, etc.) on temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or due to variations in natural (e.g. solar and volcanic) external forcing (external variability).

Rainfall variability has been analysed for the Southwest monsoon (June to September) and Northeast monsoon (October to December) seasons. Additionally, the precipitation extremes, such as the number of rainy days, Consecutive Dry Days (CDD), and heavy rainfall amounts (RX1DAY, RX5DAY), have been analysed.

Temperature has been analysed for the summer season (March to May) and the winter season (December to February). The temperature extremes such as warm days (%), cold days (%), Heat wave duration and frequency have been analysed.

To assess future climate projections for Virudhunagar, the analysis uses the NEX-GDDP (0.25 x 0.25) bias-corrected, high-resolution, statistically downscaled dataset derived from 20 Global Climate Models (GCMs) under the CMIP5 framework. Projections are made across two greenhouse gas emission scenarios: RCP4.5 (medium emission) and RCP8.5 (high emission), covering the time periods 2021-2040, 2041-2060, 2061-2080, and 2081-2100

Rainy day: A rainy day, according to the India Meteorological Department, is defined as any day receiving >2.5 mm rainfall.

Consecutive Dry Days (CDD): Maximum number of consecutive dry days per time period with daily precipitation amount of less than 1 mm.

RX1DAY: Highest 1-Day precipitation amount.

RX5DAY: Highest consecutive 5-Day precipitation amount.

Warm days: Percentage of days when maximum temperature greater than the 90th percentile

Cold days: Percentage of days when maximum temperature less than the 10th percentile

Annexure 2

Methodology- GHG Emission Profile- Virudhunagar

The GHG inventory has been developed for the period 2005 to 2022, accounting for carbon-dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. The inventory covers the four emission sectors, namely, Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry & Other Land Use (AFOLU) & Waste, and relevant sub-sectors, as per the IPCC methodology and guidelines.

The GHG inventory follows a robust approach based on information received from relevant line departments of the Government of Tamil Nadu, and reports published at national and state level, as detailed in table 2 The emission factors are extracted from Govt. of India's inventory submissions.

The GHG estimation is based on IPCC Tier 1 (T1) and Tier 2 (T2) approaches. The best effort was made to source activity data and emission factors at the state-level. Although the T2 approach was prioritised, T1 has been followed in the absence of country-specific emission factors. The sector-wise approach is as detailed in table 2.

The inventory also estimates the Global Warming Potentials (GWP) for CH_4 and N_2O based on the GWP of greenhouse gases for a 100-year timeframe, as per IPCC AR2 (IPCC, 1995).

Table 2: Sector-wise Data source, Tiers and Assumption Used for Emission Estimations

IPCC ID	Category	Data Source	Approach	Assumptions
ENERGY				
1A1 a	Captive Power Plant	a. Electricity generation data based on fuel-type (Coal and Diesel) of district for the year 2018-19 obtained from CEA b. Electricity generation data based on fuel-type (Coal) for Tamil Nadu for the years 2004-05 to 2022-23 obtained from CEA General Review Report.	T2	The activity data for the Coal and Diesel were estimated using the following assumption: • **Coal Consumption:** a. The coal consumption by Captive power plants of Tamil nadu were estimated between 2005 and 2022 using the electricity generation data and specific gas

IPCC ID	Category	Data Source	Approach	Assumptions
		c. Specific coal consumption data for the years 2005 to 2022 was obtained from CEA General Review Report.		consumption. For 2023, the activity data was estimated using the CAGR. b. For Virudhunagar district, 2018's coal consumption by Captive Power Plant was estimated using the electricity generation data and specific coal consumption. c. The percentage share of coal consumption in 2018 was calculated for Virudhunagar district , which was then applied on year-on-year (2005 to 2023) estimated gas consumption to data of Tamil Nadu by captive power plant to estimate the district's gas consumption by captive power plant. • **Diesel Consumption:** a. For Virudhunagar district, 2018's diesel consumption by Captive Power Plant was estimated using the electricity generation data and specific diesel consumption. b. The percentage share of diesel consumption in 2018 was calculated for Virudhunagar district, which was then

IPCC ID	Category	Data Source	Approach	Assumptions
				applied year-on-year (2005 to 2022) to the total Diesel consumption of Virudhunagar district (PPAC data) to estimate the diesel consumption by captive power plants.
1A2	Industrial Energy	Fuel consumption data of FO/LSHS, LDO,HSD, Bitumen, Petcoke and Others data were obtained from the Petroleum Planning and Analysis Cell (2006 to 2022)	T2	• The emissions from overall Industrial energy was estimated due to unavailability of industry-wise fuel consumption data. • The district level FO/LSHS, LDO,Petcoke and others data from the PPAC was considered solely for the Industries category. • The HSD consumption for the Industries category was estimated by applying the National-level percentage share of HSD consumption in retail and the Tamil Nadu state-level percentage share of Diesel consumption for Industrial purposes (obtained from PPAC report 2013[1] and 2021[2]) on the overall district's HSD consumption. Bulk HSD? • Bitumen consumption in industries was estimated by allocating 5% of total

1 All India Study on Sectoral Demand on Diesel and Petrol , Petroleum Planning and Analysis Cell (2013)
https://ppac.gov.in/uploads/rep_studies/1674814577_20141111032945006974OAllIndiaStudyonSectoralDemandofDiesel%20%282%29.pdf

IPCC ID	Category	Data Source	Approach	Assumptions
				bitumen consumption in Virudhunagar district.
1A3b	Road Transport	Fuel consumption data of Motor Spirit and HSD was obtained from the Petroleum Planning and Analysis Cell (2006 to 2022)	T1, T2	The fuel consumption data of Motor Spirit and HSD data was estimated using the below assumptions, since data was unavailble. **a. Motor Spirit:** The year-on-year national level retail motor spirit percentage share (obtained from Indian Petroleum and Natural Gas statistics) and the percentage share of Petrol-retail consumption in Road transport for Tamil Nadu (obtained from PPAC report 2013) was applied to the district's overall motor spirit consumption to estimate the Virudhunagar district's motor spirit consumption in road transport. **b. HSD:** The year-on-year national level road transport private sales and retail HSD percentage share (obtained from Indian Petroleum and Natural Gas statistics) and the percentage share of Diesel-retail consumption in Road transport for Tamil Nadu (obtained from

IPCC ID	Category	Data Source	Approach	Assumptions
				PPAC report 2013 and 2021) was applied to the district's overall HSD consumption to estimate the Virudhunagar district's HSD consumption in road transport. • For the year 2005, the overall district's motor spirit and HSD fuel consumption data was estimated using the CAGR method.
1A4	**Other Sector**			
1A4a	Commercial Energy	Fuel consumption data of LPG HSD and Kerosene was obtained from the Petroleum Planning and Analysis Cell (2006 to 2022)		The fuel consumption data of LPG, HSD and Kerosene data was estimated using the below assumptions, since data was unavailble. **a. LPG:** District level commercial LPG fuel consumption data was estimated by applying the National-level percentage share of LPG consumption at commercial level on the overall District-level fuel consumption data. **b. HSD:** District-level commercial HSD consumption data was estimated by applying the National-level retail and private sales percentage share and state-level percentage share Diesel

IPCC ID	Category	Data Source	Approach	Assumptions
				consumed for the other sector (obtained from PPAC report 2013) along with the percentage share of Diesel consumed in the Commercial sector on the overall district-level fuel consumption data. **c. Kerosene:** District-level commercial Kerosene fuel consumption data was estimated by applying the National-level percentage share of Kerosene consumption at commercial level on the overall District-level fuel consumption data. • For the year 2005, the overall district's motor spirit and HSD fuel consumption data was estimated using the CAGR method.
1A4b	Residential Energy	Fuel consumption data of Kerosene, LPG and HSD was obtained from the Petroleum Planning and Analysis Cell (2006 to 2022)		• The fuel consumption data of Kerosene, LPG and HSD data was estimated using the below assumptions, since data was unavailable. **a. Kerosene:** District-level residential Kerosene fuel consumption data was estimated by applying the National-level percentage share of

IPCC ID	Category	Data Source	Approach	Assumptions
				domestic Kerosene consumption and national-level percentage share of private sales of kerosene on the overall District-level fuel consumption data. **b. LPG:** District-level residential LPG fuel consumption data was estimated by applying the National-level percentage share of domestic LPG consumption and national-level percentage share of private sales of LPG on the overall District-level fuel consumption data. **c. HSD:** District-level residential HSD consumption data was estimated by applying the National-level retail and private sales percentage share and state-level percentage share Diesel consumed for the other sector (obtained from PPAC report 2013) along with the percentage share of Diesel consumed in the Residential sector on the overall district-level fuel consumption data.

IPCC ID	Category	Data Source	Approach	Assumptions
				• For the year 2005, the overall district's motor spirit and HSD fuel consumption data was estimated using the CAGR method.
1A4c	Agriculture	Fuel consumption data HSD was obtained from the Petroleum Planning and Analysis Cell (2006 to 2022)		• District-level residential HSD consumption data was estimated by applying the National-level retail and agriculture consumption percentage share and state-level percentage share Diesel consumed in the agriculture sector (obtained from PPAC report 2013 and 2021) on the overall district-level fuel consumption data. • For the year 2005, the overall district's motor spirit and HSD fuel consumption data was estimated using the CAGR method.
IPPU				
2A1	Cement Production (Mineral Industry)	Ramco Cements: Production data -2014-15 to 2021-22 from Indian Minerals Yearbook 2005-06 to 2013-14 -Data from district Tamil Nadu Cements: Production data from 2015-16 to 2022-23 from Tamil Nadu Cements Corporation Ltd Annual Reports	T1	Wherever direct data was not available, installed capacity/ preceding year production data was considered.

IPCC ID	Category	Data Source	Approach	Assumptions
2D1	Lubricant Use (Non energy products from fuels and solvent use)	Lubricant Consumption data received from the Petroleum Planning and Analysis Cell (2006 to 2022)	T1	Wherever direct data was not available, CAGR was applied to estimate consumption data

IPCC ID	Category	Data Source	Approach	Assumptions
AFOLU				
3A	Livestock	Livestock data of cattle, buffaloes, sheep, goats, pigs, horses & ponies, donkeys and poultry: **a.** 2004 and 2017 district-level livestock population data obtained from Tamil Statistical Handbook 2018 and 2022 **b.** 2019 district-level population data obtained from Open Government Data (OGD) Platform India **c.** 2012 district-level livestock population data of cattle and buffaloes (age-wise) and other livestock population data was obtained from Department of Animal Husbandry and Dairying - Govt of India	T1,T2	• District-level cattle and buffaloes' data for years 2004, 2007 and 2019 were estimated by applying the percentage share of age-wise cattle and buffaloes population data of 2012. • For years between 2004 and 2007;2007 and 2012, and 2012 and 2019, livestock population data were estimated using the interpolation method. While for the years 2020 to 2022, livestock population data were estimated using the CAGR method.
	Biomass Burning in Forestland	Not estimated		
3C1b	Biomass Burning in Cropland	The crop production data at district-level was obtained from Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, GoI **a.** Rice, Cotton, Sugarcane Groundnut and Ragi: 2004-05 to 2019-20. **b.** Maize: 2004-05, 2006-07 to 2019-20	T1	Wherever direct data was not available, suitable statistical methods were applied for estimation like the CAGR and Interpolation method.

IPCC ID	Category	Data Source	Approach	Assumptions
		c. Small millets: 2004-05 to 2009-10;2011-12 and 2013-14 and 2019-20 **d.** Bajra and Jowar: 2004-05 to 2009-10;2011-12 and 2013-14 and 2019-20		
3C7	Rice Cultivation	2004-05 to 2019-20 Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, GoI	T2	• The percentage of rice cultivated area under different water management regimes of Tamil Nadu is assumed to be the same for Virudhunagar district. • Wherever direct data was not available, suitable statistical methods were applied for estimation like CAGR.
3C4 & 3C5	Agriculture Soils	Nitrogen Consumption data 2021- District Statistical Handbook 2006- District Agriculture Plan 2008 Urea Consumption data 2011-12- 2020-21- Tamil Nadu Dashboard 2021-22, 2022-23– District Statistical Handbook	T1 and T2	Wherever direct data was not available, suitable statistical methods were applied for estimation like the CAGR and Interpolation method.
3B2,3B3, 3B5 & 3B6	Land Use (except Forest land)	2005-06, 2011-12 and 2015-16 of LULC from BHUVAN		• In the absence of the Land use Land Cover Change (LULC) matrix, the emissions from LULC was estimated by taking the difference between 2005-06 and 2011-12 ,and 2011-12 and 2015-16 for the categories of

IPCC ID	Category	Data Source	Approach	Assumptions
				Agricultural Land,Other Land and Settlements.
3B1	Forest Land	a. District-level Forest cover data for years 2004, 2006, 2008, 2010, 2013, 2015, 2017, 2019 and 2021 obtained from ISFR reports. b. Carbon stock density data of Tamil Nadu was obtained for years 2015, 2017, 2019 and 2021 from ISFR reports	T2	a. Forest Cover: For the years between 2004 and 2021 was estimated using the interpolation method. b. Carbon stock Density: 2015 CSD was applied between 2005 and 2015; 2017 CSD was applied for 2016-2017; 2019 CSD was applied for the years between 2018 and 2019; and 2021 CSD was applied for the years between 2020 and 2021 c. Since, the forest cover data for the year 2022 was not available, hence the emissions were kept the same as of 2021.
Waste				
4A	Solid Waste Disposal	**Population Data:** census 1951, 1961, 1971, 1981, 1991, 2001, 2011 **Per capita Generation:** Waste Generation and Composition for 2004-05, Central Pollution Control	T1, T2	• Population in between census years were calculated applying decadal population growth percentage. • The proportion of solid waste going to the dumpsite for years between 1951 and 2015

IPCC ID	Category	Data Source	Approach	Assumptions
		Board (CPCB), Annual Review Report: 2014-15, CPCB ; Per capita waste generation data for 2022 received from Tamil Nadu Pollution Control Board (TNPCB) **Proportion going to Landfill-** CPCB Annual reports for 2016-2020 2021-2022- Data received from the district (TNPCB). 1951 to 2015 from NATCOM 2 **DOC:** Integrated Modeling of Solid Waste in India (March, 1999) CREED Working Paper Series no 26 and CPCB, 1999 2005 CPCB and NEERI study in 59 cities The Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Urban Development, GoI (2015): Manual on Municipal Solid Waste Management-2016, Table 1.6		was taken as 70% (National Average) as per NATCOM 2 (MoEFCC,2012). • Estimates are based on state level values of per capita waste generation. • State-level DOC proportions were used to estimate GHG emissions due to lack of data at the district level
4D1	Domestic Wastewater Treatment and Discharge	**Population Data:** census 2001, 2011 **Protein Intake:** MOSPI **BOD:** National Environmental Engineering Research Institute (NEERI). 2010: Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian	T1	• Population in between census years were calculated applying decadal population growth percentage • Year-wise values of BOD generated per person are not available, hence an average national value for BOD of 40.5

IPCC ID	Category	Data Source	Approach	Assumptions
		Network for Climate Change Assessment **STP:** NGT monthly progress report 2020 to 2024 STP commissioning date was obtained from National Inventory of Sewage Treatment Plants 2021 **Urban Degree of Utilisation:** Availability and Type of Latrine facility is sourced from Census report 2011 and 2001 (Census of India, Ministry of home affairs, Government of India)		gm/person/day is used across the reporting period. While converting BOD values from daily basis to an annual basis, 365 days have been assumed across all years, including for leap years. • Since the installed and actual utilization data for STPs from 2014 is unavailable, the 2020 data was used to estimate the 2014 capacity, assuming no significant changes in the system during this period. • Based on the NATCOM 2 and the 2006 IPCC Guidelines, the default values of Correction Factor are 1.25 for 'I' for collected wastewater and 1 for uncollected wastewater respectively are used in this assessment • 2011 census data is used to find the degree of utilisation of Septic tank, Sewer and Public latrine of the year 2001. Corresponding proportions of these systems which are available in the Census

IPCC ID	Category	Data Source	Approach	Assumptions
				2011 data have been used to estimate the percentage distribution of these systems in year 2001
4D2	Industrial Wastewater	**Dairy**- Processing Installed capacity of dairies - Dairy development policy note, Animal Husbandry, Dairying and Fisheries Department. 2012-13 to 2015-16, 2018-19 to 2022-23 **Meat**- Production data from 2009-10 to 2018-19 from tn.data.gov **Fish processing** data 2010-11, 2016-17, 2020-21 data from statistical handbook Pulp and paper data latest year data from TNPCB		Wherever direct data was not available, installed capacity was taken as production data and suitable statistical methods were applied for estimation like CAGR.

Annexure 3

Scenarios

1) **Livestock**

Year	MES		
	Enteric Fermentation		Manure Management (GOBAR-Dhan Scheme)
	Balanced Rationing	Feed Supplements	
2030	20%	15%	20%
2040	40%	30%	40%
2050	60%	45%	60%

Year	AES		
	Enteric Fermentation		Manure Management (GOBAR-Dhan Scheme)
	Balanced Rationing	Feed Supplements	
2030	30%	25%	30%
2040	60%	50%	60%
2050	90%	75%	90%

2) **Agriculture Soils**

Year	Organic Fertiliser Substituted for Total Nitrogen and Urea		Nano Urea Substituted for Urea	
	MES	AES	MES	AES
2030	10%	15%	25%	35%
2035	20%	30%	50%	70%
2040	30%	45%	75%	100%

2045	40%	60%	100%	100%
2050	50%	75%	100%	100%

3) Rice Cultivation

MES							
Year	**Multiple Aeration (MA)**	**Single Aeration (SA)**	**Continuous Flooding (CF)**	**Upland**	**Rainfed flood prone**	**Rainfed drought pone**	**Deep water**
2022	20%	43%	30%	1%	1%	3%	1%
2030	27%	39%	27%	1%	1%	3%	1%
2040	42%	29%	21%	1%	1%	3%	1%
2050	60%	18%	15%	1%	1%	3%	1%
AES							
Year	**Multiple Aeration (MA)**	**Single Aeration (SA)**	**Continuous Flooding (CF)**	**Upland**	**Rainfed flood prone**	**Rainfed drought pone**	**Deep water**
2022	20%	43%	30%	1%	1%	3%	1%
2030	27%	39%	27%	1%	1%	3%	1%
2040	51%	23%	19%	1%	1%	3%	1%
2050	77%	7%	9%	1%	1%	3%	1%

4) Domestic Wastewater

Year	**Percentage of Treatment**	
	MES	**AES**
2030	50%	70%
2040	80%	100%
2050	100%	100%

5) Enhancing Carbon Sequestration Potential

a. Shifting 100 percent of 1,40,652 ha and 92,166 ha of barren or fallow or cultivable waste land or land put to non- agricultural uses to social forestry by 2050 under MES and AES Scenarios, respectively.

Land Classification	Percentage of land converted to Agro / Socio Forestry	
	MES	AES
Barren and Uncultivable Uses	10%	20%
Land putto Non-agricultural uses	5%	10%
Cultivable waste	50%	75%
Current Fallows	10%	20%
Other Fallow land	50%	75%

1. Agro/Social Forestry in Follow land under MES and AES scenarios

Year	% of Fallow land shifting to Social Forestry	Trees planted per hectare	Carbon stored per tree per year (kg)	Carbon sequestration potential with 60% survival rate (tCO_2/yr)	
				MES	AES
2030	25%	200	30	106	164
2040	60%			253	391
2050	100%			557	861

b. Increasing the Carbon stock density from 82.25 tons per hectare (as recorded in 2021) to 87.26 tons per hectare (recorded in 2015), while maintaining the forest area at its 2021 extent of 35294 hectares under

1. MES

Year	% increase in carbon stock density	Carbon stock density	Carbon sequestration potential ($ktCO_2$/yr)
2030	10%	82.75	6

2040	30%	83.75	13
2050	50%	84.76	13

2. AES

Year	**% increase in carbon stock density**	**Carbon stock density**	**Carbon sequestration potential ($ktCO_2$/yr)**
2030	30%	83.75	18
2040	60%	85.26	19
2050	90%	86.76	19

Annexure 4

Land utilization 2022-23	**Area (in ha)**
Forest	26,466
Uncultivable waste	4,525
Land put to Non- Agricultural use	70,510
Cultivable waste	9,399.275
Permanent pastures / grazing lands	804
Land under miscellaneous tree crop	2,019.10
Current fallow	8,290.63
Other fallow land	1,65,318.63
Net area sown	1,36,989.65
Total geographical area according to village records	4,24,322.98

Demography and 2050 projections for Virudhunagar District

Particulars	Year 2021	Year 2050	Percentage change
Demographic details			
Urban Population	11,83,075	15,23,203	22.33%
Rural Population	9,62,062	8,96,690	-7.88 %
Total Population	21,50,395	24,19,893	11.14%
No. of Households	6,07,770	7,30,926	16.85 %

Year	Population	Source
2011	19.4 lakhs	District Handbook 2022-23
2021	21.5 lakhs	Vasudha's analysis
2031	23.4 lakhs	Vasudha's analysis
2041	24.1 Lakhs	Vasudha's analysis
2050	24.1 Lakhs	Vasudha's analysis

Important Demographic and Economic Indicators of the District	
Location	South West of Tamil Nadu
Latitude	9.05° to 9.75° N
Longitude	77°28' to 78°50' E
Geographical area sq. km.	4243 Sq. Km
Revenue division	3 (Sivakasi, Sattur, Aruppukottai)
Taluks	10
Firkhas	39
Town Panchayats	9
Revenue villages	600
Municipality	5
Panchayath Union	11
Village Panchayats	450
Total Population (Census 2011)	19,42,288
Population Density	458
Population growth decadal (2001-2011)%	10.91
Urban Population (Census 2011)	9,80,226
% of the urban population	50.47
Rural population (Census 2011)	9,62,062
% of the rural population	49.53
Sex ratio (Females to 1000 males) (Census 2011)	1,007
Literacy rate %	80.15

List of Cement Industry captive power plants in Virudhunagar district for the year 2018-19 (as on 20.08.2020) *(Source: CEA)*

Name of Industry with Address	Fuel Used	Type of Industry	Installed Capacity (MW)	Gross Generation (GWh)
Dalmia Cements (Bharat) Ltd.,	Steam	Cement	45	188.59
Dalmia Cements (Bharat) Ltd.,	Diesel	Cement	12	0.033
Ramco Cements Ltd., PAC Ramasamyraja Nagar	Diesel	Cement	16	0.024
Ramco Cements Ltd., PAC Ramasamyraja Nagar	Steam	Cement	42	154.37
Tamilnadu Cements Corp. Ltd.	Diesel	Cement	4	0.0384

Summary Table: Sector-wise BAU, MES and AES Emissions/Removals

Sector	GHG Sources and Sink Categories	2050		
		BAU $ktCO_2e$	**MES $ktCO_2e$**	**AES $ktCO_2e$**
Energy	**Public Electricity Generation**	**NA**	**NA**	**NA**
	Captive Power Plants	146	0	0
	Industries	602	301	0
	Road Transport	483	161	107
	Commercial	45	32	10.4
	Residential	262	158	103
	Agriculture	35	22	0
	Fisheries	NA	NA	NA
	Energy Total	**1574**	**674**	**220**
IPPU	**Cement Industry**	**1383**	**1383**	1383
AFOLU	**Aggregate Sources and Non-CO_2 Emissions Sources on Land**	**115.08**	**67.08**	**48.08**
	Agriculture Soil	33	16	8

Sector	GHG Sources and Sink Categories	2050		
		BAU ktCO$_2$e	MES ktCO$_2$e	AES ktCO$_2$e
	Biomass burning in cropland	4.08	4.08	4.08
	Rice Cultivation	78	47	36
	Land emissions	**0.14**[4]	**0.14**	**0.14**
	Land removals	**-170.80**	**-995**[5]	**-1428**
	Net land emissions/removals	**170.66**	**-995**	**-1428**
	Livestock	**339**[6]	**280**	**245**
	AFOLU total	**283.42**	**-648**	**-1134**
Waste	Solid Waste Disposal	1.5	0.3	0.3
	Domestic Wastewater	112	21	21
	Industrial Wastewater	11	4	2
	Waste Total	**124.5**	**26**	**24**
Gross Emissions		**3535**	**2430**	**1921**
Net Emissions		**3364**	**1435**	**493**

[4] Land sub-sector includes emissions/removals from categories namely, Agriculture Land (-0.05 kt CO_2e), Settlements (-0.06 kt CO_2e),Other Land(0.14 kt CO_2e) and Forest Land (-170.70kt CO_2e) in 2022. Since no change in land use pattern is foreseen, the emissions/removal in 2050 from the land category is assumed to be the same as that of 2022.

[5] Under the MES and AES scenario, the enhanced sequestration is achieved through: (a) adapting agro/social forestry in land classified as cultivate waste land (MES=50%, AES=75%), other fallows (MES=50%, AES=75%), current fallows (MES=10%, AES=20%), barren and uncultivable waste land (MES=10%, AES=25%), land put to non-agriculture uses (MES=5%, AES=10%), and (b) restoring the carbon stock density recorded in 2021 (82.25 t/ha) to that recorded in 2015 (87.26 t/ha).

[6] Livestock sub-sector emissions projected in 2050 is 339 ktCO$_2$e consists of emissions from Enteric Fermentation (320 ktCO$_2$e) and Manure Management (18 ktCO$_2$e).

Annexure 5

List of Schemes and Policies for Convergence with Virudhunagar's Decarbonisation Plan

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			**Agri.**	**Buil.**	**Trans.**	**Ind.**	**Waste**	**AFOLU**
A.	**Promoting Shift to Renewable Energy**							
A.1	Development of Solar/Green Cities Programme	• Up to Rs. 50 lakh per city/town is provided for preparation and implementation of master plans with a goal of minimum 10% reduction in projected total demand of conventional energy at the end of 5 years. This is to be achieved through EE and RE installation measures. ***Who applies for it?*** State Governments nominate cities.		YES			YES	
A.2	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM)	• Focuses at de-dieselisation of the farm sector and enhancing income of farmers. • Subsidy up to 30-50% of the total cost for installation of standalone solar pumps and solarization of existing grid-connected agricultural pumps.	YES					

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			**Agri.**	**Buil.**	**Trans.**	**Ind.**	**Waste**	**AFOLU**
		• Farmers can install grid-connected power plants up to 2 MW on their barren/fallow land and sell electricity to local DISCOM at a tariff determined by state regulators. ***Who can apply?*** Individual Farmers, FPOs and Cooperatives						
A.3	PM Surya Ghar Muft Bijli Yojana	Under the scheme, households will be provided with a subsidy to install solar panels on their roofs. The subsidy will cover up to 40% of the cost of the solar panels. The scheme is expected to benefit 1 crore households across India. It is estimated that the scheme will save the government Rs. 75,000 crore per year in electricity costs. ***Who can apply?*** Individual Households		YES				
A.4	Pradhan Mantri Ujjwala Yojana	Aims at making clean cooking fuel available to rural and deprived households. LPG connections are now being released under an additional 75 lakh connections target.[7] ***Who can apply?*** Adult women belonging to SC/ST/OBC households, those enrolled in Pradhan Mantri Awas Yojana (Gramin), Anatyodaya Anna Yojana (AAY), tea and ex-tea		YES				

[7] The original target under the scheme was to release 8 crore LPG connections to deprived households by March 2020. Under Ujjwala 2.0, an additional allocation of 1.6 Crore LPG connections with special facilities to migrant households is provided. This target was achieved during December 2022.

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			Agri.	Buil.	Trans.	Ind.	Waste	AFOLU
		garden tribes, forest dwellers, SECC households (AHL TIN) and poor households as per 14-point declaration.						
A.5	Development of Green Hydrogen Hubs under National Green Hydrogen Mission	The Mission provides infrastructure support and policy incentives for private investments in Green Hydrogen Parks in areas close to renewable energy sources, industrial clusters with high hydrogen demand, access to water etc. V.O Chidambaranar Port in TN has already been selected as one of the first Green Hydrogen Parks. ***Who can apply?*** Central and State Public Sector Undertakings, Private Sector Companies, State Corporations and Consortiums through the Scheme Implementing Agency (SIA)	YES		YES	YES		
A.6	Incentives for setting up of biogas unit of size up to 25 M^3 under National Biogas Programme	Central Financial Assistance up to Rs. 70,400 per plant depending upon the State and size of the biogas plant. Additional Incentives, • An additional subsidy of Rs.1600 if the biogas plant is linked with a sanitary toilet or MNRE approved Biogas slurry filter unit. • Rs. 3,000 per biogas plant for size ranging from 1 M3 to 10 M3 and Rs. 5,000 for size ranging from 15 M3 to 25 M3 as turnkey job fee for biogas plants involving onsite construction such as fixed dome design Deenbandhu Model, floating gas holder KVIC model etc .	YES			YES		

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			**Agri.**	**Buil.**	**Trans.**	**Ind.**	**Waste**	**AFOLU**
		• Rs. 10,000 per 100% biogas based Generator set/biogas engine water Pumping System (BPS) for meeting small farm needs and water pumping from the biogas plant of 10 to 25 M3. ***Who can apply?*** Individuals will own land/space about 50 sq meter area for installation of small biogas plants.						
A.7	Incentives for setting up of biogas unit of size above 25 M^3 under National Biogas Programme	Central Financial Assistance up to Rs. 45,000 per kW for power generation and Rs. 22,500 per kWeq thermal/cooling for thermal application is provided. Administrative charges up to 10% of the CFA or Rs. 250,000 for power generation and 5% of the CFA or Rs. 100,000 for thermal application will be provided for technical supervision, submission of project completion and commissioning reports, and monitoring of projects. ***Who can apply?*** Individuals will own land/space.	YES			YES		
B.	**Incentivising Energy Efficiency in Buildings**							
B.1	Market Transformation for Energy	Aims to make energy-efficient appliances more affordable in specific sectors. It comprises of two programs - • Bachat Lamp Yojana (BLY)[8] provides CFLs at the same		YES		YES		

[8] Promoted energy efficient lighting in the country.

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			**Agri.**	**Buil.**	**Trans.**	**Ind.**	**Waste**	**AFOLU**
	Efficiency (MTEE)	price as in-candescent bulbs. The cost difference is adjusted by the project implementer through carbon credits earned. ***Who can apply?*** Residential Consumers • Super Efficient Equipment Programme (SEEP) provides financial stimulus to manufacturers to produce and sell super-efficient appliances. Ceiling fans were the first appliance to come under SEEP with a target of making them 50% more efficient than market average ***Who can apply?*** Manufacturers/Industries						
B.2	Unnat Jyoti by Affordable LEDs for All (UJALA)	Aims to make LED Lighting more affordable for all. It promotes replacement of incandescent lamps with LED (Light-Emitting Diode) bulbs by providing LED bulbs to domestic consumers at a low cost. ***Who can apply?*** Domestic Households with a Metered Connection[9]		YES				

[9] National Ujala Dashboard. Accessed at http://ujala.gov.in/

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			Agri.	Buil.	Trans.	Ind.	Waste	AFOLU
C.	Decarbonising Industrial Sector							
C.1	Perform, Achieve and Trade (PAT)[10]	Focused at reducing specific energy consumption in energy-intensive industries, improving their energy efficiency and enhancing cost effectiveness through certification of excess energy saved which can then be traded. ***Who can apply?*** Designated consumers (DCs) (industrial units notified by Central Government to participate in PAT)				YES		
C.2	**MSME Sustainable (ZED) Certification**	Envisions promotion of Zero Defect Zero Effect (ZED) practices among MSMEs to improve their productivity, reduce waste and enhance their environmental consciousness. • Subsidy up to 80% for micro, 60% for small and 80% for medium enterprises on cost of ZED certification. • Additional subsidy of 10% for women/SC/ST owned MSMEs or those in NER/Himalayan/LWE/island territories/aspirational districts, as well as another 5% for MSMEs which are also a part of the SFURTI or Micro and Small Enterprises - Cluster Development Programme (MSE-CDP). • Up to 75% of the total cost of testing, maximum of Rs. 50,000				YES		

[10] Currently, PAT Cycle VII is in progress for the FY 2022-23 to the FY 2024-25, covering 707 designated companies with an overall energy saving target of around 8.5 million tonnes of oil equivalent (MTOE) in 9 major energy intensive sectors. Also, with the introduction of the Carbon Credit Trading Scheme (CCTS) in June 2023, industries including aluminium, cement, fertilisers, petrochemicals, petroleum refining, pulp and paper have moved from PAT to CCTS. Refineries, iron and steel plants and textile industries will transition out of PAT into CCTS by 2026-27. PAT will only cover thermal power plants.

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			Agri.	Buil.	Trans.	Ind.	Waste	AFOLU
		in financial assistance for testing/quality/product certification. • Up to Rs. 200,000 for consultancy for all ZED certified MSMEs. • Up to Rs. 300,000 in support for technology upgradation to Zero Effect solutions for all ZED certified MSMEs. ***Who can apply?*** Micro, Small and Medium Enterprises						
C.3	**Tamil Nadu MSME Capital Subsidy**[11]	• Capital subsidy up to 25% or maximum of Rs. 150,00,000 on the value of eligible plant and machinery. • Additional subsidy up to 5% of the plant/machinery value or a maximum of Rs. 500,000 for enterprises set up by women/SC/ST/PwD/Transgender entrepreneurs. • Additional capital subsidy at 25% of the plant and machinery value or maximum of Rs. 10,00,000 to promote cleaner and environmentally friendly technologies. ***Who can apply?*** All new Micro, Small and Medium Enterprises (including those engaged in solar energy equipments and electric vehicle components, clean building materials, charging infrastructure, pollution control equipments, bio technology etc)		YES	YES	YES		
C.4	**Tamil Nadu**	PEACE Scheme aims to promote energy efficiency in MSME units				YES		

[11] Department of MSME, Government of Tamil Nadu. Guidelines for Availing Capital Subsidy. Accessed at https://www.msmeonline.tn.gov.in/incentives/html_cye_CS.php

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			Agri.	Buil.	Trans.	Ind.	Waste	AFOLU
	MSME Energy Audit Subsidy (PEACE) Scheme[12]	so as to enable them to reduce costs and improve competitiveness. Under this scheme, • The Government will reimburse 75% of the cost of conducting an energy audit subject to a ceiling of Rs. 100,000 per energy audit per unit. • 50% of the cost of machinery and equipment replaced, retrofitted and technology acquired for implementing the recommendations of the audit will be subject to reimbursement to a maximum of Rs. 10,00,000. ***Who can apply?*** All existing Micro, Small and Medium Enterprises						
C.5	**Tamil Nadu Quality Certification (Q-cert) Scheme**	This scheme aims to encourage MSMEs to acquire quality standards and certifications for processes and products including ZED rating. The Government reimburses payments made to certification and/or consultancy agencies up to Rs. 200,000 for national level quality certification and Rs. 10,00,000 for international level quality certification. ***Who can apply?*** All existing Micro, Small and Medium Enterprises				YES		
C.6	**Green Industry**	Industrial projects undertaking initiatives in safety and energy		YES	YES	YES	YES	

[12] Department of MSME, Government of Tamil Nadu. Guidelines for Availing Energy Audit Subsidy. Accessed at https://msmeonline.tn.gov.in/incentives/html_cye_peace1.php

S.No	Scheme	Key Highlights	Applicability to Sectors					
Central & State Policies/Schemes			**Agri.**	**Buil.**	**Trans.**	**Ind.**	**Waste**	**AFOLU**
	Incentive under the Tamil Nadu Industrial Policy 2021[13]	efficiency, water conservation and greening (including green buildings) and pollution control solutions are provided a 25% subsidy on the cost of setting up of environmental protection infrastructure to a maximum of Rs. 1 Crore. ***Who can apply?*** Industries, including MSMEs						
C.7.	**TANSEED 3.0 Grant Programme by Tamil Nadu StartUp and Innovation Mission (TANSIM)**[14]	Grant funding up to Rs. 100,00,000 and an AWS promotion credit up to US$ 100,000 is provided to grant winners in agriculture, climate action and livelihood space. Key focus is on feeds, fodder, animal nutrition and waste to value/circular economy initiatives.	YES			YES		

[13] Government of Tamil Nadu. Tamil Nadu Industrial Policy 2021. Accessed at https://tidco.com/wp-content/uploads/2021/08/Industrial%20Policy%202021.pdf

[14] StartUp Tamil Nadu. TANSEED 3.0. Accessed at https://villgro.startuptn.in/

<table>
<tr><th>S.No</th><th>Scheme</th><th>Key Highlights</th><th colspan="6">Applicability to Sectors</th></tr>
<tr><th colspan="3">Central & State Policies/Schemes</th><th>Agri.</th><th>Buil.</th><th>Trans.</th><th>Ind.</th><th>Waste</th><th>AFOLU</th></tr>
<tr><td>D.</td><td colspan="8">Decarbonising the Transport Sector</td></tr>
<tr><td>D.1</td><td>PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) Scheme 2024[15]</td><td>Promotes faster adoption of electric vehicles (EVs), setting up of charging infrastructure and development of EV manufacturing ecosystem.
• Demand incentives at Rs.5,000 per kWh for e-2W and e-3W registered in FY 24-25 and for FY 25-26 as under,
<table>
<tr><td>Category</td><td>Incentive</td><td>Total No. of Vehicles to be supported</td></tr>
<tr><td>EV 2W</td><td>Rs. 2500 per kWh</td><td>24,79,120</td></tr>
<tr><td>EV 3W L5</td><td>Rs. 2500 per kWh</td><td>2,05,392</td></tr>
<tr><td>EV Buses</td><td>Rs. 20 lakh to Rs. 30 lakh depending upon the size</td><td>14,028</td></tr>
<tr><td>e-Ambulances</td><td colspan="2" rowspan="2">To be notified separately</td></tr>
<tr><td>e-Trucks</td></tr>
</table>
</td><td></td><td></td><td>YES</td><td></td><td></td><td></td></tr>
</table>

[15] The Electric Mobility Promotion Scheme 2024, implemented for the period from 1st April 2024 to 30th September 2024 is subsumed under PM E-Drive. Another scheme, Faster Adoption and Manufacturing of Electric Vehicle (FAME) had supported development of EV infrastructure. Phase II of this scheme concluded in March 2024. The suggestions received on scope of improvements in FAME under Phase I and II have been incorporated in the PM E-DRIVE. Source: Ministry of Heavy Industries, Government of India. Lok Sabha, Unstarred Question No. 2448. Phase-III of FAME Scheme. Accessed here. https://sansad.in/getFile/loksabhaquestions/annex/183/AU2448_7DstiP.pdf?source=pqals

		Other incentives include, • Grants for creation of capital assets (charging stations, testing agencies and others) • Support for IEC activities ***Who can apply?*** EV Buyers (claim for subsidy), Original Equipment Manufacturers (claim for reimbursement of subsidy)						
D.2	**Tamil Nadu Electric Vehicle Policy 2023**[16]	The policy provides special demand and supply sided incentives for promotion of electric vehicles and allied infrastructure in the State. Under the policy, the State targets increasing the share of electric buses to 30% of the fleet by 2030. Supply-Sided Incentives: • Investment Promotion Subsidy in the form of 100% reimbursement of SGST upon achieving a minimum eligible investment threshold of Rs. 50 Crore and minimum employment threshold of 50 jobs, whichever is lesser. (OR) • Turnover based Subsidy up to 2% of the project's annual turnover subject to a cap of 4% of the cumulative investment in eligible fixed assets for a period of 10 years from the date of commercial production. (OR) • Capital Subsidy of 15% of investment in eligible fixed assets. (OR) • Special ACC Capital Subsidy of 20% of investment in eligible fixed assets			YES	YES		

[16] Government of Tamil Nadu. Tamil Nadu Electric Vehicle Policy 2023. Accessed at https://investingintamilnadu.com/DIGIGOV/StaticAttachment?AttachmentFileName=/pdf/poli noti/TN Electric Vehicles Policy 2023.pdf

- Electricity tax exemption (100%) for a period of 5 years
- 100% exemption on stamp duty for purchase/lease of land from government agencies or in case of private land, as a backup subsidy for up to 50 acre
- Other interest subvention, transition and special incentives for MSMEs.

Who can apply? Micro, Small and Medium Enterprises
Demand Sided Incentives

Type	Category	Incentive based on better capacity (Rs./kWh)	Maximu m Incentive (Rs.)	Number of vehicles to support per year
Private	e-Cycles	-	20% of cost up to Rs. 5000	6,000
Commercial	e-2Wheelers	10,000/ kWh	30,000	6,000
Commercial	e-3Wheelers (autos/ light goods carriers)	10,000/ kWh	40,000	15,000
Commercial	e-4Wheelers (cabs/good vehicles)	10,000/ kWh	1,50,000	3,000
Commercial	e-Buses	20,000/ kWh	10,00,000	300

Other demand sided incentives include,

		• Subsidy for using EVs for transportation of goods and services by industrial units. • 100% road tax exemption to EVs, waiver on registration charges and permit fees till 31.12.2025 • Incentives ranging from Rs. 5000 to Rs. 10,00,000 for procurement of electric vehicles by categories. ***Who can apply?*** Individuals The policy also provides for incentives to build charging infrastructure including public charging stations, battery swapping stations, as well as for capacity building and skilling.						

Sl No	**Schemes/ Policies**	**Key Highlights**	**Applicability to Sectors**					
			Agri	**Build**	**Transport**	**Industry**	**Waste**	**Water & carbon seq.**
1.	Prime Minister - Rashtriya Krishi Vikas Yojana (PM-RKVY)[17]	The PM-RKVY scheme aims to provide flexibility and autonomy for states to implement projects as per local farmers'	YES					

[17] https://agriwelfare.gov.in/Documents/Guidelines/PM_RKVY_Guidelines_14112024.pdf

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		needs and priorities thus making farming as a remunerative economic activity To support and scale up the startups under innovation and entrepreneurship in various fields of agriculture and allied sectors to enhance income of farmers and to create employment opportunities for youth Few major components under PM-RKVY include Per Drop More Crop (PDMC), Sub-Mission on Agriculture Mechanization (SMAM), Soil Health and Fertility (SH&F), Paramparagat Krishi Vikas Yojana (PKVY) etc.						

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
2.	Paramparagat Krishi Vikas Yojana (PKVY)[18]	PKVY aims at supporting and promoting organic farming by providing end-to-end support from production to processing certification and marketing by a cluster approach. Under PKVY, states are provided overall financial assistance of Rs.31500/ha covering on-farm and off-farm organic inputs (for this Rs.15000/ha is provided directly to farmers through DBT), marketing, packaging, branding, value addition, certification and residual analysis	YES					

18 https://pib.gov.in/PressReleasePage.aspx?PRID=2099756#:~:text=Under%20PKVY%2C%20States%2FUTs%20are,and%20off%2Dfarm%20organic %20inputs

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
3.	Bharatiya Prakritik Krishi Paddhati (BPKP)[19]	BPKP aims at promoting on-farm biomass recycling, use of cow dung-urine formulations and plant based preparations in exclusion of synthetic chemical inputs. Financial assistance of Rs 12200/ha for 3 years is provided for cluster formation, capacity building and continuous hand holding by trained personnel, certification and residue analysis Under this scheme dry lands, rainfed areas and tribal areas are to be given preference, where small and marginal farm holders, including tenant farmers being the preferred target group.	✓ YES					

[19] https://naturalfarming.dac.gov.in/Initiative/BPKP

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
4.	National Mission on Natural farming [20]	This mission aims at implementing self sustainable and self generating natural farming systems to enhance income, ensure resource conservation and soil health. Centrally sponsored scheme with an overall outlay of ₹2,481 crore targeting to initiate 1 crore farmers to natural farming spreading over 7.5 Lakh ha land.	YES					

[20] https://www.agriwelfare.gov.in/Documents/HomeWhatsNew/GuidelineofNMNF_FinalApproved_27122024.pdf

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
5.	National Mission for Sustainable Agriculture (NMSA)[21]	NMSA also aims to make agriculture more productive, sustainable, remunerative and climate resilient by promoting location specific Integrated / Composite farming systems. Components under NMSA include Rainfed Area Development (RAD), Sub-Mission on Agroforestry (SMAF), National Bamboo Mission (NBM), Soil Health Management (SHM) and Climate Change and Sustainable Agriculture: Monitoring, Modelling and Networking (CCSAMMN).	YES					

[21] https://nmsa.dac.gov.in/Default.aspx

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
6.	Soil Health Card (SHC) Scheme[22]	In the form of a soil card, farmers will get a report containing all the details about the soil of their particular farm once in every 3 years. SHC displays soil health indicators that can be assessed without the requirement of a laboratory or technical equipment, and are based on farmers' practical experience and knowledge of local natural resources.	YES					
7.	Chief Minister's Manniyur Kaathu Mannuyir Kappom Scheme (CM MK MKS)[23]	CM MK MKS aims to achieve sustainable and chemical free agricultural practices through distribution of Green Manure seeds and vermicompost pits and beds for farmers.	YES				YES	

[22] https://www.soilhealth.dac.gov.in/home

[23] http://tnenvis.nic.in/Database/TN-ENVIS_792.aspx

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		For the FY 2024-25 the scheme has an outlay of 206 crores covering 22 components to maintain soil health for supply of healthy food to society.						
8.	Kalaignarin All Village Integrated Agriculture Development Programme (KAVIADP)[24]	KAVIADP strives to increase the economic status of farmers by bringing fallow lands under cultivation and increase the cultivable area by creation of new water sources thereby to increase agricultural production and productivity. 100% funding for community water source creation (State Plan Scheme) For Union Government shared schemes	YES					

[24] https://aed.tn.gov.in/en/schemes/special-schemes/kagovvt/

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		like PM-KUSUM, PMKSY etc. based on respective guidelines and funding pattern						
9.	Kalaignarin Nagarpura Mempattu Thittam (KNMT)[25]	KNMT aims to fulfil infrastructural gaps in municipalities and town panchayats until Urban Local Bodies (ULB) level. This scheme covers funding for rejuvenation of water bodies, Solid Waste Management (SWM) infrastructure development including greening the vehicle fleet, construction of public toilets and parks etc.					YES	
10.	Namakku Naamae Thittam (Urban)[26]	This scheme improves the self support mechanism of public participation in					YES	YES

[25] https://cms.tn.gov.in/cms_migrated/document/GO/maws_e_70_2021.pdf

[26] https://www.tnurbantree.tn.gov.in/namakku-naame-thittam/

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		creating and maintaining community infrastructure. Renovation of water bodies, storm water drain,Upgradation of earthen /gravel/WBM roads / streets to all-weather roads, Community toilets / Public toilets, shops, Markets etc can be taken under this scheme. Minimum public contribution for any identified work (except renovation of water bodies) should be one third of the estimated value and for the renovation of water bodies the contribution should be 50%. There is no upper limit for public contribution						

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
11.	Atal Mission for Rejuvenation and Urban Transformation Scheme (AMRUT 2.0)[27]	AMRUT 2.0 aims to provide universal coverage of sewerage and septage management in 500 AMRUT cities while also enabling them to become self reliant and water secure Total indicative outlay is 2,99,000 crore with central share of 76,760 crore for a period of 5 years from 2021-2026.					YES	
13.	Swachh Bharat Mission-Gramin (SBM-G) - Phase II[28]	SBM-G Phase II aims to sustain the Open Defecation Free (ODF) status while also promoting sustainable solid and liquid waste management.					YES	

[27] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2078409

[28] https://swachhbharatmission.ddws.gov.in/about_sbm

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		The total outlay of SBM(G) Phase II is 1.40 lakh crore with key focus on areas like 100% scientific processing of Municipal Solid Waste, remediation of all legacy waste dumpsites and ensuring ODF status with no untreated faecal sludge or used water is discharged into environment						
14.	Galvanising Organic Bio-Agro Resources Dhan (GOBARdhan)[29]	GOBARdhan scheme aims to convert waste to wealth towards promoting a circular economy by building a robust ecosystem for setting up Biogas/Compressed Biogas (CBG) and Bio-Compressed Natural Gas (CNG) plants. 1. Any government/ private entity operating or intending to set up a	YES				YES	

[29] https://www.india.gov.in/spotlight/gobardhan-galvanizing-organic-bio-agro-resources-dhan

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		Biogas/ CBG/ Bio CNG plant can apply. 2. Supporting villages to efficiently manage their agricultural and cattle waste thereby keeping the surroundings clean. 3. Eligible entities are classified into Individual household model, Cluster model, Commercial model and Community model.						
15.	Waste to Wealth Mission[30]	This mission aims at strengthening the waste management system in India by identifying and validating innovative technology solutions and models to achieve a zero-landfill and zero-waste nation.					YES	

[30] https://www.psa.gov.in/waste-to-wealth

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		The mission aims to achieve this through effective management of solid waste and development of robust waste-to-energy and composting facilities.						
16.	Tamil Nadu Industrial Policy 2021[31]	Industrial projects undertaking green initiatives for recycling waste and water for industrial use and for sustainable energy usage, coupled with online monitoring. Wherever applicable shall be eligible for a 25% subsidy on the cost of setting up such environmental protection infrastructure subject to a limit of Rs. 1 cr.				YES	YES	
17.	Jal Jeevan Mission (JJM)[32]	JJM envisions to provide safe and adequate drinking water through individual household tap connections.						YES

[31] https://spc.tn.gov.in/policy/tamil-nadu-industrial-policy-2021/
[32] https://jaljeevanmission.gov.in/

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		Aims at providing Functional Household Tap Connections (FHTC) with 55 LPCD capacity and ensure long term sustainability with potable water The program also aims to implement source sustainability measures such as recharge and reuse through grey water management, water conservation and rainwater harvesting.						
18.	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)[33]	PMKSY focusses on sustainable water conservation practices exploring the feasibility of reusing treated municipal wastewater to the extent possible. This scheme has been conceived amalgamating various ongoing schemes and will be jointly implemented by						YES

[33] https://pmksy.gov.in/AboutPMKSY.aspx

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		agriculture, water resources and rural development departments. Creation of new water resources through minor irrigation along with repair, restoration and renovation of water bodies (Har khet ko pani scheme) Water harvesting structures like check dams, nala bund, farm ponds, tanks etc. (PMKSY-Watershed) and various components under PMKSY-PDMC scheme						
20.	National Afforestation Program (NAP)[34]	NAP is a centrally sponsored scheme aiming to restore degraded forests and develop forest resources by supporting large-scale reforestation and afforestation projects.						YES

[34] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1795073

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
21.	Green India Mission (GIM)[35]	GIM aims to protect, restore and enhance India's forest cover, improve ecosystem services and enhance carbon sinks thereby responding to climate change. Key activities include enhancing tree cover in urban and peri-urban areas, eco-restoring open forests and grasslands, restoring mangroves and abandoned mining areas etc.						YES
22.	Agroforestry Policy[36]	This policy promotes integrating trees into agricultural landscapes to sequester carbon and boost farmer income. It also involves promoting climate resilient cropping and farming systems thus conserving environment and biological diversity.	YES					YES

[35] https://www.indiascienceandtechnology.gov.in/st-visions/national-mission/national-mission-green-india-gim
[36] https://agriwelfare.gov.in/Documents/Operational%20Guidelines%20of%20AGROFOREST%20Y%20under%20RKVY.pdf

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
		The Agroforestry component under RKVY provides up to ₹50 lakh for establishing nurseries to produce Quality Planting Materials, with 100% assistance for government agencies and 50% for private agencies						
23.	Compensatory Afforestation Fund Management and Planning Authority (CAMPA)[37]	State CAMPA to submit the Annual Plan of Operations (APO) to get funds and engage the local communities in afforestation, soil water conservation and forest protection activities.						YES

[37] https://pib.gov.in/PressReleasePage.aspx?PRID=1906384

Sl No	Schemes/ Policies	Key Highlights	Applicability to Sectors					
			Agri	Build	Transport	Industry	Waste	Water & carbon seq.
24.	Nagar Van Yojana[38]	Promotes urban forestry by creating urban forests/parks. Grants limited to 50 ha, with funding up to ₹4 lakhs per hectare. At least two-thirds of the area must be under tree cover and may include biodiversity parks, butterfly conservatories, smriti vans, herbal gardens, and waterbodies.						✓ YES

[38] https://nams.nic.in/nagarvan.php

Endnotes

1 District Statistical Handbook 2022-23

2 Chennai recently deployed 120 electric buses under the MTC fleet with a total investment of Rs. 207.9 Crore. Since the cost of electric buses could vary by seating capacity and features, this investment is taken as a comparable figure for Virudhunagar too. An average of Rs. 1.8 Crore is assumed per electric bus.

3 Scheme valid till March 2026, unless extended.

4 Scheme valid till December 2025, unless extended.

5 https://tnpcb.gov.in/PDF/About_Us/Announcementgos/GONo116_16625.pdf

6 Scheme valid till December 2026, unless extended.

7 Ministry of External Affairs, Government of India. "National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow." November 02, 2021.

8 RCP 4.5 and RCP 8.5, short for Representative Concentration Pathways, are scenarios used to model future climate change based on different levels of GHG emissions. RCP 4.5 is a moderate scenario where emissions peak around 2040 and then decline. This includes a substantial growth in renewable energy resources by 2050. RCP 8.5 is a high baseline emissions scenario where emissions continue to rise on account of an increase in fossil fuel energy use throughout this century. RCP 8.5 is a scenario where energy consumption and overall consumption rates become unsustainable.

9 https://www.ipcc-nggip.iges.or.jp/public/2006gl/

10 https://cgwb.gov.in/

11 District Survey Report for Gravel, Virudhunagar District, Tamil Nadu State. Accessed at https://tnmines.tn.gov.in/pdf/dsr/2.pdf

12 According to the National Forest Policy of India 1952 and 1988

13 District Statistical Handbook Virudhunagar District 2022-23 https://cdn.s3waas.gov.in/s3c86a7ee3d8ef0b551ed58e354a836f2b/uploads/2023/12/2023120538.pdf

14 Department of Economics and Statistics, Government of Tamil Nadu

15 October is the wettest month(average rainfall of 170 mm) followed by November (average rainfall of 163 mm)

16 Representative Concentration Pathways (RCPs) are concentration pathways used by the IPCC. They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used for climate modelling. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square metre (W/m^2). There are four RCPs, RCP2.5 (low pathway where radiative forcing peaks at approximately 3 W m-2 before 2100), RCP4.5 and RCP6.0 (two intermediate stabilisation pathways in which radiative forcing is stabilised at approximately 4.5 W m-2 and 6.0 W m-2 after 2100) and RCP8.5 (high pathway for which radiative forcing reaches greater than 8.5 W m-2 by 2100).

17 "The change in maximum temperature is based on MAM, which is observed to be 32.7ºC under historical estimates, 32.8–33.8ºC under RCP4.5, and 32.9–35.5ºC under RCP8.5"

18 The number of heat wave periods not less than 5 days

19 Maximum number of consecutive days per year when the daily maximum temperature is above the 90th percentile

20 The change in minimum temperature is based on DJF, which is observed to be 20.9 °C under historical estimates, 21.6 °C-22.6ºC under RCP 4.,5 and 21.8ºC-24.2ºC under RCP 8.5.

21 Virudhunagar District Disaster Management Plan, 2024

22 'Scope 1' indicates direct greenhouse gas (GHG) emissions that are from sources owned or controlled by the reporting entity

23 CO_2e are also calculated in terms of Global Warming Potential (GWPs) as reported in the Sixth Assessment Report (AR6) of the IPCC.

24 The National Communications (NATCOM) provides information on greenhouse gas (GHG) inventories, measures to mitigate and to facilitate adequate adaptation to climate change, and any other information that the Party considers relevant to the achievement of the objective of the Convention. They are submitted every four years.

25 Biennial Update report (BUR) provides an update of the information presented in NCs, in particular on national GHG inventories, mitigation actions, constraints and gaps, including support needed and received.

26 Industries, Investment Promotion & Commerce Department, Government of Tamil Nadu. Tamil Nadu Electric Vehicle Policy, 2023.

27 Department of Economics and Statistics, Government of Tamil Nadu. District Statistical Handbook 2022-23, Virudhunagar District. Accessed at https://cdn.s3waas.gov.in/s3c86a7ee3d8ef0b551ed58e354a836f2b/uploads/2023/12/2023120538.pdf

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56 Balanced rationing: process to balance the level of various nutrients of an animal, from the available feed resources, to meet its nutrient requirements for maintenance and production. https://www.nddb.coop/services/animalnutrition/programmes/ration-balancing-programme

57 Improved Feed Supplements: Use of improved feed supplements have been shown to decrease methane emissions from livestock. ICAR-National Institute of Animal Nutrition and Physiology developed a feed supplement - Harit Dhara and Tamarin Plus, for cattle, are effective in cutting down enteric methane emissions by 20 percent http://nianp.res.in/harit-dhara-tamarin-plus.

58 Feed additives like neem cake, seaweed, tannins, essential oils and enzyme supplements.

59 Galvanizing Organic Bio-Agro Resources Dhan (GOBAR-Dhan) Scheme launched in April 2018 by the Ministry of Drinking Water & Sanitation focuses to generate energy and organic manure from cattle waste, promote circular economy, reduce GHG emissions, create rural employment opportunities etc. https://gobardhan.co.in/about-us

60 Projected based on CAGR between 2005 and 2021 data.

61 Projected based on CAGR between 2005 and 2022 data.

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71 Centralized wastewater treatment involves three stages: primary, secondary, and tertiary. In primary treatment, larger solids are removed through physical processes. Secondary treatment uses microorganisms to biodegrade remaining particulates. Tertiary treatment further purifies the water using advanced filtration, disinfection, and other methods to remove pathogens and nutrients, achieving 50-90 percent BOD removal efficiency

72 Activated sludge process- In the activated sludge process, wastewater is mixed with treated sludge in an aeration tank, where microorganisms break down organic pollutants into carbon dioxide, water, and biomass.

73 An on-site sewage system with multiple compartments allows sedimentation and sludge digestion. Solids settle as sludge, and scum is retained. Sludge undergoes anaerobic digestion, achieving 20-40 percent BOD removal efficiency.

74 An independent facility treats faecal sludge and septage for safe disposal and reuse using four modules: Sludge Drying Beds, Anaerobic Baffled Reactor, Planted Gravel Filter, and a Disinfection unit, achieving over 80 percent BOD removal efficiency

75 https://www.dpcc.delhigovt.nic.in//uploads/pdf/NGT-Order-OA-673-of-2018-22-02-2021pdf-d2c576ccba58ab628083796149355cad.pdf

76 Zero liquid discharge (ZLD) is a strategic wastewater management system that ensures that there will be no discharge of industrial

wastewater into the environment. It is achieved by treating wastewater through recycling and then recovery and reuse for industrial purpose.

77 https://msmedi-chennai.gov.in/GARMS_Admin/basictools/images/DIPSReport/Ramanathapuram.pdf

78 Swachh Survekshan, Ministry of Housing and Urban Affairs https://ss2022.sbmurban.org/#/dashboard

79 Forest Survey of India Annual Reports

80 Agroforestry involves integrating trees with agriculture through practices like planting trees along farm boundaries, alternating tree strips with crops, growing crops under a tree canopy, creating riparian buffers to prevent runoff, and using silvopasture where trees provide shade for grazing livestock.

81 https://www.globalforestwatch.org/dashboards/country/IND/31/32/?category=undefined&map=eyJjYW5Cb3VuZCI6dHJ1ZX0 percent 3D

82 Total Net Emissions include $ktCO_2e$ deducted due to carbon sequestration by land.

83 80 percent electrification proposed.

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112 Land sub-sector includes emissions/removals from categories namely, Agriculture Land (-0.05 kt CO2e), Settlements (-0.06 kt CO2e),Other Land(0.14 kt CO2e) and Forest Land (-170.70kt CO2e) in 2022. Since no change in land use pattern is foreseen, the emissions/removal in 2050 from the land category is assumed to be the same as that of 2022.

113 Under the MES and AES scenario, the enhanced sequestration is achieved through: (a) adapting agro/social forestry in land classified as cultivate waste land (MES=50 percent , AES=75 percent), other fallows (MES=50 percent , AES=75 percent), current fallows (MES=10 percent , AES=20 percent), barren and uncultivable waste land (MES=10 percent , AES=25 percent), land put to non-agriculture uses (MES=5 percent , AES=10 percent), and (b) restoring the carbon stock density recorded in 2021 (82.25 t/ha) to that recorded in 2015 (87.26 t/ha).

114 Livestock sub-sector emissions projected in 2050 is 339 ktCO2e consists of emissions from Enteric Fermentation (320 ktCO2e) and Manure Management (18 ktCO2e).

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